Infiltration and Permeability of Weathered Crystalline Rocks Georgia Nuclear Laboratory Dawson County, Georgia

GEOLOGICAL SURVEY BULLETIN 1133-D

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

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By J. W. STEWART

STUDIES OF SITES FOR NUCLEAR ENERGY FACILITIES

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

Results of experiments in the disposal of wastes at the Radiation Effects Laboratory

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CONTENTS

	Page
Abstract	D1
Introduction	1
Purpose and scope of investigation	1
Location and extent of area	2
Previous investigations	3
Acknowledgments	3
Drilling program	4
Ground water in weathered crystalline rocks	4
Occurrence	4
Recharge	5
Discharge	6
Movement	7
Geology of REL disposal pit	8
Hydrologic properties of core samples	9
REL disposal pit	10
Construction of pit	10
Infiltration tests	10
One foot of water in pit	12
Two feet of water in pit	16
Three feet of water in pit	17
Second test of pit at 1-foot level	18
Analysis of infiltration tests	20
Effects of precipitation on water level in disposal pit	21
Contour maps of the water table	22
Rainfall and evaporation	25
Gains from rainfall	25
Losses from evaporation	26
Disposal of waste into REL pit	27
Chloride and nitrate tracers	30
Chloride tests	30
Results of chloride tests	33
Nitrate tests	33
Results of nitrate tests	27
Rate of ground-water movement	39
Underground seepage from disposal pit	41
Hydrologic properties of the saprolite	43
Analysis of aquifer-test data	43
Analysis of recharge-test data	47
Deficiencies in data	51
Summary	52
References	57
Index	59

ILLUSTRATIONS

[Plates are in pocket]

PLATE 1. Contour map of the water table, April 27, 1959, and profiles of the water table during and after tests at REL disposal pit.
2–7. Contour maps of the water table—
2. At end of 1-foot test, May 20, 1959.
3. At end of 2-foot test, June 16, 1959.
4. At end of 3-foot test, July 16, 1959.
5. During 1-foot test, Dec. 29, 1959.
6. At end of 1-foot test, July 28, 1960.
7. Dec. 22, 1960.

		Page
FIGURE 1.	Index map	D3
2.	Radiation Effects Laboratory site	4
3.	Fluctuations of water levels in wells	6
4.	REL disposal pit during test at head of 1 foot	10
5.	Volume-area curves, REL disposal pit	11
6–9.	Buildup of water levels—	
6.	Paired shallow wells	13
7.	Shallow wells	14
8.	Deep wells	15
9.	Shallow and deep wells	16
10.	Decline of water level in disposal pit	18
11.	Rise of water level in disposal pit	19
12.	Effects of rainfall on the water level in disposal pit	22
13.	Chloride content of water samples	31
14.	Nitrate content of water samples from wells along strike of schistosity	34
15.	Nitrate content of water samples from wells updip and downdip	35
16.	Semilogarithmic graph of water level in TW–16	44
17–21.	Logarithmic graphs of water level—	
17.	AH–75 (recovery)	45
18.	AH–93 (recovery)	45
19.	AH–75 (buildup)	49
20.	AH–83 (buildup)	50
21.	AH–87 (buildup)	51

TABLES

		Page
TABLE 1.	Laboratory analyses of core samples, REL site	D9
2.	Water budget, REL disposal pit, April 27, 1959 to July 28, 1960	27
3.	Results of aquifer tests, REL site, March 17–19, 1959	46
4.	Results of recharge test, REL site, April 27–May 20, 1959	49

INFILTRATION AND PERMEABILITY OF WEATHERED CRYSTALLINE ROCKS, GEORGIA NUCLEAR LABORATORY, DAWSON COUNTY, GEORGIA

By J. W. STEWART

ABSTRACT

An investigation was made in the area of the Radiation Effects Laboratory of the Georgia Nuclear Laboratory, Dawson County, Ga., to determine the probable effect of discharging waste into a disposal pit constructed in weathered crystalline rocks. The infiltration rate through the weathered material was determined by discharging water into the disposal pit and maintaining heads of 1 to 3 feet in the pit for periods of 3½ to 54 weeks. The infiltration rate at the end of four different test periods was as follows: 1 foot for 23 days, 8,300 gpd; 2 feet for 27 days, 9,700 gpd; 3 feet for 30 days, 13,700 gpd; and 1 foot for 373 days, 6,000 gpd. The buildup of the ground-water mound beneath the pit ranged from about 13 to 25 feet. Two months after the water supply to the pit was cut off, the mound was about 5 feet above the water table in the area, and at the end of 5 months the mound was about 3 feet above the water table. Permeability and porosity determinations were made of the material underlying the waste-disposal pit. The coefficient of permeability of the weathered crystalline rocks ranged from 0.04 to 57 gpd per sq ft, and the porosity ranged from about 31 to 54 percent. Aquifer tests in the area indicate a transmissibility ranging from about 700 to 2,100 gpd ft and a storage coefficient from 0.00094 to 0.0083. The results of recharge data using the non-equilibrium formula gave values of transmissibility ranging from 58 to 369 gpd per ft, and a storage coefficient of 0.09 to 0.27. An analysis of the ground-water mounds for the various tests using the gradient method gave a transmissibility of 160 gpd per ft along the strike of the schistosity, 46 gpd per ft updip, and 104 gpd per ft downdip.

The ground-water velocity in the area, based on chloride and nitrate tracer tests, ranged from about 0.4 foot per day to as much as 25 feet per day. Ground-water velocities determined from the permeability and porosity of the material, and the hydraulic gradients in the area, ranged from about 0.1 foot to 3 feet per day.

The results of the infiltration tests indicate that most of the water from the pit moves along the strike of the schistosity, and some moves downdip and updip.

The report describes the geology of the disposal pit, the results of infiltration and aquifer tests, data on the hydrologic properties of core samples, the results of chloride and nitrate tracer tests, seven water-table contour maps showing the configuration of the water table before, during, and after the infiltration tests, and nine profiles of the water table during testing of the pit at heads of 1 to 3 feet.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

This report describes the results of a study of the hydrology and geology of the Radiation Effects Laboratory (REL) area within the site of the Georgia Nuclear Laboratory (GNL) of the Lockheed Aircraft Corporation near Dawsonville, Ga. The investigation was made by the Geological Survey in cooperation with the United States Air Force and the United States Atomic Energy Commission; it was a continuation of work begun in January 1956 under the sponsorship of the Atomic Energy Commission. Detailed work in the REL area was begun in March 1958 and continued through September of that year. The present investigation was started in March 1959 and continued through December 1960.

The purpose of the study was to determine the infiltration rate of the material in the REL disposal pit, to determine the buildup and lateral extent of the ground-water mound for different operating levels in the pit, to check for probable areas of emergence of waste in nearby intermittent and perennial springs, to determine the direction and rate of ground-water movement in the area, to predict the possible avenues and rate of underground travel of radioactive liquid wastes seeping from the disposal pit, and to determine the permeability of the material in the vicinity of the disposal pit.

During the period of the investigation (March 1959 to December 1960) 67 wells were augered at the GNL, of which 6 wells were in the REL site, 27 wells were in the Solid Waste Disposal (SWD) site, 25 wells were in the Radiation Effects Facility (REF) site, and 9 wells were in the area between REL and REF; four infiltration tests of the REL disposal pit were completed by maintaining heads of 1 to 3 feet of water in the pit for periods of 3½ to 54 weeks; two aquifer tests were conducted on wells at the REL pit; 21 core samples were collected for laboratory determinations of permeability, specific yield, specific retention, porosity, and moisture content; 361 water samples were collected for chloride and nitrate determinations; and periodic and continuous water-level records were obtained for 49 wells in the area.

Radioactive waste disposal investigations are made under the direction of H. E. LeGrand, chief of the Radiohydrology Section. This investigation was under the supervision of J. T. Callahan, district geologist, Atlanta, Ga.

LOCATION AND EXTENT OF AREA

The Georgia Nuclear Laboratory is about 4 miles southwest of Dawsonville, Dawson County, Ga., and about 45 miles north-northeast of Atlanta. (See fig. 1.) The REL site is in the southeast corner of the GNL and is south of the Etowah River, which flows westward through the southern half of the laboratory site. (See fig. 2.) The REL disposal pit is remote from any areas of ground-water withdrawals for domestic and industrial supplies.

PREVIOUS INVESTIGATIONS

General geology of the area was described by Crickmay (1952) and several earlier writers. R. M. Richardson (unpub. data, 1956) made a study of the geology and hydrology of the area. Two detailed investigations were made by Callahan and others (unpub. data, 1957) and Stewart and others (unpub. data, 1958).

ACKNOWLEDGMENTS

The hydrologic studies in the general area of the GNL were financed by the Atomic Energy Commission, and the detailed investigation of the REL site was financed by the Atomic Energy Commission and the Air Force. Personnel of the Lockheed Aircraft Corp. assisted in operating pumps and checking water levels in the disposal pit during this investigation. The author is indebted to the many persons who contributed information and assistance in the field and to those who aided in the preparation and review of the report.

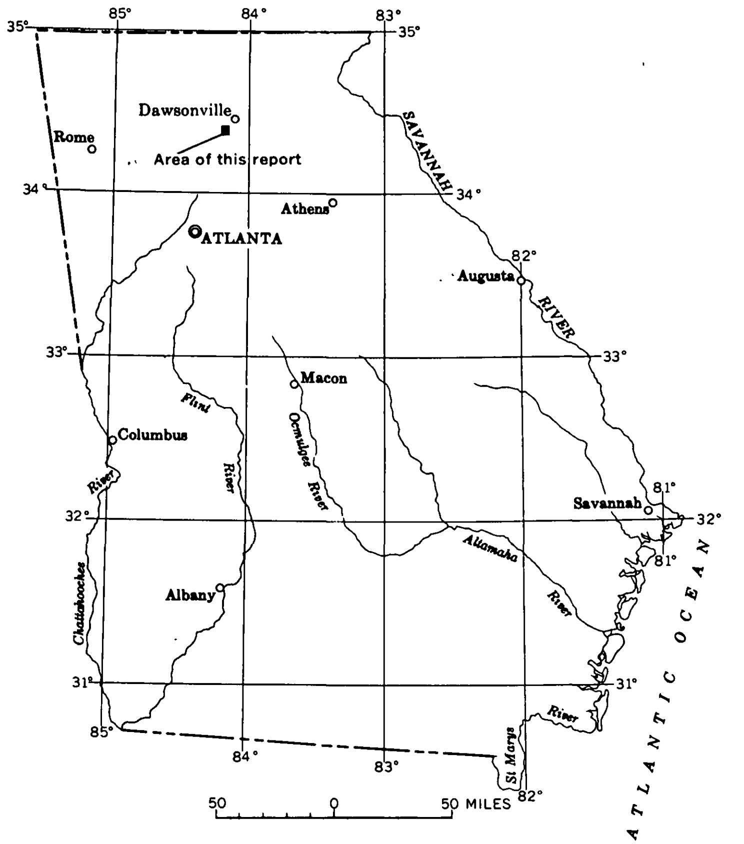

FIGURE 1.—Index map of Georgia showing location of the Georgia Nuclear Laboratory.

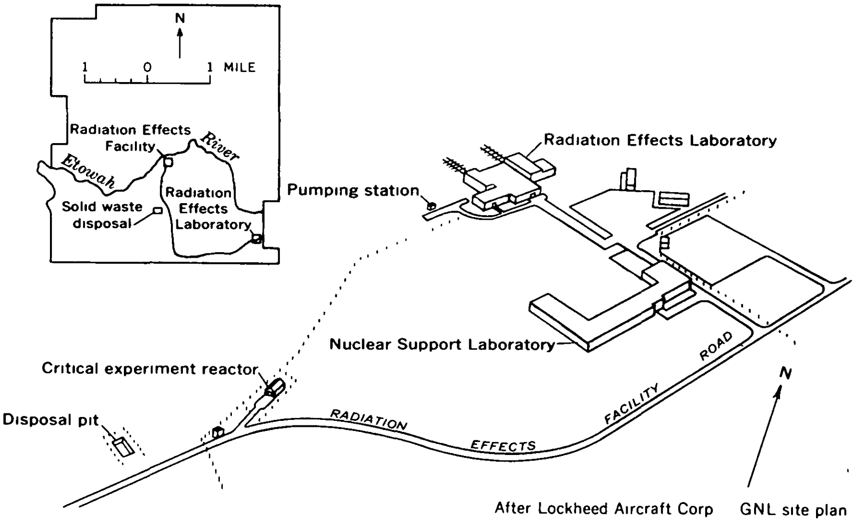

FIGURE 2.—Radiation Effects Laboratory site showing location of disposal pit.

DRILLING PROGRAM

During the investigation 67 water-level observation wells were augered at the REL, REF, and SWD sites to provide geologic and hydrologic information. The observation wells were constructed with a power-driven 4-inch rotary auger. Samples of the cuttings were collected at 5-foot intervals or closer where necessary.

At the REF site 25 wells were augered to depths of 12 to 40 feet. The average depth was about 21 feet. The wells were installed along the floodplain of the Etowah River near the REF Reactor Building.

At the SWD site 27 wells were augered. The wells ranged in depth from 15 to 62 feet, and the average depth was about 37 feet.

Six wells ranging in depth from 17 to 35 feet were installed in the immediate vicinity of the REL disposal pit. The average depth of the wells was about 41 feet.

Nine wells were augered along the REF road between the REL and REF sites. The depth of the wells ranged from 31 to 51 feet and averaged about 37 feet.

GROUND WATER IN WEATHERED CRYSTALLINE ROCKS

OCCURRENCE

The REL is underlain by metamorphic crystalline rocks and by a mantle of saprolite derived from deep weathering of quartz-mica schist. The change from saprolite to hard rock is gradational, and no sharp line of demarcation exists between the two types of material. The saprolite consists of a soil cover, a highly weathered zone, and moderately to slightly weathered zone. Bedding and foliation at the site dip about 72° SE. Ground water occurs in the pore spaces and in the fractured quartz veins in the saprolite. The unweathered rocks are dense and massive, and ground water occurs largely in joints, bedding planes, and other openings in the rocks.

The pore space within the saprolite in the REL site is filled with water to a level that ranges from about 3 to 35 feet below the land surface. In most of the area the ground water probably is confined under only slight artesian head by fine-grained materials in the zone of aeration, which impede the effect of atmosphere on the water surface. The response of the water levels in wells to changes in barometric pressure indicates that there is some degree of local confinement of the water. The barometric efficiency of wells in the area ranges from 30 to 70 percent.

In the REL site there is no distinct overlying confining bed such as occurs in a true artesian system, and the degree of confinement probably varies with the composition, thickness, and extent of the saprolite and differences in the permeability of the beds. Water at shallow depth in deposits at low altitudes probably represents water-table conditions, whereas the water in wells at higher altitudes may be under slight artesian head because the wells are more likely to penetrate one or more relatively impervious beds in the zone of aeration.

The porosity of the saprolite averages about 47 percent; however, because of the differences in the degree of weathering of the saprolite, the porosity of the material decreases with depth. On the other hand, the permeability of the slightly or moderately weathered material in the zone of gradation is greater than that of the unweathered rock below and highly weathered saprolite above. Most of the water available to wells and most ground-water movement probably occur in the gradation zone.

RECHARGE

At the REL site recharge to the ground-water reservoir is from precipitation. If the recharge into the ground-water reservoir exceeds discharge, the water table rises; if discharge exceeds recharge the water table declines. Precipitation that is not lost by evaporation, transpired by plants, or carried away by surface runoff infiltrates the zone of aeration and eventually reaches the zone of saturation.

Recharge resulting from precipitation is illustrated by the fluctuation of the water level in TW–19 and TW–20 (fig. 3). A comparison of the hydrograph of the water-level fluctuations in TW–20 with the daily record of precipitation at the GNL site shows that the water

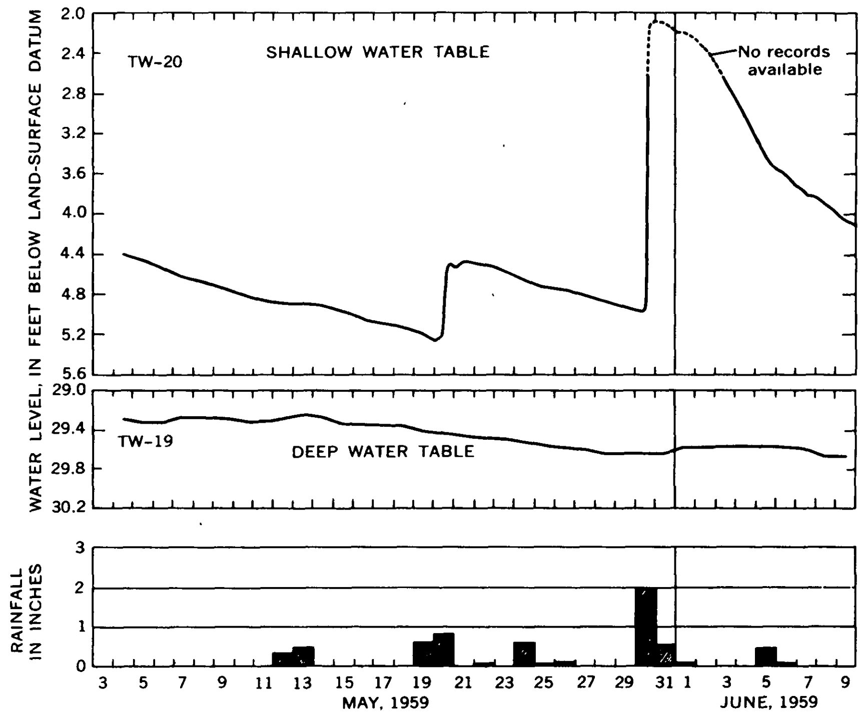

FIGURE 3.—Fluctuations of water levels in wells at REL site and daily rainfall at GNL Weather Station.

levels respond rapidly to precipitation. Such close correlation, however, was found only in wells at low altitude where the water table was shallow. The water levels in most deep wells do not show immediate response to direct infiltration of precipitation, and in several wells very little response to precipitation was noted. (See TW–19, fig. 3.)

DISCHARGE

Because of the mountainous topography in the REL site much of the precipitation leaves the area as surface flow. Discharge by both surface and subsurface outflow eventually reaches the Etowah River, about half a mile north-northwest of the disposal pit. The Etowah River drains the GNL site.

