COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

DEVELOPMENT OF GROUND-WATER SUPPLIES IN SHENANDOAH NATIONAL PARK, VIRGINIA

RICHARD H. DEKAY

MINERAL RESOURCES REPORT 10

VIRGINIA DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

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DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT

Richmond, Virginia

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DEVELOPMENT OF GROUND-WATER SUPPLIES IN SHENANDOAH NATIONAL PARK, VIRGINIA

By

Richard H. DeKay

ABSTRACT

Shenandoah National Park encompasses more than 300 square miles in portions of eight counties located in the Blue Ridge Mountains of northwestern Virginia. Thirteen geologic formations comprise the bedrock of these mountains and their foothills, eight of which occur on the lower west slopes and one on the lower east slope. The other four rock units underlie the upper portion of the eastern slope and the mountain crest; these formations are of late Precambrian and early Cambrian age, and are comprised of basaltic, granitic, and clastic sedimentary rocks. Existing public facilities in the Park are located on these impermeable rocks near the crest of the mountains, and water supplies are premium requirements.

Springs furnished water to all Park facilities from its inauguration in 1936 until 1961, but expansion of facilities had greatly increased the water demand. Efforts were made to recondition existing springs and to locate additional ones for development, but the former was unsuccessful and the latter either too far from areas of water consumption or unreliable during the summer months. From 1961 to 1971 the Virginia Division of Mineral Resources located test-hole drilling sites in predesignated areas along the mountain crest, and preliminary data indicate 20 of the 33 test holes drilled for water can be converted into wells with yields that exceed the summer flows of developed springs.

INTRODUCTION

The Blue Ridge Mountains traverse Virginia in a northeasterly direction for approximately 285 miles from the North Carolina-Tennessee-Virginia juncture on the south to the Virginia-Maryland boundary (Potomac River) on the north. Shenandoah National Park, 75 miles long and 2-13 miles wide, occupies more than 300 square miles in portions of eight counties in the northern portion of these mountains between the towns of Front Royal and Waynesboro, Virginia (Figure 1). Access to

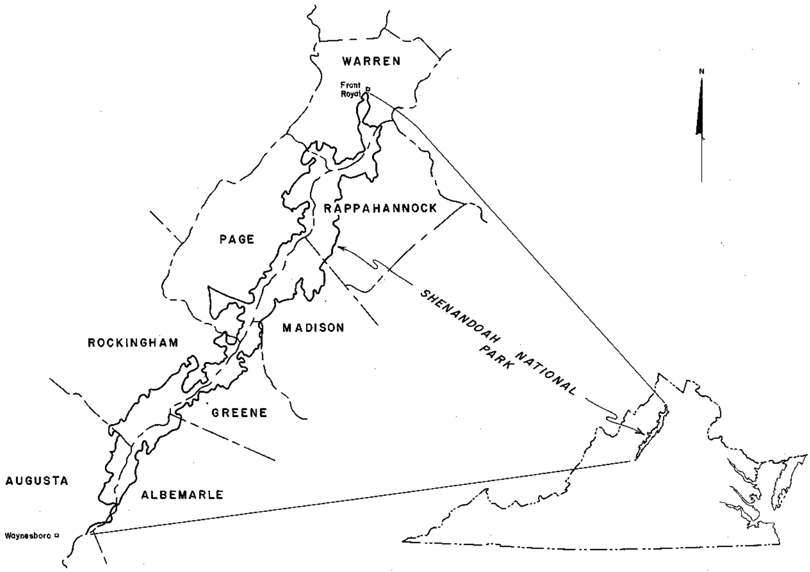

Figure 1. Location map of Shenandoah National Park, Virginia, and surrounding counties.

the Park is by U. S. highways 55, 340, and 522 at the north entrance, and by U. S. Highway 250, Interstate 64, and the Blue Ridge Parkway at the south terminus. Entrance may also be gained by U. S. highways 33 and 211 that cross the mountains through Swift Run and Thornton gaps, respectively, and divide the Park into North, Central, and South districts. The principal route of travel within the Park is Skyline Drive that follows the mountain crests for 105 scenic miles.

English, German, and Scotch-Irish settlers began to establish their farms, lumber, mining, tanning, and handicraft industries some 50 years after John Lerderer first explored the mountains near Skyland in 1669 (National Park Service, 1959). The mountains were first crossed by a turnpike road through Thornton Gap in 1785 where Francis Thornton had established his Panorama Inn, and in 1898 George Pollack opened a camp at the present-day site of Skyland. The chestnut blight and advances in mechanization and transportation slowly isolated the mountain people, and by 1915 most of those who remained were subsistence farmers.

T. S. Mather, Director of the National Park Service, recommended the area for public use in 1925, and within 3 years the U. S. Congress and the Virginia General Assembly had enacted legislation for establishment of a national park (Lassiter, 1936). By 1934 Skyline Drive had been completed in the Central District, consisting of a 34-mile segment between Thornton and Swift Run gaps, and one year later the Commonwealth of Virginia deeded 3870 tracts of land (176,429.8 acres) in portions of eight counties to the Federal government. On July 3, 1936 President Franklin D. Roosevelt officially dedicated Shenandoah National Park in ceremonies at Big Meadows. By the advent of World War II, Skyline Drive had been completed in the North and South districts, a campground and seven picnic areas constructed, and lodging and restaurant facilities at Dicky Ridge, Lewis Mountain, and Swift Run Gap added to those at Panorama, Skyland, and Big Meadows. After the war the Park was enlarged to 193,600 acres and facilities now include lodging accommodations for 800 people, four campgrounds, five restaurants, five Appalachian Trail cabins, seven picnic areas, 21 trailside shelters, and 75 parking overlooks (National Park Service, 1971). The public regard for this Park was attested to in 1971 when 2,400,000 visitors made Shenandoah the second most popular National Park in the eastern United States.

TOPOGRAPHY AND CLIMATE

The geomorphologic history of the Park exceeds one billion years. The deposition and later deformation of rock formations were followed by a prolonged period of erosion that reduced the less resistant formations and breeched numerous transverse zones of structural weakness. The resulting landform is a series of subdued peaks, ridges, and hollows that comprise a maturely dissected upland in the Northern Section of the Blue Ridge physiographic province (Fenneman, 1938). Elevations range from 550 feet above sea level in the northwest corner of the Park to 4050 feet atop Hawksbill Mountain in the Central District. Hundreds of peaks and ridges throughout the Park range in elevation from 2000 to 4000 feet, 60 of which are more than 3000 feet above sea level. Public facilities have been developed along Skyline Drive that is 1900 to 3680 feet above sea level for most of its 105 miles.

In the North District, base-level elevations along the Blue Ridge foothills average 850 feet on the west and 800 feet on the east, and peak elevations are as high as 3474 feet (Hogback Mountain). Although maximum relief is approximately 3000 feet, the average relief in most of the District is less than 2000 feet. The South District is much the same, but higher base-level elevations (1400 and 1000 feet on the west and east, respectively) reduce the maximum relief to approximately 2300 feet and average relief to less than 1500 feet. Loft Mountain has the highest elevation in this District, 3587 feet above sea level. In the Central District several peaks have elevations greater than 3000 feet, and Hawksbill Mountain (4050 feet) is the highest in the Park. At Skyland (3680 feet) the lodge and cabins overlook the Shenandoah Valley approximately 2500 feet below. Base-levels in the Central District are 1150 feet on the west and 900 feet on the east, maximum relief is approximately 3100 feet, and the average relief is greater than 2000 feet.

Weather stations are maintained by Park personnel at Big Meadows in the Central District and at Park Headquarters east of Luray. Approximately midway between Chesapeake Bay and the Appalachian Plateaus, the Blue Ridge Mountains are affected by weather systems emanating from the coastal lowlands and the interior highlands. Relatively low cloud conditions moving from either direction are forced to higher elevations to cross the mountains, resulting in sudden rains or dense fog along Skyline Drive. The varied weather conditions in different portions of the Park are reflected in the precipitation and temperature records for the Big Meadows station on a mountain top 3500 feet above sea level, and at the Park Headquarters station near the western foothills at an elevation of 1200 feet (Figure 2). Precipitation records for the weather station at Free Union are included to illustrate the amount of rainfall on the east side of the Blue Ridge Mountains.

Precipitation is well distributed throughout the year; annual averages were 37.35 and 45.05 inches at Park Headquarters and Big Meadows, respectively, for the past 10 years (U. S. Dept. of Commerce, Climatological Data, 1962-1971). December through February is normally the low-precipitation period, and May, July, and November are the high-rainfall months. The average annual rainfall at the Free Union weather station during the same period was 40.43 inches; October and December were usually the months of least precipitation, and July was generally the month of most rainfall. Annual temperatures at Park Headquarters averaged 52.2° Farenheit (F) for the last 10 years, with an average low of 28.69° F during the months

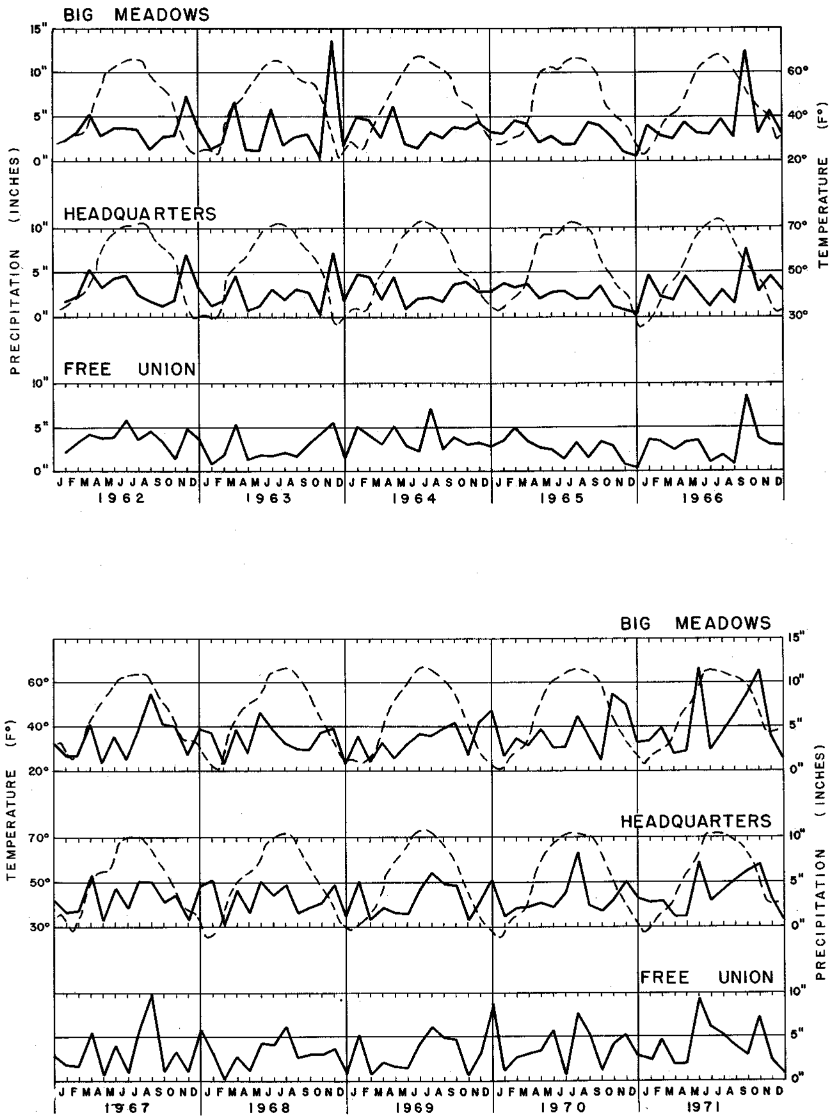

Figure 2. Monthly precipitation (solid line) and temperature (dashed line) recorded 1962-1971 at Luray and Big Meadows weather stations; only precipitation was recorded at Free Union.

of December through February and an average high of 72.51° F in July. At Big Meadows the average annual temperature was 46° F, with an average December-February low of 24.21° F and an average July high of 66.76° F. No temperature records for these 10 years are available from the Free Union station. The Park is open year-round, although most facilities are closed during the winter months and Skyline Drive may be temporarily closed because of ice, snow, or fog conditions.

PURPOSE AND ACKNOWLEDGMENTS

After the U. S. Congress and the Virginia General Assembly enacted legislation for the creation of a national park in the northern Blue Ridge Mountains of Virginia, the area being considered for the park was investigated for data to assist in planning of facilities. The studies included surveys to locate and measure streams and springs that could be utilized as water supplies, and those judged to be adequate for anticipated facilities were developed and placed into operation by the time the Park was dedicated in 1936. Twenty years later improvements in transportation and working conditions had increased the annual attendance to an extent that it was desirable to expand existing facilities and to develop new ones. Surface-water supplies were already utilized to their maximum, and the only alternative was the development of ground-water resources. As earlier studies did not include ground-water investigations, the Virginia Division of Mineral Resources was contracted to determine the availability of ground-water supplies. The entire project, which began in 1960 and concludes with this report, was conducted under the guidance of Dr. James L. Calver, Commissioner of Mineral Resources and State Geologist, and the direct supervision of the writer. Of the many contributors of assistance on the staff of the Virginia Division of Mineral Resources, the writer is particularly indebted to T. M. Gathright II, P. G. Nystrom, Jr., and E. B. Nuckols III; the cooperation of Superintendent R. T. Hoskins and numerous personnel on the Shenandoah National Park staff throughout this study is also gratefully acknowledged.

GEOLOGY

The 13 geologic formations that occur within Shenandoah National Park range in age from Precambrian on the east to

Ordovician on the west. As most of the test holes drilled in the Park are within 0.5 mile of Skyline Drive, which is near the crest of the Blue Ridge Mountains, only four of the five oldest of these formations were penetrated (Figure 3). Three general

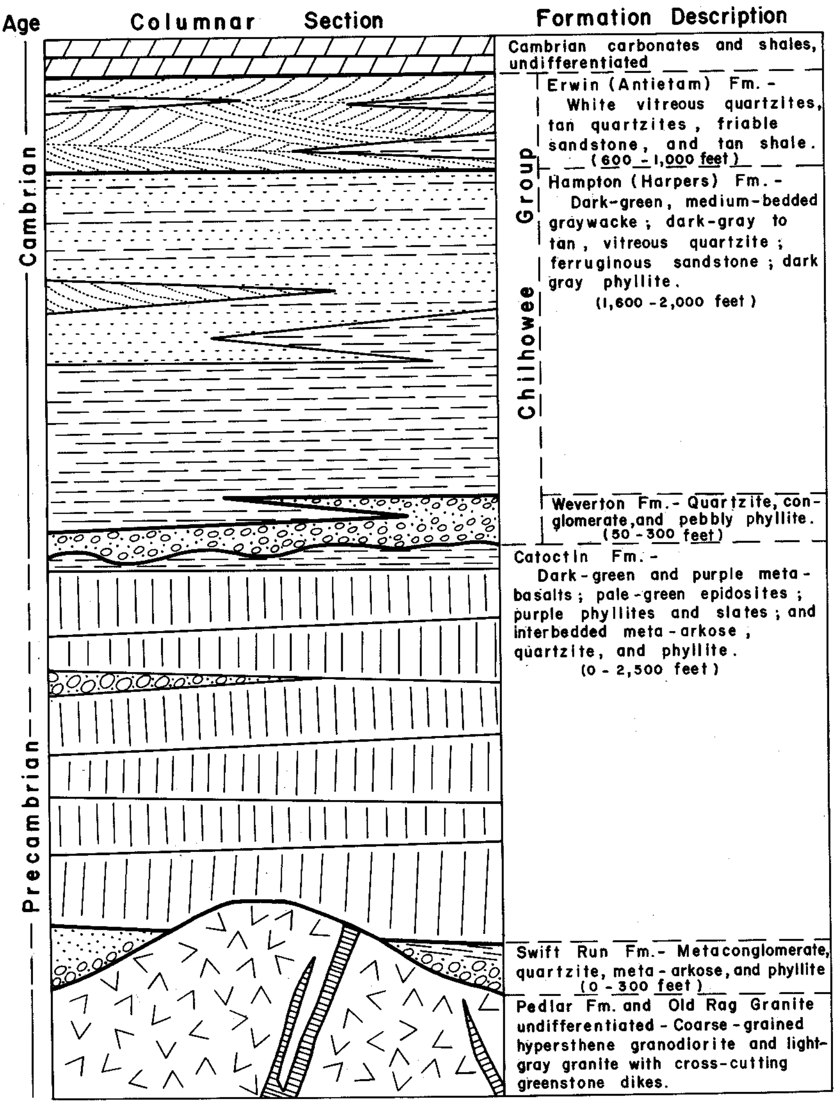

Figure 3. Generalized columnar section of rock formations in Shenandoah National Park.

rock types occur in this narrow, elevated area—granitic, basaltic, and clastic sedimentary rocks, all metamorphosed to some degree and each having a distinct geologic terrane.

STRATIGRAPHY

A granitic terrane is developed on the Precambrian Pedlar Formation (Allen, 1967) and the Old Rag Granite (Furcron, 1934) and is characterized by random peaks and knolls, sharp-crested sinuous ridges, steep-forested slopes, and generally small, steep drainage basins. The granites, granodiorites, and mafic intrusives that comprise this terrane are generally covered by only a few feet of residuum (Hack, 1965) except in areas of low relief where this material may be several tens of feet thick. Locally, talus deposits occur in the steeper areas, and broad expanses of granitic bedrock are exposed on a few mountain tops. The run-off of surface water is rapid on the steep slopes, and the generally thin soil cover provides relatively little storage for ground water. Subvertical joints and joint swarms, and sub-horizontal sheet joints that may occur in the upper few tens of feet in granitic bedrock provide local fracture permeability, but little ground-water storage.

The Swift Run and Catoctin formation of late Precambrian (?) age successively and disconformably overlie the granitic rocks. The Swift Run Formation is a discontinuous rock unit composed of metamorphosed conglomerate, arkose, and shale that has a total thickness of at least 300 feet in places. It generally occurs in low areas on the ancient granitic surface (Reed, 1955, 1969), and where present is directly overlain by basalts, phyllites, and epidosites of the Catoctin Formation that range up to more than 2500 feet in thickness. The Catoctin Formation is a series of metamorphosed basalt flows that individually may be more than 100 feet thick, and are frequently separated by thin lenses of epidotized sediments or purple, phyllitic volcanic rocks. As sedimentary rocks comprise a small portion of the total thickness of the Catoctin and Swift Run formations, these two rock units are combined to comprise the basaltic terrane that is characterized by high, broad, round-topped mountains with steep lower slopes, moderately to deeply incised streams and wide interstream areas. These features are best developed in areas where a wide expanse of gently dipping basalt is preserved, such as near Mount Marshall, Skyland, and Big Meadows. Locally, along the western crest of the Blue Ridge a very steep escarpment has developed near the Catoctin-Swift Run contact with the underlying granitic rocks. This escarpment is prominent between Front Royal and Mathews Arm in the North District, and between Hughs River Gap and Tanners Ridge in the Central District. A lesser, but more sinuous, escarpment is locally developed below this contact along the eastern boundary of the Park between Lewis Mountain in the Central District and Moormans River Reservoir in the South District. The presence of these escarpments and the lower elevations of the outlying granitic peaks illustrate the greater resistance of the basaltic rocks. The formations that comprise the basaltic terrane have no significant primary permeability, but the occurrence of joints and joint swarms provide some local fracture permeability. Appreciable ground-water storage may be present in areas of low relief where the weathered upper surface of the basaltic rocks have several tens of feet of residuum and mixed talus.

In the western foothills and ridges of the Park north of Pine Stand Gap, and in the western and central ridges south of the Gap, clastic sediments of the Chilhowee Group (King, 1950) overlie the Catoctin Formation. These rocks are divided into three lower Cambrian formations that range from 2900 to 4300 feet in total thickness. The basal 50 to 300 feet is composed of quartz-pebble conglomerates, coarse-grained phyllites, and pebbly phyllites of the Weverton Formation that is overlain by 1800 to 2000 feet of medium- to thin-bedded graywackes, ferruginous sandstones, quartzites and phyllites of the Hampton (Harpers) Formation. The very-resistant 600 to 1000 feet of white, vitreous quartzites, tan quartzites, friable sandstones, and interbedded tan shales of the Erwin (Antietam) Formation comprise the upper portion of the Chilhowee Group. The sedimentary terrane in the Park is formed by these rock units and is characterized by very steep, sharp-crested, often linear ridges, abundant quartzite talus deposits, and large, deeply incised drainage basins. The ridges and mountains developed on these rocks are generally 500 to 1000 feet lower than the adjacent mountain crests comprised of the basalts of the Catoctin Formation. Residuum on these very siliceous rocks ranges from a few inches to a few feet and, with rapid run-off of surface waters, affords very limited ground-water storage. These rocks have little primary permeability, and the occurrence of ground-water is dependent mostly upon the presence of open joints or faults below the local water table. The other undifferentiated carbonate and shale formations present near the western boundary of the Park occur outside the study area.

STRUCTURE

Folding and faulting within the Park have resulted in significant local modifications of the terrane. Relatively steep slopes and narrow, sharp-crested ridges commonly occur where the Swift Run and Catoctin formations are closely folded with rocks of the Chilhowee Group. Where faults and associated shear zones occur, major linear low areas have developed along the structure.

Well-developed cleavage, slickensides, mylonite, and ultramylonite are present in some of the fault zones, and cleavage tends to be more intense on the overturned or steeply-dipping limbs of folds. Water-well data indicate that rock formations in the intensely sheared areas have no better, and sometimes poorer, water-bearing characteristics than strata in less deformed areas.

Joints and sheeting in the granitic terrane, and joints in the basaltic and sedimentary terranes, are the major water-bearing structural features throughout the Park. It is indicated by data from wells drilled along the mountain crest that these fractures decrease in size and number with increasing depth, and at depths greater than 250 feet water-bearing fractures are rare. In areas of high joint density, weathering has occurred at a faster rate and accumulations of residuum are usually thicker than in less-fractured areas.

HYDROLOGY

Water is not only the most abundant mineral on earth, but also the most unique in its mode of occurrence—as a solid (ice and snow), liquid (water), or gas (water vapor) depending on the temperature and pressure to which it is subjected. In a climate such as that of Virginia the ice and snow are usually melted by the moderating temperatures within a few days. However, the liquid and gaseous phases of this mineral continuously change from one to the other through the processes of evapotranspiration and condensation. In the course of its flow, dependent on local topography, some of the surface water is absorbed into the ground, part is ponded on the ground, and some is evaporated into the atmosphere, the amounts depending upon the slope of the gradient, the degree of permeability and saturation of the soil, and the atmospheric conditions. A portion of the water absorbed into the ground is intercepted by plant roots during the growing season and later returned to the atmosphere through transpiration. The recurrence of water vapors released by evaporation and transpiration to the atmosphere and their eventual condensation and precipitation to earth is, in its simplest terms, the hydrologic cycle, and the science of hydrology is a study of all phases of this phenomenon (Pfannkuch, 1969, p. 57).

SURFACE WATER

PREVIOUS INVESTIGATIONS

In 1933 the Water Resources Branch of the United States Geological Survey was directed to investigate and document all springs and creeks within the then-proposed Park area; the following year preliminary reports were submitted in which measurements and recommendations were given for surface-water sources in the North and Central districts (file reports of the Shenandoah National Park prepared by the U. S. Geological Survey, Cady, 1934; Shackelford, 1934; Dirzulaitis, 1934). A later report (file report of the Shenandoah National Park prepared by the U. S. Geological Survey, Dirzulaitis, 1935) included the recommendation that adequate water supplies were available for large installations only in the Big Meadows and Skyland areas of the Central District. By 1937 the United States Geological Survey, in cooperation with the National Park Service, Civilian Conservation Corps, and Virginia Commission on Conservation and Development had completed 29 surface-water installations in the North and Central districts (file report of the Shenandoah National Park prepared by the U. S. Geological Survey, Dirzulaitis, 1938).

Shenandoah National Park personnel have continued the measurement and maintenance of the Park's water supplies since 1937, and in December 1959 an inventory was made of 854 known surface-water sources (personal communications, C. S. Dodge, F. V. Vest, C. R. Montgomery, 1959). From these data it was evident the South District lacked sufficient surface-water supplies for development, as many of the 269 sources were intermittent, most were less than 5 gallons per minute (gpm), and none exceeded 8 gpm. Conditions were not much better with the North District's 194 sources, although 18 had recorded flows of 10 to 20 gpm. Of the 391 surface-water sources in the Central District, 47 had estimated flows greater than 100 gpm, the largest of which was 500 gpm. Unfortunately, many of these water sources are located at considerable distances from and at elevations below Skyline Drive where the water is needed.

SPRING OCCURRENCE

Of the hundreds of small springs and thousands of ground-water seeps present within the Park only a relatively small number can be used for public water supplies because of their wide seasonal fluctuation in flow. More than 70 of these surface-water sources are near Skyline Drive, and most of the areas of Park facilities were originally located so as to utilize those with large or reliable flows.

In 1961 an appraisal of the most acceptable surface-water sources in the Park was made and recommendations were issued concerning their condition and possible development (personal communication, H. R. Hopkins). Shortly thereafter, a schedule was established by which Park personnel would make regular monthly readings of selected springs located throughout the Park. During the next few years the number of selected springs vacillated between 20 and 50 until it was determined which ones would furnish the most meaningful data; seven were measured each month of the year, and the others as weather and accessibility permitted. Adequate records have since been collected for evaluation of flows from 30 springs, 18 of which occur on basaltic terrane, 10 on granitic rocks, and two on sedimentary terrane. The locations of these springs (or their weirs) have been plotted on 23 maps of small areas within the Park, and identified by their spring numbers as tabulated in Appendix I.

The natural fluctuations of spring flow are controlled by the climate and geology of the individual Park areas. Climate exercises control through duration, amount, and type of precipitation, and through the seasonal variations in temperature that affect the rates of evaporation and transpiration. Geology exercises control through type and structure of the bedrock. The interrelationship of climate and geology determines the local elevation, size and slope of drainage areas, and the depth and permeability of weathered rock material.

The areas of highest elevations within the Park are underlain by basalt flows of the Catoctin Formation on which very gentle to nearly vertical slopes have been developed. Where the basalts are gently inclined relatively large drainage areas with a thick (20-60 feet) cover of residual weathered-rock material and boulders commonly overlie bedrock and act as a major reservoir for ground water, as is evidenced by the numerous springs and perennial streams. In areas of steep slopes and along the escarpments, the residual cover is very thin and bedrock is frequently exposed. In interstream areas the slopes are often covered by talus deposits of basalt boulders that may be underlain by a relatively thick development of residuum.

Areas near Skyline Drive between Land Run Gap and Mount Marshall, Little Devil Stairs and Hogback Mountain, and from Thornton Gap to Stony Man are underlain by the Pedlar Formation. Several tens of feet of residuum may develop on these felsic rocks where the relief is low, but slopes are usually steep and generally have less than 20 feet of residuum. Springs are less common on this granitic terrane, but within equivalent drainage areas are similar to those on the basaltic terrane.

Relatively few springs occur on the sedimentary terrane, largely due to the presence of a very thin residuum and very steep slopes that induce rapid runoff. Some of the springs that do exist have high discharge rates during periods of precipitation, but these flows tend to decrease rapidly during times of subnormal rainfall.

SPRING-FLOW CHARACTERISTICS

Weir readings for 30 springs were recorded monthly by the National Park Service as weather permitted from 1960 through 1970 (Appendix I). Graphs of these measurements, depicting the average monthly flow where five or more annual readings are available for each month and of the lowest annual flow recorded for each month during this period, accompany the weir readings. The graphs are quite similar in form for all springs with maximum average flows occurring in the months of March through May, and minimum average flows in the months of July through September. The curve that was constructed from the minimum monthly readings approaches the probable low-flow to be expected from these springs, and is a visual measure of their reliability during the 11-year study period.

For 24 of the 30 springs, minimum flows are less than 5 percent of the maximum recorded flow, and 15 of these have low flows of less than 1 percent of the maximum flow. Although prior to the construction of water wells the other six springs furnished water supplies for the principal developments in the Park (Lewis, Furnace, Headquarters, Lewis Mountain, Swift Run Gap, and Dickey Ridge springs), their low flows are less than 10 percent of the maximum flows. The minimum flow curve also reflects the 1965-1966 drought during which the rainfall was near or below average for all but three of 17 consecutive months beginning in May 1965, as recorded at the Shenandoah National Park Headquarters weather station near Luray. The negative effect of this drought on spring flows illustrates their direct relationship with precipitation. If the drainage areas that supply water to the various springs were larger, less steep, and contained a thicker residuum for ground-water storage, the monthly flow rates would be more uniform. Although the average flow of many of these springs is adequate to sustain the water needs of small developments, it is obvious that a more reliable water supply must be available in times of extended drought or even normal seasonal dry periods to provide probable minimum water requirements.

Two composite graphs (Figures 4 and 5) show the close correlation between variations in monthly precipitation and spring flow, and an equally close correlation between high temperature periods and times of minimum spring flow. These graphs were prepared from spring-flow data for Lewis Spring at Big Meadows and the Headquarters weir near Park Headquarters, as these installations are U. S. Department of Commerce weather stations that record daily temperature and precipitation. It should be noted that periods of above-normal precipitation during the growing season have short-term effects on spring flows, but equivalent precipitation in the months between September and May have long-term, positive effects.

Because of the great variability of seasonal flows from springs near the crest of the Blue Ridge Mountains, their sufficiency as the sole sources of public water supplies during much of the peak-use period (June through October) became increasingly tenuous as Park visitation increased. Thus, a program for the evaluation of ground-water conditions and the location of water-well drilling sites was initiated.

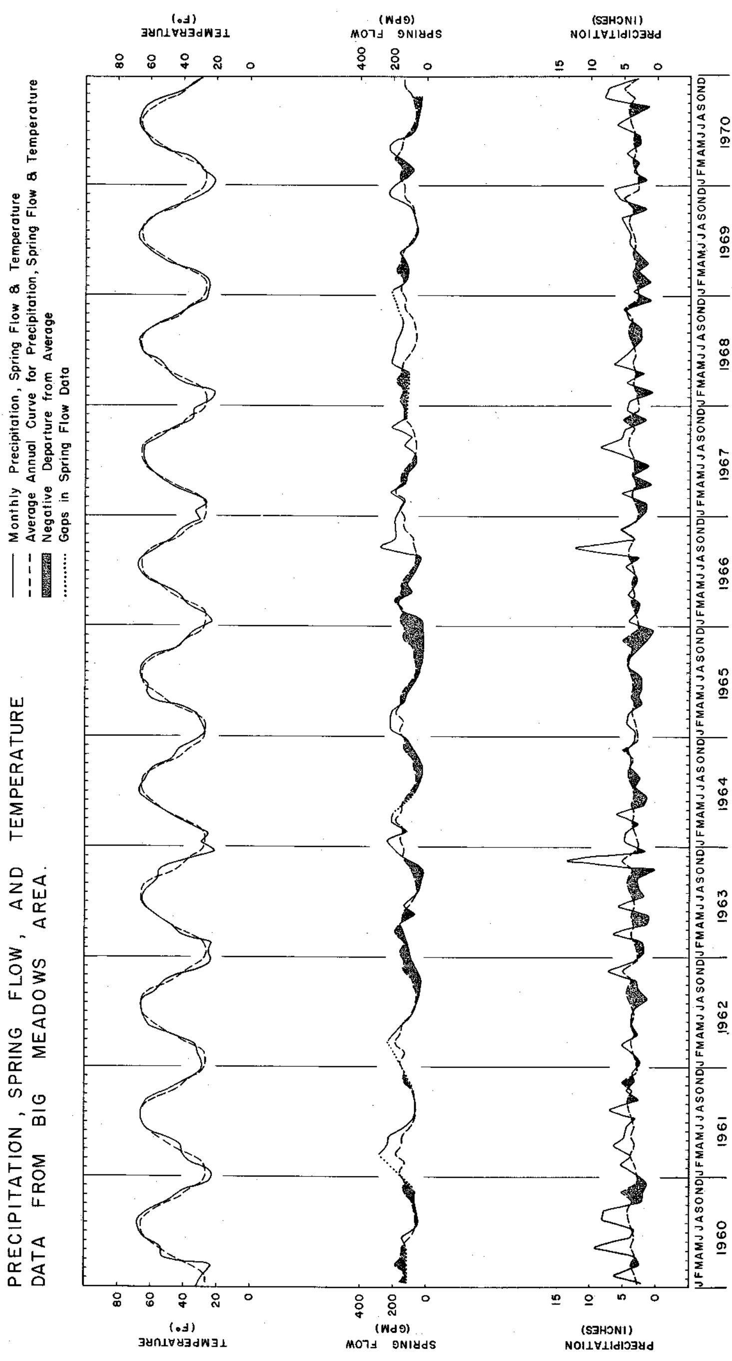

Figure 4. Interrelationship of monthly precipitation, spring flow, and temperature at Big Meadows.

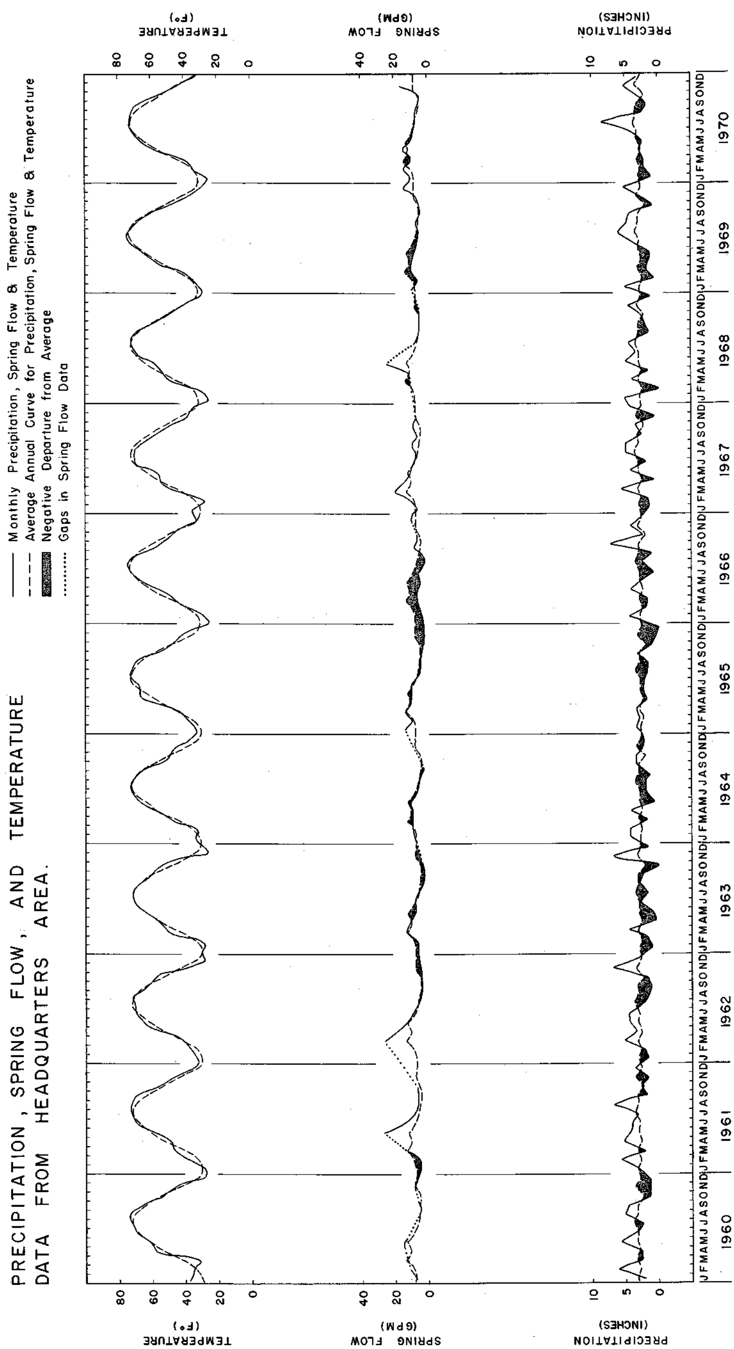

Figure 5. Interrelationship of monthly precipitation, spring flow, and temperature at Park Headquarters.

GROUND WATER

PRESENT INVESTIGATION

In the decade following World War II the number of visitors to Shenandoah National Park increased annually, and plans were formulated to enlarge existing facilities and develop new ones. In 1959 the National Park Service contacted the Commonwealth of Virginia for assistance in the location and development of ground-water supplies throughout the Park. Contractual arrangements were completed in November 1960 for a 5-year study, but the need for water supplies in additional areas and the attendant drilling costs made it necessary to expand the study to a 10-year program.

Field work began in November 1960 and the first report concerning development of ground-water supplies in the Park was submitted by the Virginia Division of Mineral Resources in March 1961. Through December 1971, 53 reports were prepared covering 22 Park areas in which 65 drilling sites were recommended and 38 test holes and several springs described (Virginia Division of Mineral Resources and Shenandoah National Park Headquarters, open-file reports). During the preparation of the first few reports it became apparent that available geologic and topographic maps were inadequate and that small portions of the Park would have to be individually mapped prior to the location of drilling sites in each area where water wells were required. As later contracts necessitated hydrogeologic investigations at several localities in each of the three districts, it was evident an extensive geologic-mapping project must be undertaken and new topographic maps obtained on which to accurately record the geology and drilling sites. These tasks were performed concurrently with the ground-water studies, and completed five months before the last of the 38 test holes was drilled in October 1971.

HYDROGEOLOGIC DISPARITY

Hydrogeology has been defined as the science of the occurrence, distribution, and movement of water below the surface of the earth, and ground water as the water that occupies all voids within a given stratum (Todd, 1963, p. 1). Tenets have been established with regard to the application of this science and the development of this resource, but in many instances the application is theoretical and the development suited only to favorable environments. Certain criteria are accepted as necessary for the installation of a successful water well in consolidated rocks, among which are permeable strata, source of perennial recharge, large drainage area, shallow surface gradients, and a thick soil cover (Davis and De Wiest, 1966, ch. 8-10). The strata may possess either primary or secondary permeability, and the source of recharge might be an adjacent stream or a widespread exposed aquifer in an area of considerable, well-distributed annual rainfall. Shallow gradients of the land surface within a drainage area is necessary to prevent rapid surface-water run-off, and a relatively thick soil cover is required to absorb the surface water and release it slowly to voids in the underlying bedrock. Examination of the area maps (Figures 6-9, 12-20, 22-31) and the 38 geologic logs (Appendix III) reveal the existence of a disparity between these criteria and the hydrogeologic conditions that occur in Shenandoah National Park.

Not mentioned in the criteria above is superposition, i.e., the greater number of these favorable conditions that occur at a given site, and the better developed each is, the more successful a production well will be. In order to locate and utilize such superposition the hydrogeologist must be permitted to select a drilling site at any location in a relatively large area and to recommend drilling to considerable depths if subsurface conditions so warrant. The Park's hydrogeologic disparity had its origin here with environmental controls, topographically inaccessible areas, lack of roads and electric power, existing facilities, drain fields, and such, which gave Park officials no choice but to require wells to be located only in certain portions of relatively small areas. That most of these areas were adjacent to Skyline Drive meant nearly all the wells had to be drilled along the crest of the Blue Ridge Mountains, which in many instances eliminated any large drainage area, shallow gradients, adequate recharge, and thick soil cover. With regard to strata, few rock units with any significant primary permeability occur in the Park, and those are too far west of Skyline Drive to have been considered. It was therefore necessary to locate drilling sites solely on the basis of secondary permeability (faults, fractures, joint systems, cleavage planes, shear zones, or weathered contacts), but not where they may occur at great depths because monetary considerations permitted few deep test holes (Table 1).

In summary, regardless of the fact that seldom were any of the favorable well-location criteria available for exploitation, it was necessary to develop wells of (1) permanent yield, (2) from moderate depths, (3) in virtually impermeable igneous and metamorphic rocks, (4) near the crest of a steep-sided ridge, and (5) at elevations usually between 500 and 2000 feet above the regional water table. There would seem to be some credance to the statement, "Few tasks in hydrogeology are more difficult than locating drilling sites for water wells in igneous and metamorphic rocks" (Davis and De Wiest, 1966, p. 318).

WELL CONSTRUCTION AND DEVELOPMENT

Several types of drilling equipment are used to construct water wells, but air rotary machines are probably the most desirable for wells of moderate depth and diameter in igneous and metamorphic (hard) rocks (Missouri Water Well Drillers Association, 1963, p. 86). All 38 test holes in the Shenandoah National Park were drilled with this type of equipment, and the 34 that penetrated only hard rock under the thin residual overburden were completed quickly with only a depth problem on two of the deeper wells. Hard-rock wells are the least complicated to construct as it is only necessary to case off the surficial unconsolidated overburden, as the remainder of well bore is in solid rock. Bedrock was encountered at depths less than 45 feet in 31 of the 38 Park test holes, necessitating less than 55 feet of casing in each.

To develop a test hole into a water well, the upper portion of the hole is reamed to a depth and diameter sufficient to accommodate grouted casing a minimum of 4 or 5 feet into unweathered bedrock. Additional casing or a liner may be required if near-surface rock fractures present a potential pollution hazard, or if zones of rock weakness are encountered at greater depths. When large resistant boulders are buried in thick overburden at the base of a cliff or mountain, as was the case in three Park test holes, it may be desirable to use a cable-tool drilling rig to penetrate this material as an air-rotary bit may be deflected to the side or wedged between boulders, or air pressure may be lost because a jacket pipe cannot be installed.

In addition to its much greater rate of hard rock penetration, the amount of water encountered can be quickly estimated during drilling with air-rotary equipment; as the air pressure blows rock chips out of the well bore during drilling, any water

Table 1. RECORDS OF TEST HOLES DRILLED IN SHENANDOAH NATIONAL PARK, VIRGINIA, 1961 - 1971

DISTRICT AND MAP NO.	TEST-HOLE DESIGNATION	EL. (ft.)	TEST-HOLE DIMENSIONS		WATER WELL DEVELOPMENT					DRILLING CONTRACTOR
			TD	CASING	SWL	Yld.	PL	TEST	HS	
NORTH										
W-1138	Fox Hollow - 1	1730	200	6 1/4" x 20'	1.5	2.0	161.5	Pump	5.0	F. W. Martin
W-1139	" 2	1630	300	6 1/4" x 14'	17.9	.2	-	Air	-	"
W- 863	Dickey Ridge - 1	1850	250	6 1/2" x 52 1/2'	96.0	1.0	-	Air	-	Sydnor P & W Co.
W- 864	" 2	2030	250	6 1/2" x 39'	247.0	.2	-	Air	-	"
W-1346	" 3(w)	1840	650	6 1/4" x 52'	200.0	35.0	55.0	Pump	1.0	Valley Drilling Co.
W- 850	Mathews Arm - 1	2730	200	6 1/2" x 59'	15.0	3.0	-	Air	-	Sydnor P & W Co.
W- 856	" 2(w)	2590	200	6 1/2" x 26 1/4'	1.5	23.0	39.9	Pump	12.5	"
W-1703	Elkwallow - 1(w)	2570	363	6" x 43'	44.0	10.0	298.0	Pump	11.0	F. W. Martin
W- 851	Headquarters - 1(w)	1135	280	6 1/2" x 52'	59.0	9.0	107.7	Pump	3.5	Sydnor P & W Co.
W- 855	" 2(w)	1120	220	6 1/2" x 52'	39.9	15.0	127.7	Pump	4.0	"
CENTRAL										
W- 948	Thornton Gap - 1(w)	2050	333	6 1/2" x 28'	19.7	5.5	271.5	Pump	2.0	Sydnor P & W Co.
W-3289	Pinnacles - 1(ow)	3280	220	Pulled	29.1	12.0	-	Air	-	C. R. Moore
W-3288	" 2(w)	3300	145	6" x 60 1/2'	19.0	12.0	-	Air	-	"
W- 591	Skyland - 1	3460	70	6" x 39'	19.7	7.0	-	Air	-	Valley Drilling Co.
W- 592	" 2(w)	3490	233	6" x 51 1/2'	29.0	20.0	146.0	Pump	66.5	"
W- 593	" 3	3480	162	6" x 43 1/2'	38.8	2.3	-	Air	-	"
W-1033	" 4(w)	3560	500	7" x 52'	84.0	25.0	398.0	Pump	6.0	F. W. Martin
W- 869	Comers Dead. - 1(w)	3240	250	6 1/2" x 52'	.5	16.5	169.6	Pump	5.0	Sydnor P & W Co.
W- 876	" 2	3160	250	6 1/2" x 52'	10.0	3.0	-	Air	-	"
W-1136	" 3(w)	3220	365	6 1/4" x 30 1/2'	9.0	30.0	212.5	Pump	5.0	F. W. Martin
W-1347	Big Meadows - 1(w)	2730	265	6 1/4" x 52'	50.0	50.0	149.9	Pump	1.0	Valley Drilling Co.
W-1348	" 2	3390	500	6 1/4" x 70'	500.0	-	-	-	-	"
W-1701	" 3(w)	3515	100	6" x 68'	18.0	92.0	24.9	Pump	20.0	F. W. Martin
W-1702	" 4	3440	350	6" x 36'	111.0	2.0	323.5	Pump	2.0	"
W-1072	Lewis Mt. - 1(w)	3390	300	7" x 52'	66.0	10.+	205.-	Pump	-	"
SOUTH										
W- 865	Swift Run Maint.-(w)	1475	60	6 1/2" x 43'	7.0	8.0	?	Pump	-	Sydnor P & W Co.
W-1704	Simmons Gap - 1(w)	2230	205	6" x 43'	14.0	25.0	113.0	Pump	1.0	F. W. Martin
W- 704	Loft Mt. - 1	3010	250	6" x 19'	-	0.0	-	Air	-	M. O. Seek
W- 710	" 2	3000	160	6" x 35'	60.0	.5	-	Air	-	"
W- 715	" 3(w)	2740	303	6" x 65'	12.0	15.0	131.0	Pump	2.0	"
W- 718	" 4(ow)	2746	250	6" x 30'	10.0	15.0	125.0	Pump	-	"
W- 754	" 5(w)	2670	320	6" x 34 1/2"	11.5	22.0	108.6	Pump	9.0	Sydnor P & W Co.
W-1073	Dundo - 1(w)	2770	615	7" x 55'	351.0	20.0	433.0	Pump	4.0	F. W. Martin
W-1074	" 2	2595	340	Pulled	-	-	-	-	-	"
W-1810	" 3(eh)	2770	104	5" x 14'	-	-	-	-	-	Sydnor P & W Co.
W-1811	" 4(eh)	2730	118	Pulled	-	-	-	-	-	"
W-1654	Grottoes - 1(ow)	1225	350	5" x 235'	150.0	3.0	-	Air	-	"
W-1137	Rockfish Gap - 1(w)	2080	535	6 1/4" x 30 1/4'	376.0	3.0	453.0	Pump	6.0	F. W. Martin

(w) - water well (ow)- observation well (eh)- exploration hole EL. - Elevation above sea level

Yld. - yield in gallons per minute (gpm) PL - Pumping Level (ft.) HS - Hours of Stabilization

DATE DRILLED	GEOLOGIC CONDITIONS ENCOUNTERED			REMARKS	DISTRICT AND MAP NO.
	DB	ROCK FORMATIONS	W-B FRACTURES (ft.)		
7/16/64	15	Catoctin	From residuum	Capped	W-1138
7/22/64	3	"	?	"	W-1139
7/5/63	6	"	125,199	Obstruction at 12'; capped	W- 863
7/12/63	6	"	?	Capped	W- 864
8/24/65	23	"	600-605,625-630	Put into use at 15 gpm	W-1346
6/17/63	50	"	68-69,94-95	Capped	W- 850
6/10/63	15	"	42,47,73,109,164	Put into use at 18 gpm	W- 856
7/21/66	35	"	70-75,140-145	Put into use at 10 gpm	W-1703
6/5/63	11	"	56,89,107,117,150	Recorder installed 8/28/63	W- 851
6/14/63	20	"	60,189	Put into use at 14 gpm	W- 855
					CENTRAL
2/11/64	15	Catoctin	25,145,195,230,270	Not currently in use	W- 948
10/27/71	78	Pedlar and Catoctin	50,75	Temporary observation well	W-3289
10/28/71	56	"	50,67	Not currently in use	W-3288
6/14/61	21	Pedlar	37,46,52	Bit stuck in hole; abandoned	W- 591
6/22/61	31	"	56,64,67,85,135,150,220	Pumped at 20 gpm periodically	W- 592
6/31/61	37	"	117	Capped; affects spring flow	W- 593
5/25/64	30	Swift Run and Pedlar	64,99	Put into use at 14 gpm	W-1033
8/2/63	22	Catoctin	40,53,58,80,102	Not currently in use	W- 869
8/21/63	25	"	55,84,114,193,210	Capped	W- 876
8/26/64	20	"	133,285	SWL + 0.9 to Sept. 1963:capped	W-1136
8/20/65	45	Catoctin and Pedlar	200-205,215-220	Capped; obstruction at 52'	W-1347
8/26/65	70	Catoctin	?	Water lost;bottom-hole fracture	W-1348
6/27/66	60	"	35-40,70-80	Put into use at 55 gpm	W-1701
7/11/66	25	"	160-165	Capped	W-1702
6/1/64	15	Swift Run and Catoctin	54,104,?	Put into use at 15 gpm	W-1072
					SOUTH
7/16/63	28	Catoctin	35-40,46-49	Not currently in use	W- 865
7/14/66	30	"	190-195	"	W-1704
8/24/62	10	"	-	Capped	W- 704
3/29/62	31	"	65-69	"	W- 710
9/10/62	14	Weverton and Catoctin	123,134	Put into use at 16 gpm	W- 715
9/14/62	10	"	38,64,155	Recorder installed 6/24/64	W- 718
11/27/62	14	"	46,50,53,56,115	Pumped at 8 gpm in 1971	W- 754
6/18/64	10	"	70,240,509,?	Pumped at 6 gpm in 1970	W-1073
6/11/64	10	Catoctin	190-200	Borehole filled in	W-1074
11/30/64	10	Weverton	-	Stratigraphic borehole	W-1810
12/1/65	4	Weverton and Catoctin	-	"	W-1811
7/2/66	200	Rome	?	Recorder installed 5/22/67	W-1654
9/3/64	25	Catoctin	510	Not currently in use	W-1137

ft. - feet TD - Total Depth (ft.) SWL - Static Water Level (ft.)

