Geologic and Hydrologic Investigation at the Site of the Georgia Nuclear Laboratory Dawson County, Georgia

GEOLOGICAL SURVEY BULLETIN 1133-F

Prepared in cooperation with the U.S. Air Force and the Atomic Energy Commission

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By J. W. STEWART, J. T. CALLAHAN, R. F. CARTER, *and others*

STUDIES OF SITES FOR NUCLEAR ENERGY FACILITIES

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By J. W. Stewart, J. T. Callahan, R. F. Carter, and others

ABSTRACT

The GNL (Georgia Nuclear Laboratory) area consists of about 10,000 acres of land about 4 miles southwest of Dawsonville, Dawson County, and 45 miles north-northeast of Atlanta, Ga. The Etowah River flows westward through the area and is the source of water for the plant.

The Laboratory area is underlain by crystalline rocks of the Carolina Gneiss (of former usage) of probable Precambrian age. The area is capped by a thick mantle of saprolite derived through weathering of quartz-mica schist, biotite schist, quartz-mica gneiss, and amphibolite gneiss. Structural features which affect the rate and direction of ground-water movement include foliation, joints, bedding, axial plane and shear cleavages, folds, faults, and linear features. The foliation throughout the GNL strikes northeastward and dips about 20° to 30° SE in the southern part of the area and about 54° to 82° SE in the southeastern part of the area.

Detailed hydrologic and geologic studies were made in the sites of the REF (Radiation Effects Facility) and the REL (Radiation Effects Laboratory) to determine the feasibility of using infiltration pits constructed in weathered crystalline rocks for the disposal of liquid waste. Laboratory tests of core samples of weathered crystalline rocks in the REL site indicated a coefficient of permeability of 0.002 to 1 gpd (gallons per day) per sq ft and a porosity of 39 to 55 percent; in the REF site the permeability was from 0.009 to 8 gpd per sq ft and the porosity ranged from 42 to 53 percent. The unweathered rock in the REF site had a coefficient of permeability of less than 0.00004 to 0.0001 gpd per sq ft and the porosity ranged from about 3 to 6 percent.

One aquifer test of the saprolite at the REL site indicated a coefficient of transmissibility of about 500 to 3.000 gpd per ft and a storage coefficient of 0.001 to 0.004.

Infiltration rates obtained from eight tests at the REL disposal pit by using 18- and 24-inch single-ring infiltrometers ranged from 0.06 to 1.24 inches per hour; those from three tests at the REF pit ranged from 0.96 to 1.94 inches per hour.

The saprolite is capable of absorbing the estimated annual discharge of 1 million gallons of liquid waste at the REL site and 300,000 gallons at the REF site. The waste-disposal systems at the GNL provide for release to the pits of waste containing between 10^{-5} and 10^{-7} microcuries per milliliter of gross unknown beta-gamma activity. The total activity of liquid waste discharged at the REL and REF sites is expected to be less than 1 curie per year.

The saprolite from the REL and REF sites is about 25 to 40 percent clay. The clay-size particles less than 4 microns are believed to provide an effective filtration of active particles in the 4 to 40 micron range.

Ion-exchange capacity of 97 samples collected in the REF ranged from 2.5 to 13.7 meq per 100 g (milliequivalents per 100 grams), and of 25 samples collected in the REL the ion-exchange capacity ranged from 1.9 to 8.1 meq per 100 g. The average for both areas is a little more than 5 meq per 100 g. Kaolinite and vermiculite are the only clay minerals present in appreciable quantities. The ion-exchange capacities indicate a relatively low capacity for base exchange, but the thick blanket of saprolite and the slow rate of ground-water movement in the sites probably provides a high overall efficiency for the retention of radionuclides.

The ground-water velocity in the REL site ranged from 0.04 to 1.06 feet per day and in the REF site from 0.09 to 0.97 feet per day. Ground-water movement within the areas tested is controlled largely by the strike and dip of the rocks and to a lesser extent by their joints.

At a maximum velocity of 1 foot per day, a year or more will elapse before the waste is released to surface streams, and this time is sufficient for the short-lived activation products to decay. Other factors which will affect the concentration of waste discharged are ion exchange and filtration action of the saprolite and the dilution effects of ground and surface waters.

The ground water in the area generally is soft, less than 50 ppm (parts per million) $CaCO_3$, and its dissolved solids content averages less than 100 ppm. Most of the analyses represent calcium and sodium bicarbonate types of water. The observed pH ranged from 4.9 to 7.9. Some samples exceeded 0.3 ppm dissolved iron. The effect of the disposal of radioactive waste on the chemical quality of the ground water cannot be predicted without a knowledge of the chemical composition of the wastes. Probably the disposal of waste will have both a chemical and a physical effect on the minerals in the weathered crystalline rocks and thus decrease the ability of the rocks to transmit water.

Streamflow records made in 1956 show that the flow of perennial streams in the GNL area on October 17 averaged 0.70 cfsm (cubic feet per second per square mile) and ranged from 0 to 1.40 cfsm. Streams flowing southeastward in a downdip direction had somewhat higher yields than streams flowing in other directions.

Waste which contains less than 10^{-7} microcuries per milliliter of gross unknown beta-gamma activity and containing no alpha emitters or Strontium 90 will be released to surface streams. During lowest recorded flow conditions Etowah River offers a dilution of 22,500 gpm (gallons per minute) and during average flow the dilution is 110,700 gpm. The discharge of waste from the pits probably will not exceed 5 gpm. Therefore, if waste containing 10^{-5} microcuries per milliliter leaks from the pits into Etowah River at a rate no higher than about 1:4,500 of lowflow discharge and 1:22,500 of average flow, the concentration after thorough mixing is still below off-site maximum permissible concentration.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

This report describes the results of a study of the geology and ground-water resources and the hydrology of two sites within the Georgia Nuclear Laboratory area (herein referred to as GNL) of the Lockheed Aircraft Corp., near Dawsonville, Ga. The investigation was made by the Geological Survey in cooperation with the U.S. Air Force and the U.S. Atomic Energy Commission. The hydrologic studies in the general area of the GNL were financed by the Atomic Energy Commission, and the detailed investigations of the REF (Radiation Effects Facility) and the REL (Radiation Effects Laboratory) sites were financed by the Air Force. A feasibility report for administrative use on the hydrology and geology of the area was completed in January 1956. A systematic program of ground-water work in the area was started in July 1956 and concluded in September 1958. The general objective of the investigation was to describe the geology and hydrology of the area. The specific purpose of the study was to describe (1) the occurrence, rate and direction of movement, discharge, and recharge of the ground water, (2) the quantity and quality of water available, and (3) the effects of liquid-waste disposal on the water table in the REF and REL sites.

The purpose of the liquid-waste disposal study was to determine the direction and rate of ground-water movement in the REF and REL sites and to predict the possible avenues and rate of underground travel of radioactive liquid wastes seeping from disposal pits in those sites.

Fieldwork was done in three phases. During the first phase, from July 1956 to June 1957, the following work was done: (1) part of the wells and springs in and near the area were inventoried; (2) 3 shallow and 4 deep test wells were drilled; (3) 6 test wells were logged; (4) a geologic reconnaissance of the area was completed; (5) third-order level lines were run to 15 wells; (6) 5 recovery and 10 bailer tests were conducted and analyzed; (7) 22 water samples for chemical analyses and 8 samples for radiochemical analyses were collected; (8) 12 saprolite samples were collected for determination of ion-exchange capacity; and (9) a preliminary network of observation wells was established in the area.

During the second phase, from July 1957 to February 1958, water levels in observation wells were measured periodically.

During the third phase, from March 1958 to September 1958, the following work was done: (1) 7 test wells and 37 auger holes were drilled in the REF site, and 12 test wells and 32 auger holes were drilled in the REL site; (2) geologic and topographic maps of both sites were constructed; (3) third-order level lines were run to 78 wells; (4) pumping and bailer tests were conducted on 6 wells; (5) 8 water samples were collected for chemical analysis; (6) 122 saprolite and rock samples were collected for the determination of ion-exchange capacity; and (7) 21 continuous water-level records were obtained.

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This investigation was made under the supervision of J. T. Callahan, district geologist, Atlanta, Ga. Several members of the Georgia district of the U.S. Geological Survey gathered parts of the information upon which this report is based. H. E. Blanchard and J. M. Harrington assisted with the well-drilling program, infiltration and pumping tests, and the observation-well network; M. G. Croft contributed to geologic mapping of waste-disposal sites and participated in other fieldwork; G. T. Condrey and A. J. Bradley made many discharge measurements of streams in and near the report area; M. T. Thomson and L. E. Newcomb assisted in planning the surface water part of the report and made many analyses of the data.

LOCATION AND EXTENT OF AREA

The GNL area consists of approximately 10,000 acres in Dawson County, Ga., about 45 miles north-northeast of Atlanta (fig. 1). Dawsonville, the county seat, is about 4 miles northeast of the GNL. The Etowah River flows westward through the southern half of the area and is joined within the area by Shoal Creek and Amicalola Creek, both of which flow southward. Both the REF and REL sites are south of the Etowah River.

ACKNOWLEDGMENTS

The cooperation and assistance of many persons from the Lockheed Aircraft Corp., Nuclear Products Branch, Georgia Division, are grate-

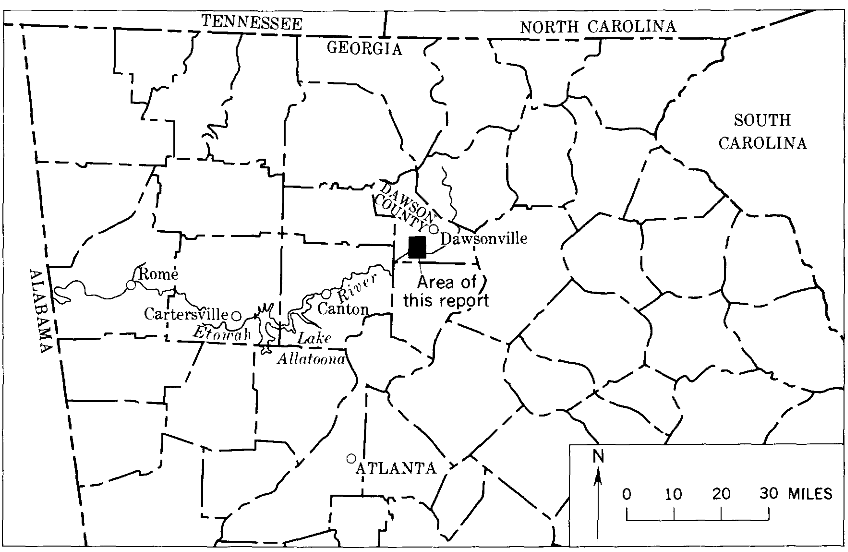

FIGURE 1.—Index map of northern Georgia showing location of the Georgia Nuclear Laboratory area, Dawson County.

fully acknowledged. Special acknowledgments are due J. M. Mohrbacker, J. H. Edgerton, and W. T. Price of the Reactors Operation Department.

Local residents in the area cooperated by furnishing information about wells and springs and by permitting measurements of wells.

SYSTEM OF NUMBERING WELLS AND SPRINGS

Wells and springs at the GNL area are plotted on a base map compiled from 15 topographic maps which were made in 1955 as a part of a study of the area. The topographic maps are at a scale of 1 inch equal 200 feet, and are based on the Georgia Geodetic Grid System (West Zone). A total of five rows, including three maps per row, comprise the area of investigation. The maps are numbered consecutively from west to east, beginning with map 1 in the northwest corner of the area. The map number is used for the first part of the well number. The second part of the well number indicates the order in which the well was inventoried within the area covered by the topographic map. The letter "S" added to the second part of the number indicates a spring.

Wells outside the GNL map area were numbered consecutively in the order in which they were scheduled and are listed as numbers 1 to 5, 8, and 9.

DRILLING PROGRAM

During the investigation, 26 test wells and 69 auger holes were drilled at the GNL to provide information about the geology and hydrology. Well cuttings were collected for ion-exchange analysis and mineralogical determinations. Most of the test wells and auger holes were located around the disposal pits to give as complete a coverage of the water table in the area as possible.

CLIMATE

The climate of the region is mild and humid. The mean annual temperature is approximately 60°F. Extreme summer temperatures of 100°F and winter temperatures of 0°F occur only occasionally. Temperatures drop below freezing from October through mid-April.

Precipitation averages about 56 inches annually at Dawsonville. Rain falls every month, but usually is heaviest during the winter and spring. The summers are characterized by thunderstorm activity and the autumns generally are dry. Precipitation at the GNL during 1957 was 54.02 inches.

Records of precipitation and temperature are necessary for an understanding of ground-water and surface-water hydrology because the ground-water levels and streamflow vary with seasonal rainfall and with water losses by evaporation and transpiration. Climatic changes and the resultant water-level and streamflow fluctuations may affect the problem of liquid-waste disposal.

DRAINAGE

The Etowah River, which crosses the southern part of Dawson County, rises on the southern slopes of the Blue Ridge Mountains and flows southwestward into the Alabama-Coosa River system. The two principal tributaries in Dawson County—Amicalola and Shoal Creeks—rise in the highlands to the north and merge with the Etowah River within the GNL site.

About 40 miles downstream from the GNL site, the Etowah River is ponded by Allatoona Dam and forms a lake. The lake is used for the generation of electric power and is an important recreational area. The dam controls the flow past Cartersville, where the river is the source of municipal and industrial water. Father downstream at Rome, the Etowah and Oostanaula Rivers merge to form the Coosa River, the source of water for the generation of electric power and industrial use. About 42 percent of the flow of the Coosa at Rome is from the Etowah River.

SURFACE FEATURES

The GNL site is in the Atlanta Plateau (LaForge and others, 1925, p. 61), a topographic division of the Piedmont province of Georgia. The boundary of the Piedmont province, some 15 to 20 miles to the north of the site, is defined by the prominent Blue Ridge escarpment. The crest of the Blue Ridge, the main divide in the region, averages about 3,000 feet, though numerous peaks are higher than 4,000 feet.

At the GNL site the Atlanta Plateau is deeply dissected, and steep slopes and sharp ridge crests characterize the topography. The total relief within the site is about 400 feet. The general altitude of the ridge tops averages about 1,400 feet. The altitude of the Etowah River where it leaves the site is about 990 feet.

In the vicinity of the REF infiltration pit the terrane is hilly and the canyons have steep gradients and steep side slopes. Because the weathered materials are removed rapidly, the bedrock is mantled by a thin layer of decomposed rock or, in many of the deeper draws, is exposed. The north-trending ridge on which the infiltration pits are located is about 250 feet above the Etowah River. The ridge is drained by intermittent streams which flow northward into the river.

The REL site is on a ridge bounded on the northwest and southeast by streams which flow northeastward into the river. The REL site is composed of a series of broad, gently sloping rock terraces that are less than 100 feet above the river. In this site the thickness of decomposed rock is somewhat greater, and the bedrock appears to be more deeply weathered than in the REF site.

The Etowah River follows a winding course through the GNL area. The major trend of the river is S. 60° W., which is the same as the strike of the regional foliation. The direction of foliation and the major joint systems appear to be lines of weakness in the area. Loops and offsets have two conspicuous trends, N. 30° W. to N. 40° W., and due north. The major trend of Shoal Creek is N. 30° W. and that of Amicalola Creek is N. 40° W., but both creeks follow the trend of the regional foliation for short distances. Most of the smaller streams in the GNL area parallel the regional foliation. Only a few trend due north or due south.

The Etowah River and other major streams in the area are deepening their channels. Many tributaries flowing off the plateau surface have steep gradients near their confluence with Etowah River.

DEVELOPMENT

The U.S. Census Bureau reported the population of Dawson County as 3,712 in 1950 and 3,590 in 1960. The Bureau's 1955 estimate was 3,300. The population is predominantly rural. Dawsonville, the county seat and largest town, has a population of 200.

Dawson County is an agricultural area. Crops, poultry, and wood are the main products. The county has no large industry.

Except at the GNL, all water supplies in the county are obtained from wells and springs. The Etowah River is the source of supply for the GNL.

GEOLOGY

By H. E. Cofer, Jr., B. M. Bowen, J. T. Callahan, and Elmer Santos

References have been made to parts of Dawson County in the early geologic literature, and the generalized bedrock pattern is shown on the geologic map of Georgia (Stose and others, 1939). The general geology of the county was described by Crickmay (1952). Additional references relating to the geology and ground-water resources of the area are included in the references at the end of this report.

The GNL area is underlain by crystalline rocks of the Ashland and Wedowee Formations of the Carolina Series (pl. 1). The northwest half of the area is underlain by biotite schist and gneiss, and the southeast half by the Ashland Mica Schist. Crickmay (1952, p. 14–15) defined the Ashland Schist as a heterogeneous group of quartz-mica schist and gneiss with associated amphibolite, quartzite, and granitic rock. This Ashland belt is considered a zone of intense differential movement, that is, a major shear zone.

Detailed geologic mapping in this part of the state is available only for a few mining properties where gold and pyrite have been investigated (Pardee and Park, 1948). However, the GNL is many miles from areas that have been mapped in detail. Because of the limited time available for this study, geologic mapping was confined to the GNL area only; no attempt was made to correlate the rock units recognized in the area with known rocks elsewhere or to determine the relative age of the rocks. The details and problems of geologic nomenclature and age do not affect the determination of the direction and rate of flow of ground water and are not discussed. The name and age given to the rocks by previous workers are therefore accepted, with reservation.

GENERAL GEOLOGY

Because of the uncertainty of geologic boundaries, the rocks within the GNL area are subdivided into five mappable zones on the basis of lithology and structural features. The zones have been designated 1 through 5 on the geologic map (pl. 1).

ZONE 1

The rocks of zone 1 are confined to the southeastern corner of the area. They consist of biotite-plagioclase gneiss, garnet-biotite schist, and thin, non-persistent amphibolitic layers. All these rocks have been partially altered by the intrusion of igneous rocks and are somewhat migmatized.

The rocks show evidence of shearing and infolding. Granulation occurred, but recrystallization and the introduction of quartz and feldspar produced a granitoid texture. The conspicuous foliation in the more micaceous rocks is a shear cleavage paralleling the axial planes of minor folds. The emplacement of quartz and feldspar along these planes produced a banding in the more intensely altered rocks.

The northern boundary of zone 1 is marked by a strongly sheared, persistent quartz-mica schist. In the mica shist and the amphibolite immediately north and south of it, the more competent layers yielded to movement by granulation and the micaceous layers by flowage. Some mineral grains, especially garnet, show the effect of internal rotation and granulation.

ZONE 2

Zone 2 lies to the northwest of zone 1. It contains granular quartzose feldspathic micaceous rocks having graywacke affinities, herein referred to as granulites. The grain size ranges from 0.05 to 0.5 millimeters, but in a few layers the average grain size is larger. Interbedded with the metasedimentary rocks are amphibolitic rocks of possible volcanic origin. All the rocks are characterized by tight folding and granulation.

The metasedimentry rocks consist of biotite-plagioclase granulite, quartz-biotite granulite, biotite-quartz schist, and biotite-hornblende-epidote-plagioclase gneiss. The plagioclase of the metasedimentary rocks ranges in composition from An_{12} to An_{22} (anorthite 12 to 22 percent). The original sedimentary character of the metasedimentary rocks is preserved at many places. Bedding and foliation coincide except on the noses of folds. Tight folds and the scarcity of exposed beds prevented the determination of the tops and bottoms of major units.

The amphibolites of this zone include hornblende-plagioclase (An_{20}) gneisses and schists, hornblende-quartz-plagioclase (An_{15}) gneiss, and hornblendic rocks containing less than 10 percent plagioclase (An_{30}). Locally the amphibolites are schistose and are chloritized.

The amphibolites occur in persistent layers which pinch and swell somewhat along the strike. Most of the units range in thickness from a few inches to 10 feet, but one unit is 50 feet thick. Contacts are concordant and vary from sharp to gradational.

ZONE 3

Zone 3 is the most distinct of the five zones. It consists of thick layers of amphibolite containing thin lenticular beds of quartz schist. The thickness of the zone ranges from 780 feet a quarter of a mile northeast of the mapped area to 480 feet in the central part of the area at the REF site, and reaches a maximum thickness of approximately 800 feet about a mile southwest of the REF site.

The rock varieties include feldspathic amphibolite, amphibolitic cataclasite, and amphibolitic quartzite. The plagioclase is An_{25} in the feldspathic amphibolites. In the cataclastic amphibolites, particularly where they contain considerable epidote, two plagioclase feldspars having a composition of An_{26} and An_{12} occur.

Plagioclase-mica-quartz schist contains plagioclase (An_{15}), muscovite biotite, and quartz. The relative amounts of all constituents vary from one place to another, and locally the rock is an impure quartzite. Magnetite quartzite occurs in small beds within and on the margins of the amphibolitic layers. Some of these units contain 40 percent magnetite by volume.

ZONE 4

The lithology of zone 4 is almost identical with that of zone 2. It contains both amphibolitic rocks and micaceous metasedimentary rocks. However, zone 4 shows less intense deformation than zone 2.

Mylonitization is confined to thin units, and the intervening layers show little or no effect. The rocks are tightly folded in the southern part of the zone. Bedding and foliation are coincident at most places. Criteria for the determination of the top and bottom of beds are rare. A graded appearance of some of the beds is attributed to slippage along finer grained layers and to the formation of porphyroblasts.

The northwestern boundary of zone 4 coincides with the northernmost outcrop of any persistent amphibolitic layer in the area. The boundary follows a strong topographic break which may be the reflection of a structural as well as a lithologic discontinuity. The rocks on the south side of the break consists of fissile amphibolite and schist.

ZONE 5

Zone 5 is the northwesternmost rock zone of the area. It is characterized by massively bedded quartzose biotite granulite interbedded with thin schistose layers. Sedimentary features, such as truncated laminae and graded bedding, are preserved at many places. Folding is generally open and the axial planes are nearly vertical. The shear zones are relatively narrow, from 4 to 8 feet in width, and some of them contain small muscovite-bearing pegmatites. Larger masses of pegmatites and vein quartz, 6 to 8 feet wide and 20 or more feet long, trend north-northwest and occupy tear faults associated with shearing. Smaller veins, a few inches in their maximum dimension, trend northeastward at a low angle to the principal foliation. Granitic masses similar to the migmatites of zone 1 occur at the northern edge of zone 5 within the area.

The granulites of zone 5, in general, have a higher plagioclase to quartz ratio (60:40) and the plagioclase a higher anorthite content, approximately An_{30}, than those of the other zones. The plagioclase shows strong polysynthetic twinning. Potassium feldspar occurs as anhedral porphyblasts in a few of the rocks.

STRUCTURAL FEATURES

The structural features in the bedrock of the area are important in that some of them affect the direction and rate of ground-water movement. Although ground water circulates mainly in the saprolite, some of it moves into and through bedrock, and drains into the streams within and adjacent to the study area. Planar features in bedrock contain open spaces along which ground water may move. These include bedding, foliation, cleavage, joints, and faults. Linear features and folds also may influence the movement of ground water, although to a lesser degree than planar features.

PLANAR FEATURES

BEDDING

Bedding is identifiable at some places in all five zones. Graded bedding and truncated laminae were observed at a few places. Foliation, flow cleavage, and shear cleavage generally follow bedding, but the direction of the cleavages may depart from the direction of bedding.

In zones 2, 4 and 5, apparent graded bedding occurs in some of the fine-grained rocks. Little or no observation could be made of graded bedding in zones 2 and 4 because the few places were it was observed are complexly folded. In zone 5, three observed occurrences of graded bedding and one of truncated laminae indicate that the rocks were not overturned.

FOLIATION

The foliation in the rocks follows closely the lithologic changes in the metasedimentary rocks and parallels the concordant contacts of the metaigneous and metasedimentary rocks. The departures of the foliation from parallelism are rare. At most places in zones 1, 2, 3, and 4 it is not possible to distinguish between foliation and axial plane cleavage except on the exposed nose or crest of a fold.

CLEAVAGE

Axial plane cleavage can be seen in isoclinal folds. Shear-cleavage is present where differential movement took place along pre-existing planar features. Where folds were not observed, foliation or bedding localized movement along shear-zones. Massively bedded or tightly folded beds deflected the shear zones and the principal shear cleavage can therefore be distinguished from the axial plane cleavage.

JOINTS

The rocks in the area are everywhere jointed and otherwise fractured into four fairly well defined sets and a multitude of minor joints and other fractures that display no recognizable pattern of orientation or attitude.

The joints of the most conspicuous set strike N. 54° W. and dip to the northeast at angles ranging from 60° to almost vertical. The orientation of this set is practically the same in all five zones. Long straight stretches of the minor streams in the area are nearly parallel to this set and the streams probably are controlled by the joints. Although the surface trace of these joints could not be observed over any great distance, they are probably fairly continuous open systems along which subsurface water moves in appreciable quantities.

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A second joint set, best seen in zone 5, strikes N. 48° E., although the trend of individual joints varies from N. 28° E. to N. 65° E. The joints dip to the southeast at angles which range from 65° to almost vertical.

A third set of joints strikes from N. 20° E. to N. 20° W. and dips to the west at angles ranging from 60° to nearly vertical. The Etowah River in the southeastern part of the area and several large tributaries throughout the rest of the area appear to be controlled locally by joints in this set. The joints appear to be fairly continuous over moderate distances and are conduits through which water may move quite freely.

A fourth set of joints has approximately the same orientation as the third set but dips to the east at angles ranging from 50° to 83°. Although this set appears to be as well defined as the third set, it has no apparent control of any of the streams in the area.

The four sets of joints, along with the many small joints and fractures, form an intricate interconnected system of openings which locally may impart to the rocks the characteristics of a homogeneous aquifer.

FOLDS

The similarity of the lithologic characteristics of zones 2 and 4 suggests the repetition of strata by folding, but the actual closure does not occur in this area and the geology outside the site has not been studied. Overturned isoclinal folds are exposed in several places in zones 1, 2, 3, and 4. The folds are small and tight.