Two perennial and five wet-weather springs occur at the head of a small draw about 300 feet west of the pit (outside map area). During May 1959 the flow of the springs averaged about 8,000 gpd (gallons per day). Several perennial springs also are found in the area about 800 feet southeast of the pit (outside map area). In May 1959 the combined flow of the springs was about 40,000 to 80,000 gpd.

Transpiration by vegetation and evaporation also account for some loss of water, but the magnitude of this loss is not known.

In 1959–60 no ground water was pumped in the GNL site.

MOVEMENT

Ground water moves from areas of recharge toward areas of discharge at lower altitude. Thus, water that reaches the zone of saturation percolates through the interstices of the aquifer toward points of discharge. In general, the rate of movement is affected by the type of material through which the water moves, and the direction of movement coincides with the greatest slope of the water table. The velocity is directly proportional to the hydraulic gradient and the permeability of the material and is inversely proportional to the porosity.

Water from precipitation that infiltrates into the ground percolates downward through the soil zones and reaches the decomposed rock, at which level its movement is controlled by the strike and the dip of the beds. The parallel arrangement of the mica crystals impedes the movement of water across the schistosity but favors movement parallel to it. Thus, the principal direction of ground-water movement is largely parallel to the schistosity and bedding planes, with minor movement occurring updip and downdip. Some water also moves along veins in fractured quartz at different depths throughout the saprolite.

The saprolite at the REL disposal pit consists almost entirely of alteration products derived from the weathering of the minerals similar to those now found in the underlying rock, and its composition, thickness, and extent differ from one rock type to another. Therefore, in relatively short distances the permeability of the material and the rate of ground-water movement in the area vary widely.

Unweathered crystalline rocks underlie the saprolite, and at the REL disposal pit the depth of the rock is more than 135 feet below land surface. The change from saprolite to hard rock occurs as a transitional zone between the two types of material. The hard rock is dense and massive (average porosity less than 5 percent) and movement of water is confined largely to joints, bedding planes, and other openings.

Laboratory analyses of 14 core samples collected from the zone of saturation in three auger holes had a permeability range of 0.09 to 57 gpd per sq ft. Under equal hydraulic gradients and effective porosities, therefore, the average velocity through the most permeable material is about 630 times faster than that through the least permeable material.

The principal factors affecting movement of water in the saprolite are as follows: (1) degree of weathering of the material; (2) mineral composition of parent rock; (3) orientation of the mineral grains; (4) strike of schistosity and dip of beds; (5) presence of quartz veins and fractures; (6) thickness and lateral extent of saprolite; and (7) presence of impervious barriers.

GEOLOGY OF REL DISPOSAL PIT

The rocks in the vicinity of the REL disposal pit are of mixed origin forming what is generally called migmatite. The host rock is a quartz-mica schist, containing a few garnets, and is probably of sedimentary origin. Numerous concordant lenses of amphibole-plagioclase gneiss occur also. Intimately injected bed by bed into these rocks and constituting up to 40 percent of the total volume are biotite-muscovite-quartz-feldspar rocks of igneous origin. Hydrothermal quartz stringers and muscovite-quartz pegmatites are numerous. They are generally concordant but a few cut the schistosity at a high angle. The mica flakes and amphiboles are oriented parallel to the schistosity planes except in the muscovite-quartz pegmatities where the mica occurs in unoriented books up to 2 inches across. Apparently the migmatization is associated regionally with a tubular granite body bordering the Ashland schist belt on the southeast.

Schistosity, migmatite injections, amphibolite bodies, and garnetiferous zones which probably represent relic bedding are all roughly parallel in the vicinity of the pit. They strike between N. 50° E. and N. 72° E., averaging N. 62° E., and dip 72° SE. Regionally the rocks form a monoclinal limb of a larger recumbent fold (C. W. Sever, oral communication, 1959).

The strike of the most prominent joint set is N. 58° W. and the dip is from 60° to vertical (Callahan and others, unpub., report, 1957). Several other directions of jointing occur but are not prominent in the pit vicinity. The amphibolites are exceptional in that they are broken into small blocks by prominent three-directional jointing.

The depth of weathering is known to be more than 135 feet in the vicinity of the pit. The weathering has been accompanied by the removal of soluble constituents in solution, greatly increasing the porosity and permeability of the residual material. During weathering, the amphiboles and feldspars are dissolved leaving behind clay-size particles of iron oxides and aluminum silicates. Quartz is relatively unaltered, having only a small part removed by solution. The micas are insoluble but expand when hydrated and contract upon dehydration, causing a physical breakdown ultimately to silt-size particles. The resultant saporolite thus is composed of still-oriented silt- to sand-size mica, fine-grained quartz, and a little residual clay. The dominant constituent by far is the silt- to sand-size mica.

HYDROLOGIC PROPERTIES OF CORE SAMPLES

In February 1959, 21 core samples were collected for laboratory analyses from three wells in the vicinity of the REL disposal pit. The samples were collected in a 1-inch diameter steel cylinder lowered to different augered depths in the wells and driven about 3 feet into the saprolite at each sampling. Quantitative analyses of the samples included the following determinations: moisture content, specific retention, porosity, specific yield, and coefficient of permeability. The analyses were made in the U.S. Geological Survey hydrologic laboratory, Denver, Colo.

The results of the laboratory analyses are summarized in table 1. The coefficient of permeability of the samples ranged from 0.09 to 57 gpd per sq ft. Samples collected in the zone of aeration had a permeability range of 0.04 to 40 gpd per sq ft and samples collected in the zone of saturation had a permeability range of 0.09 to 57 gpd per sq ft. The specific yield of the saprolite below the water table ranged from 9.1 to 34.5 percent and averaged about 20.3 percent. The porosity of the material ranged from 30.7 to 58.4 percent and averaged about 47 percent.

Stewart (1962) found that the porosity and specific yield of saprolite is greatest at depths of about 30 to 40 feet below land surface and that these values decrease markedly as saprolite grades into unweathered rock.

TABLE 1.—*Laboratory analyses of core samples, REL site*

Well	Depth of sample (feet)		Moisture content (percent)	Specific retention (percent)	Porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)
	From	To					
AH-109	24.5	25.0	----------	33.7	52.2	18.5	0.6
	31.5	32.0	----------	23.9	58.4	34.5	35
	34.0	34.5	----------	39.4	48.5	9.1	.1
	48.5	49.0	----------	27.6	51.5	23.9	1
	50.5	51.0	----------	33.6	47.4	13.8	.3
AH-172	24.5	25.0	17.6	27.3	40.7	13.4	.1
	28.0	28.5	----------	26.4	49.5	23.1	.1
	30.5	31.0	26.3	20.2	49.3	29.1	57
	33.2	33.7	----------	32.0	54.3	22.3	.3
	35.2	35.7	41.3	31.8	52.3	20.5	.09
	39.4	39.9	----------	31.6	52.9	21.3	.3
	43.5	44.0	----------	26.7	47.3	20.6	2
	45.0	45.5	28.6	27.9	42.2	14.3	.8
AH-173	14.0	14.5	10.9	19.7	51.3	31.6	20
	24.0	24.5	----------	19.1	53.4	34.3	40
	25.5	26.0	18.9	30.7	35.1	4.4	.04
	30.5	31.0	----------	20.5	36.7	16.2	.3
	34.0	34.5	----------	21.1	42.6	21.5	5
	35.5	36.0	26.8	24.8	41.5	16.7	.5
	38.0	38.5	----------	20.5	46.9	26.4	2
	40.5	41.0	17.5	13.9	30.7	16.8	3

REL DISPOSAL PIT

CONSTRUCTION OF PIT

The REL pit is trapezoidal in vertical cross section and the slope of sides is about 1:1. The dimensions of the bottom are 26.6 by 60.6 feet and of the top are 40.0 by 75.2 feet. The bottom is covered with 6 to 7 inches of gravel ranging in size from one-half to three-quarters of an inch. The depth of the pit ranges from 5.0 to 6.0 feet above the gravel fill. The sides are lapped with biotite schist to prevent material from washing into the pit. (See fig. 4.)

The capacity of the disposal pit at the 1-foot level (1 foot above top of gravel fill) is about 13,500 gallons. For a head of 2 feet the capacity is about 28,500 gallons, and for a head of 3 feet it is about 45,700 gallons. The total capacity of the pit for a maximum head of 5 feet is about 83,000 gallons. The volume-area curves of the pit are shown in figure 5.

INFILTRATION TESTS

Four infiltration tests of the REL pit were made during the period April 27, 1959 to July 28, 1960 by discharging water into the pit and maintaining water levels of 1 foot to 3 feet for periods of 3½ to 54 weeks.

During the first part of the test water was pumped into the pit from two 20,000-gallon waste storage tanks at the Radiation Effects Labora-

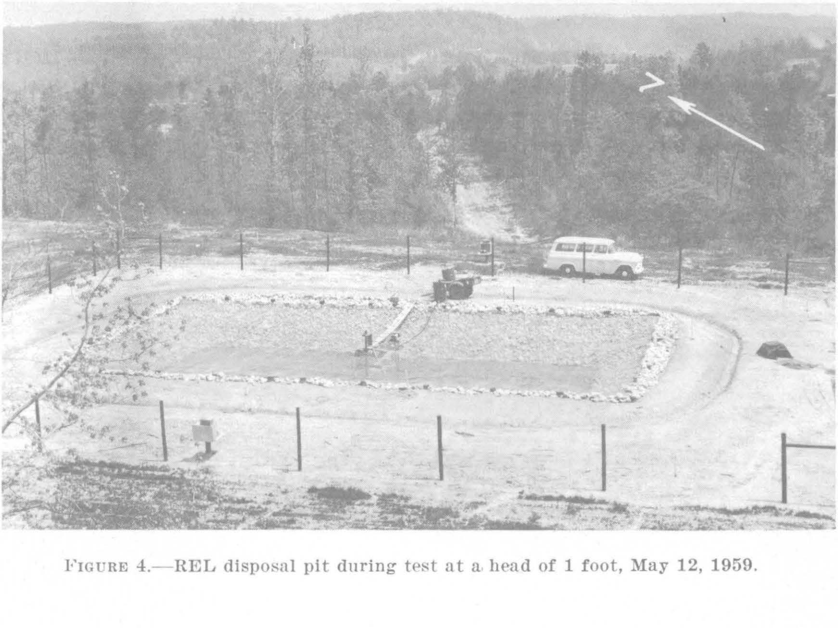

FIGURE 4.—REL disposal pit during test at a head of 1 foot, May 12, 1959.

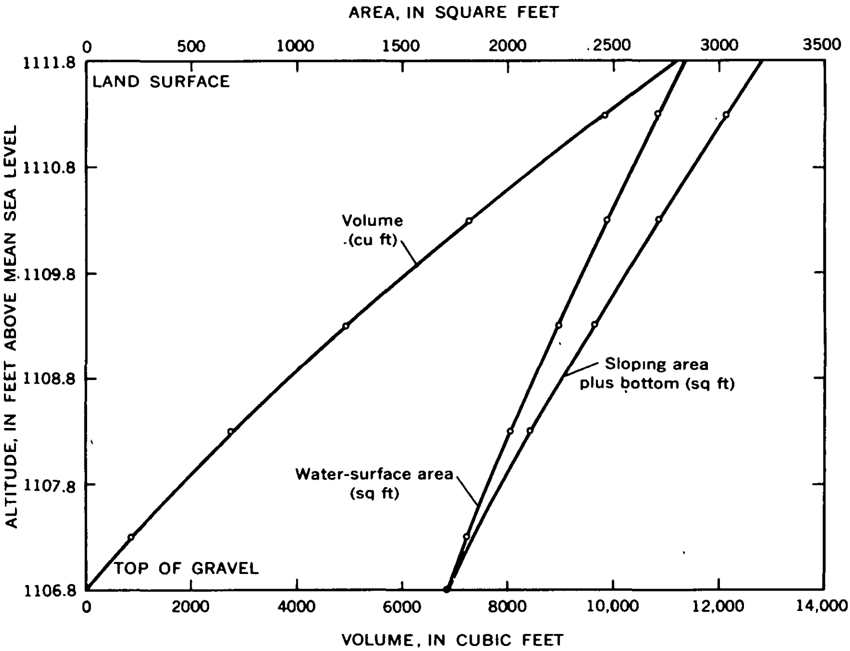

FIGURE 5.—Volume-area curves, REL disposal pit.

tory, about 2,500 feet northeast of the pit. (See fig. 2.) The water used for the test was obtained from the distribution system. A surface-water treatment plant on the Etowah River supplies water for drinking and cooling purposes at the GNL site.

The waste storage tanks were filled by opening several water taps with drains discharging into the tanks. However, because of the problems involved in keeping an adequate supply of water in the tanks and maintaining a constant water level in the pit, the pumping method was abandoned at the end of the 1-foot test. In order to insure that an ample supply of water would be available for the test a 1¼-inch pipeline was laid from the pit to the distribution system at the Critical Experiment Reactor. A meter was installed in the pipeline to obtain a record of the quantity of water discharged into the pit. Two automatic float valves were installed in the pit to regulate the flow of water and to maintain a uniform water level. This method of regulating the flow proved very satisfactory and was used throughout the remainder of the tests.

Because of the relatively long period of the tests it was necessary to correct for seasonal changes in water levels throughout the area, and for this reason, control points were established at several wells outside the area of influence of seepage from the pit. The net increase in water levels in the area was determined by taking into consideration the changes in ground-water storage that occurred on the respective dates of the various tests of the pit.

During the infiltration tests water-level measurements were made periodically in 37 auger holes and recording gages were operated on 12 test wells. A recording gage was installed in the disposal pit to obtain a continuous record of water-level fluctuations in the pit during the period of the tests.

ONE FOOT OF WATER IN PIT

The infiltration test of the REL pit was started April 27, 1959, and a head of 1 foot of water was maintained in the pit until May 20, 1959, at which time the head was increased to 2 feet. An estimated 184,300 gallons of water was discharged into the pit during the 23-day period. The average pumping rate was about 8,000 gpd. An estimated 9,000 gallons of water was required to raise the level in the pit to 1 foot. Because it was necessary to pump water into the pit at frequent intervals it was not possible to maintain a uniform head of water in the pit. For this reason the stage in the pit fluctuated slightly above and below the 1-foot level. However, an average head of about 1 foot was maintained for most of the test with the exception of the last 4 to 5 days when the water level declined slightly and the head averaged about 0.8 foot.

Figures 6 to 9 show the buildup of the water levels in several shallow and deep wells in the REL site during the infiltration test of the disposal pit.

The first noticeable rise in ground-water levels at the REL disposal pit occurred May 2, about 4 days after discharging water into the pit. The water levels in several shallow wells near the pit probably commenced to rise about May 1, but because the wells were measured only once a day it was not possible to determine when the rise in water levels first started (figs. 6, 7 and 9). However, on May 2 the water levels in the shallow wells were well above the levels of the previous day.

On May 2, 11 wells ranging in depth from about 31 to 137 feet showed rises in water levels as a result of seepage from the disposal pit. The distances of the wells from the pit ranged from 9 to 51 feet. Of the 11 wells affected by water from the pit, 6 wells were along the strike of the schistosity, 2 wells were updip, and 3 wells were downdip from the pit. At the end of the 1-foot test on May 20, rises in water levels ranging from about 0.2 foot to 10.3 feet were shown in 24 of the 49 wells measured in the area.

The most distant well that showed a rise in water level on May 20 was AH–93, about 87 feet southwest of the pit. The well is along

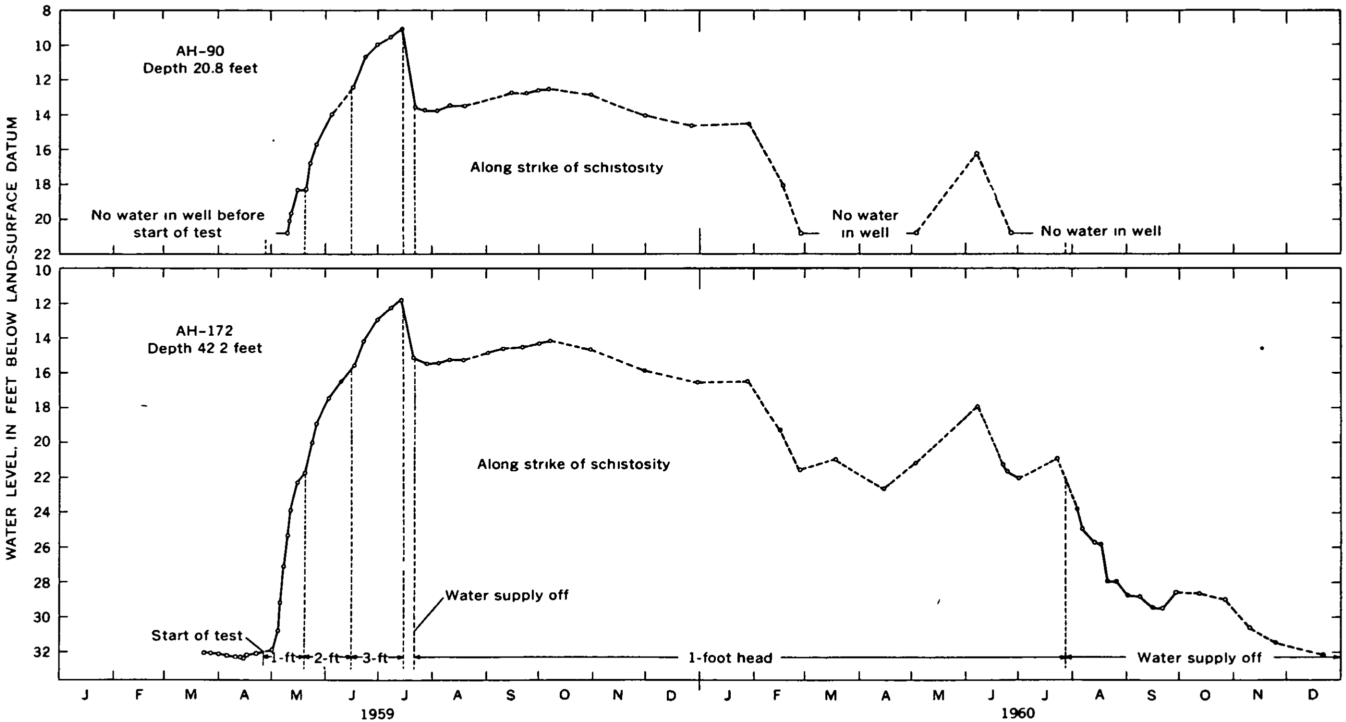

FIGURE 6.—Buildup of water levels in paired shallow wells during infiltration test at REL disposal pit. Dashed line indicates observations were more than 1 week apart.