DB - Depth to Bedrock (ft.) W-B - Water Bearing is similarly and simultaneously expelled. When drilling is terminated the air hammer can be raised to any level in the hole and, with continued air pressure, blow the water to the surface where it can be measured by a bucket or temporary weir. As some air is lost in rock crevices, the rough sidewalls inhibit the upward flow of water, and the test is usually of insufficient duration, this method should only be used to obtain yield and drawdown estimates by which test-pump equipment can be properly selected and installed. Before the pump test is conducted, geophysical logs of the open hole should be made, as they were for 25 of the 38 test holes, eight of which are shown in Appendix II. Resistance, self-potential and gamma-ray logs are made by means of probes lowered in the well bore at the end of an armored cable through which the impulses are transmitted to recording instruments at the surface. Because of the diversity of mineralization in most igneous and metamorphic rocks, geophysical logs of this type are difficult to interpret, but correlations of gross structure and lithology between test holes may be of considerable importance to wells drilled nearby at a later date. If proper sampling techniques are employed, these correlations may be verified by geologic logs prepared from microscopic examination of sample drill cuttings collected during drilling, as was done for each of the Park test holes (Appendix III).

Few of the standard development procedures are either necessary or effective in open-bore hard rock wells, although the use of explosives is sometimes employed to increase the specific capacity when there is reason to believe fracturing of the sidewalls may intercept nearby water-bearing crevices. None of the Park test holes were dynamited because the bedrock was judged too resistant for inducement of fractures more than a few inches or feet from the well bore. Probably the most common, singular development procedure for wells of this type is a pump test, such as was conducted on 23 of the 38 Park test holes using a submersible pump, air line and pressure gage (Appendix IV). Based on data obtained during drilling, a pump of selected capacity was lowered into the test hole to a predetermined depth. Attached to the pump assembly was a 0.25-inch copper line connected to a pressure gage at the surface; pressure readings were taken at regular intervals and computed to indicate the drawdown during pumping. Pump tests of 24-hour duration were planned with the anticipation that eight hours of drawdown stabilization could be achieved, but equipment problems, and the unpredictable nature of fracture aquifers prevented such a stabilization from being reached in several tests. It should be pointed out that seldom can results of a 24-hour pump test be accepted as conclusive evidence of specific capacity of newly-completed hard rock wells. Not only do water-filled fractures vary in length, but some are no longer connected with a source of recharge. A 24-hour test may therefore be inadequate to dewater such "blind" fractures, in which case a reduction in yield will occur sometime after the well has been put into production. Also, water samples should be collected for chemical and bacteriological analyses for each new well, and the best time to do this is at the conclusion of the pump test. This was done for only 14 of the test holes drilled in Shenandoah National Park (Table 2).

According to statistical studies conducted on wells in south-central Virginia, only 33 percent of the wells drilled in igneous and metamorphic rocks yield more than 14 gpm; in North Carolina wells at or near hill crests have lower average yields than wells in any other topographic location (Davis and De Wiest, 1966, p. 323-327). Of the 33 test holes and one stand-by observation well drilled for the development of water supplies in the Park, 50 percent had initial yields greater than 12 gallons per minute. The writer submits, however, that in an unfavorable ground-water environment such as this project encompassed, a "successful" test hole is one which can be converted into a production well capable of furnishing a useable quantity of water. In this respect, 20 of the 33 Park test holes drilled have been or could be developed into successful water wells.

DRILLING RESULTS

In June 1961 the Valley Drilling Corporation began drilling Skyland Test Hole No. 1, and in November 1971 the C. R. Moore Well Drilling Company completed testing Pinnacles Test Hole No. 2. In the intervening 10.5 years these and three other contractors drilled 31 additional test holes, two exploratory holes, and three observation wells in 15 other areas throughout the three districts of Shenandoah National Park (Table 1). Twenty-eight preliminary and reconnaissance reports prepared by the Virginia Division of Mineral Resources preceded these drilling operations, and 18 final and two addendum reports succeeded them. Geologic maps were prepared for each area and drilling results for each test hole were evaluated (Appendices I-IV). These data are here summarized in the same north-to-south order

TABLE 2. CHEMICAL ANALYSES OF WATER SAMPLES FROM WELLS AND SPRINGS IN SHENANDOAH NATIONAL PARK, VIRGINIA, 1962-1968*

DISTRICT AND MAP NO.	WATER-BEARING LITHOLOGY	pH	TH	CH	TDS	T	SiO_2	Mn	Fe	SO_4	NO_3	PO_4	Cl	F	ANALYST + AND DATE	DISTRICT AND MAP NO.
NORTH																NORTH
W-1138	Saprolite	7.0	20.0	18.0	-	Trace	6.6	0.25	Trace	Trace	Trace	Trace	-	-	(1)- 8/64	W-1138
W-1346	Epidosite and basalt	7.65	75.0	50.0	82.0	0.16	8.1	0.0	0.005	5.0	1.20	0.55	4.5	0.1	(2)- 9/68	W-1346
W- 856	Saprolite and basalt	7.25	-	-	50.8	2.4	-	0.002	0.028	5.0	0.8	-	1.4	0.1	(2)- 9/68	W- 856
W-1703	Basalt	8.2	33.6	-	67.0	-	3.5	0.01	0.35	7.2	0.3	-	-	Trace	(3)- 9/66	W- 703
CENTRAL																CENTRAL
W- 948	Saprolite and basalt	6.7	40.0	5.0	-	-	1.5	0.0	0.10	25.0	0.01	0.2	-	-	(1)- 2/64	W- 948
W-1033	Phyllite	6.8	30.0	10.0	-	-	1.0	0.00	0.20	15.0	0.03	0.80	-	-	(1)- 6/64	W-1033
S-19	-	7.1	-	-	32.8	0.14	-	0.00	0.17	5.0	1.1	-	2.1	0.1	(4)- 9/68	S-19
W-1136	Basalt and sub-arkose	8.0	21.0	20.0	-	0.0	3.0	0.25	0.10	4.0	0.01	0.01	-	-	(1)- 8/54	W-1136
W-1346	Granodiorite	7.3	60.0	50.0	-	0.0	6.4	0.0	0.10	3.0	0.004	0.55	-	-	(1)- 9/65	W-1347
S-23	-	7.6	-	-	19.2	0.12	-	0.02	0.34	5.0	0.6	-	4.0	0.1	(4)- 9/68	S-23
W-1701	Basalt	8.3	69.5	-	90.0	-	0.5	Trace	0.02	4.5	0.7	-	5.0	Trace	(3)- 9/66	W-1701
W-1702	Basalt	8.2	71.2	-	89.0	-	0.5	Trace	0.02	4.9	0.6	-	4.0	Trace	(3)- 9/66	W-1702
W-1072	Schist	7.2	50.0	20.0	-	-	1.3	0.25	0.25	10.0	0.02	0.5	-	-	(1)- 6/64	W-1072
SOUTH																SOUTH
W-1704	Basalt	8.3	43.0	-	76.0	-	1.0	Trace	0.02	2.7	0.4	-	4.0	Trace	(3)- 9/66	W-1704
W-1073	Phyllite and basalt	7.0	30.0	20.0	-	0.0	44.0	0.25	0.01	0.60	0.01	0.01	-	-	(1)- 8/64	W-1073
W-1137	Metamorphosed basalt and arkose	6.8	35.0	20.0	-	60.0	-	0.4	0.3	2.5	1.0	-	-	-	(1)- 9/64	W-1137
W- 754	Phyllite and schist	-	43.0	33.0	-	-	38.0	-	0.0	10.0	-	1.3	5.0	-	(4)-12/62	W- 754

* In parts per million, except for pH TH- Total Hardness CH - Calcium Hardness TDS - Total Dissolved Solids T - Turbidity

\+ (1) Va. Div. of Mineral Resources, (2) U. S. Public Health Service, (3) Froehling and Robertson, (4) National Park Service W - Well S - Spring (#1 & 4 are field analyses) as they are listed in Table 1; each area description is accompanied by a portion of a topographic map (Figures 6-9, 12-20, 22-24) on which the following symbols are used:

Boundary of drainage area	— — — —
Fault	U/D ———
Formation contact	———
Overturned syncline	
Overturned anticline	
Spring (Weir), location and number	30
Test-Hole, location and number	• W-1138
Cambrian Carbonates and Shales undifferentiated	Ꞓcsu
Hampton Formation	Ꞓh
Weverton Formation	Ꞓw
Catoctin Formation	ꞒpꞒc
Catoctin Sediments	cs
Swift Run Formation	ꞒpꞒs
Pedlar Formation	pꞒp

Fox Hollow-Dickey Ridge

In 1963 the Dickey Ridge Visitor Center obtained its water supply from a spring in Lands Run Gap, 3.75 miles to the southeast. As either necessary repairs or replacement of the long pipeline would be costly, it was considered desirable to drill a water well on the east side of Skyline Drive near the Visitor Center. Field studies revealed the upper portion of the west side, the crest, and the entire east side of Dickey Ridge to be comprised of southeastward-dipping, massive, metamorphosed basalt flows of the Catoctin Formation; no evidence of the underlying Swift Run Formation was found in this area, with only granite of the Pedlar Formation exposed beneath the basalt on the west side of the ridge. With a thin soil cover over impermeable and unfractured rocks at the crest of a steep-sided ridge, prospects of obtaining water from a relatively shallow well were considered poor, but a new water supply was needed. Drilling sites were selected at elevations of 1850 and 2030 feet on minor lineations in a small drainage area 0.7 and 0.8 miles southeast of the Visitor Center (Figure 6, W-863 and W-864). As any water-bearing fractures were most likely to occur either at depths less than 200 feet or greater than 700 feet, 250 feet was recommended as the maximum drilling depth.

Each Dickey Ridge test hole penetrated dense, fine-grained metamorphosed basalt of the Catoctin Formation from approximately 6 to 250 feet, and encountered only hairline cracks between 100 and 200 feet. As neither test hole furnished more than one gallon per minute, each was capped and temporarily abandoned. Sample drill cuttings were collected for preparation of geologic logs (Appendix III), but no pump tests or water analyses were conducted. Geophysical logs could not be made of the Dickey Ridge holes because an obstruction was lodged in the casing of Test Hole No. 1 at 12 feet, and the static water level in Test Hole No. 2 was 247 feet. The preliminary evaluations, which were corroborated by drilling results at these locations, suggested recharge conditions and drilling-depth requirements would be more favorable at sites of lower elevation.

Park officials decided drilling sites would be acceptable in Fox Hollow and two were selected approximately 0.45 and 0.55 miles northeast of the Visitor Center at elevations of 1730 and 1630 feet, still nearly 1000 feet above base level (Figure 6, W-1138 and W-1139). It was not feasible to locate wells further north because of the distance to the Visitor Center and the lack of electric power, or further east because of the Park boundary. Geologic conditions were the same as at the two Dickey Ridge test-hole sites, and a maximum drilling depth of 200 feet was recommended.

The two Fox Hollow test holes each penetrated only metamorphosed basalt of the Catoctin Formation; Test Hole No. 1 had 15 feet of overburden and was 200 feet deep, Test Hole No. 2 had 3 feet of overburden and was terminated at 300 feet. A 24-hour pump test indicated a yield of two gallons per minute from Test Hole No. 1 (Appendix IV), but as this water was obtained from the overburden it (1) may be intermittent and (2) would be sealed off when the casing was grouted into firm bedrock. A partial chemical analysis indicated the water was

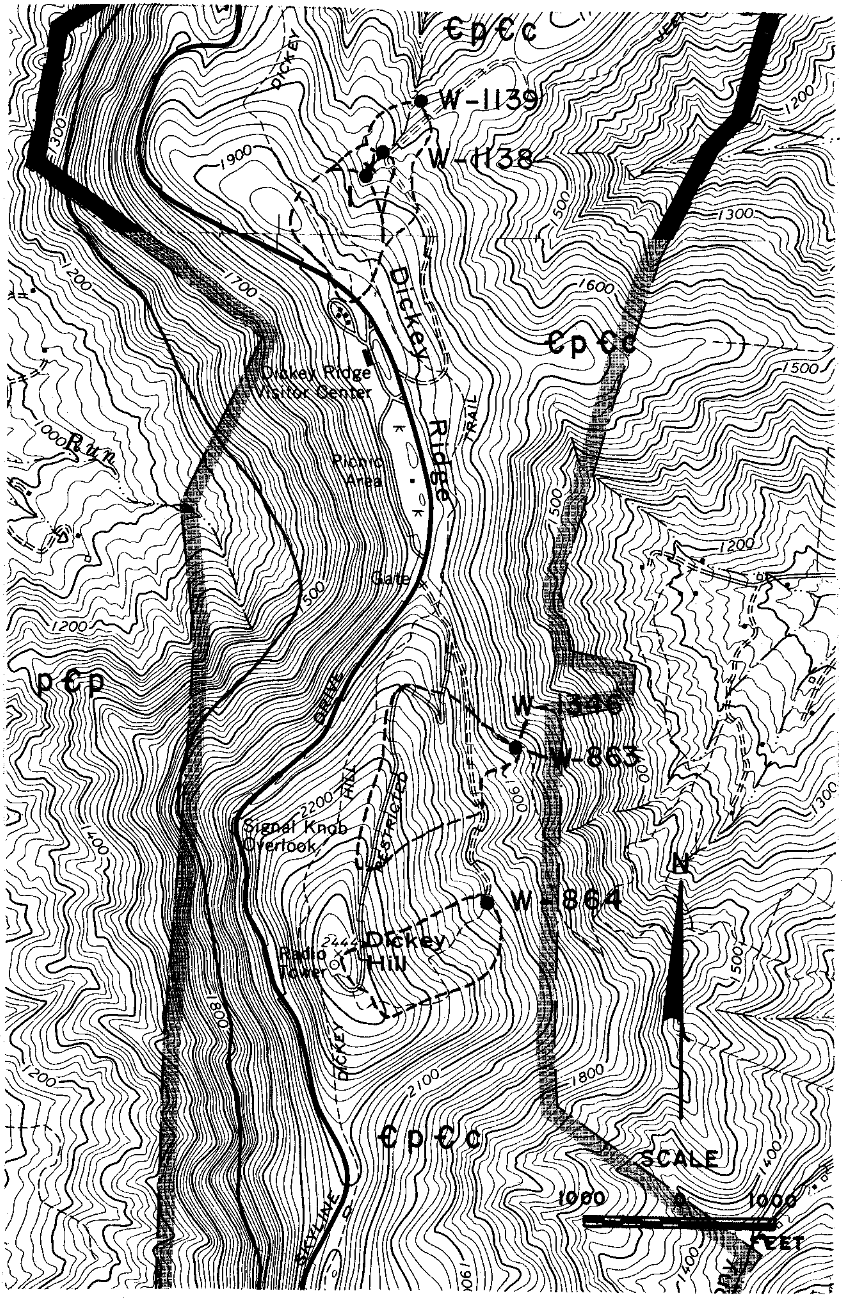

Figure 6. Fox Hollow-Dickey Ridge area showing geology, drainage, well and spring locations on portions of the Front Royal and Chester Gap, 7.5-minute topographic quadrangle maps.

soft and of good chemical quality (Table 2). No measurable quantity of water was encountered in Test Hole No. 2, so it was not possible to conduct a pump test or water analysis. Geologic (Appendix III) and geophysical logs confirmed field evaluations and drilling results with regard to the non-water-bearing properties of the unfractured, metamorphosed basalt in this area.

With four abandoned test holes to substantiate initial negative evaluations for wells of moderate depth on the east side of Dickey Ridge, approval was obtained to investigate the west side. Although hydrogeologic conditions were more favorable, the piping distance, inadequate electric power, and necessity to acquire drilling options were not. Accordingly, permission was granted to drill a 1000-foot exploratory hole near Dickey Ridge Test holes 1 and 2.

For a depth of 600 feet Dickey Ridge Test Hole No. 3 (Figure 6, W-1346) encountered the same rock formation as the two nearby test holes; massive, unfractured, metamorphosed basalt beneath 23 feet of overburden. Water-bearing fractures were then penetrated, a small one between 600 and 605 feet and a larger one between 625 and 630 feet; drilling was terminated at 650 feet. Examination of the sample drill cuttings (Appendix III) revealed no evidence of the thin-fracture aquifers, and geophysical logs were equally unrewarding. A 26-hour pump test was conducted at the end of which 41.5 gallons per minute was being discharged from a pumping level of 577 feet (Appendix IV). As only 10 gallons per minute are required at the Visitor Center, and an analysis indicated the water to be of good chemical quality (Table 2), Dickey Ridge Test Hole No. 3 was converted into a water well.

Mathews Arm

As no records were available to substantiate the permanence of flows for eight local springs, one or two test holes were needed to determine if ground water could be obtained for the proposed campground. Field studies revealed bedrock to be southwestward-dipping metamorphosed basalt of the Catoctin Formation in most of the area, with Pedlar granodiorite and metamorphosed sedimentary rocks of the Swift Run Formation present approximately 0.5 mile northeast of the area to be developed. Two test-hole sites were selected at intersections of minor lineations in the metamorphosed basalt, with 300 feet recommended as the maximum drilling depth.

Mathews Arm Test Hole No. 1 was drilled at an elevation of 2730 feet near the junction of Mathews Arm and Knob Mountain roads (Figure 7, W-850). Metamorphosed basalt was penetrated from 50 to 200 feet and small water-bearing crevices were encountered from 68 to 69 and 94 to 95 feet; three gpm was discharged with 175 feet of drawdown during a two-hour air test. As it was not anticipated this test hole would be converted to a water well, no pump test was conducted or water sample collected for analysis, but geophysical and geologic logs were prepared for study and correlation of subsurface data (Appendices II and III).

Mathews Arm Test Hole No. 2 was located near Jeremys Run at an elevation of 2590 feet (Figure 7, W-856). Only metamorphosed basalt was penetrated from 15 to 200 feet, but fracture aquifers were encountered at depths of 42, 47, 73, 109, and 164 feet. A 25.5-hour pump test was conducted during which the pumping-level stabilized for 13 hours at 38.5 feet, a drawdown of only 37.0 feet at a pumping rate of 23 gallons per minute (Appendix IV). Geophysical and geologic logs were prepared and successfully correlated as to the water-bearing fractures in this test hole (Appendices II and III). An analysis showed the water to be of excellent chemical quality (Table 2), and Test Hole No. 2 was successfully converted into a water well.

Elkwallow

In 1966 Park officials decided that the spring-fed water supply should be supplemented by wells if the wayside facilities were to be expanded. Although nearly all of these facilities are located on the northwest side of Skyline Drive, most of the field studies for test-hole drilling sites were on the southeast side where the electric power, reservoir and pipelines are located. Bedrock in the immediate area is metamorphosed basalt of the Catoctin Formation, but exposures of sedimentary rocks in the Weverton and Hampton formations occur approximately 0.5 mile southwest of the picnic grounds. Two drilling sites were selected near Piney River approximately 4000 feet east of Skyline Drive where rock structure and recharge conditions were most favorable, but Park officials requested other sites because the cost of building access roads was prohibitive. Two alternate sites were recommended with a 350-foot maximum drilling depth for each.

Elkwallow Test Hole No. 1 was drilled at alternate site No. 2, approximately 1000 feet southeast of Skyline Drive near the

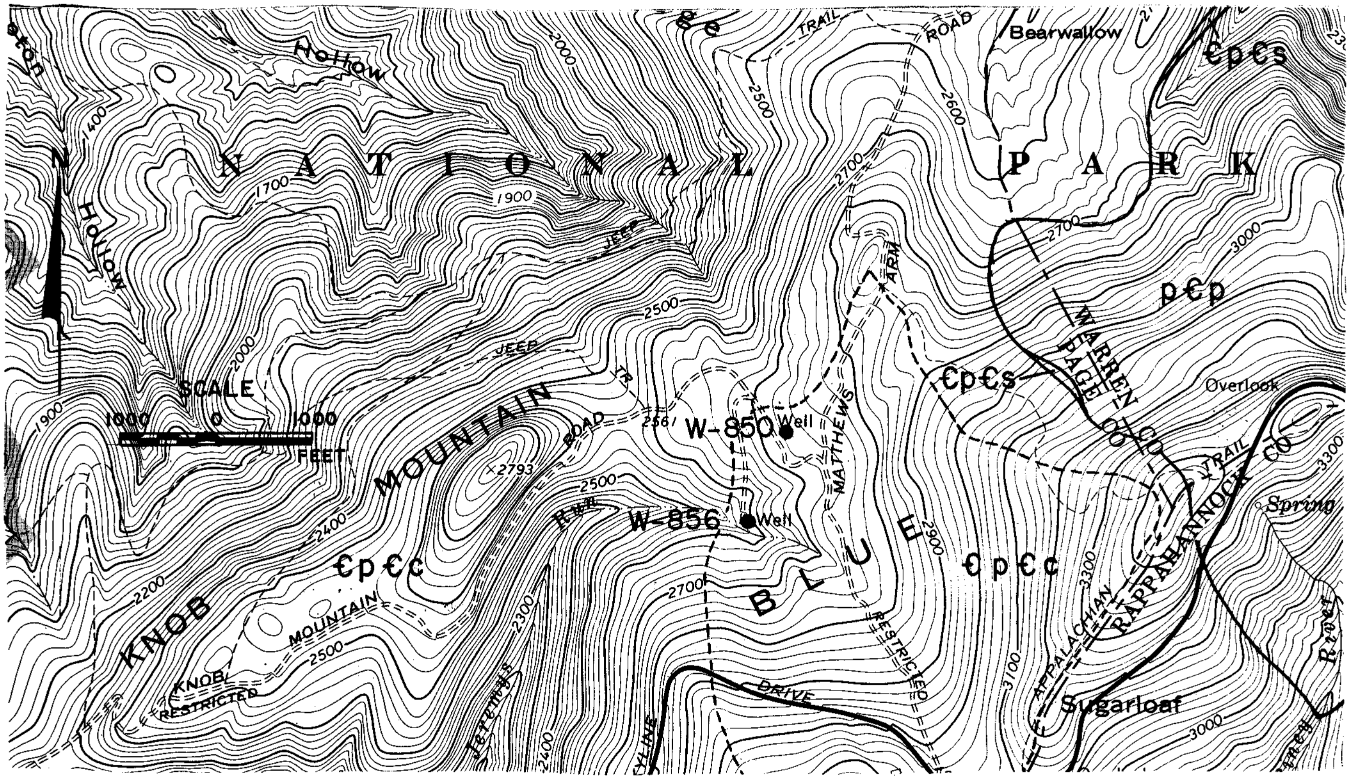

Figure 7. Mathews Arm area showing geology, drainage, well and spring locations on a portion of the Bentonville 7.5-minute topographic quadrangle map.

reservoir at an elevation of 2570 feet (Figure 8, W-1703). Metamorphosed basalt was penetrated from 35 to 363 feet, and water-

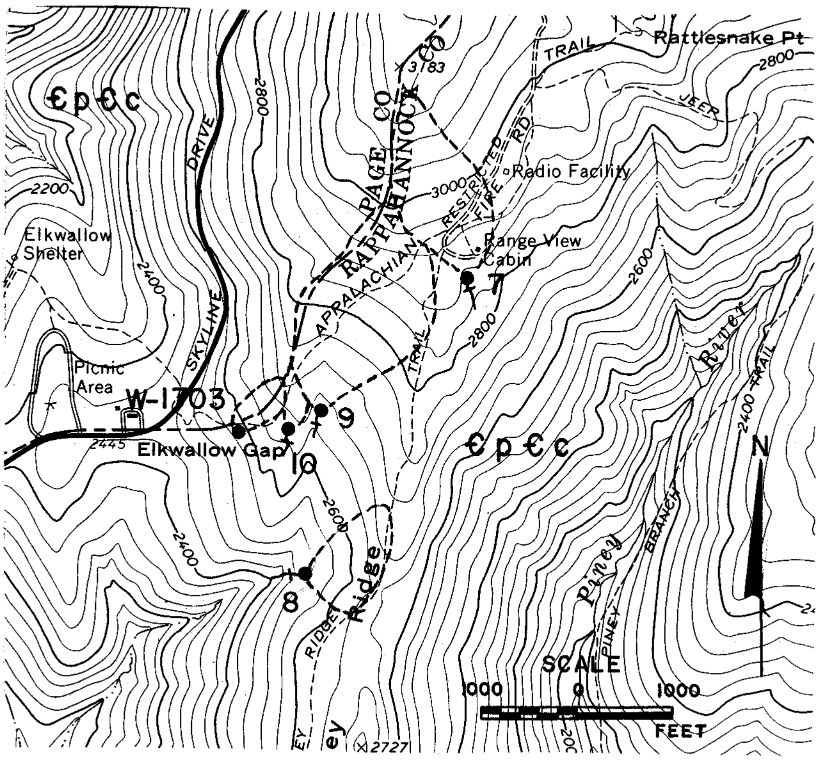

Figure 8. Elkwallow area showing geology, drainage, well and spring locations on a portion of the Thornton Gap 7.5-minute topographic quadrangle map.

bearing fractures were encountered from 70 to 75 and 140 to 145 feet below ground level. A 24-hour pump test was conducted during which the pumping level stabilized for 10.67 hours at 298 feet, a drawdown of 254 feet at a pumping rate of 10 gallons per minute (Appendix IV). Geologic (Appendix III) and geophysical logs were prepared and correlated, and an analysis proved the water to be of good chemical quality (Table 2) except for a slightly high iron-manganese content (American Water Works Association, 1951, p. 72). As Test Hole No. 1 could be converted into a well that provided an adequate water supply, no further drilling was required in this area.

Park Headquarters

As of 1962, two springs in Shenks Hollow furnished the Headquarters complex with a water supply that ranged from 5.5 to 17 gallons per minute through a mile-long pipeline that was partly on private property. It was desired to replace this often inadequate supply with a dependable yield from wells in the north portion of the Headquarters Area that is divided by U. S. Highway 211. Two rock formations cross the area, basalt of the Catoctin Formation on the east and sedimentary rocks of the Weverton Formation on the west. These resistant rock units, which are overturned and dip steeply to the southeast, are separated by approximately 200 feet of relatively soft phyllitic rocks in the uppermost part of the Catoctin Formation. These fractured, thin-bedded strata were considered the most likely to contain water-bearing openings to which ample recharge was available from Pass Run south of U. S. Highway 211. However, as all the residences, maintenance and administration buildings are located in the north portion, it was requested by Park officials that the test holes be drilled north of the highway. The water table was expected to be shallow beneath any drilling sites in the north portion because it is bounded by Pass Run and the Shenks Hollow drainage. Three test-hole sites were selected, two to penetrate the soft, laminated phyllites for maximum depths of 500 feet, and the third to encounter quartzites and phyllites and reach basalt at approximately 550 feet.

Headquarters Test Hole No. 1 was drilled in the northwest corner of the Headquarters area at an elevation of 1135 feet (Figure 9, W-851). In the absence of rock outcrops near this site the location of the narrow phyllitic-rock zone was an interpretation that proved to be in error as the bedrock encountered at 11 feet was hard, dense, metamorphosed basalt. However, water-filled fractures were penetrated at depths of 56, 89, 107, 117, and 150 feet, and drilling was terminated at 280 feet. A test pump was installed and after 20.5 hours of pumping 9 gpm was being discharged from a pumping level of 107.67 feet. With nearly four hours of stabilization at this rate with a drawdown of only 49 feet the discharge rate was increased to 25 gallons per minute, but the pumping level lowered to the pump intake at 206 feet in 1.5 hours (Appendix IV). Ten gallons per minute is considered a safe yield for this well from a pumping level of 145 feet. Geologic (Appendix III) and geophysical logs were prepared, but no chemical analysis was made.

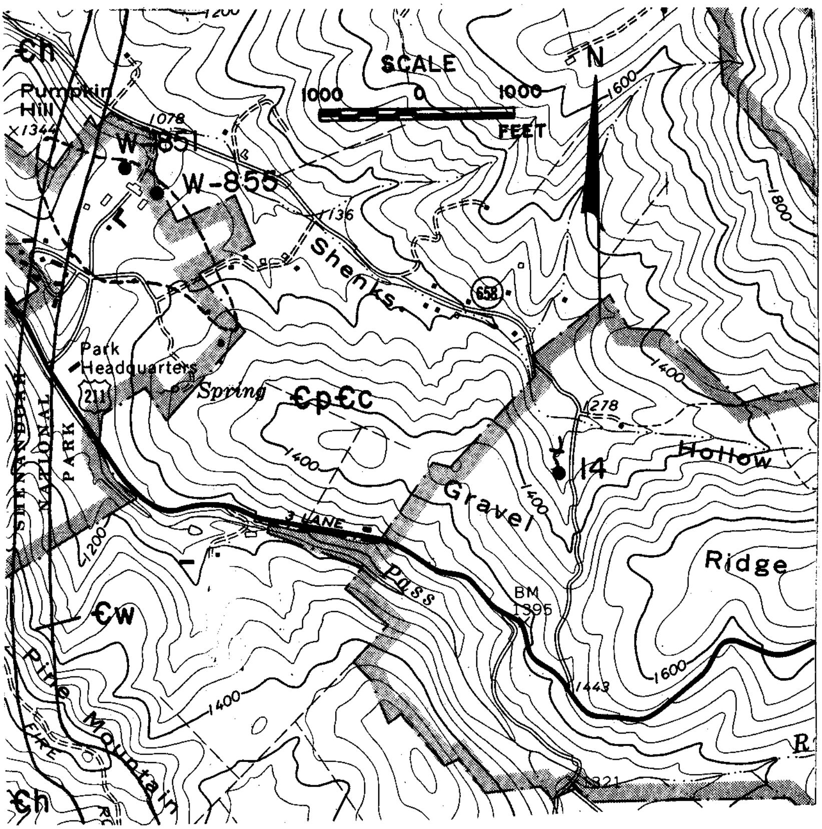

Figure 9. Park Headquarters area showing geology and well and weir locations on a portion of the Thornton Gap 7.5-minute topographic quadrangle map.

As the locations of two other drilling sites near U. S. Highway 211 were unacceptable to Park officials, Headquarters Test Hole No. 2 was drilled at an alternate site approximately 400 feet east of Test Hole No. 1 at an elevation of 1120 feet (Figure 9, W-855). Metamorphosed basalt was penetrated from 20 to 220 feet, and fracture aquifers were encountered at 60 and 189 feet below ground level. At the end of a 24-hour pump test the pumping level was rising while discharging at the rate of 23 gallons per minute (Appendix IV). Although the test was terminated before the pumping level had stabilized, this well has an estimated safe yield of 20 gallons per minute. Geologic (Appendix III) and geophysical logs were prepared, but no chemical analysis is available for water from this well.

After the pump test confirmed that Test Hole No. 2 could satisfy the water requirements of the Headquarters area, the Virginia Division of Mineral Resources installed an automatic water-level recorder in Test Hole No. 1 on August 28, 1963. Protected by steel housing provided by the National Park Service, over eight years of continuous water-level measurements were obtained aside from occasional interruptions because of mechanical problems. As most of these interruptions occurred during the first year of operation, the average monthly water levels are shown only for the last seven years of record (Figure 10).

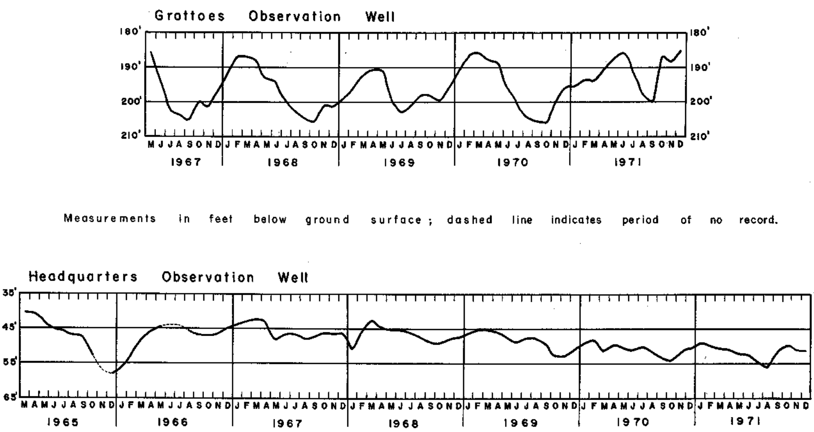

Figure 10. Monthly static water-level measurements in the Grottoes and Park Headquarters observation wells.

It is interesting to note that despite a gradual decline of the average monthly water levels during the last half of this period, the record terminates with a December 1971 water level that is eight feet higher than when the well was drilled (Table 1). Although the water level may occasionally fluctuate 15 or 20 feet in a given month, the usual monthly variance is 4 to 8 feet—about the same as the average annual fluctuation. Such a water-level cycle is a normal occurrence; the low levels are usually reached in September after several months of heavy pumping, low rainfall, and high evapotranspiration, and the high levels by March after a period of opposite conditions.

One of the most significant, and certainly the most rapid water-level changes from Test Hole No. 1 occurred at 10:50 p.m. EST on March 27, 1964 when shock waves from the Alaskan earthquake reached the Headquarters area. Figure 11 is a tracing of this well's March 26-29 chart on which the instantaneous 0.6-foot water-level displacement is readily discernable. Al-

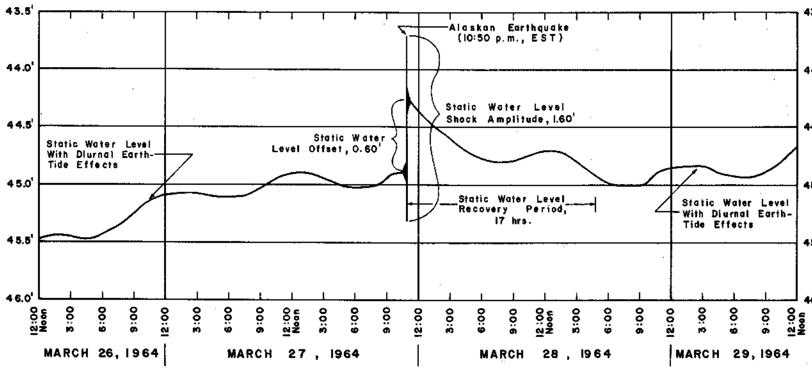

Figure 11. Affect of the March 27, 1964 Alaskan Earthquake on the water level in the Park Headquarters observation well.

though somewhat masked by the diurnal earthtide effects, the water-level's gradual return to an estimated normal position is recorded in approximately 14 hours following the shock waves' impact. As the water well (Test Hole No. 2) is only 300 feet away and in the same rock formation, its water level was probably subjected to a similar temporary dislocation, but there is no record of any variation in the production of this well.

In 1970 Park officials decided a stand-by well should be available in the Headquarters area in the event of increased water requirements or a decrease in yield from Test Hole No. 2. Two drilling sites were selected on the basis of previous mapping and test-hole drilling, but alternate sites were requested in 1971 because of potential landscape scars to one and the inaccessability of the other. The Virginia Division of Mineral Resources then suggested utilization of the observation well (Test Hole No. 1) as it was planned to remove the water-level recorder at the end of that year. This test hole, with a previously determined safe yield of 10 gallons per minute, should serve adequately in a standby capacity as Headquarters water well No. 2.

Thornton Gap

The Panorama complex in Thornton Gap obtains its water supply from springs on Pass Mountain to the north, but in late

1963 it was necessary to haul water from the recently-completed Headquarters production well three miles away, after a prolonged period of subnormal rainfall caused a decrease in the flow from these springs. In order to avoid similar water shortages in the future a standby well was needed that could furnish 5 to 10 gallons per minute in times of deficient spring flow. Field studies indicated the only formations present in the area had been faulted into their present position, the Pedlar granodiorite having been thrust to the northwest over the Catoctin basalt. These massive and resistant rock units are nevertheless brittle and have been shattered to some degree in a narrow zone on either side of the fault that crosses the mountain through Thornton Gap on the south side of U. S. Highway 211. As the rock openings in this shattered zone would act as a subsurface reservoir, a well that penetrated the fault near a source of perennial recharge would probably furnish more water than required for the Panorama facilities. Springs on the slopes of Marys Rock Mountain coalesce into two small creeks, but at their juncture about 1100 feet west of the restaurant, outcrops of basalt and granodiorite are separated by a 100-yard-wide boulder-strewn gully beneath which the fault trace is buried. Test-hole sites were selected in a northwesterly-southeasterly direction to be certain one test hole would begin in the edge of the Pedlar granodiorite and penetrate the steeply southeastward-dipping fault at a depth of approximately 100 feet.

Thornton Gap Test Hole No. 1 was located approximately 1100 feet west-southwest of the restaurant and 500 feet southeast of U. S. Highway 211 at an elevation of 2050 feet (Figure 12, W-948). Large basalt boulders prevented the drill hole from reaching bedrock at the original site, and the same conditions caused drilling to be abandoned at alternate site 1, a short distance to the south. This bouldery overburden was finally penetrated at alternate site 2 about 60 feet northeast, but this amount of site relocation was apparently too great as metamorphosed basalt instead of granodiorite was encountered at 24 feet. Because it was likely the basalt would be shattered to some extent this short distance from the fault where recharge conditions were still favorable, it was decided to continue drilling to at least 300 feet at this alternate site 2. Small water-bearing fractures were penetrated at 25, 145, 195, 230, and 270 feet; when no more had been encountered by a depth of 333 feet, drilling was terminated with an estimated yield of six gpm. In a subsequent 18-hour pump test 5.5 gallons per minute was discharged from a pumping level that had stabilized at 271.49 feet for two

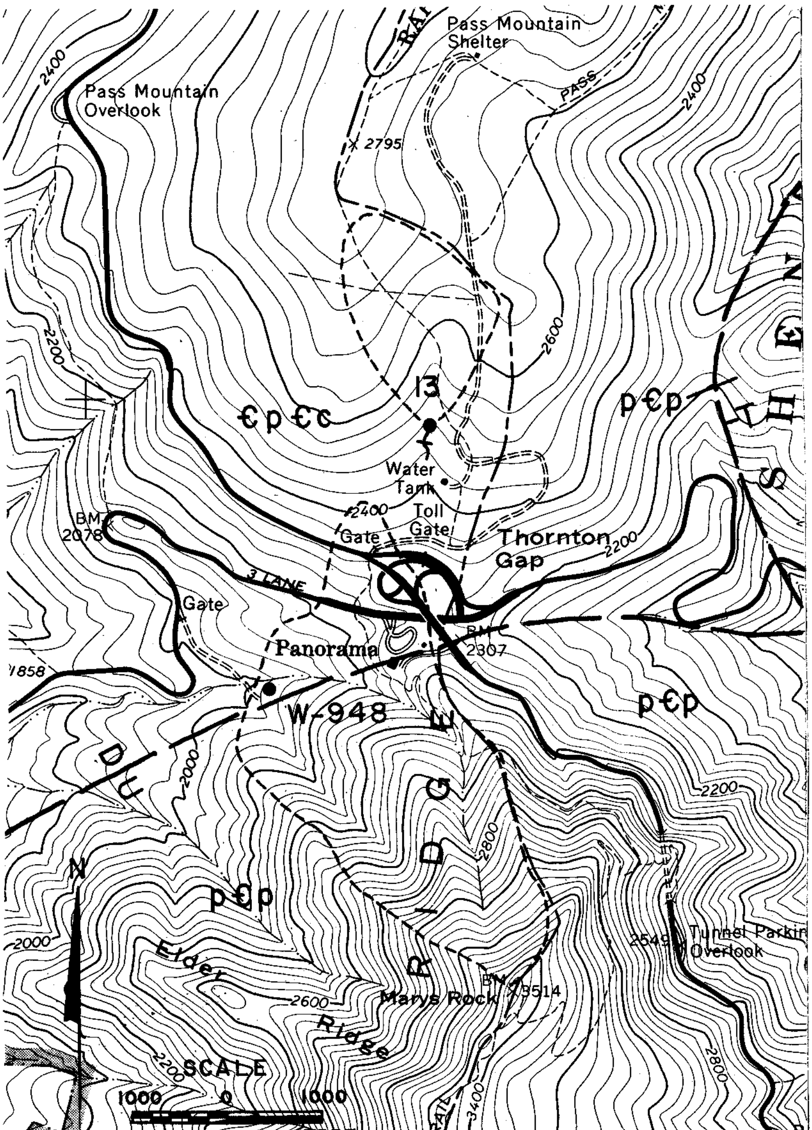

Figure 12. Thornton Gap (Panorama) area showing geology, drainage, well and spring locations on a portion of the Thornton Gap 7.5-minute topographic quadrangle map.

hours (Appendix IV). As the well was completed during the time of year when the water level is highest, it was not considered likely this well had a safe yield in excess of the minimum requirement of five gpm, although a recovery rate of 8.39 gallons per minute was measured for the first 15 minutes after the pump test. Geologic (Appendix III) and geophysical logs were prepared and a partial chemical analysis was made of a water sample collected during the pump test (Table 2). No other test holes were drilled because it appeared this well and the springs would provide sufficient water for all the Panorama facilities in Thornton Gap.

Pinnacles

The water supply for the Pinnacle Picnic Grounds had been furnished by springs in the nearby Sexton Shelter area for about 28 years when recommendations were made to recondition the collection galleries and recepticles in 1961. Some of this work was accomplished, but complete reconditioning or replacement plus new pipelines would be costly, and in 1970 drilling sites were requested by Park officials for wells to supplement or replace this water system. A well near the Pinnacle Ranger Station was desired, but if necessary a site would be acceptable anywhere along the crest of the ridge west of Skyline Drive between the Ranger Station and the Picnic Grounds. Field investigations revealed the entire ridge crest is underlain by relatively unfractured Pedlar granodiorite, and with only a few acres drainage the prospects for a successful well were poor. A drilling site was located on a minor fracture trace west of the Ranger Station, about 300 feet north of Skyline Drive; a preferred drilling site was selected in a larger drainage area about 1500 feet east of Skyline Drive where the bedrock was more fractured. Minimum drilling depths recommended for these two sites were 300 and 150 feet, respectively.

Pinnacles Test Hole No. 1 was drilled as an observation well at a site selected by Park officials near the Ranger Station at an elevation of 3280 feet, about 200 feet north of Skyline Drive (Figure 13, W-3289). The granodiorite that was encountered beneath an unusually thick zone of soil and partially weathered rock (78 feet) was unfractured and, as anticipated, had furnished no water when drilling was terminated at 220 feet. Water was present in the thick overburden, however, and entered the drill hole at depths of 50 and 75 feet. As the 6-inch diameter casing was not grouted into the 9-inch well bore, 12 gpm was estimated to have been discharged during a short air-lift test. Properly grouted into bedrock, the casing would seal off the two overburden aquifers and relegate this well to a dry hole.

Pinnacles Test Hole No. 2 was drilled near the site selected for Test Hole No. 1, at an elevation of 3300 feet about 70 feet north of the observation well (Figure 13, W-3288). Pedlar

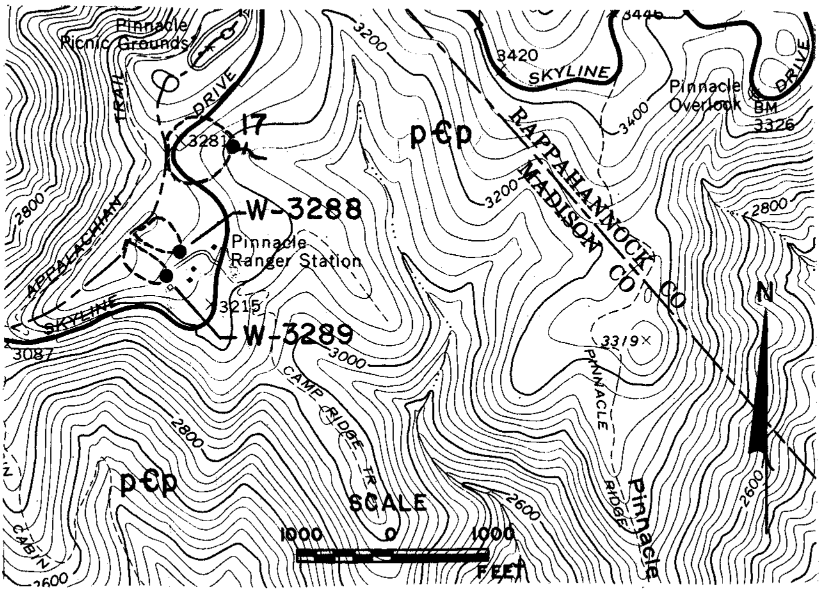

Figure 13. Pinnacles area showing geology, drainage, well and spring locations on a portion of the Old Rag 7.5-minute topographic quadrangle map.

granodiorite was encountered at 56 feet in this test hole, but for some unknown reason drilling was terminated at 145 feet although a minimum depth of 300 feet had been recommended. Once again water from the overburden entered the drill hole at 50 feet, and one small water-filled fracture was also penetrated at 67 feet. An estimated 12 gpm was air-lifted for a short time, but if the casing had been grouted into bedrock about half of this yield would have been eliminated. Geologic logs were prepared (Appendix III), but results of the pump tests and water analyses are not available. Following the pump test of this well, the casing is reported to have been pulled from the observation well and the hole filled in.