In zones 4 and 5, gently dipping metasedimentary rocks are warped into broad open folds whose axial planes are approximately vertical and plunge at very low angles to the northeast.

FAULTS

Faults in the area are restricted almost exclusively to shear zones. Nearly all the rocks in zones 1, 2, 3, and 4 have been affected by shearing forces. Movement along shear zones took place in most rock layers regardless of lithology, but the greatest amount of movement was absorbed by thinly laminated schistose layers interbedded with more massive layers. Almost all the shear planes are parallel to the foliation.

Rock movement took place along the plane of least resistance. Shearing movements tended to be localized along preexisting planar features. Because the folding in this area is nearly isoclinal, the planes of bedding, foliation, and cleavage generally coincide. Some shear zones were deflected locally by the noses of folds or massive, competent rocks, and were thus cut across the preexisting planar features.

Tear faults occur in all five zones, trend to the north-northwest, and are associated with shear zones. In zones 1, 2, 3, and 4, tear faults consist of small, discontinuous mineralized fracture systems and have large horizontal displacement relative to their length. These faults die out in flexures where slight changes in lithology occur.

Normal faults are not evident in this area, although they probably occur. If present, the faults probably are as tight as the joints that are approximately at right angles to the structural trend and, in the absence of other evidence, may be mistaken for joints.

LINEAR FEATURES

Linear elements consist of fold axes, axes of plications, axes of nearly vertical undulation or wrinkling of schistose beds, mineral grain orientation, mineral grain elongation, and elongate aggregates of mineral grains.

The axes of folds which exhibit the characteristics of flexure folding are regular and trend northeastward. The axes plunge at low angles, rarely exceeding 15°.

Shear-fold axes are abundant and are less regular in the direction of strike. They parallel the trend of strongly sheared rocks, but may diverge as much as 15° from the direction of the shear zone. The plunge of the axes varies from nearly horizontal to 60°.

The axes of plications (small tight wrinkles) parallel the strike of schistose beds.

The axes of vertical undulations or open wrinkled folds are present in most of the steeply dipping schistose beds. The axes plunge steeply, the angles ranging from 60° to vertical, and for the most part lie in the plane of schistosity.

Mineral grain orientation is conspicuous in all the rocks possessing flat or elongate minerals. Hornblende and mica are strongly oriented. In the mica-rich rocks of zones 2 and 4, the orientation of single tablets of muscovite is down the dip of the foliation and along a north-northeasterly strike.

STRUCTURAL HISTORY

The rocks were tightly folded prior to the formation of the existing shear zones. The strong isoclinal folding in areas nearly free of differential movement indicates strong compressive forces. The continued application of these forces resulted in the overturning of folds and caused differential movement along the newly formed cleavages. Recrystallization kept pace with movement for a time, but when differential movement became more intense, granulation and reduction of grain size occurred.

Granitic materials were introduced into the rocks of the southeastern and northwestern parts of the area at the height of metamorphic activity. In the open structures of the central part of the area the introduction of potassium resulted in the formation of feldspar-quartz stringers and potassium feldspar porphyroblasts.

In general, the mineral assemblages of the rocks of the whole area represent the maximum intensity of metamorphism. The metamorphic rank of the minerals did not increase because of the igneous intrusion, and the minerals have not retrogressed.

Rapid lowering of pressure-temperature conditions or the low fluid content of the rocks caused the recrystallization of components, but large grains were not produced nor were cataclastic textures completely eliminated. The elimination of polysynthetic twinning and the lack of rims and inclusions in the plagioclase of both the metasedimentary and metaigneous rocks show the rather thorough recrystallization which took place even though the rocks retained fine-grained texture.

Local reactivations of earlier shear-zones produced some late granulation and retrograde effects. Local formation of chlorite and sericite may be attributed to recrystallization at lower temperatures or to the introduction of water into the minerals.

GEOLOGY AND PERMEABILITY

The water-bearing rocks of this area are of two main types: the saprolite, the chemically and physically altered material at and below the surface; and the fresh, relatively unaltered bedrock below the saprolite. The saprolite is separated from the bedrock from which it was derived by a transition zone. The saprolite and the fresh rock are different but hydraulically connected aquifers, and the problem of liquid waste disposal into the ground or the removal of water from the ground is dependent on their different hydraulic characteristics. In general, the bedrock grades into the saprolite through a transition zone whose hydraulic characteristic also may be gradational.

A less extensive geologic unit is the narrow band of alluvial fill that borders the Etowah River. The alluvial fill is less than 30 feet thick where it has been drilled, and is less than 20 feet thick adjacent to the SWD (Solid Waste Disposal) site. The alluvial fill has a maximum width of only a few hundred yards.

The saprolite was derived by the physical and chemical breakdown of the underlying rock, and it has been reduced in volume by the removal in solution of certain minerals. It consists mostly of clay- and silt-sized particles, and varies in composition from one rock type to another. At the sites of the REL and the SDF (Shielding Device Facility), many stringers of fractured and granular quartz crop out at the surface. These units are from a few inches to a few feet thick and have not been altered chemically as much as the other minerals. The resistant quartz stringers form conduits through the saprolite through which water may move more freely than through clayey saprolite. Where they are not fractured, quartz stringers may act as dams and divert the movement of ground water. Where the bedrock is mainly composed of sedimentary materials, many side-hill springs occur at the outcrop of quartzite beds.

The saprolite is penetrated by roots, both living and dead, and these, plus the accumulation of organic material at the land surface, form an absorptive surface that retards overland flow, increases the permeability of the saprolite, and facilitates the downward percolation of water.

The transition zone between the saprolite and unaltered rock of some rock types is more permeable than the rest of the saprolite and contains most of the ground water. This zone probably has been altered chemically to a lesser degree, contains fewer clay-sized particles than the saprolite near the surface, and is at that stage of mineral alteration in which the expansion of certain minerals has created minute cracks and increased voids in the rock.

None of the fresh rocks of this area are very permeable. Permeability is due to joints and shear zones through which the ground water moves. At no place in the area were highly fractured rocks observed. In fresh rock, the joints are generally only a fraction of an inch wide. In the saprolite, they are filled with red clay and silt or completely obliterated. Some joints in the fresh rock may have been partially sealed by clay which filtered downward. However, this sealing effect probably does not extend far below the water table. The apparent artesian conditions shown in some of the wells may be a result of the confinement of ground water locally by the complete filling of all void space in the upper part of the fresh rock by clay and silt.

Geologic mapping indicates an apparent correlation between the volume of flow of the minor streams and the geology. Minor streams that flow southeastward at right angles to the strike of the beds have a greater volume of flow per unit area than those that flow in other directions. Although the joints are not apparent in the stream beds, the position of the streams apparently is controlled by a line of weakness in the rock. The joints dip steeply, cutting nearly at right angles to the strike of the southeastward-dipping beds, and thus cut a maximum number of rock units per lineal foot of joint. Ground water moving along the strike of the beds drains into the joints and then into the stream channels.

In the initial stage of weathering, hydration of the more unstable minerals such as plagioclase causes an increase in the volume of these minerals; this increase ruptures the fabric of the rock and increases its permeability. As weathering progresses, the alteration of the plagioclase to kaolinite results in a further increase in volume. However, the clay-size particles of kaolinite fill in and clog the openings created in the initial stage of weathering and thereby decrease the permeability. Thus, where the saprolite is only slightly weathered, as in the zone immediately above the unweathered rock, it is more permeable than either the parent rock or the more completely weathered saprolite near the surface.

The movement of ground water in the parent rock depends on the texture of the rock and the presence and number of openings, such as joints, shear planes, and fractured quartz veins. In general, coarse-grained crystalline rocks are more permeable than fine-grained rocks of the same composition. Because many of the shear zones and quartz veins in this area are parallel to the structural trend, zones of differentially weathered saprolite are parallel to the regional foliation.

Most minerals react with or are dissolved by ground water to some extent. The ability of ground water to react with and dissolve minerals varies with the pH of the water and with the amount of oxygen and carbon dioxide contained in solution. In general, ground water having a pH value significantly above or below 7 has a greater ability to dissolve and react with minerals than ground water having a pH of about 7.

The imbricate arrangement of the mica flakes controls the direction of movement of ground water through the saprolite. Tests indicate that permeability is much greater parallel to the foliation than normal to it. Because the foliation throughout the area strikes northeastward and dips from 54° to 82° to the southeast, water entering the ground at any point, instead of moving vertically downward, moves southeastward down the dip to the zone of saturation and then laterally in a northeast or southwest direction. Fractured quartz veins and shear zones, most of which are parallel to the foliation, augments the flow of ground water in the same direction in the saprolite.

However, where the northeastward-trending units are cut by open joints, ground water may drain through them in a northwestward or southeastward direction, but only in the fresh rock. The joints are not open in the saprolite.

Joints probably are the best avenues of water movement in the fresh rock, but no areas were found where they are so close together that the rocks may be described as highly fractured. However, where two or more joint sets intersect, the rocks may yield or accept the recharge of great amounts of water. The joints are not wide, and close to the land surface many are filled with clay and silt. The apparent artesian conditions shown in some wells may be caused by the local confinement of ground water by the complete filling of all void spaces by clay and silt.

GEOLOGY OF THE REF SITE

The REF disposal pits are in the south-central part of the GNL area (pl. 1) near the northern boundary of zone 2. Although this zone contains gneiss, schist, and amphibolite, the area in the immediate vicinity of the pits appears to be underlain entirely by quartz-biotite schist and garnet-biotite schist. Cuttings of unweathered rock from wells drilled near the pits consist of quartz, biotite, and garnet. Quartz veins ranging in thickness from one-eighth of an inch to 18 inches are common in or around the pits. The crystalline rocks at the site are deeply weathered; the mantle of saprolite there is as much as 60 feet thick.

The quartz-biotite schist is a hard dense medium-gray to dark-gray aggregate of fine-grained quartz, biotite, plagioclase, and some muscovite. Because of its fine and even grained texture, this rock may be classified as a granulite. The plagioclase in these rocks ranges in composition from An_{12} to An_{22}. The garnet-biotite schist is identical with the quartz-biotite schist except for the presence of euhedral porphyroblasts of garnet as much as 5 mm in diameter. The garnet is predominantly the dark-red variety, almandite, but cinnamon-colored and purplish-red to pink varieties occur also.

Bedrock crops out in several places and was found in all tests wells drilled on the site. Most of the exposures are at or near the bottom of gulleys but one is high on a hillside about 300 feet northwest of REF pit 2.

The attitude of the foliation in the exposed rocks agrees with that of the saprolite. This agreement indicates that the saprolite has not slumped and that measurements of strike and dip of the saprolite generally can be relied on in mapping the structure of the area.

Quartz veins occur as lenticular bodies parallel to the foliation of the enclosing saprolite. Some quartz veins thicken abruptly and form eye-shaped pods along the strike of the vein; the schistosity of the saprolite at such contacts follows the contorted contour of the pods. A few small quartz veins occur in shear planes or tear faults that do not conform to the regional foliation.

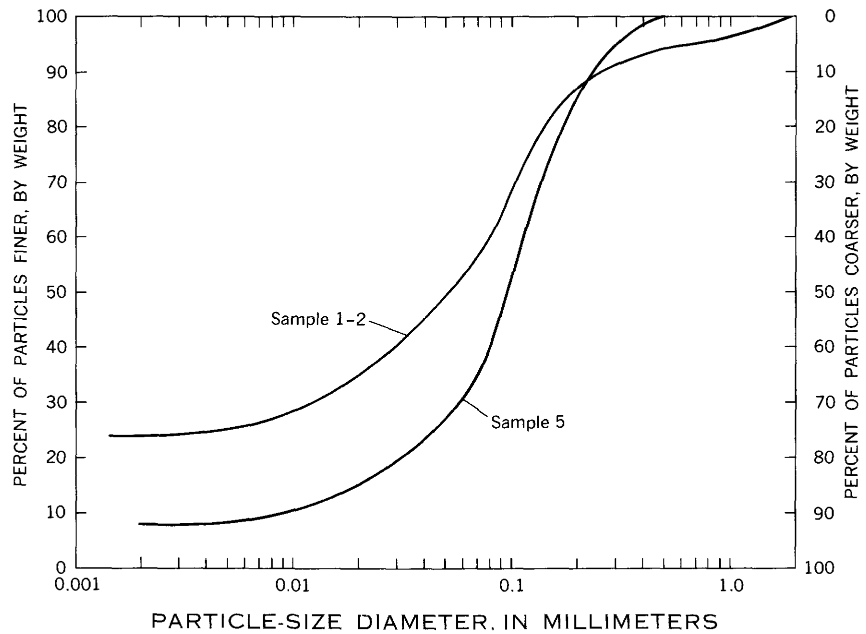
All quartz veins exposed at the surface are highly fractured. The saprolite adjacent to a vein is more weathered than the saprolite a few inches from it. Concentrations of hematite and manganese oxide occur in the saprolite at the contact and on fracture surfaces in the quartz veins. The hematite and manganese oxide were precipitated from ground water and indicate that the quartz veins and the saprolite in contact with them form conduits through which ground water moves freely.

Mineral determinations and grain-size distribution analyses were made on 97 samples collected at the surface and at various intervals to a depth of 18 feet below the surface at the REF site.

The soil at the REF site is approximately 50 percent sand and gravel, 25 percent silt, and 25 percent clay; the near-surface saprolite is approximately 45 percent sand and gravel, 35 percent silt, and 20 percent clay (fig. 2). The change in grain-size distribution is abrupt and occurs at the base of the soil zone at each sample location.

The clay-size fraction of the sample from the REF site consisted mainly of kaolinite, gibbsite, and biotite-vermiculite; it also contained variable but small amounts of muscovite, goethite, quartz, and chlorite. The silt-size fraction of the soil sample consisted mainly of biotite-vermiculite, muscovite, kaolinite, and quartz; it also contained small amounts of gibbsite and feldspar. The sand-size fraction of the sample consisted mainly of kaolinite, biotite-vermiculite, and gibbsite, and also contained small amounts of muscovite, goethite, quartz, chlorite, and lepidocrocite; the larger than sand-size fraction of this sample consisted mainly of quartz, muscovite, and garnet.

The differential weathering at this site does not appear to be related to differences in texture or composition of the unweathered rock. Bed-



Clay	Silt	Sand				
		Very fine	Fine	Medium	Coarse	Very coarse
< 0.004	0.004–0.0625	0.0625–0.125	0.125–0.25	0.25–0.5	0.5–1	1–2

FIGURE 2.—Particle-size distribution curves of saprolite from REF pit 1.

rock exposures are all fairly uniformly fine grained. Garnetiferous schist appears to weather the same as schist containing little or no garnet. Differential weathering probably is related to the shear zones and fractured quartz veins because the rocks adjacent to them are more accessible to ground water.

GEOLOGY OF THE REL SITE

The REL disposal pit is in the southeastern corner of the GNL area near the northern boundary of zone 1 (pl. 1). This zone is underlain by biotite-gneiss, garnet-biotite schist, and thin, nonpersistent amphibolites. All rocks in the site have been partially altered by the intrusion of igneous rocks to the south and are somewhat migmatized. A pegmatite vein is exposed in the north corner of the disposal pit. Within the saprolite, a fresh piece of amphibolite schist was found at a depth of 15 feet in well 16 and at a depth of 90 feet in well 10 (pl. 2). Slightly micaceous quartzite was found in the saprolite in all the test wells at various depths.

The rocks at the REL site are deeply weathered. In one well the saprolite exceeded 137 feet in thickness. The presence of many injected bodies of granitic material produced a strongly banded appearance to the saprolite near the pit. The silty to sandy micaceous clay soil at the REL site is 1 to 2 feet thick and is yellowish brown, pale brown, and reddish brown.

The schistosity is preserved in the saprolite beneath the soil zone. The composition and texture of the saprolite suggests a granitic rock as the source rock.

Mineral determinations and grain-size distribution analyses were made on 25 samples collected at the REL site. The samples were collected at the surface and at various intervals to a depth of 16 feet below the surface.

The saprolite at the REL site is approximately 31 percent sand and gravel, 29 percent silt, and 40 percent clay (fig. 3); the near-surface saprolite is approximately 49 percent sand and gravel, 40 percent silt, and 11 percent clay. The change in grain-size distribution is abrupt and occurs at the base of the soil zone at each sample location.

The clay-size fraction of the soil consists mainly of kaolinite and vermiculite and also contains traces of quartz, geothite, gibbsite, and biotite. The silt-size fraction of the soil consists mainly of kaolinite, quartz, and muscovite, and also contains traces of goethite. The larger than silt-size fraction is mainly quartz, muscovite, and feldspar.

The clay-size fraction of the saprolite at the REL site consists mainly of kaolinite, biotite, and muscovite, and also contains small amounts of quartz, goethite, and gibbsite. The silt-size fraction of

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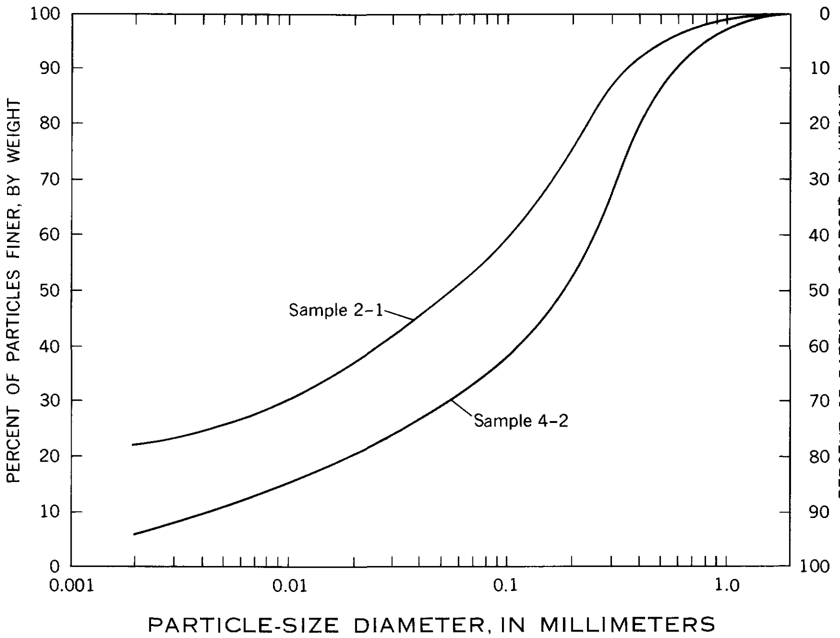

Clay	Silt	Sand				
		Very fine	Fine	Medium	Coarse	Very coarse
<0.004	0.004-0.0625	0.0625-0.125	0.125-0.25	0.25-0.5	0.5-1	1-2

Figure 3.—Particle-size distribution curves of saprolite from REL pit.

the saprolite consists mainly of kaolinite, biotite, muscovite, and quartz, and also contains small amounts of goethite, feldspar, and gibbsite. The larger than silt-size fraction consists mainly of quartz, feldspar, and muscovite.

The saprolite at the REL site is thicker and more highly weathered than at the REF site. Factors that appear to have influenced the greater degree of weathering at the site are the intense shearing of the parent rock and the occurrence of coarse-grained granitic rocks. Open spaces along many closely spaced shear planes allowed ground water to penetrate more uniformly and to greater depth.

Local barriers to the movement of ground water may be formed by the amphibolite in this area. The amphibolite weathers less rapidly than other rocks, and below a depth of 15 feet appears to form isolated impermeable masses containing few fractures. Where these concordant units are thick and continuous they may be expected to impede the movement of ground water in a northwest direction.

Edgerton and Bowen (1959, p. 7) indicated that clay-size particles of less than 4 microns probably would provide effective physical filtration of active particles in the 4- to 40-micron range. Particles of greater than 40 microns are filtered from the primary coolant and pool systems of the RER (Radiation Effect Reactor). The REL waste system is not equipped with a filtration system.

ION-EXCHANGE CAPACITY

Much of the following brief discussion of ion exchange has been adapted by permission from Grim (1953, p. 126–129), and a more complete discussion of the subject is given in that reference.

Clay minerals are capable of adsorbing certain anions and cations and of retaining these ions in an exchangeable state. Exchange of these ions may take place in an aqueous or nonaqueous solution. Ion-exchange capacity generally is measured in meq per 100 g (milliequivalents per 100 grams) at pH 7. The common exchangeable cations in clays are Ca^{+2}, Mg^{+2}, H^{+1}, K^{+1} NH_4^{+1}, and Na^{+1}. Common exchangeable anions are SO_4^{-2}, Cl^{-1}, PO_4^{-3}, and NO_3^{-1}. Clay minerals are products of weathering of certain rocks; the amount and type of clays produced depends upon the type of parent rock from which they are derived. The ability of a clay to exchange ions is affected by the particle size; in general the smaller the particle the greater its exchange capacity. Other conditions which may affect the ion-exchange capacity are the concentration of the solution applied, the length of time the reaction continues, and the ions involved in the exchange reaction. According to Grim (1953, p. 129), "Since the cation-exchange capacity of a given mineral type may vary with so many factors, capacity values are rigorously comparable only if they have been obtained by the same standard procedure on material of comparable textural and structural attributes."

All inorganic minerals of extreme fineness other than clays have a small, generally insignificant ion-exchange capacity. Zeolite minerals and some organic materials which are occasionally found in clays have rather high ion-exchange capacities.

Table 1 from Grim (1953, p. 129), gives cation-exchange capacity ranges of clay minerals.

TABLE 1.—*Cation-exchange capacity of clay minerals, in milliequivalents per 100 grams*

Kaolinite	3–15	Vermiculite	100–150
Halloysite ($2H_2O$)	5–10	Chlorite	10–40
Halloysite ($4H_2O$)	40–50	Sepiolite-attapulgite-palygorskite	20–30
Montmorillonite	80–150		
Illite	10–40		

Ion-exchange capacity determinations were made in the Geological Survey Hydrologic Laboratory, Denver, Colo., on 97 samples collected from 30 auger holes at the REF site, on 25 samples collected from 9 auger holes and test wells at the REL site, and on 12 samples from a borrow pit near the REL site. The auger samples were collected at the surface and at various depths to a maximum of 18 feet. The borrow pit samples were collected from the side and bottom of the pit.

Samples from the borrow pit (300 ft south of the REL disposal pit) were taken at every change in rock formation and at every 3 feet in depth. A description of the material collected from the borrow pit is given below.

Description	*Depth (feet)*
Soil, red to brown clay, containing angular to subangular quartz, sand, gravel, and cobbles	0–4
Quartz mica schist, weathered to brownish-red saprolite	4–9
Pegmatite sill, light-gray, containing weathered feldspar, quartz, and fresh muscovite mica	9.0–9.1
Quartz mica schist weathered to saprolite; red and yellow mottled sandy clay containing large muscovite mica flakes	9.1–27
The quartz mica schist includes:	
Migmatite zone ¼-inch thick at depth of 12	
Do 15	
Saprolite, yellow to brown, sandy, micaceous 18	
Migmatite zone 2 in. thick, sandy, much decomposed 21	
Irregular body of migmatite and saprolite 24	
Saprolite, yellow to brown, sandy, micaceous, containing decomposed feldspar at floor of pit at 27.	
Floor of pit	27

The ion-exchange capacity of the samples was determined by Bower and Truog's (1940) colorimetric manganese method. In addition, the clay and silt fractions of each sample were analysed to determine the type of clay and silt minerals present. The clay and silt samples were dispersed in distilled water by using sodium metaphosphate as a dispersing agent, and fractionated by repeated centrifuging and decanting to separate the silt (2–62μ) and clay ($<2\mu$) fractions. X-ray diffractometer patterns were made for each fraction as follows:

Clay fraction

1. Oriented aggregate, air dried.
2. Oriented aggregate, treated with ethylene glycol.
3. Oriented aggregate, heated to 400°C in diffractometer furnace.
4. Oriented aggregate, heated at 500°C in diffractometer furnace.
5. Randomly oriented powder.

Silt fraction

1. Randomly oriented powder.

The principal minerals found in the pit samples as determined by X-ray diffraction patterns were kaolinite, gibbsite, hematite, quartz, muscovite, goethite, and a vermiculite-type mineral. The minerals are listed in table 2 with estimated amounts given as parts in ten. Inasmuch as these estimates are derived from the relative intensities of the diffracted lines and many factors in addition to the quantity of a mineral affect diffraction intensity, they are not intended to give more than a general indication of the relative amounts of the various minerals present.

The maximum ion-exchange capacity of the minerals was 5 meq per 100 g, and kaolinite, which has an exchange capacity ranging from 3 to 15 meq per 100 g, was in every sample. The ion-exchange capacity of the samples from this pit is low. There is no way to determine the precise amount of available kaolin clay in the samples nor its grain size, which has an important bearing on exchange capacity.

Ion-exchange capacities of the samples from the REF site range from 2.5 to 13.7 meq per 100 g and average 5.3 meq per 100 g; those from the REL site range from 1.9 to 8.1 meq per 100 g and average 5.1 meq per 100 g. (See tables 3 and 4.) Kaolinite and vermiculite are the only clay minerals occurring in appreciable quantities at the two sites. The exchange capacities determined for the samples from the two sites are within the range given for kaolinite by Grim (1953, p. 129), and apparently the vermiculite is not important as an ion exchanger because of the small amounts available. There is no consistent difference in values between near-surface samples, where most of the organic material is concentrated, and those at depth.

White fine-grained zeolite crystals coat the fracture surfaces in some amphibolite beds in the REF site. These minerals may act as ion exchangers as wastes move through cracks in the unweathered rocks. However, the amount of isotopes that may be retained or exchanged by the available minerals still cannot be predicted because of the great number of variable conditions that exist. All the minerals present have a low potential for ion exchange, but water movement should be slow enough in the saprolite to allow a maximum amount of exchange to take place.

