FREDERICK CO.

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in cooperation with

MARYLAND DEPT. OF GEOLOGY, MINES AND WATER RESOURCES
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TEST DRILLING AND AQUIFER TEST IN THE MARBURG SCHIST NEAR MOUNT AIRY, FREDERICK COUNTY, MARYLAND

by Gerald Meyer

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Introduction

This memorandum[1/] summarizes briefly the data obtained by test drilling and in an aquifer test at Mount Airy, Md. The tests were a part of the State - Federal cooperative study of the ground-water resources of Frederick County, and it is intended that a more complete analysis of the test data will be included in a future report describing the ground-water resources of Frederick County. The purpose of this memorandum is to make the test data immediately available to the general public.

Mount Airy is located along the Carroll - Frederick County boundary about 2 miles north of the intersection of U. S. Highway 40 with the county boundary. Its population is approximately 1,000. The municipal well field, consisting of two drilled wells (fig. 1) is in a valley about one-half mile west of the center of Mount Airy, within about 400 feet of a small stream, and north of Prospect

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1/ Open-file report. Not reviewed for conformance with stratigraphic nomenclature and editorial standards of the Geological Survey.

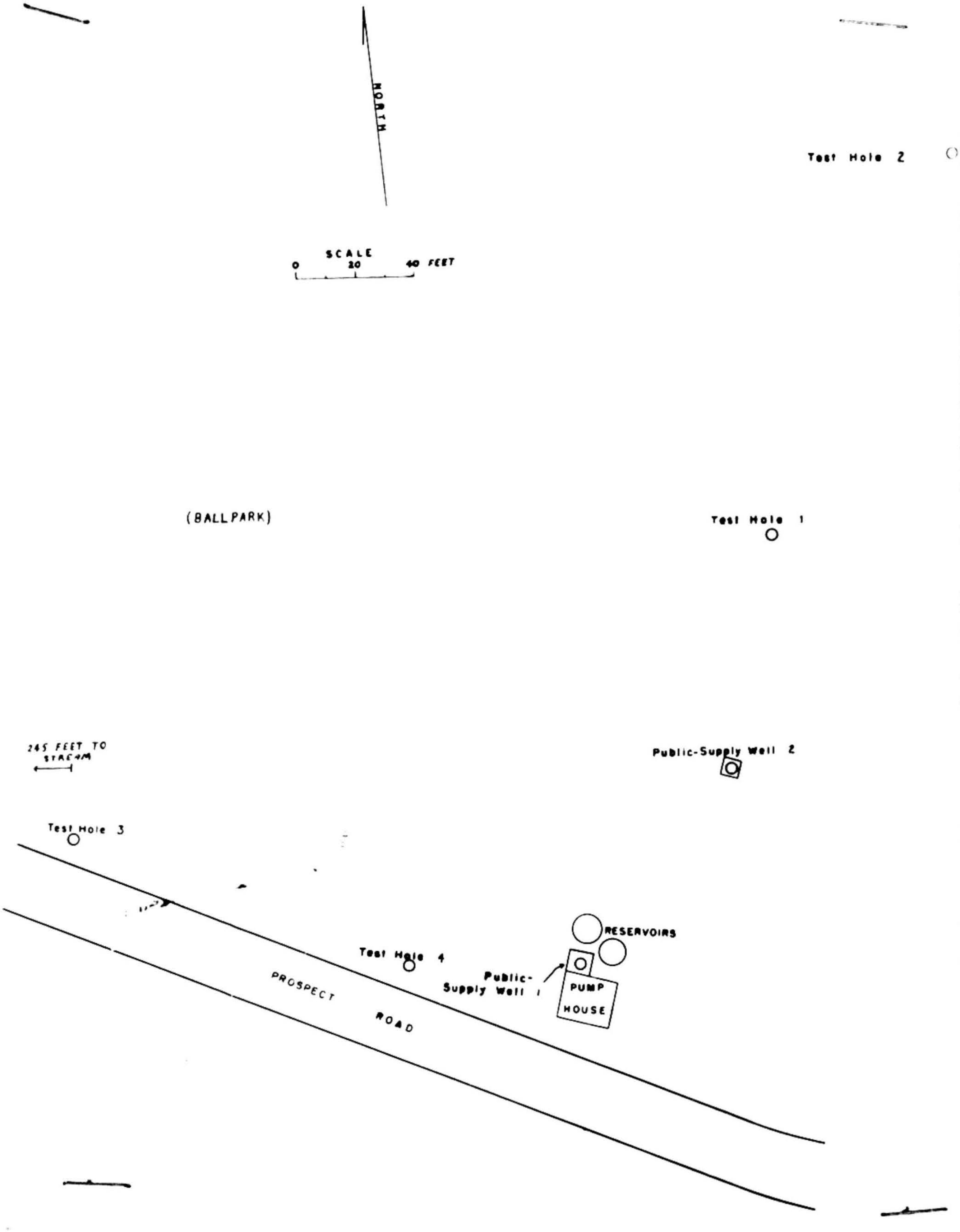

Figure 1. Map showing the location of the Mount Airy public-supply wells and test holes.

Road. Well 1, about 40 feet north of Prospect Road, is 125 feet deep, 8 inches in diameter, and reportedly yielded 265 gallons per minute (gpm) in 1947 and 201 gpm in a half hour test in March 1955. The writer determined during the tests described in this memorandum that the well has about 34 feet of casing. Well 2, 85 feet north of well 1, is 96 feet deep, 8 inches in diameter, and reportedly yielded 120 gpm in 1947 and 127 gpm in a half hour test in March 1955. The wells are equipped with deep-well turbine pumps powered by electric motors. Generally only well 1 is used, and it is pumped for only a few short intervals each day to meet the water requirements of the town (about 75,000 - 80,000 gallons daily). The reported yields of these wells are considerably higher than the average for crystalline-rock wells in the Piedmont of Maryland.

The test drilling was done under contract with Edward I. Brown, well driller, between May 3 and May 12, 1955. Water-supply facilities of the town of Mount Airy were kindly made available for the aquifer tests from May 22 to May 30, 1955.