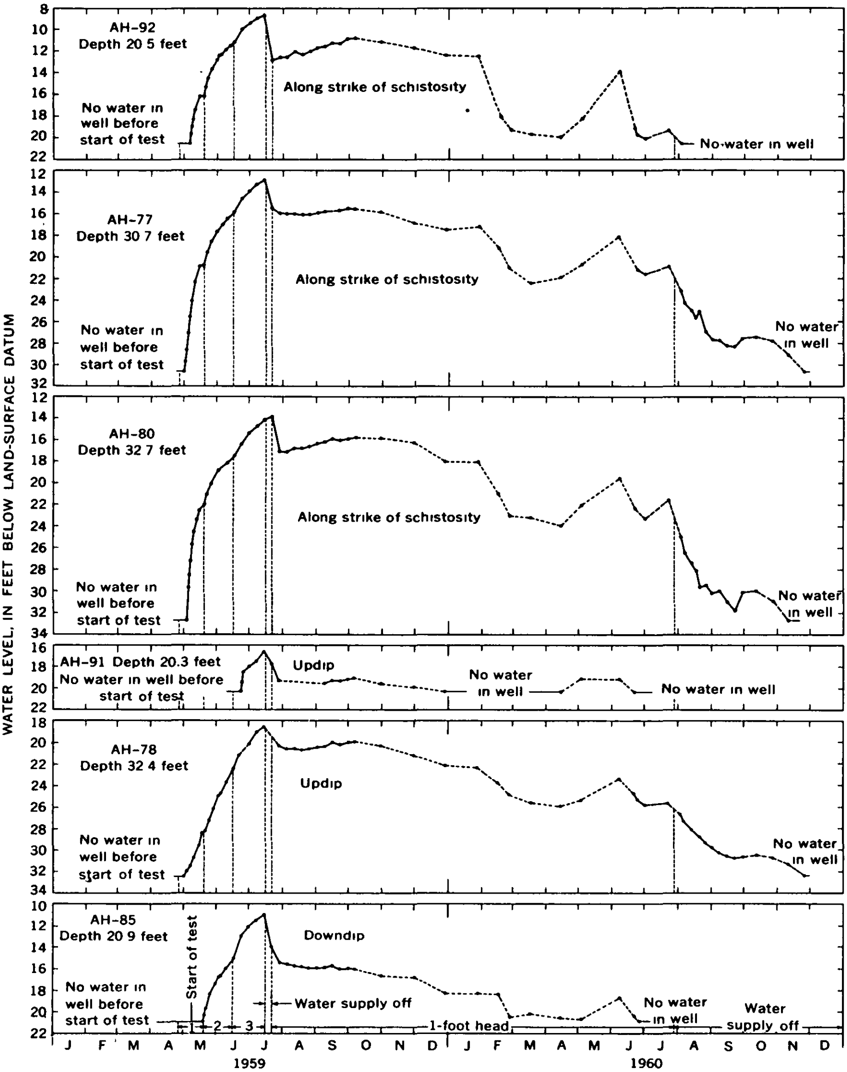

FIGURE 7.—Buildup of water levels in shallow wells during infiltration test at REL disposal pit. Dashed line indicates observations were more than 1 week apart.

the strike of the schistosity in relation to the pit. The water level in the well rose about 1 foot during this period of the test.

The greatest change in water level in a well drilled below the zone of saturation occurred in AH–172, 42.2 feet deep and about 11 feet east of the pit along the strike of the schistosity. The water level in the well rose about 10 feet during the test. On the other hand, the highest water level in the area was found in AH–90, 2 feet northwest of AH–172. AH–90 was drilled to a depth of 20.2 feet, and the bottom of the hole was about 11 feet above the zone of saturation before the start of the test.

At the end of the 1-foot test on May 20 the water level in AH–90 was about 3.3 feet above the water level in AH–172 (fig. 6). The differences in levels probably was due to the fact that the wells reflected water levels in different parts of a ground-water mound having relatively large vertical components of flow. The top of the ground-water mound was about 12 feet above the general water table in the area.

The hydrographs in figure 6 show that the two wells had about the same pattern and amount of water-level fluctuations during the test period, indicating that the same body of water was tapped by the wells. Core samples collected at different depths in AH–172 show that the permeability of the material varies considerably within short distances, and this difference may be as much as 570 to 1. (See table 1.) However, data indicate that these zones of low permeability probably are localized, and may differ in composition, thickness, and lateral extent. Moreover, the various zones may overlap or grade into each other, resulting in different degrees of confinement throughout the area. It appears, therefore, that ground-water movement throughout the deposits may be retarded in places as a result of the changes in the saprolite.

During the test of the pit at a head of 1 foot it was found that wells along the strike of the schistosity generally showed the greatest change in water levels, and wells updip showed the least change in water levels.

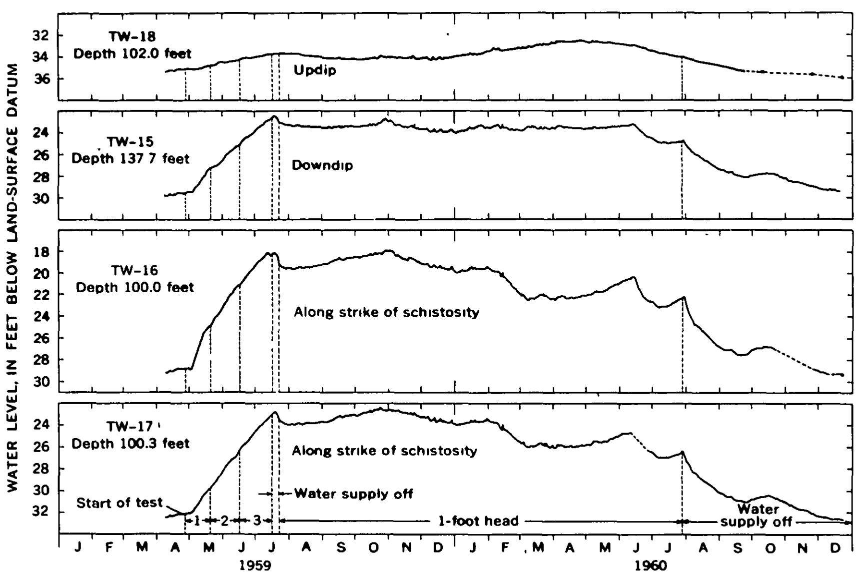

FIGURE 8.—Buildup of water levels in deep wells during infiltration test at REL disposal pit. Dashed line indicates observations were more than 1 week apart.

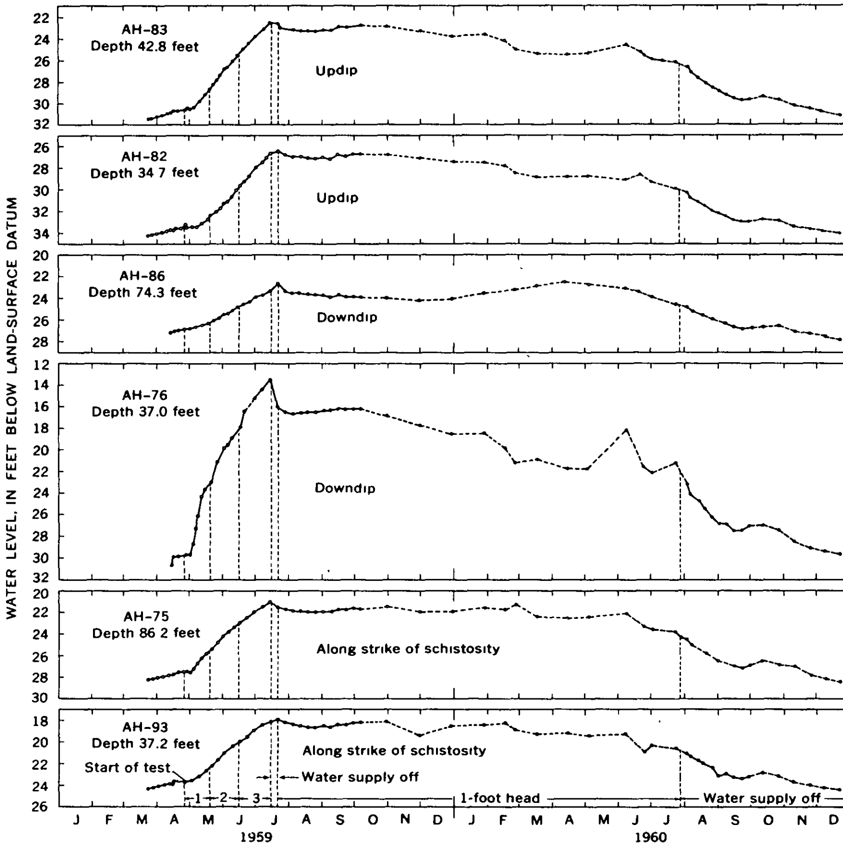

FIGURE 9.—Buildup of water levels in shallow and deep wells during infiltration test at REL disposal pit. Dashed line indicates observations were more than 1 week apart.

TWO FEET OF WATER IN PIT

On May 20 the water level in the pit was increased to 2 feet by discharging water through a 1¼-inch line connected to the distribution system at the Critical Experiment Reactor. (See fig. 2.) An estimated 15,000 gallons of water was required to raise the water level in the pit to 2 feet. The test was continued until June 16 at which time the head was increased to 3 feet. A total of 242,000 gallons of water was discharged into the pit during a 27-day period for an average rate of about 9,000 gpd.

Rises in water levels at the end of the 2-foot test period ranged from about 0.8 to 6 feet. (See figs. 6 to 9.) The water levels in wells along the strike of the schistosity rose about 2.4 to 5.8 feet; in wells downdip water levels rose about 1 foot to 5.9 feet; and in wells updip water levels rose about 0.8 foot to 6 feet. The greatest rise in water levels occurred in the six originally dry shallow wells (AH–77, –78, –80, –85, –91, and –92) along the edges of the pit. The water levels in these wells rose from 4.8 to 6 feet. Only one well (AH–172) drilled below the zone of saturation was close to the center of the water-table mound. The water level in the well rose about 5.8 feet, which was comparable to the rise in the shallow wells.

During the test of the disposal pit at the 2-foot head for 27 days, no additional wells at the site were affected by infiltration from the pit. It is possible that the water level in several shallow wells about 200 feet from the pit along the strike may have risen slightly because of recharge from the pit, however, any small rise in water level that may have occurred in the wells was masked by the large water-level fluctuations caused by rainfall.

Throughout the period of the 2-foot test the water level in AH–172 continued to remain about 3 feet below the water level in AH–90. (See fig. 6.) The rate of increase in water levels in the two wells remained about the same, and at the end of the test a head differential of about 3.1 feet existed between the water levels in the wells.

AH–91 20.3 feet deep and 8½ feet updip from the northwest edge of the pit, did not contain any water at the end of the 2-foot test.

THREE FEET OF WATER IN PIT

On June 16 the water level in the pit was raised to 3 feet in the same manner as for the 2-foot test. A total of 375,300 gallons of water was discharged into the pit during a 30-day period. The average discharge rate was 12,000 gpd during the first 14 days of the test and about 13,000 gpd the last 16 days of the test. An estimated 17,600 gallons of water was required to raise the water level from 2 to 3 feet. The test was continued until July 16 at which time the flow of water to the pit was cut off. (See figs. 6 to 9.)

During the test of the pit at the 3-foot head, water levels in wells rose an additional 0.6 foot to 9.6 feet. The only new well to show the effects of infiltration from the pit was AH–91, about 8½ feet updip from the pit. The depth of the well was 20.3 feet. On June 23 water was first observed in the well, and at the end of the test on July 16 the well contained about 9.6 feet of water.

A rise in water level of 4.4 feet was registered in AH–76 and AH–88, about 10 and 33 feet, respectively, downdip from the pit; the smallest rise (0.6 ft) occurred in TW–18, about 50 feet updip. The shallow wells near the edges of the pit had increases in water levels ranging from 2.5 to 4.2 feet. During the period of the 3-foot test water levels in wells along the strike showed increases of 1.3 to 4.2 feet; in wells updip water levels increased 0.6 foot to 4.0 feet; and in wells downdip water levels increased about 1.1 to 4.4 feet.

In general, the net increase in ground-water levels at the 3-foot head averaged slightly less than that observed at the 2-foot head, although several wells updip and downdip had gains of 0.1 to 0.6 foot at the higher head.

Figure 10 shows the decline of the water in the pit after the flow of water was stopped on July 16, 1959. The rise in water level of 0.7 foot at 1:00 p.m. on July 16 was caused by additional water flowing into the pit when the floats were lifted to prevent damage to the valves prior to pumping waste into the pit. The flow was stopped at 1:45 p.m. The water level in the pit declined 0.7 foot from 1:45 p.m. on July 16 to 8:00 a.m. on July 17. At 8:00 a.m. on July 17, for a period of about 5½ hours, 15,400 gallons of waste was pumped into the pit from the storage tanks at the Radiation Effects Laboratory. The average pumping rate was about 47 gpm. The level in the pit rose about 0.6 foot, but at the end of pumping at 1:40 p.m. on July 17 the water level began a steady decline and at 4:00 a.m. on July 21 the pit was empty.

SECOND TEST OF PIT AT 1-FOOT LEVEL

On July 21 water was discharged into the pit to rerun the test at the 1-foot level over an extended period of time. During a 6-hour period on July 21 about 6,200 gallons of water was discharged into the pit and the water level rose about 0.7 foot. On July 22 when the test was resumed the pit was empty. An estimated 7,600 gallons of water was required to raise the water level 1 foot.

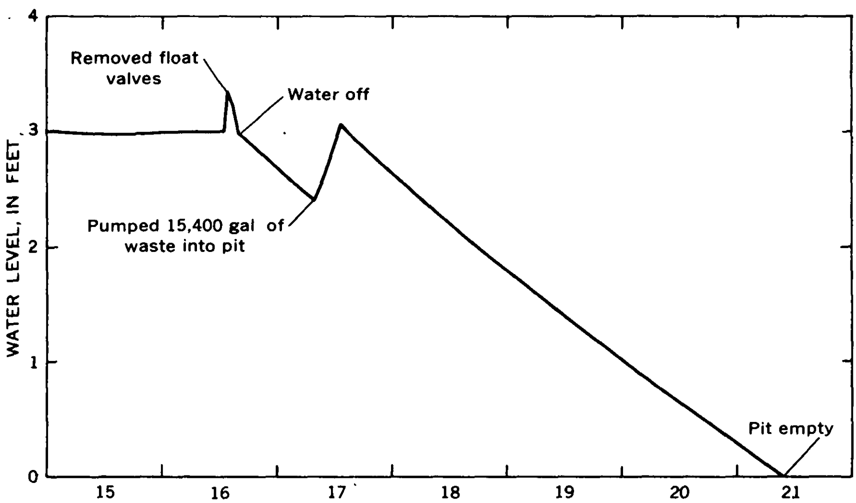

FIGURE 10.—Decline of water level in disposal pit at end of infiltration test at 3-foot level.

The test at the 1-foot level was continued until July 28, 1960, at which time the water supply to the pit was cut off. Measurements of water levels in the area were continued through December 1960 in order to obtain information on the dissipation of the ground-water mound beneath the pit.

On July 31, 1959 an estimated 14,400 gallons of waste was pumped into the pit during a 7-hour period from 9:15 a.m. to 4:15 p.m. A head of about 1 foot of water was being maintained at the time the waste was discharged. Figure 11 shows the effect on the water level

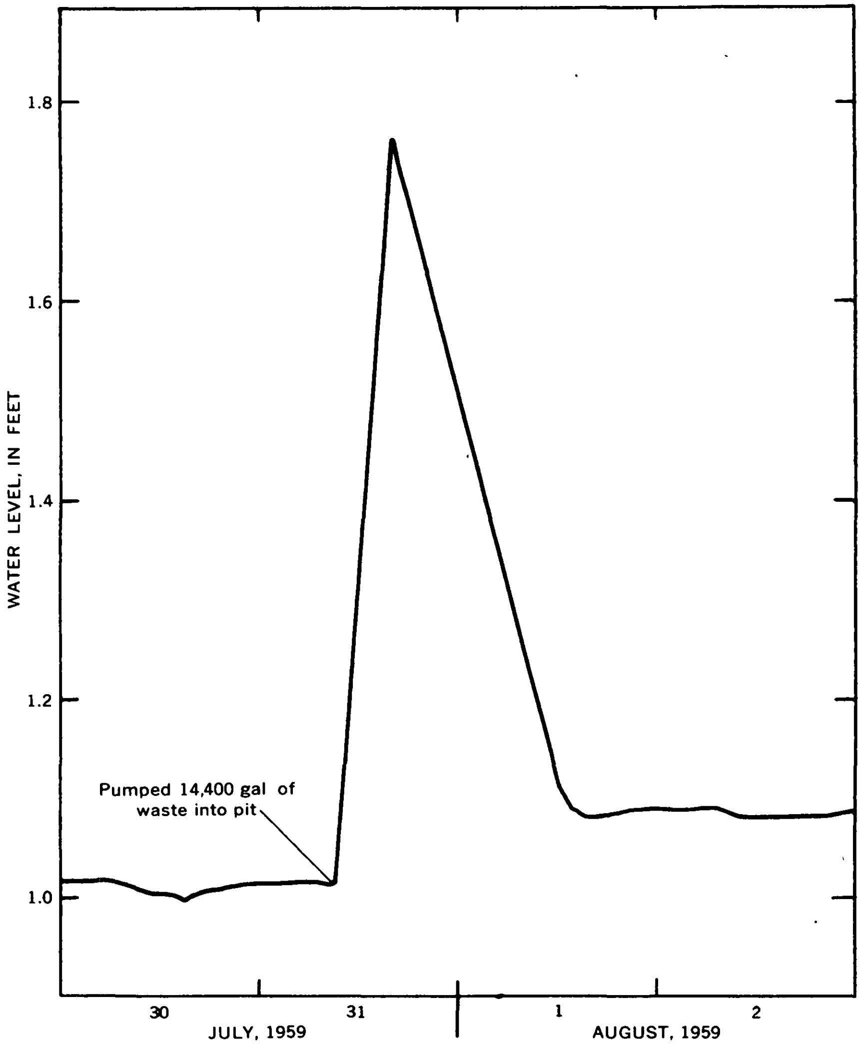

FIGURE 11.—Rise of water level in disposal pit caused by pumping waste into pit during test at 1-foot level.

in the pit as a result of pumping additional water into the pit. The water level in the pit rose about 0.8 foot during the pumping period. After pumping was stopped the water declined rapidly and by 4:00 p.m. on August 1 it was about 0.07 foot above the prepumping level. The higher water level in the pit was a result of the float rods having been bent, thereby requiring a higher water level in the pit before the float valves would operate to cut off the water. The disposal of excess water into the pit during operation at the 1-foot level illustrates the feasibility of discharging large quantities of waste in a short period of time, as may be necessary during an emergency. At an operating level of 1 foot the full capacity of the waste storage tanks (40,000 gallons) could be discharged into the pit without raising the water level above 3 feet. Moreover, it is expected that the water would decline to its previous operating level within a period of about 2 days.