Skyland

Water resources surveys prior to the opening of Shenandoah National Park found Skyland to be one of two places in the Park where water supplies were sufficient for large congested areas (file report of the Shenandoah National Park prepared by the U. S. Geological Survey, Dirzulaitis, 1935). In the fall of 1959, however, the principal source of water (Furnace Spring) had a flow of approximately 10 gallons per minute, and as the Skyland complex included lodging and dining facilities for several hundred people it was apparent a supplemental water supply must be obtained. A reconnaissance study indicated other springs could be developed for this purpose, but most had small flows during the summer months, were east of Skyline Drive, and would require construction of collection galleries, weirs, power, and pipelines. It was decided test holes should be drilled to explore the possibilities of obtaining ground-water supplies near existing facilities west of Skyline Drive. Field investigations disclosed that three rock formations in the area have a northeasterly direction; the Catoctin metamorphosed basalt, Swift Run metamorphosed sedimentary rocks, and Pedlar granodiorite. Unfractured basalt and granodiorite are virtually non-water bearing, and much of the primary permeability of the sedimentary rocks had been destroyed by metamorphism. Of the three, the Swift Run Formation appeared most favorable for the location of successful wells, and two test-hole and two observation-well sites were selected to assess its potential.

Skyland Test Hole No. 1 is located 2000 feet northwest of the north entrance to Skyland from Skyline Drive, at an elevation of 3460 feet (Figure 14, W-591). No nearby exposures of bedrock were available by which the boundaries of the relatively thin Swift Run Formation could be located, and granodiorite was encountered beneath 21 feet of cobbly overburden. Small water-bearing fractures had been penetrated at 37, 46, and 52 feet before the drill bit became lodged in the well bore at 70.1 feet, terminating drilling with an estimated yield of six gpm. A geologic log was prepared from examination of sample drill cuttings collected during drilling (Appendix III).

Skyland Test Hole No. 2 is located approximately 130 feet southeast of Test Hole No. 1 (W-591) where an observation well

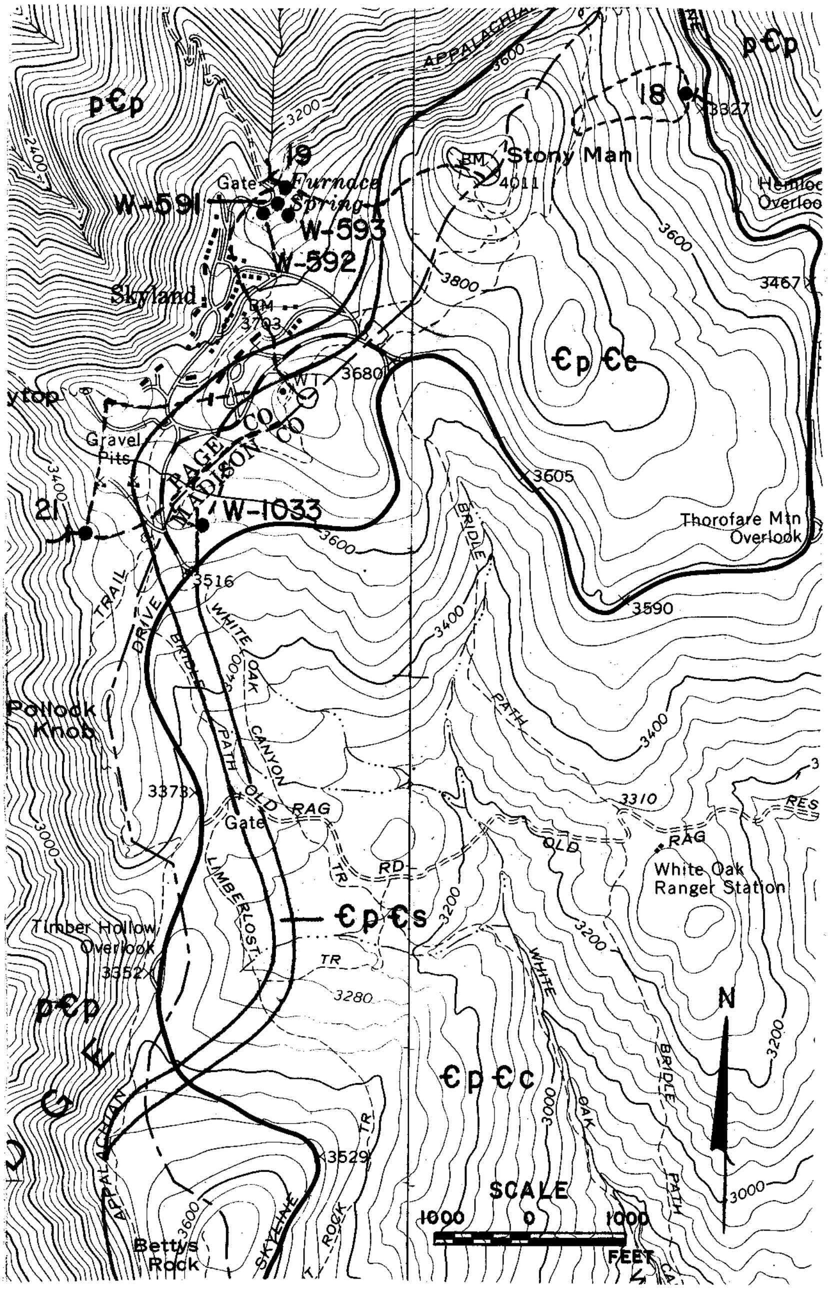

Figure 14. Skyland area showing geology, drainage, well and spring locations on portions of the Big Meadows and Old Rag 7.5-minute topographic quadrangle maps.

had been proposed at an elevation of 3490 feet (Figure 14, W-592). Approximately 20 feet of partially-weathered bedrock was penetrated beneath the overburden before firm granodiorite was reached at 31 feet. Fracture aquifers were encountered at 56, 64, 67, 85, 135, 194, and 220 feet, which furnished an estimated 50 gallons per minute when drilling was terminated at 233 feet. A 10-hour pump test was conducted in conjunction with flow measurements of the nearby Furnace Spring as these sources were to be supplemental water supplies (Appendix IV). Unfortunately, the test was of too-short duration and the discharge rates too erratic to accurately determine either the well capacity or combined well-and-spring yield. During this test the pumping rate was changed six times, the longest period of constant discharge being 4.5 hours at 50 gpm with the pumping level declining throughout. The initial pumping rate was 90 gpm with a spring flow of 70 gpm; 10 hours later, with the pumping level in a near-vertical decline, the well was discharging 62 gpm and the spring 50 gpm. Computations indicated that if the spring and well simultaneously produced 50 gpm, 28 percent more water would be discharged than from the spring flow alone. These computations were theoretical, however, and a more extensive pump test in the fall when ground-water levels are lowest indicated only 20 gpm could be pumped from the well without reducing the spring flow. It was therefore decided to develop Test Hole No. 2 as a water well to be used only at times when the spring flow is less than 20 gpm. Geologic (Appendix III) and geophysical logs were prepared and the spring water was analyzed (Table 2), but no analysis of the well water is available.

Skyland Test Hole No. 3 is located 90 feet north of Test Hole No. 2, at an elevation of 3480 feet (Figure 14, W-593). Granodiorite was again encountered beneath 37 feet of overburden, and the water-filled fracture at 117 feet furnished an estimated three gpm. As such a small withdrawal from the ground-water reservoir affected the nearby Furnace Spring (120 feet), drilling was terminated at 162 feet and the hole capped. Geologic (Appendix III) and geophysical logs were prepared, but no chemical analysis was made of the water.

If facilities were to be expanded it was anticipated another water well would be needed west of Skyline Drive. Previous studies indicated that at the South Entrance to Skyland the Swift Run Formation has a slight dip to the southeast where recharge conditions are better than at the previous drilling sites. Two test hole sites were selected, one on a linear trace west of Furnace Spring, and one near the South Entrance to Skyland where a 600-foot hole would penetrate the bottom of the Catoctin, all of the Swift Run, and the top of the Pedlar formations.

Skyland Test Hole No. 4 (Figure 14, W-1033) is located 450 feet north of the South Entrance-Skyline Drive junction, and is the highest well in the Park (3560 feet). The Swift Run Formation was encountered beneath 30 feet of overburden, and granodiorite of the Pedlar Formation was penetrated from 365 to 500 feet. Incomplete driller's records note water-filled fracture openings at 64 and 99 feet, but it is likely others were penetrated to account for the estimated 25 gpm yield. After approximately 20 hours of testing, the pumping level had stabilized at 398 feet with a discharge rate of 25 gpm, but when increased to 30 gpm the pumping level dropped below the air line at 435 feet in less than one hour (Appendix IV). As it was indicated that this test hole had a safe yield of at least 15 gallons per minute, it was developed as Skyland Well No. 2 and no further drilling was undertaken in the area. Geologic (Appendix III) and geophysical (Appendix II) logs were prepared, and a partial chemical analysis showed the water to be slightly irony but otherwise of good quality (Table 2).

Comers Deadening

Directly across Skyline Drive from Skyland, the Comers Deadening area was considered for development in 1961 and springs were surveyed as possible sources for the required water supply. Of those examined, no records were available for several and the flows of many others were too small to be developed. Recommendations were made for repair or construction of galleries and weirs and the establishment of regular flow measurements for a few springs, but it was decided water wells would be more acceptable and field studies were made for the location of drilling sites. As Comers Deadening is on strike with the four Skyland test holes, bedrock is the same in each of these adjoining areas. Only a very limited amount of the Pedlar granodiorite is exposed east of Skyline Drive, but it occurs at a relatively shallow depth beneath the southeastward-dipping Swift Run metamorphosed sedimentary rocks along the northwest side of the area; metamorphosed basalt of the Catoctin Formation underlies the remainder of the Comers Deadening area east of the Swift Run rocks. Three drilling sites were selected where test holes would begin in the Catoctin, penetrate the Swift Run, and terminate in the Pedlar Formation.

Comers Deadening Test Hole No. 1 is located 4300 feet southeast of the South Entrance to Skyland, 800 feet south of the Old Rag Road at an elevation of 3240 feet (Figure 15, W-869). Two hundred feet of metamorphosed basalt was penetrated beneath 22 feet of overburden; the lower 28 feet of the test hole were in softer phyllitic rocks that occur near the bottom of the Catoctin Formation. Small supplies of water were obtained from fractures in the basalt at depths of 40, 53, 58, 80, and 102 feet, and after 14 hours of testing the pumping level had stabilized for 5 hours at 169.6 feet while discharging 17 gallons per minute (gpm) (Appendix IV). A safe yield of 10 gpm was postulated for this well. Geologic (Appendix III) and geophysical logs were prepared, but no chemical analysis of the water is available.

Comers Deadening Test Hole No. 2 was drilled 1800 feet east-northeast of Test Hole No. 1, 100 feet south of Old Rag Road at an elevation of 3160 feet (Figure 15, W-876). Metamorphosed basalt was encountered at 25 feet and penetrated to the total depth of 250 feet. Traces of water from hairline fractures were obtained at 55, 84, 114, 193, and 210 feet, but as the estimated air-lift yield was only three gpm, no pump-testing was performed. Geologic (Appendix III) and geophysical logs were prepared, but no chemical analysis was made of the water.

Shortly thereafter information was received from National Park Service personnel that no wells should be drilled immediately south of the Old Rag Road because withdrawal of water from this area may prove injurious to certain types of protected vegetation (personal communication). The supposedly successful Test Hole No. 1 was therefore capped and new drilling sites were selected on the north side of Old Rag Road. Drilling was projected to 300 and 400 feet at sites 3 and 4, respectively, in order to penetrate the lower Catoctin, all of the Swift Run, and the upper Pedlar formations.

Comers Deadening Test Hole No. 3 was drilled at site 4, approximately 1100 feet north of Test Hole No. 2 at an elevation of 3220 feet (Figure 15, W-1136). Basalt of the Catoctin Formation was encountered beneath 20 feet of overburden and penetrated to a depth of 265 feet where the Swift Run Formation was reached. Fracture aquifers were encountered at 133 and 285 feet, and drilling was terminated at 365 feet. During the

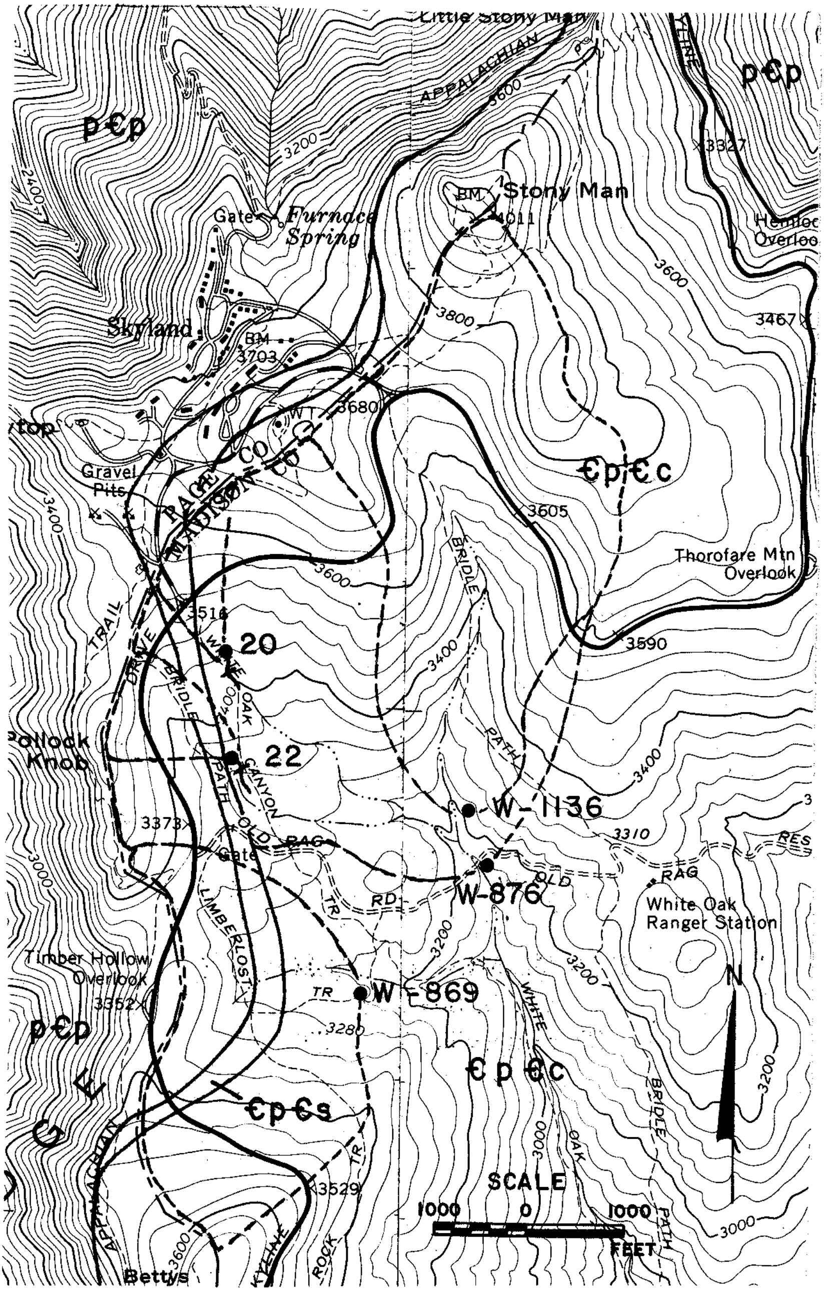

Figure 15. Comers Deadening area showing geology, drainage, well and spring locations on portions of the Big Meadows and Old Rag 7.5-minute topographic quadrangle maps.

25.75-hour pump test (Appendix IV), the pumping level had apparently stabilized at 212.5 feet while discharging at the rate of 30 gpm when the rate was increased to 35 gpm and the level dropped to 304.9 feet. Geophysical and geologic logs were prepared (Appendices II and III, respectively); of particular interest is the fact that when the geophysical logs were made 6 days after the pump test, the static water level had risen from 9 feet below to 0.9 feet above ground level—*a flowing artesian well near the crest of the Blue Ridge Mountains!* This well has an estimated safe yield of 20 gpm, and a partial chemical analysis indicated the water was soft and of good quality (Table 2). Because this test hole could be developed into a water well adequate for the provision of the area's anticipated water requirements, no further drilling was planned.

Big Meadows

Big Meadows was one of two areas within the Park named as having sufficient water supplies for large congested areas (file report of the Shenandoah National Park prepared by the U. S. Geological Survey, Dirzulaitis, 1935). As stated in a later report (file report of the Shenandoah National Park prepared by the U. S. Geological Survey, Dirzulaitis, 1938) that planned facilities would require 94 gallons per minute (gpm) from Lewis Spring, it is likely spring-flow records were inadequate. Recent measurements reveal that during times of peak water demand (June through September) the flow from Lewis Spring is frequently less than half that amount (Figure 4), and in 1964 drilling sites were required for wells to supply water for the campground east of Skyline Drive. Preliminary field investigations indicated only metamorphosed basalt of the Catoctin Formation occurred in that immediate area, and it was suggested that test holes be drilled 0.5 mile north of the campground where structural and recharge conditions were more favorable and where the Pedlar granodiorite was also exposed. Four drilling sites were selected in Dark Hollow, three to penetrate basalt and granodiorite to depths between 350 and 550 feet and one to be entirely in granodiorite for 400 feet. Another site was selected near Lewis Spring west of Skyline Drive if the other sites were unacceptable; this was the least favorable site as the recharge was poor and only basalt of the Catoctin Formation would be encountered. A later request for another water source west of Skyline Drive resulted in the recommendation of a shallow (200 foot) exploration hole to verify concepts of hydrogeologic conditions between the Ranger Station and the west campground.

Big Meadows Test Hole No. 1 was drilled at site 2 approximately 6000 feet east-northeast of the entrance to the east campground, on the south side of the Fire Road at an elevation of 2730 feet (Figure 16, W-1347). Forty-five feet of overburden covered the basalt of the lower Catoctin Formation; apparently the Swift Run Formation is not present in this area because Pedlar granodiorite was encountered next at 115 feet and penetrated to the termination depth of 265 feet. Water-bearing fractures were encountered from 200 to 205 and 215 to 220 feet below ground level, and a yield of 60 gpm was estimated by air lift. A 36.5-hour pump test was conducted, but because of mechanical problems, readings for only the last 14 hours are valid (Appendix IV). At the end of this test the discharge rate was 60 gpm, but as the pumping level was still declining a safe yield of 40 to 50 gpm is more realistic. A geologic log was prepared (Appendix III), but geophysical logs could not be made later as an obstruction was encountered 52 feet below the top of casing. A partial chemical analysis indicated the water to be moderately hard but otherwise of good quality (Table 2). If the obstruction were removed and the well bore cleaned and perhaps cased another 10 feet, this test hole could probably be developed into a successful water well.

Big Meadows Test Hole No. 2 was drilled west of Skyline Drive, about 1000 feet northwest of Lewis Spring at an elevation of 3390 feet (Figure 16, W-1348). This drilling site was recommended only in the event the other sites were unacceptable and also to check recharge conditions in the Lewis Spring area. As anticipated, only basalt of the Catoctin Formation was penetrated beneath 70 feet of overburden. During geophysical-logging operations, a noticeable trickle of water could be heard entering the well bore; as no measurable static water level was recorded, it can only be assumed this 500-foot test hole terminated in a dry fracture that was draining water from the well bore. As the amount of water lost was small and the test hole 100 feet deeper than planned, no attempt was made to grout the opening or drill further for deeper water-bearing fractures. A geologic log was prepared (Appendix III), but as no water was recovered from the test hole a chemical analysis was made of water from Lewis Spring instead (Table 2).

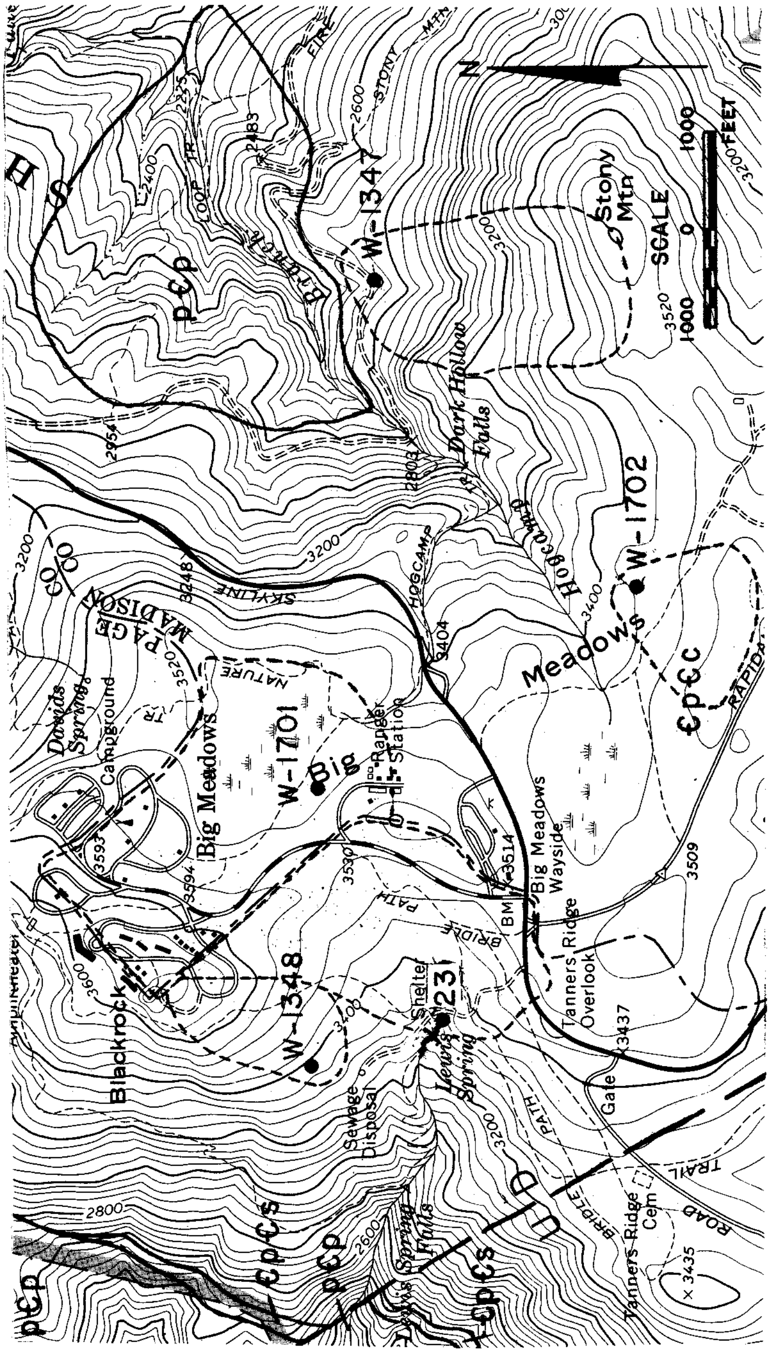

Figure 16. Big Meadows area showing geology, drainage, well and spring locations on a portion of the Big Meadows 7.5-minute topographic quadrangle map.

Big Meadows Test Hole No. 3 was drilled as an exploratory hole west of Skyline Drive, 2500 feet northeast of the entrance to Big Meadows at an elevation of 3515 feet (Figure 16, W-1701). Expansion of facilities west of the Drive necessitated a supplemental water supply in that area, but as no data were available by which to evaluate theories of ground-water conditions in the large, flat expanse between Skyline Drive and the west campground, a 200-foot exploratory hole was recommended. Beneath the zone of soil and partially-weathered rock, metamorphosed basalt of the Catoctin Formation was penetrated from 60 to 80 feet, and epidotized basalt from 80 to 100 feet. Drilling was terminated at 100 feet because the driller estimated 500 gpm entered the well bore from 35 to 40 feet in the overburden and from fracture aquifers between 70 and 80 feet in the basalt. Sixty-eight feet of casing was installed in the well bore and grouted to a depth of 66 feet to seal off the entry of near-surface water in the overburden, and the well was pump-tested for 24 hours. After only 4 hours the pumping level stabilized at 24.9 feet from which it never varied during the last 20 hours of constant discharge at 92 gpm (Appendix IV). The 6.9-foot drawdown and pumping level some 45 feet above the aquifer zone would indicate that a greater yield was possible; this well was later pumped at 200 gpm for several hours, and has been in operation at the rate of 55 gpm for five years. Largest in yield, only one other well in the Park is at a higher elevation (Skyland No. 4, 3560 feet), and only two wells are of a more shallow depth. Although other wells have larger drainage areas than the one that furnishes water to this site (152 acres), the difference in well production is in the right combination of favorable hydrogeologic factors: the near-horizontal attitude of the bedrock, the low-angle cleavage and sheet fractures at shallow depths in an otherwise impermeable bedrock, a relatively thick overburden composed of fine-grained, moderately permeable residual soil (Appendix III), very low relief within the drainage basin (Figure 16), well distributed annual precipitation of 45 inches (Figure 2), and relatively sparse vegetation and moist air to reduce evapotranspiration. No geophysical logs were made of this shallow well as there is only 32 feet of open hole below the casing, but water samples were analyzed and indicate the moderately soft water is of very good chemical quality (Table 2).

Difficulties in reconstruction of the bridged Test Hole No. 1 required another test hole be drilled for a water supply near the campground east of Skyline Drive. As the three other previously recommended drilling sites north of the campground could be made accessible only at prohibitive cost, Park officials requested a drilling site near the campground and existing pipe and electric lines. The site selected was the most favorable in a generally unfavorable area underlain by basalt. Therefore, Big Meadows Test Hole No. 4 was drilled 3500 feet east-southeast of the entrance to the campground from Skyline Drive, near the electric power line at an elevation of 3440 feet (Figure 16, W-1702). The hole was drilled to the recommended maximum depth of 350 feet, and beneath 25 feet of overburden it penetrated only metamorphosed basalt of the Catoctin Formation (Appendix III). Small water-bearing fractures were encountered between 160 and 165 feet, and a 24-hour pump test indicated only two gpm were available from a pumping level of 323.5 feet (Appendix IV). Geophysical logs were made (Appendix II), and although an analysis indicated the water to be of good chemical quality (Table 2), the test hole was not developed into a water well because of the small yield.

Lewis Mountain

Lodging, dining, and camping facilities at the Lewis Mountain development required a minimum water supply of 14 gallons per minute (gpm) from Lewis Mountain Spring, 1200 feet southwest of the area. As the flow from this spring frequently decreased to less than 10 gpm during late summer months, a survey was conducted to locate other springs to supplement this water supply. When the only possibility appeared to be the development of Bear Wallow Spring, 4700 feet southwest of the area, it was decided to drill a water well instead. Field studies indicated the Pedlar, Swift Run, and Catoctin formations are exposed in the area and have a northeasterly trend; a minor fault is present north of the entrance to the area, where steeply dipping cleavage was well-developed in the rocks. Two test holes were recommended, one to be 300 feet deep and the other 500 feet in order to penetrate the lower Catoctin, all of the Swift Run, and terminate in the Pedlar Formation.

Lewis Mountain Test Hole No. 1 is located 50 feet east of Skyline Drive and 30 feet north of the entrance road at an elevation of 3390 feet (Figure 17, W-1072). This site was selected

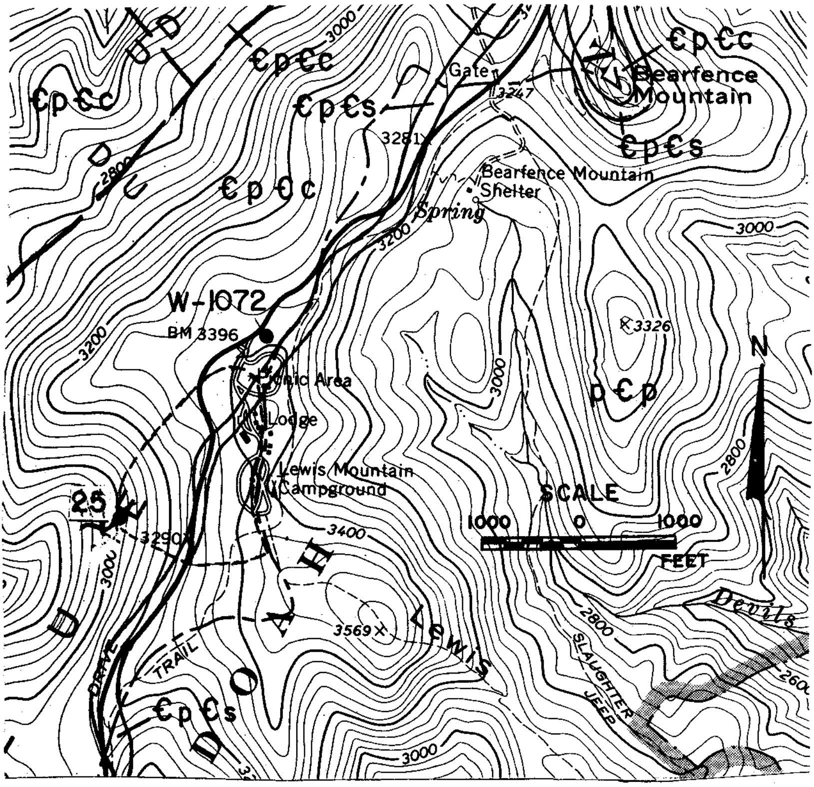

Figure 17. Lewis Mountain area showing geology, drainage, well and spring locations on a portion of the Fletcher 7.5-minute topographic quadrangle map.

not only because of its accessibility and proximity to facilities within the area, but also to penetrate the slightly permeable Swift Run metamorphosed sedimentary rocks where they may be shattered by the cross fault. It was discovered during drilling, however, that the strata were folded near the fault and were in a near-vertical position at the well site, eliminating any possibility of penetrating the full thickness of the Swift Run Formation. Examination of the sample drill cuttings indicated the well bore crossed and recrossed the undulating, vertical Catoctin-Swift Run contact and penetrated water-filled openings at 54 and 104 feet below ground level (Appendix III). Any other fracture aquifers encountered at greater depths were neither recorded by the driller nor discernable on geophysical logs, which were made later. When it became obvious the Pedlar

Formation could not be reached, drilling was terminated at a depth of 300 feet and a 25-hour pump test conducted. Because of equipment problems, the results of this test were unsatisfactory; the well was tested again for 19 hours, at the end of which a probable safe yield of 12 gpm was indicated (Appendix IV). A partial analysis of the water determined it was soft and of good chemical quality aside from a slightly high iron-manganese content (Table 2). As this test hole could be developed into a successful water well there was no need for drilling the second test hole.

Swift Run Maintenance

Of the 38 test holes drilled for this project only six are at a distance more than 2500 feet from Skyline Drive or at elevations less than 1500 feet; three of these six wells are at lower elevations than the one in this area, but none has a larger drainage area (541 acres). West Swift Run Creek flows through the area and four springs have an estimated total flow of 15 gallons per minute (gpm). As only one of these springs was developed and its permanence is questionable, it was decided to drill a water well within the maintenance area. Bedrock consists of basalt and phyllite of the Catoctin Formation, but with the excellent recharge to fracture traces that cross the area, only one 150-foot test hole was recommended.

Swift Run Maintenance Test Hole No. 1 is located 800 feet south of U. S. Highway 33 and 10 feet west of the maintenance road, at an elevation of 1475 feet (Figure 18, W-865). Twenty-eight feet of dirt, clay and bouldery rubble and 12 feet of partially-weathered phyllite were penetrated before basalt was encountered at 40 feet. In order to prevent this unconsolidated material from caving into the well bore and at the same time to preserve the five gpm obtained from between 35 and 40 feet in the partially weathered rock, 43 feet of casing was installed, slotted from 35 to 40 feet, and gravel-packed from 35 to 43 feet. Another 5 gpm was obtained from fractures between 46 and 49 feet, but by the time 60 feet had been reached enough back pressure had been developed by circulation of air through the gravel pack and around the ungrouted casing to render the air rotary drill incapable of further penetration. The open hole was too short (17 feet) to justify geophysical logging and no water samples were collected, but a geologic log was prepared (Appendix III). Although only a 6-hour pump test was conducted

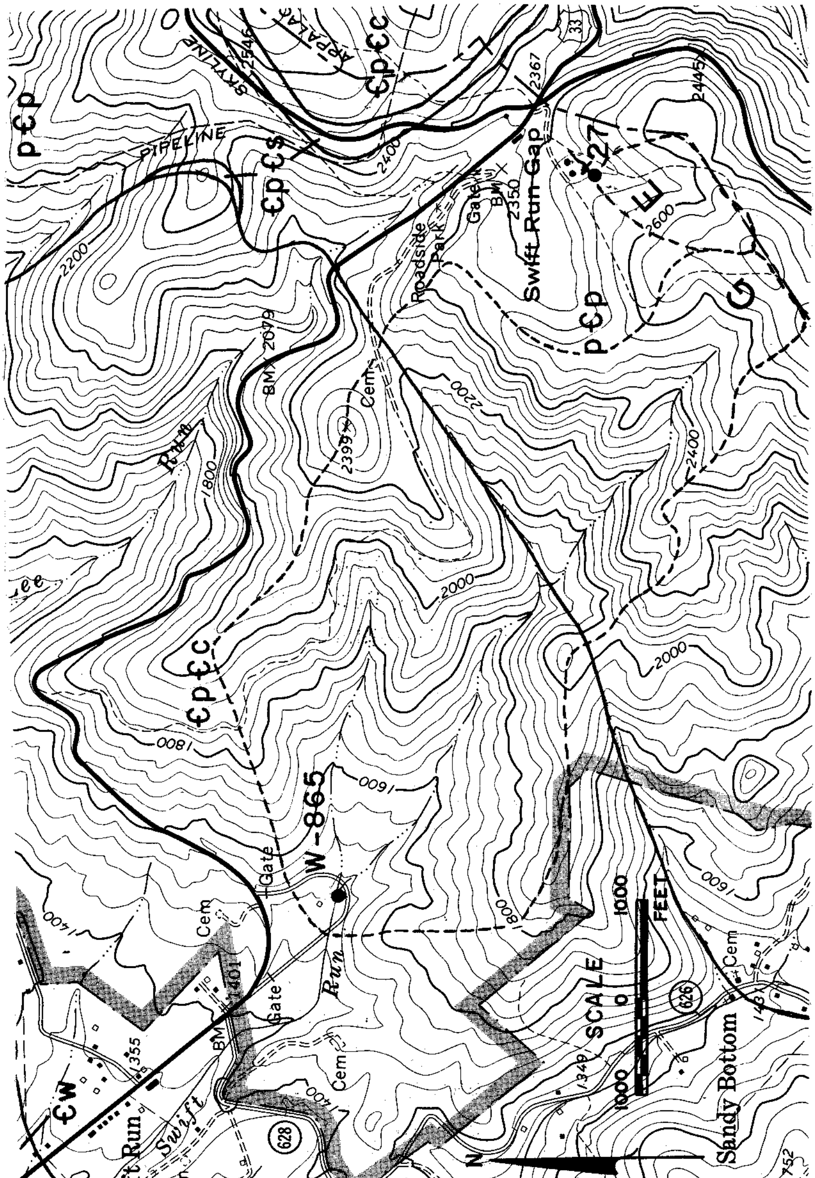

Figure 18. Swift Run Maintenance area showing geology, drainage, well and spring locations on a portion of the Swift Run Gap 7.5-minute topographic quadrangle map.

the estimated safe yield of 8 gpm was sufficient for the area's needs and no further drilling was planned. If the well is to be deepened at a later date, it will be necessary to either grout the casing into bedrock or continue the drilling with a cable-tool rig.

Simmons Gap

After a survey determined perennial springs could not be developed at an adequate elevation within a reasonable distance of the Ranger Station, investigations were made for the location of drilling sites. Test holes located on fracture traces in the southwestward-dipping basalt of the Catoctin Formation should encounter a moderate supply of ground water as recharge conditions were relatively good. A drilling site was selected at the intersection of two hollows, one of which is occupied by Fork Hollow Creek; only basalt would be penetrated to the maximum recommended depth of 400 feet.

Simmons Gap Test Hole No. 1 is located 400 feet southeast of Skyline Drive in Simmons Gap, and 150 feet north of the Ranger Station access road at an elevation of 2230 feet (Figure 19, W-1704). Basalt and phyllite of the Catoctin Formation were en-

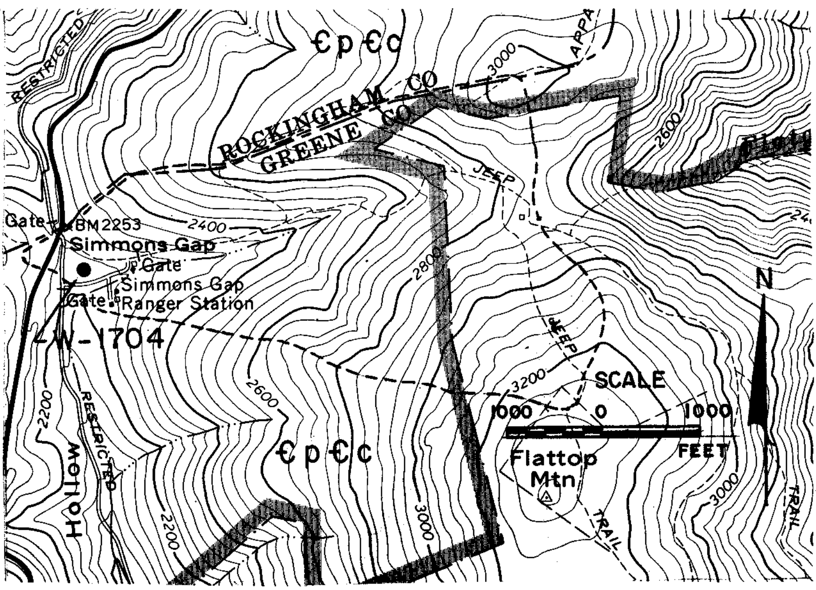

Figure 19. Simmons Gap area showing geology, drainage, well and spring locations on a portion of the Swift Run Gap 7.5-minute topographic quadrangle map.

countered beneath 30 feet of overburden, and drilling was terminated at 205 feet to pump test the quantity of water obtained from fractures that were penetrated between 190 and 195 feet. Twenty-five gpm were discharged from a pumping level that had stabilized at 164 feet for 21 hours (Appendix IV). Geophysical and geologic logs were prepared for correlative purposes (Appendices II and III, respectively) and an analysis indicated the water was soft and of excellent chemical quality (Table 2). As it was evident this well could furnish more than the small amount of water required for this installation, further drilling was not necessary.

Loft Mountain

Since the inauguration of the Park, housing and dining facilities had been located almost exclusively in the Central District at Skyland, Big Meadows, and Lewis Mountain. By 1960 these accommodations were being utilized to the maximum during the summer and fall months, and plans were formulated for the construction of a large development at Loft Mountain in the South District. During early 1962 tentative plans included provisions for a wayside, campstore, dining room, lodge, stables, amphitheater, picnic area, and a 250-site campground. It was estimated a 94-gallon-per-minute (gpm) water supply would be needed to sustain these facilities, and a survey was conducted to assess the available surface-water sources—three springs, two weirs, and a seepage area. The one-year records compiled at the time indicated the combined monthly flow of these six sources for June through September averaged between 16 and 25 gpm. If restoration even succeeded in doubling the yield from these sources, only half the estimated water requirement would be fulfilled; therefore field investigations were made for the location of test-hole sites to evaluate the ground-water potential on the east side of Skyline Drive in the Loft Mountain-Big Flat area. Electrical resistivity surveys were conducted in areas where aerial-photograph interpretations indicated possible fault zones occurred in the Weverton and Catoctin formations, and three drilling sites were recommended and numbered in order of apparent favorability.

Loft Mountain Test Hole No. 1 was drilled at site 3, 550 feet east of Skyline Drive and 20 feet west of the service road, at an elevation of 3010 feet (Figure 20, W-704). Metamorphosed basalt was penetrated from 10 to 250 feet (Appendix III), and not even

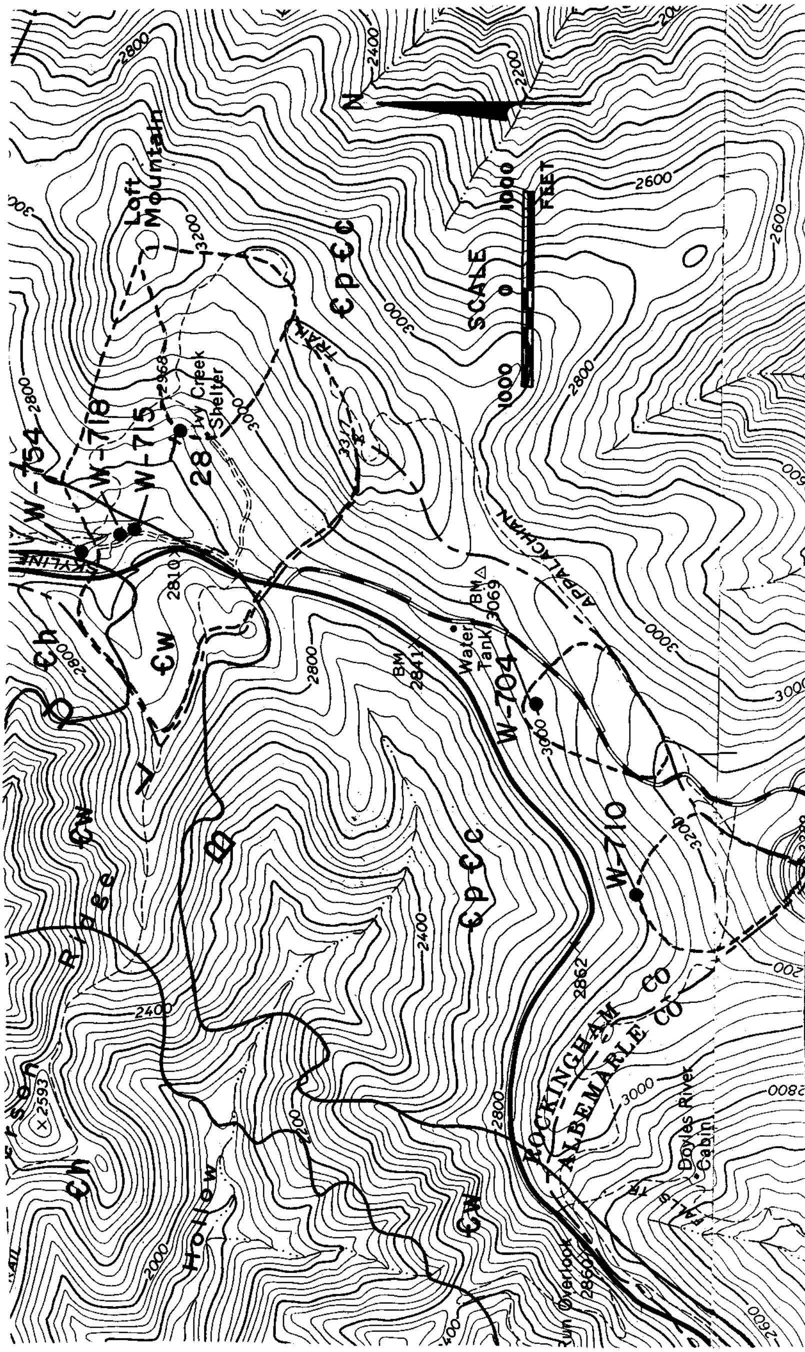

Figure 20. Loft Mountain area showing geology, drainage, well and spring locations on portions of the McGaheysville and Browns Cove 7.5-minute topographic quadrangle maps.

enough water was encountered to obtain a static-water-level measurement.

Loft Mountain Test Hole No. 2 was drilled at site 2, approximately 1800 feet southwest of Test Hole No. 1 and 200 feet east of Skyline Drive, at an elevation of 3000 feet (Figure 20, W-710). Although this site was located near the intersection of several fracture traces, the drilling results were not much better than for Test Hole No. 1. Bedrock was reached beneath 31 feet of residual soil, and only one small water-bearing fracture was encountered between 65 and 69 feet in the phyllite and metamorphosed basalt of the Catoctin Formation (Appendix III). Drilling was terminated at 160 feet with an estimated yield of 0.5 gallon per minute.

Loft Mountain Test Hole No. 3 was drilled at site 1, on the west side of Ivy Creek, 400 feet east of Skyline Drive at an elevation of 2740 feet (Figure 20, W-715). The bedrock, which was encountered at five feet consisted of weathered sandstone, quartzite, and phyllite of the lower Weverton Formation; phyllites of the upper Catoctin Formation penetrated from 45 to 80 feet were underlain by basalt to the total depth of 303 feet. Water-bearing openings were encountered in the phyllitic basalt at 123 and 134 feet below ground level, and pump tests were subsequently conducted at this test hole alone and while pumping simultaneously with the later-completed Loft Mountain Test Hole No. 4. Although not conclusive because of the short pump test, it was indicated Test Hole No. 3 could be converted into Loft Mountain Water Well No. 1 with a safe yield of approximately 10 gallons per minute (Appendix IV). A geologic log was prepared (Appendix III), but no water analysis is available.

Loft Mountain Test Hole No. 4 was drilled for observation-well purposes approximately 20 feet north of Test Hole No. 3 (Figure 20, W-718). As might be expected in bore holes 20 feet apart on strike, the rock strata penetrated were similar in lithology and thickness to those in Test Hole No. 3 (Appendix III). Water-filled openings in the Weverton and Catoctin phyllites at 38, 64, and 155 feet furnished an estimated 22 gallons per minute, and subsequent pump tests of this test hole alone and simultaneously with Test Hole No. 3 proved this estimate correct (Appendix IV). Although this test hole may not be used as a water well, it has been cased and grouted so it could be put into use at approximately 20 gpm should Test Hole No. 3 have to be taken out of production.