The pumping tests consisted of a step-drawdown and interference test on the public-supply wells on May 30, 1955, and an aquifer test in which public-supply well 1 was pumped constantly for 48 hours and the effect of this pumpage was measured in all the wells and test holes on May 23 - 25.

General Geology and Hydrology

Mount Airy lies near the western edge of the belt of crystalline schists of the Maryland Piedmont. The town and its vicinity are underlain by a northeast-trending band of schist (Marburg) about 6 miles in width. The schist is closely folded, medium to fine-grained schist or phyllite, bluish gray to silvery green where fresh, and is injected with quartz along the layering.[2/] Where strongly weathered the schist is brown or tan.

2/ Stose, A. J., and Stose, G. W., The physical features of Carroll County and Frederick County, p. 74, 1946. (Md. Dept. Geol., Mines and Water Res.)

In the vicinity of the Mount Airy municipal well field, which is on the east side of a small stream in a north-northeast trending valley about one-half mile west of the town, the schist is exposed in road cuts and gutters on hillsides bordering the valley. It does not crop out in the valley or stream channel. Quartz veins one or two inches thick cut the schist, many of them striking in the general direction of the schistosity, north-northeast. Cuttings from the deeper parts of the test holes show the presence of marble (or limestone) and crystalline calcite, but these were not noted in the hillside exposures. The calcareous material may be related to the Wakefield marble or the Silver Run limestone, as described by Stose and Stose[3/]. The marble may be found in the well cuttings in sharp, planar contact with pieces of the schist, but is not found as an integral part of the schist.

Local precipitation is the sole source of ground water in the valley in which the municipal well field is located. A part of the precipitation that falls within the valley and on the hills bordering the valley enters the ground and moves downward to the water table, the top of the zone of saturation. Water in the zone of saturation moves slowly towards the stream where it is discharged as seeps along the banks or upwards through the channel floor to become a part of the stream, and is carried out of the area. Some water is brought into the valley by streams draining the hills bordering the valley. It is likely that during and immediately following heavy rains some rain water flows into the valley as surface runoff down the steeply sloping hillsides.

3/ Stose, A. J., and Stose, G. W., The physical features of Carroll County and Frederick County, p. 59-60, p. 62. (Md. Dept. Geol.,Mines and Water Res.)