ANALYSIS OF INFILTRATION TESTS

During the 80-day test period from April 27 to July 16, 1959, an estimated 801,600 gallons of water was discharged into the pit. The tests consisted of maintaining a head of 1 foot of water in the pit for 23 days, 2 feet of water for 27 days, and 3 feet of water for 30 days. The retest of the pit at the 1-foot level was continued for 373 days (July 21, 1959 to July 28, 1960), and about 2.6 million gallons of water was discharged into the pit.

An analysis of the data obtained during the 80-day test of the disposal pit from April 27 to July 16, 1959 indicated the following:

1. The first noticeable increase in ground-water levels occurred about 4 days after discharge to the pit began. Of 11 wells showing initial rises in water levels. 6 wells were along the strike of schistosity, 2 wells were updip, and 3 wells were downdip. The wells were 31 to 137 feet deep and were about 9 to 51 feet from the pit.
2. The greatest increase in ground-water levels was along the strike of the schistosity and the smallest increase was updip.
3. At the end of the 3-foot test on July 16 the water levels in shallow and deep wells about 8½ to 87 feet along the strike increased about 4.4 to 20.3 feet; at distance of 8 to 74 feet downdip water levels increased 3.3 to 16.1 feet; and at distances of 8½ to 50 feet updip water levels increased 1.4 to 14.2 feet. Generally, the wells closest to the pit showed the greatest rise in water levels.
4. Six shallow wells (AH–77, –78, –80, –85, –91, and –92) that were drilled into the zone of aeration near the edges of the pit had the highest water levels at the end of the test. The water levels in the shallow wells reflected the level of the upper part of the ground-water mound.
5. In the immediate vicinity of the pit, infiltration of water was controlled largely by the impervious material in the zone of aeration, and most movement was parallel to the strike of the schistosity.

At the end of the 3-foot test on July 16, 1959, the water level in shallow and deep wells continued to rise for about 1 to 2 days after shutdown because the water was still moving toward the wells as the recharge mound decayed (figs. 6 to 9). The decline in water levels in shallow wells was about 1.2 to 4.4 feet during the period July 16–21. In wells at distances of 30 to 74 feet updip and downdip, water levels began to decline from July 21 through July 28, about 5 to 12 days later. The water level in two test wells along the schistosity began to decline about 2 days after the flow of water to the pit was stopped. In a test well downdip, the water level declined after about 3 days, and in a test well updip, it did not decline until August 1, about 16 days later.

After the initial decline in water levels in mid-July and early August, water levels in most wells began a steady increase during the latter part of August, and were still rising at the end of the test. However, water levels in the immediate vicinity of the pit averaged about 4 feet lower in late August than at the end of the 3-foot test on July 16. During the same period water levels in shallow and deep wells outside the area of influence of the pit declined about 0.6 foot to 2.3 feet, and averaged about 1 foot lower than on April 27.

EFFECTS OF PRECIPITATION ON WATER LEVEL IN DISPOSAL PIT

The REL disposal pit is covered only with 1-inch open wire and therefore is subject to direct precipitation. In order to illustrate the effects of precipitation on the water level in the pit during the test, several periods of heavy rains that occurred during the infiltration test are described briefly.

Figure 12*A* shows the effect of rainfall on the water level in the pit during the test at a head of 2 feet. On June 12, 1959, total rainfall was 1.63 inches, of which 0.52 inch occurred from 6:00 to 7:00 p.m. and 1.11 inches occurred from 1:00 to 8:00 p.m. The quantity of water contributed by rainfall amounted to about 3,150 gallons. The maximum rise in water level in the pit was about 0.2 foot, and at the end of 18 hours the water level declined to its original 2-foot level.

Figure 12*B* illustrates the effect of rainfall during a head of 3 feet of water in the pit. On July 11 total rainfall amounted to 1.98 inches during a 3-hour period from 4:00 to 7:00 a.m.; and on July 13, 0.12 inches of rain occurred from midnight to 2:00 a.m. The total rainfall during the above period was 2.10 inches, which represented a contribution of 4,050 gallons of water to the pit. The water level in the pit rose about 0.2 foot during a 2-hour period but declined rapidly after the initial rise. At the end of 14 hours the water level in the pit was at the 3-foot level.

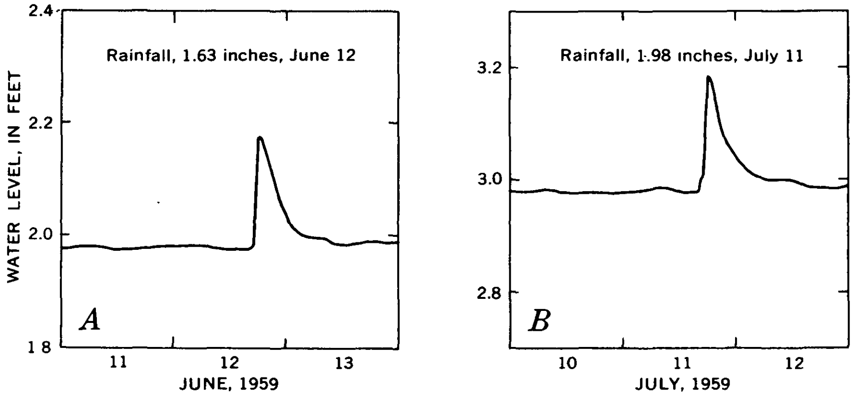

FIGURE 12.—Effects of rainfall on the water level in disposal pit during infiltration tests at heads of *A*, 2 feet and *B*, 3 feet.

It is expected, therefore, that the quantity of water added to the pit during periods of heavy rainfall will not cause any appreciable changes in the water level in the pit.

CONTOUR MAPS OF THE WATER TABLE

Seven contour maps of the water table were constructed for the REL site in order to determine the shape and slope of the water table, the direction of ground-water movement, areas of recharge and discharge, ground-water divides, and the effects of discharging water into the disposal pit. Two profiles of the water table were constructed for each head of water maintained in the pit in order to show the buildup and lateral extent of the ground-water mound along the strike of the schistosity and normal to the schistosity.

The contour lines connect points on the water table having the same altitude at the time that water levels were measured. The general direction of ground-water movement is normal to the contour lines and is in the direction of maximum slope.

Plate 1 shows the contour map of the area just prior to the beginning of the test on April 27, 1959. Beneath the pit the altitude of the water table ranged from about 1,080 to 1,082 feet. The main ground-water divide had a northeast trend and was about 90 feet southeast of the pit. The altitude of the mound in this area was about 1,084 feet. The nose of the mound was about 110 feet east of the pit. The upland area southwest of the pit, where the water table had the highest altitude, was a source of water moving beneath the site.

The general direction of ground-water movement was to the northwest and southeast. The hydraulic gradients slope about 3 to 5 feet per 100 feet to the northwest, and about 4 to 7 feet per 100 feet to the southeast between TW–24 and TW–25. The steeper gradient to the southeast was caused by a steep decline in elevation of about 27 feet from well TW–25 to TW–24.

Plate 2 shows the water levels in the area at the end of the 1-foot test on May 20, 1959. The most noticeable difference in the maps for April 27 and May 20 was the buildup of the water-table mound beneath the pit shown by the closed and partly closed contour lines. The water level rose from an altitude of about 1,080 to 1,082 feet before the test to more than 1,092 feet after the test. The smallest rise in water levels occurred in wells drilled into the zone of saturation, and the highest water levels occurred in a number of wells that were drilled into the zone of aeration and were dry before the start of the test. The contour maps were based on water levels in the shallow wells around the edges of the pit, and therefore probably represent the maximum water levels in the vicinity of the pit. Owing to the steep gradient away from the pit, water levels in two deep wells 6 and 13 feet from the rim of the pit were 2 to 3 feet lower than the water levels in the shallow wells at the rim of the pit.

At the end of the 1-foot test water levels near the pit rose about 12 feet above the pretest levels. The steepest gradients in the immediate vicinity of the pit were updip and the gentlest gradients were along the strike of the schistosity. The gradient updip was about 8 feet in 7 feet near the pit sides, but at a distance of 10 feet from the pit the gradient decreased to about 7 feet in 50 feet. The slope downdip was about 6 feet in 50 feet near the pit, and along the schistosity it was about 9 feet in 50 feet. The buildup of the water table was noted at distances of 100 feet updip, about 140 feet downdip, and about 210 feet along the strike of the schistosity. (See pl. 1.)

The ground-water divide southeast of the pit shifted about 120 feet southwest to a position slightly east of AH–108.

The small rises in water levels in TW–24 and TW–25 were due to a general rise in water levels throughout this part of the area during the test period.

Upon completion of the test at the 2-foot level on June 16, 1959, the ground-water mound increased significantly in height and lateral extent along the schistosity and downdip, and was considerably larger than the mound at the end of the 1-foot test (pl. 3). The altitude of the water table at the pit was about 1,098 to 1,100 feet, about 6 to 7 feet higher than the level during the 1-foot test and about 18 feet higher than the general water table in the area. The lateral extent of the mound was observed at distances of about 120 feet updip, about 160 feet downdip, and about 220 feet to about 280 feet along the strike of the schistosity (pl. 1).

In the immediate vicinity of the disposal pit ground-water gradients were about 22 feet in 50 feet updip, and about 14 feet in 50 feet downdip and along the strike of the schistosity. In areas that were not affected by recharge from the pit, ground-water gradients were about the same as for the earlier test.

Plate 4 shows the configuration of the water table in the area at the end of the 3-foot test on July 16, 1959. The altitude of the water table at the pit was about 1,101 to 1,104 feet, about 3 to 4 feet higher than at the 2-foot head. The maximum buildup of the water level beneath the pit since the start of the test in April was about 21 feet.

In the vicinity of the pit hydraulic gradients were high because of the relatively slow movement of water away from the pit and the large buildup of the mound in the area. Near the pit ground-water gradients updip averaged about 25 feet in 50 feet, along the schistosity northeast of the pit the gradient was about 17 feet in 50 feet, and southwest of the pit it was about 15 feet in 50 feet. In areas updip and downdip that were not affected by the test, gradients averaged about 2 feet in 50 feet, about the same as for the earlier tests.

The higher water levels southwest of the pit were caused by a piling up of the water as a result of recharge from the pit and natural recharge from the area southwest of the pit. The buildup of the water table is shown by the curved contours that form a ridge having a maximum altitude of about 1,086 feet. (See pl. 4.)

At the end of the 3-foot test the buildup of the water table in the area was observed at distances greater than 200 feet updip and downdip, and about 250 feet to greater than 280 feet along the strike of the schistosity (pl. 1).

Plate 5 shows the water level in the area during testing of the pit at a head of 1 foot on December 29, 1959. The water levels did not change significantly during the test period and the configuration of the water level in the area was similar to that observed at the end of the 2-foot test (pl. 3). On December 29, 1959 the altitude of the water surface at the pit was about 1,098 feet, which represented a decline of about 2 to 4 feet during the 161-day test period.

In the vicinity of the disposal pit, gradients decreased slightly and averaged about 19 feet in 50 feet updip and about 10 feet in 50 feet downdip and along the schistosity.

On July 28, 1960 the water supply to the pit was cut off and the infiltration test at the 1-foot head was terminated after an operating period of slightly more than a year. However, in order to observe the decay of the ground-water mound in the area, periodic measurements of water levels were continued through December 1960. The water levels in the vicinity of the pit at the end of the test period are shown on plate 6. The altitude of the mound under the pit was 1,092 feet, or about 6 feet lower than the mound in December 1959. (See pl. 5.) In the vicinity of the pit water levels were about 2 feet higher, and in outlying areas water levels generally were about 1 to 3 feet higher than at any time since the start of the 1-foot test in July 1959. The high water levels in July 1960 were due to heavy rains throughout June and July.

As a result of the higher water levels in July 1960, ground-water gradients increased slightly and averaged about 14 feet in 50 feet updip, 6 feet in 50 feet downdip, and about 6 to 7 feet in 50 feet along the strike of the schisosity.

Plate 1 shows profiles of the water table in directions normal to and along the strike of the schistosity during and after the 1-foot retest of the REL disposal pit. Of the seven profiles included, four show the water table during different seasons of the 1-foot test, two show the decay of the mound after the water supply was cut off, and one shows the approximate general water table in the area for December 1960.

Plate 7 shows the configuration of the water table in the area on December 22, 1960, 147 days after the flow of water to the pit was cut off. The altitude of the ground-water mound was about 1,082 feet, which represented a decline of about 10 feet since termination of the test in July.

In general, water levels in outlying areas in December 1960 were slightly lower than in December 1959. In December 1960 ground-water gradients were about 6 feet in 50 feet updip, and about 3 feet in 50 feet downdip and along the strike of the schistosity. The profile of the water table for September and December 1960 is shown on plate 1. During the period July–September 1960 the ground-water mound declined about 9 feet, whereas for the period September–December 1960 the decline was about 2 feet. At the end of December the mound was about 3 to 4 feet above the general water table in the area.

RAINFALL AND EVAPORATION

In order to determine the infiltration rate of the material in the REL pit, it was necessary to compute the quantity of water added to the pit from rainfall and the quantity of water lost by evaporation. The net gains and losses by rainfall and evaporation were computed for different test periods from April 27, 1959 to July 28, 1960.

GAINS FROM RAINFALL

During the test of the disposal pit at the 1-foot level from April 27 to May 20, a total of 2.26 inches of rainfall was recorded at the GNL

Weather Station, about 0.3 mile northeast of the REL pit. Contribution by rainfall during the test at the 1-foot head amounted to about 4,700 gallons. The quantity of water contributed by rainfall was computed on the basis of the dimensions of the top of the pit, because the rock lapping on the sides would permit water to flow directly into the pit.

During the test at a head of 2 feet from May 20 to June 16, total rainfall amounted to 5.67 inches and the net gain to the pit was about 10,600 gallons. During the test at a head of 3 feet from June 16 to July 16, the total rainfall was 3.94 inches, and about 7,400 gallons of water was added to the pit. From July 22, 1959, to July 28, 1960, a head of 1 foot of water was maintained in the pit. The total rainfall during this period was about 44 inches, and the net gain to the pit was about 93,000 gallons.

LOSSES FROM EVAPORATION

An estimate of the evaporation losses from the pit at different heads was based on records obtained from a gage installed on a 2-foot diameter pan sunk into the ground near the REL pit. Although a standard pan was not used and the results obtained are at most an approximation of the evaporation losses, the figures serve to show that the losses may be large over an extended period of time.

An estimate of the evaporation losses in the area based on data obtained from evaporation maps (Kohler and others, 1959) is about 28 to 32 inches for the period May to October. This value of evaporation is slightly greater than that obtained from the pan at the REL disposal pit. The computed infiltration rate based on the higher evaporation loss averaged about 100 gpd larger than that obtained using pan data at the pit. Because of the relatively small differences in the infiltration rate obtained by the two methods, the rates obtained from the pan data are used in this report.

Table 2 shows the quantity of water pumped or discharged into the pit, the amount contributed by rainfall, and the estimated amount lost from evaporation, for heads of 1 to 3 feet of water in the disposal pit. During the test at the 1-foot head in April and May, 1959, a total of 186,000 gallons of water infiltrated the saprolite during a 23-day period. The average daily recharge rate was about 8,100 gallons. During the test of the pit at a head of 2 feet for 27 days a total of 248,600 gallons of water infiltrated the saprolite. The average daily recharge rate was about 9,200 gallons. A head of 3 feet was maintained in the pit for 30 days and during this period a total of 377,800 gallons of water infiltrated the ground for an average daily recharge rate of about 12,600 gallons.

TABLE 2.—*Water budget, REL disposal pit, Apr. 27, 1959, to July 28, 1960*

[Quantities in gallons except as noted]

Period of test	Duration of test in days	Head of water in feet [1]	Gains			Losses		Recharge rate per day	
			Water pumped or discharged into pit	Precipitation	Total	Evaporation	Total recharge to ground	Average	End of test
1959									
Apr. 27–May 20	23	1	184,300	4,700	189,000	−3,000	186,000	8,100	8,300
May 21–June 16	27	2	242,000	10,600	252,600	−4,000	248,600	9,200	9,700
June 17–July 16	30	3	375,300	7,400	382,700	−4,900	377,800	12,600	13,700
July 22–Oct. 6	77	1	762,600	16,400	779,000	−10,200	768,800	10,000	10,000
Oct. 7–Dec. 31	86	1	824,700	16,400	841,100	−5,400	835,700	9,700	8,800
1960									
Jan. 1–Feb. 29	60	1	334,900	20,600	355,500	−3,100	352,400	[2] 5,870	[2] 7,000
Mar. 1–Apr. 14	45	1	108,000	21,600	129,600	−5,900	123,700	[2] 2,750	[2] 4,000
Apr. 15–July 28	105	1	521,900	17,100	539,000	−13,900	525,100	[3] 5,000	[3] 6,000

[1] Distance measured from original pit bottom to top of water surface.
[2] Recharge rate low because flow of water into pit was stopped several times during freezing weather.
[3] Flow of water cut off several times during June and July.