After geophysical logging had been completed, Test Hole No. 4 (W-718) was converted into an observation well to monitor the effect pumping of Test Hole No. 3 had on the local water table. An automatic water-level recorder was installed in the summer of 1964, and although more than seven years of continuous record is available the charts are artificially distorted daily from June through October, whenever the adjacent Test Hole No. 3 is pumped. Records indicate the normal static water level in the observation well fluctuates three to five feet each month and about 10 feet during the year, but when Test Hole No. 3 is pumped the water level in the observation well drops as much as 20 feet in eight hours (Figure 21). Recovery of the

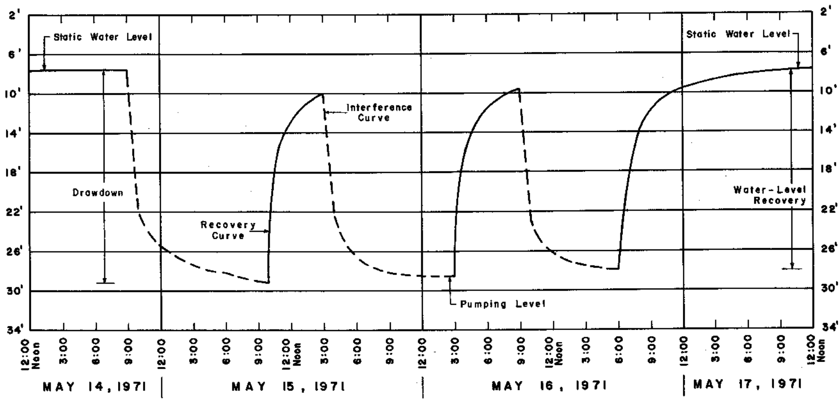

Figure 21. Water-level response in the Loft Mountain observation well during pumping of Water Well No. 1.

static water level usually is completed in an equal period of time, and after more than seven years of pumping there has been no noticeable change in the normal static water levels of these two test holes.

Loft Mountain Test Hole No. 5 is located 450 feet north of Test Hole No. 4, on the west side of Ivy Creek at an elevation of 2670 feet (Figure 20, W-754). Although further down the structural trough in which Ivy Creek flows, the Weverton and Catoctin formations were penetrated as in Test Hole Nos. 3 and 4. Water from cleavage partings in the Catoctin phyllites was obtained at 46, 50, 53, 56, and 115 feet, the basalt being nonwater bearing in the lower portion of this 320-foot well bore. A 24-hour pump test was conducted, and during the last 9 hours the pumping level stabilized at 108.6 feet at the rate of 22 gpm

(Appendix IV). This test hole was converted into Loft Mountain Water Well No. 2 after geophysical and geologic logs were prepared (Appendices II and III, respectively), but no water samples were collected for analyses. It is of interest that pumping of Test Hole No. 3 lowers the water level in the observation well rapidly and markedly whereas 24 hours of continuous pumping of Test Hole No. 5 lowered the water level in the observation well less than two inches.

Dundo

The water supply for the Dundo picnic-campground area was obtained from a spring on Pinestand Mountain one mile to the southwest. During the summer months the flow from this spring decreases to a trickle; in August 1961 the discharge measured 0.44 gallons per minute (gpm). Two months later a study was initiated to locate other water sources that could be developed, and when only a line of springs 0.5 mile south in Jones Hollow were found the study was expanded to include the location of test-hole drilling sites. Westward-dipping strata of the Weverton and Catoctin formations are exposed in this area and test holes at three selected sites would penetrate both, site 1 designated the most favorable because it was on a cross fault in Browns Gap just north of the campground; site 3 had the largest drainage area but would necessitate the deepest test hole (400 feet). None of the rock types present had an exploitable primary permeability, and none of the sites had drainage areas larger than two acres, smallest of any of the Park test-hole sites.

Dundo Test Hole No. 1 was drilled at site 3, approximately 500 feet east of Skyline Drive and 25 feet north of the area road at an elevation of 2770 feet (Figure 22, W-1073). Sandstone, quartzite, and phyllite of the Weverton Formation were encountered beneath a very thin soil cover and penetrated to 140 feet where phyllite and chlorite schist of the Catoctin Formation were reached. Basalt was encountered from 235 to 410 feet where drilling was temporarily halted because only an estimated 0.5 gpm had been obtained from small fractures at 70 and 240 feet. The driller was instructed to cap this test hole and drill at site 1 in Browns Gap, but three days later this second test hole was abandoned (see Test Hole No. 2 below). Because hydrogeologic conditions had now been assessed at sites 1 and 3, it was recommended site 2 be relocated in Jones Hollow south of the campground, but when the drilling rig could not traverse the

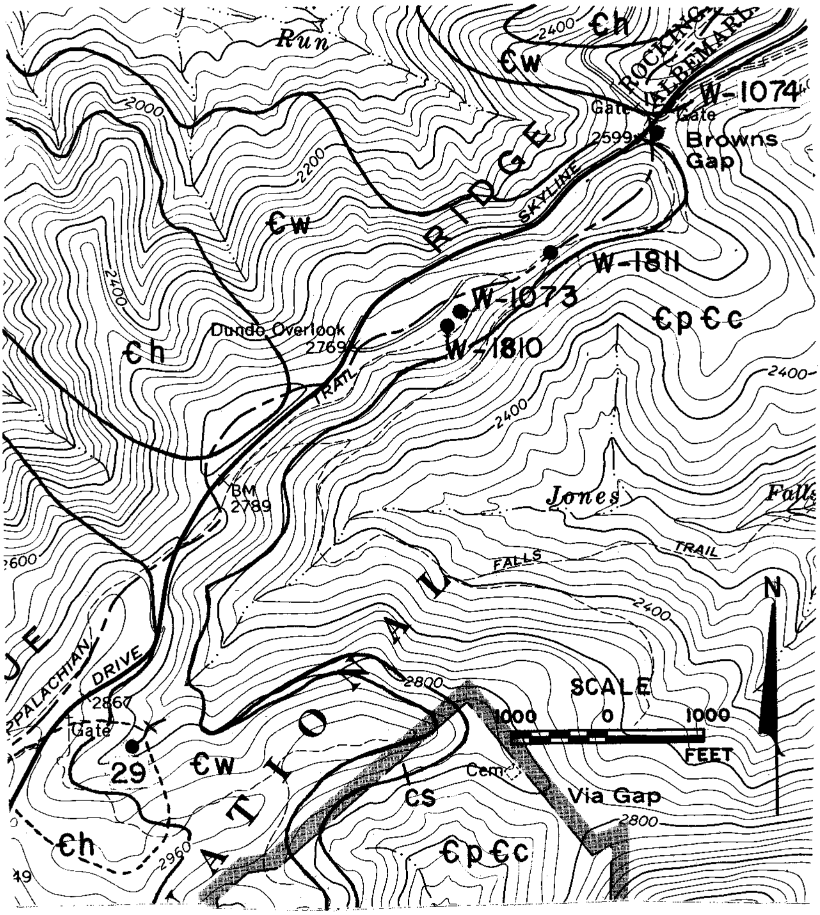

Figure 22. Dundo area showing geology, drainage, well and spring locations on a portion of the Browns Cove 7.5-minute topographic quadrangle map.

fire road to this site the driller was instructed to deepen Test Hole No. 1 to 635 feet. An estimated 25 gpm was obtained from fractures in the basalt between 500 and 600 feet, but drilling had to be terminated at 615 feet when material from the sidewalls at 603 feet began to jam the drill bit. During the subsequent 24.5-hour pump test the pumping level stabilized quickly at 15 gpm with 46 feet of drawdown, and at 20 gpm with a drawdown of 82 feet. After 1.25 hours of interruption for equipment repair the pump test was resumed at 25 gpm, at the end of which the pumping level had apparently stabilized with a total drawdown of 178 feet (Appendix IV). Geophysical and geologic logs were prepared (Appendices II and III, respectively), and a partial analysis indicated the soft water was slightly high in manganese content but otherwise of excellent chemical quality (Table 2).

Dundo Test Hole No. 2 is located in Browns Gap, approximately 50 feet west of Skyline Drive at an elevation of 2595 feet (Figure 22, W-1074). Partially-weathered phyllite of the upper Catoctin Formation was penetrated to 130 feet, below which only epidotized and andesitic basalts were encountered except for a zone of magnetic phyllite between 170 and 180 feet below ground surface. Several quartz-filled fractures were penetrated indicating little secondary permeability remained in these rocks; only an estimated 0.5 gpm entered the well bore between 190 and 200 feet. Unfortunately, the casing was pulled and the well bore filled before any water measurements or geophysical logging could be accomplished, but a geologic log was prepared from examination of sample drill cuttings collected at 5-foot intervals (Appendix III).

When test-hole drilling was concluded, geophysical-logging and electrical-resistivity surveys were conducted to resolve the differences between the geology as originally mapped and as later interpreted from sample drill cuttings. Upon completion of these field studies it was decided more samples from specific depths were needed and permission was obtained from Park officials to drill two stratigraphic exploration holes after the camping area was closed for the winter. Dundo Exploration Hole No. 1 was drilled five feet from Test Hole No. 1, and Dundo Exploration Hole No. 2 is located at the original Test Hole Site No. 2 northeast of the camping area at an elevation of 2730 feet (Figure 22, W-1810, and W-1811). After the samples had been examined by petrographic and X-ray methods, and the Weverton-Catoctin boundary properly located (Appendix III), the casing was pulled and Exploration Hole No. 1 filled; Exploration Hole No. 2 was capped in the event it was desired to deepen the 118-foot well bore at a later date.

Grottoes

In 1966 stratigraphic and recharge studies were made in an area of thick colluvium along the west foot-hills of the Blue Ridge Mountains. The locality selected was 1 mile east of Grottoes on the north side of State Road 661, approximately two miles west of Furnace and Hall mountains. The study area is at elevations from 1220 and 1240 feet between Miller and Stull runs that flow westward from these mountains, whose summit elevations are 2657 and 2771 feet, respectively. Bedrock beneath the colluvial material was unknown although it was anticipated carbonate rocks of the Rome or Elbrook (Cambrian) formations were present. Electrical resistivity surveys were conducted to determine depth to the water table and thickness of the overburden, and a stratigraphic test hole was then drilled 100 feet north of State Road 661, at an elevation of 1225 feet (Figure 23, W-1654).

Partially-weathered bedrock was encountered at approximately 200 feet beneath a heterogenous overburden of sand, gravel, clay,

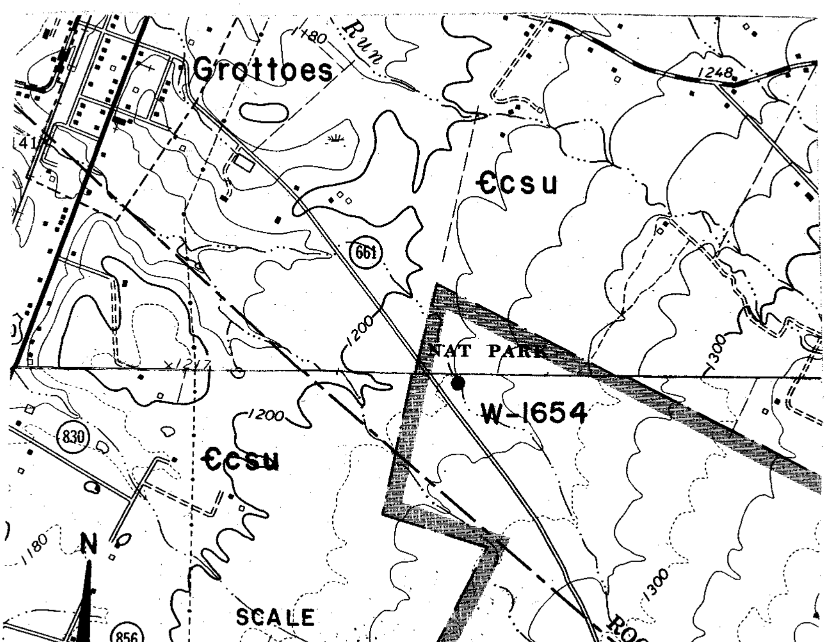

Figure 23. Grottoes observation-well area showing geology, drainage and well location on portions of the Grottoes and Crimora 7.5-minute quadrangle topographic maps.

and assorted cobbles and boulders of sandstone and quartzite. Drilling continued through calcareous sandstones and shales to a total depth of 350 feet, but at 282 feet enough air circulation was lost into a weathered shale horizon to prevent any further return of drill cuttings. The bedrock apparently dips steeply to the east, opposite from the direction of surface run-off, and a portion of the overburden is of low permeability that inhibits vertical recharge to deep aquifers at the test site. As the only ground water encountered was in the overburden, 235 feet of 5-inch casing was installed in the 6.5-inch drill hole and slotted from 210 to 230 feet; an estimated yield of three gpm was obtained. Geophysical logging was unsuccessful because the well bore had filled with sediments to within 15 feet of the bottom of casing, but a geologic log was prepared from examination of the sample drill cuttings collected at 20-foot intervals between 6 and 282 feet (Appendix III).

An automatic water-level recorder was then installed on the hole to measure the unusually deep static water level. Although in a large drainage area that receives considerable run-off from mountains 2 miles to the east, and the South Fork of Shenandoah River is located 1.5 miles to the west, the static water level vacillates at depths below the elevation of the river (1100 feet). During the 4.75 years of record the water level had a maximum range of 24.35 feet (March through November 1968) with an average annual range of 21.2 feet (Figure 10).

Rockfish Gap

A survey was conducted for springs that had minimum flows of three gallons per minute (gpm) to supply water to the entrance station 0.6 mile north of the south terminus of Skyline Drive. The surface hydrology is one of intermittent run-off only; no springs occur near the station and no creeks cross the Drive near it. In addition to impermeable bedrock, the problem of locating drilling sites was compounded by the very steep topographic profile, the 200-foot width of the Park near the entrance station, and a drainage area of only 14.7 acres. This was further complicated by tree-lined rock ledges or gullies filled with huge boulders that made egress from Skyline Drive nearly impossible for a drilling rig. Because of these conditions, a site was selected north of the entrance station at about the only place a rig could get more than 20 feet off Skyline Drive. Because of an anticipated deep water table, a minimum drilling depth at 250 feet was recommended.

Rockfish Gap Test Hole No. 1 is located 600 feet north of the entrance station and about 50 feet east of Skyline Drive at an elevation of 2080 feet (Figure 24, W-1137). Twenty-five feet

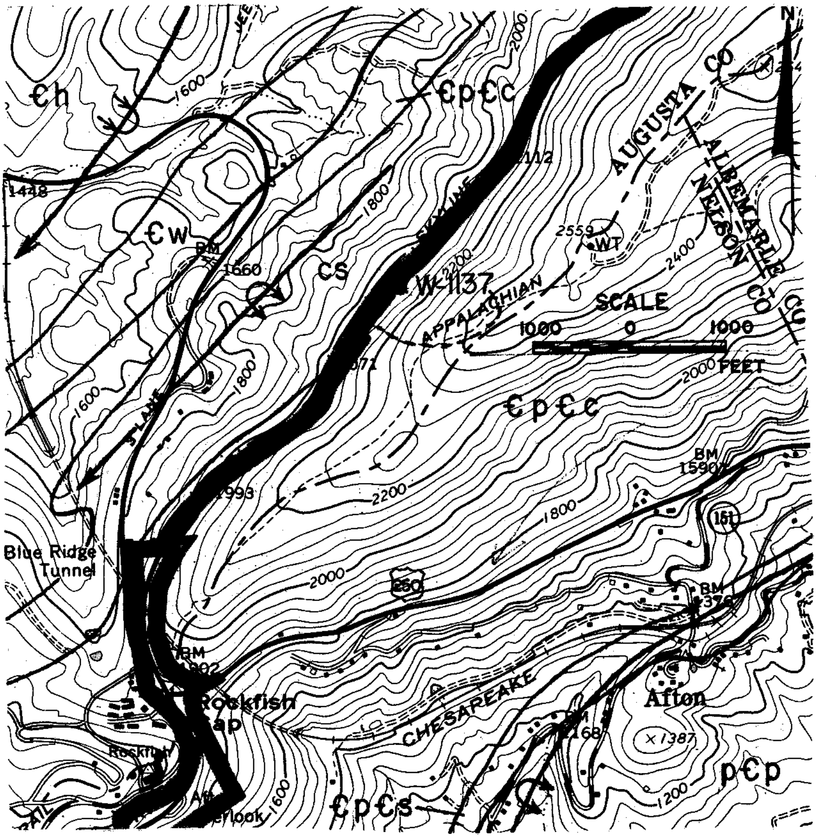

Figure 24. Rockfish Gap Entrance Station area showing geology, drainage, and well locations on a portion of the Waynesboro East 7.5-minute topographic quadrangle map.

of soil and boulders were penetrated before bedrock was reached, and the remainder of the 535-foot well bore encountered basalt, phyllite, and metamorphosed sedimentary strata in the Catoctin Formation. Although several fractures may have been penetrated none were water-filled except one at 510 feet. A 24-hour pump test was conducted at the end of which the pumping level had stabilized for 2 hours at 453 feet while discharging at the rate of approximately three gpm (Appendix IV). As this was the amount of water requested for the entrance station no further drilling was necessary. Geophysical and geologic logs were prepared for correlation (Appendices II and III, respectively), and a partial chemical analysis indicated the water was soft but slightly acidic, irony, and turbid (Table 2). It is possible these undesirable characteristics will be reduced or eliminated after the well has been pumped regularly for a period of weeks.

SUMMARY

CONCLUSIONS

Development of ground-water supplies from impermeable igneous and metamorphic rocks is accomplished by the selection of drilling sites where the greatest number of favorable hydrogeologic conditions occur within a given area. These conditions include fracture openings below the water table, thick permeable residuum or extensive fracture openings for ground-water storage, a drainage area of sufficient size to furnish perennial recharge to these reservoirs, adequate precipitation, topography, and vegetation. It is likely there are sites within the boundaries of Shenandoah National Park that satisfy all or most of these conditions, but few occur along the crest of the Blue Ridge Mountains where successful water wells were completed in 15 small areas.

In this project it was necessary to locate wells only in or adjacent to the undeveloped portions of small areas. As a result, drilling sites with the most favorable conditions frequently were in small, often steep drainage areas, some of which were less than two acres in size near the ridge crest. Even if fracture (secondary) permeability did occur at such locations, the thin soil cover and rapid run-off limited recharge, and the topographic position frequently caused the openings to be non-water bearing to considerable depths.

The depths at which fractures occur in impermeable rocks is of paramount importance; therefore, the reported depths of water-bearing fractures in 30 of the Park test holes have been evaluated for the frequency of their occurrence within 50-foot depth intervals. In the total footage of bedrock penetrated between the overburden and a depth of 50 feet there were 2.18 water-bearing fractures per 50 feet of bedrock, and between depths of 50 and 100 feet 1.38 water-bearing fractures were encountered per 50 feet of drill hole. At greater depths the frequency of fracture aquifers per 50 feet of drill hole decreased uniformly from .60 for the 100 to 150-foot depth interval to .17 for the 250 to 300-foot depth interval. Ten of the 30 test holes exceeded depths of 300 feet, the deepest having a completion depth of 650 feet. In these 10 test holes, 1575 feet were drilled at depths greater than 300 feet, but only four water-bearing fractures were encountered and they were at depths between 500 and 630 feet. This fracture-drilling footage ratio of 1:393.6 illustrates the futility that usually results from deep drilling, even in mountain-top areas, where fractures might be expected to be open and water bearing to greater depths than they normally occur in areas of low relief. As the number of water-filled fracture openings decreases rapidly with depth in igneous and metamorphic rocks, it was imperative to locate drilling sites in areas with shallow-water tables if the aquifer and storage properties of the more numerous near-surface fractures were to be utilized to their maximum; one test hole located in such an area on a high, gentle slope in Comers Deadening had a static water level of 0.9 feet above ground level at the time geophysical logging was accomplished.

Location of concealed water-bearing fractures is by interpretation, even in drilling areas with abundant bedrock exposure; when lateral as well as vertical extrapolations must be made to drill in small areas with few outcrops the interpretation is difficult. Zones of joint swarms, large joints, and near-vertical faults of low displacement are frequently visible on stereo-pair aerial photographs as linear lows that transect topographic forms for distances ranging up to one mile (Lattman, 1958). Such fracture traces are most apparent in basaltic and granitic terranes, although some of the linear lows seen on aerial photographs are the result of differential weathering of transecting mafic dikes. Fracture-trace intersections may delineate optimum fracture-aquifer conditions in impermeable rocks if perennial ground-water levels are not too deep, and if adequate recharge is available. Of particular interest is the 500-foot deep test hole at Big Meadows that has no measurable static water level although water can be heard splashing into the drill hole. This test hole is located near a very prominent fracture trace that crosses the escarpment west of Big Meadows and intersects nearby hollows on the escarpment at elevations several hundred feet below the bottom of the drill hole. These conditions suggest that extensive, open fracture zones in areas of high relief may act as local ground-water drains, lowering the water table considerably in the immediate area of the fractures. Although many fracture traces are discernable on aerial photographs of the Shenandoah National Park, few are in the small areas that were delineated for well drilling, and they were consequently of little significance to this project.

Although folded and faulted rocks occur in the Park, most of the test holes were drilled in areas of relatively unsheared, low-dipping strata. Exceptions to this are the Rockfish Gap, Thornton Gap, Lewis Mountain, and two Headquarters wells that penetrate overturned, steeply-dipping or intensely-sheared basalts very close to a major fault. Including the two Headquarters test holes that produce useable quantities of water, these five test holes produce an average of one gallon per minute per 30.8 feet of drill hole compared to one gallon per minute per 15.8 feet of drill hole for the remaining test holes that penetrate low-dipping or relatively unsheared bedrock. The combination of topographic and structural conditions also has a significant influence on well yields. The test holes located on elevated flats, very gentle slopes, and in draws or hollows in areas of relatively unsheared bedrock furnished an average of one gallon per minute per 11.2 feet of drill hole. Test holes located in relatively undeformed areas on ridge crests, hill tops, steep slopes, or adjacent to steep escarpments produced an average of one gallon per minute for every 20.9 feet of drill hole. Only three test holes were drilled in intensely deformed rocks at poor topographic positions; these holes averaged one gallon per minute per 44 feet of drill hole.

Another group of interrelated data that should be considered is the soil thickness and yield/depth ratio of a water well. The conditions that favor development of a thick residual soil—fractured, partly-soluble bedrock, a shallow water table, low run-off rates, dense plant cover, and a warm humid climate—are also conditions sought for the location of well sites. Aside from the Grottoes observation well, which was intentionally located at a site covered by thick colluvial materials at the base of the Blue Ridge foothills, test-hole drilling began mostly in residual soil at high elevations.

The average thickness of overburden penetrated varied from 10 feet on the Weverton Formation (6 wells), 25 feet on the Catoctin Formation (25 wells), and 45 feet on the Pedlar Formation (5 wells); one other well began in soil covering the Swift

Run Formation and encountered 30 feet of residual soil. In these 37 test holes the more feldspathic rocks have a thicker residual soil cover than the more quartzose rocks. When these data are compared with the drilling depths and quantities of water obtained, those wells that encountered less than 10 feet of residual soil produced only .0185 gallons per minute per foot of drill hole; where 10 to 25 feet of residuum was present the yield/depth ratio was .0445 gallons per minute per foot of drill hole, and when more than 25 feet of overburden was penetrated the yield/depth ratio was .0876 gallons per minute per foot of drill hole.

From these observations it may be concluded that (1) large yields cannot be expected from water wells located on steep slopes, narrow ridge crests, or near escarpments where ground-water levels are usually below the zone of maximum fracture permeability and recharge rates are low because of rapid run-off; (2) drilling depths should not exceed 300 feet unless specific geologic evidence indicates the presence of deeper fracture aquifers; (3) drilling sites should not be selected in areas of intensely sheared or mylonitized bedrock; (4) areas of low relief on granitic and basaltic terranes frequently have thick residual soil and shallow water table conditions that are favorable for the location of relatively shallow wells; and (5) fracture-trace analyses of low-relief areas may determine drilling sites of optimum favorability that are not apparent in field investigations.

RECOMMENDATIONS

Thirty-eight test holes were drilled for this project, five expressly for water-level or stratigraphic evaluations; of the 33 drilled for ground-water exploration 20 have been or could have been developed into water wells adequate for their intended purpose. Successful development of nearly two-thirds of the test holes drilled would normally be considered a satisfactory percentage, but in an area the size and with the variety of hydrogeologic conditions such as exist in Shenandoah National Park this success ratio could be improved and more firm determinations of ground-water conditions made. For example, during Park-wide geologic investigations, 13 different rock formations were recognized and mapped, but because it was required to locate drilling sites near Skyline Drive only four of these formations were penetrated; although all or part of 36 test holes encountered only two of these formations, even they cannot be properly evaluated because adequate production and quality data are not available; half of all the test holes drilled were at elevations greater than 2700 feet where relief and depth to the regional water table greatly exceeded the drilling depths; and although hydrogeologic conditions for large or even moderate ground-water production are poor along the crest of the Blue Ridge Mountains, some potential water-bearing structures could not be evaluated because drilling sites were limited to small, predetermined areas. It will be helpful to those responsible for the selection of additional water-well drilling sites in the Park if some of the following considerations are afforded.

(1) All favorable hydrogeologic drilling sites within a reasonable distance of an existing facility should be considered; improvement of access roads, water, and power lines may not be as expensive as several "dry" holes drilled at sites selected for convenience.

(2) For a recreational development, ground-water studies should be made over a large area prior to deciding where the facility will be located; in igneous and metamorphic rocks, particularly at high elevations, superposition of favorable drilling conditions is not a frequent occurrence.

(3) All responsible agencies should approve recommended well sites prior to drilling; pre-drilling exclusion of certain localities may cause the loss of a favorable drilling site, but this is preferable to abandoning a successful water well because of post-drilling considerations.

(4) Even though only a small water supply is needed, alternate drilling sites should always be selected and clearly designated in the order in which they should be drilled; adherence to such drilling priorities may result in fewer test holes having to be drilled.

(5) Cost analyses should not discriminate against deep test holes; although test-hole results may indicate a general maximum depth, sometimes deeper drilling to a recognized potential water-bearing structure may avoid drilling several shallow "dry" holes in a given area.

(6) If field examinations reveal bouldery overburden or if fractured rock may prevent or delay air-rotary drilling, a cable-tool rig should be considered; relocation of a drilling site because these conditions cannot be penetrated by air-rotary drilling may result in missing a small subsurface water-bearing zone.

(7) Pump tests of 24-hour duration can be utilized as development guides, but do not provide valid figures for determining long-term yields from continuously-pumped igneous and metamorphic mountain-top wells; open discharge is recommended for several days before a pump test is made.

(8) Water samples should not be collected for analyses until a new well has been pumped at open discharge for several days to flush stagnant water and weathered material from the fractures; complete laboratory

analyses are recommended as partial analyses prepared in the field are incomplete and of questionable reliability.

(9) Pump tests should be made and water samples collected during the "dry" part of the annual water cycle; tests made during the late winter or springtime months when water levels are highest and production requirements lowest may provide misleading quantity and quality determinations.

(10) Production rates should be recorded regularly and water analyses performed periodically; final quantity and quality evaluations from a locale or formation cannot be made without these data.

(11) Just as no formation in the Park can yet be fully evaluated, no formation should be rated as to its water-bearing potential until wells have penetrated it at more favorable sites than have yet been drilled.

(12) Unsanitary surface sources can lead to bacteriological and chemical degradation of water resources that may be difficult to replace; the location of such pollutants should not be permitted anywhere within the well and spring drainage areas noted on area topographic maps included in this report.

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APPENDIX I

WEIR TABULATIONS AND MONTHLY SPRING-FLOW CURVES*

The following springs are included in this tabulation:

No.	Name
1	Fox Hollow Springs—West Weir
2	Dicky Ridge Spring
3	Indian Run Shelter Spring
4	Little Hogback Springs—East Weir
5	Hogback Springs Weir "B"
6	Hogback Springs Weir "A"
7	Range View Shelter Spring
8	Elkwallow Spring
9	North Thornton River Springs—East Weir
10	North Thornton River Springs—West Weir
11	Beahms Gap Spring # 2 (Birdnest # 4)
12	Beahms Gap Spring # 3 (Birdnest # 4)
13	Panorama Spring
14	Headquarters Springs Weir
15	Hazel Mtn. Overlook Spring
16	Pinnacles Springs Lower Weir
17	Sexton Shelter Spring
18	Stony Man Springs—North Weir
19	Furnace Spring
20	Park Springs—East Weir
21	Powwow Grounds Springs—West Weir
22	White Oak Canyon Spring—New Weir
23	Lewis Spring
24	Colvin Springs Weir
25	Lewis Mountain Spring
26	Dean Mountain Spring
27	Swift Run Gap Spring
28	Ivy Creek Spring
29	Dundo Spring
30	Pond Ridge Spring

* In gallons per minute (gpm).

No. 1—Fox Hollow Springs—West Weir (Figure 6)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	—	—	5	4	4	1	—	—
1962	—	—	—	—	7	8	8	5	2	2	3	—
1963	—	—	—	8	—	4	3	2	1	1	—	—
1964	—	—	—	10	10	7	4	2	2	—	—	—
1965	—	—	—	16	12	10	5	3	2	1	1	0
1966	—	—	1	1	2	1	0	0	1	3	—	—
1967	—	—	—	—	8	5	3	4	1	1	1	—
1968	—	—	—	9	—	—	4	3	0	2	—	—
1969	10	—	—	7	7	10	3	3	—	5	5	7
1970	—	12	12	14	12	5	10	4	3	2	4	—

No. 2—Dicky Ridge Spring (Figure 25)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	52	—	23	15	12	—	7	—
1961	—	—	31	—	52	31	18	11	8	6	—	—
1962	—	—	—	—	—	22	15	10	8	8	6	—
1963	—	—	—	23	16	25	15	12	7	5	—	—
1964	—	—	—	29	43	28	16	9	8	—	—	—
1965	—	—	—	35	28	16	14	14	7	6	4	3
1966	—	—	5	6	13	19	12	6	16	20	—	—
1967	—	—	—	—	24	15	11	39	8	16	14	—
1968	—	—	—	28	—	—	19	12	14	16	—	—
1969	21	—	—	31	14	22	10	12	—	12	21	24
1970	—	27	14	19	35	22	22	12	10	4	47	—

No. 3—Indian Run Shelter Spring (Figure 25)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	27	—	9	8	5	2	—	—
1961	—	—	15	—	60	20	9	9	5	3	—	—
1962	—	—	—	—	18	6	9	5	3	2	3	—
1963	—	—	—	17	5	20	4	3	2	1	—	—
1964	—	—	—	20	20	14	9	4	2	—	—	—
1965	—	—	—	15	—	8	4	2	2	1	1	0
1966	—	—	4	4	12	7	4	1	15	9	—	—
1967	—	—	—	—	10	5	3	10	3	6	9	—
1968	—	—	—	12	—	—	6	5	4	3	—	—
1969	11	—	—	14	12	10	4	5	—	11	10	11
1970	—	14	14	12	20	12	15	10	5	4	40	—

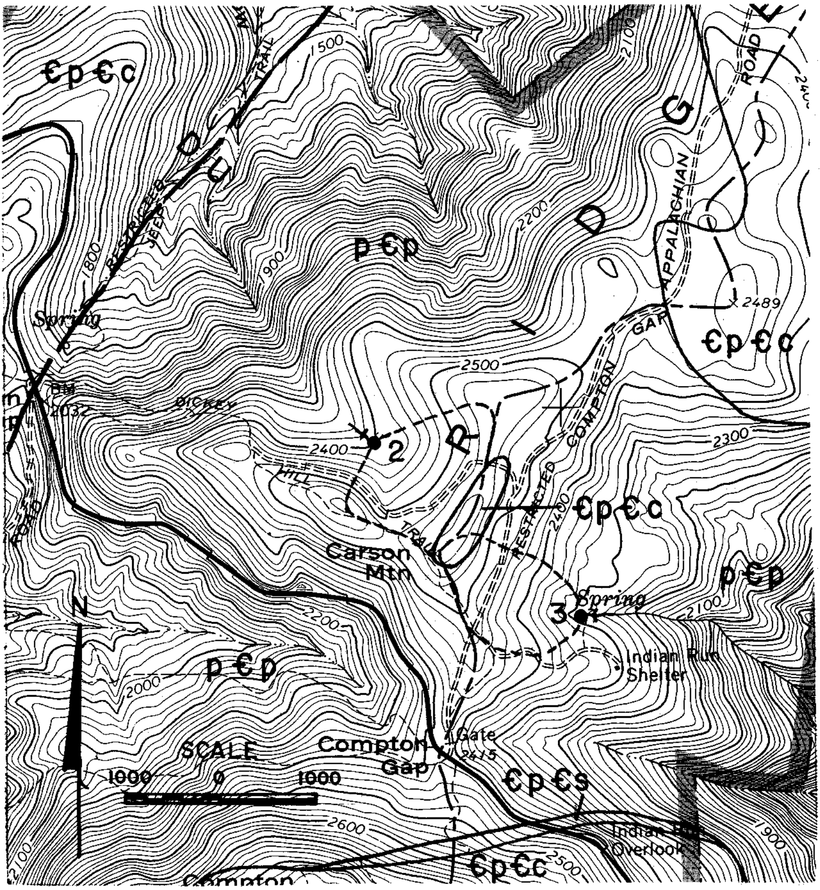


Figure 25. Location of the Dickey Ridge and Indian Run Shelter springs (No. 2 and No. 3), on a portion of the Chester Gap 7.5-minute topographic quadrangle map.

No. 4—Little Hogback Springs East Weir (Figure 26)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	39	—	8	6	4	3	—	—
1962	—	—	—	—	—	—	—	—	3	2	8	—
1963	—	—	—	14	10	14	4	4	3	2	—	—
1964	—	—	—	27	25	12	7	3	2	—	—	—
1965	—	—	—	—	—	10	8	4	4	3	3	1
1966	—	—	10	18	19	16	7	5	14	14	—	—
1967	—	—	—	—	14	18	7	57	14	8	8	—
1968	—	—	—	10	—	—	22	4	5	8	—	—
1969	25	—	—	18	—	19	8	12	—	9	18	21
1970	—	—	12	10	12	7	7	7	3	0	19	—

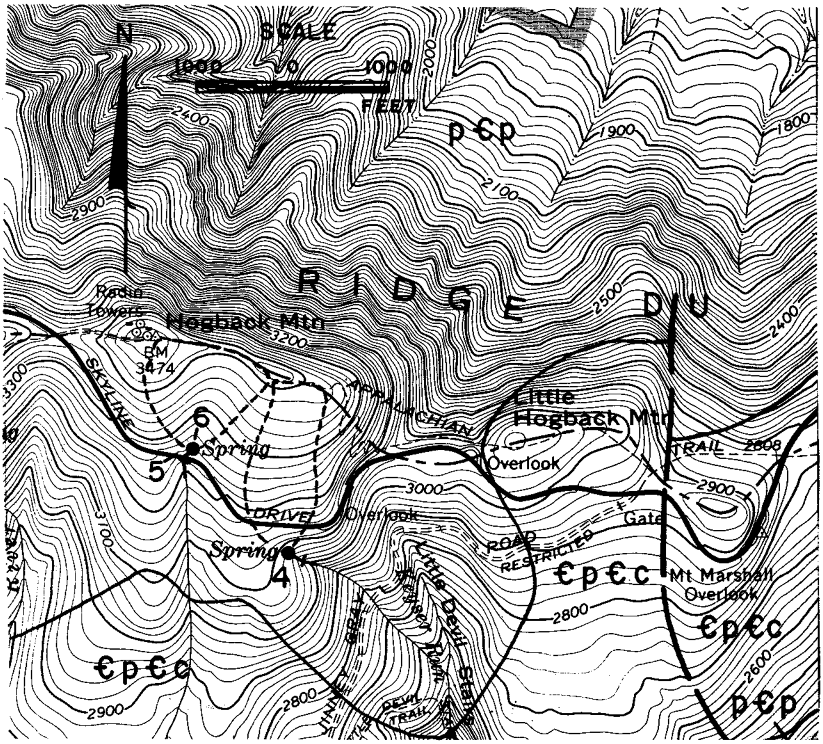


Figure 26. Location of Little Hogback Springs, East Weir (Spring No. 4) and Hogback Springs, B and A weirs (springs No. 5 and No. 6) on a portion of the Bentonville 7.5-minute topographic quadrangle map.

No. 5—Hogback Springs Weir "B" (Figure 26)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	18	—	3	3	1	0	—	—
1962	—	—	—	—	13	11	7	1	0	0	7	—
1963	—	—	—	4	3	4	1	0	0	0	—	—
1964	—	—	—	9	6	2	1	0	0	—	—	—
1965	—	—	—	5	5	2	1	0	2	0	0	1
1966	—	—	4	5	4	2	1	0	8	8	—	—
1967	—	—	—	—	8	4	1	19	4	14	7	—
1968	—	—	—	2	—	—	7	2	3	8	—	—
1969	14	—	—	10	22	14	5	5	—	3	7	16
1970	—	—	4	5	5	4	2	4	2	1	28	—

No. 6—Hogback Springs Weir "A" (Figure 26)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	45	—	—	—	8	5	2	1	—	—

	J	F	M	A	M	J	J	A	S	O	N	D
1962	—	—	—	—	—	34	5	1	0	0	19	—
1963	—	—	—	11	5	12	2	0	0	0	—	—
1964	—	—	—	29	25	4	1	0	0	—	—	—
1965	—	—	—	13	14	4	1	0	0	0	0	0
1966	—	—	16	8	12	8	2	0	16	19	—	—
1967	—	—	—	—	23	10	1	47	3	31	8	—
1968	—	—	—	7	—	—	7	2	2	7	—	—
1969	31	—	—	23	14	25	4	2	—	6	16	26
1970	—	—	8	8	7	7	4	7	3	0	92	—

No. 7—Range View Shelter Spring (Figure 8)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	12	—	—	—	3	3	1	1	—	—
1962	—	—	—	—	7	6	5	3	1	1	2	—
1963	—	—	—	7	4	6	3	1	—	0	—	—
1964	—	—	—	6	7	4	2	1	—	—	—	—
1965	—	—	—	11	14	6	2	1	0	0	0	0
1966	—	—	12	10	14	6	3	0	1	3	—	—
1967	—	—	—	—	14	5	3	7	6	16	8	—
1968	—	—	—	7	—	—	5	2	1	1	—	—
1969	10	—	—	8	5	7	4	3	—	2	10	10
1970	—	14	10	12	10	4	4	10	4	1	43	—

No. 8—Elkwallow Spring (Figure 8)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	16	12	6	—	3	—
1961	—	—	—	—	79	19	15	12	9	7	—	—
1962	—	—	—	—	—	—	—	—	—	—	—	—
1963	—	—	—	29	14	22	14	7	4	2	—	—
1964	—	—	—	31	28	16	11	5	3	—	—	—
1965	—	—	—	25	28	16	12	5	3	2	1	0
1966	—	—	16	16	31	20	13	5	5	9	—	—
1967	—	—	—	—	42	16	11	43	14	10	8	—
1968	—	—	—	22	—	—	10	5	5	16	—	—
1969	19	—	—	22	19	19	12	14	10	8	8	18
1970	—	25	22	25	22	19	12	22	15	7	62	—

No. 9—North Thornton River Springs—East Weir (Figure 8)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	—	—	—	—	—	—	—	—
1962	—	—	39	—	22	18	6	—	—	—	6	—
1963	—	—	—	8	9	10	0	0	0	0	—	—
1964	—	—	—	21	12	7	0	0	0	—	—	—
1965	—	—	—	5	8	3	0	0	0	0	0	0
1966	—	—	7	5	5	0	0	0	7	4	—	—
1967	—	—	—	—	11	5	1	35	2	10	1	—

1968	—	—	—	8	—	—	—	—	—	3	—	—
1969	14	—	—	7	4	14	7	5	7	7	7	14
1970	—	19	5	4	3	2	2	5	2	0	—	—

No. 10—North Thornton River Springs—West Weir (Figure 8)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	16	—	—	—	7	7	5	3	—	—
1962	—	—	—	—	17	19	12	5	3	2	3	—
1963	—	—	—	16	—	16	7	3	2	1	—	—
1964	—	—	—	20	14	10	7	1	0	—	—	—
1965	—	—	—	14	16	4	7	0	0	0	0	0
1966	—	—	19	19	14	12	5	0	1	12	—	—
1967	—	—	—	—	18	4	2	47	4	8	3	—
1968	—	—	—	10	—	—	2	1	—	2	—	—
1969	14	—	—	7	14	14	7	—	—	—	—	14
1970	—	19	—	—	—	—	—	—	—	—	—	—

No. 11—Beahm's Gap Spring # 2 (Birdnest # 4) (Figure 27)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	—	—	—	—	—	—	—	—
1962	—	—	—	—	—	—	—	—	—	—	—	—
1963	—	—	—	—	—	—	—	—	—	—	—	—
1964	—	—	—	—	—	—	—	—	—	—	—	—
1965	—	—	—	30	20	12	8	6	2	0	0	0
1966	—	—	15	20	25	15	12	4	3	12	—	—
1967	—	—	—	—	20	15	10	30	12	18	8	—
1968	—	—	—	20	—	—	15	6	4	12	—	—
1969	15	—	—	14	12	14	6	12	—	7	20	20
1970	—	25	18	24	26	19	12	14	—	—	—	—

No. 12—Beahm's Gap Spring # 3 (Birdnest # 4) (Figure 27)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	—	—	—	—	—	—	—	—
1962	—	—	—	—	—	—	—	—	—	—	—	—
1963	—	—	—	—	—	—	—	—	—	—	—	—
1964	—	—	—	—	—	—	—	—	—	—	—	—
1965	—	—	—	6	4	2	2	1	2	1	1	0
1966	—	—	2	2	10	2	1	1	15	3	—	—
1967	—	—	—	—	4	2	2	4	2	3	2	—
1968	—	—	4	—	—	—	1	1	2	—	—	—
1969	2	—	—	3	2	2	2	2	—	2	4	5
1970	—	8	7	10	10	3	4	3	—	—	—	—

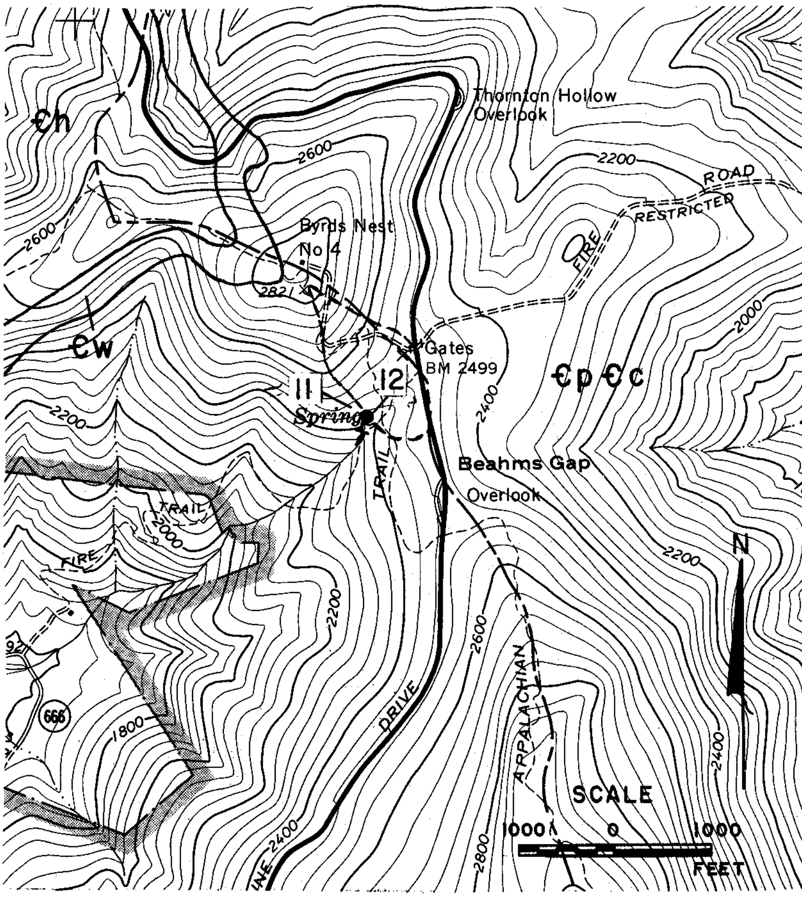


Figure 27. Location of the Beahms Gap springs (No. 11 and No. 12) on a portion of the Thornton Gap 7.5-minute topographic quadrangle map.

No. 13—Panorama Spring (Figure 12)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	18	19	—	—	39	—	8	6	5	5	4	—
1961	—	—	32	41	39	25	16	7	10	7	—	—
1962	—	—	—	—	28	14	11	6	3	3	—	—
1963	—	—	18	25	11	9	—	3	3	1	—	—
1964	—	—	—	18	28	14	10	4	3	—	—	—
1965	—	25	28	20	16	16	7	3	3	2	—	2
1966	2	14	6	8	20	9	7	3	8	5	—	14
1967	16	16	39	20	16	11	5	11	8	12	10	—
1968	—	—	—	14	31	—	12	5	2	2	—	—
1969	9	8	12	14	8	7	4	19	11	2	8	19
1970	6	2	16	25	14	10	7	7	4	2	57	—

No. 14—Headquarters Springs Weir (Figure 9)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	7	11	—	—	15	—	—	6	6	—	4	—
1961	6	6	15	—	28	16	9	7	7	8	—	—
1962	—	—	28	—	14	11	8	6	4	5	—	6
1963	—	8	14	12	8	8	—	4	4	4	—	—
1964	8	—	10	10	12	8	7	5	4	—	—	—
1965	14	10	14	10	10	10	6	5	4	4	3	2
1966	3	5	6	7	5	7	4	3	8	7	—	10
1967	7	12	20	11	11	9	8	10	6	8	8	—
1968	—	—	—	12	25	—	8	5	5	4	—	—
1969	10	7	10	10	8	7	5	7	5	5	7	14
1970	10	14	10	14	10	8	7	7	5	4	16	—

No. 15—Hazel Mtn. Overlook Spring (Figure 28)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	6	—	—	—	21	19	15	16	—	—
1962	—	—	—	—	21	18	17	5	3	3	8	—
1963	—	—	—	10	7	8	7	5	3	2	—	—
1964	—	—	—	5	5	5	5	1	0	—	—	—
1965	—	—	—	7	7	5	0	0	0	—	3	4
1966	4	—	6	7	8	5	3	3	6	7	—	—
1967	—	—	—	—	4	3	3	14	1	0	—	—
1968	—	—	—	—	—	—	—	—	—	—	—	—
1969	—	—	—	—	—	—	—	—	—	—	—	—
1970	—	—	—	—	—	—	—	—	—	—	—	—

No. 16—Pinnacles Springs Lower Weir (Figure 28)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	12	19	—	—	21	12	4	3	11	2	2	—
1961	4	—	52	43	53	79	17	4	25	7	—	—
1962	—	—	—	—	30	28	14	2	0	0	—	—
1963	—	—	—	—	—	19	3	0	0	0	—	—
1964	—	—	—	34	—	7	—	2	1	—	—	—
1965	—	—	—	16	14	8	5	1	0	0	0	0
1966	0	—	31	18	22	7	2	—	47	22	—	—
1967	—	—	—	—	18	7	7	92	7	68	10	—
1968	—	—	—	12	—	—	5	2	0	1	—	—
1969	38	—	—	19	16	14	7	22	39	7	31	24
1970	—	28	16	—	31	—	14	12	2	2	106	—

No. 17—Sexton Shelter Spring (Figure 13)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	19	—	—	8	8	—	4	—

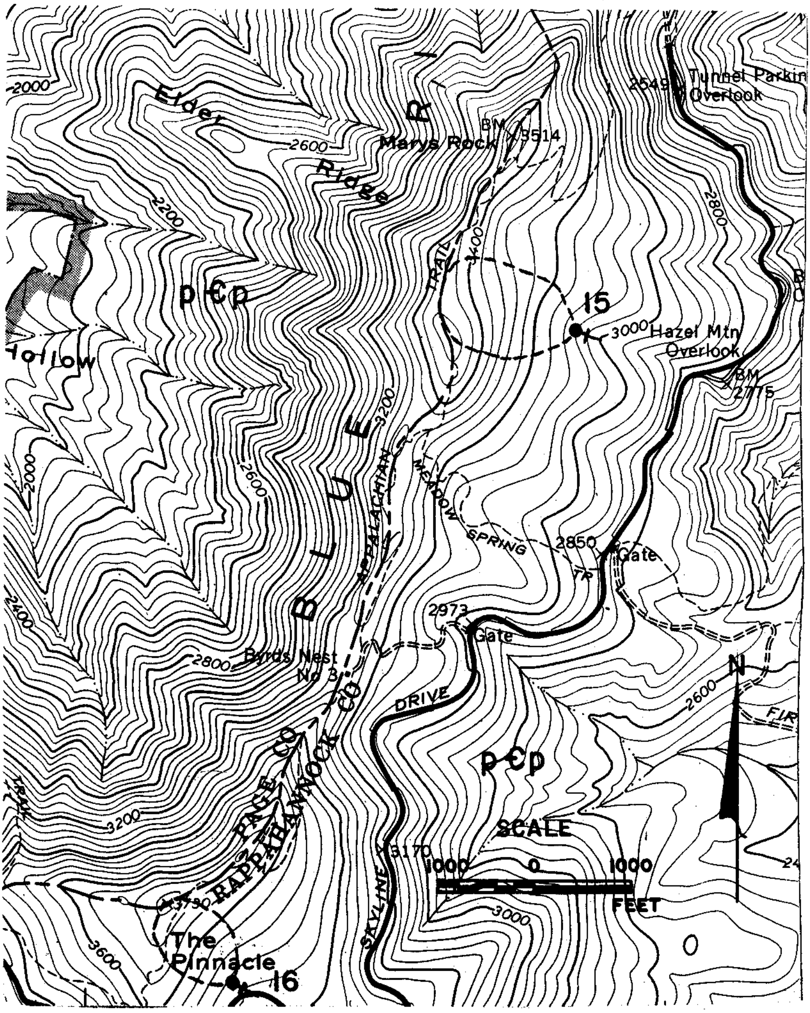


Figure 28. Location of Hazel Mountain Overlook and Pinnacles Lower weirs (spring No. 15 and No. 16), on a portion of the Thornton Gap 7.5-minute topographic quadrangle map.