Test Drilling

Four test holes (fig. 1) were drilled with a percussion, or cable-tool, drilling machine in the vicinity of the municipal well field to determine the geology of the valley, vertical and lateral differences in thickness and character of the water-bearing material, and for later use as water-level observation wells during the aquifer-evaluation tests. The holes were 6 inches in diameter and were cased only as deep as was necessary to prevent slumping of the walls.

Cuttings bailed from the holes were examined under a binocular microscope. Short pumping tests, using the bailer to remove water, were run at various depths in each test hole to measure changes in capacity with depth, and to measure the effects of changes in casing length on capacity. An approximate drilling-time log was kept for each hole; however, many variable factors govern the drilling rate when using a cable-tool machine, so that these logs are useful for general comparisons of drilling time only.

Test Hole 1

Test hole 1 was drilled 158 feet north of public-supply well 1 and to a depth of 55 feet below the land surface. Casing was installed to a depth of of $37\frac{1}{2}$ feet. The lrg of this well, based on examination of wet sample cuttings under the binocular microscope, is as follows:

Test Hole 1

Material	Thickness (feet)	Depth (feet)	Approx. rate of drilling (min/ft)	Remarks
Soil, clayey, dark	1	1	-	Excavated with shovel.
Schist, rotten, silty, soft, yellow-brown; 3-inch fragments vein quartz.	3	4	-	Do.
Schist, quartzose, soft, yellow-brown, platy fragments.	8	12	1.7	Drill-cuttings sample.
Schist, quartzose, soft, brown; numerous brownish-black limonite cubes (pseudomorphs after pyrite).	12	24	1.7	Muddy sample.
Schist, abundantly quartzose; less weathered appearance than above; cuttings coarse; large limonite cubes.	6	30	1.7	Cleaner sample.
Schist, as above, with finer cuttings.	7	37	-	Fairly clean sample.
Schist, soft, brown, and fresher bluish gray schist laminated with quartz; quartz fragments; some black minerals and fresh pyrite; calcareous material about 25% of sample.	5	42	-	Fairly hard drilling, Very little mud with sample. Bottom of weathered zone in this interval.
Quartz fragments, and weathered schist, brown, rather soft; limonite cubes. No calcareous material noted.	3	45	28	Brown schist probably contamination from above.
Schist, gray-blue, quartzose; calcareous material about 20% of sample.	3.5	48.5	17	
Schist, as above, with some golden-brown softer schist fragments; limonite cubes; calcareous material about 25% of sample.	6.5	55	21	

Two brief bailer pumping tests were made during the drilling of this test hole to determine the specific capacity. The specific capacity of a well may be defined as the yield divided by the drawdown required to produce that yield and is commonly expressed as gallons per minute per foot of drawdown (gpm/ft). It is a convenient unit for comparing the performances of different wells. Summary data on these tests are tabulated below:

Depth of test hole (feet)	Length of casing (feet)	Duration of bailer pump test (minutes)	Average bailing rate (gpm)	Drawdown of water level (feet)	Specific capacity (gpm/ft)
42	37½	17	21	10	2.1
55	37½	30	24.7	10	2.4

After the first bailer test, drilling between 42 and 48½ feet was hampered by coarse quartz and schist fragments apparently moving downward from shallower levels along the annular space between casing and well wall to the bottom of the hole. In order to correct this the casing was driven down one inch. This "seating" of the casing effectively cased off the producing zone, for when the test hole was bailed the water level lowered quickly to the bottom of the hole, and 14 hours later the water level was still 18 feet below the static level. This demonstrated also that the uncased section of the hole from 37½ to 48½ feet was essentially unproductive. The vibrations set up by continued drilling, to 55 feet, loosened and destroyed the casing seat and the water level recovered rapidly nearly to its static position. The casing was raised 3/4 inch to enlarge the area through which water could enter the well, and the second bailer test outlined in the table above was run to determine the effect on the well capacity of drilling to 55 feet and of raising the casing. The test indicated that the capacity was only slightly higher than when the test hole was 42 feet deep, and this small increase was probably due to freer passage of water through the annular space around the lower end of the casing rather than the penetration of additional water-bearing material.