The pit was retested at a head of 1 foot for 373 days beginning July 22, 1959 and ending July 28, 1960. During the test period an estimated 2.6 million gallons of water infiltrated into the saprolite for an average recharge rate of about 7,000 gpd. However, the recharge rate decreased steadily throughout the test largely as a result of silting of the pit and seasonal changes in temperature, and for this reason, the recharge rate at the 1-foot head was computed for five separate periods. (See table 2.) The recharge rate during the first 77 days of the test averaged 10,000 gpd, but at the end of a year the recharge rate was about 6,000 gpd, a reduction of 40 percent in the efficiency of the pit. The recharge rates obtained for the periods January 1–February 29 and especially March 1–April 14, 1960, are low, because the flow to the pit was cut off several times when the pipes and meter burst as a result of below freezing weather. The recharge rate for April 15–July 28 also is slightly low because the water pipes were broken on several occasions during late June and early July.

DISPOSAL OF WASTE INTO REL PIT

An estimated maximum of 10,000 gpd (7 gpm) of low-level waste will be discharged at the REL site. The waste-disposal system provides for release to the pit of waste containing between 10^{-5} and 10^{-7} microcuries per milliliter of gross unknown beta-gamma activity (Edgerton and Bowen, 1959). The total activity contained under normal operation is expected to be less than 1 curie per year. The waste is composed mainly of activated products from the reactor cooling system and, to a lesser extent, building contamination. It is proposed to retain the waste in two 20,000-gallon hold tanks for a period of time prior to final discharge.

The results of the infiltration tests indicate that the disposal of 10,000 gpd of waste into the REL pit is feasible at a head of about 2 feet above the top of the gravel fill, and that substantially larger quantities could be disposed by maintaining higher levels in the pit. During the tests from April to July 1959, the recharge rates averaged about 8,100 to 12,600 gpd for heads of 1 to 3 feet. However, the recharge rate steadily decreased during the 1-foot test that began July 22, 1959, and it is expected that continuous use of the pit over an extended period of time will result in further decreases in the recharge rate.

That continuous use of the pit at a head of 1 foot or more will result in a relatively large buildup of the water table in the vicinity of the pit is evident from the tests made at heads of 1 to 3 feet, and particularly from the results of the 1-foot test made during the period July 22, 1959, to July 28, 1960. (See pl. 1.) The latter test followed the test of the pit at the 3-foot head when water levels in the area were at a maximum. At the end of 77 days of testing at the 1-foot head water levels remained unusually high and, except for a decline of about 4 to 5 feet shortly after the flow of water was cut off at the end of the 3-foot test, the mound remained about 20 to 22 feet above the pretest level. The buildup of the water table was comparable to that observed at the end of the 2-foot test in June. On December 29, 1959, 161 days after the start of the 1-foot test, the mound was about 3 to 4 feet lower than in October 1959; at the end of the test in July 1960 (373 days after the start of the 1-foot test) the mound declined an additional 6 to 8 feet but still was about 13 feet above the general water table in the area (pl. 1).

It is expected that for a 1-foot head of water in the pit over an extended period of time the mound would continue to dissipate slowly and water levels probably would stabilize at an altitude of about 1,090 to 1,092 feet, or about the same as the levels observed at the end of the first 1-foot test on May 20, 1959 and the second 1-foot test on July 28, 1960.

On September 29, 1960, 63 days after the water supply to the pit was cut off, the mound was about 5 feet above the water table in the area, and on December 22, 1960, 147 days after the test was terminated, the mound was about 3 feet above the water table. (See pl. 1.)

In addition to the decrease of the infiltration rate with time, the following factors will affect the operating characteristics of the pit: (a) the composition of waste discharged into the pit, (b) the possible interaction of waste and saprolite, which would increase the viscosity of the water or form suspended solids that clog the pores in the saprolite, and (c) the accumulation of silt and clay along the sides and on the bottom of the pit.

The fine silt and clay washed into the pit from the sides will contribute substantially to a reduction in the capacity of the pit to take water. On September 9, 1960, the silted area covered about 15 to 20 percent of the surface area of the gravel fill in the pit. Most of the material was concentrated in irregular patterns along the east and south sides of the pit, and some was concentrated in a narrow strip along the west and north sides of the pit. The thickness of the washed-in material ranged from about 0.3 foot near the sides of the pit to less than 0.01 foot toward the center of the pit.

A combination of all or some of these factors may eventually decrease the infiltration rate and the pit would not handle efficiently all the waste discharged into it. Then a higher water level in the pit could be maintained until the gravel fill was cleaned. For maximum safety the operating level should not exceed 4 feet because of the danger of waste becoming perched on top of a shallow silt or clay zone and emerging at the surface near the pit.

It is suggested that future plans include the construction of a second pit about 150 feet north of the first pit. This location would place the pit outside the area of high water levels updip from the first pit and would minimize the effects of a cumulative rise in water levels between the pits when both are operating simultaneously. The second pit would be used as a standby reservoir to take the overflow at a specified level from the first pit.

The new pit should be so constructed that its longest sides are normal to the direction of schistosity and the shortest sides are updip and downdip. This would assure that the greatest surface area is exposed in the direction of greatest ground-water flow. The sides of the pit should be protected to prevent erosion during periods of heavy rains. The dimensions of the pit should be such that its length (normal to direction of schistosity) is about 6 to 10 times greater than its width. The depth should not be less than 6 feet and preferably about 8 feet. A pit 60 feet long, 10 feet wide, and 6 feet deep would have a storage capacity of about 27,000 gallons, about three-fourths of the capacity of the waste storage tanks. However, it is expected that such a pit would handle easily all excess waste discharged into it at operating levels of 1 to 3 feet.

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CHLORIDE AND NITRATE TRACERS

In order to learn something about the direction and velocity of ground water in the vicinity of the REL pit, sodium chloride and sodium nitrate were used as ground-water tracers during the infiltration tests of the pit. On April 27, 1959, 200 pounds of sodium chloride was mixed with 200 gallons of water and the solution dumped into the pit, which contained 1 foot of water. On April 28 an additional 200 pounds was added. Water samples were collected periodically from wells in the immediate vicinity of the disposal pit for about 1 week, after which the sampling program was expanded to include wells at greater distances from the pit.

On May 20, during raising of the head of water in the pit from 1 to 2 feet, 200 pounds of sodium nitrate was dumped into the pit. About 3½ hours later an additional 200 pounds of sodium nitrate was added to the pit. The sodium nitrate was mixed with water in the same manner as the sodium chloride. Sampling of the wells was continued until about mid-August 1959.

Water samples were collected from the test wells using a thief sampler lowered to different levels in the wells. The 1¼-inch diameter wells were sampled by lowering an iron cylinder open at the top into the wells. The samples collected by the cylinder represented water from the upper part of the saturated zone.

The chloride tests were made on samples collected from April to August 1959, and the nitrate tests were made on samples collected from May to June 1959. The samples for which analyses were made were selected on the basis of the depth of the well and the distance and location of the well in relation to the pit. Thus the samples selected for analyses represent both shallow and deep auger holes and test well along the strike of the schistosity, updip, and downdip

It should be noted, however, that the results obtained from the chloride and nitrate tests probably are subject to error owing to adsorption and ion exchange between the tracers and the saprolite. In addition, some investigators found that the nitrate ion may have been reduced to nitrates or ammonia, thereby making the tracer difficult to detect.

CHLORIDE TESTS

Chloride tests were made on 264 samples collected from 36 wells ranging in depth from 20.8 to 137.7 feet. Water from two auger holes showed marked increases in concentrations of chloride, and water from two others showed less pronounced changes in chloride content. Figure 13 shows the changes in the chloride content of the water in the auger holes.

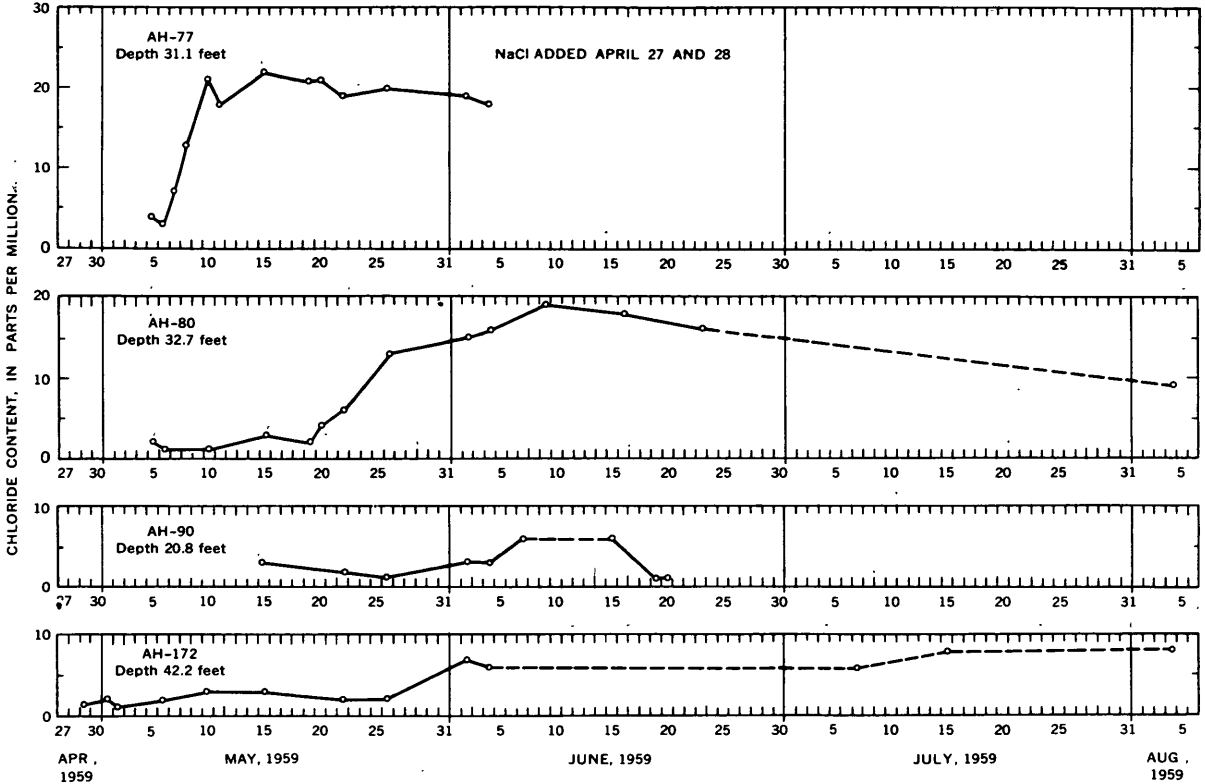

Figure 13.—Chloride content of water samples from wells along strike of schistosity, REL disposal pit. Dashed line indicates that observations were more than 1 week apart.

The first noticeable change in the chloride content of water was found in AH–77. Water from this well had the highest concentration of chloride at the REL site. The well was 31.1 feet deep and about 9 feet southwest of the disposal pit; however, the top of the slotted casing in the well was about 19 feet from the bottom edge of the pit. The well was dry prior to adding water to the pit, but at the end of the 1-foot test the well contained about 9 feet of water. Samples collected from the well on May 5 and 6 contained 2 to 3 ppm of chloride, which was about the average chloride content of the water for the area. On May 7 the chloride content was 7.0 ppm and on May 8 it increased to 13 ppm. Thereafter, the chloride content increased progressively until May 15 when the maximum was 22 ppm. The first noticeable increase of the chloride content occurred about 10 days after the addition of the salt solution to the pit. The rate of movement of the tracer between the pit and well averaged slightly less than 2 feet per day.

Water samples from AH–80 had the second highest concentration of chloride at the REL site. The well was 32.7 feet deep and was 10 feet northeast of the pit; however the top of the perforated casing in the well was about 20 feet from the bottom edge of the pit. The well was dry before the start of the test, but at the end of the 1-foot test on May 20 it contained about 8 feet of water. The first water collected on May 20 had a chloride content of 4 ppm; on May 22 it increased to 6 ppm. A maximum chloride concentration of 19 ppm occurred June 9. Thereafter the chloride content decreased, and by August 4 it was 9 ppm. The chloride content at the well increased noticeably about 24 days after the tracer had been added to the pit. The average rate of ground-water movement from the pit to the well was about 0.8 foot per day.

Water collected from AH–90 and AH–172, about 10 and 11 feet from the pit, respectively, along the schistosity also had noticeable increases in concentrations of chloride. AH–90 was 20.8 feet deep and was dry before the start of the test; AH–172 was 42.2 feet deep and the bottom 10 feet of perforated casing was below the water table.

The first sample from AH–90 was collected May 15. Because of the progressive decrease in amount of chloride in the first three samples tested it is possible that the chloride front may have arrived at the well prior to May 15. The chloride content increased after May 26 and a maximum of 6 ppm chloride was noted in the samples collected June 7 and 15. Thereafter the chloride content decreased and on June 19 and 20 it was 1 ppm.

The first noticeable increase in chloride in samples collected from AH–172 began after May 26. The arrival of chloride in the well occurred within a period of about 30 to 36 days. On the basis of the distance from the bottom edge of the pit to the top of the perforated casing, the average rate of ground-water movement was estimated at about 0.8 to 1 foot per day.

Water samples collected from several other shallow and deep wells in the vicinity of the pit also had slight increases and decreases in concentrations of chloride, but the amount of these changes was well within the range of chloride content of the water before the infiltration test.

RESULTS OF CHLORIDE TESTS

The chloride tracer was detected in four wells ranging in depth from 20.8 to 42.2 feet, and located at distances from the pit of 9 to 11 feet along the schistosity. The samples collected from wells updip and downdip did not show changes in concentrations of chloride great enough to indicate any effect of the tracer in the wells.

Of the four wells showing increases in chloride content of the water, three wells were drilled into the zone of aeration and were dry before the test, and one well was drilled about 10 feet below the water table. All wells had significant increases in water level during the period of the test.

From information gathered during the chloride test, the ground-water velocity was estimated at about 1 to 2 feet per day for a head of 1 foot of water in the disposal pit.

NITRATE TESTS

Nitrate determinations were made on 97 water samples collected from 10 shallow wells ranging in depth from 20.8 to 49.3 feet, and from 10 deep wells ranging in depth from 74.3 to 137.7 feet. The samples were collected during the period May 19 to June 30, 1959. Three samples collected before nitrate was added to the pit contained 0.0 to 0.9 ppm of nitrate. Of the 20 wells from which water samples were collected for analyses, 9 had significant changes in the nitrate content of the water (figs. 14 and 15). Samples from three test wells (TW–16, –17 and –18) showed small changes in concentrations of nitrate, but the amount of increase probably was within the limit of error of the analyses.

The most marked differences in concentrations of nitrate occurred in samples collected from four shallow wells about 9 to 10 feet from the pit. Three wells (AH–77, –80, –90) were along the strike of the schistosity, and one well (AH–78) was updip from the pit. (See pl. 5.) The depth of the wells ranged from 20.8 to 32.7 feet, and the bottom 10 feet of casing in each well was slotted. The shallow wells did not penetrate the zone of saturation and were dry before the start

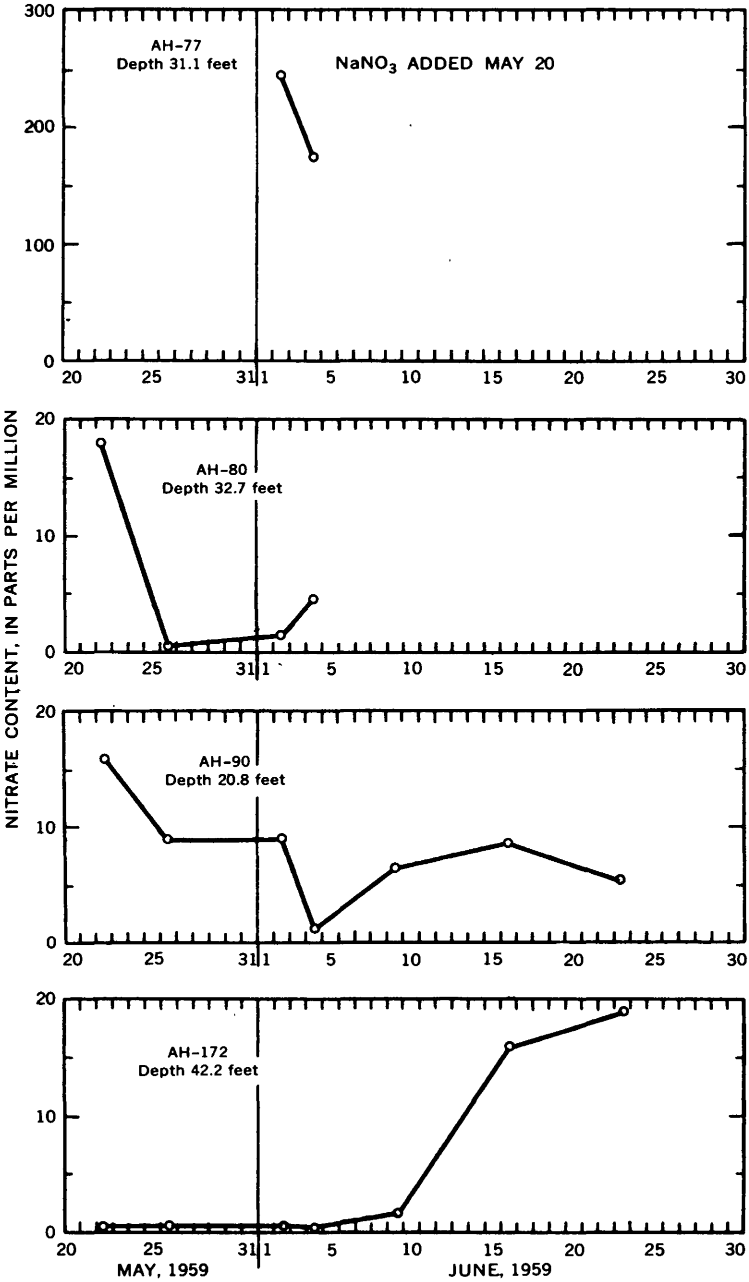

FIGURE 14.—Nitrate content of water samples from wells along strike of schistosity, REL disposal pit.