1961	14	—	39	25	23	22	9	3	4	3	—	—
1962	—	—	—	—	—	—	—	—	—	5	—	—
1963	—	—	35	39	18	20	10	10	5	2	—	—
1964	—	—	—	39	—	10	16	9	7	—	—	—
1965	—	35	39	33	26	22	12	7	5	4	4	5
1966	2	—	31	19	31	12	10	3	22	20	—	—
1967	28	26	35	31	56	14	16	68	16	73	28	—
1968	—	—	—	31	—	—	—	7	10	10	—	—

1969	47	21	18	39	25	25	10	14	18	11	27	27
1970	21	37	31	31	25	12	14	22	7	8	79	—

No. 18—Stony Man Springs—North Weir (Figure 14)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	—	—	—	—	—	—	—	—
1962	—	—	—	—	—	—	—	—	—	—	—	—
1963	—	—	—	19	9	15	4	1	0	0	—	—
1964	—	—	—	52	—	4	2	0	0	—	—	—
1965	—	—	—	14	14	7	3	1	0	1	—	1
1966	2	—	25	25	14	5	0	—	43	25	—	—
1967	—	—	—	—	24	7	5	57	10	52	14	—
1968	—	—	—	12	—	—	5	3	0	5	—	—
1969	25	—	—	14	22	28	18	25	56	7	31	31
1970	—	31	19	47	43	39	35	25	10	4	139	—

No. 19—Furnace Spring (Figure 14)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	59	83	—	—	97	73	31	24	20	19	15	—
1961	—	22	111	92	110	126	75	42	52	61	—	—
1962	—	—	114	—	106	85	72	31	16	16	—	57
1963	—	73	89	83	40	103	45	20	19	—	32	—
1964	130	65	114	99	—	41	35	20	21	—	99	99
1965	130	106	122	89	68	54	28	—	—	—	—	9
1966	8	92	106	62	106	35	27	—	139	59	—	114
1967	85	99	130	73	85	34	35	139	57	130	62	—
1968	—	—	—	68	122	—	39	45	28	25	—	—
1969	99	56	47	92	73	68	77	92	85	84	114	114
1970	—	73	130	106	106	47	47	92	47	28	139	—

No. 20—Park Springs—East Weir (Figure 15)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	28	35	—	—	70	—	16	7	3	—	1	—
1961	—	—	—	—	89	79	33	19	15	10	—	—
1962	—	—	—	—	24	67	31	7	3	1	16	—
1963	—	—	—	33	4	49	12	8	2	1	—	—
1964	—	—	—	47	—	14	7	2	2	—	—	—
1965	—	—	—	26	23	16	6	4	2	1	—	0
1966	0	—	57	14	43	14	8	2	22	29	—	—
1967	—	—	—	—	27	12	7	19	10	20	10	—
1968	—	—	—	19	—	—	12	12	4	14	—	—
1969	28	—	—	—	28	19	18	28	31	18	47	18
1970	—	25	28	39	31	14	19	29	14	5	79	—

No. 21—Powwow Grounds Springs—West Weir (Figure 14)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	10	—	—	—	5	4	2	7	—	—

	J	F	M	A	M	J	J	A	S	O	N	D
1962	—	—	—	—	9	10	6	3	1	1	2	—
1963	—	—	—	13	4	8	5	3	1	1	—	—
1964	—	—	—	9	—	5	2	1	2	—	—	—
1965	—	—	—	10	5	5	2	1	2	1	—	1
1966	1	—	5	4	7	3	2	1	6	8	—	—
1967	—	—	—	—	5	3	—	12	1	10	5	—
1968	—	—	—	5	—	—	3	2	1	2	—	—
1969	10	—	8	5	—	—	—	—	—	—	—	—
1970	—	—	—	—	—	—	—	—	—	—	28	—

No. 22—White Oak Canyon Spring—New Weir (Figure 15)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	39	54	—	—	64	—	11	7	5	—	1	—
1961	—	—	—	—	110	70	22	20	48	16	—	—
1962	—	—	—	—	39	47	31	8	4	2	35	—
1963	—	—	—	—	—	—	14	4	3	1	—	—
1964	—	—	—	56	—	18	6	2	1	—	—	—
1965	—	—	—	33	29	28	12	5	1	1	—	0
1966	0	—	45	57	73	23	9	3	31	47	—	—
1967	—	—	—	—	56	20	25	79	25	139	43	—
1968	—	—	—	25	—	—	31	14	7	31	—	—
1969	38	—	—	57	39	9	10	25	21	16	14	26
1970	—	43	31	43	47	14	35	19	14	7	—	—

No. 23—Lewis Spring (Figure 16)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	122	126	—	—	130	156	79	57	68	76	70	—
1961	—	—	289	243	230	172	83	69	77	84	—	—
1962	—	—	218	—	156	92	73	—	43	37	—	92
1963	—	122	139	166	70	143	68	45	32	24	123	—
1964	242	122	218	201	—	79	62	38	29	—	85	114
1965	218	218	218	135	122	85	57	37	28	25	—	20
1966	23	156	175	92	122	79	57	39	280	186	—	196
1967	166	139	218	122	122	67	65	139	92	218	130	—
1968	—	—	—	114	218	—	92	68	45	57	—	—
1969	219	122	122	130	166	92	56	68	73	92	218	218
1970	156	73	139	218	218	79	57	52	39	28	218	—

No. 24—Colvin Spring Weir (Figure 29)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	22	—	—	—	—	—	—	—	—
1962	—	—	—	—	—	—	—	—	—	—	—	—
1963	—	—	—	12	10	12	10	7	4	3	—	—
1964	—	—	—	11	—	10	8	2	1	—	—	—
1965	—	—	—	14	10	7	8	7	2	4	—	6
1966	6	16	14	10	10	5	8	1	12	12	—	—
1967	—	—	—	—	18	15	8	23	10	28	16	—

1968	—	—	—	10	—	—	5	4	4	8	—	—
1969	7	—	—	14	7	7	7	7	5	5	7	10
1970	—	15	7	7	7	2	3	7	5	4	22	—

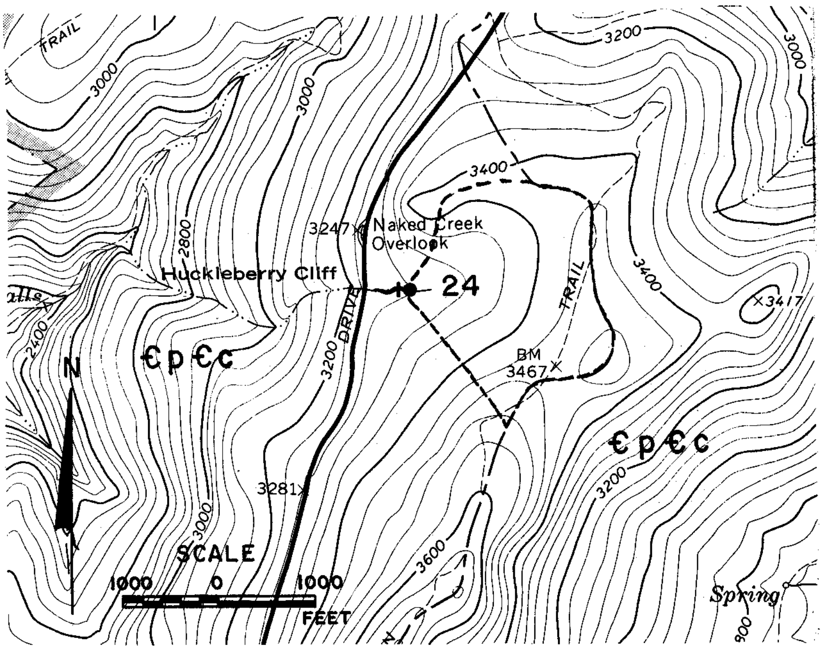


Figure 29. Location of Colvin Spring (spring No. 24), on a portion of the Fletcher 7.5-minute topographic quadrangle map.

No. 25—Lewis Mountain Spring (Figure 17)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	25	28	—	—	24	22	11	7	8	7	6	—
1961	14	14	47	25	25	25	25	29	28	25	—	—
1962	—	—	31	—	33	22	15	10	6	4	—	20
1963	—	23	28	25	18	28	16	14	8	3	14	—
1964	35	23	28	26	16	—	10	8	4	—	35	25
1965	28	28	31	28	23	15	14	8	8	22	—	10
1966	3	28	31	28	62	16	10	5	25	22	—	43
1967	20	23	29	22	38	16	19	42	19	47	25	—
1968	—	—	—	25	35	—	22	12	7	14	—	—

1969	24	18	18	24	18	25	18	25	18	18	21	27
1970	19	25	25	19	22	12	12	12	7	7	28	—

No. 26—Dean Mountain Spring (Figure 30)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	16	20	—	—	—	—	7	5	3	—	2	—
1961	—	—	57	58	37	25	10	10	12	10	—	—
1962	—	—	—	—	15	8	9	3	1	1	4	—
1963	—	—	—	—	—	16	8	4	2	1	1	—
1964	—	—	—	24	—	8	4	1	2	—	—	—
1965	—	—	—	16	16	8	4	2	3	2	—	2
1966	3	57	25	11	25	8	4	2	14	19	—	—
1967	—	—	—	14	27	11	5	7	3	39	14	—
1968	—	—	—	16	—	—	10	5	2	4	—	—
1969	10	10	24	12	25	14	10	28	8	16	24	38
1970	—	38	12	25	28	7	19	2	2	1	57	—

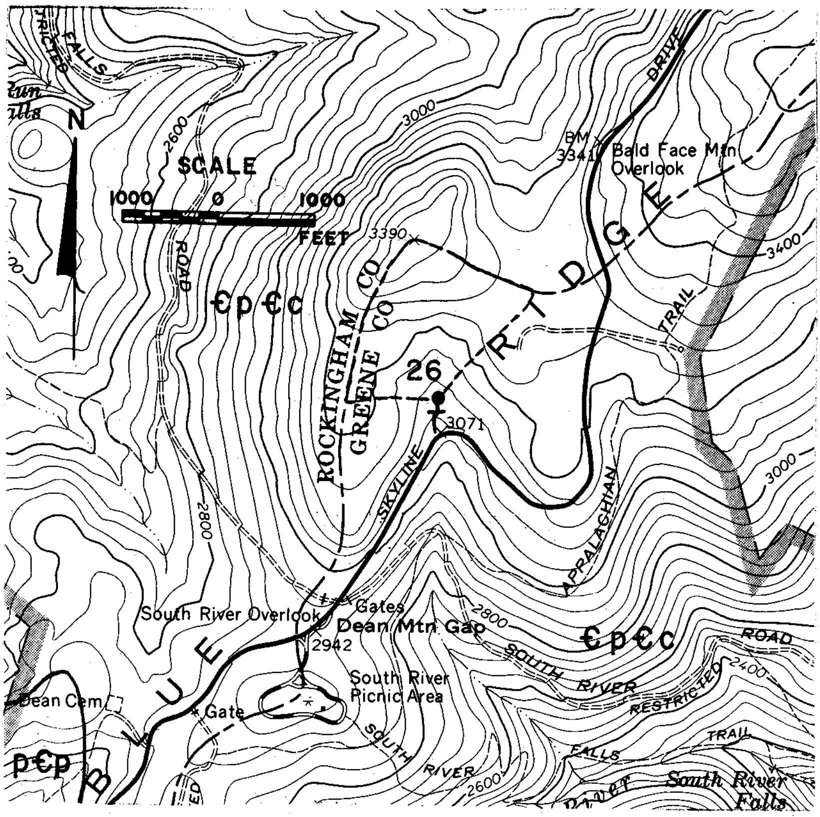


Figure 30. Location of Dean Mountain Spring (spring No. 26) on a portion of the Elkton East 7.5-minute topographic quadrangle map.

No. 27—Swift Run Gap Spring (Figure 18)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	11	—	—	8	—	5	5	5	—	—	—
1961	—	—	—	14	10	8	8	7	6	6	—	—
1962	—	—	—	—	9	7	6	5	4	3	—	—
1963	—	—	—	—	8	7	5	3	2	2	—	—
1964	—	—	—	4	—	5	5	2	3	—	—	—
1965	—	—	—	4	3	4	3	3	2	2	—	2
1966	—	4	5	—	4	2	4	3	8	7	—	—
1967	—	—	—	—	3	3	3	11	4	9	8	—
1968	—	—	—	6	—	—	5	—	3	4	—	—
1969	8	6	11	10	7	—	18	31	16	18	10	—
1970	—	14	18	19	18	15	14	10	7	7	20	—

No. 28—Ivy Creek Spring (Figure 20)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	—	—	—	—	—	—
1961	—	—	—	—	12	—	9	5	25	65	—	—
1962	—	—	—	—	9	12	—	4	4	6	—	—
1963	—	—	—	—	—	20	6	5	1	8	—	—
1964	—	—	—	40	—	13	12	2	1	—	—	—
1965	—	—	—	20	16	5	2	1	1	7	—	2
1966	—	25	23	22	18	12	3	1	23	22	—	—
1967	—	—	—	—	18	7	5	62	4	19	14	—
1968	—	—	—	14	—	—	15	5	5	10	—	—
1969	26	—	—	16	39	—	9	14	14	10	18	24
1970	—	50	25	19	19	14	12	5	2	1	35	—

No. 29—Dundo Spring (Figure 22)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	6	—	—	—	—	2	2	7	—	2	—
1961	—	—	—	26	19	7	3	0	13	89	—	—
1962	—	—	—	—	6	6	—	0	0	0	—	—
1963	—	—	—	—	—	10	2	0	0	—	—	—
1964	—	—	—	21	—	3	1	0	0	—	—	—
1965	—	—	—	31	18	2	1	0	—	0	—	0
1966	—	16	12	7	12	3	1	0	19	20	—	—
1967	—	—	—	—	16	8	1	57	1	80	10	—
1968	—	—	—	10	—	—	1	1	0	4	—	—
1969	18	—	—	10	10	—	2	1	38	8	14	18
1970	—	39	10	16	14	7	1	3	1	0	39	—

No. 30—Pond Ridge Spring (Figure 31)

	J	F	M	A	M	J	J	A	S	O	N	D
1960	—	—	—	—	—	—	7	13	18	—	8	—
1961	—	—	—	—	60	18	6	4	9	28	—	—
1962	—	—	—	—	20	12	—	6	4	2	—	—
1963	—	—	—	—	—	—	4	—	—	—	2	—

1964	—	—	—	25	—	17	8	3	3	—	—	—
1965	—	—	—	38	24	6	4	4	3	2	—	3
1966	—	30	20	25	28	12	5	4	18	15	—	—
1967	—	—	—	—	20	8	10	20	11	30	20	—
1968	—	—	—	20	—	—	19	8	4	8	—	—
1969	4	—	—	30	23	—	21	15	25	14	—	30
1970	—	40	40	42	40	30	28	6	4	3	30	—

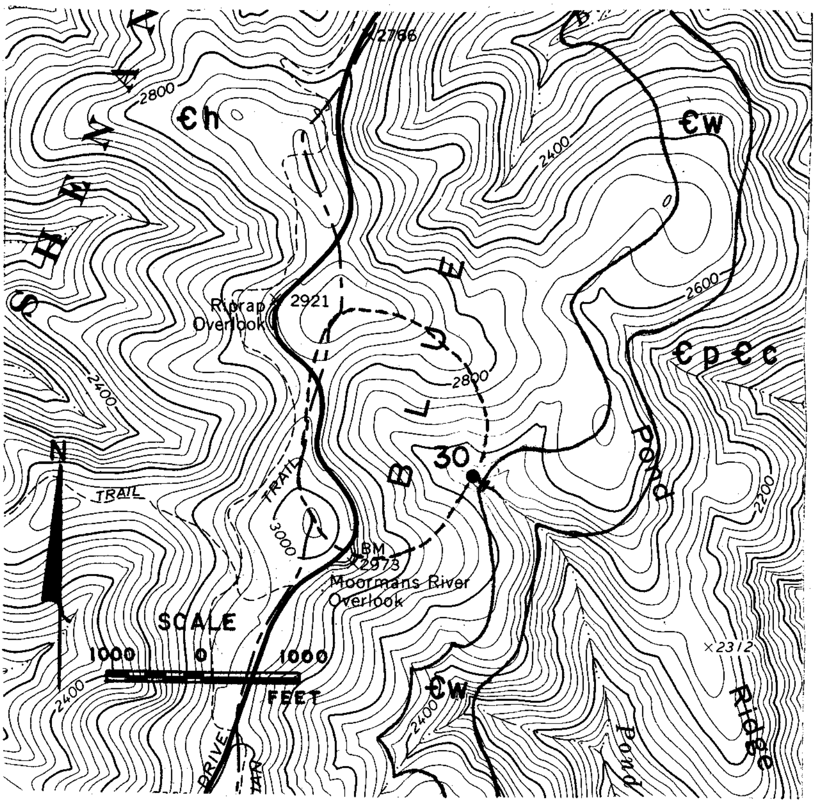
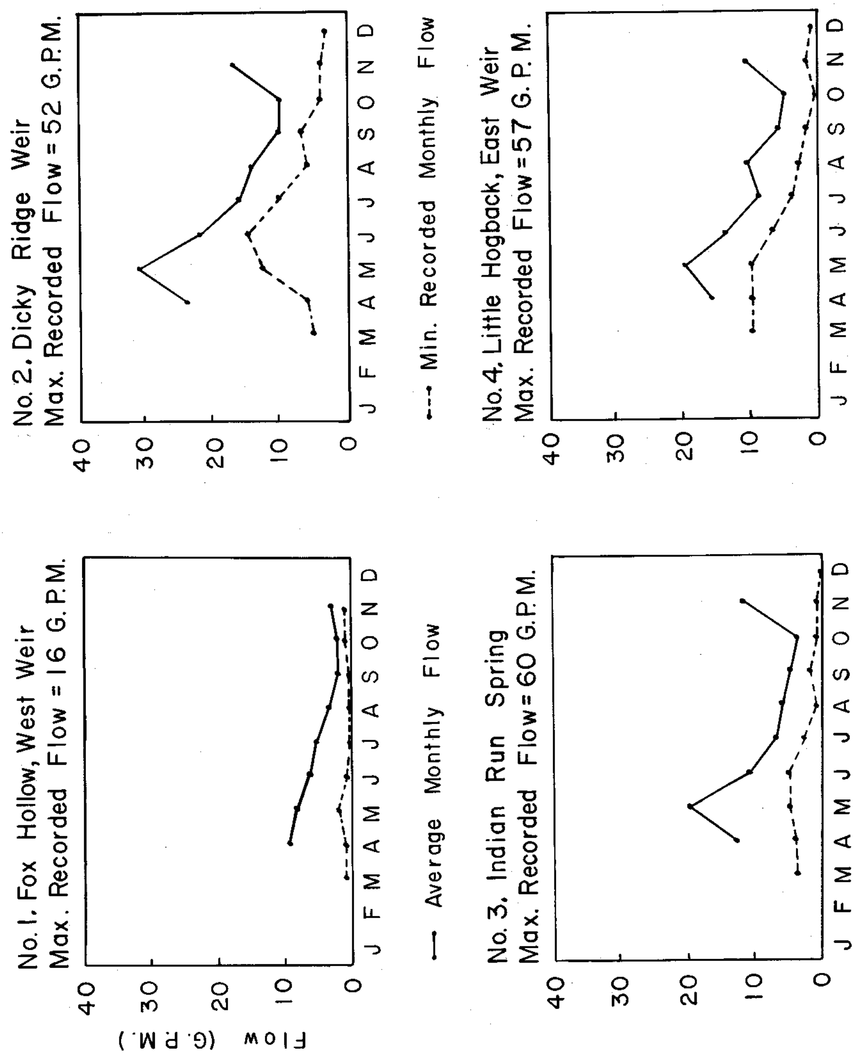
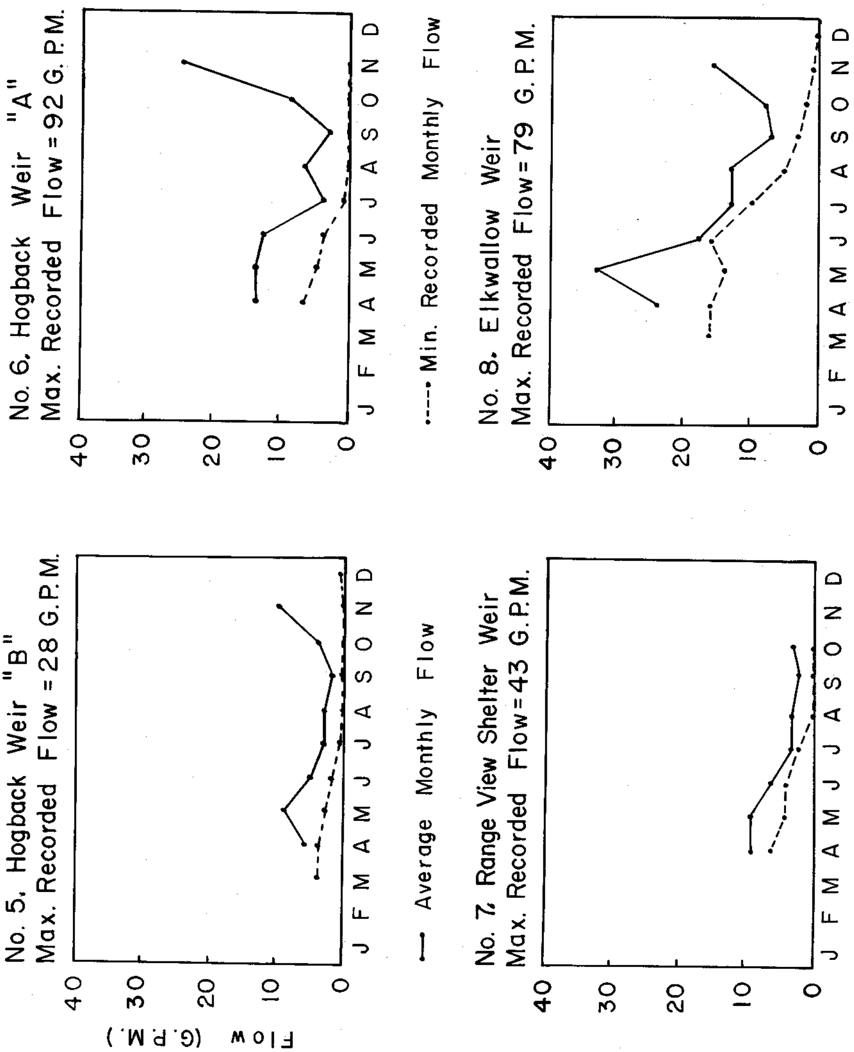
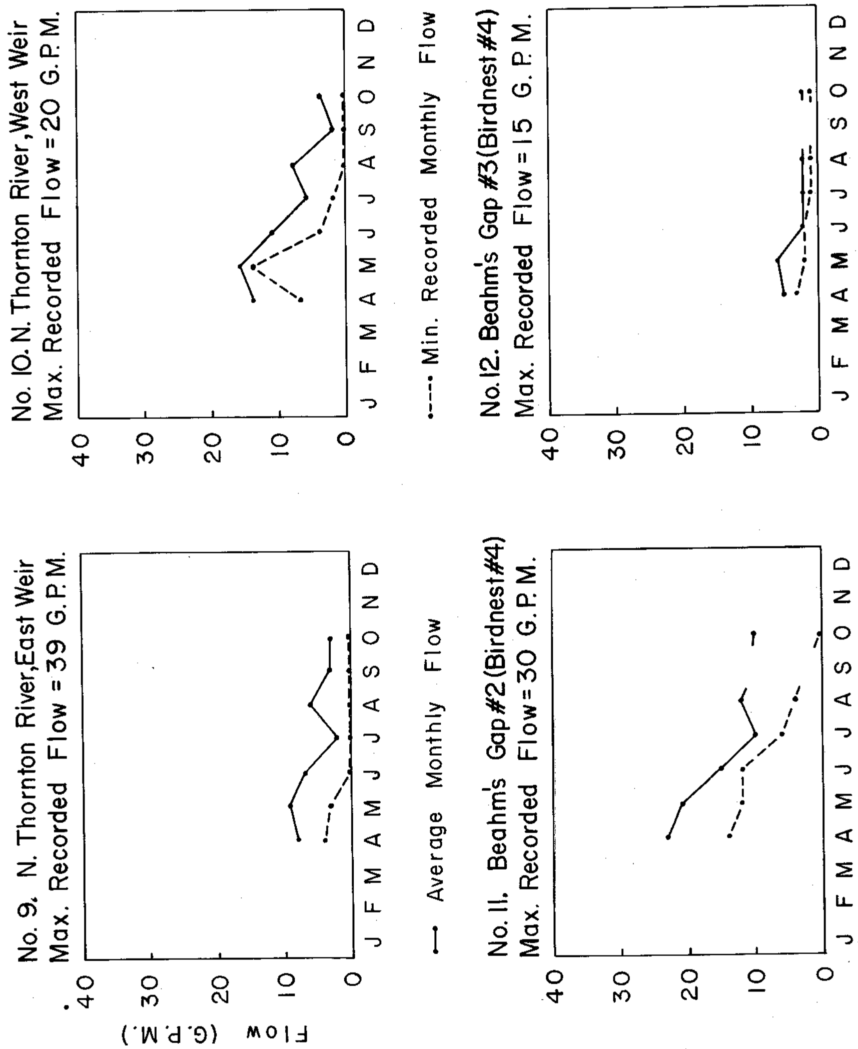
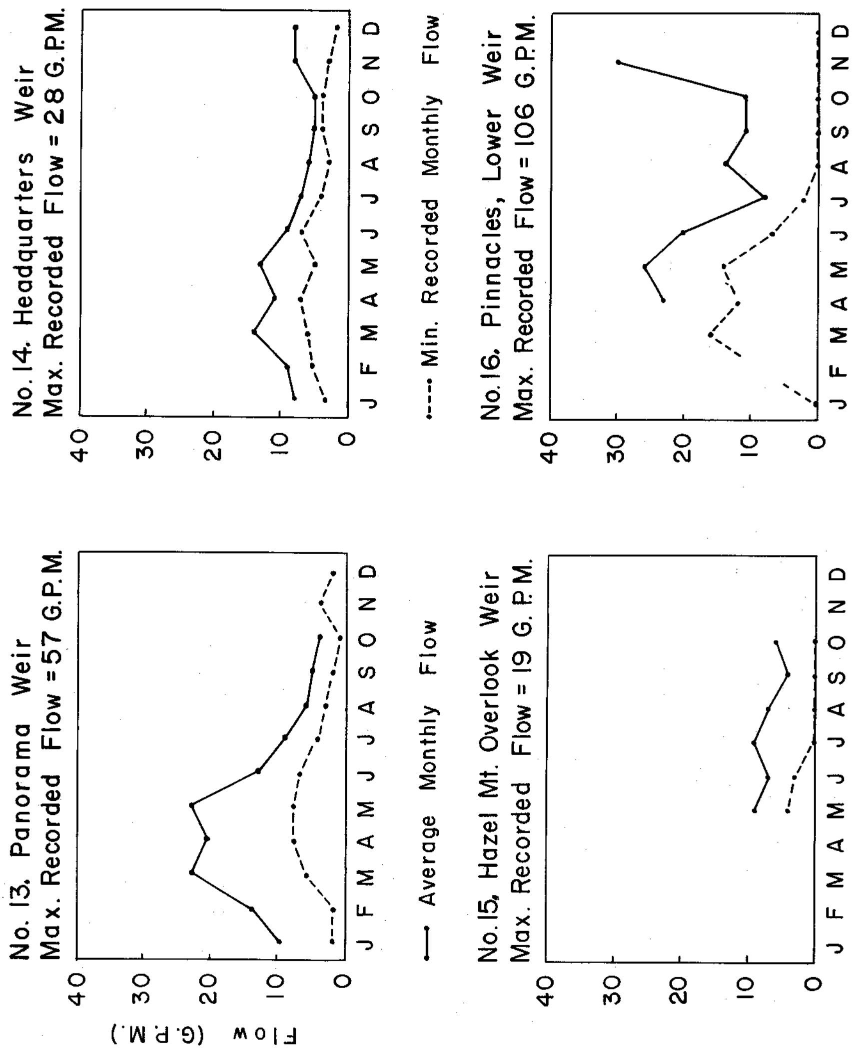


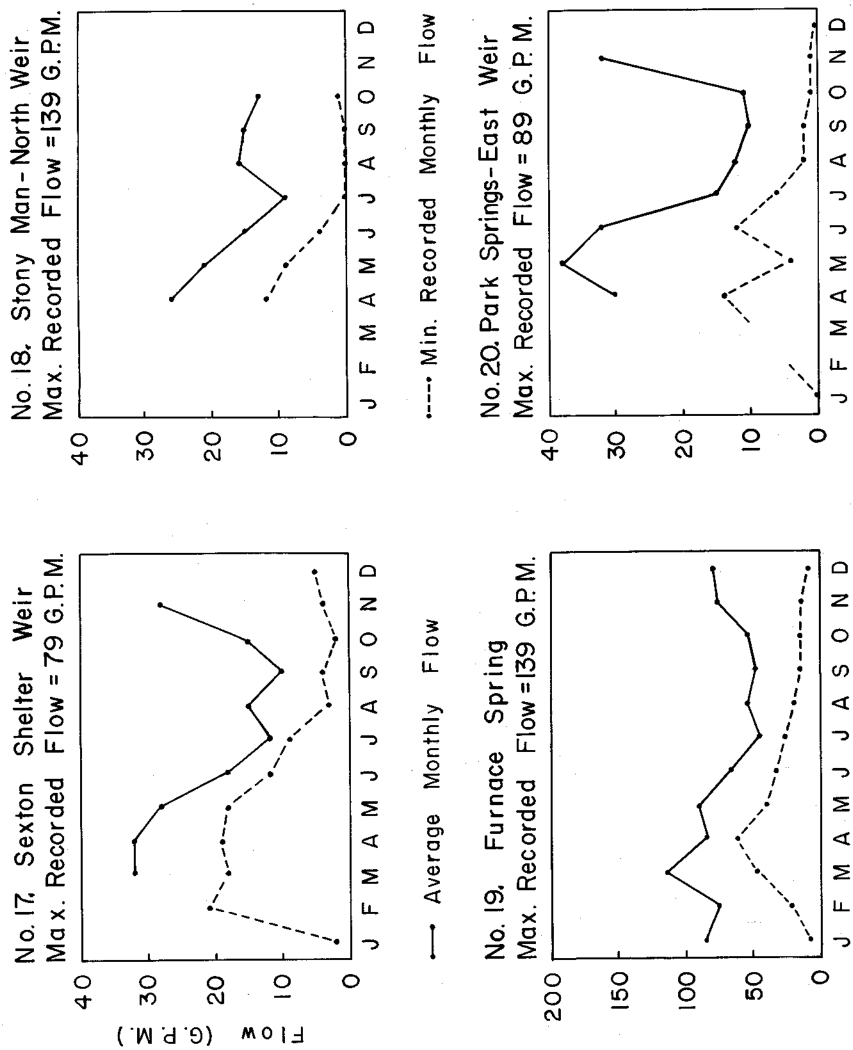
Figure 31. Location of the Pond Ridge Spring flow pipe (spring No. 30), on a portion of the Crimora 7.5-minute topographic quadrangle map.

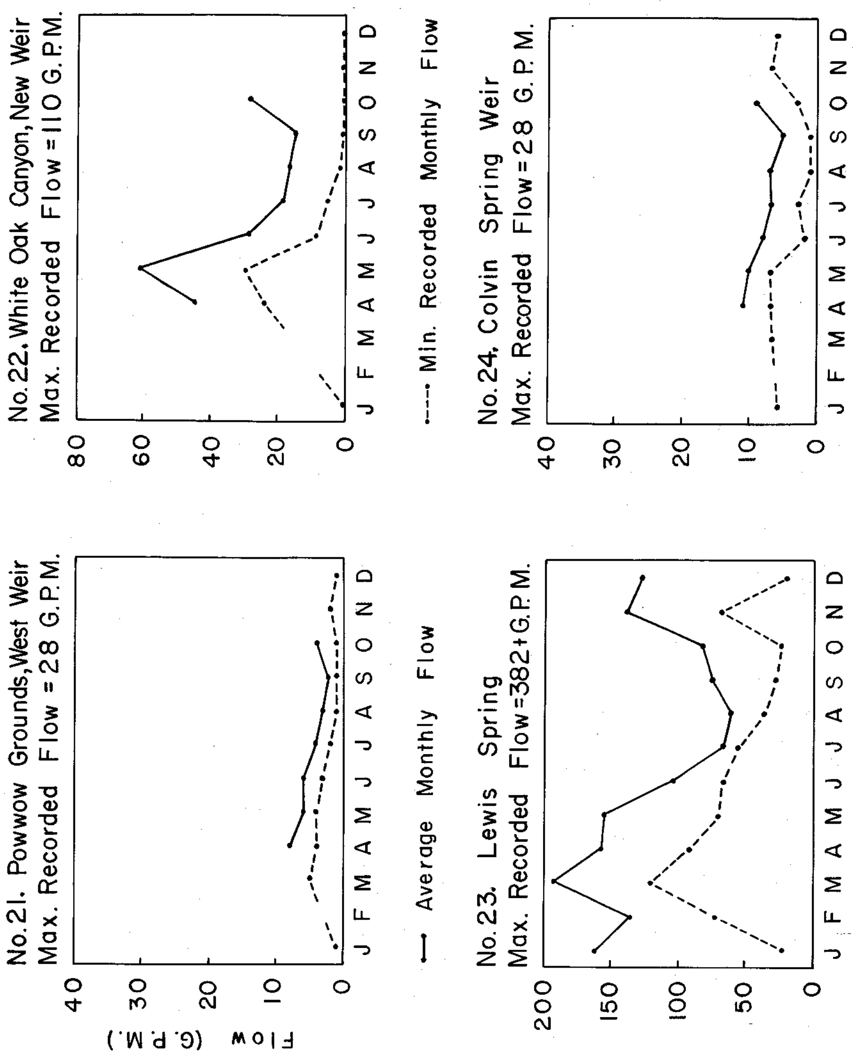

No. 1. Fox Hollow, West Weir
Max. Recorded Flow = 16 G.P.M.
No. 2. Dicky Ridge Weir
Max. Recorded Flow = 52 G.P.M.
No. 3. Indian Run Spring
Max. Recorded Flow = 60 G.P.M.
No. 4. Little Hogback, East Weir
Max. Recorded Flow = 57 G.P.M.
Average Monthly Flow
Min. Recorded Monthly Flow
Flow (G.P.M.)
0
10
20
30
40
J F M A M J J A S O N D

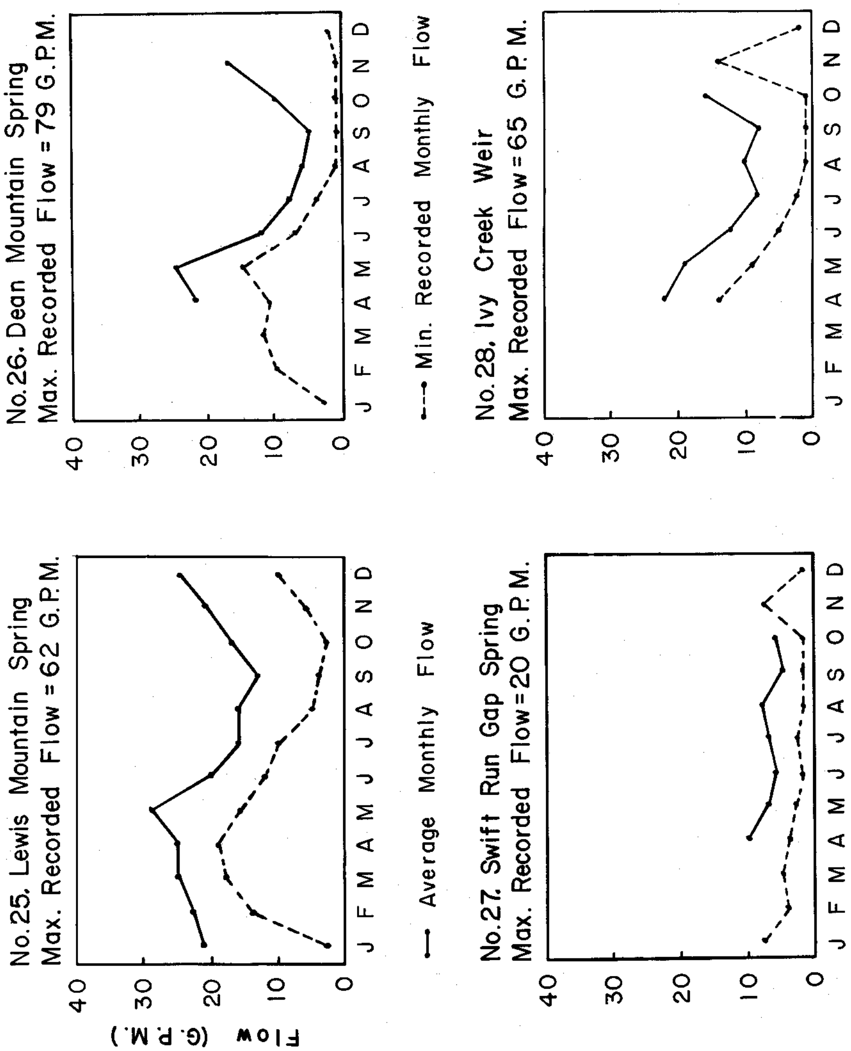

No. 5. Hogback Weir "B"
Max. Recorded Flow = 28 G.P.M.
No. 6. Hogback Weir "A"
Max. Recorded Flow = 92 G.P.M.
No. 7. Range View Shelter Weir
Max. Recorded Flow = 43 G.P.M.
No. 8. Elkwallow Weir
Max. Recorded Flow = 79 G.P.M.
Flow (G.P.M.)
0
10
20
30
40
J F M A M J J A S O N D
Average Monthly Flow
Min. Recorded Monthly Flow

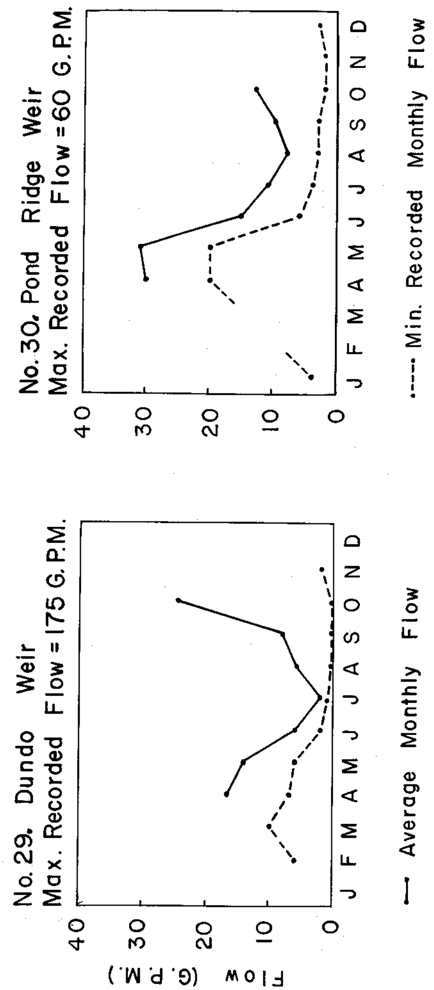

No. 9. N. Thornton River, East Weir
Max. Recorded Flow = 39 G.P.M.
No. 10. N. Thornton River, West Weir
Max. Recorded Flow = 20 G.P.M.
No. 11. Beahm's Gap #2 (Birdnest #4)
Max. Recorded Flow = 30 G.P.M.
No. 12. Beahm's Gap #3 (Birdnest #4)
Max. Recorded Flow = 15 G.P.M.
Flow (G.P.M.)
0
10
20
30
40
J F M A M J J A S O N D
Average Monthly Flow
Min. Recorded Monthly Flow


No. 13. Panorama Weir
Max. Recorded Flow = 57 G.P.M.
No. 14. Headquarters Weir
Max. Recorded Flow = 28 G.P.M.
No. 15. Hazel Mt. Overlook Weir
Max. Recorded Flow = 19 G. P. M.
No. 16. Pinnacles, Lower Weir
Max. Recorded Flow = 106 G.P.M.
Flow (G.P.M.)
40
30
20
10
0
J F M A M J J A S O N D
Average Monthly Flow
Min. Recorded Monthly Flow


No. 18. Stony Man-North Weir
Max. Recorded Flow = 139 G.P.M.
No. 20. Park Springs-East Weir
Max. Recorded Flow = 89 G.P.M.
No. 17. Sexton Shelter Weir
Max. Recorded Flow = 79 G.P.M.
No. 19. Furnace Spring
Max. Recorded Flow = 139 G.P.M.
Flow (G.P.M.)
J F M A M J J A S O N D
0 10 20 30 40
0 50 100 150 200
Average Monthly Flow
Min. Recorded Monthly Flow


No. 21. Powwow Grounds, West Weir
Max. Recorded Flow = 28 G.P.M.
No. 22. White Oak Canyon, New Weir
Max. Recorded Flow = 110 G.P.M.
No. 23. Lewis Spring
Max. Recorded Flow = 382+ G.P.M.
No. 24, Colvin Spring Weir
Max. Recorded Flow = 28 G.P.M.
Flow (G.P.M.)
J F M A M J J A S O N D
Average Monthly Flow
Min. Recorded Monthly Flow

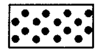
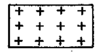
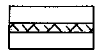

No.25. Lewis Mountain Spring
Max. Recorded Flow = 62 G.P.M.
No.26. Dean Mountain Spring
Max. Recorded Flow = 79 G.P.M.
No.27. Swift Run Gap Spring
Max. Recorded Flow=20 G.P.M.
No.28. Ivy Creek Weir
Max. Recorded Flow=65 G.P.M.
Average Monthly Flow
Min. Recorded Monthly Flow
Flow (G.P.M.)
0
10
20
30
40
J F M A M J J A S O N D


No. 30. Pond Ridge Weir
Max. Recorded Flow = 60 G.P.M.
No. 29. Dundo Weir
Max. Recorded Flow = 175 G.P.M.
Flow (G.P.M.)
0 10 20 30 40
J F M A M J J A S O N D
Average Monthly Flow
Min. Recorded Monthly Flow

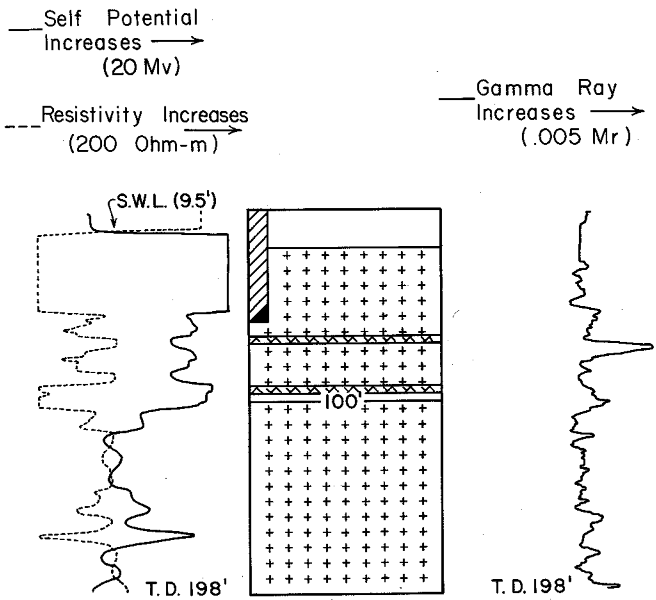
APPENDIX II

SELECTED GEOPHYSICAL LOGS

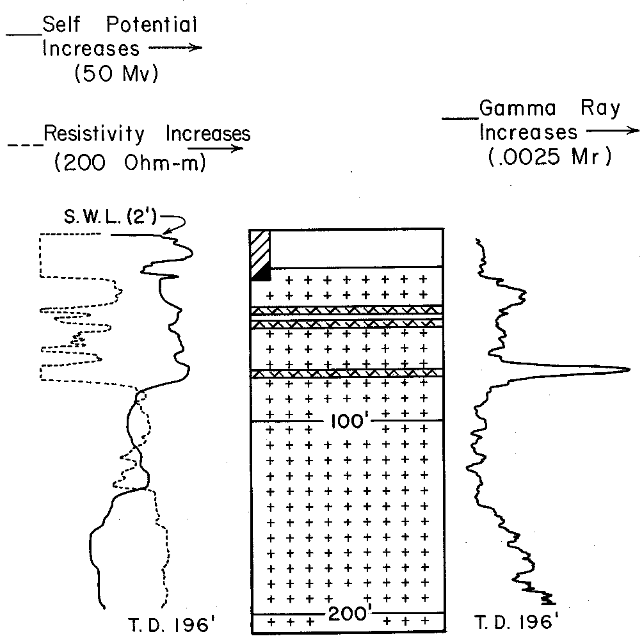
EXPLANATION

OVERBURDEN	
PHYLLITE	
METAGRAYWACKE, META-ARKOSE and PHYLLITE	
METABASALT	
GRANODIORITE	
WATER-BEARING FRACTURES	
BASALT FLOW BOUNDARIES	
CASING	
MANUAL SHIFT	M. S.
TOTAL DEPTH	T. D.
STATIC WATER LEVEL	S. W. L.