In summary, the producing zone in this test hole is the weathered schist between about 10 and 37½ feet below the land surface. The clayey upper ten feet of this interval is much less permeable than the lower part. The specific capacity is 2.4 gpm/ft, at least for small discharge rates and short periods of pumping. If, for the purpose of comparison of its capacity with the other test holes, it is assumed that the specific capacity of this test hole would decline with consecutively increased pumping increments at the same rate as determined later for public-supply well 2 (fig. 3), then with drawdown of the water level nearly to the bottom of the producing zone, this test hole would yield about 50 gpm for short periods of pumping and the specific capacity would be about 2 gpm/ft.

<u>Test Hole 2</u>

Test hole 2 was drilled 300 feet north of public-supply well 1 and to a depth of 89 feet. The description of wet sample cuttings from this well is as follows:

Test Hole 2

Material	Thickness (feet)	Depth (feet)	Approx. rate of drilling (min/ft)	Remarks
Loam, brown.	1.5	1.5	-	Excavated with shovel.
Clay, yellow-brown; few fragments brown weathered schist.	1.5	3	-	Do.
Schist, quartzose, yellow-brown, soft; few limonite cubes. Flashlight on test-hole wall shows material to be fragments of schist and quartz in a loose, sandy matrix with ghost schistose structure.	8	11	1.3	Drill-cuttings sample; slightly muddy.
Schist, as above; few pieces platy, slate-colored schist or phyllite.	7	18	3.5	Sample moderately muddy.
Schist, yellow-brown, with moderate amount of quartz.	3	21	5	Rather clean sample.
Schist, quartzose, yellow-brown.	12	33	-	Muddy sample.
Schist, brown, with less quartz fragments than above.	4	37	-	Less muddy sample.
Quartz, predominantly; a little quartz-saturated gray schist and a few platy pieces greenish-gray phyllite.	6.5	43.5	20	Drilling rate for 43-43.5 ft. interval. Very muddy sample.
Schist, quartzose, yellowish brown; some limonite cubes.	1	44.5	10	
Schist, brown; less quartz than above.	5.5	50	13	Very muddy sample.

Test Hole 2 (continued)

Material	Thickness (feet)	Depth (feet)	Approx. rate of drilling (min/ft)	Remarks
Schist, brown, with a few gray pieces; moderate amount of quartz; numerous limonite cubes, other dark minerals. Small amount of calcareous material.	5	55	13	Fairly clean sample.
Schist, brown and yellowish brown; a few pieces quartz-saturated schist and gray schist. Calcareous material about 5% of sample.	6	61	5	Harder drilling beginning at 60 feet. Base of weathered zone in this interval. Clean sample; partly granulated by bit.
Schist, predominantly gray, with some brown; quartz abundant; calcareous material about 5% of sample.	1.5	62.5	20	Clean sample; partly granulated by bit.
Schist, dark gray; moderate amount of quartz. Few particles of limonite sand cemented by calcite.	11.5	74	3.5	Clean sample; partly granulated by bit.
Schist, dark gray, with quartz.	6	80	3.5	Do.
Schist, as above, with some weathered, brown schist fragments (contamination from above?); few cubes of fresh pyrite. Few small particles of calcareous material.	7	87	6.4	Do.
No sample.	2	89	24.5	

The table below summarizes four brief bailer tests at different depths during the drilling of this hole:

Depth of test hole 2 (feet)	Length of casing (feet)	Duration of bailer pump test (minutes)	Average bailing rate (gpm)	Drawdown of water level (feet)	Specific capacity (gpm/ft)
44.5	38	8	17.5	24	0.7
55	38	15	23	11.5	2.0
80	38	15	22.9	7	3.3
89	38	20	24.5	4.5	5.4

In summary, the capacity of this test hole increased substantially as the hole was deepened, indicating that the water-bearing material extends from the top of the zone of saturation, about 10 feet below the land surface, to about 89 feet. Although it is possible that further drilling would have increased the capacity of this hole, the slow drilling of the last two feet suggests that the hole ended in or near hard, fresh rock; and if this is so, further drilling probably would not increase the capacity appreciably. However, if a production well were to be drilled in the vicinity of this test hole, it would seem desirable to drill several feet into unquestionable hard, fresh rock so as to assure complete penetration of the water-bearing section. The specific capacity of this hole for short periods of pumping and small pumping rates is 5.4 gpm/ft. If, for the purpose of comparison with the other test holes, it is assumed that the specific capacity would decline with consecutively increased increments of pumping at the same rate as determined for public-supply well 2 (fig. 3), then with a decline of the water level nearly to the bottom of the producing zone, this test hole would yield about 150 gpm for short periods of pumping and the specific capacity would be about 2.1 gpm/ft.