TABLE 2.—*Ion-exchange capacity and estimated amounts of minerals in saprolite samples from a borrow pit in the REL site*

Sample depth (feet)	Ion-exchange capacity (meq per 100 g)	Type of material	Minerals present	Estimated amount (parts in 10)
1	2.2	Clay	Kaolinite	3
			Gibbsite	2
			Vermiculite-type mineral.	2
			Hematite	2
			Quartz	Tr.
			Goethite?	Tr.
		Silt	Quartz	8
			Gibbsite	Tr.
			Kaolinite	Tr.
9	3.2	Clay	Gibbsite	3
			Hematite	3
			Kaolinite	3
		Silt	do	8
			Quartz	1
			Gibbsite?	Tr.
			Mica?	Tr.
9.0–9.1	1.9	Clay	Kaolinite (disordered).	4
			Hematite	3
			Gibbsite	2
			Goethite	Tr.
		Silt	Kaolinite (disordered).	5
			Mica	2
			Quartz	2
			Goethite?	Tr.
9.4	4.8	Clay	Kaolinite (disordered).	3
			Hematite	2
			Gibbsite	1
			Vermiculite-type mineral.	1
			Goethite?	1?
		Silt	Kaolinite (disordered).	8
			Goethite	1?
			Mica	Tr.
			Quartz	Tr.
10.5	5.0	Clay	Kaolinite (disordered).	5
			Hematite	2
			Gibbsite	1
			Goethite?	1
			Vermiculite-type mineral.	Tr.
		Silt	Kaolinite (disordered).	8
			Quartz	1
			Goethite	Tr.
			Mica	Tr.
12	4.0	Clay	Hematite	3
			Kaolinite (disordered).	3
			Gibbsite	2
		Silt	Kaolinite (disordered).	8
			Quartz	Tr.
			Mica?	Tr.
15	4.0	Clay	Kaolinite (disordered).	3
			Gibbsite	2
			Hematite	2?
15			Vermiculite-type mineral.	1?
			Goethite?	1?
		Silt	Kaolinite (disordered).	8
			Quartz	Tr.
			Goethite?	Tr.
			Mica	Tr.
18	3.0	Clay	Kaolinite (disordered).	3
			Hematite	3
			Mica	1
			Goethite	Tr.?
		Silt	Kaolinite (disordered).	7
			Quartz	1
			Mica	1
			Goethite	?
21	2.4	Clay	Kaolinite (disordered).	7
			Hematite	1?
			Gibbsite	Tr.
			Vermiculite-type mineral.	Tr.
			Mica	Tr.
		Silt	Kaolinite (partially disordered?).	6
			Quartz	2
			Mica	1
24	2.2	Clay	Kaolinite (disordered).	5
			Mica	2
			Hematite	1
			Goethite	1
			Quartz	Tr.
		Silt	Kaolinite	5
			Mica	2
			Quartz	2
27	4.0	Clay	Kaolinite (disordered).	4
			Mica	2
			Hematite	2
			Goethite	1
			Quartz	Tr.
		Silt	Kaolinite (disordered).	5
			Mica	2
			Goethite	1
			Quartz	1
27 (floor of pit).	1.0	Clay	Gibbsite	8
			Kaolinite	1
			Mica	Tr.
			Quartz	Tr.
		Silt	Quartz	3
			Feldspar	2
			Gibbsite	2
			Kaolinite	1
			Mica	1

TABLE 3.—*Ion-exchange capacity of saprolite samples from wells at the REF site*

Sample depths shown as a single number were taken from the drill bit; those sample depths shown as a range were taken from a mixture of material from that interval of the well]

Well	Sample depth (feet)	Type of material	Ion-exchange capacity (meq per 100 g)	Well	Sample depth (feet)	Type of material	Ion-exchange capacity (meq per 100 g)
11–26	0.0– 1.5	Soil	4.7	11–40	2.0– 4.0	Saprolite	5.6
	6.0	Saprolite	5.0		8.0	do	4.5
	13.0–13.5	do	3.2		11.0–13.0	do	4.7
–27	2.0	Soil	6.5	–41	0.0– 2.0	Soil	5.3
	10.0	Saprolite	7.3		5.0	Saprolite	4.4
	15.0	do	3.8		10.0	do	4.5
–28	1.0– 2.0	Soil	5.1		15.0	do	4.9
	7.0	Saprolite	8.9	–42	8.0	do	3.8
	9.0	do	7.2	–43	0.0– 2.0	Soil	3.6
	14.0	do	3.2		6.5	Saprolite	6.8
–29	0.0– 2.0	Soil	7.0		4.0– 7.0	do	4.3
	7.0	Saprolite	4.2		1.0	Soil	8.5
–30	1.0	Soil	6.5		7.0	Saprolite	5.1
–31	2.0	do	4.9		9.0	do	8.0
	4.0	Saprolite	4.7	–45	0.0– 2.0	Soil	5.6
	10.0	do	5.1		2.0	Saprolite	4.8
–32	2.0	Soil	8.0		15.0	do	6.0
	7.0	Saprolite	3.8		16.0	do	8.0
	8.0	do	4.3	–46	2.0– 5.0	do	11.6
	12.0	do	3.4		8.0	do	5.8
	17.0	do	5.1		12.0	do	6.4
–33	2.0	Soil	5.3		13.0	do	4.6
	5.5	Saprolite	3.0	–47	0.0– 3.0	do	8.0
	10.0–11.0	do	2.7		5.0	do	3.6
	14.0	do	2.5		9.0	do	4.0
–34	2.0	Soil	5.3	–48	0.0– 3.0	Soil	5.6
	8.0	Saprolite	3.0		3.0– 7.0	Saprolite	3.8
	12.0	do	3.1		12.0	do	4.2
–35	2.0	Soil	4.6		17.0	do	5.6
	6.0	Saprolite	5.1	–49	0.0– 3.0	Soil	4.5
	8.0	do	5.6		5.0	Saprolite	13.7
	9.5	do	4.5		10.0	do	4.7
–36	2.0	Soil	5.4	–50	0.0– 3.0	Soil	4.7
	6.0	Saphrolite	3.8		8.0	Saprolite	3.9
	8.0	do	3.4		13.0	do	5.9
–37	0.0– 2.0	Soil	8.3	–51	0.0– 3.0	Soil	5.4
	7.0	Saprolite	3.8	–53	0.0– 3.0	do	6.4
	12.0	do	2.7		3.0– 8.0	Saprolite	6.7
	15.0	do	3.8		13.0	do	5.3
–38	0.0– 2.0	Soil	6.0	–54	0.0– 3.0	Soil	5.4
	4.0– 6.0	Saprolite	5.3		4.0	Saprolite	3.6
	7.0– 8.0	do	4.9	–55	0.0– 3.0	Soil	11.0
	10.0	do	5.5		6.0	Saprolite	7.0
	15.0	do	5.1		10.0	do	3.8
	18.0	do	4.3		15.0	do	6.5
–39	0.0– 2.0	Soil	6.2	–56	0.0– 3.0	Soil	6.5
	6.0– 7.0	Saprolite	3.8		5.0– 8.0	Saprolite	6.7
	11.0	do	3.2		12.0	do	5.6
–40	0.0– 2.0	Soil	7.0				

TABLE 4.—*Ion-exchange capacity of saprolite samples from wells at the REL site*

Well	Sample depth (feet) 9	Type of material	Ion-exchange capacity (meq per 100 g)	Well	Sample depth (feet)	Type of material	Ion-exchange capacity (meq per 100 g)
15–9	0 – 2	Saprolite	4.6	15–30	14 –15	Saprolite	4.5
–13	2 – 6	do	3.0		15 –16	do	4.9
–14	8 –15	do	1.9	–31	0 – 4	Soil and saprolite.	7.2
–17	7 –11	do	4.4		4 – 5	Saprolite	4.1
–18	3 – 5	do	3.1		5 – 7	do	5.9
–28	0 – 5	do	7.6		7 – 9.5	do	6.5
–30	0 – 3	Soil	4.5		9.5–14	do	5.4
	4 – 6	Saprolite	5.1	–32	0 – 3	Soil	8.1
	8.5–10	do	4.9		5 – 7	Saprolite	4.6
	10 –11	do	6.2		7.5	do	5.8
	11 –12	do	2.8		8.5	do	3.6
	12 –13	do	4.3		14	do	4.0
	13 –14	do	4.7				

WATER RESOURCES

SURFACE WATER

By R. F. Carter

This part of the report contains the results of a brief investigation of the surface-water characteristics of the GNL. The surface-water resources of the site consist entirely of the flow of streams; there are no ponds or lakes within the reservation. The principal stream is the Etowah River which flows in a generally westerly direction through the southern part of the area. Two major tributaries, Shoal Creek and Amicalola Creek, flow generally southward and join the Etowah within the site. Many minor tributary streams, most of which appear to be perennial for most of their length, drain into these three larger streams.

Streamflow characteristics were determined from records at stream-gaging stations in the vicinity and from actual measurements of base flow at 25 places on small tributaries within the site and 9 measurements of base flow at 5 places on larger streams in or near the site. Stream-gaging stations pertinent to the investigation have been maintained on the Etowah River and Amicalola Creek in the vicinity of the GNL, and on the Etowah River at Canton.

A summary of gaging-station information and the results of the streamflow measurements are included in this report. In addition, some analyses of the basic data are included to provide a more complete appraisal of the surface-water resources.

Several reports have been prepared by various persons or agencies that include information on the surface-water resources of the region within which the GNL is located. These reports are listed in the references.

GAGING-STATION INFORMATION

Streamflow data collected at three stream-gaging stations, two on the Etowah River and one on Amicalola Creek, and at one crest gage on the Etowah River, are considered pertinent to the appraisal of surface water in the GNL.

ETOWAH RIVER NEAR DAWSONVILLE

The gage, operated since 1940, is at lat 34°23′ N., long 84°04′ W., on the left bank, 4.6 miles east of the GNL. The record is obtained from a recording gage. Some diurnal fluctuation of the flow is caused by mills above the station during periods of low flow. The accuracy of published records is considered good.

AMICALOLA CREEK NEAR DAWSONVILLE

This gage, operated from 1939 to 1952, was at lat 34°26′ N., long 84°13′ W., on the left bank under a birdge on State Highway 53, 5 miles upstream from the mouth, and 1.3 miles northwest of the GNL. The record was obtained from a recording gage. Moderate diurnal fluctuation of the flow was caused by mills above the station during periods of low flow. Published records are considered good.

ETOWAH RIVER AT CANTON

The gage, operated from 1892 to 1905 and since 1937, is at lat 34°14′ N., long 84°30′ W., on the left bank 100 feet downstream from the bridge on State Highways 5 spur and 140 at Canton, and about 18 miles southwest of the GNL. The record is obtained from a recording gage. Published records are considered good.

ETOWAH RIVER AT U.S. HIGHWAY 19

In addition to the three recording gages in the area, a crest stage indicator station has been maintained at the bridge on U.S. Highway 19 (State Highway 9) 1.1 miles east of the GNL. Several measurements have been made at this site and a high-stage rating curve has been drawn. By using this rating curve and the regional flood information given by Carter (1951), the flood flows and stages listed in table 5 were determined for this site.

Most of the data given in table 5 are self-explanatory. The "period of record" includes all records through September 1955. Operation of the gages on the Etowah River has continued beyond September 1955.

The period 1937–55 has been adopted by the U.S. Geological Survey as a standard period for the purpose of comparing flow figures. It will be noted that the gaging-station records for Etowah River and Amicalola Creek near Dawsonville do not cover the entire period. Monthly flows for the periods of no record were estimated from correlations with records at other gaging stations and were used to compute the figure given for the period 1937–55.

The recurrence interval for flood flows is the average interval at which a specified flow will be equalled or exceeded. For example, the flood flow having a 10-year recurrence interval is the rate of flow that will be equalled or exceeded at average intervals of 10 years, or for which there is a 1-in-10 chance that it might be equalled or exceeded in any year. For minimum flows, the recurrence interval represents the average interval at which a given flow will fail to be equalled or exceeded. In other words, a minimum flow having a

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recurrence interval of 10 years will be available 9 years out of 10 on the average. The low-flow frequency data in table 5 are based on the period 1937–55 and are representative of the future only to the extent that the period is a representative sample of long-term conditions.

TABLE 5.—*Gaging-station information*

[Cfs, cubic feet per second; cfsm, cubic feet per second per square mile; R.I., recurrence interval]

	Etowah River near Dawsonville	Amicalola Creek near Dawsonville	Etowah River at Canton	Etowah River at bridge on U.S. Highway 19 (crest gage)
Drainage area (sq mi)	103	84.7	605	128
Datum (ft above msl)	1,050	1,203.9	844.6	1,022.0
Period of record	1940–55	1939–52	1896–1904 1937–55	1949–55
Average flow:				
Cfs	246	215	1,150	
Number of years	15	12	24	
Maximum flood flow:				
Cfs	4,780	7,450	36,700	[1] 6,000
Stage (ft)	15.8	7.0	25.0	[2] 1,038
Date	Jan. 1946	Feb. 1942	[3] Jan. 1892	[1] Jan. 1946
Minimum daily flow:				
Cfs	50	51	178	
Stage (ft)	.8	.4	1	
Date	Oct. 1954	Sept. 1951	Sept. 1954	
Average flow 1937-55:				
Cfs	239	214	1,090	
Stage (ft)	1.8	.9	3.6	
Cfsm	2.32	2.52	1.78	
Inches	31.49	34.34	24.16	
Bankfull flow:				
Cfs	2,730		7,720	
Stage (ft)	11		15	
Cfsm	26.5		12.8	
Flood flow—mean annual:				
Cfs	3,200	4,640	11,800	3,500
Stage (ft)	12.3	5.2	19.6	[2] 1,036
Cfsm	31.1	54.8	19.5	27.3
Flood flow—10-year R.I.:				
Cfs	5,950	8,640	18,600	6,500
Stage (ft)	[4] 18	[4] 8	23.0	[2] 1,038
Cfsm	57.8	102	30.7	50.8
Flood flow—50-year R.I.:				
Cfs	8,650	12,500	25,500	9,500
Stage (ft)	[4] 23	[4] 10	25.3	1,039.5
Cfsm	84.0	148	42.1	74.2
Min monthly avg flow 1937–55:				
2-year R.I. (cfs)	92	84	381	
2-year R.I. (cfsm)	.89	.99	.64	
10-year R.I. (cfs)	66	68	251	
10-year R.I. (cfsm)	.64	.81	.42	
20-year R.I. (cfs)	54	54	214	
20-year R.I. (cfsm)	.52	.64	.35	
Min 7-day avg flow 1937–55:				
2-year R.I. (cfs)	81	67	322	
2-year R.I. (cfsm)	.79	.79	.53	
10-year R.I. (cfs)	58	56	223	
10-year R.I. (cfsm)	.56	.66	.37	
20-year R.I. (cfs)	50	52	194	
20-year R.I. (cfsm)	.48	.61	.32	
Min 1-day avg flow 1937–55:				
2-year R.I. (cfs)	81	67	318	
2-year R.I. (cfsm)	.78	.78	.52	
10-year R.I. (cfs)	55	51	211	
10-year R.I. (cfsm)	.53	.60	.35	
20-year R.I. (cfs)	50	49	178	
20-year R.I. (cfsm)	.48	.58	.29	

[1] For period 1940–55.
[2] Above mean sea level.
[3] Based on high-water mark of period before record.
[4] Estimated.

CHARACTERISTICS OF STREAMFLOW OF ETOWAH RIVER NEAR DAWSONVILLE

HYDROGRAPH

Figure 4, a hydrograph of the mean daily discharges of the Etowah River near Dawsonville for 1956, is an example of the seasonal distribution of flow. The average flow of each month for the standard period 1937–55 is indicated by a heavy horizontal line. The average flow for the calendar year 1956 was 205 cfs (cubic feet per second), in comparison with the average flow for the period 1937–55, which was 239 cfs. The dashed line on the hydrograph is the estimated base flow from ground-water discharge during 1956. The difference between the dashed line and the solid line is a measure of the direct runoff. For the year 1956, the estimated direct runoff was 6.8 inches and the estimated base flow 20.3 inches. Similar quantities have not been computed for other years. Direct runoff is closely related to current rainfall while base flow is closely related to prior rainfall and the ability of the land to store and release water.

DURATION CURVES

Figure 5 shows the duration curve of mean daily discharges record of the Etowah River at Dawsonville for the period 1940–55. The duration curve is a useful variation of the daily discharge that permits ready appraisal of the flow characteristics.

SELECTED SITE INFORMATION

Streamflow was measured at 29 sites in the GNL and at one site on the Etowah River downstream from the GNL during September

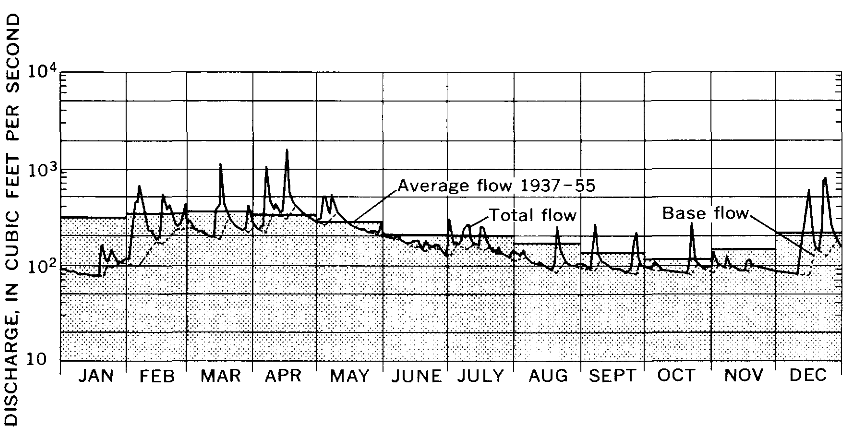

FIGURE 4.—Hydrograph of Etowah River near Dawsonville.

and October 1956. The measurements were made when practically all of the streamflow came from ground-water discharge.

The locations of the measurement sites are shown on figure 6, and the data are given in table 6. The east and north coordinates listed in table 6 are those of the Georgia Geodetic Grid (West Zone).

On September 19, 1956, a temporary recording gaging station was established on Shoal Creek within the GNL to determine if there was any regulation of the flow from mills upstream. Record was obtained for about a week. The stage graph for this period indicated no evidence of regulation.

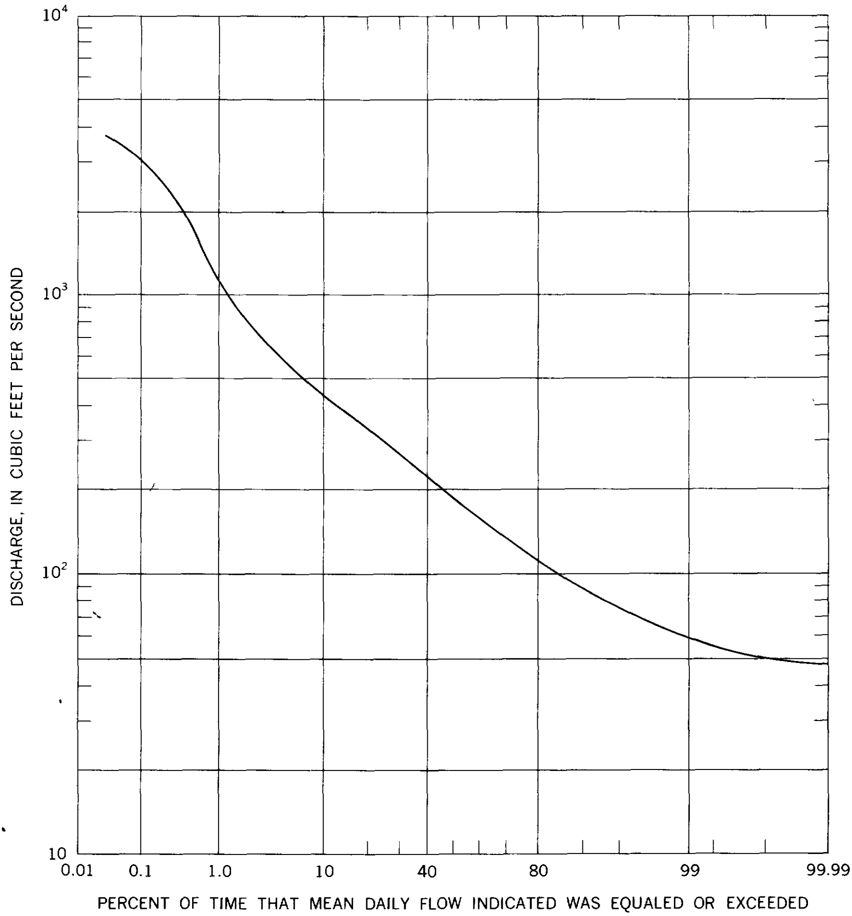

FIGURE 5.—Duration curve of Etowah River near Dawsonville, 1940–55.

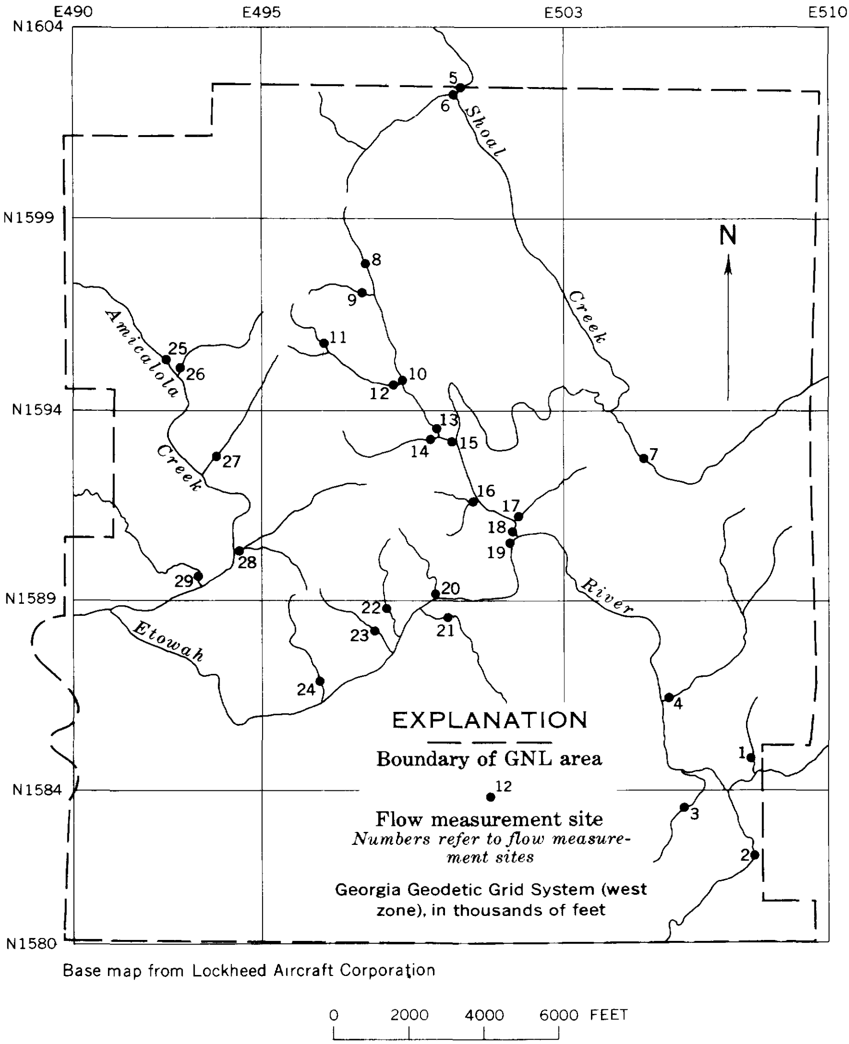

FIGURE 6.—Map showing streamflow measurement sites, GNL area.

TABLE 6.—*Streamflow measurements in the GNL*

Measurement site (fig. 6)	Stream	Drainage area (sq mi)	Date	Measured flow		Coordinates	
				Cfs	Cfsm	East	North
1	Tributary to Etowah River	0.027	10-18-56	0	0	508,000	1,584,950
2	do	2.21	10-18-56	1.31	.593	508,100	1,582,500
3	do	1.26	10-18-56	.424	.336	506,180	1,583,540
4	do	.46	10-18-56	.349	.76	505,700	1,586,550
5	Shoal Creek	30.79	10-17-56	25.7	.835	500,300	1,602,400
6	Tributary to Shoal Creek	.36	10-17-56	.256	.71	500,120	1,602,250
7	do	.59	10-18-56	.323	.55	505,050	1,592,780
8	do	.079	10-17-56	.111	1.40	497,800	1,597,610
9	do	.038	10-17-56	.011	.29	497,850	1,596,920
10	do	.24	10-16-56	.155	.65	498,700	1,594,790
11	do	.048	10-16-56	.048	1.00	496,750	1,595,590
12	do	.19	10-16-56	.121	.64	498,550	1,594,650
13	do	.49	10-16-56	.272	.56	499,800	1,593,420
14	do	.16	10-16-56	.086	.54	499,700	1,593,270
15	do	.66	10-16-56	.469	.71	500,080	1,593,210
16	do	.11	10-16-56	.120	1.09	500,750	1,591,610
17	do	.078	10-16-56	.049	.63	501,600	1,591,120
18	Shoal Creek above Etowah River	37.26	9-18-56	33.7	.90	501,650	1,590,800
			9-18-56	29.9	.80		
			10-16-56	28.2	.76		
			10-31-56	33.1	.89		
19	Etowah River below Shoal Creek	173.89	9-18-56	143	.826	501,650	1,590,550
			10-16-56	133	.768		
20	Tributary to Etowah River	.093	10-17-56	.060	.65	499,620	1,589,070
21	do	.39	10-17-56	.206	.53	499,960	1,588,400
22	do	.11	10-17-56	.112	1.02	498,380	1,588,680
23	do	.054	10-17-56	.045	.83	498,050	1,588,150
24	do	.097	10-17-56	.110	1.13	496,580	1,586,840
25	Amicalola Creek	92.28	10-17-56	77.1	.836	492,520	1,595,100
26	Tributary to Amicalola Creek	.11	10-17-56	.040	.36	493,750	1,595,030
27	do	.11	10-17-56	.030	.27	493,810	1,592,750
28	do	.31	10-18-56	.196	.63	494,260	1,590,190
29	do	.86	10-18-56	.705	.82	493,370	1,589,470
(1)	Etowah River at covered bridge below Lockheed project.	277.41	10-31-56	239	.863		

1 Station beyond map area.

ANALYSIS OF DATA

STREAMFLOW ENTERING AND LEAVING THE SITE

The three largest streams entering the GNL—Etowah River, Amicalola Creek, and Shoal Creek—drain regions in which streams characteristically have high rates of runoff per unit of area. The tributary area of Etowah River downstream from the GNL produces lower rates.