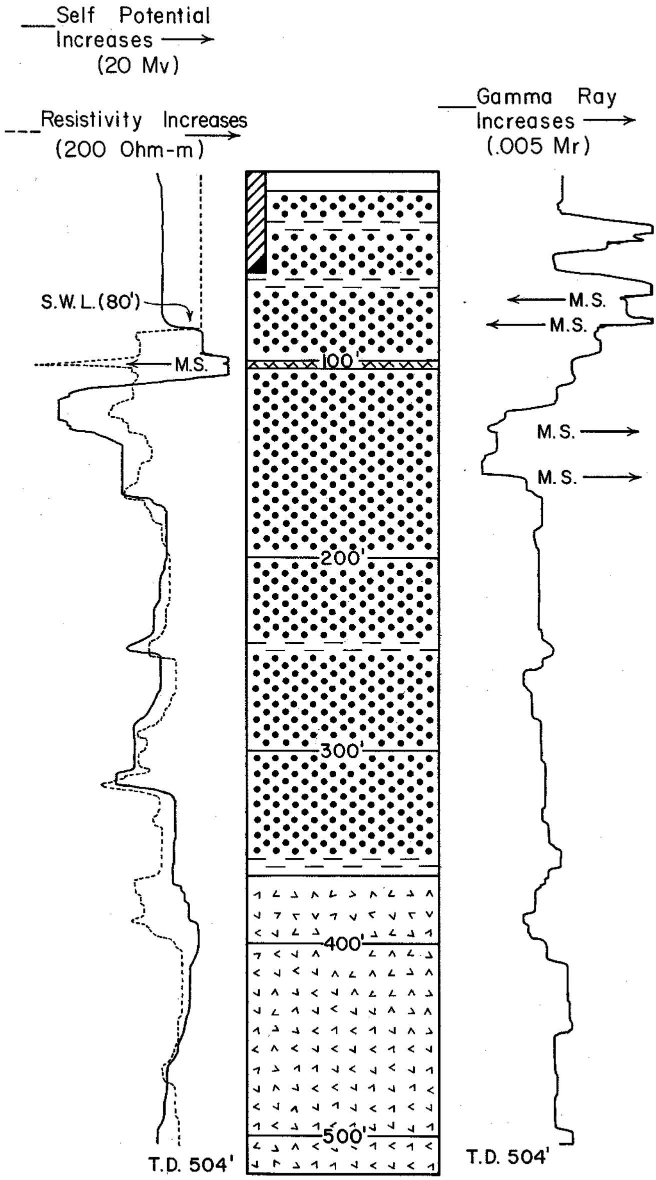
Lithologic information obtained from log of well cuttings.



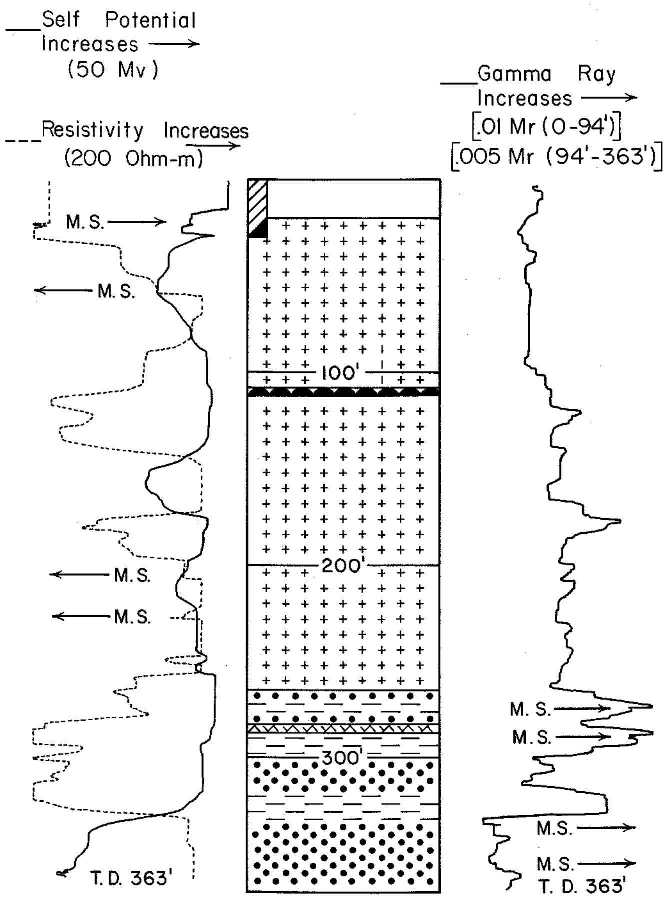
Geophysical and lithologic log of Mathews Arm Test Hole No. 1, W-850 (Figure 7)



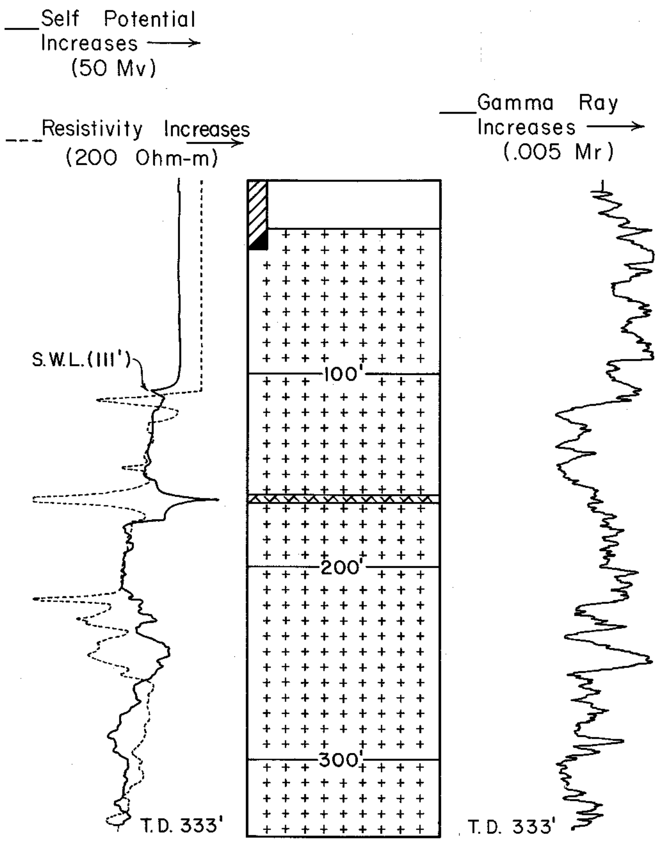
Geophysical and lithologic log of Mathews Arm Test Hole No. 2, W-856 (Figure 7)



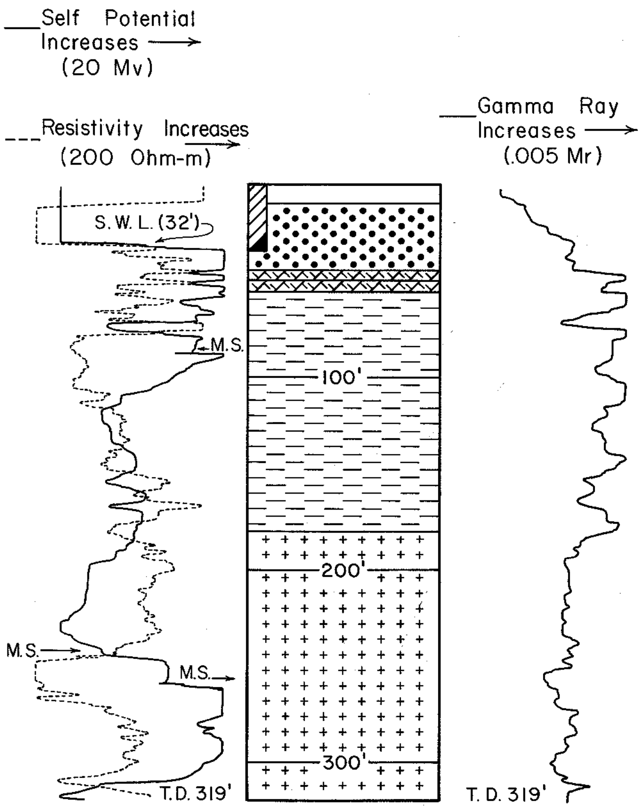
Geophysical and lithologic log of Skyland Test Hole No. 4, W-1033 (Figure 14)



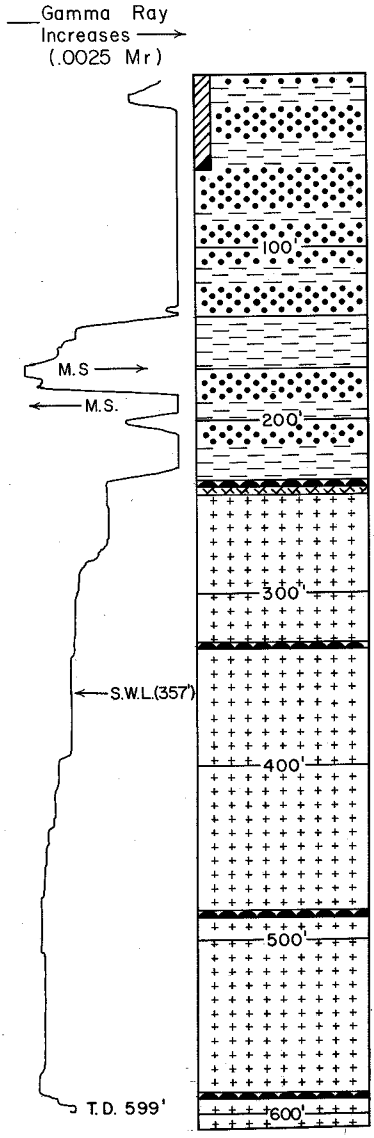
Geophysical and lithologic log of Comers Deadening Test Hole No. 3, W-1136 (Figure 15)



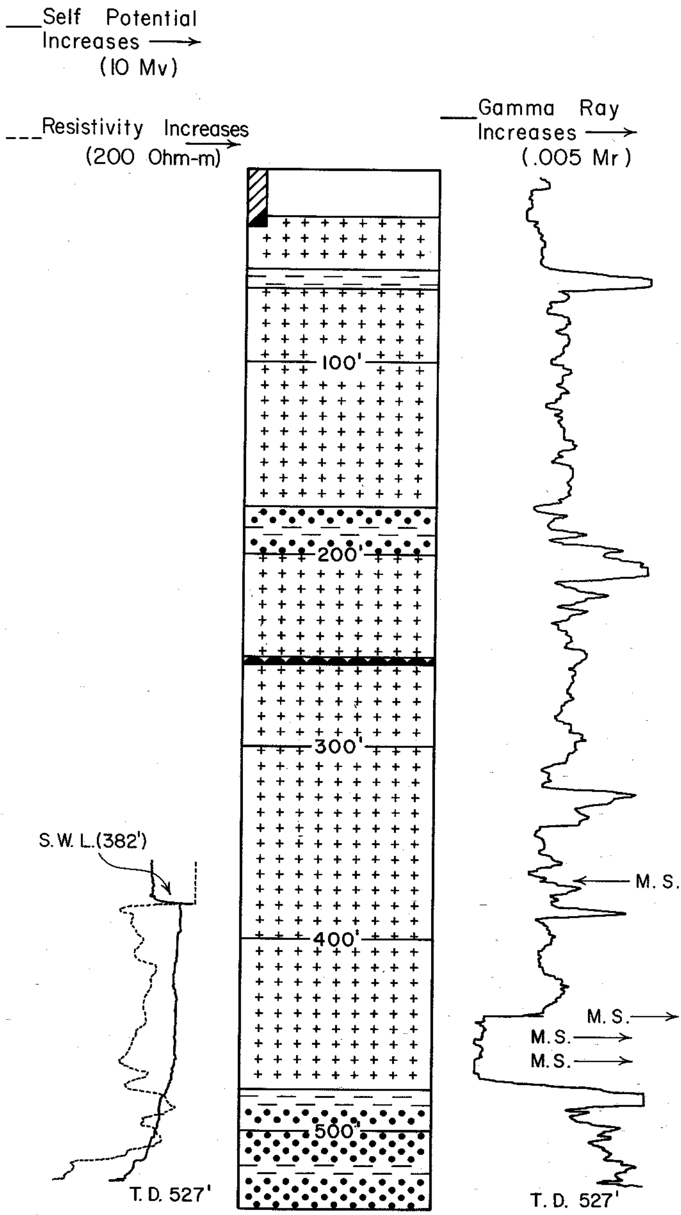
Geophysical and lithologic log of Big Meadows Test Hole No. 4, W-1702 (Figure 16)



Geophysical and lithologic log of Loft Mountain Test Hole No. 5, W-754 (Figure 20)



Geophysical and lithologic log of Dundo Test Hole No. 1, W-1073 (Figure 22)



Geophysical and lithologic log of Rockfish Gap Test Hole No. 1 (Figure 24)

APPENDIX III

GEOLOGIC LOGS AND SUMMARIES

Repository number (as shown on maps)	Name
W-1138	Fox Hollow Test Hole No. 1
W-1139	Fox Hollow Test Hole No. 2
W- 863	Dicky Ridge Test Hole No. 1
W- 864	Dicky Ridge Test Hole No. 2
W-1346	Dicky Ridge Test Hole No. 3
W- 850	Mathews Arm Test Hole No. 1
W- 856	Mathews Arm Test Hole No. 2
W-1703	Elkwallow Test Hole No. 1
W- 851	Headquarters Test Hole No. 1
W- 855	Headquarters Test Hole No. 2
W- 948	Thornton Gap Test Hole No. 1
W-3288	Pinnacles Test Hole No. 2
W-3289	Pinnacles Test Hole No. 1
W- 591	Skyland Test Hole No. 1
W- 592	Skyland Test Hole No. 2
W- 593	Skyland Test Hole No. 3
W-1033	Skyland Test Hole No. 4
W- 869	Comers Deadening Test Hole No. 1
W- 876	Comers Deadening Test Hole No. 2
W-1136	Comers Deadening Test Hole No. 3
W-1347	Big Meadows Test Hole No. 1
W-1348	Big Meadows Test Hole No. 2
W-1701	Big Meadows Test Hole No. 3
W-1702	Big Meadows Test Hole No. 4

W-1072	Lewis Mountain Test Hole No. 1
W- 865	Swift Run Gap Maintenance Area Test Hole No. 1
W-1704	Simmons Gap Test Hole No. 1
W- 704	Loft Mountain Test Hole No. 1
W- 710	Loft Mountain Test Hole No. 2
W- 715	Loft Mountain Test Hole No. 3
W- 718	Loft Mountain Test Hole No. 4
W- 754	Loft Mountain Test Hole No. 5
W-1073	Dundo Test Hole No. 1
W-1074	Dundo Test Hole No. 2
W-1810	Dundo Exploration Hole No. 1
W-1811	Dundo Exploration Hole No. 2
W-1654	Grottoes Exploration Hole No. 1
W-1137	Rockfish Gap Test Hole No. 1

FOX HOLLOW TEST HOLE NO. 1, W-1138 (FIGURE 6)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 20	Overburden	—
20-200	Catoctin Formation	Metabasalt

FOX HOLLOW TEST HOLE NO. 2, W-1139 (FIGURE 6)

Depth (in feet)

CATOCTIN FORMATION (0?-300′)

0- 15	Metabasalt, dark greenish-gray, dense; some brownish-maroon, finely crystalline, andesitic basalt; a few fragments of altered plagioclase with disseminated chlorite and traces of green epidote and red jasper.
15- 35	Metabasalt, dark greenish-gray, dense; a few chlorite flakes and a trace of epidote and red jasper.
35-115	Metabasalt, greenish-gray, dense; some red jasper, epidote, chlorite, and altered plagioclase with disseminated chlorite; a trace of albite and iron-oxide stains.
115-125	Epidosite, light-green, fine-grained; some fragments of red jasper and minor amounts of albite, quartz, and chlorite; a few fragments of dark bluish-gray, dense metabasalt.
125-160	Metabasalt, dark greenish-gray, dense; a minor amount of red jasper with slickensides and a well-developed cleavage on some fragments; traces of light-green epidote, altered plagioclase with disseminated chlorite, and epidote-albite-calcite-chlorite amygdules.
160-165	Epidosite, light-green, fine-grained; with a few fragments of dark-gray dense metabasalt; traces of red jasper and white albite.
165-175	Metabasalt, dark bluish-gray, dense; some light-green epidote and traces of albite, red jasper, and calcite.
175-180	Epidosite, light-green, fine-grained; with a few fragments of dark bluish-gray dense metabasalt; some fragments of white albite and quartz; with a trace of red jasper, iron-oxide stains, and magnetite.
180-230	Metabasalt, dark greenish-gray, dense; some light-green epidote, altered plagioclase with disseminated chlorite, red jasper, albite, chlorite, and calcite.
230-245	Epidosite, light-green, fine-grained; amygdules of red jasper, calcite, and albite.

245-265 Metabasalt, dark bluish-gray, dense; with some chlorite, a trace of red jasper, calcite, and albite.

265-270 Epidosite, light-green, dense; some calcite; traces of red jasper, chlorite, and quartz.

270-300 Metabasalt, dark bluish-gray, dense; some epidote and red jasper; a trace of calcite, altered plagioclase and disseminated chlorite, and iron-oxide stains.

DICKY RIDGE TEST HOLE NO. 1, W-863 (FIGURE 6)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 30	Overburden	—
30-250	Catoctin Formation	Metabasalt

DICKY RIDGE TEST HOLE NO. 2, W-864 (FIGURE 6)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 15	Overburden	—
15-250	Catoctin Formation	Metabasalt and epidosite

DICKY RIDGE TEST HOLE NO. 3, W-1346 (FIGURE 6)

Depth (in feet)

OVERBURDEN (0′-23′)

0- 23 Clay and residual metabasalt, yellowish-gray brown, dense; abundant magnetite; minor vein quartz and pale-green epidote.

CATOCTIN FORMATION (23′-650′)

23- 55 Metabasalt, dark-gray and grayish-yellow green; darker material is dense with relict sub-ophitic texture; with epidote, chlorite, albite, and magnetite; a minor amount of veinlets and amygdules of epidote, chlorite, and jasper; a trace of pyroxene, calcite, and plagioclase.

55- 70 Metabasalt, gray, dense; with some epidote, albite, chlorite, calcite, and magnetite; a trace of red jasper and black chlorite amygdules.

70- 85 Metabasalt, medium- to dark-gray, slightly reddish, dense to porphyritic and vesicular; albite phenocrysts and calcite, epidote, and chlorite amygdules in a groundmass of saussurite, magnetite, and hematite.

Depth (in feet)	
85-115	Metabasalt, greenish-gray, dense; with a magnetite-chlorite groundmass; some albite phenocrysts and amygdules of epidote and chlorite; minor amounts of calcite, iron-oxide stains, and maroon-red jasper.
115-130	Metabasalt, dark greenish-gray, dense; slightly foliated to massive; with chlorite and epidote; a minor amount of quartz and traces of jasper and porphyritic metamorphosed basalt; vein fillings of yellowish-green epidosite.
130-135	Epidosite, pale yellowish-green, fine-grained; with epidote and calcite; a trace of amphibole and pink leucoxene.
135-175	Metabasalt, dark- to greenish-gray, dense; with albite, epidote, chlorite, magnetite, and calcite; a trace of pale-green epidote.
175-180	Metabasalt, reddish dark-gray, dense; ferruginous saussurite with minute plagioclase crystals; vesicle and vein fillings of calcite, epidote, and chlorite; a minor amount of coarse-grained, ferruginous, arkosic quartzite.
180-200	Epidosite, bright yellowish-green and medium-gray; with epidote, albite, quartz, and calcite; a minor amount of vein quartz and a few fragments of dense metabasalt.
200-220	Metabasalt, dark greenish-gray, dense; with epidote, plagioclase, chlorite, calcite, and magnetite; some epidote, chlorite, and jasper vesicle and fracture fillings; a trace of pale-green, fine-grained epidosite.
220-250	Metabasalt, dark greenish-gray, dense; with some albite, chlorite, magnetite, epidote, and calcite.
250-255	Metabasalt, light-gray and greenish-gray, dense; with chlorite, epidote, and plagioclase; numerous chlorite amygdules and partial replacement of matrix by epidote; a trace of white calcite.
255-270	Epidosite, light grayish-green, fine- to medium-grained; with epidote, plagioclase, quartz, calcite, and magnetite; a trace of red jasper and iron-oxide stains.
270-275	Metabasalt, dark-gray, slightly reddish, porphyritic, dense; with plagioclase, epidote, chlorite, and magnetite; abundant amygdules and irregular fillings of calcite, chlorite, and epidote; some minor replacement by epidote and a trace of white albite.
275-290	Epidosite, yellowish-green, fine- to medium-grained; with epidote, calcite, albite, and quartz; a trace of chalcopyrite and some relict amygdaloidal structures; a few fragments of metabasalt as described above.
290-310	Metabasalt, dark bluish-gray, dense; with albite, chlorite, epidote, and calcite; some relict amygdules and amygdules filled with epidote, calcite, and chlorite.

Depth (in feet)

310-315	Epidosite, yellowish-green and gray, fine-grained; with epidote, plagioclase, calcite, and magnetite; some relict amygdules.
315-325	Metabasalt, dark-gray, dense; with albite, magnetite, epidote, chlorite, and calcite; some amygdules filled with quartz and chlorite.
325-335	Epidosite, yellowish-green and gray, medium- to fine-grained; with epidote, plagioclase, chlorite, calcite, quartz, and magnetite.
335-360	Metabasalt, dark bluish-gray, dense; slightly foliated; with chlorite, epidote, calcite, and magnetite; a minor amount of coarse to fine sand; a trace of pink albite, white quartz, and amygdules of calcite, epidote, and pink albite.
360-595	Metabasalt, dark greenish-gray, dense to medium-grained; with albite, epidote, chlorite, calcite, magnetite, and a trace of pyroxene; some amygdules of albite, epidote, chlorite, calcite, and serpentine; a trace of vein quartz and red jasper.
595-605	Epidosite and metabasalt, yellowish-green and gray, fine-grained; with epidote, quartz, calcite, albite, siderite, and magnetite; some relict amygdaloidal structures; appreciable iron-bearing vein calcite; metabasalt as described above.
605-620	Metabasalt, bluish-gray to yellowish-green gray, dense; with albite, epidote, chlorite, and magnetite.
620-635	Epidosite and metabasalt, yellowish-gray and green, fine-grained; with epidote, calcite, magnetite, and albite; abundant veinlets of hematite-bearing calcite; minor amounts of quartz and serpentine; metabasalt is bluish-gray; dense; with plagioclase, chlorite, and epidote; a few amygdules.
635-650	Metabasalt, greenish-gray, dense; with albite, epidote, and chlorite; a trace of epidotized basalt, vein calcite, and epidote amygdules.

MATHEWS ARM TEST HOLE NO. 1, W-850 (FIGURE 7)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 20	Overburden	—
20-200	Catoctin Formation	Metabasalt

MATHEWS ARM TEST HOLE NO. 2, W-856 (FIGURE 7)

Depth (in feet)

OVERBURDEN (0′-20′)

0- 20	Weathered metabasalt, tannish-brown; the few unweathered fragments are greenish-gray and dense; some red jasper, albite, epidote, and iron-oxide stains are found on a few fragments; a trace of asbestos and vein quartz.

Depth (in feet)

CATOCTIN FORMATION (20′-200′)

20- 60	Metabasalt, dark greenish-gray, dense; some light-green epidote, dark-green chlorite flakes, and vein quartz; amygdules of epidote, pink albite, and white quartz; a few fragments of altered plagioclase with disseminated chlorite and a trace of iron-oxide stains.
60- 70	Metabasalt, dark greenish-gray, dense; minor amounts of albite, epidote, and altered plagioclase with disseminated chlorite; trace of red jasper and calcite; some slickensides.
70- 75	Metabasalt, dark greenish-gray, dense; copper mineralization (chalcopyrite and malachite); amygdules of epidote, albite, and quartz; trace of calcite and magnetite.
75- 80	Metabasalt, dark greenish-gray, finely crystalline; some epidote, pink albite, and a trace of iron-oxide stains on a few fragments.
80- 85	Epidosite, pea-green, fine-grained; the few metabasalt fragments are greenish-gray and dense; some iron-oxide staining and a trace of chalcopyrite.
85-165	Metabasalt, dark greenish-gray, dense; with chlorite, epidote, quartz, and altered plagioclase with disseminated chlorite; minor iron-oxide stains and red jasper; some fragments exhibit a well-developed foliation.
165-175	Metabasalt, dark bluish-gray, dense; few fragments of dense andesitic metabasalt; amygdules of epidote, albite, quartz, and chlorite; minor amount of chlorite flakes and altered plagioclase with disseminated chlorite.
175-200	Metabasalt, maroon and greenish-gray, dense; with amygdules of albite, quartz, epidote, and calcite; some chlorite, altered plagioclase with disseminated chlorite and iron-oxide stains.

ELKWALLOW TEST HOLE NO. 1, W-1703 (FIGURE 8)

Depth (in feet)

0- 45	No samples.

CATOCTIN FORMATION (45′-363′)

45- 85	Metabasalt, greenish-gray, dense; with a hackly fracture; some albite, amphibole, and epidote; a trace of vein quartz, red jasper, and hematite stains.
85- 95	Andesitic basalt, dark purplish-gray, dense; subconchoidal fracture; with some epidote amygdules and veinlets; a trace of red jasper and chlorite.
95-125	Metabasalt, dark greenish-gray, dense; hackly fracture; some epidote amygdules, and dark purplish-gray, dense, andesitic basalt; a trace of chlorite, epidote, quartz, albite, and hematite stains.

Depth (in feet)

125-135 Metabasalt, dark greenish-gray, dense; massive with a hackly fracture; a trace of maroon-red hematite and epidote veins.

135-145 Andesitic basalt, dark purplish-gray, dense; subconchoidally fractured; some epidote and chlorite amygdules; with calcite along fracture planes; trace of chlorite.

145-190 Metabasalt, light greenish-gray, dense; hackly fracture; some red jasper, epidote, and chlorite; a trace of vein quartz, calcite, albite, quartz-replaced asbestos, chalcopyrite, and amygdules of epidote and chlorite.

190-245 Metabasalt, medium-gray, dense; subconchoidally fractured; with a trace of epidote, red jasper, calcite, chlorite and chalcopyrite.

245-250 Metabasalt, dark greenish-gray, dense; some chlorite and chlorite blebs; a minor amount of purplish-gray, dense, andesitic basalt.

250-290 Metabasalt, medium-gray, dense; with amygdules of epidote and albite; some chlorite; a trace of albite, red hematite, red jasper, vein quartz, and magnetite.

290-305 Metabasalt, dark greenish-gray, dense; with a trace of red jasper, chlorite, epidote, quartz, and calcite.

305-340 Metabasalt, dark greenish-gray, dense; some epidote and chlorite; a few fragments with jasper, epidote, and chlorite amygdules; a trace of calcite.

340-350 Metabasalt, dark greenish-gray, dense; massive with subconchoidal fracturing; some chlorite blebs and a trace of maroon-red jasper on a few fragments.

350-355 Metabasalt, dark greenish-gray, dense; massive with subconchoidal fracturing; amygdules of epidote; some albite with a trace of calcite.

355-363 Metabasalt, dark greenish-gray, dense; subconchoidal fracturing; pale-green, fine-grained epidosite; some albite, epidote, quartz, chlorite, and red jasper on a few fragments.

HEADQUARTERS TEST HOLE NO. 1, W-851 (FIGURE 9)

Depth (in feet)

OVERBURDEN (0′-20′)

0- 20 Weathered metabasalt, reddish-tan, brown to green, medium-grained; some feldspars, epidote, albite, quartz, chlorite, and altered plagioclase with disseminated chlorite; a trace of red jasper and quartz-replaced asbestos; a few unweathered fragments are bluish-gray to purple and dense with some epidote and red jasper.

Depth (in feet)

CATOCTIN FORMATION (20′-280′)

20-155	Metabasalt, dark greenish-gray, dense; with epidote, epidote veins, chlorite, maroon to red jasper, vein quartz, and quartz replaced asbestos; a trace of iron-oxide stains and calcite.
155-170	Metabasalt, dark greenish-gray, dense; with epidote, quartz, and albite-filled amygdules; iron-oxide stains and maroon to red jasper on a few fragments.
170-175	Epidosite and metabasalt, light-green and greenish-gray, fine-grained to dense; with some epidote, vein quartz and white calcite; iron-oxide stains and dark-green chlorite flakes on a few fragments.
175-205	Metabasalt, dark greenish-gray, dense; chlorite flakes and altered plagioclase with disseminated chlorite; some iron-oxide stains and maroon to red jasper.
205-280	Metabasalt, dark greenish-gray, dense; with chlorite, epidote, altered plagioclase with disseminated chlorite, maroon to red jasper and iron-oxide stains; a trace of quartz replaced asbestos, calcite, albite, and chalcopyrite.

HEADQUARTERS TEST HOLE NO. 2, W-855 (FIGURE 9)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 25	Overburden	—
25-220	Catoctin Formation	Metabasalt

THORNTON GAP TEST HOLE NO. 1, W-948 (FIGURE 12)

Depth (in feet)

OVERBURDEN (0′-60′)

0- 60	Weathered metabasalt and granodiorite, tannish brown; some albite, quartz and iron-oxide stains; a few partly weathered fragments are bluish-gray and dense.

CATOCTIN FORMATION (60′-330′)

60-125	Metabasalt, dark bluish-gray, dense; with green epidote, clear to stained quartz, chlorite, albite and red jasper; a few fragments of weathered metabasalt and granodiorite; some iron-oxide stains.
125-145	Metabasalt, dark bluish-gray, dense; with amygdules of epidote, quartz, albite and red jasper; some quartz and feldspar fragments; a few slickensides and a trace of chlorite.
145-250	Metabasalt, dark bluish-gray, dense; with some green epidote, chlorite, albite, red jasper, quartz, amphibole and clinopyroxene; a few fragments have slickensides and a well-developed foliation.

Depth (in feet)	
250-275	Metabasalt, dark bluish-gray, dense; with chlorite, albite, amphibole, clinopyroxene and calcite; some amygdules of albite, quartz, epidote and red jasper; some well-developed foliation on a few fragments and a trace of epidote.
275-310	Metabasalt, dark bluish-gray, dense; with green epidote, red jasper, quartz, plagioclase and chlorite; a trace of clinopyroxene, amphibole and pyroxene.
310-315	Metabasalt and epidosite, dark bluish-gray, dense; light green, fine crystalline; with a minor amount of red jasper, chlorite, plagioclase and quartz replaced asbestos.
315-325	Metabasalt, dark bluish-gray, dense; with epidote, chlorite, plagioclase, clinopyroxene and amphibole; a minor amount of quartz, red jasper and amygdules of epidote and quartz.
330	Metabasalt, dark purple, dense; with a minor amount of red jasper, chlorite, epidote, and plagioclase; a well-developed foliation on most fragments.

PINNACLES TEST HOLE NO. 2, W-3288 (FIGURE 13)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 55	Overburden	—
55-145	Pedlar Formation	Granodiorite

PINNACLES TEST HOLE NO. 1, W-3289 (FIGURE 13)

Depth (in feet)

OVERBURDEN (0′-80′)

0- 80	Weathered granodiorite, light to dark brown, medium-grained; with clear to opaque quartz, potassium feldspar, muscovite and kaolinite; a trace of ilmenite.

PEDLAR FORMATION (80′-220′)

80-135	Granodiorite, light to dark green and light brown, medium-grained; clear to opaque quartz, potassium feldspars, plagioclase, biotite and ilmenite; a trace of muscovite and a few fragments of weathered granodiorite.
135-195	Granodiorite, light green to gray, medium-grained; clear to opaque quartz, potassium feldspars, plagioclase, ilmenite and biotite.
195-200	Metabasalt and granodiorite; metabasalt is dark purple-gray, dense; with green epidote, white quartz, albite and calcite: granodiorite is light grayish-green, medium-grained, with clear to opaque quartz, potassium feldspars, plagioclase and ilmenite.

Depth (in feet)

200-220 Granodiorite, light green to gray, medium-grained; clear to opaque quartz, potassium feldspar, plagioclase, ilmenite and biotite.

SKYLAND TEST HOLE NO. 1, W-591 (FIGURE 14)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 21	Overburden	—
21- 70	Pedlar Formation	Granodiorite

SKYLAND TEST HOLE NO. 2, W-592 (FIGURE 14)

Depth (in feet)

0- 29 No samples.

OVERBURDEN (29′-62′)

29- 62 Weathered granodiorite, light tan, fine-grained; abundant clear to opaque quartz; some tannish kaolinite, plagioclase and iron-oxide stains; with a trace of muscovite.

PEDLAR FORMATION (62′-230′)

62-100 Granodiorite, dark to light greenish-gray, medium-grained; abundant quartz, potassium feldspar and plagioclase; with a trace of muscovite and hydromuscovite; some up-hole contamination from surficial debris of the Swift Run and Catoctin formations.

100-135 Granodiorite, dark greenish-gray to light pink, medium- to coarse-grained; abundant quartz, potassium feldspar, perthite and plagioclase; with a trace of muscovite, kaolinite, ilmenite and hornblende.

135-165 Granodiorite, dark greenish-gray to light pink, medium- to coarse-grained; abundant quartz, potassium feldspar, perthite and plagioclase; with a trace of hornblende, kaolinite and reddish garnet; some slickensides.

165-189 Granodiorite, dark greenish-gray to pink, medium- to coarse-grained; abundant quartz, potassium feldspar, perthite and plagioclase; with a trace of muscovite, epidote, magnetite and ilmenite.

189-230 Granodiorite, dark greenish-gray to pink, medium- to coarse-grained; abundant quartz, potassium feldspar, perthite, plagioclase and kaolinite; with a trace of ilmenite, epidote and iron-oxide stains.

SKYLAND TEST HOLE NO. 3, W-593 (FIGURE 14)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 30	Overburden	—
30-162	Pedlar Formation	Granodiorite

SKYLAND TEST HOLE NO. 4, W-1033 (FIGURE 14)

Depth (in feet)

OVERBURDEN (0′-10′)

0- 10 Weathered metabasalt, light-green and brown, medium-grained; with epidote, chlorite, quartz, serpentine and iron-oxides.

SWIFT RUN FORMATION (10′-365′)

10- 40 Weathered phyllite, light-olive-brown, fine-grained; with chlorite, sericite, quartz and iron-oxide.

40- 65 Chloritic phyllite, medium-gray-green, fine-grained; shiny; exhibits two foliations; with chlorite, sericite, iron-oxides and a minor amount of quartz.

65- 75 Sericitic phyllite, medium-gray, fine-grained; shiny, foliated and knotted; with sericite, chlorite and quartz; some porous quartz veins and limonite stains.

75-105 Phyllite and sandy phyllite, 50% as above; 50% gray-green to brownish, fine- to medium-grained quartz sand; trace of goethite after pyrite; grain mount: abundance of dusty opaques, minor relicts of amphibole and feldspar in a fibrous chlorite-sericite matrix.

105-145 Sandy phyllite, medium-gray, slightly greenish; translucent and shiny; with sericite and chlorite; abundant sand, medium-grain to granule size; X-ray examination: abundant sericite and quartz; chlorite and stilpnomelane present in minor amounts.

145-175 Chloritic metamorphosed arkose, green-gray, fine-grained; shiny and slightly foliated; medium to very coarse quartz sand and irregular patches of pink albite in a chlorite-sericite matrix; purple-red hematite stains; tiny calcite veins; and a trace of magnetite; grain mount: minor epidote, amphibole, garnet, apatite and distorted granules of feldspar.

175-200 Chloritic metamorphosed arkose, medium-gray, greenish, medium- to very coarse-grained quartz sand; abundant anhedral partially rounded pink albite; greenish-white albite, subhedral, up to 5 mm; fine-grained matrix of chlorite and sericite; quartz sand is colorless, gray, blue, white and pink; a trace of calcite.

Depth (in feet)

200-240 Chloritic metamorphosed arkose, dark greenish-gray; pebbles and granules, composed of quartz and pink albite to 10 mm with medium- to very coarse-grained quartz sand (colorless, yellow, white, and gray); matrix: fine-grained chlorite, sericite, epidote, calcite and dusty magnetite; no foliation; a trace of iron-oxide stains; X-ray examination: chlorite and plagioclase are most abundant minerals.

240-280 Chloritic metamorphosed arkose, dark-greenish-gray; fragments of quartz-albite rock (to 20 mm), and coarse sand in a fine-grained chlorite, sericite matrix; some portions of sample are fine-grained chlorite-sericite with very little included quartz or feldspar; some minor calcite and a slight foliation in low quartz portions.

280-335 Chloritic metamorphosed arkose, medium greenish-gray, medium to very coarse quartz sand; fine pebbles of quartz; fine pebbles of pale pink to light green plagioclase which have been veined and altered to chlorite, sericite, and epidote; matrix of chlorite, sericite, epidote and calcite; grain mount examination: minor apatite and zircon; slight foliation in small part of sample.

335-365 Metamorphosed granodiorite conglomerate, dark gray, and greenish, dull and dense in appearance in dry cuttings; saussuritized granodiorite; with albite, quartz, epidote and chlorite; it is nearly impossible to distinguish sericite, chlorite and saussurite cement of the conglomerate from veins in the granodiorite; the sample appears to contain stream worn pebbles of quartz and feldspar; thin section: hypidomorphic granular texture; albite to 10 mm, quartz to 5 mm; accessories are apatite, zircon, magnetite; the plagioclase is partially to completely altered to epidote, sericite and calcite; minor chlorite; some traces of twinning are preserved; abundant fine-grained veins of sericite, saussurite, and calcite, often on mineral boundaries.

PEDLAR FORMATION (365′-500′)

365-395 Granodiorite, medium gray, slightly greenish; with albite to 10 mm, quartz to 4 mm, garnet to 1 mm, chlorite, sericite, and calcite; grain mount: saussuritization of feldspar, relicts of pyribole and minor additional minerals such as zircon, apatite and magnetite; some veins of yellow-green epidote and dark green chlorite; minor calcite.

395-425 Granodiorite, greenish-black and pale green, average crystalline size 1.5-2 mm; with quartz, feldspar, pyroxene, chlorite and occasional light green plagioclase to 10 mm; some chlorite and epidote veins.

Depth (in feet)

425-470	Granodiorite, dark to light gray-green, average crystalline size 0.5 to 5 mm; with plagioclase, quartz, chlorite and saussurite; some minor magnetite and yellow-green epidote; a trace of pyrite.
470-490	Granodiorite, pale green to greenish-black; splotchy; pale yellow-green saussuritized plagioclase and white potash feldspar to 10 mm; 1-3 mm irregular grains of quartz; fine crystalline dark chlorite stringers in patches and veins; some minor magnetite and pyrite (X-ray evidence for potash feldspar).
490-500	Granodiorite, medium-gray, slightly greenish, average grain size one mm; with plagioclase, quartz, pyroxene, epidote, chlorite and minor magnetite.

COMERS DEADENING TEST HOLE NO. 1, W-869 (FIGURE 15)

Depth (in feet)

OVERBURDEN (0′-30′)

0- 30	Weathered metabasalt, tannish-brown; some partly weathered fragments are bluish-gray and dense.

CATOCTIN FORMATION (30′-250′)

30- 50	Metabasalt, dark bluish-gray, dense; some light-green fine-grained epidosite and a few weathered metabasalt fragments; a trace of calcite, quartz and iron-oxide stains.
50- 55	Epidosite, light pale-green, fine-grained; with a trace of red jasper.
55- 65	Metabasalt, dark bluish-gray, dense; with epidote, chlorite and a few weathered metabasalt fragments.
65- 80	Epidosite and metabasalt, pale-green, fine-grained: bluish-gray, dense; with some calcite and a trace of quartz and iron-oxide stains.
80- 85	No sample.
85- 95	Epidosite, pale-green, fine-grained; with red jasper and quartz; a few fragments of dark bluish-gray, dense metabasalt and a trace of albite.
95-115	Metabasalt, dark bluish-gray, dense; some pale-green, fine-grained epidosite; with a trace of red jasper, quartz, albite and calcite.
115-120	No sample.
120-125	Metabasalt, dark bluish-gray, dense; with some light green epidote, red jasper, quartz, white albite and calcite; some light gray phyllite; several fragments exhibit cleavage.

Depth (in feet)

125-130	Epidosite and metabasalt, light green, fine-grained: dark bluish-gray, dense; with some red jasper, albite, epidote and quartz; a trace of chloritic phyllite.
130-160	Metabasalt, dark bluish gray, dense; with some light green epidosite; minor amount of red jasper, epidote, calcite, chlorite and albite; a few strongly foliated phyllitic fragments.
160-165	No sample.
165-200	Metabasalt, dark bluish-gray, dense; with green epidote, red jasper, albite, chlorite, quartz and calcite; some fragments have a strong foliation.
200-205	No sample.
205-220	Metabasalt, dark bluish-gray, dense; with fragments of light to dark gray phyllite; some green epidote; chlorite and calcite.
220-250	Phyllitic metabasalt, dark bluish-gray, dense; foliated; with some calcite, chlorite, quartz, albite, and red jasper.

COMERS DEADENING TEST HOLE NO. 2, W-876 (FIGURE 15)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 40	Overburden	—
40-250	Catoctin Formation	Metabasalt

COMERS DEADENING TEST HOLE NO. 3, W-1136 (FIGURE 15)

Depth (in feet)

OVERBURDEN (0′-20′)

0- 20	Weathered metabasalt, tannish-brown; much iron-oxide staining; with some green epidote and quartz; a few partly weathered fragments are bluish-gray and dense.

CATOCTIN FORMATION (20′-265′)

20- 40	Metabasalt, bluish-green, dense; with quartz, epidote, albite, biotite, chlorite, red jasper, and calcite; minor iron-oxide stains.
40- 55	Epidosite, light green, fine-grained; with quartz, feldspars, biotite, calcite, chlorite, red jasper, and epidote; a few fragments of bluish-gray, dense metabasalt; a trace of iron-oxide stains.
55- 65	Metabasalt, dark bluish-gray, dense; with quartz, feldspars, biotite, chlorite, red jasper and epidote; a minor amount of light green fine-grained epidosite.
65- 70	Epidosite, bluish-green, fine-grained; with quartz, biotite, chlorite, feldspar, epidote and calcite; a few fragments of dark bluish-gray dense metabasalt.

Depth (in feet)	
70- 80	Metabasalt, dark bluish-gray, dense; some quartz, biotite, chlorite, albite, epidote and calcite; with a few fragments of light green fine-grained epidosite.
80- 85	Epidosite, light green, fine-grained; minor amount of calcite and iron-oxide stains; with a few fragments of dark bluish-gray dense metabasalt.
85- 90	Metabasalt, dark greenish-gray, dense; some chlorite with a minor amount of iron-oxide stains.
90- 95	Epidosite, light green, fine-grained; some albite, calcite, quartz and chlorite; with a few fragments of dark bluish-gray, dense metabasalt.
95-135	Metabasalt, dark greenish-gray, dense; foliated; with some green epidote, chlorite, feldspars and calcite; a minor amount of red jasper and epidote amygdules.
135-190	Metabasalt, dark to light bluish-gray, dense; with some light green epidote, albite, chlorite, red jasper and feldspars; a trace of iron-oxide stains and calcite.
190-215	Metabasalt, dark to light bluish-gray, dense; foliated; with some vein quartz, albite, green epidote, calcite and chlorite.
215-265	Metabasalt, dark bluish-gray, dense; foliated; with green epidote, calcite, chlorite, quartz and albite.

SWIFT RUN FORMATION (265′-365′)

265-270	Metabasalt and phyllite, dark bluish-gray, dense; light to dark gray, fine-grained; with chlorite, clear to red stained quartz, albite, calcite and red jasper.
270-275	Metamorphosed graywacke, light gray to purple, fine- to medium-grained; with clear and stained quartz, plagioclase, chlorite and mafics.
275-285	Metamorphosed subarkose, brownish-gray, fine-grained; rounded to subangular, clear to stained quartz; with some plagioclase, chlorite, calcite and mafics; a trace of muscovite.
285-290	Phyllite, metamorphosed subarkose and metamorphosed graywacke; the phyllite is reddish-purple, fine-grained; the subarkose is brownish-gray, medium-grained; the graywacke is light gray, fiine- to medium-grained; with rounded to angular, clear to stained quartz, plagioclase, chlorite, muscovite and mafics; some fragments have a well-developed foliation.
290-295	Phyllite, purplish, fine-grained; some chlorite, quartz, plagioclase and mafics; a few fragments of a medium-grained metamorphosed subarkose.

Depth (in feet)

295-320 Metamorphosed subarkose, light brownish-gray, medium-grained; poorly sorted; with subangular clear to stained quartz, chlorite, plagioclase, muscovite and mafics.

320-340 Phyllite and metamorphosed subarkose; the phyllite is greenish to purple, fine-grained; the subarkose is light gray, medium-grained; poorly sorted; with subangular clear to stained quartz, chlorite, plagioclase, muscovite and mafics. and mafics.

340-365 Phyllite, dark greenish-gray, dense; some epidosite fragments, and metamorphosed subarkose fragments; with plagioclase, quartz, epidote, calcite, chlorite and iron-oxide stains.

BIG MEADOWS TEST HOLE NO. 1, W-1347 (FIGURE 16)

Depth (in feet)

OVERBURDEN (0′-55′)

0- 35 Weathered metabasalt, orange-brown to gray-green, angular fragments of fine to coarse pebble size; with some plagioclase, chlorite, iron-oxide stains, epidote and magnetite.

35- 55 Pebbles and clay, light gray, gray-green and orange-brown; angular pebbles of chloritic phyllite, metabasalt and epidotized basalt; some orange-brown clay and vein quartz; a minor amount of hematitic metabasalt with slender veins of iron-oxide stained calcite.

CATOCTIN FORMATION (55′-100′)

55- 85 Metabasalt, blue-gray, dense; with plagioclase, epidote, chlorite, magnetite and calcite; thin section: micro-subophitic texture with phenocrysts of pyroxene and plagioclase.

85-100 Metabasalt and jasper, dark gray-green, dense; amygdules of epidote, chlorite and plagioclase; some dark purple-gray conchoidally fractured jasper; with small veins of hematite, quartz and epidote.

CONTACT ZONE (100′-115′)

100-115 Epidotized metabasalt, light green-gray, slightly yellowish, medium-grained; relict amygdaloidal structure with epidote, plagioclase, chlorite and magnetite; angular quartz fragments imbedded in matrix; amygdules filled with green quartz, red calcite, jasper and epidote; part of the sample is epidotized granodiorite; plagioclase is almost completely altered to epidote, quartz and chlorite.

PEDLAR FORMATION (115′-265′)

115-130 Epidotized granodiorite, light green-gray, yellow-green and dark blue-gray, fine to very coarse-grained; with epidote, feldspars (mostly albite), quartz, chlorite, apatite, zircon and zeolite veins.