Test Hole 3

Test hole 3 was drilled 175 feet west of public-supply well 1 to a depth of 79½ feet. This hole is approximately midway between public-supply well 1 and the small unnamed stream. The log of this test hole is as follows:

Test Hole 3

Material	Thickness (feet)	Depth (feet)	Approx. rate of drilling (min/ft)	Remarks
Soil, dark brown.	1	1	-	Excavated with shovel.
Clay, residual, brownish yellow, with small pieces quartz; shows slight ghost schistose structure; small amount of black minerals.	2	3	-	Do.
Clay and silt, residual, light tan, with small pieces quartz.	6	9	2.5	Drill-cuttings sample.
Clay and silt, residual, darker tan, with small amount of quartz and sand-size particles of yellow-brown schist.	6	15	0.8	
Schist, yellow-brown, and quartz fragments; a few pieces gray schist; limonite cubes, other dark minerals.	6	21	2.5	
Schist, yellow-brown, with abundant quartz.	7.5	28.5	3.3	Cleaner sample.
Schist, brownish gray, harder fragments than above, and abundant quartz.	7.5	36	3.7(?)	Moderately muddy sample.
Schist, gray, hard, with a few soft pieces; much less quartz than above.	11	47	5.9	Bottom of weathered zone in this interval. Fairly clean sample.
Schist, gray, with moderate amount of quartz; fine particles of iron-stained quartz and yellow-brown schist give sample a speckled appearance; fresh pyrite.	3	50	-	Last foot of drilling hard. Fairly clean; cuttings granulated by bit.
Schist, similar to above, except much coarser particles. Small amount of calcareous material.	5.5	55.5	16	Clean sample.

Test Hole 3 (continued)

Material	Thickness (feet)	Depth (feet)	Approx. rate of drilling (min/ft)	Remarks
Schist, similar to above; brown schist particles more abundant. Calcareous material about 1% of sample.	5	60.5	21	Clean sample.
Quartz, coarse granules, with large amount of gray and brown schist particles; abundant pyrite, both crystalline and amorphous. Calcareous material about 1% of sample.	8	68.5	17	Do.
Schist, gray, flakey particles, with large amount of quartz. Calcareous material about 1% of sample.	6.5	75	18	Cuttings granulated; clean sample.
Schist, as above, with calcareous material about 5% of sample.	4.5	79.5	18	Do.

The table below summarizes three brief bailer pumping tests at different depths in this hole.

Depth of test hole 3 (feet)	Length of casing (feet)	Duration of bailer pump test(minutes)	Average bailing rate (gpm)	Drawdown of water level (feet)	Specific capacity (gpm/ft)
36	22	15	21	4	5.2
55.5	41.5	17	27.2	2.5	10.9
79.5	41.5	(17 (45	(27.2 (26.7	(2.3 (2.5	(11.8 (10.7

When the hole was 47 feet deep the addition of 10 feet of casing, which placed the bottom of the casing 32 feet below land surface, reduced the capacity of the hole to a few gallons a minute, indicating that relatively poor water-bearing material was encountered from 32 to 47 feet. With further drilling the casing seat presumably was loosened and good water-bearing material was penetrated, for the test at 55.5 feet showed the capacity of the hole to be twice what it was when the hole was 36 feet deep.

The final bailer test in this hole lasted 45 minutes at the end of which the specific capacity was 10.7 gpm/ft, or slightly lower than indicated by the 17-minute test when the well was 55.5 feet deep (10.9 gpm/ft). However, for the same interval of pumping as the shallower test, 17 minutes, a specific capacity of 11.8 gpm/ft was computed (see above table), showing that the capacity of the hole probably was increased slightly by the drilling below 55.5 feet.