Flow records from the gaging stations on the Etowah River near Dawsonville, Amicalola Creek near Dawsonville, Etowah River near Canton, and Etowah River near Cartersville were used to interpolate flow per square mile for the area for several conditions. The following values were determined:

1. The 18-year average flow for streams in the GNL is 1.80 cfsm (cubic feet per second per square mile).
2. The minimum monthly mean flow having a recurrence interval of 20 years is estimated as 0.35 cfsm.
3. The flow of the largest streams in the area on October 17, 1956, as computed from gaging-station records, averaged 0.70 cfsm. This figure agrees with the artithmetic average of the yields (0.70 cfsm) measured on tributary streams within the site during the

period October 16–18, 1956. This agreement suggests that most of the increment in flow in Etowah River in the GNL enters the main channel as surface flow from the tributaries rather than by ground-water seepage into the river channel—at least under the conditions prevailing at that time.

CORRELATION WITH LAND CHARACTERISTICS

The variations in the yield of flow per square mile of drainage area of the streams measured in the GNL in 1956 are an indication of variations in basic characteristics of the land. The measurements were made near the end of one of the longest rainless periods of the year. The effect on streamflow of unequal distribution of previous rainfall should have greatly diminished, and it is extremely unlikely that in an area of this size the distribution of previous rainfall would have varied as much as the measured yield of the streams.

For purposes of strict comparison, minor adjustments were made where necessary in the measured flows so as to represent the flows on October 17, 1956, and the flows in cubic feet per square mile were shown at the point of measurement for local streams on figure 7 as a circle, the area of which represents the comparative rate of flow. This figure shows a 5-to-1 variation in yield throughout the area, without any discernible regular pattern and without any obvious relation to variations in geology.

Figure 8 shows the yield of the local streams in cubic feet per square mile plotted against drainage area. As might be expected, the larger streams had yields near the average for the area because the larger stream basins include a combination of high-yielding and low-yielding subbasins. The smaller streams, those having drainage areas of less than 0.2 square mile, showed the 5-to-1 variation in yield.

The large variation in yield in an area that is superficially homogeneous suggests that this yield may be a sensitive indicator of variations in ground-water storage capacity or transmissibility.

A study was made to determine if any of the observed variation in yield could be correlated with or explained by topographic features that could be measured on the available topographic map of the area, or if the variations could be correlated with physical factors observed by engineers making the measurements.

The character of the streambed at the measurement site—whether sand, clay, gravel, or bedrock—did not explain the variations in yield. Inasmuch as outcrops of bedrock were noted at or near many measuring sites, even including some having very low yield, it is unlikely that observed low yields were due in any part to the flow's bypassing the measuring site by traveling underground in the valley fill.

Ground-water geologists suggested that the flow of a stream might vary with respect to its orientation, that is, that streams flowing parallel to the strike of the bedding planes might have yields significantly different from streams flowing at right angles to this direction. They had observed that the stream pattern tends to follow either the strike of the beds or in a downdip direction at right angles to the strike, and that streams flowing downdip tended to have more water in them. To test this suggestion, the relative yields of the streams were plotted as vectors in the direction of the major axis of the stream

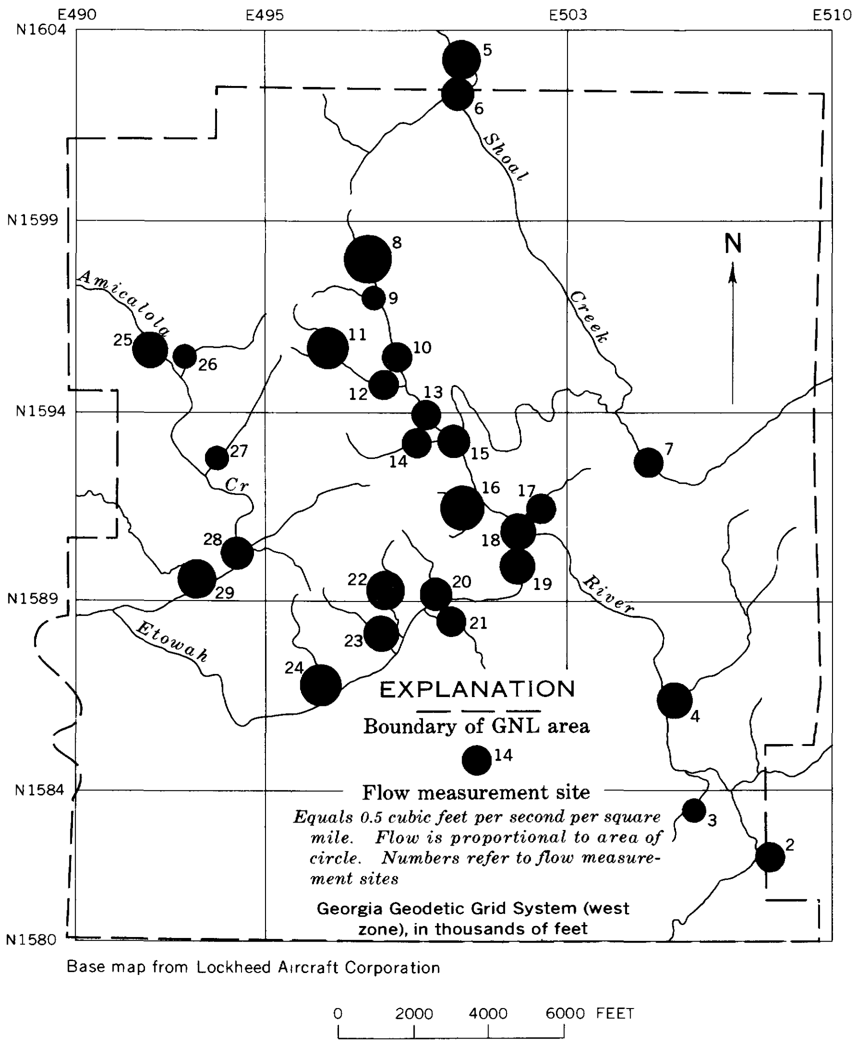

FIGURE 7.—Discharge per square mile at measurement sites, October 17, 1956, GNL area.

valley (fig. 9). This figure indicates that most of the streams having more than average yield flow in the downdip direction of the foliation while streams flowing in other directions have less than the average yield for the area.

Merely using the major axis of the stream valley oversimplifies the problem because some of the streams make abrupt right angle turns, all the streams have tributaries at approximately right angles to the main stream, and the tributaries have smaller tributaries. Therefore, in order to test further the possible correlation between stream orientation and yield, the drainage basins were subdivided into areas drained by streams flowing in the direction of the dip of the foliation and into areas drained by streams flowing in other directions.

In October 1956 most valleys longer than about 1,000 feet contained a flowing stream. Tributary valleys less than 1,000 feet long were not considered separately in subdividing the drainage basins; this was the criterion used in making the subdivision. Only those streams that were entirely or almost entirely on the topographic map could be used in this study.

When the subdivision was made, it was found that the average yield of streams that were oriented 100 percent in the downdip direction was 0.81 cfsm and the average yield of streams that were oriented

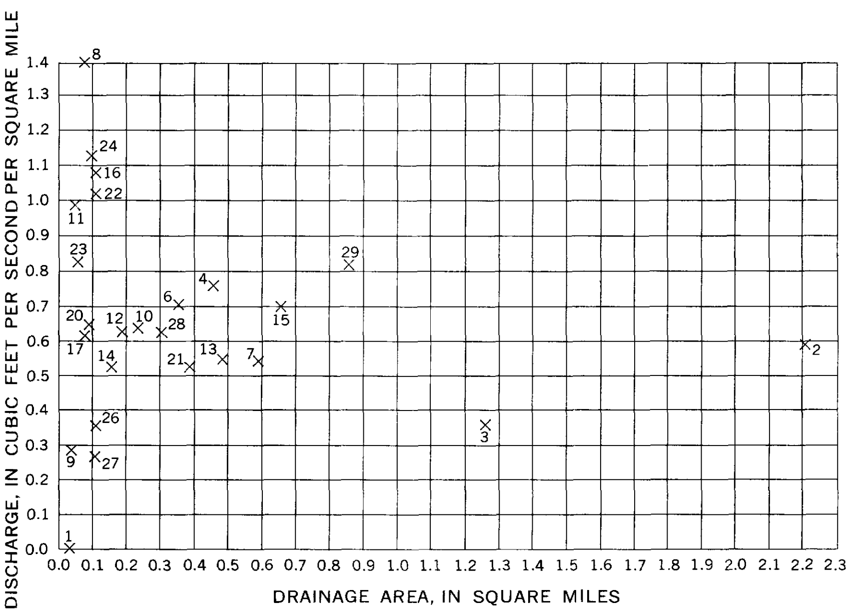

FIGURE 8.—Discharge per square mile versus drainage area of measurement sites, October 17, 1956, GNL area. Numbers refer to flow measurement sites shown in figure 6.

entirely in other directions was 0.48 cfsm. The discharge of the stream is shown plotted against percent of area drained in the direction downdip in figure 10. It will be noted that for the streams which drain partly in the direction of the dip and partly in other directions (Nos. 3, 4, 6, and 14) the yields roughly average the line drawn from 0.81 (at 100 percent) to 0.48 (at 0 percent) and vary from the line in inverse proportion to the percentage of the area draining in the direction of the dip.

The average of the discharge data used in this study is 0.70 cfsm and the standard deviation of the data is 0.29 cfsm. The average adjusted for direction of flow as shown in figure 10, gives the standard

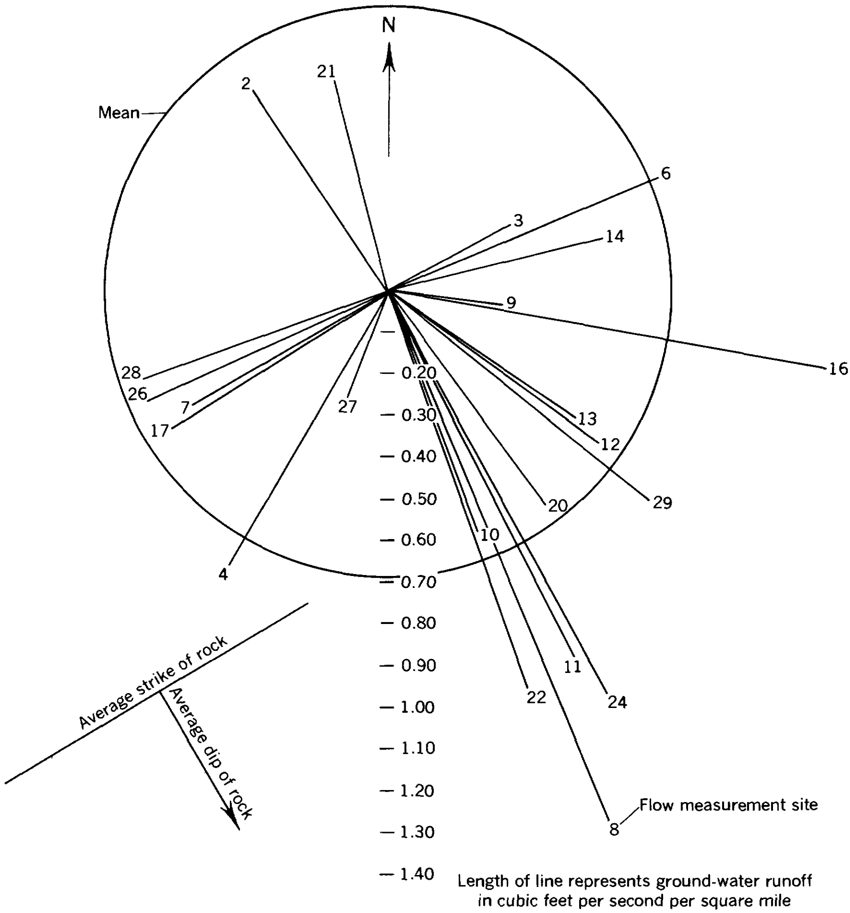

FIGURE 9.—Relative ground-water runoff plotted in the direction of the major axis of stream basins at GNL area.

error of estimate for the data of 0.25 cfsm. The relationship of the variation of the data to the direction of flow is statistically significant at the 3 percent level and thus has a fairly high degree of significance; that is, the probability that this relationship is due to chance is only 1 in 33.

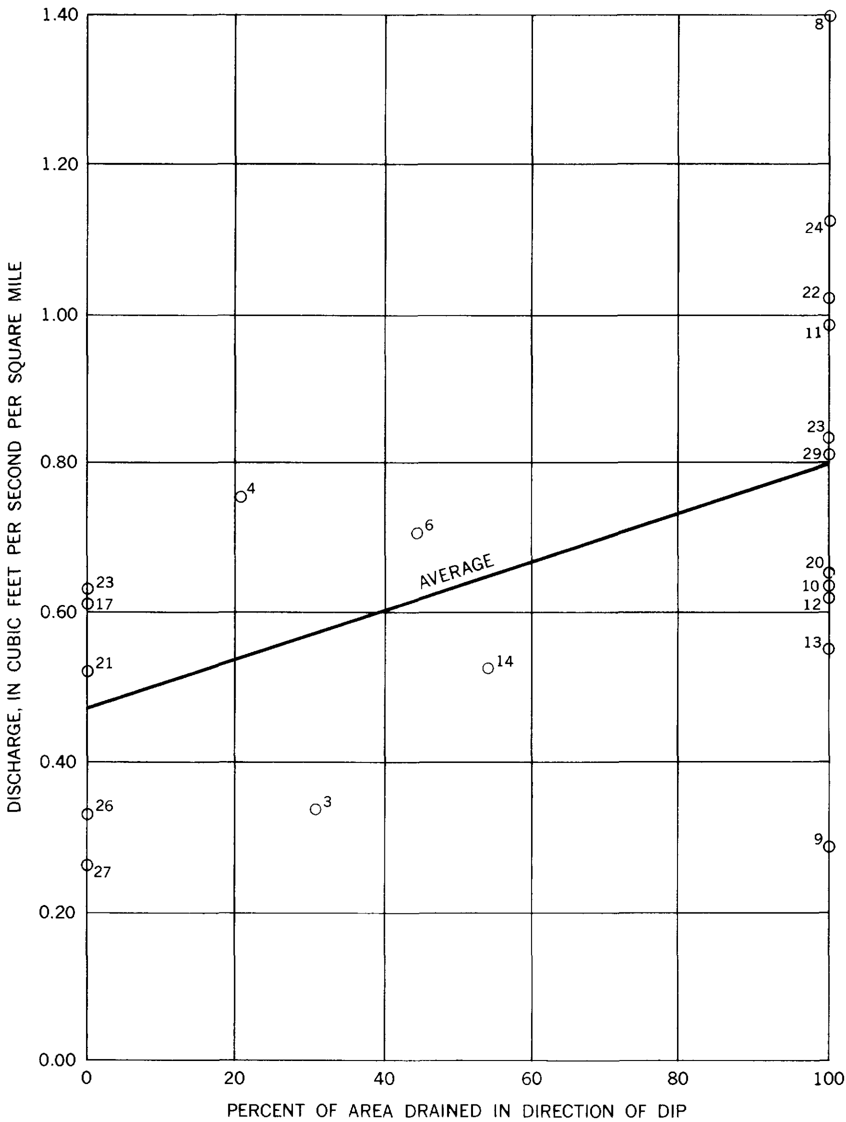

FIGURE 10.—Discharge per square mile versus percent of area drained in direction of the dip for measurement sites, GNL area. Numbers refer to flow measurement sites shown in figure 6.

Comparison of the areal distribution of variations in yield as shown by figure 7 with a geological map of the area indicates that there is no recognizable correlation between streamflow yield and the type of underlying rock.

The yield of the streams was plotted against other geographic features of their drainage basins. The factors investigated included:

1. Average slope of streambed based on the lower third of the stream length.
2. Average depth of the valley based on the average vertical distance from streambed to valley rim at proportionally spaced points.
3. Shape factor for the basin based on the length divided by the average width.
4. Maximum fall, or the vertical distance from the highest point in the basin to the lowest point (the measurement site).
5. Average fall, or the vertical distance from the average elevation of the basin rim to the lowest point.

The yield of the streams did not show any definite trend or correlation when plotted against the factors listed above or against combinations of those factors.

VELOCITY OF FLOW

Figure 11 shows curves of discharge versus average velocity for the three gaging stations near the GNL. At the gage near Dawsonville, Amicalola Creek flows in a typical mountain valley, practically a gorge. The stream banks are very high and the streambed slope is steep. For these reasons, the average velocity of flow increases with increasing discharge throughout the recorded range. The Etowah River, in the reach between the Dawsonville and Canton gages, flows in a meandering channel having low banks and a moderate stream bed slope. Flood plains border the stream almost the entire distance. As may be seen from the discharge versus velocity curves, the average velocity increases with increasing discharge for low flows; but for higher flows, the average velocity increases very little or may decrease where the streamflow spreads onto the flood plain. Sufficient data are not available to compute separate average velocities for the parts of flow in the main channel and on the flood plain.

The discharge-velocity curve for Amicalola Creek near Dawsonville (fig. 11) is typical of streams flowing in young mountain valleys in this vicinity, and the curve for Etowah River near Dawsonville and at Canton is typical of streams flowing in mature valleys and having broad meanders and flood plains.

The maximum point velocity of flow observed in streams of northern Georgia is usually much more than the average velocity in a section, often as much as twice the average.

The curves of figure 11 may be used to compute the probable time for material introduced into the Etowah River in the vicinity of the GNL to travel to downstream sites. For example, during times of moderately high discharge the Etowah River flows about 3.5 feet per second, or 2.4 miles per hour. If conditions at the gaging stations were representative of those in the reach, the time of travel to the city of Canton would be about 17 hours, with the improbable chance that some water could travel the distance in only half that time by traveling at the maximum velocity through the reach.

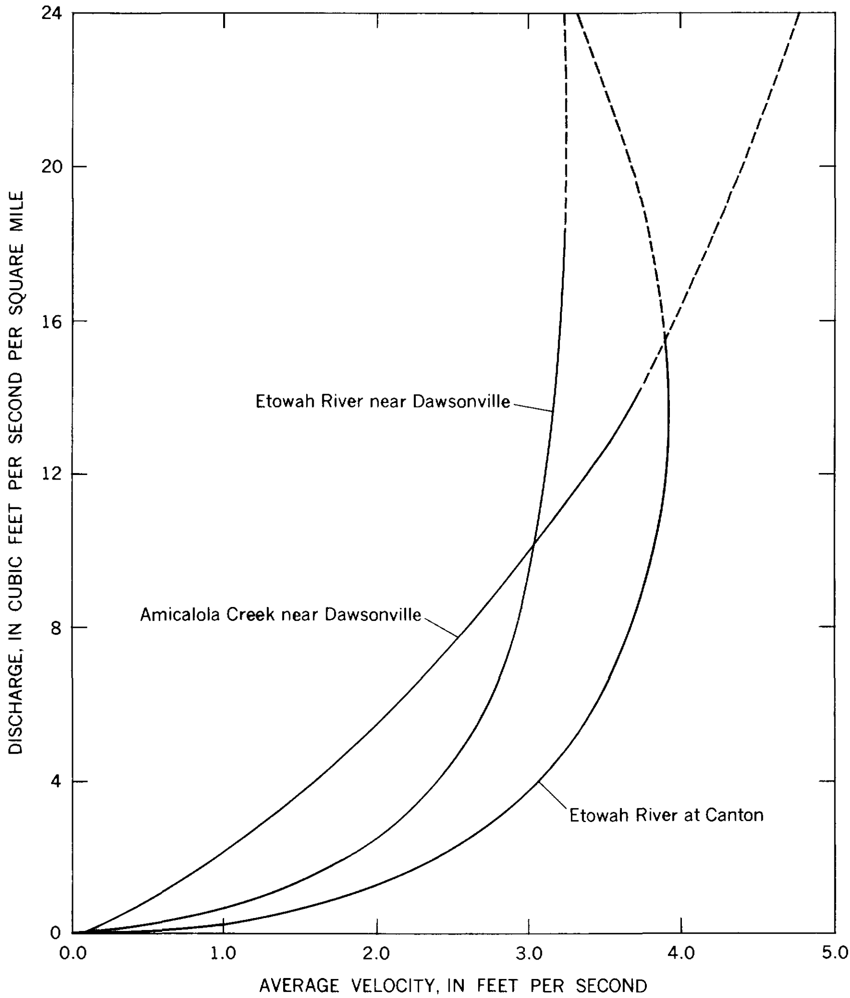

FIGURE 11.—Discharge-velocity curves for streams near GNL area.

DISCHARGE OF WASTE INTO STREAMS

The maximum permissible concentration of waste to be discharged into surface streams has been established at less than 10^{-7} microcuries per milliliter of gross unknown beta-gamma activity containing no alpha emitters or Strontium 90 (Bowen, Edgerton, and others, 1960, p. 46).

The minimum recorded flow of Etowah River near Dawsonville was 50 cfs and the average flow (1937–55) was 239 cfs. Thus, Etowah River offers a dilution of about 22,500 gpm (gallons per minute) at the lowest recorded flow and about 110,700 gpm at average flow. The minimum daily and average flows of Amicalola Creek near Dawsonville were about the same as those for Etowah River.

The discharge of waste from the REL and REF disposal pits probably will not exceed 5 gpm. If waste containing 10^{-5} microcuries per milliliter leaks from the pits into Etowah River at a rate no higher than about 1 : 4,500 of low-flow discharge and 1 : 22,500 of average flow, the concentration after thorough mixing is still below off-site maximum permissible concentration.

DOWNSTREAM UTILIZATION OF ETOWAH RIVER

MUNICIPAL WATER SUPPLY

The towns of Canton and Cartersville obtain their water supply from Etowah River downstream from the GNL.

The intake for the town of Canton is 40 river miles downstream. About 2,800 people are served by this system which pumped an average of 0.47 mgd (million gallons per day), or 0.073 cfs, during 1955. The maximum monthly rate of use was 0.59 mgd (0.91 cfs). On the basis of projections of population and per capita use, it is estimated that by 1970 Canton's water use will have increased 17 percent.

Cartersville is about 70 miles downstream. Its municipal water supply system serves about 7,900 people. The average use during 1955 was 1.21 mgd (1.87 cfs) and the maximum monthly rate of use was 1.27 mgd (1.97 cfs). It is estimated that by 1970 water use at Cartersville will have increased 32 percent.

RECREATION

The lake above Allatoona Dam extends upstream almost to Canton, and is used for boating and fishing by thousands of people in northern Georgia. Around the lake are many excellent public recreational areas and several permanent homes. Lake water probably is not used for drinking water, but many people swim in the lake and many eat the fish from it.

HYDROELECTRIC POWER

There are two hydroelectric power plants on the Etowah River—Allatoona (operated by the Corps of Engineers) about 65 miles downstream from GNL and the Thompson-Weinman Co. plant about 70 miles downstream from GNL. Data relative to the water use of these plants are:

		Allatoona	*Thompson-Weinman Co.*
Drainage area	square miles	1, 110	1, 120
Design head	feet	135	13
Installed capacity	kilowatts	74, 000	625
Average annual generation	million kilowatt-hours	169	3. 5
Water use at full capacity	cubic feet per second	8, 200	730
Average annual water use	do	2, 200	460
Surface area of reservoir	acres	19, 200	---
Usable storage of reservoir	million cubic feet	25, 600	---

Allatoona Reservoir is operated for flood control and regulation of river flow as well as for power.

INDUSTRIAL WATER SUPPLY

In 1956, industries did not use significant amounts of water from the Etowah River above Rome. Plant Hammond, a large steam power-plant, and the Rome Kraft Paper Mill used water from the Coosa River just below Rome below the confluence of the Etowah River and Oostanaula River. Rome's municipal water supply is pumped from the Oostanaula River.

GROUND WATER

By J. W. STEWART, J. T. CALLAHAN, C. W. SEVER, Jr., and R. L. WAIT

SOURCE AND OCCURRENCE

All water below the surface of the earth is termed subsurface water. The upper surface of the zone of saturation is known as the ground-water table. Water above the zone of saturation is called suspended or vadose water. A discussion of the occurrence of ground water is given by Meinzer (1923).

Precipitation recharges the ground-water reservoir at the GNL area. Part of the moisture that falls runs off in surface streams and part is lost by evaporation and transpiration. The water that is not lost eventually becomes a part of the ground water in the zone of saturation.

CONFINED AND UNCONFINED GROUND WATER

Ground water may occur under either confined or unconfined conditions. Confinement, however, is a matter of degree because water will pass through all rocks. Ground water is said to be unconfined or under water-table conditions when the zone of saturation is not confined by an impervious overlying stratum and the water is under atmospheric pressure. If the zone of saturation is confined in the aquifer by an overlying, relatively impermeable barrier which causes the water to rise in wells above the top of the aquifer, the water is said to occur under confined or artesian conditions. In the GNL, ground water occurs under confined and unconfined conditions in the saprolite and the bedrock and under unconfined conditions in the alluvial fill along the Etowah River. Ground water occurs in the pore spaces and along fractured quartz veins in the saprolite, in the cracks and joints of the bedrock, and in the pore spaces in the sand and gravel in the alluvium.

The degree of confinement of water in the site depends upon the composition, thickness, and extent of the saprolite and rock units and on differences in the permeability along the strike and dip of the beds.