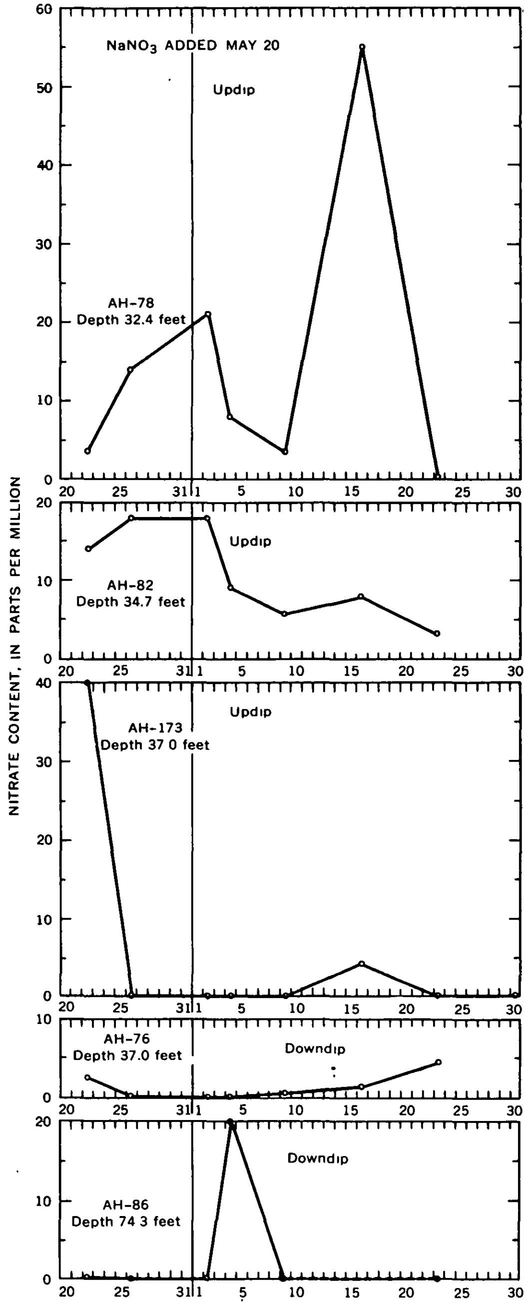

FIGURE 15.—Nitrate content of water samples from wells updip and downdip, REL disposal pit. Dashed line indicates that observations were more than 1 week apart.

of the infiltration test. However, at the end of the 1-foot test on May 20, the wells contained 8 to 14 feet of water.

The nitrate content of the water in the wells increased significantly about 1 to 2 days after adding sodium nitrate to the pit, indicating very rapid movement of water at shallow depths near the disposal pit. The first water tested from AH–77 was collected June 2, about 14 days after the tracer was discharged into the pit. However, the high concentration of nitrate (247 ppm) in the water on June 2, suggests that the tracer probably arrived at the well within 1 to 2 days.

Water collected from four shallow wells (AH–76, –82, –172, and –173) and one deep well (AH–86) also had marked increases in concentrations of nitrate. The wells were at distances of 10 to 65 feet from the pit and included locations along the strike of the schistosity, updip, and downdip. The bottom 10 feet of casing in the wells was slotted in the same manner as the casing in the dry wells.

AH–76, 10 feet downdip from the pit, was drilled to a depth of 37 feet, and prior to the start of the test had about 7 feet of perforated casing below the water table. At the end of the 1-foot test the water level in the well rose about 7 feet. Water collected on May 22 had a nitrate content of 2.4 ppm, indicating that the tracer front reached the well about 1 to 1½ days after adding sodium nitrate to the pit. Samples collected from the well on May 26, June 2, and June 4 contained no nitrate, but on June 9 the nitrate increased to 0.5 ppm and on July 23 it was 4.4 ppm.

AH–172, 11 feet northeast of the pit, was drilled to a depth of 42.2 feet. Prior to the start of the test the top of the perforated casing was 0.2 foot below the water table. During the period April 27 to May 20, with a head of 1 foot of water in the pit, the water level in the well rose 10.5 feet. By June 9 the water level in the well rose an additional 5.2 feet. Water from the well did not show a change in nitrate until June 9, about 20 days after the tracer was added to the pit. Analyses were not made of samples collected between June 4 and June 9, and it is possible that the nitrate front may have reached the well several days earlier than that indicated by the sample collected June 9. The rate of movement of the water averaged about 1½ feet per day.

AH–82, 27 feet northwest of the pit, was drilled to a depth of 34.7 feet. Before the start of the infiltration test there was about 1 foot of water in the well, and at the end of the 1-foot test there was about 2 feet of water in the well. Water collected on May 22, 2 days after the tracer was added, had a nitrate content of 14 ppm. The tracer front probably arrived at the well much sooner than May 22. A secondary increase in nitrate content was noted in the water collected on June 16, when the head in the pit was increased to 3 feet. Increases in nitrate also were observed in several other wells sampled on the same day. The increased head of water in the pit was sufficient to induce a greater volume of water to move through the saprolite at a higher rate of movement. It appears, therefore, that nitrate that had been concentrated in parts of the saprolite by adsorption and ion exchange was taken into solution again by the greater flow of relatively uncontaminated water at the higher head.

AH–173, 46 feet west of the pit, was drilled to a depth of 37 feet. Before the start of the test the water level in the well was about 1 foot below the top of the perforated casing. On May 22 when the well was sampled the water level had risen about 2 feet. The sample contained 40 ppm nitrate. The high concentration of nitrate in the sample indicates that the tracer arrived at the well within a period of 1 day or less. A second increase in nitrate occurred June 16 when the water level was raised to 3 feet.

AH–86, 65 feet southeast of the pit, was drilled to a depth of 74.3 feet. Before the start of the test the water level in the well was 27 feet below land surface; at the end of the 1-foot test it was 26 feet below land surface. Water collected June 4 had a nitrate content of 20 ppm, a marked increase from the sample collected on June 2, which contained 0.1 ppm of nitrate. On June 23 the nitrate content decreased to zero. The nitrate test affected the well about 14 to 15 days after the tracer was added to the pit. The rate of movement of the tracer, an average of about 6 feet per day for a head of 2 feet of water in the disposal pit, was computed on the basis of the distance of the bottom edge of the pit to the top of the slotted casing in the well.

RESULTS OF NITRATE TESTS

A high concentration of nitrate was noted in water collected from four shallow wells near the sides of the pit about 2 days after adding sodium nitrate. However, the tracer probably arrived at the wells much sooner than the time the first sample was collected.

The early arrival of nitrate in the shallow wells is attributed largely to the movement of water along the upper part of the saturated zone and the shorter distance required for water to travel from the pit to the top edge of the slotted casings in the wells. The water level in the shallow wells during the test was well above the general water table in the area and indicated the upper level of the groundwater mound. Thus, in the vicinity of the pit the water moved at relatively shallow depths through the pretest zone of aeration, whereas the water in wells at greater distances from the pit had moved through the zone of saturation.

In shallow wells near the disposal pit the shortest paths of movement of water would be from the sides of the pit to the top of the perforated casing, and in most wells this distance was as much as twice as great as the horizontal distance between the pit and wells. Therefore, the minimum distance required for water to reach these wells would be considerably greater than the actual measured distance as shown by the well locations on the contour maps of the water table. However, this difference becomes negligible for wells located at greater distances from the pit.

The occurrence of nitrate in samples from three wells drilled below the zone of saturation also was observed about 1 to 2 days after adding the tracer to the pit. The high concentration of nitrate in two wells at distances of 10 and 27 feet from the pit would be expected in view of the shallow depth of the slotted casing and the nearness of the wells to the pit. The presence of high nitrate in a well 46 feet from the pit within a period of 1 to 2 days indicates that movement of water was along a highly permeable zone such as a quartz vein or other fractured zone.

The occurrence of nitrate in AH–172 was observed 20 days after adding the tracer, whereas AH–90, 2 feet northwest of AH–172, had a high concentration of nitrate within a period of 1 to 2 days. The early arrival of nitrate in AH–90 was due to the fact that the water in the well was about 3 feet above the general water table, and the sample represented water from the upper part of the mound.

The arrival of the chloride tracer was observed in AH–77 at the end of 10 days and in AH–172 at the end of 26 to 36 days. On the other hand, the arrival of nitrate was observed in AH–77 within a period of 1 to 2 days, and in AH–172 about 20 days after adding the tracer to the pit.

In view of the smaller number of wells that showed changes in the chloride content of the water and the great differences in the time of arrival of the tracers at the wells, it appears that nitrate may be a more satisfactory tracer to use in the area. However, the appearance of nitrate in wells much sooner than the chloride may be due to the following reasons: (1) the composition and character of the saprolite may be such that it has a greater affinity for chloride than nitrate, (2) a higher head of water was maintained in the pit during injection of the nitrate, and (3) the injection of chloride into the pit several weeks before adding nitrate may have substantially satisfied the adsorptive and ion-exchange capacity of the sapolite, thus permitting the water containing the nitrate to move along with relatively little dilution. Moreover, the four wells showing changes in chloride were only about 9 to 11 feet from the pit along the schistosity, whereas the nitrate was detected in nine wells at distances of 9 to 46 feet along the schistosity, 10 feet updip, and 10 to 65 feet downdip.

RATE OF GROUND-WATER MOVEMENT

The results of the chloride and nitrate tests indicate a wide range in ground-water velocity, depending upon the permeability of the material along the strike and dip of the beds and the hydraulic gradients in the area. In addition, the occurrence of the tracer in the wells depended largely on the depth of the well and its location and distance from the pit and the head of water being maintained in the pit. The four wells showing increase in chloride content of water were near the sides of the pit along the strike of the schistosity. Of the nine wells showing increases in concentrations of nitrate, five wells were along the schistosity; two wells were updip, and two wells were downdip.

In general, the velocities obtained were as varied as the number of wells in which the tracers were detected, indicating that ground-water velocities in the area cannot be predicted with any high degree of accuracy using these tracers.

The tracer tests indicate rapid movement of water at shallow depths in the vicinity of the pit, as shown by the early arrival of the nitrate and chloride in the shallow wells around the edges of the pit. On the basis of data obtained from the chloride tests, ground-water velocities in the shallow wells averaged about 0.4 to 1.5 feet per day. On the other hand, the results of the nitrate tests gave velocities of 9 to 20 feet per day for the same wells. The greater part of the differences in velocity is attributed to the reasons discussed on page 38 and the possibility that when the chloride tests were made the saprolite below the pit may not have been saturated completely (at the beginning of infiltration) but by the time nitrate was used, all air had been removed from the saprolite.

On the basis of the arrival of the nitrate tracer in three wells at distances of 27 to 65 feet from the pit, the ground-water velocity was estimated at 16 feet per day updip, 5 to 6 feet per day downdip, and 25 feet per day along the strike of the schistosity. It should be emphasized, however, that the above values are based on data obtained from one well at each of the respective locations, and therefore are not necessarily representative of the average ground-water velocities in the area. However, the values obtained probably represent maximum ground-water velocities along highly permeable zones such as fractured quartz veins and other large openings. For this reason a wide range in ground-water velocity can be expected to be measured at the disposal pit.

The estimated ground-water velocities in the immediate vicinity of the disposal pit and also in outlying areas was computed by the following formula:

$$V=\frac{PI}{7.48p}$$

where V is velocity in feet per day, P is permeability in gpd per sq ft, I is hydraulic gradient in feet per foot, and p is porosity of material.

The permeability of the saprolite is about 7 to 20 gpd per sq ft, which represents the minimum and maximum values obtained from the aquifer test; the average porosity of the material is 47 percent, as determined from laboratory analyses of core samples; and the hydraulic gradients varied depending upon the head of water being maintained in the pit and the direction in which the gradient was measured. For purposes of these computations it is assumed that the 1-foot test ending July 28, 1960, represents more accurately the configuration of the water table during long-term use of the pit. Therefore the velocities were computed on the basis of the hydraulic gradients in the area in July, permeability of 7 and 20 gpd per sq ft, and a porosity of 47 percent.

In the immediate vicinity of the pit ground-water velocity along the strike of the schistosity ranged from 0.4 to 1.1. feet per day, and at distances of about 20 to 60 feet from the pit the velocity ranged from about 0.2 to 0.6 foot per day.

The steepest gradients in the area were observed updip, and the computed velocity near the pit ranged from about 1.2 to 3.4 feet per day; at distances of 70 to 80 feet updip the gradient was relatively flat and the velocity was about 0.01 to 0.3 foot per day.

In the nearby area downdip from the pit the velocity was about 0.3 to 0.7 foot per day, and about 250 to 275 feet southeast of the pit ground-water gradients increased slightly and the velocity was about 0.2 to 0.5 foot per day.

The maximum velocities computed at the end of the 3-foot test ranged from about 0.6 to 1.7 feet per day near the pit along the strike of the schistosity; downdip the velocities were about 0.8 to 2.8 feet per day near the pit, about 0.08 to 0.25 foot per day 80 to 230 feet southeast of the pit, and about 0.1 to 0.4 foot per day 250 to 275 feet southeast of the pit; updip the velocities were about 1.0 to 2.5 feet per day near the pit and about 0.06 to 0.17 foot per day about 70 to 80 feet north of the pit.

Except for the rapid movement of water along highly permeable zones such as was observed in several wells during the tracer tests, at a head of 1 foot of water in the pit, the average velocity near the pit probably will range from about 0.4 to 1.1 feet per day. At distances of 75 to 200 feet from the pit, where the ground-water gradients changed very little during the tests, the velocity probably will range from about 0.1 to 0.5 foot per day.

Assuming that the ground-water mound was in equilibrium with the water table at the end of the 1-foot test in July 1960, the estimated quantity of water moving out from the pit along the strike of the schistosity was computed using the following modified form of Darcy's equation:

$$Q=PIA$$

where Q is the quantity of water in gpd, P is permeability in gpd per sq ft, I is hydraulic gradient in feet per foot, and A is cross-sectional area through which water moves.

The average permeability of the material is estimated to be about 10 gpd per sq ft. On July 28 the hydraulic gradient along the strike of schistosity was 0.15 foot per foot. The thickness of the material through which water is moving is estimated to be about 25 feet and the length of the section is 122 feet, giving a total cross-sectional area of 3,050 square feet. Therefore, the quantity of water moving along the strike of schistosity is

$$Q=10\times 0.15\times 3{,}050=4{,}575.$$

The infiltration rate per day at the end of the 1-foot test was about 6,000 gpd, indicating that about 75 percent of the water was moving out from the pit along the strike of the schistosity.

UNDERGROUND SEEPAGE FROM DISPOSAL PIT

Several possible outlets of underground seepage from the pit should be considered at the site, particularly those areas of perennial springs about 300 feet west and about 800 feet southeast of the pit, and the small draw north of TW–21, about 210 to 450 feet northeast of the pit.

For purposes of estimating the time of arrival of waste at the springs it is assumed that the test ending July 1960 represents an approximation of the buildup of the water table in the area during continuous use of the pit for an average discharge of 6,000 gpd of waste. Therefore, within a distance of about 40 feet west of the pit, ground-water gradients would be relatively steep and the average velocity would range from about 0.3 to 0.9 foot per day. On the basis of these values about 45 to 135 days would be required for water to move 40 feet from the pit. In areas farther from the pit, gradients would decrease significantly and the average velocity would range from about 0.1 to 0.4 foot per day. Thus, an additional 650 to 2,600 days would be required for water to move the remaining distance to the springs. The estimated arrival of the waste at the springs would range from a minimum of 695 days (1.9 years) to a maximum of 2,735 days (7.5 years) depending upon the permeability of the material through which it moves.

During the nitrate test a velocity of 25 feet per day was obtained at AH–173, about 46 feet west of the pit. The unusually high velocity probably was the result of water moving along a highly permeable zone under a steep hydraulic gradient. It is unlikely that the permeable zone extends to the springs. Moreover, the rate of ground-water movement would decrease significantly in areas where the gradients became flatter. However, it should be emphasized that quartz veins and other fractures in the area provide avenues along which water can move rapidly from the pit, and which also may be potential outlets to nearby springs.

On July 28, 1960, 373 days after water was first discharged into the pit, the lateral extent of the mound along the strike of the schistosity southwest of the pit was about 200 feet. However, it is not expected that the pit will operate at the higher water levels maintained during the tests in June and July 1959, except for periods of 1 to 2 days when it becomes necessary to discharge excess waste into the pit. Therefore, the lateral extent of the mound southwest of the pit probably will be about 4 to 7 feet less than that observed at the end of the 1-foot test in July 1960. (See pl. 6.)

The arrival of waste at the springs about 800 feet southeast of the pit, on the basis of computed values of ground-water velocities (p. 40), would range from about 8 to 20 years. On the other hand, on the basis of the velocity of about 6 feet per day obtained from the nitrate test at AH–86, the waste would reach the spring in a much shorter period of time. However, the rate of ground-water movement would decrease significantly in the area southeast of AH–86 where the gradients were relatively flat.

Except for the change in water levels in the area about 50 to 200 feet southeast of the pit, ground-water gradients downdip changed very little during the infiltration tests. Therefore, there is no evidence to indicate that the rate of ground-water movement between AH–86 and the springs would be the same as that obtained between AH–86 and the pit. It is anticipated that the ground-water velocity in the area about 250 to 400 feet southeast of AH–86 probably would range from about 0.2 to 0.5 foot per day.

The arrival of waste at TW–21, about 210 feet northeast of the pit, would range from about 2 to 5 years, depending upon the permeability of the material in this area. The well is at the head of a small draw and natural drainage in the area is to the northeast. Land-surface altitude in the area about 175 feet north of AH–100 is about 16 feet lower than at TW–21, and about 40 feet lower than at the pit site near AH–172.

In the area north of TW–21 water-table gradients are relatively flat, averaging about 0.05 foot per foot. Therefore, an additional 1½ to 4 years would be required for waste to reach AH–100. It should be recognized, however, that all the low-lying area northeast of TW–21 and AH–100 is a potential source of subsurface leakage, and wells in these areas should be monitored periodically after the pit is placed in operation.

HYDROLOGIC PROPERTIES OF THE SAPROLITE

The capacity of the saprolite to transmit water (coefficient of transmissibility) and to yield water from storage (coefficient of storage) was determined at the REL disposal-pit site by the pumping-test and recovery methods.

On March 17–18, 1959, TW–16 was pumped for 30 hours at an average rate of 8.7 gpm using a jet pump. A water meter was installed in the discharge line. The pumping rate was controlled by a gate valve on the discharge line. The pumping rate fluctuated continually but the discharge rate increased slightly during the latter part of the test.