Depth (in feet)

130-150 Granodiorite, dark green-blue-gray, very fine to very coarse-grained; cataclastic texture; with albite, quartz, chlorite and epidote; a minor amount of potash feldspar and a trace of magnetite.

150-200 Epidotized granodiorite, light gray-green, yellow-green, and minor dark gray, very fine to very coarse-grained mortar structure; perthitic and antiperthitic alkali feldspar, cracked, distorted and partially to completely altered to epidote; fine-grained mortar structure of chlorite, epidote and quartz; part of the potash feldspar is pink colored; a trace of zircon.

200-265 Altered granodiorite, dark blue-gray, minor light gray, yellow-green and pink, very fine to very coarse-grained; with chlorite, epidote, albite and quartz; a minor amount of magnetite and mica and a trace of pyrite and zircon.

BIG MEADOWS TEST HOLE NO. 2, W-1348 (FIGURE 16)

Depth (in feet)

OVERBURDEN (0′-70′)

0- 30 Clay and pebbles, dark gray-purple to orange-brown and tan; pebbles; fragments of kaolinized to fresh amygdaloidal metabasalt; with minor quartz and epidosite.

30- 60 Pebbles and sand, medium brown, green-gray and purple-gray; water worn, rounded to subangular, coarse sand to coarse pebble size; with metabasalt, epidotized basalt and quartz fragments.

60- 70 Weathered metabasalt, medium to light green-gray, and purple-gray, dense; with plagioclase, epidote, magnetite and chlorite; some minor small rounded pebbles of kaolinized metabasalt.

CATOCTIN FORMATION (70′-500′)

70- 80 Partially weathered metabasalt, medium light green and purple-gray, dense; minor amygdules; with plagioclase, epidote, chlorite, magnetite and clay.

80- 85 Metabasalt, medium gray to medium light green-brown; with epidote, chlorite and plagioclase.

85-110 Epidotized scoriaceous metabasalt, dark purplish-gray, and bright yellow-green; amygdules of quartz and epidote; a groundmass of fine-grained hematitic epidote.

110-115 Metabasalt and epidotized scoriaceous metabasalt, epidotized metabasalt as above; the metabasalt is medium gray and dense; with plagioclase, epidote and chlorite; a trace of foliated chlorite and sericite.

Depth (in feet)

115-155	Metabasalt, medium gray, dense; with plagioclase, chlorite, epidote and pyroxene.
155-175	Phyllitic metabasalt and metabasalt; the phyllitic metabasalt is medium gray, dense; foliated; with traces of flow banding; some chlorite, sericite and plagioclase; the metabasalt is dark purple-gray, dense; amygdaloidal; with epidote, plagioclase, chlorite, pyroxene and quartz.
175-200	Metabasalt, dark gray, dense; with plagioclase, sericite, epidote, quartz, magnetite and pyroxene.
200-215	Metabasalt, dark gray to dark purple-gray, dense; with chlorite, epidote, plagioclase, sericite and magnetite; minor amygdules and fracture zones filled with epidote.
215-265	Metabasalt, purple-gray, dense; amygdaloidal; with plagioclase, epidote, chlorite, jasper and pyroxene; a slight foliation on some fragments; minor vein epidote and quartz.
265-290	Metabasalt, greenish-gray, dense; slight lineation; with chlorite, epidote, plagioclase and sericite; some replacement by epidote.
290-295	Metabasalt, dark purple-gray, dense; with yellow-green epidote alteration; amygdaloidal; with plagioclase, epidote and pyroxene.
295-325	Metabasalt, dark blue-gray, dense; slightly amygdaloidal with plagioclase, chlorite, epidote, sericite and magnetite.
325-330	Epidosite, light yellow-green gray, medium- to fine-grained; with epidote, quartz, plagioclase and chlorite.
330-370	Metabasalt, dark gray to yellow-green gray, dense; with epidote, plagioclase, chlorite, quartz and a trace of asbestos.
370-375	Epidosite, grayish-yellow-green, medium- to fine-grained; with epidote, quartz, plagioclase and chlorite.
375-380	Metabasalt, green-gray, dense; with epidote, plagioclase and chlorite.
380-385	Epidotized metabasalt, gray and gray-yellow-green, dense; with epidote, quartz, plagioclase and chlorite.
385-420	Metabasalt, dark gray, slightly purple, dense; with plagioclase, magnetite, epidote, chlorite and a minor vein of epidote.
420-475	Metabasalt, dark blue-gray, dense; some minor amygdules; with plagioclase, epidote, chlorite, sericite, calcite and pyroxene; minor replacement by epidote.
475-480	Metabasalt, gray, dense; a trace of amygdules; with chlorite, epidote, calcite, plagioclase and magnetite.

Depth (in feet)

480-500 Phyllitic metabasalt, gray, dense; foliated; with chlorite, magnetite, plagioclase, epidote and sericite.

BIG MEADOWS TEST HOLE NO. 3, W-1701 (FIGURE 16)

Depth (in feet)

OVERBURDEN (0′-65′)

0- 45 Weathered metabasalt, light yellow-brown to reddish-brown, dense; much iron-oxide staining and a trace of vein quartz.

45- 65 Weathered metabasalt, dark green to light yellow-brown, dense; with quartz, epidote veins and jasper; some light reddish-brown clay.

CATOCTIN FORMATION (65′-100′)

65- 80 Metabasalt, light to dark brownish-green, dense; with quartz, vein quartz, epidote, feldspars aand chlorite; some quartz-feldspar amygdules and weathered metabasalt.

80- 85 Epidosite and metabasalt; the epidosite is light green, fine-grained; with quartz, feldspars and some intermixed metabasalt; the metabasalt is reddish-purple, dense with vein quartz, quartz amygdules, red jasper and feldspars; a few weathered metabasalt fragments.

85-100 Epidosite, light green, very fine-grained; with some red jasper and quartz amygdules; a few reddish-purple, dense metabasalt fragments; some weathered metabasalt.

BIG MEADOWS TEST HOLE NO. 4, W-1702 (FIGURE 16)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 25	Overburden	—
25-350	Catoctin Formation	Metabasalt and epidosite

LEWIS MOUNTAIN TEST HOLE NO. 1, W-1072 (FIGURE 17)

Depth (in feet)

SWIFT RUN FORMATION (0′-145′)

0- 35 Phyllitic sandstone (weathered), buff, slightly pink, fine-grained; foliated; sericite matrix containing 50% rounded to subangular and lens-shaped grains of quartz; abundant fine-grained ilmenite-magnetite; some kaolin and iron-oxides; a minor amount of plagioclase and a trace of zircon.

35- 50 Phyllitic quartz conglomerate, pale gray to green; fine-grained matrix of sericite and chlorite containing abundant grains of subangular to lens shaped quartz (medium to granular sand); less sericitization of quartz; some epidote, saussuritized albite and knots of dark chlorite; a minor amount of magnetite, pink quartz and feldspar.

Depth (in feet)

50-125	Phyllitic quartz conglomerate, pale green to pale pink, fine-grained; matrix of sericite, epidote and chlorite; slightly foliated; abundant rounded to lens-shaped quartz grains (0.5 to 4 mm); platy matrix curves around quartz; quartzitic in part; a trace of vein quartz.
125-130	Epidotized phyllitic sandstone, interbedded pale green and red-brown; with quartz, epidote and minor chlorite, chlorite schist and feldspar; a vein of quartz and a trace of chrysocolla.
130-140	Epidotized conglomeratic sandstone, pale green to pale pink; granule to silt size sand grains in a matrix of sericite and epidote; bedding apparent; grains are rounded not lens shaped; some vein quartz.
140-145	Epidotized conglomeratic sandstone, pale green to gray; medium sand to granule size quartz with sericite-epidote cement; arkosic and quartzitic; some minor metamorphosed siltstone and vein quartz.

CATOCTIN AND SWIFT RUN FORMATIONS (145′-265′)

145-150	Schistose metabasalt, dark green, fine crystalline; foliated; some chlorite, epidote, quartz and vein quartz; with minor tremolite asbestos and quartz; semischist as above.
150-155	Schistose metabasalt, epidotized conglomeratic sandstone and epidosite, schistose metabasalt and epidotized conglomeratic sandstone as above; epidosite is pale yellow-green and fine-grained; hard and quartzitic; with epidote, quartz; minor feldspar and sericite.
155-160	Epidotized conglomeratic sandstone, pale pink to light green; coarse sand and granules of quartz; feldspar cemented with epidote and sericite; with minor chlorite and quartz veins; some of the detrital grains are lens shaped.
160-165	Epidotized phyllite and schistose metabasalt, 50% epidotized phyllite; feldspathic sand (medium size) cemented with epidote and chlorite; 50% schistose metabasalt; very dark green dense; with chlorite, epidote and sericite; foliated with an occasional grain of sand.
165-170	Schistose metabasalt, dark-green, dense; foliated with chlorite, sericite and epidote; minor metabasalt with tiny spots of red hematite; X-ray analysis: chlorite, epidote, amphibole, minor plagioclase and quartz.
170-175	Metabasalt, gray-green, dense; slightly foliated; with chlorite, epidote, sericite and tiny spots of hematite.
175-180	Epidotized conglomeratic sandstone, green-gray, fine-grained; sericite-chlorite-epidote matrix with abundant sand and granules of quartz; some minor feldspar; quartzitic in part.

Depth (in feet)

180-205 Schistose metabasalt, medium gray, fine crystalline; foliated; thin section: curved plates of chlorite, minor needles of actinolite, anhedral epidote and streaks of dusty opaques.

205-215 Epidotized conglomeratic sandstone and phyllite, pale green, salmon pink, and white, subangular to rounded coarse sand and granules interbedded with very fine pink sand and silt; (both are cemented with epidote and sericite); quartzitic in part; with some vein quartz and plagioclase.

215-225 Schistose metabasalt, greenish-gray, dense; foliated; with chlorite, epidote, sericite, quartz, vein quartz, actinolite and minor vein calcite; some red-brown phyllite as above.

225-245 Metabasalt, greenish-gray, dense; thin section: fine-grained chlorite, actinolite, and epidote; many hematite and epidote pseudomorphs after mafic minerals; some small amygdules filled with epidote and chlorite.

245-260 Metabasalt, blue-gray, dense; slightly foliated with chlorite, epidote, sericite, amphibole and tiny red hematite spots.

260-265 Schistose metabasalt, dark green to light green, fine crystalline; foliated; with chlorite, sericite and amphibole.

CATOCTIN FORMATION (265′-300′)

265-270 Metabasalt, dark green to gray, dense; with chlorite, epidote and amphibole; minor yellowish-green epidosite.

270-275 Epidosite, yellowish-green to gray, fine-grained; with epidote, quartz, plagioclase, amphibole and chlorite.

275-280 Metabasalt, greenish-gray, dense; with some chlorite, epidote and amphibole; tiny hematite spots; 30% of the sample is epidosite.

280-285 Epidosite, yellowish-green to grayish-green, fine-grained; with epidote, quartz, amphibole, chlorite and tiny red hematite spots; some vein quartz, asbestos, and a trace of calcite.

285-295 Metabasalt, gray-green, dense; with chlorite, sericite, amphibole, magnetite, epidote plagioclase and tiny hematite spots; minor epidosite.

295-300 Epidosite, yellow-green, fine-grained; with quartz, plagioclase, spots of hematite, vein quartz and calcite; 30% gray metabasalt.

SWIFT RUN GAP MAINTENANCE AREA TEST HOLE NO. 1, W-865 (FIGURE 18)

Depth (in feet)

OVERBURDEN (5′-40′?)

5- 25 Weathered metabasalt, dark brown; with some quartz fragments and weathered feldspars.

25- 40 No samples.

Depth (in feet)

CATOCTIN FORMATION (40′?-60′)

40- 60 Metabasalt, dark bluish-gray, dense; with some stained quartz, red jasper, calcite and feldspar; a few fragments of weathered metabasalt and granodiorite; some amygdules of albite and quartz.

SIMMONS GAP TEST HOLE NO. 1, W-1704 (FIGURE 19)

Depth (in feet)

0- 25 No samples.

CATOCTIN FORMATION (25′-205′)

25- 50 Metabasalt and epidosite, dark purplish-gray, dense; with epidote and epidote-quartz amygdules: very light green, medium- to coarse-grained epidosite, with anhedral quartz grains; some vein quartz, asbestos and weathered gray phyllite.

50- 75 Metabasalt, dark purplish-gray, dense; with epidote, feldspars and quartz amygdules; some asbestos and phyllite.

75- 80 Metabasalt, light gray, dense; foliated; phyllitic; with plagioclase, chlorite and traces of epidote and quartz.

115-125 Metabasalt, greenish-gray, dense; generally massive with chlorite along cleavage planes; amygdaloidal; some asbestos, quartz, vein quartz, epidote and feldspars.

125-180 Metabasalt, purplish-gray, dense; massive with epidote and feldspar amygdules; some asbestos, quartz replaced asbestos, quartz, feldspars and chlorite.

180-205 Metabasalt, light gray, dense; with chlorite and a trace of epidote and feldspars; most fragments have a well developed foliation.

LOFT MOUNTAIN TEST HOLE NO. 1, W-704 (FIGURE 20)

Depth (in feet)

OVERBURDEN (0′-5′)

0- 5 Weathered metabasalt, a deep tannish-brown; with some green epidote, clear quartz, chlorite and red jasper; a few unweathered fragments are light bluish-green and dense.

CATOCTIN FORMATION (5′-250′)

5- 10 Metabasalt, dark bluish-gray, dense; with some green epidote, stained quartz, chlorite and albite; many fragments of tannish-brown weathered metabasalt.

10-110 Metabasalt, dark bluish-gray, dense; with some stained quartz, green epidote, albite, chlorite and red jasper; a few fragments have slickensides and some are well foliated.

Depth (in feet)

110-140	Metabasalt, dark bluish-gray, dense; with some green epidote, white quartz, albite, chlorite and red jasper; a few albite-quartz-epidote-red jasper amygdules and a trace of copper mineralization.
140-175	Schistose greenstone, dark bluish-gray, strongly foliated to dense; with some epidote, magnetite and red jasper; X-ray analysis reveals biotite, muscovite, chlorite, quartz and orthoclase.
175-195	Metabasalt, dark bluish-gray, dense; with some red jasper and chlorite; a trace of epidote, albite and quartz (50% of the sample is a reddish-gray, foliated metabasalt).
195-205	Schistose metabasalt, dark greenish-blue, dense to foliated; with chlorite, white quartz, red stained plagioclase and a trace of epidote.
205-225	Metabasalt, dark bluish-gray, dense to strongly foliated; with chlorite, epidote, stained quartz and plagioclase; with some dark greenish-gray, schistose metabasalt fragments.
225-235	Schistose metabasalt and metabasalt; the schistose metabasalt is dark reddish-purple, foliated to dense; the metabasalt is dark blue-gray, dense; with white quartz, chlorite, epidote, plagioclase and a trace of magnetite and muscovite.
235-250	Metabasalt, dark bluish-gray, dense; with some quartz, chlorite, red jasper, albite and epidote; a trace of magnetite.

LOFT MOUNTAIN TEST HOLE NO. 2, W-710 (FIGURE 20)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 35	Overburden	—
35-160	Catoctin Formation	Metabasalt and phyllite

LOFT MOUNTAIN TEST HOLE NO. 3, W-715 (FIGURE 20)

Depth (in feet)

WEVERTON FORMATION (0′-45′)

0- 45	Weathered subarkose to graywacke, tan-green-red-brown, fine- to coarse-grained; poorly sorted; with clear to stained quartz, feldspars, red hematite and sericite-chlorite; a trace of purple and green phyllite.

CATOCTIN FORMATION (45′-303′)

45- 80	Phyllite, light tan to grayish-green, fine crystalline; with a chlorite, sericite cemented matrix; some iron-oxide stained to white quartz and feldspars; most fragments are well foliated.

Depth (in feet)

80-130 Phyllitic metabasalt, light purple to greenish-gray, dense; with chlorite, sericite, white to stained quartz, feldspars and a trace of vein calcite.

130-220 Phyllitic metabasalt, light gray to dark reddish-gray, dense; with chlorite, sericite, white to stained quartz, plagioclase, orthoclase and calcite; a trace of pyrite and magnetite; X-ray analysis reveals 30-45% chlorite, 35% quartz, 35% mica and 20% plagioclase.

220-303 Phyllitic metabasalt, dark bluish-gray to reddish, dense; with chlorite, white quartz, feldspars and a trace of magnetite, calcite and epidote; X-ray analysis reveals 35-40% chlorite, 20-40% plagioclase, 25% quartz, 10-30% mica, 15% amphibole and 10% orthoclase.

LOFT MOUNTAIN TEST HOLE NO. 4, W-718 (FIGURE 20)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 10	Overburden	—
10- 65	Weverton Formation	Phyllite and quartzite
65-250	Catoctin Formation	Metabasalt and phyllite

LOFT MOUNTAIN TEST HOLE NO. 5, W-754 (FIGURE 20)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 10	Overburden	—
10- 45	Weverton Formation	Phyllite
45-320	Catoctin Formation	Phyllite and metabasalt

DUNDO TEST HOLE NO. 1, W-1073 (FIGURE 22)

Depth (in feet)

WEVERTON FORMATION (0′-140′)

0- 20 Arenaceous phyllite, light gray and light reddish-brown, medium to fine grained quartz sand in a clay matrix; some quartz-granule conglomerate; trace of graphite; all fragments iron-oxide stained and weathered.

20- 45 Argillaceous sandstone, light gray to buff, medium- to coarse-grained; slightly conglomeratic, with a clay matrix; iron-oxide stained; slightly weathered.

45- 50 Quartzite, quartzite conglomerate, and arenaceous phyllite, light gray to buff, fine-grained; iron-oxide stained; conglomerate contains angular quartz granules and small pebbles.

Depth (in feet)	
50-105	Quartz-sericite-phyllite and sandy phyllite, light gray to light tan, fine- to medium-grained quartz sand in clay matrix; traces of quartzite and vein quartz.
105-130	Quartzite, light grayish-tan, fine-grained; well sorted angular quartz sand; some quartz-sericite-phyllite and conglomeratic quartzite; many fragments are well-foliated.
130-140	Conglomeratic quartzite, blue quartz granules with red iron cement; some light greenish-gray quartz-sericite-phyllite, and coarse-grained iron-cemented quartzite.
CATOCTIN FORMATION (140′-615′)	
140-170	Chlorite schist, light grayish-green, very fine grained; with chlorite slickensides; some plagioclase, sericite-phyllite and conglomeratic quartzite; a trace of epodite.
170-205	Phyllite, dark purplish-gray-green; very fissile; zones of quartz clasts, grains of epidote and orange-red feldspars (probably pyroclastic material).
205-210	Quartzite conglomerate, pebbles or boulders of medium-grained quartzites with iron cement, in a matrix of fire-grained sand and green very fine-grained silt or pyroclastic material.
210-235	Phyllite, purplish gray-green; very fissile; disseminated fine-grained quartz sand; with a few fragments of metamorphosed graywacke, composed of rounded to subangular quartz and feldspars in a chlorite-sericite-phyllite matrix; some slickensides.
235-250	Metabasalt, dark greenish-gray and purplish-gray, dense; massive; slickensides; with chlorite, plagioclase and traces of epidote and hematite.
250-315	Chlorite schist, dark greenish- and purplish-gray; considerable slickenside development; very fissile; with some white quartz, chlorite and feldspars.
315-330	Metabasalt, dark gray-green and purplish-gray, dense; massive; slickensides; with red jasper, quartz, chlorite, calcite, feldspars and a trace of epidote.
330-380	Metabasalt, dark purplish-gray, dense; feldspar, quartz, calcite and epidote amygdules; some asbestos and calcite along slickenside surfaces; with a trace of chlorite.
380-420	Phyllitic metabasalt, dark purplish-gray to dark greenish-gray, very fine-grained; tuffaceous; sheared feldspar and epidote amygdules; trace of asbestos.
420-485	Metabasalt, dark bluish-gray, dense; with a minor amount of chlorite, quartz, epidote and quartz replaced asbestos.

Depth (in feet)

485-490	Metabasalt, dark purplish-gray, dense; massive; many feldspar and epidote amygdules; a trace of slickensides and vein quartz.
490-505	Metabasalt, dark greenish-gray, dense; schistose; a few feldspar amygdules; with chlorite, albite, epidote, quartz and calcite.
505-590	Metabasalt, dark purplish-gray, dense; massive; quartz, feldspar and epidote amygdules; with some chlorite, quartz, feldspars and epidote; a trace of asbestos.
590-615	Metabasalt, dark purplish-gray, dense; massive; white and pink feldspar amygdules with epidote and quartz centers; a trace of calcite, chlorite and ilmenite.

DUNDO TEST HOLE NO. 2, W-1074 (FIGURE 22)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 5	Overburden	—
5-340	Catoctin Formation	Phyllite, metabasalt, and andesitic basalt

DUNDO EXPLORATION HOLE NO. 1, W-1810 (FIGURE 22)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 2	Overburden	—
2-104	Weverton Formation	Quartz-sericite-phyllite, quartzite and conglomeratic quartzite

DUNDO EXPLORATION HOLE NO. 2, W-1811 (FIGURE 22)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0- 2	Overburden	—
2- 91	Weverton Formation	Quartz-sericite-phyllite, conglomeratic phyllite, pebble conglomerate and quartzite
91-117	Catoctin Formation	Phyllite, schist and metabasalt

GROTTOES EXPLORATION HOLE, W-1654 (FIGURE 23)

Geologic Summary

Depth (in feet)	Stratigraphic unit	Rock type
0-200	Overburden	—
200-282	Rome Formation (?)	Sandstone, limestone and clay
282-350	No Sample	—

ROCKFISH GAP TEST HOLE NO. 1, W-1137 (FIGURE 24)

Depth (in feet)

OVERBURDEN (0′-25′)

0- 25	Weathered metabasalt, dark olive-green; with some black phyllite, chlorite, feldspars, quartz and epidote.

CATOCTIN FORMATION (25′-535′)

25- 50	Metabasalt, dark gray, dense; with some cloudy quartz, feldspar, red jasper and chlorite; a well developed foliation on most fragments; X-ray analysis: 40% plagioclase, 40% chlorite, 15% quartz and 5% epidote and biotite.
50- 80	Metabasalt and phyllitic metabasalt, greenish-blue; dense; with quartz, epidote, calcite, feldspar, chlorite and biotite; good quartz and calcite crystals indicating openings; some vein quartz and oxidation stains.
80-145	Metabasalt, greenish-blue, dense; foliated; with quartz, epidote, calcite, feldspar, chlorite and biotite.
145-160	Epidosite and metabasalt, pale green, fine-grained: greenish-blue, dense; with red jasper, epidote, vein quartz, feldspar, chlorite and biotite.
160-170	Metabasalt, greenish-blue, dense; some quartz, biotite, epidote, chlorite and feldspar; with a trace of magnetite; many fragments have a well developed foliation.
170-175	Epidosite, pale green, fine-grained; with a few fragments of greenish-blue dense metabasalt.
175-200	Meta-arkose and metabasalt; the meta-arkose is reddish-brown, fine- to medium-grained; the matebasalt is dark bluish-gray, dense; with epidote, quartz, feldspars and red jasper.
200-225	Metabasalt, greenish-blue, dense; with quartz, feldspar, biotite, chlorite, epidote and minor pyrite; most fragments have a well developed foliation.
225-235	Metabasalt, greenish-blue, dense; some quartz, biotite, chlorite, feldspar and epidote; with a few amygdules of quartz, feldspar, epidote and red jasper.
235-330	Metabasalt, greenish-blue, dense; foliated; with quartz, biotite, chlorite, feldspar and epidote.
330-355	Metabasalt, greenish-blue, dense; with quartz, biotite, feldspar, chlorite, epidote, jasper and minor pyrite; with some dark gray, dense phyllitic metabasalt.
355-395	Metabasalt, greenish-blue, dense; with quartz, biotite, feldspar, chlorite, epidote, and jasper; amygdules of quartz, epidote, feldspar and red jasper; a trace of ilmenite and vein quartz.

Depth (in feet)	
395-480	Metabasalt, greenish-blue, dense; with quartz, biotite, feldspar, chlorite, epidote and red jasper; a trace of calcite.
480-510	Metabasalt and meta-arkose; the metabasalt is the same as in the previous interval; the meta-arkose is fine- to medium-grained with quartz and feldspar; some minor sericite, magnetite, clay and mica; a trace of calcite.
510-530	Meta-arkose, light to dark gray, fine- to medium-grained; subrounded; clear to stained quartz and feldspars (albite); minor sericite, clay or mica, and chlorite.
530-535	No sample.

APPENDIX IV

PUMP-TEST DRAWDOWN CURVES

S.W.L. .... Static Water Level

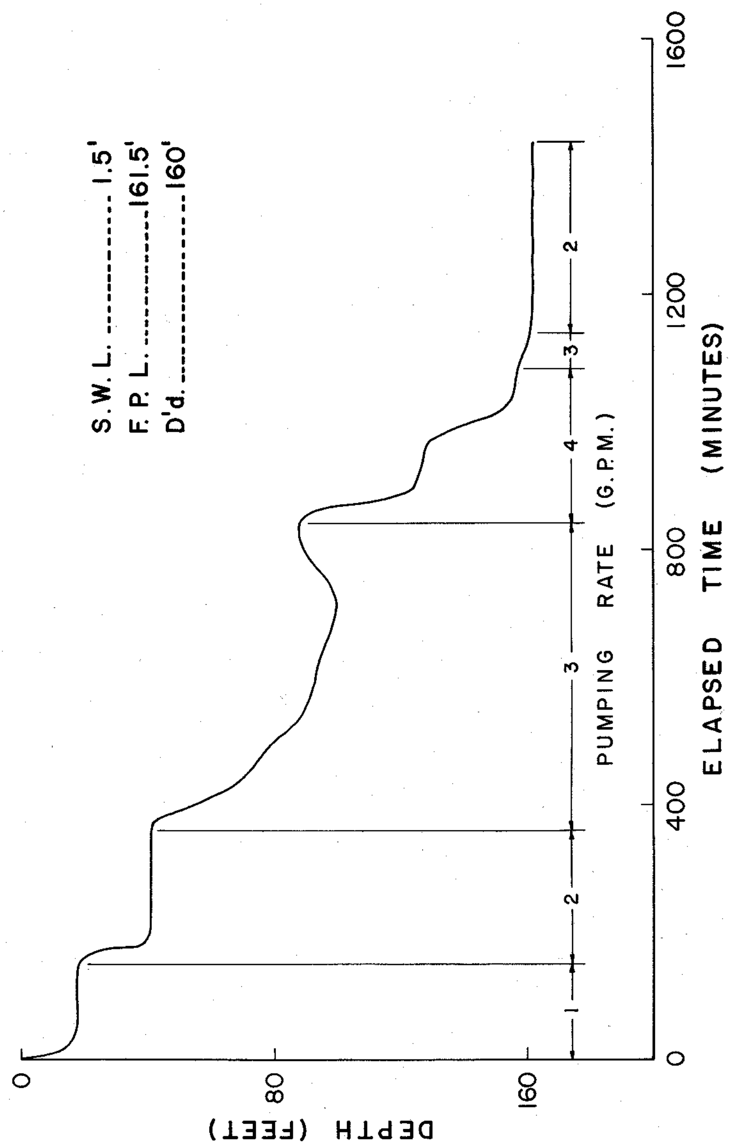
F.P.L. .... Final Pumping Level

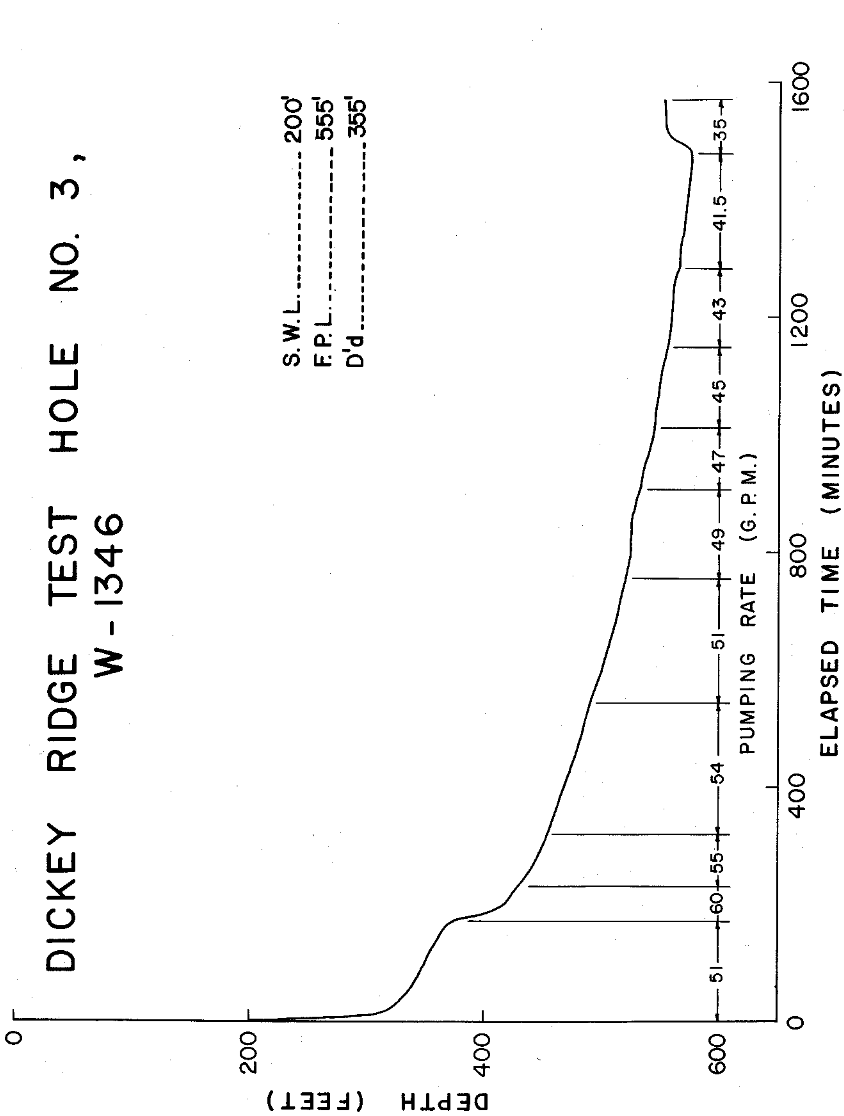
D'd. .... Drawdown

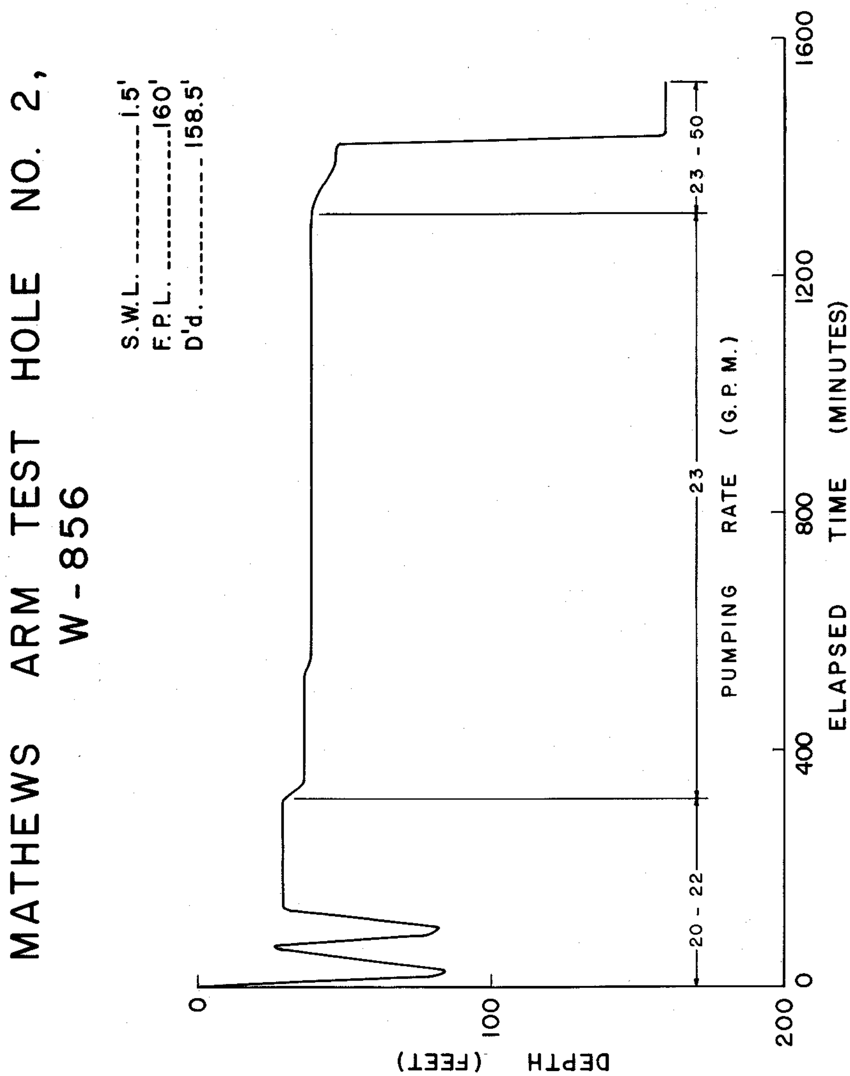
G.P.M. .... Gallons Per Minute

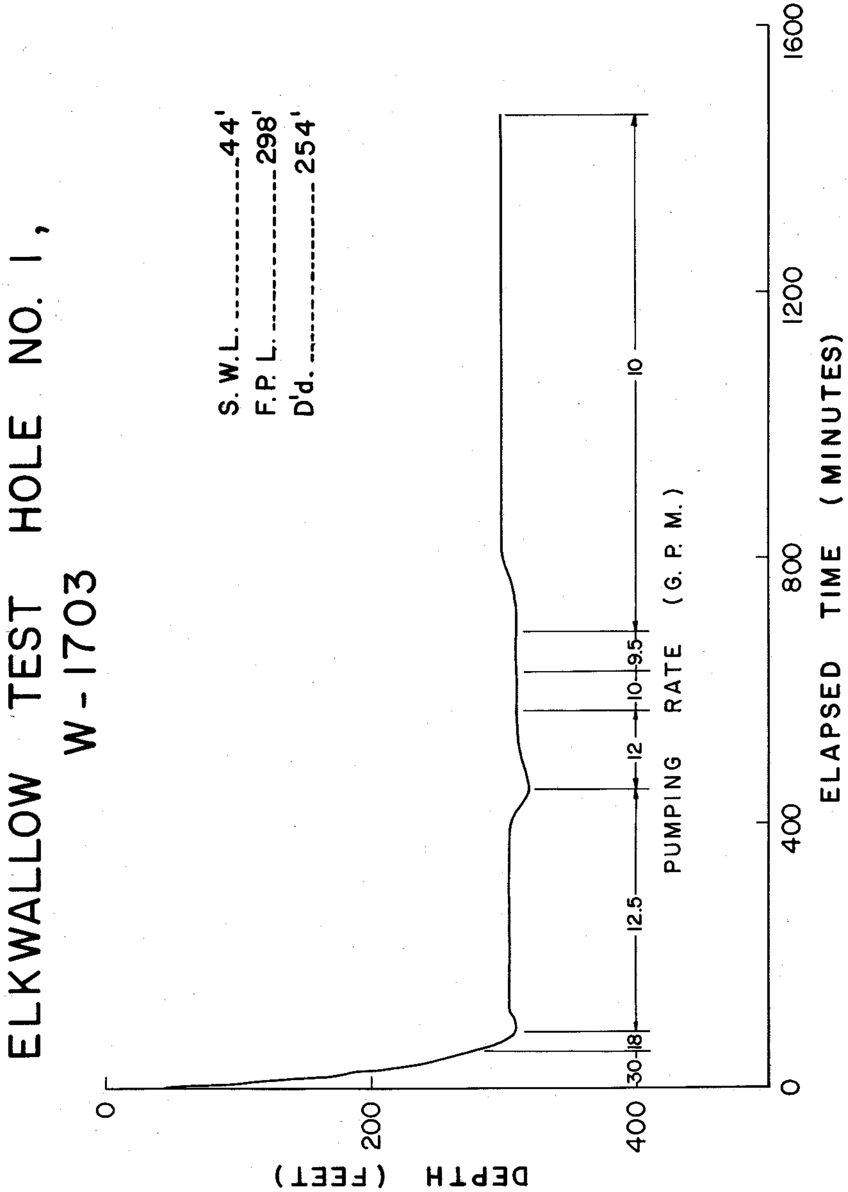
Repository Number	Name	Map location
W-1138	Fox Hollow Test Hole No. 1	Figure 6
W-1346	Dicky Ridge Test Hole No. 3	Figure 6
W- 856	Mathews Arm Test Hole No. 2	Figure 7
W-1703	Elkwallow Test Hole No. 1	Figure 8
W- 851	Headquarters Test Hole No. 1	Figure 9
W- 855	Headquarters Test Hole No. 2	Figure 9
W- 948	Thornton Gap Test Hole No. 1	Figure 12
W- 592	Skyland Test Hole No. 2	Figure 14
W-1033	Skyland Test Hole No. 4	Figure 14
W- 869	Comers Deadening Test Hole No. 1	Figure 15
W-1136	Comers Deadening Test Hole No. 3	Figure 15
W-1347	Big Meadows Test Hole No. 1	Figure 16
W-1701	Big Meadows Test Hole No. 3	Figure 16
W-1702	Big Meadows Test Hole No. 4	Figure 16
W-1072	Lewis Mountain Test Hole No. 1	Figure 17
W-1704	Simmons Gap Test Hole No. 1	Figure 19
W- 715	Loft Mountain Test Hole No. 3	Figure 20
W- 718	Loft Mountain Test Hole No. 4	Figure 20
W- 754	Loft Mountain Test Hole No. 5	Figure 20
W-1073	Dundo Test Hole No. 1	Figure 22
W-1137	Rockfish Gap Test Hole No. 1	Figure 24

FOX HOLLOW TEST HOLE NO. 1, W-1138



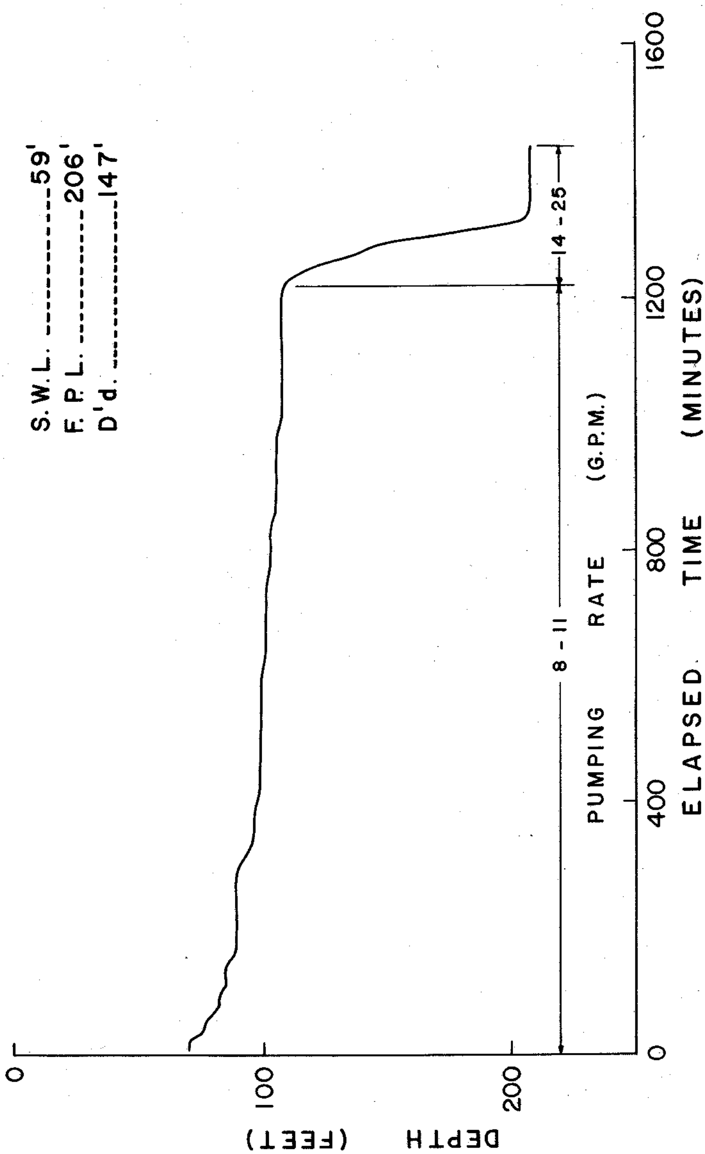

DICKEY RIDGE TEST HOLE NO. 3,
W-1346
S.W.L. 200'
F.P.L. 555'
D'd 355'
DEPTH (FEET)
0
200
400
600
51
60
55
54
51
49
47
45
43
41.5
35
PUMPING RATE (G.P.M.)
0
400
800
1200
1600
ELAPSED TIME (MINUTES)

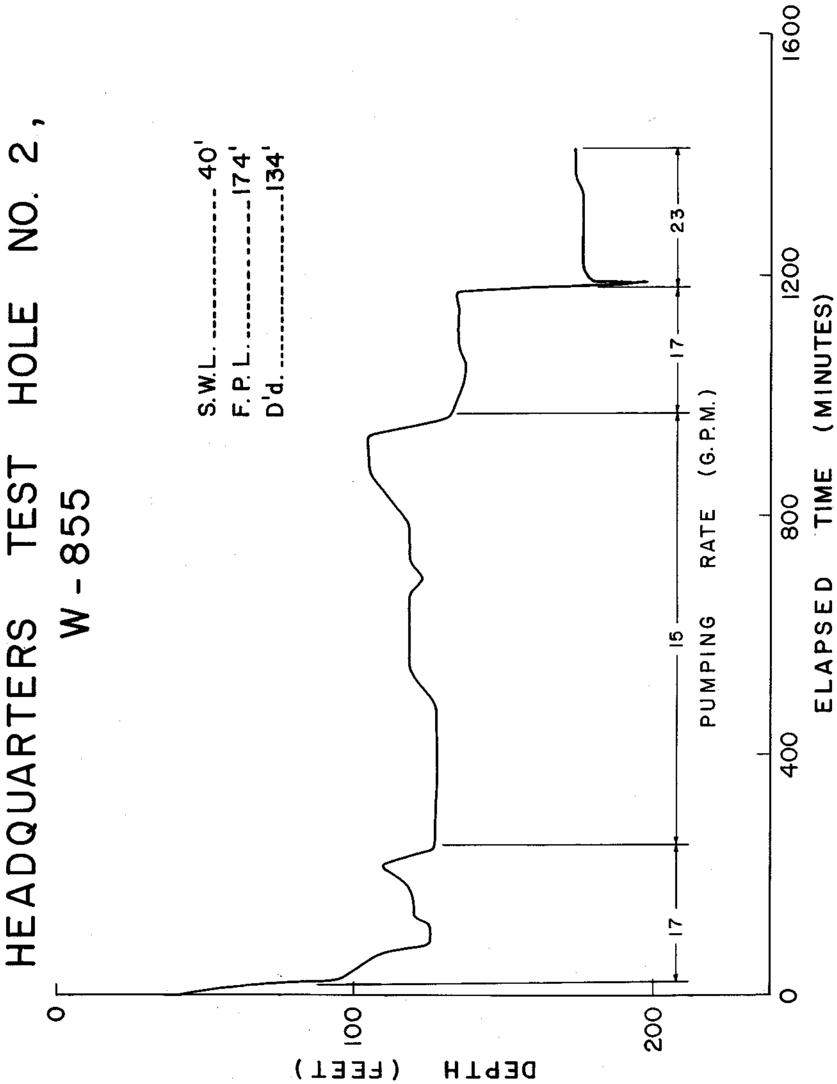

MATHEWS ARM TEST HOLE NO. 2,
W-856
S.W.L. ---------- 1.5'
F.P.L. ---------- 160'
D'd. ---------- 158.5'
20 - 22
23
23 - 50
PUMPING RATE (G.P.M.)
0
400
800
1200
1600
ELAPSED TIME (MINUTES)
0
100
200
DEPTH (FEET)

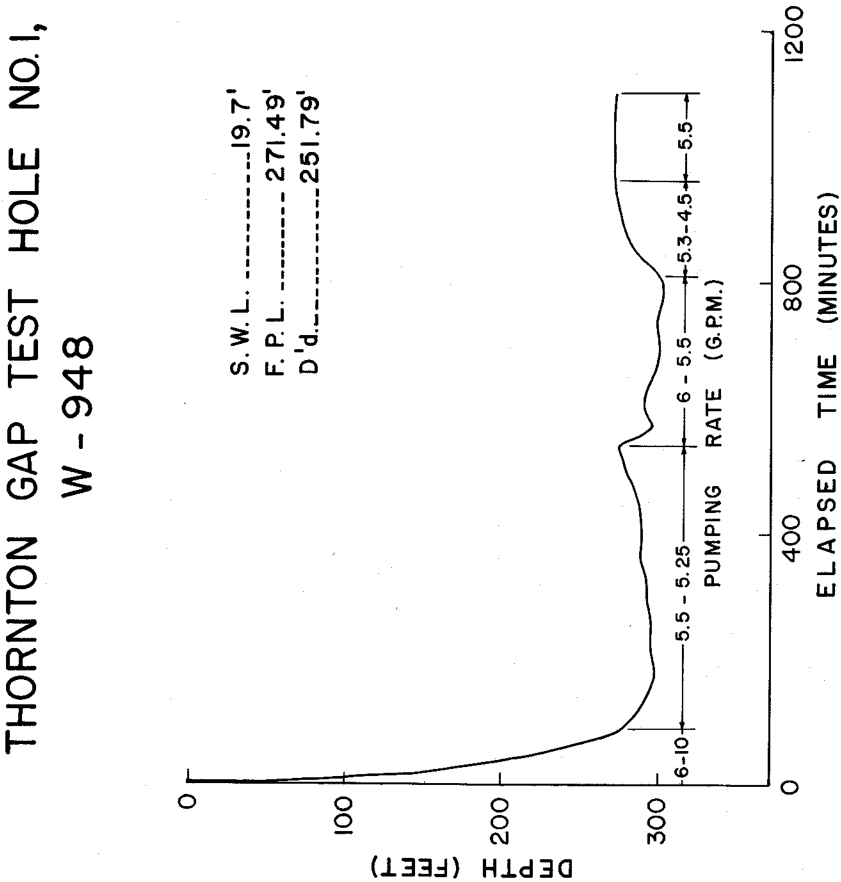


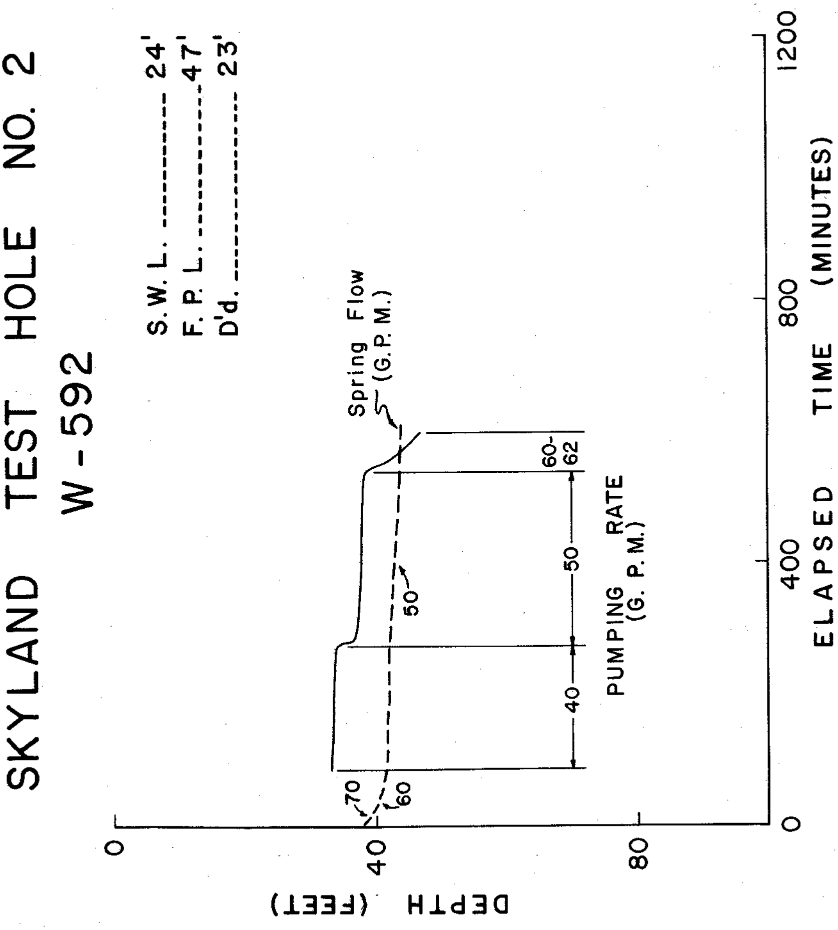
ELKWALLOW TEST HOLE NO. 1,
W-1703
S. W. L. 44'
F. P. L. 298'
D'd. 254'
30
18
12.5
12
10
9.5
10
PUMPING RATE (G. P. M.)
ELAPSED TIME (MINUTES)
0
400
800
1200
1600
DEPTH (FEET)
0
200
400