The response of the water levels in deep wells to barometric pressure changes indicates that there is some degree of local confinement of the water. The barometric efficiency of the wells ranged from 20 to 70 percent. In addition, most deep wells respond to earthquake shocks, and such responses normally are associated with confined aquifers.

WATER IN ALLUVIUM

Alluvial sands and gravels along the Etowah River are water bearing. They consist of narrow deposits paralleling the river, and are as much as 30 feet thick. The water occurs in thin stringers of sand and gravel. Close to the river the water table is about at river level. A few hundred feet back from the river in the SWD site the water table is above the river level and within 4 feet of land surface at some places.

The alluvial terrace materials in the SWD site are underlain by fresh rock at some places and saprolite at others. They do not appear to be connected with the alluvium along the stream channel, but are perched above them. They do not appear to be water bearing.

No field or laboratory tests were made on the alluvium to determine its value as an aquifer. The water level in this material responds to rainfall, but the rate of movement has not been established. The rate of water movement may affect waste disposal because ground water must move from the saprolite into the alluvium at some places in order to drain into the Etowah River.

WATER IN SAPROLITE

The saprolite contains a greater percentage of void space and holds more water in storage per unit volume than the underlying fresh rock (Stewart, 1962). The saprolite becomes less porous with depth, but most of the water available is obtained from the transition zone. Water enters the saprolite readily and percolates downward to the ground-water reservoir, but owing to changes in the horizontal and vertical permeability of the material the rate and direction of movement are devious.

The porosity of the saprolite at the REL and REF sites averaged about 46 percent, whereas samples of unweathered rock collected at the REF site averaged less than 5 percent. Thus the storage capacity of a unit volume of saprolite is at least 9 times greater than that of the dense unbroken rock. The average specific yield of the saprolite was about 26 percent, ranging from about 40 percent in the upper part of the saprolite to zero in unweathered rock.

The saprolite of the different rock zones varies according to the mineralogy of the zones. The amphibolite, composed mostly of hornblende, breaks down to a dark-red clay which appears to be relatively impervious. The quartzitic and micaceous schists break down less completely, and the saprolite consists of small fragments of quartz, mica, silt, and clay. This saprolite appears to be more permeable than that derived from the amphibolite. The quartzite breaks down to a sandy soil. The light-brown saprolite of zone 5 is sandier than that of any other zone. This material appears to be the most permeable saprolite in the area.

The water table is in the saprolite at the SWD (zone 1), REL (zone 1), and REF (zones 2 and 3) sites, but in the SDF (zone 5) site it is in bedrock about 10 feet below the transition zone. The SDF site is on a high, steep hill, and the lack of water in the saprolite is the result of complete drainage, laterally to side-hill wet-weather springs, and vertically to the rocks below.

Movement of water is probably more rapid in the saprolite than in the bedrock, and water in excess of the amount capable of being taken by the bedrock will be rejected and will move laterally in a down-gradient direction. Where the saprolite is thin or absent, marshy areas and springs are likely to occur where ground water discharges to the surface.

In the bedrock of the area, most of the ground water occurs in joints and cracks. Although some of the schist may contain water between the minerals grains, it is not available for withdrawal, and probably moves at a very low rate.

The amphibolite and quartzite are dense and contain few pore spaces. They are brittle and have been broken by earth movement. These brittle rocks contain joints that are more numerous and more clearly defined than those in the schist, and are believed to be the more permeable.

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In zones 2 and 3 (pl. 1) most of the water available is in the quartzite.

The most common type of spring in the GNL occurs in gullies and on hillsides where the contact between different rock types is exposed. Springs 11–S2, 12–S1, 12–S2, and 12–S3 flow from the contact between quartzite and schist.

The damming effect created by rocks of low permeability causes ground water locally to move laterally or obliquely to the general gradient. Where the water intersects the land surface in valleys it is discharged as springs, as at the REF site.

WATER-LEVEL FLUCTUATIONS IN WELLS

Changes in the position of the water table indicate changes in the amount of ground water in storage. If the recharge to the ground-water reservoir exceeds discharge, the water table rises; conversely, when discharge exceeds recharge, the water table declines. The rise of the water table in the GNL site is dependent upon the amount of precipitation that reaches the water table. The factors controlling the decline of the water table are the amount of water lost by natural drainage to springs and streams, the amount of water used by plants, and the amount of water evaporated directly from the zone of saturation.

Water-level records at the REL and REF sites were obtained for periods of about 5 months to 2 years. In general, water levels are highest during late winter and early spring and lowest in the fall and early winter.

The position of the water table at the REL and REF sites is significant because discharge of the liquid waste to the ground is planned through seepage pits. Because most of the liquid waste eventually will reach the zone of saturation and become a part of the ground-water reservoir, discharge to springs and streams in the area will be increased as storage in the ground is increased. In order to observe and evaluate the water-table fluctuations, a network of observation wells was maintained near the disposal sites.

WATER-LEVEL FLUCTUATIONS CAUSED BY RECHARGE FROM PRECIPITATION

The average annual precipitation for the Dawsonville area is 56 inches. A part of the rainfall is lost within a few days to the Etowah River and its tributaries, and a part is lost to evaporation and transpiration. The water that is left infiltrates into the soil and saprolite and moves downward to recharge the ground-water reservoir.

The quantity of water that is lost to surface runoff in the area is determined by several dependent and variable factors: (1) the intensity of the rainfall, (2) the type of soil covering, (3) topography, (4) time of year, and (5) vegetation mantle.

The amount of rainfall entering the ground varies with the slope of the land; consequently, the steeper the slope, the larger the amount of runoff in a given period of time. On the other hand, a greater proportion of water enters the soil during periods of steady rains than during heavy downpours. The more open and porous the soil cover, the better able it is to absorb water and prevent it from running off immediately.

The use of water by vegetation and the time of year are interrelated factors. During the growing season, vegetation intercepts and consumes large amounts of water before it reaches the water table, especially from April through September. As a result of the consumptive use of water by plants, the water table declines gradually throughout the summer and fall months, and usually is lowest in the late fall. The lower temperatures, long steady rains, and no transpiration losses favor the recharge of ground water during the winter months.

In the GNL site, the fluctuations of the water table in most wells show a direct relation to rainfall. The magnitude of the fluctuations depends upon the depth to the water table and construction of the wells, location with respect to topographic features, and geology. Except for the deep wells in unweathered rock, the water levels in most wells respond to precipitation within a period of 8 to 45 hours, depending upon soil moisture conditions, amount and rate of precipitation, and temperature.

The water level in the immediate vicinity of the REL pit is about 35 feet below land surface, and precipitation reaches the zone of saturation in about 35 hours. In areas where the water table is about 6 to 8 feet below land surface, water levels in the well show a rise within a period of about 8 hours.

The response of the water levels in most wells at the REF site is quite similar to that observed in wells at the REL site.

The water levels in wells in areas of steep topography and complex geologic conditions show the greatest fluctuations. Well 11–4, on the crest of a ridge, is 74.5 feet deep and is cased to 44 feet (pl. 1). The lower 35 feet of the well is in amphibolite schist. The water level in the well rose 2.5 feet during the heavy rains of July 1958, but following the rains it declined rapidly. The amplitude of water-level fluctuation in wells of corresponding depth appears to be greater in areas of steep topography than in areas of low relief.

The rise and decline of water levels in wells in draws are more abrupt and extend over shorter periods of time than in wells on gentle slopes. For example, wells 15–13 and 15–17 are at the REL site where relief is low. The shallower well, 15–17, is in a draw where the depth to the water table is approximately 6 feet. Well 15–13 is on a slope where the water table is about 30 feet below land surface.

During the heavy rains the latter part of July 1958, the water level in well 15–17 rose 0.32 foot, whereas the water level in well 15–13 rose only 0.16 foot (fig. 12). In well 15–17 the reaction to rainfall occurred within 6 to 8 hours, whereas in well 15–13 the water level reacted after a lag of about a day. Water levels generally declined in these wells 0.02 to 0.03 foot a day during periods of no rainfall in June and July 1958.

In general, the deeper water levels show a smaller magnitude of fluctuation than the shallower water wells. A slow gentle rise of 0.5 foot was recorded in well 11–3 throughout July 1958 (fig. 13), a period of time when the water levels in wells 15–13 and 15–17 (fig. 12) showed very pronounced rises. Well 11–3, on top of a hill at the REF site, was 400 feet deep and was cased into bedrock, and the lower 350 feet of the well was in bedrock. The depth to which a well is cased is one of the controlling factors influencing the water-level fluctuations in the wells.

WATER-LEVEL FLUCTUATIONS CAUSED BY EARTHQUAKE SHOCKS

Water-level fluctuations caused by seismic tremors have been observed on many recording-gage charts from wells in the GNL. The amplitude of the water-level fluctuations seldom exceeded 0.05 foot, and indicated only very minor disturbances of shocks which originated hundreds of miles from the GNL. The seismic water-level fluctuations registered by wells in the GNL show that most earthquakes

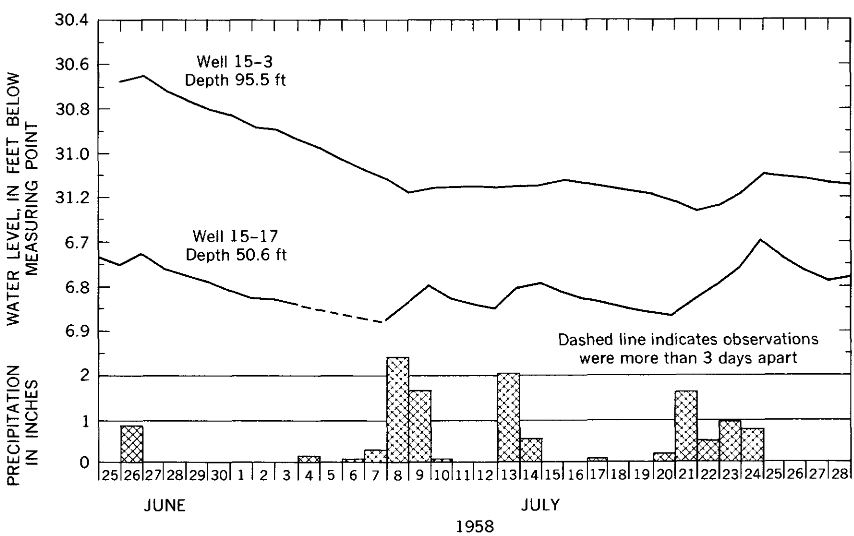

FIGURE 12.—Water-level fluctuations in a shallow and a deep well at REL site, and daily precipitation.

go unnoticed in the State, but the shock waves may affect the water levels in wells many miles from the epicenters of the quakes. The seismic water-level fluctuations are of interest because they disclose significant facts about the weathered and unweathered crystalline rocks in Georgia. The effect of earthquakes on water levels in wells in Georgia has been discussed by Stewart (1958, p. 129–131).

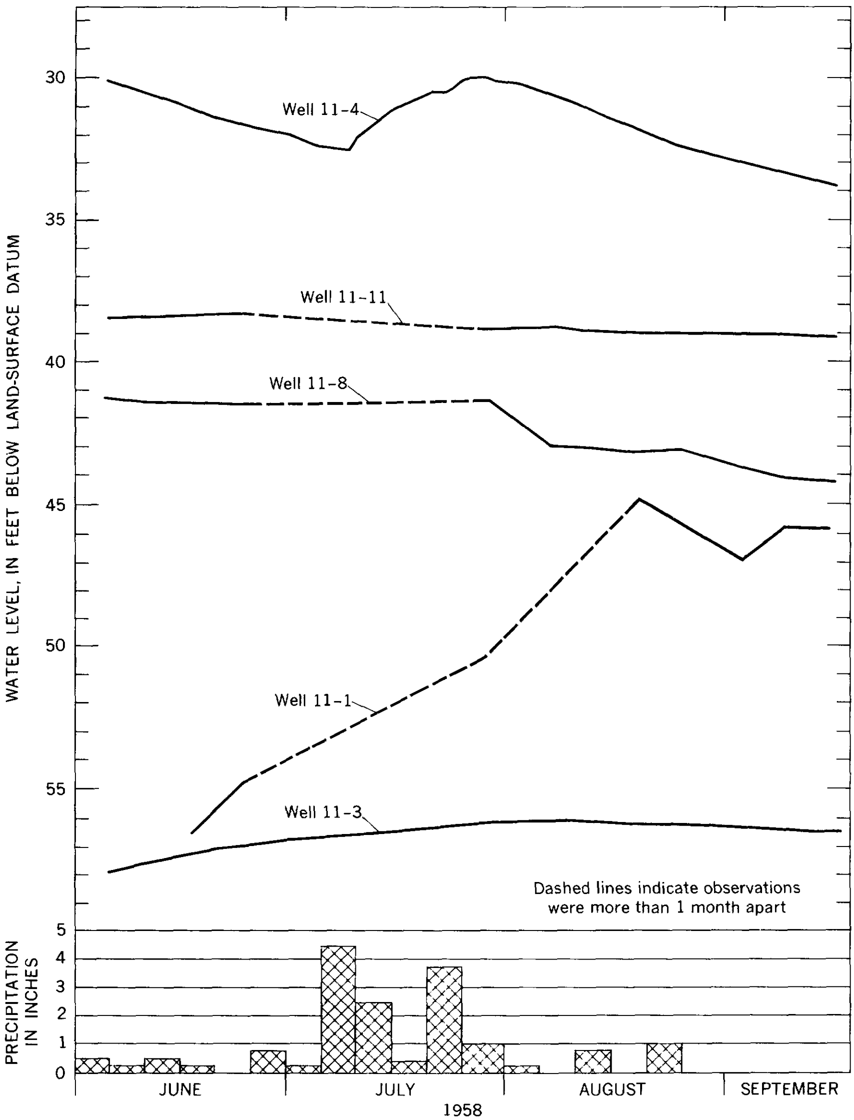

FIGURE 13.—Water-level fluctuations in wells at REF site, and daily precipitation.

RECORDS OF EARTHQUAKE SHOCKS FELT IN GEORGIA

Earthquake records show that north Georgia is not entirely quiescent and that earthquakes may occur in the region. The probability of an earthquake affecting the GNL should be considered in planning the foundation and construction of buildings and other structures in the area.

According to Heck (1947), the eastern region of the United States is one of considerable but moderate earthquake activity. Georgia has felt strongly many earthquakes occurring outside of its borders, especially the New Madrid, Mo., earthquakes of 1811 and 1812, the Charleston, S.C., earthquake of 1886, and the Union County, S.C., earthquake of 1913. Heck lists five earthquakes having epicenters in Georgia and having a range from 10,000 to 50,000 square miles and an intensity range on the Rossi-Forel scale of 6 to 7 (strong shocks). Table 7 lists in chronological order six earthquakes having epicenters in Georgia and two earthquakes which have occurred in adjacent states but which have been felt in Georgia. Other events in the seismic history of Georgia for the period 1811 to 1957 have been listed by Stewart (1958).

TABLE 7.—*Records of earthquake shocks felt in Georgia*

[Records cover period through 1959]

Date of earthquake	Locality	Remarks
Nov. 1, 1875	North Georgia and adjacent South Carolina.	Felt from Spartanburg and Columbia, S.C., to Atlanta and Macon, Ga., and from Gainesville to Augusta, Ga. Area affected, approximately 200 by 150 miles. The shock lasted 30 seconds at Washington and Augusta, Ga., and there were several aftershocks.
Oct. 18, 1902	Southeast Tennessee and northwest Georgia.	Felt along east face of Rock Face Mountain west of Dalton, Ga. Felt with force 5-6 at LaFayette, Ga. Felt at Johnson City and Chattanooga, Tenn.
Jan. 23, 1903	Georgia and South Carolina.	Felt at Tybee Island, Savannah, Ga., with force 6; Charleston, S.C., 4-5; Columbia, 3-4; and Augusta, Ga., 3. Houses strongly shaken.
Mar. 5, 1914	Thirty miles southeast of Atlanta.	Intensity 6. Felt in western North Carolina, as far east as Cherokee Co., and in Alabama and Tennessee. Area covered 100-mile radius.
Oct. 20, 1924	West North Carolina	Felt in west North Carolina, South Carolina, northeast Georgia, and east Tennessee. At epicenter, buildings were shaken and furniture overturned. A loud roar accompanied the shock.
Jan. 1, 1935	Border of Georgia and North Carolina.	Intensity 5-6. Area affected, 7,000 sq mi. Slight damage at Dahlonega, Ga., and Almond and Gay, N.C.
Dec. 27, 1947	Tennessee and Georgia	Moderately strong shock felt in Missionary Ridge area. In Rossville, Ga., a concrete block house was rocked, and at Ft. Oglethorpe, Ga., the disturbance lasted 2 to 3 seconds.
April 23, 1957	Northern Alabama	Intensity 6. Area affected, approximately 11,500 sq mi in Alabama and Georgia.

DISCHARGE OF GROUND WATER

SPRINGS AND SEEPS

Beginning in 1956, 19 springs were canvassed in the GNL. Of the 19 springs, 3 were near the REF disposal pits and 4 were near the REL disposal pit. The maximum flows of all springs at each site were estimated to be 10 gpm and the minimum flows were about 2 gpm. Discharge measurements were made on spring 11–S1 which flowed at a fairly constant rate of between 8 and 9 gpm for a period of 2 years. A slight increase in the rate of flow occurred during April and May and a slight decrease during August and September.

Numerous seepage areas were noted throughout the site, and these contributed substantially to the total ground-water discharge. The total combined flow of springs and seeps in the GNL site was estimated to be about 1 mgd.

STREAMS

The fact that water levels in wells near streams were at the same elevation as the stream surfaces indicates that, for the most part, the base flow of streams was maintained by the discharge of ground water to the streams. However, recharge to ground water takes place at some time along some stretches of the major streams in the lower elevations.

WELLS

Ground-water withdrawals were not made from wells in the GNL area.

LABORATORY TESTS OF SAPROLITE AND ROCK SAMPLES

In December 1957 and May and July 1958, 37 undisturbed samples of rock and saprolite were collected for laboratory analyses from the REL pit and REF pits 1 and 2. The saprolite samples were collected in 2-inch-diameter brass cylinder liners by using a Pomona core barrel. Four rock samples were collected from the bottom of the operations building excavation at the REF site about 5,000 feet north of REF pit 2. The rock samples were later cored by a diamond-core drill in the laboratory.

Quantitative analyses of the samples included the following determinations: particle-size distribution, porosity, void ratio, moisture content, specific retention, specific yield, and coefficient of permeability. The analyses were made in the Hydrologic Laboratory, U.S. Geological Survey, Ground Water Branch, Denver, Colo.

The results of the laboratory analyses are summarized in tables 8 and 9; figures 2 and 3 show the particles-size distribution curve for four samples. The coefficient of permeability of the saprolite ranged from 0.007 to 1 at the REL pit, 0.008 to 9 at REF pit 1, and 0.4 to 4 at

REF pit 2. These values probably represent the extremes in the weathered material at the individual sites. The coefficient of permeability of unweathered amphibolite ranged from 0.0001 to less than 0.00004. The coefficient of permeability of the amphibolite indicates that these rocks could act as a barrier to ground-water movement where they remain unweathered in the saprolite. Exposures of the amphibolite at the surface are partially weathered, but moderately weathered fragments were found in wells.

TABLE 8.—*Laboratory analyses of samples of undisturbed saprolite, REL site*

Sample	Depth (feet)	Moisture content (percent)	Void ratio	Specific retention (percent)	Porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)
1-1	4.8-5.0	26.4	1.06	26.9	51.4	24.5	0.007
1-2	4.8-5.0	20.0	.70	16.1	41.2	25.1	.2
2-1 [1]	4.8-5.0	25.3	.89	23.5	47.1	23.6	.01
2-2	4.8-5.0	22.3	.83	17.0	45.3	28.3	.5
3-1	4.8-5.0	26.1	.84	23.6	45.5	21.9	.005
3-2	4.8-5.0	20.7	.75	19.1	43.0	23.9	.3
4-1	3.1-3.3	23.8	.80	21.8	44.5	22.7	.007
4-2 [1]	3.1-3.3	16.8	.64	13.9	38.9	25.0	.5
5	[2] 3.1-3.3	22.9	.84	16.3	45.5	29.2	.008
6	[2] 3.1-3.3	24.7	.87	22.8	46.4	23.6	.01
7	[2] 2.8-3.0	25.1	.81	30.6	44.8	14.2	.002
8	[2] 2.8-3.0	34.3	1.08	18.3	51.8	33.5	.009
9	[2] 4.3-4.5	23.5	.85	20.3	45.8	25.5	.4
10	[2] 3.7-3.9	29.7	1.21	19.7	54.7	35.0	1.0
11	[2] 3.8-4.0	24.4	.92	26.3	47.8	21.5	.02
12	[2] 3.1-3.3	22.8	.74	18.1	42.4	24.3	.005
13-1	[2] 2.8-3.0	19.1	.71	24.1	41.5	17.4	.2
13-2	[2] 2.8-3.0	18.8	.71	22.5	41.5	19.0	.009
13-3	[2] 2.8-3.0	22.4	.76	23.3	43.2	19.9	.009

[1] See fig. 3 for mechanical analyses of samples.
[2] Collected in sides of pit; the depths shown represent the distance below the projected land surface.

At the REL pit an apparent relation exists between the permeability of the material and the direction of schistosity. Sample 13–1 was taken parallel to the schistosity and the permeability was 0.2; sample 13–2 taken normal to the schistosity had a permeability of 0.009; a horizontal sample collected at an angle to the schistosity also gave a permeability of 0.009. The permeability of sample 13–1 was about 23 times greater than that of samples 13–2 and–3. The difference in permeability is caused by the alinement of the flat, platy mica flakes which tend to retard the movement of water normal to the flakes but which offer less resistance to movement of water between the flakes.

In general, the average porosities and specific yields of the saprolite at the REL pit and REF pits 1 and 2 were about the same. At the REL pit the average porosity was 45 percent and average specific yield 23 percent; at REF pit 1 the average porosity was 49 percent and the average specific yield 29 percent; at REF pit 2, the average porosity was 44 and the average specific yield was 30 percent. The samples of hard rock collected at the REF site averaged 4.5 percent for both porosity and specific retention. The specific yield for the samples was zero.

TABLE 9.—*Laboratory analyses of samples of undisturbed saprolite and rock, REF site*

Sample	Depth (feet)	Moisture content (percent)	Void ratio (percent)	Specific retention (percent)	Porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)
SAPROLITE SAMPLES							
REF Disposal Pit 1							
1-1	5.0- 5.2	25.9	1.02	10.1	50.5	40.4	0.009
1-2 [1]	5.0- 5.2	33.3	1.12	16.4	52.9	36.5	.02
2-1	5.0- 5.2	43.3	1.03	38.8	50.7	11.9	.008
2-2	5.0- 5.2	22.6	.97	27.9	49.1	21.2	2
3-1	5.0- 5.2	35.5	.88	20.3	47.0	26.7	.2
3-2	5.0- 5.2	25.3	1.11	26.3	52.0	25.7	8
4	[2] 4.5- 4.7	17.3	.92	13.1	47.9	34.8	2
5 [1]	[2] 4.5- 4.7	13.8	.83	15.2	45.3	30.1	3
6	[2] 4.5- 4.7	14.2	.98	11.4	49.5	38.1	9
7	[2] 4.5- 4.7	14.2	.82	13.3	45.1	31.8	2
8	[2] 4.5- 4.7	16.2	.77	26.0	43.5	17.5	.3
9	[2] 4.5- 4.7	14.6	1.06	20.9	51.5	30.6	3
REF Disposal Pit 2							
1	5.0- 5.2			13.6	41.6	28.0	0.5
2	5.0- 5.2			18.1	43.5	25.4	.4
3	5.0- 5.2			15.4	49.3	33.9	4
4	5.0- 5.2			12.9	42.2	29.3	4
5	5.0- 5.2			10.3	43.5	33.2	2
ROCK SAMPLES							
REF, Operations Building							
SP-1	65 -70			6.1	6.1	0	0.00004
LP-1	65 -70			4.8	4.8	0	.0001
LP-1a	65 -70			4.4	4.4	0	(3)
LP-2	65 -70			2.5	2.5	0	.00004

[1] See fig. 2 for mechanical analyses of samples.
[2] Collected in sides of pit; the depths shown represent the distance below the projected land surface.
[3] Permeability so low that sample could not be saturated under high pressure and vacuum in a 2-month period. Thus, permeability is less than that of samples SP-1 and LP-2.

Particle-size distribution curves for the samples at the REF pits were similar except for REF 1–2 which showed an increase in the clay- and silt-size particles and a decrease in the very fine and the fine sand in relation to the other sample (fig. 2). Sample REF 1–2 also contained coarse and very coarse sand which was not found in the other sample. The distribution curves for the samples taken at the REL pit also were similar except for sample REL 4–2 (fig. 3). The curve for REL 4–2 showed fewer particles in the clay and silt range and an increase in medium and coarse sand. At the REL site the clay content increased with a corresponding decrease in the amount of medium to coarse sand, whereas at the REF site the clay content increased as the proportion of fine to very fine sand decreased.

Table 10 shows the relation between the coefficient of permeability of samples of fresh saprolite from the bottom of the pits and samples from the bottom of the pits which contained a layer of fine silt and clay puddled on the saprolite. Except for sample REF 2–1 which contained large amounts of silt, the permeability of the fresh saprolite was 29 to 71 times greater than that obtained for the top samples collected in the pits. The permeability ratio for REF sample 2–1 was 1:250. The fine silt and clay was washed into the pits during rain storms. The samples were collected at depths of 3.1 to 3.3 and 4.8 to 5.0 feet below the pit bottoms. The upper part of the samples contained the layer of washed-in silt and clay. The samples collected from the lower part of the saprolite were taken immediately below the shallow samples, and the silt and clay layer generally constituted only a small part of the total sample. The flat micaceous particles in the washed-in material settled on the pit bottoms with their flat surfaces normal to the bottoms. Orientation of the micaceous particles in this manner forms a barrier and impedes the downward movement of water into the soil zone below the pits.