TW–16 was drilled to a depth of 100 feet and was completed as a 6-inch gravel-packed well with perforated casing from 36.4 to 58.2 and 78.7 to 100.0 feet below land surface. The auger holes and test wells in the vicinity of the disposal pit were used as observation wells during the pumping and recovery periods.

The discharge-drawdown test of TW–26 was made by pumping the well for 21 hours at an average rate of 4 gpm and measuring the recovery of water level in the well for about 2 days. The discharge of the well was measured in the same manner as for the test of TW–16. TW–26 was drilled to a depth of 72.3 feet and completed as a 6-inch gravel-packed well with perforated casing from 18.8 to 60.4 feet below land surface.

ANALYSIS OF AQUIFER-TEST DATA

Data from the tests were analyzed by means of the nonequilibrium formula (Theis, 1935) and the straight-line graphical method (Cooper and Jacob, 1946), which is a modified form of the nonequilibrium formula. The nonequilibrium formula assumes (1) a steady rate of withdrawal of water from an aquifer of infinite areal extent and uniform thickness and permeability, (2) instantaneous release of water from storage simultaneously with the decline in head, and (3) penetration by the well of the entire thickness of the aquifer.

The saprolite is neither uniform nor homogeneous and its full thickness is not penetrated by the wells at the REL disposal pit. Therefore, the results obtained from the tests are useful only as approximations of the average conditions in the vicinity of the wells, and on the basis of the hydrology and geology of the area.

Figures 16 to 18 show one semilogarithmic and two logarithmic plots of data obtained for three wells, of which one (TW–16) was pumped and two (AH–75 and –93) along the strike of the schistosity were used as observation wells. Water-level measurements obtained for several deep wells during the latter part of the test declined at a slower rate than most wells in the area and a plot of the points for the deep wells lies below the type curve, indicating a departure from the assumptions of the nonequilibrium formula. The pumping rate increased slightly during the last half of the test, therefore, the smaller drawdowns in the wells were not caused by a decrease in pumpage.

The computed coefficient of transmissibility varied widely within relatively short distances, depending upon the depth of the observation well and its direction and distance from the pumped well. Table 3 lists the results of the tests at the disposal pit. The coefficient of transmissibility ranged from 720 to 2,100 gpd per ft and the storage coefficient ranged from 0.00094 to 0.0083.

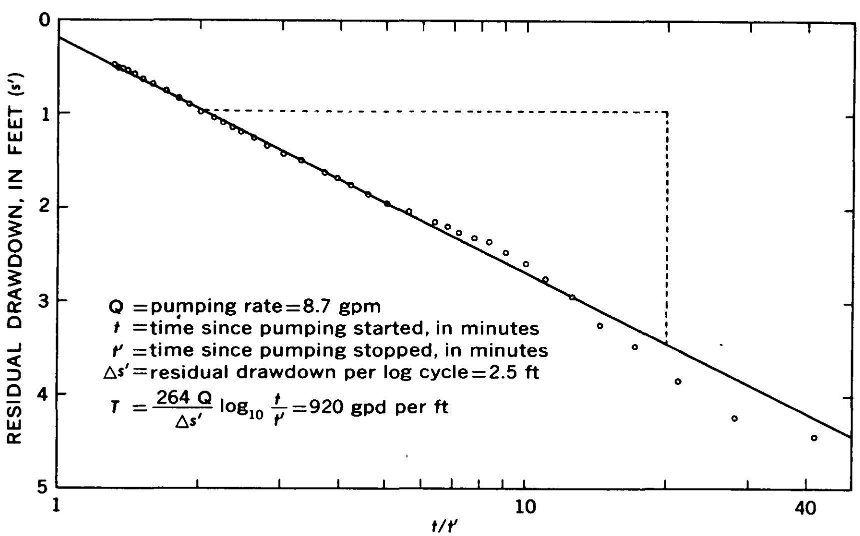

FIGURE 16.—Semilogarithmic graph of the recovery of water level in TW–16.

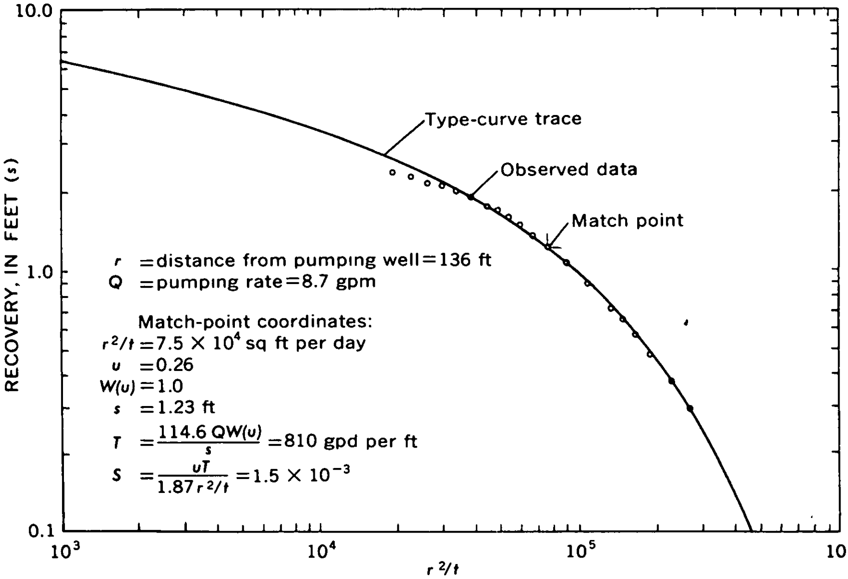

FIGURE 17.—Logarithmic graph of the recovery of water level in AH-75.

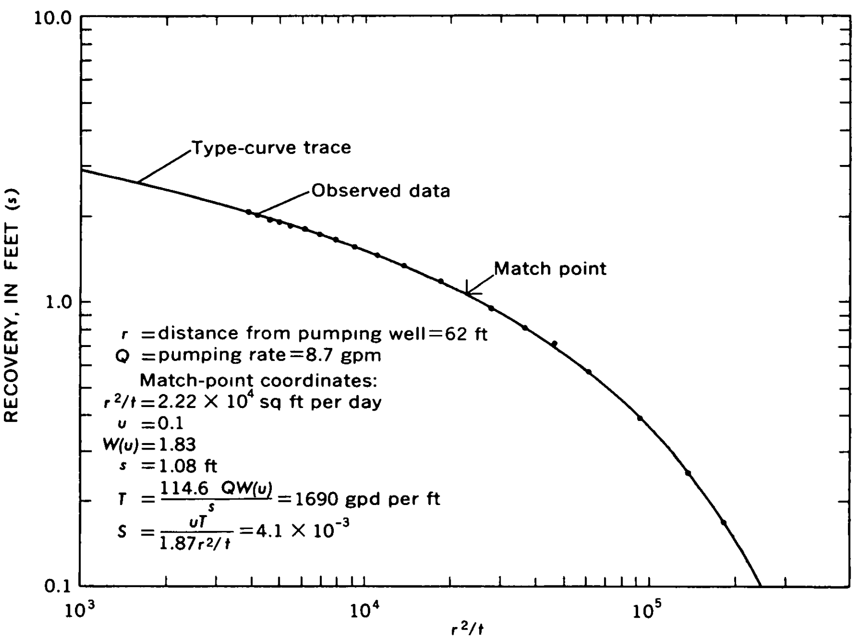

FIGURE 18.—Logarithmic graph of the recovery of water level in AH-93.

TABLE 3.—*Results of aquifer tests, REL site, Mar. 17–19, 1959*

[UD, updip; DD, downdip]

Well	Depth of perforated casing (ft)	Distance from pumped well (ft)	Angle from strike of schistosity	Drawdown at end of 30 hours (ft)	Coefficient of transmissibility (T) (gpd per ft)	Coefficient of storage (S)	Remarks
AH-71	57.0– 67.0	28	88° UD	5.73	1,310	----------	Residual drawdown.
75	83.0– 86.0	136	4° DD	2.40	810	0.0015	
79	72.0– 75.8	49	47° DD	2.37	1,240	.0061	
83	32.8– 42.8	49	79° UD	2.34	1,960	.0074	
93	27.2– 37.2	62	16° UD	2.52	1,690	.0041	
172	32.0– 42.0	71	3° UD	1.66	2,100	.0083	
173	27.0– 37.0	47	54° UD	2.82	1,510	.0069	
TW-15	32.1– 53.0 72.8– 92.9 113.1–136.7	76	139° DD	2.22	1,510	.0015	
16	36.4– 58.2 78.7–100.0	Pumped well	----------	31.3	920	----------	Do.
17	38.4– 58.4 79.0– 99.0	108	17° UD	2.79	720	.00094	
26	18.8– 60.4	Pumped well	----------	----------	1,000	----------	Discharge-drawdown test. Drawdown 58 feet at end of 21 hours.

The shallow wells along the schistosity had considerably less drawdown than the deeper wells at greater distances along the schistosity. For example, AH–172, 42 feet deep and 71 feet along the schistosity had a total drawdown of about 1.7 feet at the end of the test, whereas AH–75, 86 feet deep and 136 feet along the schistosity in the direction of AH–172 had a total drawdown of 2.4 feet. The deeper wells downdip also had the greater drawdowns, but updip most of the shallower wells had the greater drawdowns. TW–18, 102 feet deep and 93 feet updip, had a drawdown of 0.3 foot, whereas AH–81, 50.9 feet deep and 94 feet updip had a drawdown of about 0.9 foot, nearly three times as great as that found in the deeper well. On the other hand, AH–79 which is 75.8 feet deep and 49 feet diagonal to the schistosity and downdip, had a drawdown of about 2.4 feet, and AH–84, 41 feet deep and 48 feet downdip, had a drawdown of only 0.4 foot. Because the deeper wells along the schistosity had the greatest drawdowns, indications are that most of the water pumped from TW–16 probably came from below a depth of 58 feet.

The foliation of the saprolite at the REL disposal pit dips from 69° to 71° SE. Thus wells of comparable depth updip and downdip from TW–16 would not necessarily penetrate the same water-bearing zones as those penetrated by the pumped well unless the same set of joints were intersected by the wells. On the other hand, the deep wells along the schistosity from TW–16 probably penetrate the same zones, and therefore the water levels in the wells would show more response to the effects of pumping. Except for several wells less than 50 feet from TW–16, the greatest drawdowns were in wells along the schistosity and the smallest were in wells normal to the schistosity.

The permeability of the silt and clay zones varies widely, depending upon the thickness and lateral extent of the zones and the type of material from which the saprolite is derived. The shallow wells may penetrate only one zone whereas the deeper wells probably pass through several. Thus the response of the water levels in the wells depends upon the degree of interconnection between the water-bearing zones.

The computed coefficients of transmissability for wells about 100 to 200 feet updip were about 4 to 16 times greater than those computed for wells along the schistosity, and for several nearby wells updip and downdip from TW–16. The unusually small response of the water levels indicated very little, if any, interconnection between the water-bearing zones in TW–16 and those of the wells updip and downdip. For this reason the observed drawdowns in these wells are not believed to be representative, and computations based on them would give excessively high values of transmissibility. Therefore, the transmissibility for these wells is not included in table 3. For example, in 1958, TW–18, 93 feet updip from TW–16, was pumped dry in less than an hour at a pumping rate of about 2 gpm.

The rate of water-level decline decreased in two deep test wells and several deep auger holes during the last half of the test. (See fig. 16.) During the first half of the test, the cone of depression apparently developed as if the water were confined, but during the latter part of the test, drainage from the clay and silt zones retarded further development of the cone.

The saprolite contains large amounts of silt and clay, and very slow drainage and refilling of the material would be expected. This would result in a more rapid decline in the water level during the early part of pumping than if instantaneous and complete drainage occurred. Thus, after the initial rapid decline, the addition of water by delayed drainage would cause the water level to decline more slowly.

In view of the many factors affecting the results of the test, a coefficient of transmissibility greater than 2,000 gpd per ft probably is too high for the type of material tested. The computed values of transmissibility range from 700 to 2,000 gpd per ft and probably average about 1,000 gpd per ft. The coefficient of storage ranges from 0.00094 to 0.0083.

ANALYSIS OF RECHARGE-TEST DATA

The water-bearing properties of the saprolite also were computed using water-level data obtained during the test of the disposal pit at a head of 1 foot for the period April 27 to May 20, 1959. For purposes of computation the recharge area was assumed to be the center of the disposal pit. This method is not applicable to the shallow wells near the edges of the pit because of the great difference in the actual and assumed distances from the pit. For wells at greater distances from the pit this difference becomes less significant, and the computations were fairly consistent.

According to a modified form of Darcy's law the velocity of ground water is directly proportional to the hydraulic gradient and the permeability of the material and is inversely proportional to the porosity. Thus, the increase in water levels in the wells during the recharge test depends on the quantity of water that infiltrates the saprolite and reaches the water table, and subsequent percolation of the water toward the wells. Because the permeability of the material in the zone of aeration largely controls the amount of water that reaches the water table, the computed coefficients of transmissibility and storage probably more nearly represent the capacity of the material to transmit water to the saturated zone.

Computations using the center of the disposal pit as the point of recharge gave inconsistent results when applied to data obtained from wells near the edges of the pit; for this reason the computed values for these wells are not included in the report. Moreover, the large values of transmissibility obtained for most wells updip and downdip are attributed to the fact that very little water moved in the direction of these wells, and as a result the water levels showed very little response to recharge from the pit. Therefore, the small rises in water levels in the wells are not necessarily indicative of increased permeability of the saprolite normal to the strike of the schistosity. The large buildup of water levels in wells along the schistosity during the seepage test and the results obtained from aquifer tests at the disposal pit indicate that most of the water moves along the schistosity. Therefore, computations based on water-level data obtained for wells updip and downdip would give values of transmissibility considerably greater than that obtained for wells along the schistosity.

Table 4 shows the results of the recharge test. The coefficient of transmissibility ranged from 58 to 369 gpd per ft and the storage coefficient ranged from 0.09 to 0.27. In wells along the schistosity the coefficient of transmissibility ranged from 79 to 201 gpd per ft and the storage coefficient ranged from 0.09 to 0.27. Figures 19 to 21 show logarithmic plots of data for three wells.

TABLE 4.—*Results of recharge test, REL site, Apr. 27–May 20, 1959*

Well	Depth of perforated casing (ft)	Distance from center of pit (ft)	Direction from pit	Coefficient of transmissibility (T) (gpd per ft)	Coefficient of storage (S)
AH-71	57.0– 67.0	45	Along schistosity	190	----------
75	83.0– 86.0	97	do	201	0.10
79	72.0– 75.8	88	Downdip	170	.13
81	40.9– 50.9	66	Updip	228	----------
82	24.7– 34.7	58	do	204	----------
83	32.8– 42.8	62	do	98	.23
84	31.0– 41.0	60	Downdip	95	.27
86	64.3– 74.3	99	do	369	.26
87	60.0– 70.0	107	do	214	.27
88	31.0– 41.0	67	do	58	.13
93	27.2– 37.2	108	Along schistosity	79	.09
173	27.0– 37.0	75	Updip	166	.21
TW-15	32.1– 53.0; 72.8– 92.9; 113.1–136.7	62	Downdip	193	.26
16	36.4– 58.2; 78.7–100.0	42	Along schistosity	93	.27
17	38.4– 58.4; 79.0– 99.0	65	do	146	.20

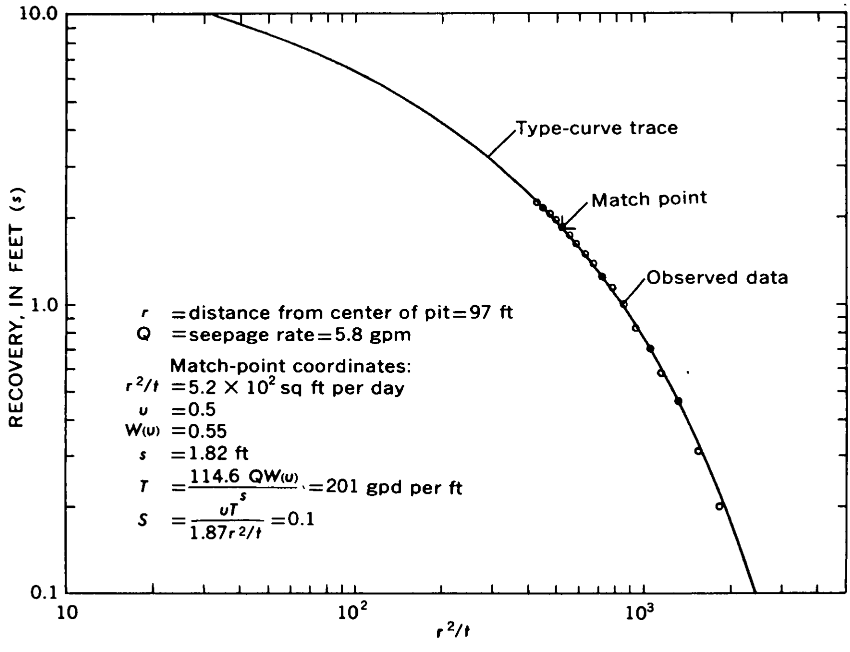

FIGURE 19.—Logarithmic graph of the buildup of water level in AH–75 (along strike of schistosity).

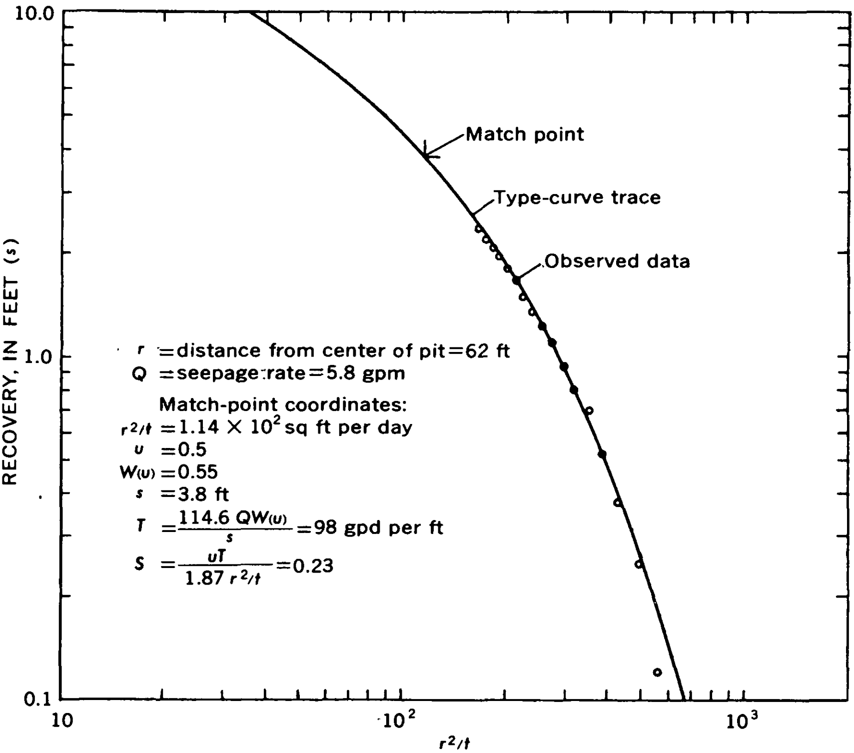

FIGURE 20.—Logarithmic graph of the buildup of water level in AH–83 (updip).