HEADQUARTERS TEST HOLE NO. 1, W - 851

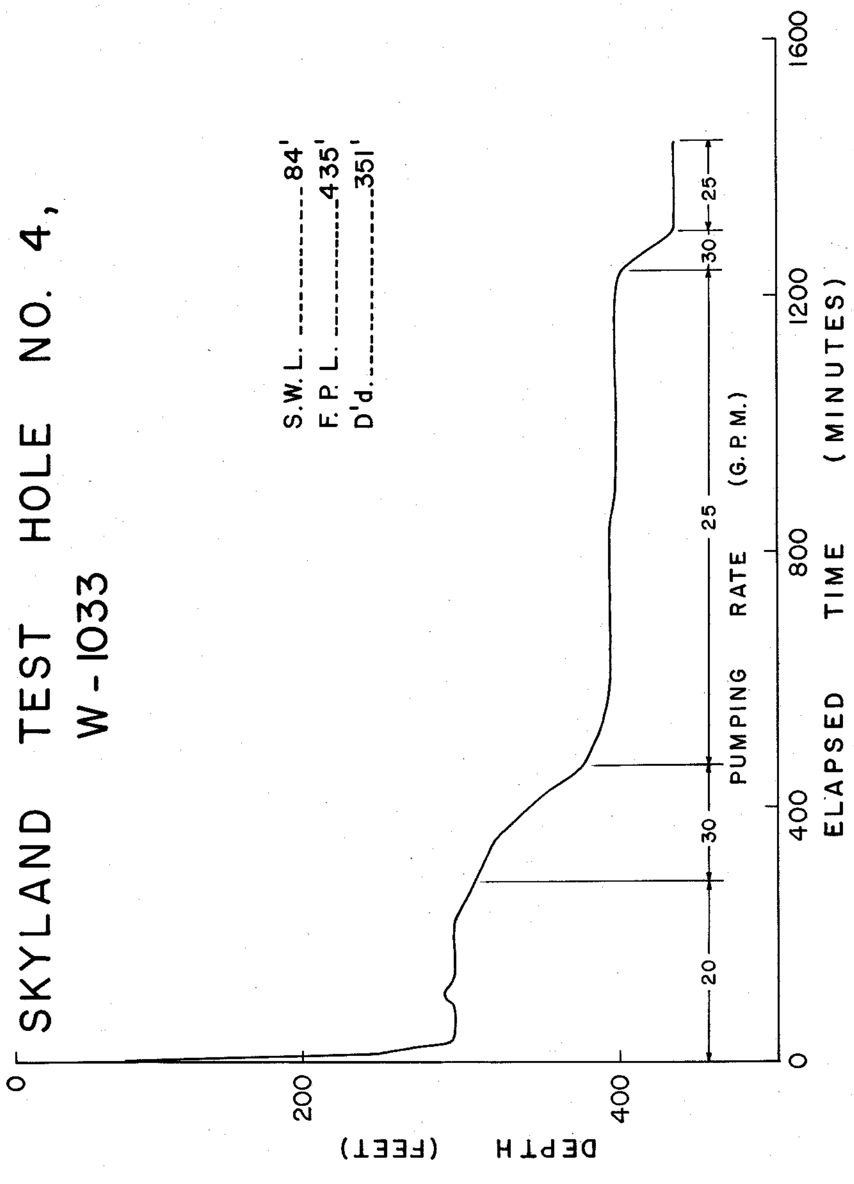


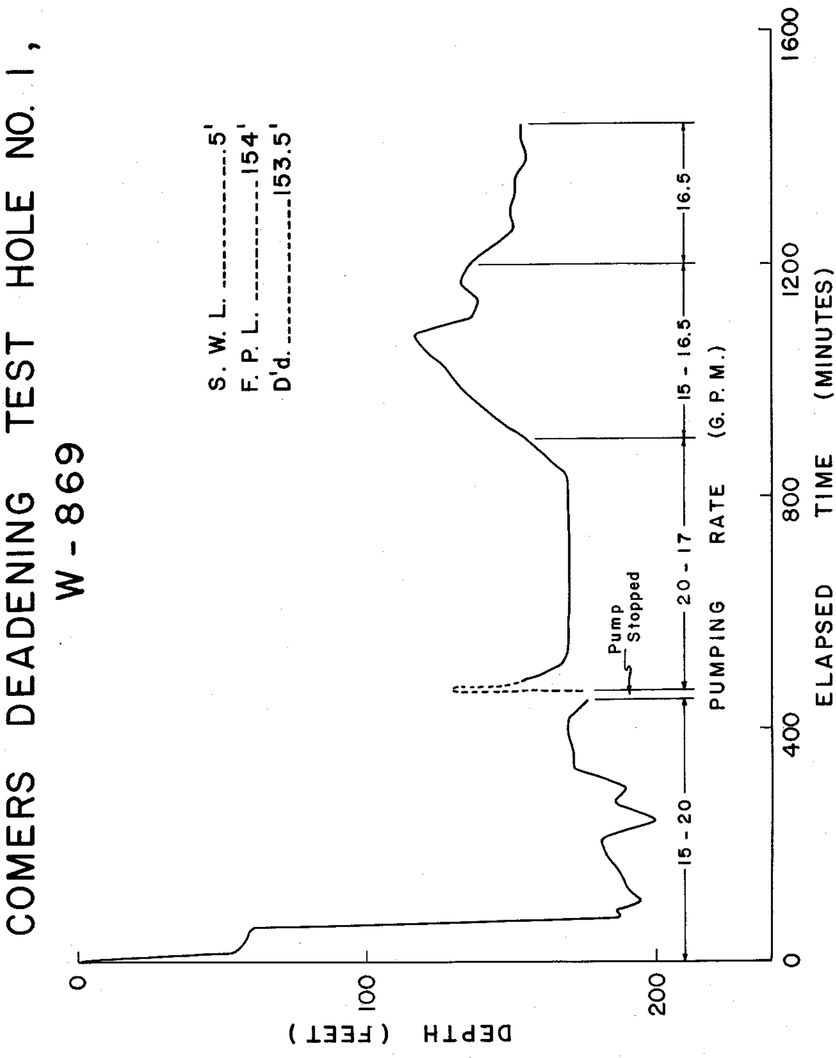

HEADQUARTERS TEST HOLE NO. 2,
W-855
S.W.L. 40'
F.P.L. 174'
D'd. 134'
17
15
17
23
PUMPING RATE (G.P.M.)
0
400
800
1200
1600
ELAPSED TIME (MINUTES)
0
100
200
DEPTH (FEET)

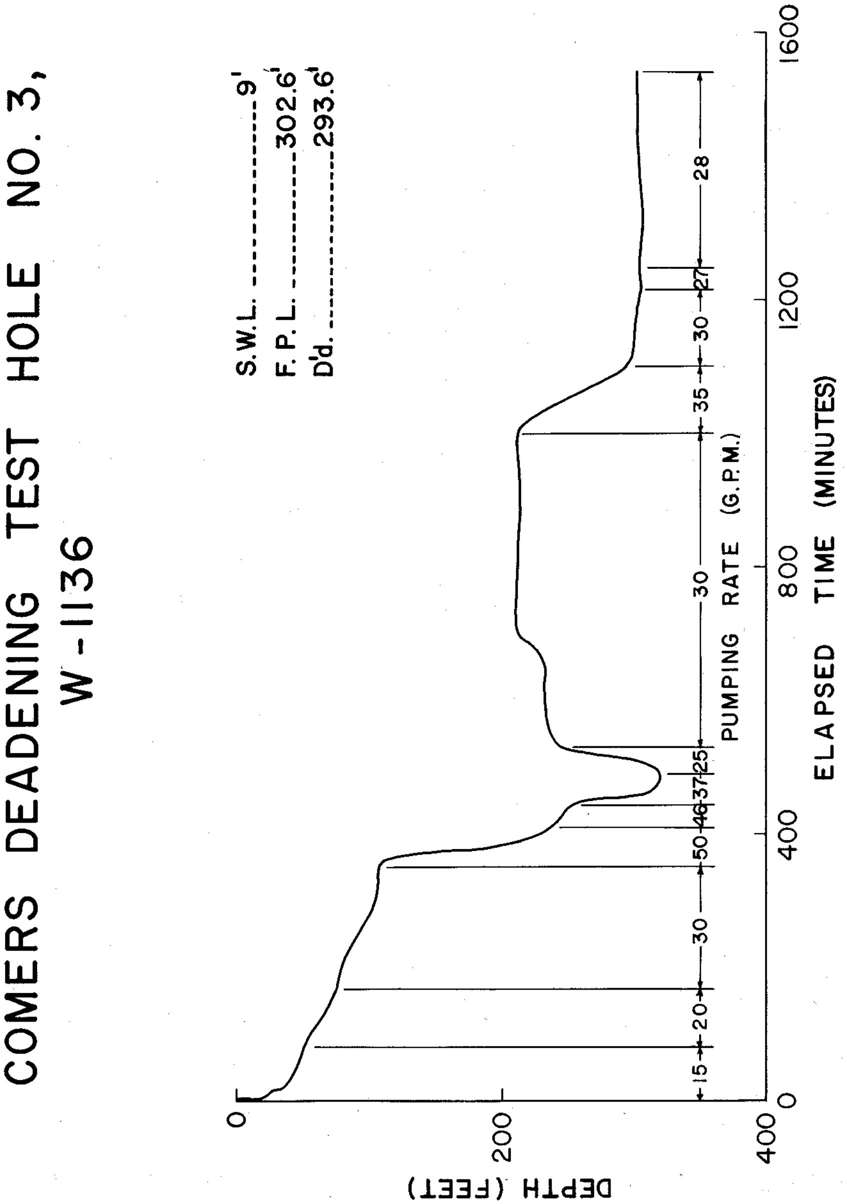

THORNTON GAP TEST HOLE NO.1,
W - 948
S. W. L. ....19.7'
F. P. L. ....271.49'
D'd. ....251.79'
6-10
5.5 - 5.25
6 - 5.5
5.3-4.5
5.5
PUMPING RATE (G.P.M.)
0
100
200
300
DEPTH (FEET)
0
400
800
1200
ELAPSED TIME (MINUTES)

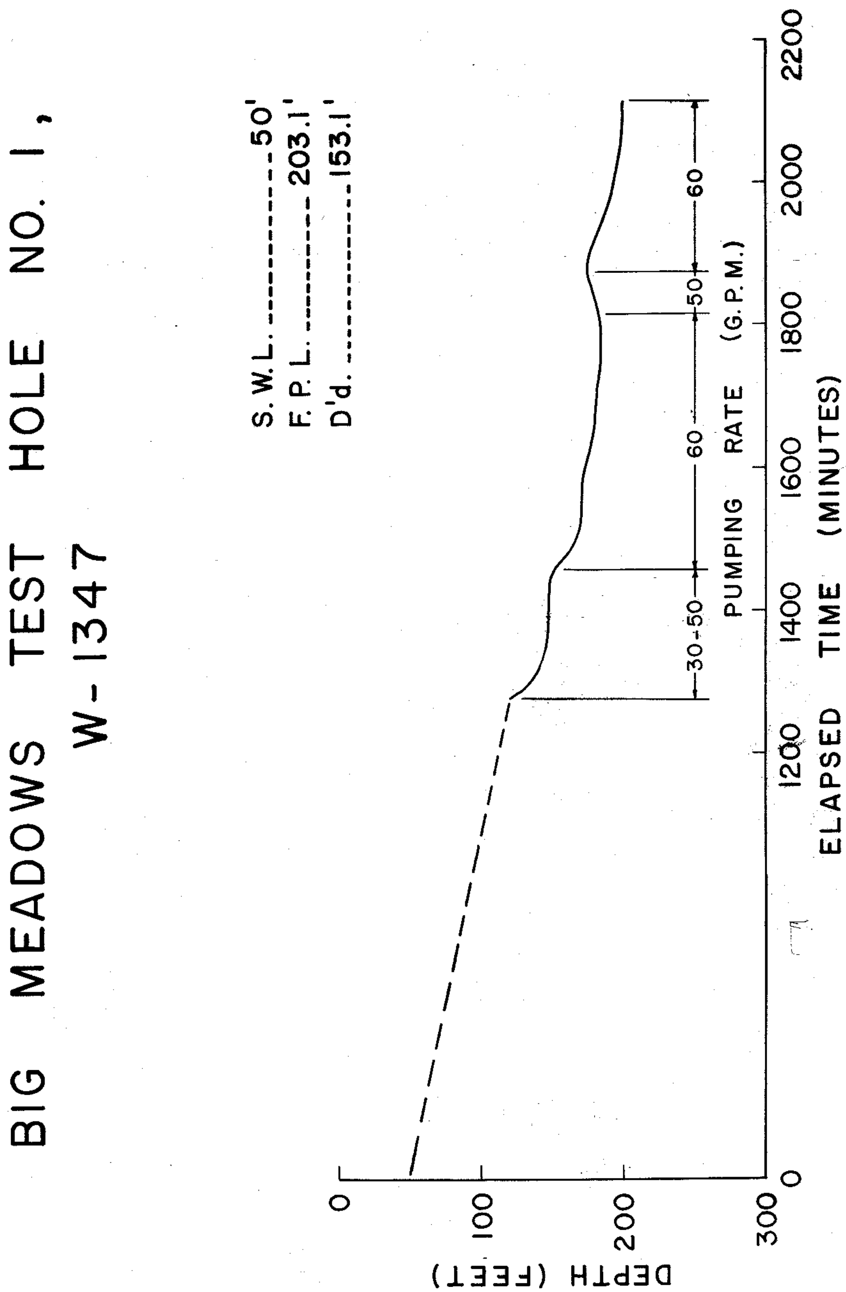


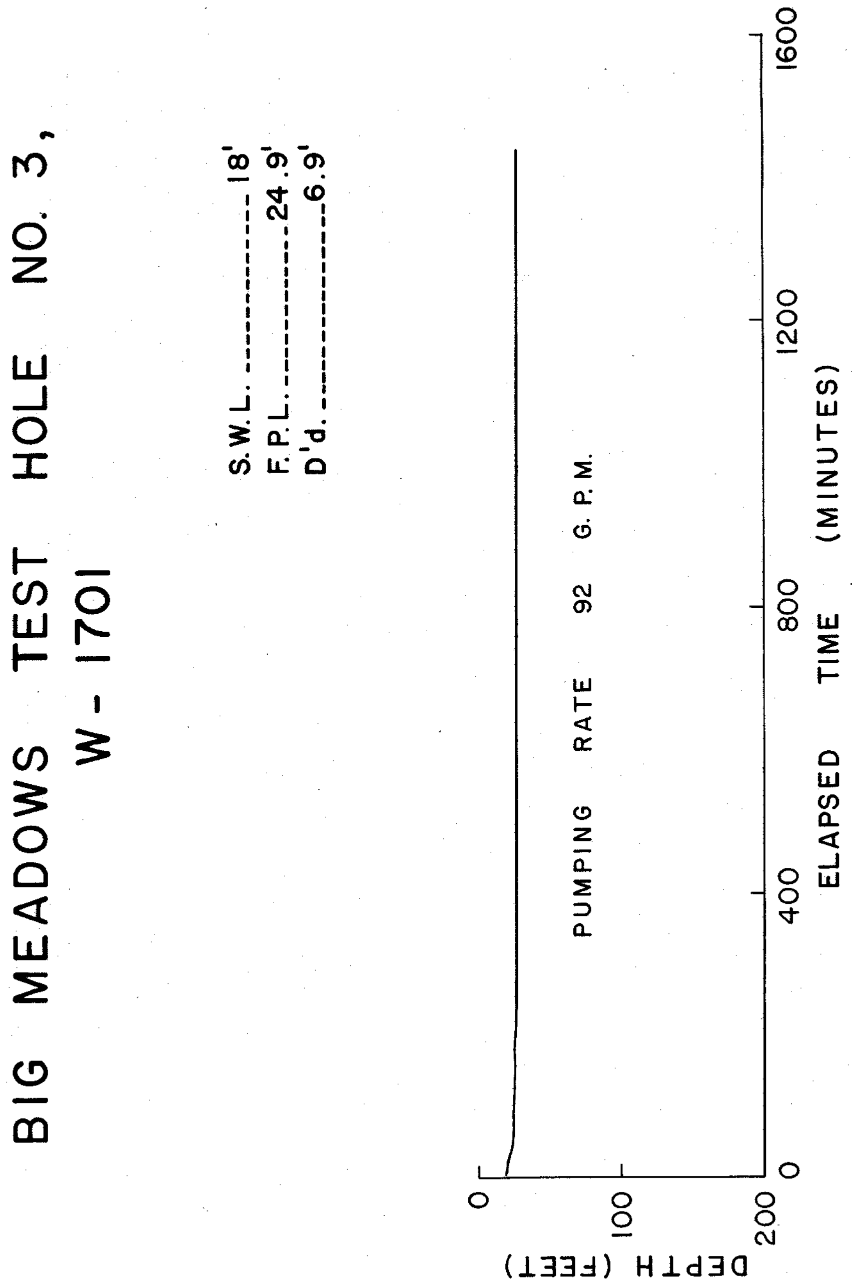
SKYLAND TEST HOLE NO. 2
W-592
S. W. L. ---------- 24'
F. P. L. ---------- 47'
D'd. ---------- 23'
Spring Flow (G.P.M.)
70
60
50
40
50
60-62
PUMPING RATE (G. P. M.)
DEPTH (FEET)
0
40
80
0
400
800
1200
ELAPSED TIME (MINUTES)

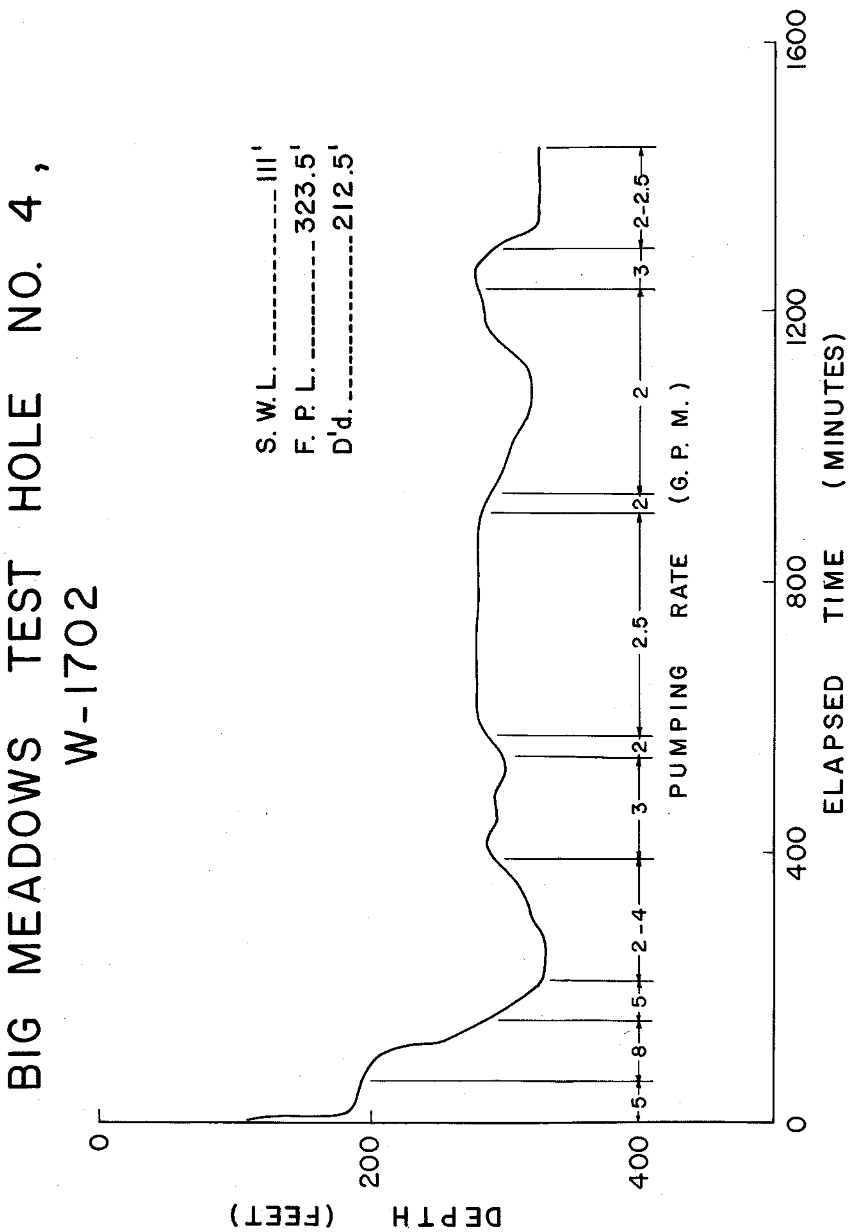

SKYLAND TEST HOLE NO. 4,
W-1033
S.W.L. ---- 84'
F.P.L. ---- 435'
D'd. ---- 351'
PUMPING RATE (G.P.M.)
20
30
25
30
25
ELAPSED TIME (MINUTES)
0
400
800
1200
1600
DEPTH (FEET)
0
200
400

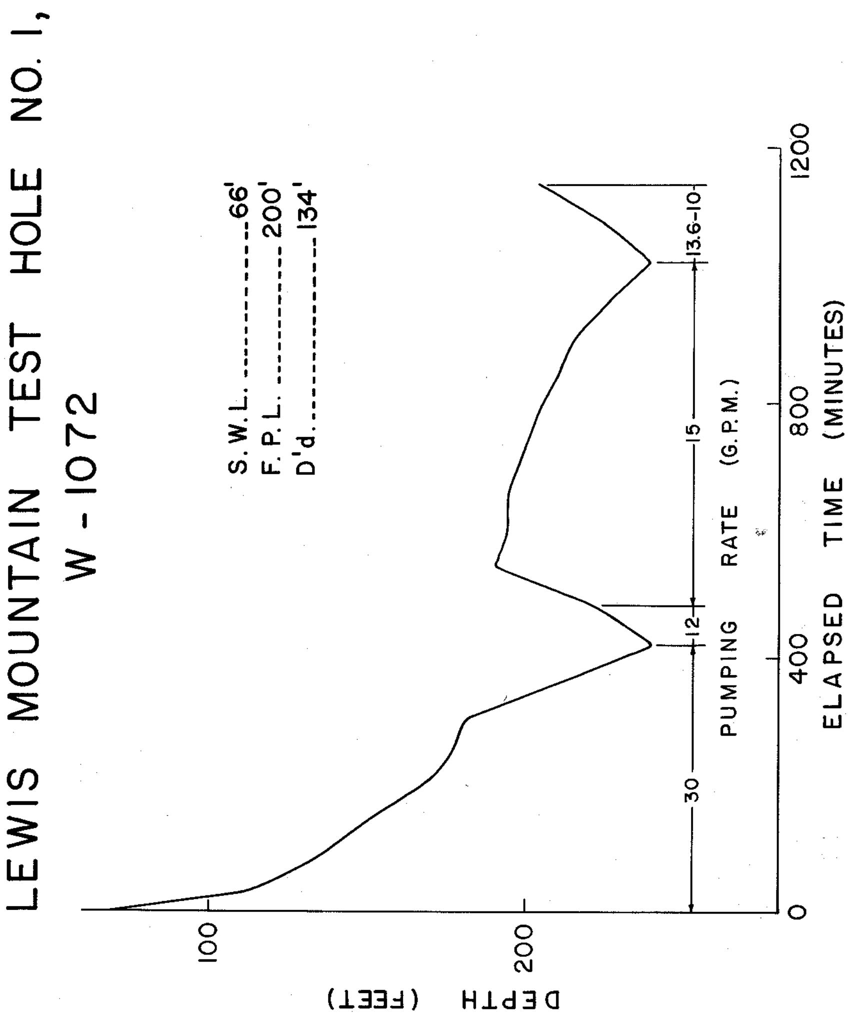

COMERS DEADENING TEST HOLE NO. 1,
W - 869
S. W. L. ....5'
F. P. L. ....154'
D'd. ....153.5'
Pump Stopped
15 - 20
20 - 17
15 - 16.5
16.5
PUMPING RATE (G. P. M.)
0
400
800
1200
1600
ELAPSED TIME (MINUTES)
0
100
200
DEPTH (FEET)

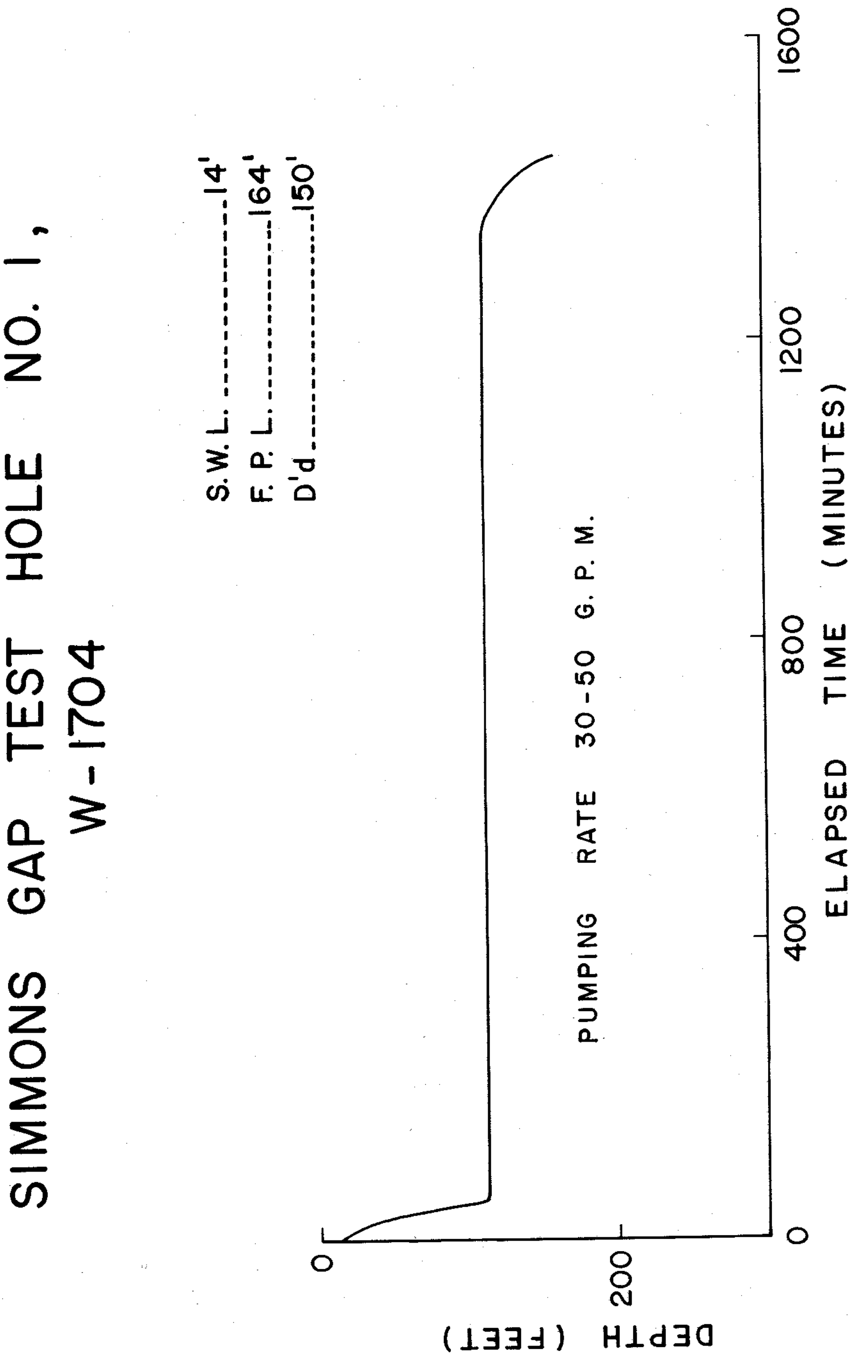

COMERS DEADENING TEST HOLE NO. 3,
W-1136
S.W.L. 9'
F.P.L. 302.6'
D'd. 293.6'
DEPTH (FEET)
0
200
400
PUMPING RATE (G.P.M.)
15
20
30
50
46
37
25
30
35
30
27
28
ELAPSED TIME (MINUTES)
0
400
800
1200
1600

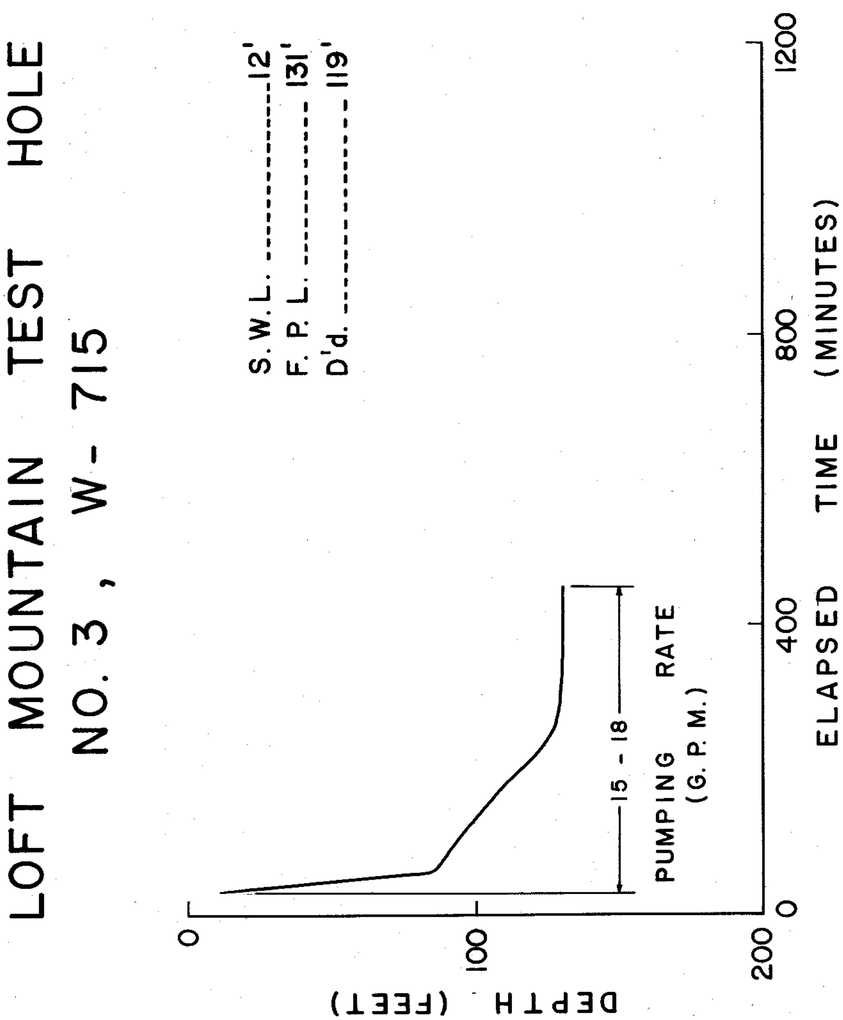

BIG MEADOWS TEST HOLE NO. 1,
W-1347
S.W.L. .... 50'
F.P.L. .... 203.1'
D'd. .... 153.1'
30-50
60
50
60
PUMPING RATE (G.P.M.)
DEPTH (FEET)
0
100
200
300
0
1200
1400
1600
1800
2000
2200
ELAPSED TIME (MINUTES)

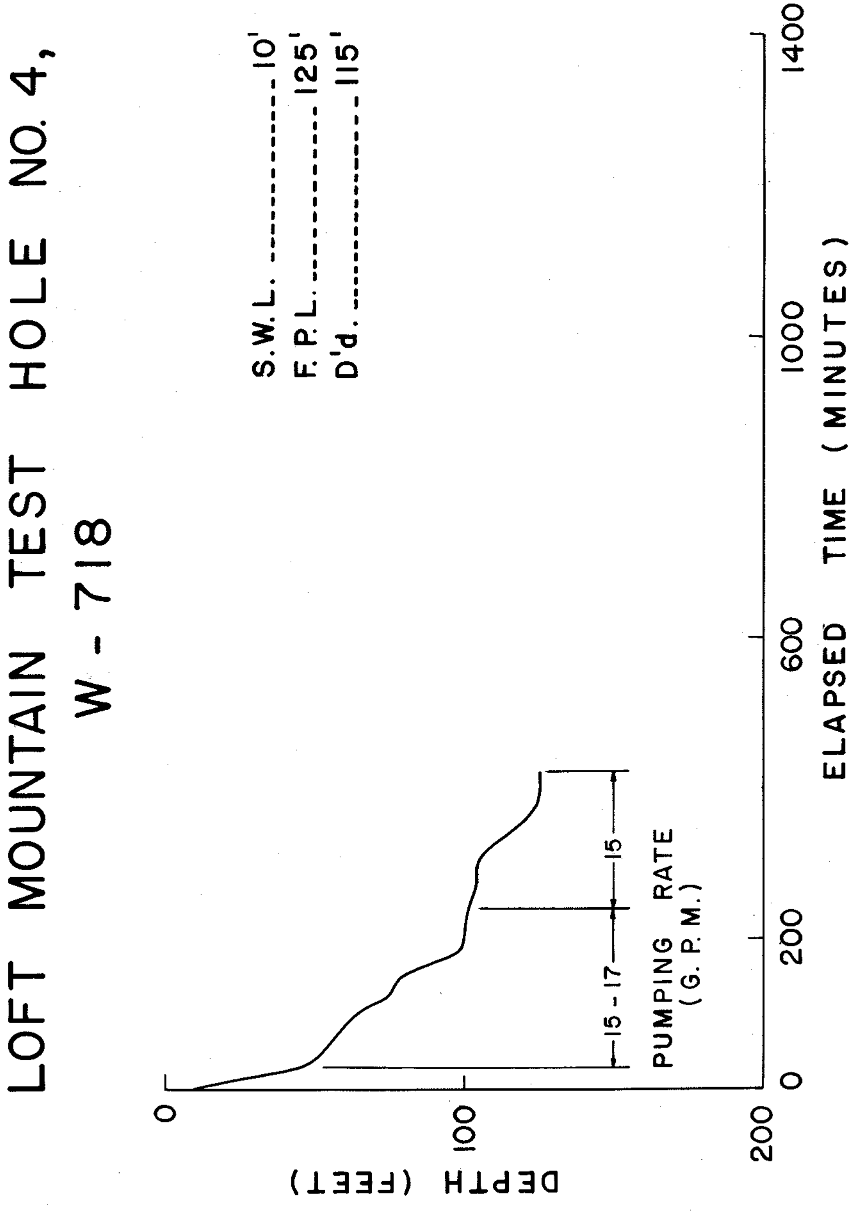

BIG MEADOWS TEST HOLE NO. 3,
W - 1701
S.W.L. 18'
F.P.L. 24.9'
D'd. 6.9'
PUMPING RATE 92 G.P.M.
0
100
200
DEPTH (FEET)
0
400
800
1200
1600
ELAPSED TIME (MINUTES)

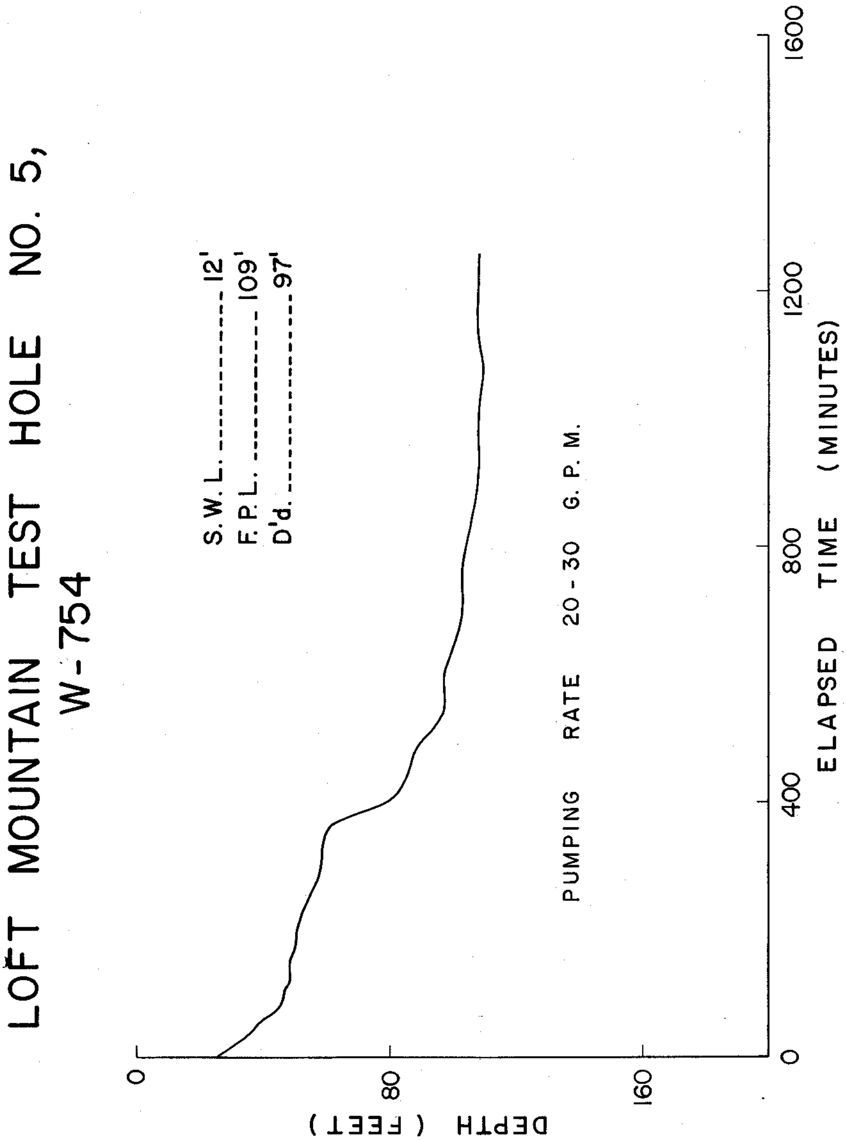

BIG MEADOWS TEST HOLE NO. 4,
W-1702
S. W. L. ---------- 111'
F. P. L. ---------- 323.5'
D'd. ---------- 212.5'
5
8
5
2-4
3
2
2.5
2
2
3
2-2.5
PUMPING RATE (G. P. M.)
0
400
800
1200
1600
ELAPSED TIME (MINUTES)
0
200
400
DEPTH (FEET)


LEWIS MOUNTAIN TEST HOLE NO. 1,
W-1072
S. W. L. ....66'
F. P. L. ....200'
D'd. ....134'
100
200
DEPTH (FEET)
30
12
15
13.6-10
PUMPING RATE (G. P. M.)
0
400
800
1200
ELAPSED TIME (MINUTES)

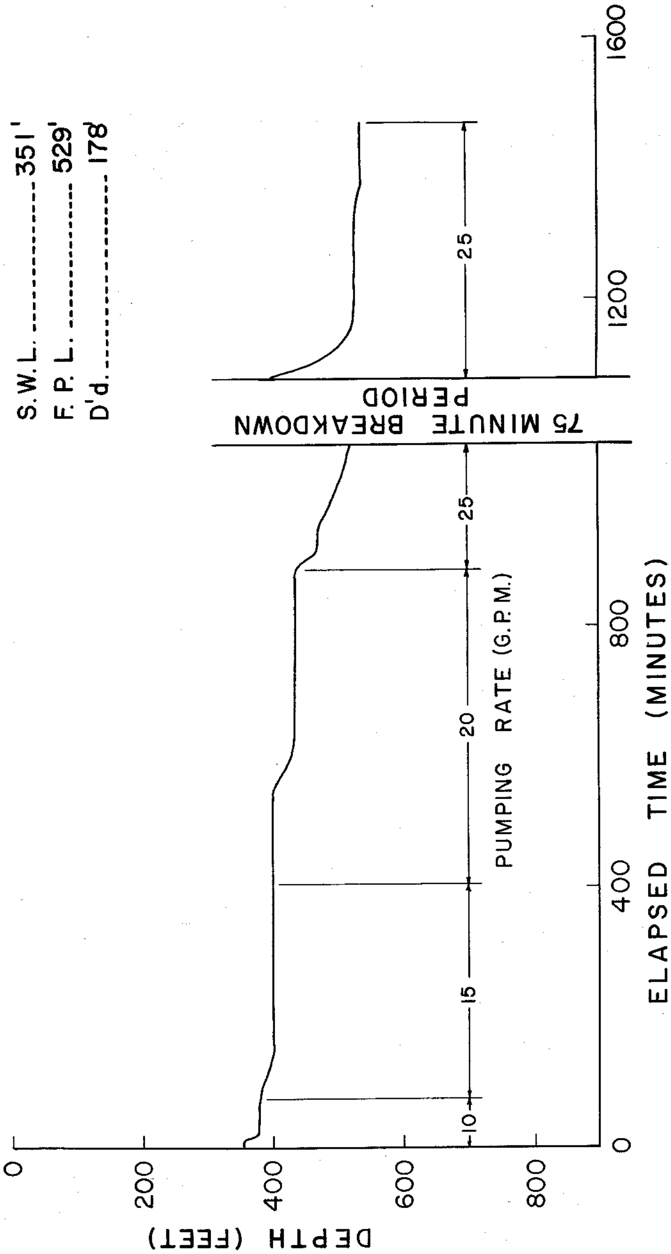

SIMMONS GAP TEST HOLE NO. 1,
W-1704
S.W.L. 14'
F.P.L. 164'
D'd 150'
PUMPING RATE 30-50 G.P.M.
0
400
800
1200
1600
ELAPSED TIME (MINUTES)
0
200
DEPTH (FEET)


LOFT MOUNTAIN TEST HOLE
NO. 3 , W- 715
S. W. L. ---------------- 12'
F. P. L. ---------------- 131'
D'd. ---------------- 119'
15 - 18
PUMPING RATE
(G. P. M.)
0
100
200
DEPTH (FEET)
0
400
800
1200
ELAPSED TIME (MINUTES)

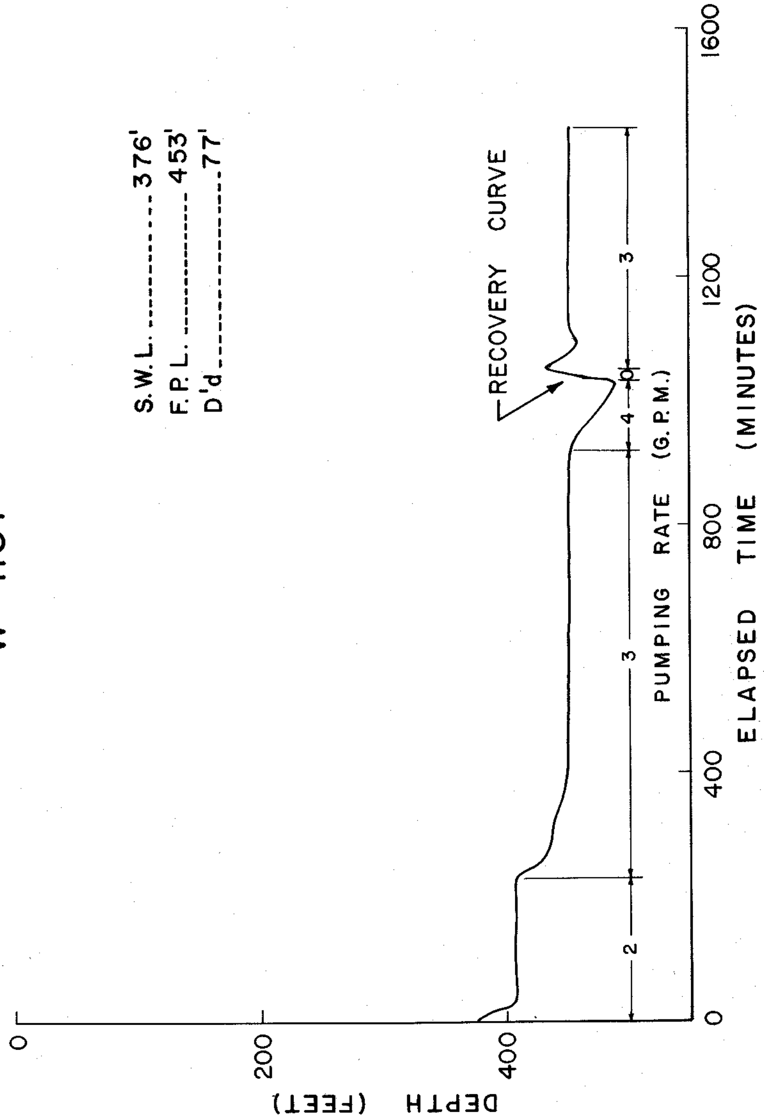

LOFT MOUNTAIN TEST HOLE NO. 4,
W - 718
S.W.L. ....10'
F.P.L. ....125'
D'd. ....115'
15 - 17
15
PUMPING RATE
(G. P. M.)
DEPTH (FEET)
0
100
200
0
200
600
1000
1400
ELAPSED TIME (MINUTES)


LOFT MOUNTAIN TEST HOLE NO. 5,
W-754
S.W.L. 12'
F.P.L. 109'
D'd. 97'
PUMPING RATE 20 - 30 G.P.M.
DEPTH (FEET)
0
80
160
ELAPSED TIME (MINUTES)
0
400
800
1200
1600

DUNDO TEST HOLE NO. 1, W-1073



ROCKFISH GAP TEST HOLE NO. 1,
W-1137



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