TABLE 10.—*Relation between the coefficient of permeability of fresh and of washed-in saprolite, REL and REF sites*

[See tables 8 and 9 for laboratory tests of samples]

Coefficient of permeability (gpd per sq ft)				Permeability ratio
Washed-in saprolite		Fresh saprolite		
REL 1–1	0.007	REL 1–2	0.20	1:29
2–1	.01	2–2	.5	1:50
3–1	.005	3–2	.3	1:60
4–1	.007	4–2	.5	1:71
REF 1–1	.009	REF 1–2	.02	1:2
2–1	.008	2–2	2	1:250
3–1	.2	3–2	8	1:40

Analyses of samples of material from test holes show a decrease in clay and an increase in silt at a depth of 6 to 8 feet below land surface.

The permeability of the fresh saprolite in the REL pit bottom ranged from 0.2 to 0.5 gpd per sq ft (gallons per day per square foot), and the permeability of the samples from REF pit 1 ranged from 0.02 to 8.0 gpd per sq ft. The most consistent high values of permeability were those obtained from REF pit 2, and ranged from 0.4 to 4.0 gpd per sq ft. The large range in permeabilities obtained for the infiltration pits was attributed largely to the fact that the upper part of the samples were contaminated with washed-in silt and clay. As a result the computed permeabilities probably reflect the capacity of the clay and silt to transmit water, and are not necessarily representative of the freshly exposed material in the pits. On the other hand, the samples from REF pit 2 were collected shortly before its completion and therefore represent freshly exposed material not contaminated by clay and silt.

AQUIFER TESTS

In the fall of 1956, nine bailer tests and five discharge-drawdown tests were made in the GNL site, and in the summer of 1958, one pumping test and five bailer tests were made. The purpose of the tests was to obtain information about the water-bearing properties of the saprolite, the discharge and drawdown of wells, and the lateral extent of the cones of influence around the tested wells. Knowledge of the water-bearing properties of the saprolite and of the rate and direction of movement of water in the area is significant both for the development of ground-water supplies and the disposal of liquid waste into the ground.

PUMPING TESTS

Data from the pumping test were analyzed by means of the nonequilibrium formula (Theis, 1935) and the straight-line graphical method (Cooper and Jacobs, 1946) which is a modified form of the nonequilibrium formula.

On June 18–19, 1958, a 30-hour pumping test was made on well 15–9 at the REL site. The bottom of the casing was seated in saprolite. Sixty-two feet of the casing was perforated between depths of 32 and 135 feet. The annular space between the casing and the wall of the hole was filled with washed and graded gravel ranging in size from $\frac{1}{4}$ to $\frac{5}{16}$ inch. The pumped water was discharged into a small gully about 200 feet west of the well, and the discharge was measured by a water meter installed in the discharge line.

The observation wells used in the pumping test varied in size, depth, and construction and included seven 6-inch wells and eight $1\frac{1}{4}$-inch auger holes. Periodic measurements were made of the water level during the 30 hours of pumping and for about 18 hours after pumping ceased. The average pumping rate for the period of the test was about 15.5 gpm.

Before the start of the pumping test, the static water level in well 15–9 was 29 feet below land surface. At the end of 30 hours of pumping the total drawdown in the well was about 50 feet. The cone of depression was elliptical in shape, and its major axis was parallel to the strike of the foliation. The greatest drawdowns occurred in the two deep wells along the plane of schistosity. A maximum drawdown of about 8.4 feet occurred in well 15–38 about 88 feet southwest of 15–9, and a drawdown of 8.9 feet occurred in well 15–34 about 84 feet northeast of 15–9. The water levels in wells about 70 feet downdip from 15–9 were affected slightly, and the water level in wells about 125 feet updip showed small changes amounting to several tenths of a foot. Water-level fluctuations at the site are discussed in detail in the section on water-table maps.

Table 11 shows the coefficients of transmissibility (*T*) and storage (*S*) obtained by application of the nonequilibrium formula to data obtained from the pumping test of well 15–9. The coefficient of transmissibility ranged from 500 to 3,100 gpd per ft, and the storage coefficient ranged from 0.001 to 0.004.

TABLE 11.—*Summary of results of pumping test, REL site*

Well	Depth of well (feet)	Distance from pumped well (feet)	Drawdown		*T* (gpd per ft)	*S*
			End of 17 hrs. (feet)	End of 30 hrs. (feet)		
15-9 (pumped well)	137.7			50	1,500	
15-10	100	77.2	3.8	4.5	1,900	0.001
15-11	100.3	90.7	2.4	2.7	2,500	.003
15-34	86.2	84.1	8.2	8.9	500	
15-35	37.0	37.0	2.4	2.8	2,600	
15-38	75.3	88.1	7.5	8.4	500	.001
15-43	41.0	41.8	2.6	2.8	3,100	.004
15-47	41.0	35.8	1.7	2.1	2,500	
15-52	37.2	136	.14	.16	2,800	.004

Data from the discharge-drawdown tests were analysed by means of the recovery formula developed by Theis (1935, p. 522) which permits the determination of the coefficient of transmissibility from the rate of recovery of the water level in a pumped well after the pump is shut down, or in an observation well close to the pumped well. Table 12 summarizes the results of the recovery tests made at the GNL.

TABLE 12.—*Summary of results of recovery tests*

Well	Well depth (feet)	Site	Trans-missibility (gpd per ft)	Water-bearing material
5-4	400	SDF	60	Hard rock.
12-3	400	SWD	215	Probably hard rock.
15-3	60	REL	1,995	Saprolite.
15-6	400	REL	1,440	Probably saprolite and hard rock.

BAILER TESTS

A total of 14 bailer tests were made at 3 sites, of which 5 tests were made on 2 wells at different depths during drilling, and 9 tests were made after the wells were completed.

Data from the bailer tests were analysed by the bailer method developed by Skibitzke (1958). A summary of the results of the bailer tests is listed in table 13.

TABLE 13.—*Summary of results of bailer tests*

[No. 30-slot screen was used for screen setting]

Well	Well depth (feet)	Casing depth (feet)	Screen setting (feet)	Bailing time (minutes)	Bailing rate (gpm)	Drawdown (feet)	Transmissibility (gpd per ft)	Water-bearing material
SWD site								
12-3	74	47.0	None	11	23	38	1,860	Saprolite.
	245	79.2	None	47	28	181	600	Hard rock.
	400	79.2	None	50	10	38	260	Do.
12-4	81	60.7	50.2-60.7	8	40	11	960	Largely saprolite.
REF site								
11-3	400	62.8	None	32	25	337	2	Hard rock.
11-4	75	44.0	34-44	22	46	24	1,800	Saprolite and hard rock.
11-8	75.4	32.2	None	20	1.8	27.2	1	Hard rock.
11-10	59.1	[1] 59.1	None	50	2	25.9	16	Do.
REL site								
15-6	165	100.0	None	10	7.6	8	710	Saprolite and hard rock.
15-7	93.5	93.5	83-93	215	1.5	16.7	880	Saprolite.
15-13	75.3	[1] 75.3	None	53	5	31.2	470	Do.
15-19	61.8	[1] 61.8	None	36	6.8	22.7	350	Do.
15-20	72.3	[1] 72.3	None	120	4	15.5	620	Do.
SDF site								
5-4	400	42.2	None	57	21.5	312	30	Hard rock.

[1] Slotted casing.

ANALYSIS OF WATER-LEVEL FLUCTUATIONS

Data obtained for the pumping test of well 15–9 were plotted on logarithmic paper and the resulting curves matched, by superposition, with a type curve derived from the Theis nonequilibrium formula.

The field data obtained during the early part of the pumping of well 15–9 match the trace of the type curve, but later data showed a water-level decline at a slower rate, and the data plotted below the type curve. The changes in pumping rate probably explain most of the rise and decline in water levels during the period of the test. When the discharge was maintained at a steady rate for a period of a few hours after pumping was started, the water levels declined at a more uniform rate. Water levels fluctuated erratically the last 13 hours of the test because the pumping rate fluctuated between 1 and 25 gpm.

During the period of the test a small stream about 1,000 feet north and another about 750 feet south of well 15–9 were flowing at a rate of about 200 to 400 gpm. The water levels in wells near the streams did not respond to pumping of well 15–9, and recharge probably did not come from the streams during the pumping period.

It is assumed that wells in this area have penetrated nearly all the saprolite and that the saturated thickness is about 100 feet. Hard rock occurred at a depth of 110 feet in a deep hole about 1,200 feet north of the REL pit. The bottoms of the deep wells at the REL pit probably are within 25 feet of the top of hard rock.

If an aquifer is limited in extent by one or more boundaries, a plot of the field data will depart from the form that would be expected if the aquifer were of infinite extent. The presence of a boundary within the radius tested may cause the curves to deviate above or below the type curve. A deflection of the observed-data curve above the type curve indicates a barrier or discharging area, whereas a deflection of the observed-data curve below the type curve indicates a recharging area. The departure of the observed data from the type-curve trace represents the effects of the boundary of the drawdown in the wells.

The presence of probable boundaries was determined by means of the image-well theory (Ferris, 1948) by using both logarithmic and semilogarithmic plots of observed drawdown and recovery data. Analysis of the data indicate probable changes in the hydraulic properties great enough to approximate the effects of one or more boundaries. However, because of the erratic pumping rate, the shallow depths, and the nearness of the wells to the pumped well the effects of the boundaries could not be determined.

The observational data departed from the type curve during the early part of the test because during the early period of pumping the aquifer did not respond instantaneously as would an aquifer which is uniform and homogeneous.

During pumping, the cone of depression expanded through materials having different hydraulic properties. The 30-hour pumping period was insufficient to adjust the flow between areas of different permeability within any appreciable distance of the pumped well. The material composing the aquifer contains large amounts of silt and clay and has a low permeability; it would be slow to drain and to be recharged. During the early part of the pumping period the water level in a well would decline rapidly, and as pumping continued the rate of water-level decline would decrease because of delayed drainage from the silt and clay. Thus the condition of instantaneous release of water from storage simultaneously with a decline in head was not satisfied. Therefore, a short test would give a computed value of transmissibility that would be too high and a storage coefficient that would be too low.

The response of the water levels in the wells depends upon the degree of connection between the individual silt and clay zones. The unusually small drawdowns obtained in most wells close to the pumped well indicate that the connection between the water-bearing zones is poorly developed. For this reason the water levels in the shallow wells did not respond to the pumping well 15–9 in the same manner as would the deeper wells.

The foliation of the saprolite at the REL site dips about 70° SE. Wells of comparable depths updip and downdip from well 15–9 did not penetrate the same water-bearing zones as those penetrated by the pumped well. On the other hand, wells placed in the plane of schistosity along the strike from well 15–9 probably penetrated the same zones. During the test the greatest drawdowns were along the schistosity; the least were normal to the schistosity. The observed drawdowns in wells updip and downdip from well 15–9 gave values of transmissibility nearly double those computed for wells closer to the pumped well. Computations based on the drawdowns in these wells would therefore give an apparent rather than true value of transmissibility. The depth, direction, and distance of the observation wells from the pumped well have a significant bearing on the results obtained by using observed data in the different wells.

The computed values of transmissibility and storage for most wells probably are only approximate because the observation wells are shallow and near the pumped well. Table 11 lists eight observation wells in which water levels were measured during the test; three of these wells are at distances of 36 to 42 feet from well 15–9, and five wells are at distances of 84 to 136 feet from well 15–9.

Several wells at the REL site were bailed and test pumped upon completion of drilling. The fact that none of the wells tested yielded more than 5 gpm and all the wells were either bailed or pumped dry within a period of 1 to 2 hours indicates material of low permeability in the vicinity of the wells. However, transmissibilities greater than 20,000 gpd per ft were computed for the same wells by using data obtained during the pumping test of well 15–9. The large transmissibilities were due largely to the fact that the wells were shallow ($<$ 75 ft deep) and were updip from the pumped well and therefore did not penetrate the same water-bearing zones found in the pumped well. As a result, the transmissibility values are not a true representation of the water-yielding potential of the saprolite in the GNL area.

Silting or plugging of the horizontal slots in the plastic well casing probably contributed to the high water levels in some auger holes. None of the auger holes were developed upon completion, and the water levels in the wells may have responded sluggishly and may not have reflected the true drawdowns in the wells.

A coefficient of transmissibility greater than 3,000 gpd per ft was discounted as being too high for the type of material tested because of the many factors affecting the results of the pumping test. The computed values of transmissibility ranged from 500 to 3,100 gpd per ft and averaged about 1,500 gpd per ft. The coefficient of storage ranged from 0.001 to 0.004.

The specific capacity of well 15–9 at the end of 30 hours was 0.3 gpm per ft of drawdown. The specific capacity is unusually low in view of the high transmissibility obtained from the test. The excessive drawdown in the well may be the result of partial screening of the water-bearing formation and of head loss through the gravel pack and the perforated slots in the casing. The specific capacity of a well varies with the rate of discharge and the duration of pumping. For purposes of comparison, the average discharge rate during the first day of pumping, divided by the drawdown at the end of the day, was used to compute the specific capacity of several wells. Table 14 gives the specific capacity of the wells tested at the various sites.

TABLE 14.—*Specific capacities of wells in the GNL area*

Well	Pumping rate (gpm)	Drawdown of water level (feet)	Duration of test (days)	Specific capacity (gpm per ft)
SDF				
5–4	2.5	52	1	0.05
REL				
15–3	3.4	1.2	1.0	2.8
15–6	24.0	44.0	.9	.5
15–9	15.5	47.0	1.0	.3
SWD				
12–3	31	112	1	0.3

INFILTRATION TESTS

The infiltration rate (infiltration capacity) of the material in the REL and REF seepage pits was determined by field tests by using single-ring infiltrometers. A total of 11 tests was made during the period June 24 to July 24, 1958. Eight tests were completed at the REL site and three tests at the REF site.

The tests were made by using single-ring infiltrometers 20 inches high and 18 or 24 inches in diameter. Each ring was driven vertically into the soil to a depth of 6 inches. A Mariotte's tube was used to maintain a constant water level of 6 inches in each ring and to measure the quantity of water used hourly throughout the tests. The water used for the tests was obtained from the temporary GNL water-supply well and was almost the same type as that found at both test sites. For several tests the infiltration rate increased slightly during periods when the air and water temperatures were highest and decreased slightly when the temperatures were lowest. Evaporation of the water was minimized by placing an aluminum cover and canvas over the top of the rings.

CONSTRUCTION OF INFILTRATION PITS

REL Pit.—The REL pit was trapezoidal in profile and the slope of the sides was 3 : 5. The dimensions of the bottom were 25 by 60 feet and of the top 40 by 75 feet. The depth of the pit averaged 4 to 5 feet. The bottom was covered with 6 to 8 inches of gravel ranging from ½ to ¾ inch. The sides were not reinforced to prevent clay and silt from washing into the pit.

REF Pit 1.—The REF pit was trapezoidal in profile and the slope of the sides was about 3 : 5. The bottom measured 10 by 30 feet and the top 40 by 60 feet. The depth of the pit averaged 9 to 10 feet. The sides were lapped with slabs of biotite schist to prevent material from washing into the pit. The bottom was bare saprolite without a gravel cover.

REF Pit 2.—REF pit 2 was under construction in July 1958 when the infiltration tests were made.

GEOLOGY OF REL AND REF PITS

The material in the REL pit was saprolite derived from mica-quartz-garnet schist and migmatized granite gneiss. A few joints, quartz stringers, and small pegmatites cut through the saprolite in the pits. Because the material composing the floor of the pit differed considerable within short distances, no two tests were of the same type of material.

Although the biotite-schist saprolite underlying REF pit 2 was more homogeneous than the migmatite underlying the REL pit, it differed somewhat from place to place and contained biotite-garnet schist, quartz-biotite schist, and garnet-biotite-plagioclase schist.

RESULTS OF INFILTRATION TESTS

The results of the infiltration tests at the REL and REF sites are shown graphically in figures 14, 15, and 16 and are summarized in table 15. Because of the heterogeneity of the material in the pits, the results obtained at the different test sites are widely different. However, some of the differences in the values probably resulted from the use of the two different sizes of infiltration ring; in only one test was the infiltration rate obtained with the 18-inch ring larger than that

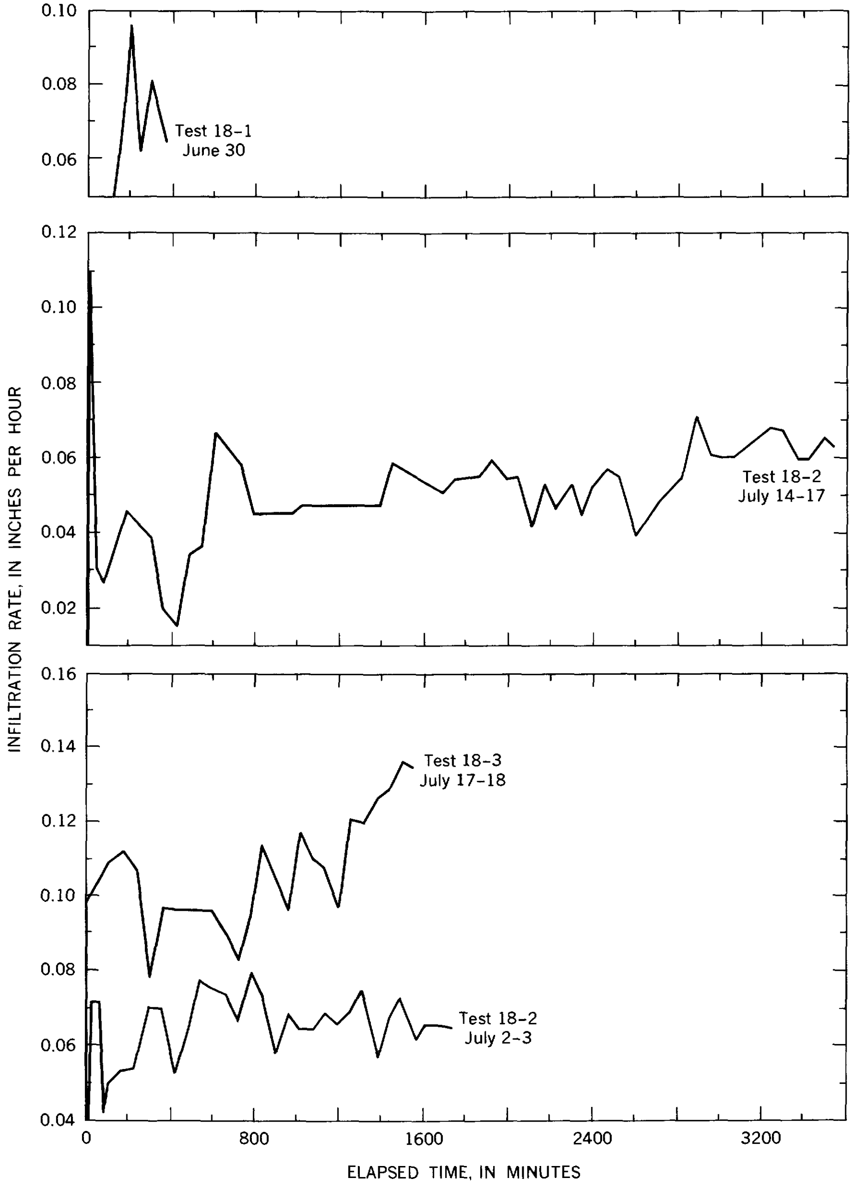

FIGURE 14.—Infiltration rates, 18-inch infiltrometer ring, REL disposal pit.

obtained with the 24-inch ring. (See sample 18–4, table 15.) For several tests, 3-foot auger holes placed 6 to 18 inches from the rings showed no increase in soil moisture during the tests—a feature that indicates vertical flow into and through the saprolite near the infiltrometer rings.

The results obtained for seven tests were affected by heavy rains during the test periods; four tests were made when the soil was dry or moderately wet.

The infiltration rates obtained at the REL site by use of the 18-inch rings were consistent for three tests (two setups) on the material in the south end of the pit (tests 18–1 and 18–2). The 6- and 29-hour tests were made when the soil was dry, and the 59-hour test was made when the soil was wet. The infiltration rate for the three tests averaged about 0.06 inches per hour.

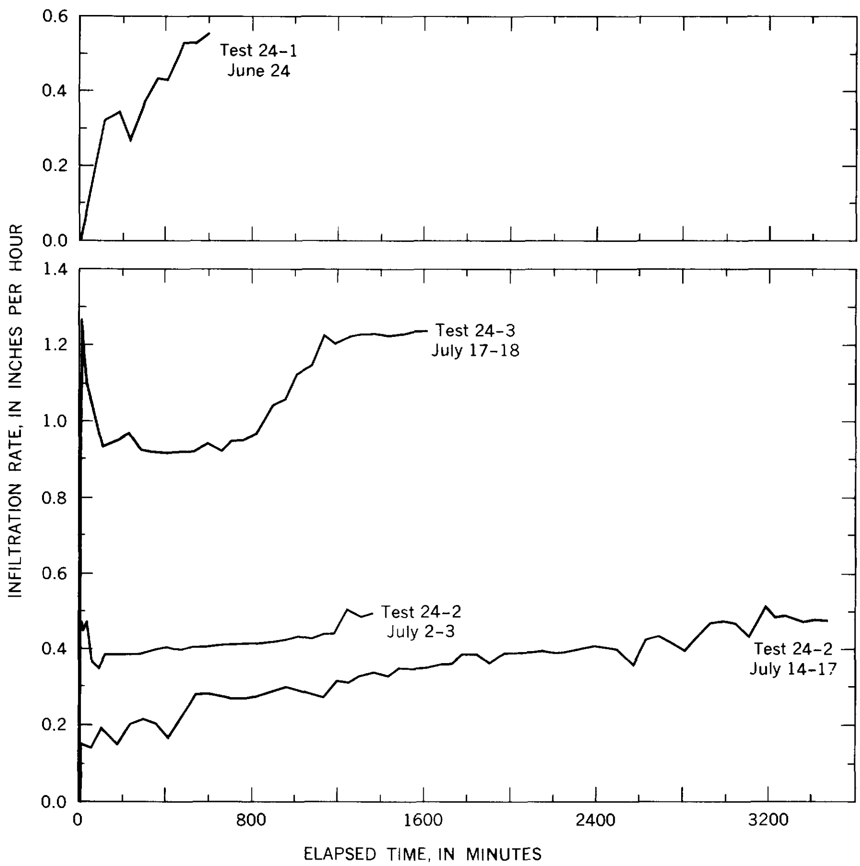

FIGURE 15.—Infiltration rates, 24-inch infiltrometer ring, REL disposal pit.

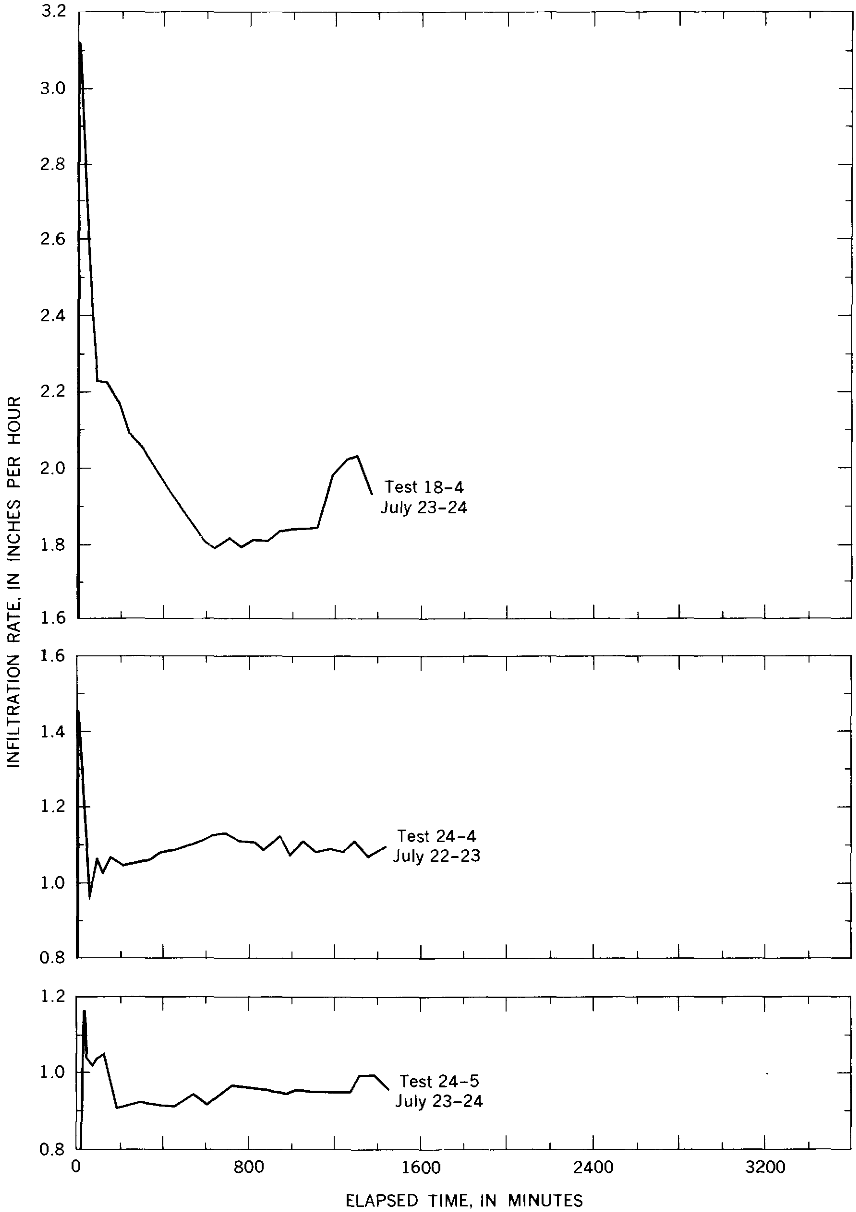

FIGURE 16.—Infiltration rates, 18- and 24-inch infiltrometer rings, REF disposal pit 2.