The storage coefficients obtained for the recharge test were considerably greater than those computed from results of aquifer tests in the area and more nearly represent water-table conditions; on the other hand, results of the aquifer tests gave storage coefficients that indicate some degree of confinement of the water. It appears that during the recharge test, water infiltrating into the saprolite was not restricted by clay and silt zones, which under normal conditions probably act to produce partial confinement of the water. The specific yields of three wells at the REL site (table 1) ranged from 4.4 to 34.5 percent and compare favorably with the results obtained from the recharge test. On the basis of recharge-test data, the transmissibility was about 5 to 15 times less than that computed from the aquifer tests.

The values of permeability were computed on the basis of the velocities obtained from the nitrate test, the hydraulic gradients in the area, and the porosity of the saturated material, and ranged from about 13 to 290 gpd per sq ft. Permeabilities greater than 100 gpd per sq ft were based on ground-water velocities of 16 to 25 feet per day and appear to be much too high for the entire area.

The estimated saturated thickness of the saprolite at the pit site is about 100 feet. The values of permeability computed on the basis of aquifer-test data and the estimated thickness range from about 7 to 20 gpd per sq ft and fall within the range of the lower values obtained from the tracer test.

The transmissibility of the saprolite also was determined by using hydraulic-gradient data obtained from the buildup of the water table in the vicinity of the disposal pit. (See pls. 2–6.) The transmissibility averaged 160 gpd per ft along the strike of the schistosity, 46 gpd per ft updip, and 104 gpd per ft downdip. The transmissibility along the schistosity was about 3 to 3½ times greater than updip and about 1½ to 2 times greater than downdip. The results obtained using hydraulic-gradient data compare favorably with the results obtained from recharge data using the nonequilibrium formula method. (See table 4.)

DEFICIENCIES IN DATA

During the investigation information was obtained about the infiltration rate of the material in the REL disposal pit, the direction and rate of ground-water movement, and the buildup and lateral extent of the ground-water mound for different heads of water in the pit. How-

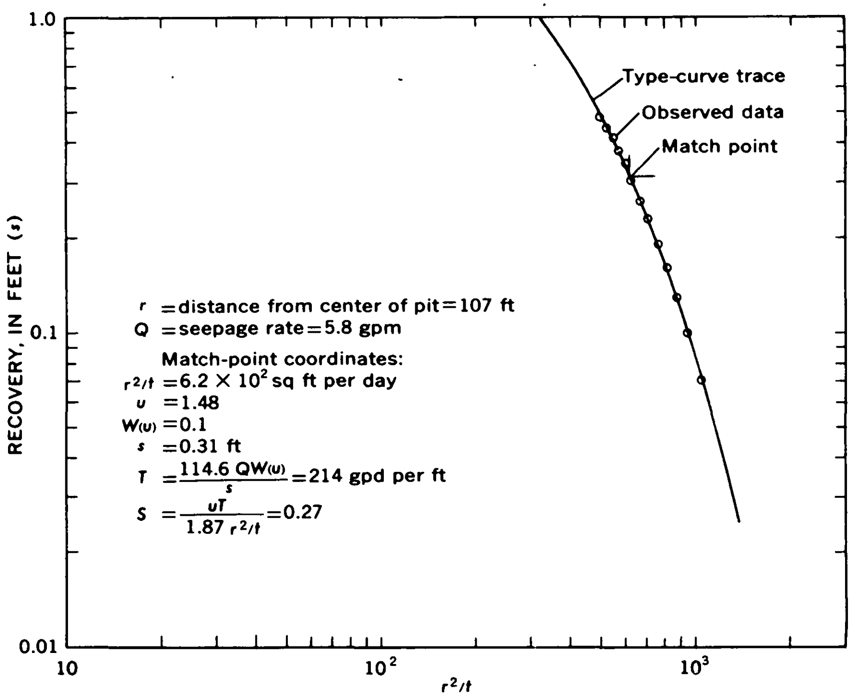

FIGURE 21.—Logarithmic graph of the buildup of water level in AH-87 (downdip).

ever, several important problems in regard to long-term operation of the pit remain unsolved, largely because of the relatively short period of the investigation.

The most likely outlets of waste from the pit are the springs about 300 feet west and about 800 feet southeast of the pit. During the short period of the investigation it was not possible to determine whether any water discharged into the pit reached the springs. In April 1959 weirs were installed on two of the larger springs west of the pit and additional dams were constructed on four smaller springs in order to measure the discharge during the period of the infiltration tests. However, because the springs were in a narrow draw they were susceptible to surface-water runoff, and as a result the dams were washed out or filled with sediment following periods of heavy rain. For this reason measurements of spring flows were discontinued in May 1959. Similar difficulties probably would be encountered in measuring the flow of the springs southeast of the pit.

Because the spring flows represent ground-water discharge in the area, they are likely sources of subsurface leakage of contaminated water from the pit. The springs should therefore be protected from surface-water runoff by concrete structures housing weirs and recording gages. These permanent structures would assure reliable sampling points in probable areas of ground-water leakage.

During the infiltration tests the shallow wells that were dry before the start of the test had the highest water levels in the area. Although data from the tests indicate that the movement of water may vary considerably in different zones in the saprolite, additional information is needed to determine more accurately the direction and rate of ground-water movement at shallow depths in the vicinity of the pit.

In order to obtain information about the ground-water mound it would be necessary to auger several shallow holes ranging in depth from 10 to 25 feet at distances of 25 to 200 feet from the disposal pit.

Additional information that is lacking at the REL disposal site includes the following:

1. Rate of ground-water movement at various distances from the pit.
2. Changes in permeability of the saprolite with increasing depth.
3. Permeability of unweathered rock in the area and the degree of interconnection between shallow and deep water-bearing zones.
4. Quantity of water percolating into unweathered rock and rate of movement of water at greater depths.

SUMMARY

The results of the infiltration tests indicate that the disposal of 10,000 gpd of waste into the REL pit is feasible at a head of about 2 feet above the top of the gravel fill, and that substantially larger quantities could be discharged by maintaining higher water levels in the pit.

It is possible, however, that the type and composition of waste discharged into the pit may cause a decrease in the infiltration rate over a long period of time. Any interaction of waste and saprolite that increases the viscosity of the water or forms suspended solids that clog the pore spaces in the saprolite, and any fine silt and clay washed into the pit from the sides, would affect the operating characteristics of the pit. When the infiltration rate decreases the discharge rate can be maintained by raising the water level in the pit; later when the rate is even less the gravel should be removed and the pit cleaned of silt and clay. The maximum operating level probably should not exceed 4 feet because of the danger of waste becoming perched on silt and clay zones at shallow depths and emerging at the surface near the pit.

At the end of a 23-day test of the pit at a head of 1 foot the infiltration rate was about 8,300 gpd; at a head of 2 feet for 27 days it was about 9,700 gpd; and at a head of 3 feet for 30 days it was about 13,700 gpd. The pit was retested at a head of 1 foot for 373 days, and the infiltration rate decreased from 10,000 gpd in July 1959 to 6,000 gpd in July 1960. However, because of difficulty during freezing weather the water supply was cut off several times and the infiltration rate at the end of the test was somewhat less than expected. For this reason, an infiltration rate of about 6,000 to 8,000 gpd probably is more nearly representative of the value to be expected during long-term use of the disposal pit at an operating level of 1 foot above the gravel fill.

The maximum buildup of the ground-water mound at the end of the 1-foot test in May 1959 was about 12 feet; at the end of the 2-foot test the buildup was about 20 feet; and at the end of the 3-foot test it was about 25 feet. The buildup of the water level during the 1-foot test that ended July 1960 was about 10 to 12 feet, or slightly less than that observed at the end of the 1-foot test in May 1959.

At the end of the 1-foot test in May 1959 the buildup of the water table was noted about 100 feet updip, about 140 feet downdip, and about 210 feet along the strike of the schistosity. At the end of the 2-foot test in June 1959 the mound extended about 120 feet updip, about 150 feet downdip, and about 220 to more than 280 feet along the schistosity. For the 3-foot test ending July 16, 1959, the mound extended more than 200 feet updip and downdip, and about 250 to more than 280 feet along the schistosity.

Because of the relatively low permeability of the material at the site, long-term use of the pit at a head of 1 foot will result in a buildup of the water table to a height of about 10 to 12 feet above the general water table in the area. At the end of the first 1-foot test for 23 days the altitude of the ground-water mound was about 1,092 feet, or about the same as that observed at the end of the second 1-foot test which lasted slightly more than a year. It is expected, therefore, that the ground-water mound will be about the same as that developed during the test of the pit at the 1-foot level which ended July 1960. Moreover, because of the great differences in permeability of the material within short distances, the rate of movement of water in the area varies widely, especially near the pit, where the mound is highest and the gradients are steepest.

The results of the 80-day test of the disposal pit at heads of 1 to 3 feet from April 27 to July 16, 1959, indicated the following:

1. The first noticeable increase in ground-water levels occurred about 4 days after discharge to the pit began. Of 11 wells showing initial rises in water levels, 6 were along the schistosity, 2 were updip, and 3 were downdip.
2. The greatest increase in ground-water levels was along the strike of the schistosity and the smallest increase was updip. At the end of the 3-foot test on July 16 water levels in shallow and deep wells about 8½ to 87 feet along the strike of the schistosity increased about 4.4 to 20.3 feet; at distances of 8 to 74 feet downdip water levels increased 3.3 to 11.9 feet; and at distances of 8½ to 50 feet updip water levels increased 1.4 to 14.2 feet.
3. Six shallow wells, which were drilled into the zone of aeration near the edges of the pit, had the highest water levels at the end of the test. The water levels in the shallow wells reflected the level of the upper part of the ground-water mound.
4. In the immediate vicinity of the pit infiltration of water was controlled largely by the impervious material in the zone of aeration, and most movement was parallel to the strike of the schistosity.

During operation of the pit at the 1-foot level in April and May 1959, ground-water velocities in the immediate vicinity of the pit, computed on the basis of the chloride tests, were about 0.4 foot to 1.5 feet per day. At a head of 2 feet in the pit velocities of 9 to 20 feet per day for the same wells were computed from the nitrate tests. The results of the nitrate tests for three wells at distances of 57 to 65 feet from the pit gave velocities of 5 to 6 feet per day downdip, 16 feet per day updip, and about 25 feet per day along the strike of the schistosity. However, because of the unusually high velocities obtained for each of the directions from the pit the values are believed to represent maximum rates of movement along highly permeable zones.

On the basis of the results obtained from the aquifer test and the 1-foot infiltration test made during the period July 1959 to July 1960, the computed ground-water velocity along the strike of the schistosity near the pit ranged from 0.4 to 1.1 feet per day, and at a distance of about 20 to 60 feet along the schistosity it ranged from 0.2 to 0.6 foot per day. Updip ground-water velocity near the pit was about 1.2 to 3.4 feet per day, and at distances of 70 to 80 feet updip, the gradient was relatively flat and the velocity was about 0.01 to 0.3 foot per day. Downdip the velocity near the pit was 0.3 to 0.7 foot per day, and about 250 to 275 feet southeast of the pit, the gradient increased slightly and the velocity was about 0.2 to 0.5 foot per day.

In general, the velocity at the 3-foot level near the disposal pit averaged slightly higher than at heads of 1 and 2 feet. However, at greater distances from the pit the velocity was about the same for all the tests.

Before the start of the infiltration test, the general direction of ground-water movement in the REL site was northwest at gradients of 3 to 5 feet in 100 feet, and southeast at gradients of 4 to 7 feet in 100 feet. A ground-water divide southeast of the pit resulted from recharge from the upland area southwest of the pit. The divide extended about 110 feet east of the pit.

During the 1-foot test the buildup of the water table was sufficient to induce movement of water in all directions from the pit. The steepest gradients were updip, and the gentlest gradients were downdip and along the strike of the schistosity. Ground-water movement outside the immediate area of the pit was northwest and southeast.

At the end of the 2-foot test the ground-water mound showed significant increases along the strike of the schistosity and smaller increases downdip. The increase in movement of water along the schistosity is indicated by the curved contours northeast and southwest of the pit.

In the vicinity of the pit the hydraulic gradient increased significantly and averaged about 22 feet in 50 feet updip and about 13 feet in 50 feet downdip and along the schistosity. At distances beyond the effects of seepage from the pit the gradient averaged from 2 to 3 feet in 50 feet.

Upon completion of the 3-foot test there was a pronounced increase in movement of water along the strike of the schistosity, and the lateral extent of the mound in this direction was more than double that updip and downdip. Ground-water gradients in the vicinity of the pit continued to increase and were slightly greater than the gradients observed during the 2-foot test. In the vicinity of the pit updip the ground-water gradient was about 26 feet in 50 feet, and in the area between AH–73 and AH–26 it was about 2 feet in 50 feet; downdip the gradient near the pit was about 16 feet in 50 feet and between AH–89 and TW–25 it was about 3 feet in 50 feet; along the strike of the schistosity near the pit the gradient was about 15 feet in 50 feet, and 40 to 150 feet southwest of the pit it was about 5 feet in 50 feet.

During the 1-foot test of the pit from July 22, 1959, to July 28, 1960, an estimated 2.6 million gallons of water infiltrated the saprolite. At the end of the test the altitude of the mound beneath the pit was about 1,092 feet, or about 10 to 12 feet above the water table in the area. On December 22, 1960, 147 days after the test was terminated, the mound was about 3 feet above the general water table in the area.

The most likely areas of ground-water seepage are the perennial springs about 300 feet west and about 800 feet southeast of the pit, and the draw about 210 to 450 feet northeast of the pit.

On the basis of the permeabilities obtained from the aquifer tests, the hydraulic gradients in the area at the end of the 1-foot test in July 1960, and a porosity of 47 percent for the saprolite, the estimated time of arrival of waste at the springs about 300 feet west of the pit would occur within a period of about 1.9 to 7.5 years; in the area about 800 feet southeast of the pit waste would arrive at the springs within a period of about 8 to 20 years; and in the low-lying area northeast of the pit an estimated 2 to 5 years would be required for waste to reach well TW–21.

The results of the aquifer tests at the REL disposal site indicate a coefficient of transmissibility of 700 to 2,100 gpd per ft and a storage coefficient of 0.00094 to 0.0083.

The coefficients also were computed by the nonequilibrium formula using data obtained during the 1-foot test of the disposal pit from April 27 to May 20, 1959. The transmissibility ranged from 58 to 369 gpd per ft, and the storage coefficient ranged from 0.09 to 0.27. The storage coefficient probably was high because the water infiltrating into the saprolite was not restricted by clay and silt zones, which under normal conditions probably produce partial confinement of the water. In addition, computations using the hydraulic gradient of the ground-water mound during tests of the pit at various heads gave transmissibility values of 160 gpd per ft along the strike of the schistosity, 46 gpd per ft updip, and 104 gpd per ft downdip. The computed values compare favorably with those obtained from recharge data using the nonequilibrium method.

The large range in transmissibility obtained for the aquifer tests is attributed to changes in the character of the material, the nearness of the observation wells to the pumped well, and the depth and location of the wells with respect to the pumped well. The foliation of the saprolite dips about 72° SE., and wells of the same depth updip and downdip from the pumped well would not necessarily penetrate the same water-bearing zones. On the other hand, the deeper wells located along the strike of the schistosity probably penetrate the same water-bearing zones found in the pumped well.

The low storage coefficient computed from the aquifer tests indicates that the water in the area is under some degree of confinement. The degree to which water levels in most wells in the area respond to changes in barometric pressure indicates that the clay and silt beds in the zone of aeration impede communication between the atmosphere and the water table. In addition, core samples collected from three wells at the site indicate that the permeability of the material above the saturated zone varies as much as 1 to 1,000 in a distance of 1 to 2 feet.

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INDEX

[Major references are in italic]

	Page
Acknowledgments	D3
Aquifer-test data, analysis of	43
Barometric efficiency	5
Chloride and nitrate tests	*30*
chloride tests	30
nitrate tests	33
results of chloride tests	33
results of nitrate tests	27
Contour maps of water table	*22*
Data, deficiencies in	*51*
Drilling program	4
Etowah River	2
Evaporation	25
Geology of REL disposal pit	*8*
Georgia Nuclear Laboratory	2
Gradients, hydraulic	22, 24
Ground water, in weathered crystalline rocks	
discharge	6
movement	7, *39*
occurrence	4
recharge	5
Hydraulic properties, of core samples	*9*
saprolite	*43*
Introduction	*1*
Infiltration tests	*10*
analysis of	20
1 foot of water	12
second test at 1-foot level	18
Infiltration tests—Continued	
3 feet of water	D17
2 feet of water	16
Investigation, previous	3
purpose and scope	1
Location and extent of area	2
Permeability, coefficient of	9
Porosity	5, 9
Precipitation, effects on water levels	*21*
Profiles of water table	23, 25
Rainfall and evaporation	*25*
gains from rainfall	25
losses from evaporation	26
References	57
REL disposal pit, construction and capacity	*10*
Recharge tests, analysis of	47
Saprolite	4, 7
Seepage, underground from disposal pit	*41*
Specific yield	9, 50
Springs	6
Storage, coefficient of	43, 47, 49
Summary	*52*
Transmissibility, coefficient of	43, 47, 49, 51
Water budget	27
Waste, composition	27
disposal into pit	*27*
Water levels, buildup of	12
decline	18, 21
effects of precipitation	21
effects of waste disposal	19

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