TABLE 15.—*Infiltration tests, REL and REF disposal pits*

Test	Type of material	Diameter of infiltration ring (inches)	Date of test (1958)	Duration of test (hours)	Rate of infiltration at end of test (inches per hour)
	REL pit				
18-1	Saprolite containing kaolin, quartz, and mica	18	June 30	6	0.06
18-2	Mica-quartz-garnet schist saprolite containing some kaolin.	18	July 2-3	29	.06
18-2 [1]	do	18	July 14-17	59	.06
18-3	Mica-quartz-garnet schist saprolite containing some kaolin; upper half of sample clay and silt.	18	July 17-18	26	.13
24-1	Mica-quartz-garnet schist saprolite containing abundant kaolin; upper part of sample clay and silt, quartz pebbles, and mica.	24	June 24	10	.55
24-2	Mica-quartz-garnet schist saprolite containing some kaolin; upper third of sample clay and silt.	24	July 2-3	23	.49
24-2 [1]	do	24	July 14-17	59	.48
24-3	Mica-quartz-garnet schist saprolite and granite-gneiss saprolite; upper half of sample clay and silt.	24	July 17-18	27	1.24
	REF pit 2				
18-4	Biotite-garnet-schist saprolite	18	July 23-24	23	1.94
24-4	Biotite-garnet-schist saprolite; contains secondary limonite cementation and dark micaceous fracture coatings.	24	July 22-23	23½	1.09
24-5	Biotite-garnet-schist saprolite and biotite-schist saprolite.	24	July 23-24	24	.96

[1] Rerun test of sample.

The infiltration capacity for three tests (two setups) determined by using the 24-inch ring in the north end of the REL pit ranged from 0.48 to 0.55 inches per hour (tests 24–1 and 24–2). The highest infiltration rate (0.55 in. per hr) was obtained for the 10-hour test. The time of application was of such short duration that the value obtained probably represents the maximum infiltration rate. The other two tests were made with the ring in the same location but under different conditions of soil moisture. The infiltration rate at the end of 23 hours for the dry material was 0.49 inch per hour. The infiltration rate for the wet material increased steadily throughout the test, and at the end of 59 hours it was 0.48 inch per hour, about the same as for the shorter test.

The infiltration rate for the test made in the south end of the pit (test 24–3) was 1.24 inches per hour, or about 2 to 2½ times greater than that obtained at the other test sites. The sample tested was a granite-gneiss saprolite and mica-quartz-garnet schist, a material different from others tested at the REL site, and was in a localized zone of high permeability.

The infiltration rate obtained at the REF site for the one test made by using the 18-inch ring was 1.94 inches per hour, and for two tests made by using the 24-inch ring it was 0.96 and 1.09 inches per hour.

The material in the 18-inch ring consisted of biotite-garnet schist saprolite and was cut by a curved joint. The material tested in the 24-inch rings was biotite-garnet-schist saprolite and biotite-schist saprolite. However, for test 24–4, thin limonite-rich zones occurred in the tested section. The saprolite in the ring was cut by fractures whose surfaces were coated with very fine flakes of a micaceous mineral.

DISPOSAL OF LIQUID WASTES INTO PITS

The liquid waste-disposal systems at the GNL provide for release to the infiltration pits of wastes containing as much as 10^{-5} microcuries per milliliter of gross beta-gamma activity (Edgerton and Bowen, 1959, p. 1). Edgerton and Bowen listed the following radioactive nuclides found in the Materials Testing Reactor primary coolant-process water: N^{16}, Al^{28}, Mg^{27}, Mn^{56}, F^{18}, Na^{24}, Cu^{64}, Cd^{115}, Cr^{51}, Ni^{65}, Fe^{59}, Co^{58}, and Co^{60}; radionuclides found in the RER primary coolant water include Si^{31}, Ag^{110}, Zn^{65}, and others.

The estimated annual volume of liquid waste to be discharged at the REL site is 1 million gallons, but the total activity is expected to be less than 1 curie per year. Two 20,000 gallon hold tanks for liquid waste are included in the waste-disposal system. No demineralizers are provided in the system. Depending upon activity level, the waste may be released to an open ditch, pumped into an uncovered surface-infiltration pit, or pumped into tank trucks for storage elsewhere.

The total capacity of the REL pit was about 65,000 gallons. The capacity of the bottom 6 inches of the pit, assuming a porosity of 20 percent for the gravel bed, was about 1,150 gallons, and of the bottom 1 foot it was about 7,200 gallons.

The estimated volume of waste resulting from the REF operation is 300,000 gallons per year. The total activity contained under normal operation is estimated to be less than 1 curie per year, and is mainly composed of activated products from the reactor cooling system and, to a lesser extent, building contamination. Depending on the concentration, the waste may be released directly to the Etowah River, pumped into an uncovered surface-infiltration pit, or allowed to decay in a 150,000-gallon hold and drain tank or two 5,000-gallon waste decay tanks. The REF disposal system allows recirculation of the waste through a waste-cleanup demineralizer prior to discharge into the river or pit.

At an infiltration rate of 0.48 inches per hour and a head of 6 inches, the REL pit would take about 450 gph (gallons per hour) or about 7.5 gpm. At an infiltration rate of 1.2 inches per hour the pit would take about 1,150 gph or about 19 gpm. The minimum infiltration rates of 0.06 and 0.13 inches per hour obtained by using the 18-inch ring gave values of 60 and 120 gph, or about 1 to 2 gpm. Although the infiltration rate may be this low in some parts of the pit, lower values obtained by using the 18-inch ring for all the tests indicates that these rates may be somewhat less than the actual values. The results obtained by using the 24-inch ring probably are more representative of the infiltration rates of the material underlying the pit.

The infiltration rates at REF pit 2 were slightly higher than those obtained at the REL pit. The minimum infiltration rate of 0.96 inch per hour is equivalent to a rate of about 13 gpm, and the maximum infiltration rate of 1.94 inches per hour is equivalent to about 32 gpm.

The infiltration rates obtained at the pits varied considerably because the permeability of the material differs within short distances. In order to dispose of any appreciable quantities of water in the pits, it would be necessary to maintain a higher head in the pits than that used during the infiltrometer tests. Moreover, the higher the level of water in the pit, the greater the surface area through which infiltration can take place. The disposal of 3 to 5 gpm of waste into the pits can be done by maintaining a pressure head ranging from 12 to 30 inches. For greater head differentials the rate of flow would be greater. The capacity of the pits to take water will decrease as the bottoms become silted with fine material washing off the unprotected sides. Therefore, the sides of the pits should be protected as was done at REF pit 1.

The rate of infiltraton depends primarily on the permeability of the sediments and on the head of water in the pit. At the GNL site the permeability of the saprolite increases with depth, and the controlling factor is the less permeable material in the upper part of the saprolite. The presence of quartz veins and fractures will complicate the ground-water flow pattern and may increase the rate of infiltration. The rate and direction of movement of the water will depend upon the extent and interconnection of the fractures. The infiltration of large quantities of water into the zones of aeration and saturation will be sufficient to create a ground-water mound below the pits.

SILTING OF REL PIT

Because of the design and construction of the REL pit, large quantities of fine sand, clay, and silt were eroded from the sides during periods of heavy rains and deposited on the pit bottom. The slope of the sides was about 3:5. The total surface area of the sides was about 1,750 square feet, all of which was exposed to the elements. Because provisions were not made to protect the sides, as was done at REF pit 1, the fine-grained material flowed unchecked into the pit during each rain. Following the heavy rains of July, clay and silt covered the gravel at the bottom of the pit. The silt that covered the gravel bed reduced the effectiveness of the pit as a seepage basin for the disposal of liquid waste, and probably reduced its potential capacity by less than half.

The effect of silt on the infiltration rate was aptly illustrated by the silting of several small test pits constructed at the GNL area in 1956. The pits were left unprotected and the bottoms filled with 6 to 10 inches of fine sand and silt. The fact that in the summer of 1958 these pits retained water for several days after a rain indicates that the fine-grained material retarded downward movement of water.

Silting of the pits may eventually decrease the infiltration rates to such a point that the pits would not handle efficiently all the waste discharged at the REL and REF sites. Then a higher water level in the pits could be maintained until necessary to clean the gravel fills.

If the volume of waste discharged at the GNL is increased substantially, an additional pit will be needed at the REL and REF sites. The second pit would be used as a standby reservoir to take the overflow at a specified level from the first pit.

DISPOSAL OF WATER INTO REF PIT 1

REF pit 1 was on the side of a steep hill about 500 feet northeast of REF pit 2. On the west side the pit was cut into the hillside; on the east side the wall of the pit was earthfill from the excavation. On the east the ground sloped downward about 20 feet in a distance of 30 feet, and on the west the ground sloped upward about 15 feet in 50 feet. A small spring discharged 2 to 3 gpm in a draw about 400 feet south-southeast of the pit.

To test the durability of the pit under operational conditions, to determine the infiltration rate of the material in the pit, and to check the probable areas of leakage, water was dumped into the pit from a truck-mounted, 1,000-gallon capacity tank. The truck was operated 5 days a week, weather permitting, for about 2 months. An estimated 200,000 gallons of water was dumped into the pit at the rate of 6,000 gpd during the days the tank truck was in operation. Water was not hauled on weekends and on days when the roads were made impassable by heavy rains. Water for the test was obtained from the surface-water treatment plant on the Etowah River.

Ten 3-inch holes were hand-augered to depths of about 5 feet on the east side of the pit in order to determine the rate and direction of movement of water from the pit. Six of the holes were about 25 feet east of the pit and were constructed in the material constituting the earth-filled embankment; four holes were about 100 feet east of the pit and were augered into undisturbed soil and saprolite. Because of the steep slopes north and south of the pit, and the exposed quartz veins in the material west of the pit, auger holes could not be drilled in these areas. No water was observed in the holes during the test period.

Four days after the test was begun, a damp area occurred at the downhill base of the pit, and in a period of 1 week, the damp area widened and at least three others occurred on the east side of the pit near the top of the earth fill.

During most of the first month the infiltration rate of the pit averaged about 6 gpm. Evaporation losses were not considered in computing the infiltration rate because of the erratic discharge of water into the pit. During the second month the infiltration rate averaged about 3 gpm. Precipitation during the second month of 12.29 inches caused silting of the pit bottom from washed-in material to a depth of about 3 inches. Sealing of the pit bottom and a decrease in the evaporation losses caused the reduction of the infiltration rate. The rainfall also caused erosion and gullying of the earthfill on the east side of the pit. The seepage area along the east side of the pit grew steadily during the test. This growth, combined with the erosion, would make the pit impractical for the disposal of radioactive liquid waste.

WATER-LEVEL CONTOUR MAPS

Three water-table contour maps were constructed for the REL and REF sites in order to determine the shape and slope of the water table, the direction of ground-water flow, areas of discharge, ground-water divides, and the effects of pumping. In addition, the water-level maps were used in conjunction with other hydrologic data to determine the rate of ground-water movement in each site.

The contour lines were drawn through points on the water table having the same altitude, and these show the configuration of the water surface, just as topographic maps show the shape of the land surface. The general direction of ground-water movement is normal to the contour lines.

Plate 2 shows the configuration of the water table at the REL site during a period when no rain had occurred for several days and the water levels were declining. Plate 3 represents the change in the shape and slope of the water table at the end of 30 hours of pumping one well at an average rate of 15½ gpm. The construction of the latter map was based on the drawdowns in auger holes and in test wells deeper than 65 feet because the shallow auger holes and test wells apparently did not reflect the true changes in water levels during the pumping test.

The water-table contour map (pl. 2) indicates that the general direction of ground-water movement in the REL site is northwest and southeast from a ground-water divide that occurs under the topographic ridge about 150 feet southeast of the pit. The slight irregularities in the shape of the contour lines in the vicinity of the pit are due largely to the differences in head in the shallow and deep wells, but differences in the permeability and thickness of the saprolite also affect the shape of the water table. The slope of the water table southeast of the ground-water divide is about twice as great as the slope northwest of the pit.

The steepest ground-water gradients in the site are southeast and northwest of the pit; the shallowest gradients are in the vicinity of and northeast of the pit. In general, the slope of the water table varies inversely with the permeability of the water-bearing material; where the materials are relatively impermeable, the slope of the water table is steep; where the material is permeable, the slope of the water table is shallow.

In the area between wells 15–9 and 15–37 (pl. 2) the slope of the water table was approximately 4 feet in 140 feet. In a distance of about 300 feet north of well 15–9, in the vicinity of well 15–13, the slope steepens to 10 feet in 220 feet. About 225 feet northwest of the pit the slope is 12 feet in 250 feet, and southwest of the pit in the area between wells 15–18 and 15–19 the slope is 14 feet in 160 feet.

In June 1958 the altitude of the water table in the immediate vicinity of the REL pit was 1,080 to 1,083 feet, and the altitude of the ground-water divide southeast of the pit was about 1,086 feet (pl. 2). The mounding of the water table beneath the pit would cause a southwestward shifting of the divide, and some of the ground water then would move toward the southeast.

Other probable areas of potential ground-water seepage are the intermittent springs between wells 15–16 and 15–17, about 300 feet west of the pit.

During the 30-hour pumping test of well 15–9 an elliptical cone of depression was formed in the water table in the saprolite, and the major axis of the cone of depression was parallel to the strike of the foliation. Along the minor axis the slope of the northern part of the cone was nearly equal to the dip of the foliation, whereas along the major axis the slope of the cone was much more gentle; a greater permeability along the strike of the foliation is thus indicated.

The cone of depression produced by pumping well 15–9 was about 250 feet long and about 100 feet wide. The cone of depression was not nearly as elliptical as that shown in plate 3. The water levels in the shallow and deep wells updip and downdip from well 15–9 responded differently during the pumping period.

The pumped well 15–9 was completed by using three 20-foot sections of perforated casing placed at different depths in the well. None of the observation wells were drilled into all the material tapped by well 15–9. As a result, the shallow wells tapped material that was less permeable than the underlying material, and when well 15–9 was pumped the water levels in the shallow wells declined as a result of downward drainage into the more permeable material. The drawdowns obtained in the shallow wells, therefore, did not represent the same change in water levels as those which would occur in wells that completely penetrated the same material as the pumped well. The unusually small drawdowns in many wells during the pumping test were due largely to the shallow depths of the wells.

Plate 4 represents the configuration of the water table at the REF site during the same period as shown for the REL site (pl. 2). Water was not tapped in any of the auger holes and test wells drilled in the immediate vicinity of REF pit 2; as a result, the configuration of the water table was shown only where data were obtained. In the area between wells 11–19 and 11–45 (pl. 4), the direction of movement was north-northwestward and the hydraulic gradient was about 15 feet in 180 feet. In the vicinity of wells 11–46 and 11–53, the flow was in a southwesterly direction and the hydraulic gradient was 25 feet in 400 feet. Near well 11–11, ground-water movement is northeastward; however, data are not available for more positive determination. A perennial spring (11-S1), about 800 feet northwest of the pit, flows an average of 7 to 9 gpm. The computed ground-water velocity in this area is about 0.12 to 0.97 feet per day. Therefore, water from pit 2 may arrive at the spring in a period of about 800 to 6,700 days (2 to 18 years).

Another area of probable ground-water discharge was the small draw about 450 feet south and southwest of the pit in the vicinity of wells 11–51 and 11–53. The discharge of ground water also may occur in a draw about 400 feet east of the pit. Several small springs occur in this area, and throughout the summer of 1958 water flowed from spring 11-S6.

The permeability along the major northwest joints is not known, but because they are partially open fractures, the permeability is thought to be relatively great. These joints are approximately normal to the foliation and are fed by water moving along the strike of the schistosity. Because the movement of water is generally parallel to the schistosity in the vicinity of pit 2 and because the fractures are highly permeable, water will move rapidly along any joints which cut these rock units. If movement of water takes place along these joints to a surface outlet, the velocities will be greater than the computed velocities and water will emerge at the surface in less time.

RATE OF GROUND-WATER MOVEMENT

An approximation of the rate of movement of ground water at the REL and REF sites was computed using the following formula given by Wenzel (1942, p. 71, equation 50):

$$P=\frac{7.48\ pvc}{I}$$

where

P=permeability gpd per sq ft,
p=porosity, in percent,
v=velocity, in feet per day,
c=temperature of ground water in °F,

and

I=slope of water table, in feet per foot.

The computations were based on the minimum and maximum permeabilities computed from the pumping and bailer tests, the hydraulic gradients at each site, and the porosity of the saprolite. The porosity of the material averaged 45 percent at the REL site and 44 percent at the REF site. The permeability of the material ranged from 5 to 40 gpd per sq ft. The temperature of the ground water was 60° F.

The maximum rate of ground-water movement in the REL and REF sites is about 1 foot per day. The computed velocity reflects the movement of water in the saprolite near the disposal pits, but other factors such as changes in the composition of the saprolite, changes in hydraulic gradients, and the presence of localized permeable quartz veins may change the velocity of the ground water. In addition, the volume of waste discharged into the pits will cause the buildup of ground-water mounds beneath the pits and may change the direction and rates of ground-water movement near the pits. However, the increased hydraulic gradients in the immediate vicinity of the pits probably would not affect the slope of the water table at distances from the pits.

Under the conditions assumed, a rate of 1 foot per day will require several years before the waste is released to surface streams, which will allow sufficient time for the short-lived activation products to decay. However, several perennial springs about 300 feet west of the REL pit are likely sources for waste to emerge at the surface in less than a year, especially during the wet season when ground-water levels are high and spring discharges are maximum.

On the basis of tests made at the REL and REF sites for different types of material, a maximum velocity of 1 foot per day is probably representative of the rate of ground-water movement in the saprolite.

Slight increases in velocity probably would not affect the concentration of waste discharged into surface streams and springs because other factors such as the ion exchange and filtration action of the saprolite and the dilution effects of ground and surface waters will further reduce the activity per unit volume of effluent.

The computed ground-water velocity in feet per day is shown in table 16.

TABLE 16.—*Computed ground-water velocities, REL and REF sites*

Wells (pls. 2, 4)	Permeability (gpd per sq ft)		Hydraulic gradient (ft per ft)	Porosity (percent)	Velocity (ft per day)	
	Minimum	Maximum			Minimum	Maximum
REL						
15-15 to 15-14	5	40	0.03	45	0.04	0.35
15-14 to 15-22	5	40	.05	45	.07	.59
15-19 to 15-18	5	40	.09	45	.13	1.06
15-23 to 15-17	5	40	.05	45	.07	.59
REF						
11-19 to 11-45	5	40	0.08	44	0.12	0.97
11-46 to 11-53	5	40	.06	44	.09	.73

QUALITY OF WATER

Beginning in 1956, chemical analyses were made of water collected from 31 wells, 4 springs, and 3 streams on or in the immediate vicinity of the area. Radiochemical determinations were made on four samples from wells, and on one sample from Shoal and Amicalola Creeks, and the Etowah River. A total of 35 chemical and 8 radiochemical analyses were made during the period of investigation. All analyses were made by the U.S. Geological Survey.

Table 17 lists the chemical analyses of water from wells, springs, and streams in the GNL and adjacent areas. Figure 17 represents graphically the principal mineral constituents in the water from selected wells and springs in the waste-disposal sites.

Specific limits for hardness have not been established, but the following gradations are generally recognized and are used in this report:

Degree of hardness	*Hardness as $CaCO_3$ (ppm)*
Soft	60
Moderately hard	60–120
Hard	121–200

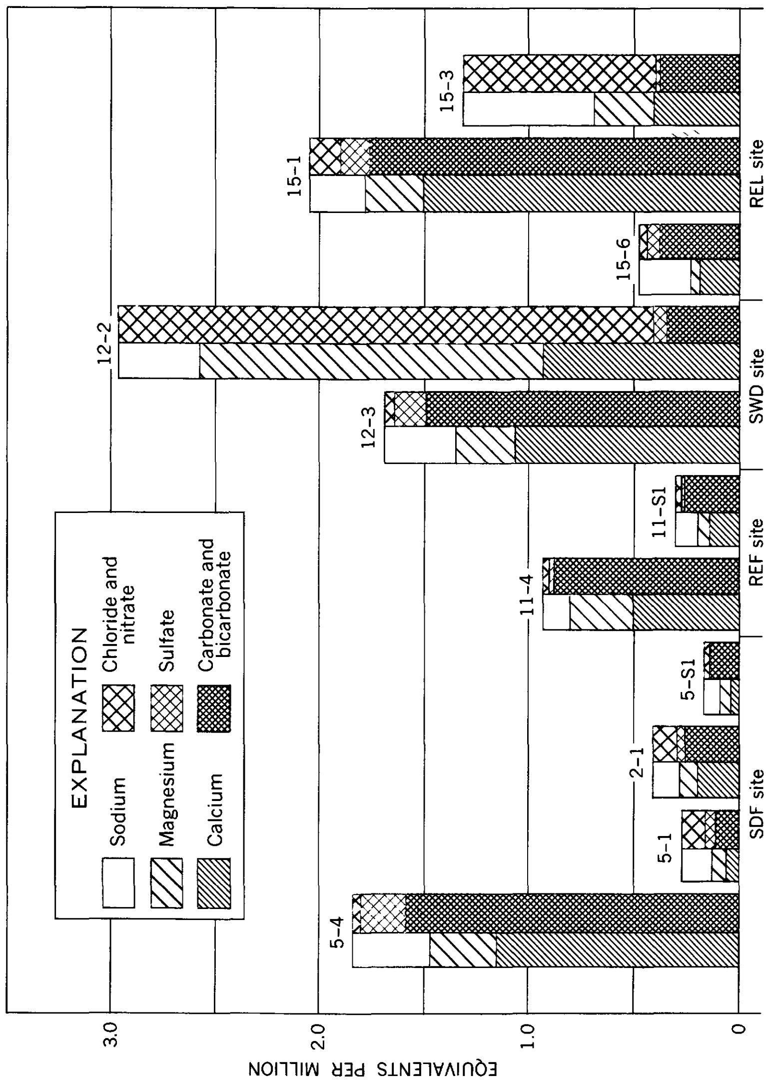

FIGURE 17.—Composition of water from selected wells and springs in the GNL area.

TABLE 17.—*Chemical analyses of water from wells, springs, and streams in the Georgia Nuclear Laboratory and adjacent areas, Dawson County, Ga.*

[Analyses by U.S. Geological Survey. Results in parts per million except as indicated]

Well, spring, or stream	Date of collection	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromos at 25° C)	pH	Color
WELLS																									
Shielding device facility																									
1-1	7-12-56	59	6.3	----	0.38	----	----	----	3.2	1.2	3.6	1.6	----	22	0.0	2.0	0.0	0.2	----	37	13	0	49	6.8	12
1-2	7-12-56	69	7.2	----	.27	----	----	----	2.4	.5	2.1	1.3	----	15	.2	2.5	.0	.3	----	24	8	0	34	6.8	7
1-3	7-12-56	66	6.7	----	.26	----	----	----	37	2.3	9.5	2.3	----	120	1.2	3.0	.0	8.8	----	135	102	4	238	7.6	2
2-1	7-12-56	59	11	----	5.9	----	----	----	4.0	1.0	2.4	1.4	----	16	.5	2.5	.2	3.2	----	35	14	1	42	6.6	5
5-1	7-12-56	60	11	----	.45	----	----	----	1.2	.7	2.3	1.7	----	7	2.0	4.5	.3	.8	----	20	6	0	30	6.3	14
5-4 [1]	10-31-56	66	22	0.0	1.3	0.15	0.05	0.28	23	3.8	5.0	4.2	0.2	97	10	.9	.2	.1	0.1	117	73	0	168	7.9	20
Radiation effects facility																									
11-4	10-18-56	69	21	0.0	0.31	0.85	0.00	0.04	10	3.6	2.7	0.6	0.1	56	0.2	1.3	0.1	0.0	0.1	66	40	0	90	6.9	2
7	7-31-58	----	13	----	.06	----	----	----	21	2.2	4.5	9.4	----	95	6.0	2.0	.1	.0	----	105	62	0	171	7.1	----
9	7-31-58	----	12	----	.78	----	----	----	10	2.7	4.8	4.5	----	60	2.0	2.8	.1	.2	----	76	36	0	110	6.8	----
10	7-31-58	----	3.5	----	.12	----	----	----	.8	.6	.8	.9	----	10	1.5	.5	.0	.0	----	13	4	0	20	5.6	----
11	7-31-58	----	12	----	.09	----	----	----	3.0	1.3	4.5	2.5	----	31	1.8	1.8	.1	.0	----	30	13	0	53	6.5	----
Solid-waste disposal																									
2-1	7-11-56	----	28	----	0.01	----	----	----	19	20	8.7	0.8	----	22	3.0	59	0.0	44	----	194	130	112	334	6.8	2
3 [1]	10-16-56	62	26	.6	.30	.35	1.2	.00	22	3.2	7.0	1.4	.2	92	8.6	1.0	.2	.2	0.1	107	68	0	164	7.8	2

TABLE 17.—*Chemical analyses of water from wells, springs, and streams in the Georgia Nuclear Laboratory and adjacent areas, Dawson County, Ga.*—Continued

Well, spring, or stream	Date of collection	Temperature (°F)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (residue at 180° C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromos at 25° C)	pH	Color
Clark Road, southwest of radiation effects facility																									
13-1	7-11-56	60	8.4	----	1.8	----	----	----	2.4	3.2	6.1	2.0	----	8	3.0	8.5	0.1	6.4	----	44	19	12	77	6.1	7
2	7-12-56	60	5.9	----	4.9	----	----	----	2.4	1.5	1.4	1.6	----	13	3.2	2.0	.0	3.6	----	33	12	2	36	6.4	160
14-2	7-17-56	60	9.3	----	.03	----	----	----	3.6	2.4	14	2.6	----	4	6.0	16	.1	24	----	80	19	16	125	5.4	5
3	7-11-56	----	5.9	----	2.8	----	----	----	12	1.0	1.4	1.9	----	41	3.2	1.0	.1	2.2	----	48	34	0	76	7.4	3
Radiation effects laboratory																									
15-1	7-13-56	60	7.9	----	0.64	----	----	----	30	3.4	2.5	6.4	----	105	7.0	3.5	0.1	2.9	----	116	89	3	199	7.4	2
3[1,2]	5-3-56	60	11	----	1.3	----	----	----	8.2	3.6	12	4.1	----	23	.8	18	.1	27	----	97	36	17	159	6.6	20
6	10-16-56	62	27	.0	.11	.00	.00	.00	4.0	.6	4.8	.7	.2	22	2.6	.5	.1	1.2	.4	53	12	0	42	6.9	3
9	7-31-58	----	5.1	----	.02	----	----	----	.8	1.1	1.2	1.2	----	10	2.8	1.0	.0	.0	----	16	6	0	24	5.8	----
13	7-31-58	----	5.0	----	.03	----	----	----	.6	.5	.5	.7	----	8	.8	1.0	.0	.0	----	12	4	0	16	5.7	----
17	7-31-58	----	15	----	.16	----	----	----	3.2	1.0	5.0	1.3	----	26	2.8	.5	.0	.0	----	48	12	0	48	6.6	----
19	7-31-58	----	3.9	----	.05	----	----	----	.4	1.0	.9	1.0	----	8	.5	.5	.0	.2	----	19	5	0	16	5.7	----
Settlement northeast of Nuclear Support Laboratory																									
1	7-17-56	62	9.0	----	0.12	----	----	----	2.8	1.0	2.8	1.1	----	13	5.8	2.5	0.0	0.4	----	32	11	0	41	6.7	2
2	7-17-56	60	5.8	----	.05	----	----	----	5.6	7.3	75	16	----	2	8.2	120	.1	75	----	314	44	42	588	4.9	2
3	7-17-56	59	5.1	----	.03	----	----	----	2.4	1.9	30	2.4	----	4	5.5	36	.1	27	----	112	14	10	187	6.4	4
4	7-17-56	57	7.0	----	.12	----	----	----	2.8	2.2	3.2	2.4	----	8	4.2	6.5	.0	6.8	----	39	16	10	56	6.2	2
5	7-17-56	65	16	----	.02	----	----	----	2.0	1.2	2.6	1.0	----	14	3.2	1.0	.0	1.1	----	35	10	0	28	6.8	3

Sweetwater community

8	7-12-56	66	6.3	----	2.0	------	------	------	1.2	0.5	3.2	0.6	----	7	0.0	4.0	0.0	3.1	------	22	5	0	30	6.4	3
9	7-12-56	67	4.4	----	4.4	------	------	------	1.2	.7	1.4	1.2	----	6	.2	2.0	.0	1.1	------	15	6	1	23	6.6	4

SPRINGS
Shielding device facility

2-S1	7-12-56	58	11	----	0.05	------	------	------	1.2	0.5	1.8	0.8	----	11	0.5	1.0	0.1	0.3	------	23	5	0	19	7.1	2
5-S1	7-12-56	65	10	----	.24	------	------	------	.8	.5	1.4	.6	----	9	1.5	.5	.1	.3	------	20	4	0	14	-----	8
5-S2	7-12-56	65	12	----	.11	------	------	------	1.2	.5	1.4	.7	----	10	1.2	.5	.0	.2	------	23	5	------	17	6.8	2

Radiation effects facility

11-S1	7-17-56	60	13	----	.03	------	------	------	2.8	0.7	2.0	1.1	----	16	0.5	1.0	0.1	0.2	------	29	10	0	27	6.8	4

STREAMS

Etowah River [1]	5- 3-56	63	8.8	0.0	0.96	0.12	0.00	0.00	1.0	0.3	1.2	0.7	0.1	9.2	0.2	0.3	0.1	0.3	0.0	18	4	0	19	6.5	70
Shoal Creek [1]	5- 3-56	----	6.8	.0	.42	.09	.00	.00	.8	.1	1.0	.8	.1	6.8	.2	.5	.0	.4	.0	14	3	0	16	6.5	70
Amicalola Creek [1]	5- 3-56	60	7.2	.0	.62	.09	.00	.00	.7	.0	1.0	.7	.0	6.2	.2	.3	.0	.3	.0	13	2	0	14	6.5	90

[1] See radiochemical data in table 18.
[2] Ignition loss: Well 15-3, 10; Amicalola Creek, 16; and Etowah River, 13.

GEOCHEMICAL RELATIONS

Most ground water in the GNL area is soft to moderately hard, and the dissolved solids content generally averages less than 100 ppm (parts per million). The figures listed in table 17 are not necessarily the extremes for water from various sources but are believed to be generally representative. Most of the analyses represent calcium and sodium bicarbonate types of water. The observed pH ranges from 4.9 in shallow well 2 northeast of the Nuclear Support Laboratory to 7.9 in well 5–4 in the SDF site. Most chemical constituents are well below the concentration limits recommended by the U.S. Public Health Service (1961) in its drinking-water standards. The iron content of water samples from 12 wells and 3 streams exceeds the recommended upper limit of 0.3 ppm iron for water used in public carriers. The copper content of water from well 12–3 (1.2 ppm) exceeds the recommended limit of 1 ppm. The manganese content exceeds 0.3 ppm for samples from wells 12–3 and 11–4, and it may be just as high in other samples in which manganese was not determined.

High nitrate (44 ppm or more) and chloride (59 ppm or more) contents of water from the uncovered dug wells indicate contamination and pollution by surface agents such as decomposing vegetation and animal remains. None of the wells had been properly protected against surface contamination, and some of the wells were close to barns and outdoor privies.

The most distinctive differences in the chemical quality of water appears to have been caused by the pollution of dug wells. Water from wells on hilltops does not appear to be different from that obtained in the lowlands. In general, all the analyses show that ground water in the GNL area generally is soft, is well below the recommended limit of 500 ppm dissolved solids, and contains 0.01 to 5.9 ppm of dissolved iron. The constituents are those that might be expected in crystalline rocks in a warm humid climate.

In the REL site, water samples from two dug wells and five drilled wells were tested. The water from well 15–1 is a calcium bicarbonate type water and has a dissolved-solids content of 116 ppm, which is high for this area. The hardness of 89 ppm is considerably above the average of 30 ppm computed from 19 samples from dug wells in the area. Water from well 15–3 is of the sodium chloride type and has a hardness of 36 ppm and a dissolved-solids content of 97 ppm. The nitrate content of the sample is high (27 ppm) compared to the dissolved-solids content. Water from well 15–6 is of the sodium and calcium bicarbonate type, has a low dissolved-solids content, and has a hardness of only 12 ppm. All three wells are in the area of the migmatized rocks; but wells 15–1 and 15–3 are shallow wells bottomed in the saprolite, whereas well 15–6 is 400 feet deep and penetrated about 300 feet of solid rock.

Ground water from wells 15–9, 15–13, 15–17, and 15–19 is from saprolite derived from the weathering of a granitized quartz-mica schist. The water is soft (4 to 12 ppm), acidic (pH, 5.7 to 6.6), and low (12 to 40 ppm) in dissolved solids. Water from well 15–17, north of the disposal pit, contains more than twice the dissolved solids of water from other sources, and is similar to water from well 15–6. These wells are on the strike of the beds, with reference to each other, and the analyses indicate that the lithology to the north is different from that in the vicinity of the pit and that the quality of the water is different in the amphibolite units to the north. Wells 15–6 and 15–17 contain comparable quantities of silica, iron, and bicarbonate.

Ground water from the pit area (15–9, 15–13, and 15–19) contained less than half the dissolved solids and hardness, one-third the silica and iron, and had a lower pH than water from wells 15–6 and 15–17.

None of the samples at REL contained appreciable fluoride, and chloride did not exceed 1 ppm.

In the REF site, five wells and one spring were sampled. Water from the spring was soft, had a dissolved-solids content of 13 to 105 ppm, and was of the calcium bicarbonate type. The spring appears to flow from the quartz-mica schist. Water from well 11–4 was also of the calcium bicarbonate type, and had a dissolved-solids content of 66 ppm and a hardness of only 40 ppm. The well was 75 feet deep, and its water represents a composite sample from the amphibolite schist and the saprolite on top of the schist.

Ground water from wells 11–7, 11–9, 11–10, and 11–11 is from saprolite derived from garnitiferous-mica schist in a lithologic zone characterized by amphibolite schist and gneiss. The water is soft to moderately hard (4 to 62 ppm), and the dissolved-solids content ranges from 13 to 105 ppm. In general, the iron, magnesium, potassium, bicarbonate, and fluoride contents of the ground water from these wells exceeds that of water from the REL site.

With some treatment, all water from both sites (REF and REL) would be satisfactory for most uses.

If the pH values of the wastes discharged at the REL and REF sites are neutral or slightly acidic, the pH values will be similar to those of the ground water. Similar pH values can reduce the possibility of chemical reactions that might take place because of pH change.

The quality of slowly moving ground water can be assumed to be in harmony with its environment at any given time and place provided that the environment is not disturbed by artificial addition or withdrawal. Though chemical changes take place with time and as the water moves from one mineralogic suite to another, samples analyzed from a given well at different times should be similar, bacause their history is similar.

The addition of radioactive waste to the environment should change the quality of the ground water because new chemical entities and quantities that would change the environment would be added. These changes would result in the exchange of ions among the waste, ground water, and the minerals in the rocks. The chemical changes may then cause physical changes in the mineralogy of the saprolite, which can have an effect on the permeability of the material and its ability to allow water to drain from the disposal areas.

Water samples were collected from three wells and two springs at the SDF site. The water in well 5–4 is of the calcium bicarbonate type and its hardness and dissolved-solids average exceed those of the other samples. The well is on the highest hill in the SDF site, is about 400 feet deep, and is cased to 42 feet. The lower 357 feet of the well is mostly in biotite schist. Dug well 5–1 is 11 feet deep and is in a valley east of well 5–4. Water from this well is soft and is of the sodium chloride type. Dug well 2–1 is 34 feet deep and is about 2,500 feet north of well 5–4. It yields a calcium bicarbonate water which is soft and has a dissolved-solids content of 35 ppm.

Two wells (12–1 and 12–3) at the SWD site were sampled for chemical analysis of the water. Dug well 12–1 is 28.5 feet deep and ends in the saprolite formed on amphibolite schist. Water from this well is of the magnesium chloride type and contains 194 ppm of dissolved solids, which is high for the area. The water is hard (130 ppm), and is about 4.5 times the the average hardness of the water samples tested in the GNL. The high concentration of nitrate in this and other shallow wells indicates probable contamination from decaying organic matter in the wells. The shallow wells were open and unused, and leaves, wood, algae, frogs, snakes, and insects were observed in some of them.

Water from well 12–3 is of the calcium bicarbonate type. The well is 400 feet deep and is in quartz-mica schist. The water is moderately hard and is slightly higher than average in dissolved solids content.

RADIOCHEMICAL ANALYSES

Radiochemical analyses were made on water samples from Amicalola and Shoal Creeks, the Etowah River, and wells 5–4, 11–4, 12–3, 15–3, and 15–6. The surface-water samples were taken about 24 hours after a rain, and the flow in the streams was above normal. The clay component of the suspended matter in these samples may have affected the results obtained. The sampling of the streams and dug well 15–3 anteceded the bomb tests conducted in the Pacific testing ground in the spring of 1956. The four test wells were sampled during the pumping tests made in October 1956. Beta-gamma activity ranged from less than 5 to 13 picocuries per liter, radium from less than 0.1 to 0.7 picocuries per liter, and uranium from 0.1 to 3.5 micrograms per liter.

The maximum permissible amount of radium in water for continuous exposures is 40 picocuries per liter; uranium, 31 micrograms per liter; and the provisional level in water of beta or gamma emitters is approximately 100 picocuries per liter (U.S. Nat. Bur. Standards, 1953). The radiochemical data listed in table 18 are well below the recommended limits.

TABLE 18.—*Radiochemical analyses of water from wells and streams, Dawson County*

Well or stream	Date of collection	Beta-gamma activity (picocuries per liter)	Radium (Ra) (picocuries per liter)	Uranium (U) (micrograms per liter)
Wells				
5–4	10–31–56	13	0.7	0.8
11–4	10–18–56	5	.1	3.5
12–3	10–16–56	5	.3	.1
15–3	5– 3–56	9.3	.1	.1
15–6	10–16–56	5	.1	2.2
Streams				
Amicalola Creek	5– 3–56	6.0	0.3	0.3
Etowah River	5– 3–56	7.2	.4	.3
Shoal Creek	5– 3–56	8.4	.3	.4

SUMMARY AND SUGGESTIONS

The GNL area is underlain by crystalline rocks of the Ashland-Wedowee Schist of the Carolina Series of probable Precambrian age. The northwest half of the area is underlain by biotite schist and gneiss, and the southeast half by quartz-mica schist and gneiss with associated amphibolite, quartzite, and granitic rock. No attempt was made to correlate the rock units recognized in the area with known rock units elsewhere. Therefore, the rocks in the GNL are subdivided on the geologic map into five mappable zones on the basis of lithology and structural features.

Many structural features in the rocks affect the rate and direction of ground-water movement. These include foliation, joints, bedding, axial-plane and shear cleavages, folds, faults, and linear features. Four well-defined sets of joints were observed in the area, of which the most conspicious set dips to the northeast at angles ranging from 60° to almost vertical. The foliation throughout the GNL strikes northeastward and dips about 20° to 30° SE in the northern part of the area and about 54° to 82° SE in the southeastern part of the area.

Three main water-bearing units occur in the area: the fresh, unweathered crystalline rocks, the saprolite derived from the weathering of the crystalline rocks, and alluvium that borders short stretches of the wider parts of Etowah River valley. In general, ground water occurs in the area under water-table conditions as a large single aquifer, but in any small area the water body is divided by impermeable beds of clay or massive crystalline rock units and artesian conditions may exist locally in these small areas. The confining clay and other barriers, plus the cracks in the crystalline rocks, cause ground water to move in directions other than directly down the hydraulic gradient.

The thickness of the saprolite varies from place to place. It is more than 130 feet thick on one hilltop in the REL site but is as thin as 40 feet on nearby hills. It is less than 20 feet thick along the Etowah River near the SWD but probably averages about 60 feet in thickness in this site. The saprolite consists of a soil cover, a zone of highly weathered saprolite, and a zone of moderately to slightly weathered saprolite. The permeability of the saprolite increases with depth and is greatest in the transition zone (the moderately to slightly weathered saprolite) immediately above the unweathered rock.

The saprolite contained ground water everywhere it was penetrated except at the SDF site at the top of a high hill. This saprolite is the material into which liquid waste is to be disposed in the GNL. In general, the saprolite should be capable of absorbing the estimated annual discharge of 1 million gallons of liquid waste at the REL site and 300,000 gallons at the REF site. The waste-disposal systems at the GNL provide for release to the pits of waste containing between 10^{-5} and 10^{-7} microcuries per milliliter of gross unknown beta-gamma activity. However, the total activity of liquid waste discharged at the REL and REF sites is expected to be less than 1 curie per year. The waste is composed mainly of activated products from the reactor cooling systems and, to a lesser extent, from building contamination.

The most suitable sites for disposal pits are on the tops of hills, such as those on which the REL pit and REF pit 2 are constructed. Of the two sites, the REL pit is in a more favorable location because the saprolite is thicker and the hydraulic gradients less than at REF pit 2. A disposal pit located on the side of a steep hill, such as REF pit 1, is vulnerable to erosion and surface-water runoff, and is the least favorable site for a pit location. The effects of rain on the exposed earth-filled sides of REF pit 1, were demonstrated during a period of heavy rainstorms when several large gullies were eroded into the sides and slumpage of the material occurred along the base of the sides. Unless adequate means are provided to protect the sides of the pit, it may rupture and slide downhill or a major maintenance problem may develop, and use of the pit may prove to be impractical. For these reasons the location of pits on steep hillsides is undesirable because sufficient time may not elapse for the waste to decay before it emerges on the hillsides below the pits; moreover, pits along the Etowah River might be too close to the river to allow sufficient time for decay of the radioactive waste before the water discharges into the river.

The disposal of about 4,000 gpd of waste is feasible at REF pit 1 and about 7,000 gpd is feasible at the REL pit. However, the disposal of larger quantities of waste may require the construction of a second pit at each site to be used as a standby reservoir to take the overflow from the first pit.

The crystalline rocks that underlie the saprolite contain ground water, mostly in the joints and other cracks. The unweathered rock is relatively impermeable and has low transmissibility and storage capacity. In general the saprolite and unweathered rock act as two distinct aquifers because of their different physical and hydrologic properties. The disposal of waste into seepage pits will affect both aquifers.

Water infiltrating the saprolite in excess of the moisture-holding capacity of the materials in the zone of aeration will move downward until it reaches the zone of saturation. Because of the low permeability of the unweathered rock, most of the water will percolate laterally through the lower part of the saprolite towards points of discharge. The rate of percolation is related directly to the permeability of the material and to the hydraulic gradient.

The field measurements of streamflows within the GNL were made only at those places that were readily accessible and recognizable on the ground and on the planimetric map. A precise coordination of measured flows and possibly related land or geologic factors was not attempted.

The measurements and streamflow records obtained in 1956 show that the flow of perennial streams in the area on October 17 averaged 0.70 cfsm and ranged from 0 to 1.40 cfsm. Direction of flow was the only land or geologic factor that had any significant correlation with flow per square mile. Streams which flow in a southeasterly direction, parallel to the strike of one major direction of jointing, have the greatest yield per unit of area. These joints are the most continuous and open, and drain the rocks through which they have cut.

Unless extensive detailed research is undertaken to correlate stream yields with land and geologic data, a reasonably reliable forecast of the flow of a small stream within the GNL cannot be made. Actual measurements must be made at the site or sites where the flow information is needed.

Waste which contains less than 10^{-7} microcuries per milliliter of gross unknown beta-gamma activity and which contains no alpha emitters of strontium 90 will be released to surface streams.

The minimum daily flow of the Etowah River near Dawsonville was 50 cfs, and the average flow for the period 1937–55 was 239 cfs. During lowest recorded flow conditions the river offers a dilution of 22,500 gpm, and during average flow conditions the dilution factor is 110,700 gpm. The minimum daily and average flows of Amicalola Creek near Dawsonville were about the same as those for the Etowah River, and the dilution factor would be about the same.

It might be possible for liquid waste to be disposed of directly into the bedrock through large-diameter wells cased into bedrock. This procedure might prevent the waste from breaking through in hillside springs and probably would insure that the material would travel for a longer period of time underground before it reached the rivers. However, such wells would have limited storage capacities, and because of the low permeability of the unweathered rock the wells could not handle the quantity of waste discharged at the sites.

The alluvial fill occurs in narrow bands along the Etowah River in the vicinity of the SWD, REF, and REL sites. The greatest known thickness is about 30 feet. Ground water moving to the Etowah River from the sites must pass through the alluvium where it occurs, and for this reason the hydraulic characteristics of this material should be determined.

The infiltration rate of the seepage pits decreases as the pit bottoms become covered by a layer of fine silt and clay. The effects of silting on the infiltration rate was observed at the REL pit and several smaller infiltration pits. Most of the small pits retained water for several days after a rainstorm. When the pit bottoms become sealed with silt and clay, the gravel fill should therefore, be removed and washed and the pits cleaned.

Most wells at the REL and REF sites in which water levels are about 35 feet below land surface respond to rainfall within a period of 35 to 45 hours after the start of the rain. In areas where the water table is about 6 to 8 feet below land surface,water levels in wells show a rise within a period of about 8 hours.

Infiltration tests were made at the REL pit and REF pit 2 by using 18- and 24-inch infiltrometer rings. At the REL pit the infiltration rate at the end of the tests ranged from 0.06 to 1.24 inches per hour; at REF pit 2 the infiltration rate ranged from 0.96 to 1.94 inches per hour. On the basis of the REL tests, the material in the pit will take water at rates of 1 to 19 gpm for a head differential of 6 inches; REF pit 2 will take about 13 to 32 gpm for the same pressure head.

The infiltration rates obtained at the pits are variable because the permeability of the material changes within relatively short distances. In order to overcome resistance in zones of less permeability, it will be necessary to maintain a higher head in the pits than that used during the tests. Both pits should take water at rates of 3 to 5 gpm for head differentials ranging from 12 to 30 inches, provided the bottom of the pits do not become silted.

The results of a pumping test on one well at the REL site indicate a coefficient of transmissibility of about 500 to 3,000 gpd per ft and a storage coefficient of 0.001 to 0.004. The large range in transmissibility is attributed to changes in the character of the material and to the shallow depths and nearness of the observation wells to the pumped well. The foliation of the saprolite dips about 70° SE., and wells of comparable depths updip and downdip from the pumped well would not necessarily penetrate the same water-bearing zones.

The low storage coefficient indicates that the water in the area is under some degree of confinement. There are no distinct overlying impervious beds, and the degree of confinement probably varies with the type of materials penetrated by the individual wells. The large amounts of clay and silt in the zone of aeratin locally confine the ground water to some extent and impede communication between the atmosphere and the water surface. In addition, the clay and silt mixture has a high porosity and is capable of storing large amounts of water. During the pumping test at the REL site, drainage of the material retarded the growth of the cone of depression around the pumped well.

The largest drawdowns were in wells along the schistosity in relation to the pumped well; the smallest were in wells normal to the schistosity. Test data and laboratory analyses of saprolite samples indicate that the permeability of the material is greater along the schistosity than it is normal to the schistosity.

The rate of ground-water movement at both sites was computed on the basis of the hydraulic gradients in the areas, and the porosity and permeability of the saprolite. At the REL site the computed velocity ranged from 0.04 to 1.06 feet per day; at the REF site the velocity ranged from 0.09 to 0.97 foot per day. Joints and fractures could cause an increase in the rate of ground-water movement in the sites. In addition, the volume of waste discharged into the pits will cause the buildup of ground-water mounds beneath the pits, and may change the direction and rate of ground-water movement in the vicinity of the pits.

However, on the basis of tests made at the REL and REF sites for different types of material, a maximum velocity of 1 foot per day probably is representative of the rate of ground-water movement in the saprolite. Therefore, a velocity of 1 foot per day will require several years before the waste is released to surface streams, which will allow sufficient time for the short-lived activation products to decay. Slight increases in velocity probably would not affect the concentration of waste discharged into springs and surface streams because other factors such as ion exchange and filtration action of the saprolite and the dilution effects of ground and surface waters will further reduce the activity per unit volume of waste discharged.

In the REL site the general direction of ground-water movement is northwest and southeast. A ground-water divide occurs southeast of the pit. It is probable, therefore, that a buildup of the water table of several feet under the pit could cause additional movement to the southeast. Indications are that much of the water from the pits will move along the schistosity until a joint is encountered, or until sufficient head has been established for water to move normal to the schistosity.

The configuration of the water table at REF pit 2 is such that water may move in one of several directions. A likely discharge point is the small perennial spring about 800 feet northwest of the pit. Other areas of probable ground-water discharge are the small draws about 450 feet south and 400 feet east of the pit.

Two perennial and four wet-weather springs are near the REL and REF disposal pits. The combined flow of the springs averages about 50,000 gpd during the dry season and probably exceeds 150,000 gpd during the wet season. Most of the springs are down the water-table gradient from the pits and are possible surface outlets of waste from the seepage pits. For this reason the springs should be checked periodically for changes in water quality.

Samples were collected at the REF and REL sites for the determination of minerals, grain-size distribution, and ion-exchange capacity. The samples were collected at the surface and at various depths to a maximum of 18 feet. The ion-exchange capacity of the samples from the REF site ranges from 2.5 to 13.7 meq per 100 g and averages 5.3 meq per 100 g, and those from the REL site ranges from 1.9 to 8.1 meq per 100 g and average 5.1 meq per 100 g. Kaolinite and vermiculite are the only clay minerals occurring in appreciable quantities at the two sites. The values determined for the samples from the two sites are within the range given for kaolinite and vermiculite by Grim (1953, p. 129). No consistent differences in values were noted between near-surface samples where most of the organic material is concentrated and those at depth. The ion-exchange capacities indicate a relatively low capacity for base exchange, but the thick blanket of saprolite and the slow rate of ground-water movement in the REL and REF sites probably provides a high overall efficiency for the retention of radionuclides.

Mineral determinations and grain-size distribution analyses were made on 97 samples collected at the REF site and 19 samples collected at the REL site. The samples were collected at the surface and at various intervals to a depth of 18 feet below the surface. Grain-size distribution in the soil at the REF site is approximately 50 percent sand and gravel, 25 percent silt, and 25 percent clay. At the REL site grain-size distribution in the soil is approximately 31 percent sand and gravel, 29 percent silt, and 40 percent clay.

The clay-size particles less than 4 microns are believed to provide an effective physical filtration of active particles in the 4 to 40 micron range. Particle sizes greater than 40 microns are filtered from the primary coolant and pool systems of the RER. The REL waste system is not equipped with a filtration system.

Chemical analyses were made of water collected from 31 wells, 4 springs, and 3 streams on and in the immediate vicinity of the area. All analyses show that ground water generally is soft to moderately hard, and the dissolved solids content generally averages less than 100 ppm. Most of the analyses are of calcium and sodium bicarbonate types of water.

Radiochemical analyses of water samples from four wells and three streams in the GNL show that the beta-gamma activity ranges from 5 to 13 picocuries per liter, radium from less than 0.1 to 0.7 picocuries per liter, and uranium frm 0.1 to 3.5 micrograms per liter.

The addition of radioactive waste to the environment may change the quality of the ground water because new chemical entities and quantities will be added that will react with the environment. These changes will result in the exchange of ions between the waste, ground water, and the minerals in the rocks. The chemical changes may result in physical changes in the saprolite, which may have an effect on the permeability of the material and its ability to allow water to drain from the disposal areas.

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