In summary, the major water-bearing zone in this test hole was penetrated between depths of about 10 or 15 feet and 55 feet below the land surface, and consists of quartz veinlets and weathered schist. The bailer tests, well cuttings, and drilling rate suggest that the capacity could have been increased very little by drilling deeper. The specific capacity of this hole for short periods of pumping and small pumping rates is about 10.7 gpm/ft. If, for the purpose of comparison with the other test holes, it is assumed that the specific capacity would decline with consecutively increasing pumping increments at the same rate as determined for public-supply well 2 (fig. 3), then with a decline of the water level nearly to the bottom of the producing zone, this test hole would yield about 130 gpm for short periods of pumping and the specific capacity would be about 3.2 gpm/ft.

Test Hole 4

Test hole 4 was drilled 58 feet west of public-supply well 1 and to a depth of 99½ feet. The log of this well is as follows:

Test Hole 4

Material	Thickness (feet)	Depth (feet)	Approx. rate of drilling (min/ft)	Remarks
Soil, loamy, with 3-inch quartz fragments at bottom.	3	3	1.7	Excavated with shovel.
Clay, residual, gritty, tan, with fragments of quartz and yellow-brown and gray schist.	7	10	2	Drill-cuttings sample.
Clay, residual, as above, with less quartz.	6	16	-	Easy drilling.
Schist, brown, quartzose; some gray schist; a few limonite cubic crystals.	5	21	-	Muddy sample. Easy drilling.
Schist, yellow-brown, soft, and quartz.	10	31	5	Muddy sample.
Schist, yellow-brown, tabular particles, some larger fragments; quartz abundant.	7	38	12.5	Do.
Schist, sericitic; dark minerals; quartz fragments abundant.	4	42	20(?)	Do.
Schist, brown fragments with some gray; quartz; a little cubic limonite.	4	46	7.7	Sample moderately muddy.
Schist, brown, and quartz.	6.5	52.5	-	Do.
Schist, brown and light gray, and quartz.	6.5	59	6.7	Muddy sample.
Schist, darker brown, small particles; some quartz.	9	68	3.6	Very muddy sample.
Schist, gray and brown fragments, with quartz.	9	77	11.7	Moderately muddy sample.
Schist, as above, with brown fragments more plentiful.	7	84	13.8	Soft spots encountered by drill. Moderately muddy sample.
Schist, light gray; moderate amount of brown schist and quartz; calcareous material about 10% of sample.	6	90	25	Last 4 feet drilled much harder. Muddy sample.
Schist, light gray, and quartz; some brown schist; fresh pyrite and limonite cubes; calcareous material 10% of sample.	9.5	99.5	30	Fairly clean sample.

As drilling progressed, four bailer tests were made in this hole. These are summarized in the table below. Analysis of these tests was hampered by interference from nearby public-supply well 1 which was pumped several times during the bailer tests. The computed specific capacities are probably only of the correct order of magnitude.

Depth of test hole 4 (feet)	Length of casing (feet)	Duration of bailer pump test (minutes)	Average bailing rate (gpm)	Drawdown of water level (feet)	Specific capacity (gpm/ft)
46	36.6	10	23.8	13.5±	1.8±
46	35.9	12	24.5	9.5	2.6±
84	49	10	26.6	5	5.3±
99.5	49	(12 (47	(26.7 (26.7	(5 (7.5	(5.3± (3.6±

When this hole was 38 feet deep and contained 30½ feet of casing, it apparently was a good well as indicated by the rapid recovery of the water level after bailing cuttings. However, because of slumping of the wall of the hole, it was necessary to install an additional 6 feet of casing, which reduced the well capacity to practically nothing. When the hole was 46 feet deep its capacity had increased to about 1.8 gpm/ft. It is not known how much of this increase in capacity can be attributed to the additional drilling and how much was leakage past the annular space between casing and test-hole wall. The casing was raised 0.7 foot, and a second bailer test indicated a moderate increase in capacity (see second line of table above).

A third bailer test at 84 feet showed that the capacity had approximately doubled. The fourth and final bailer test in this hole lasted 47 minutes at the end of which time the specific capacity was about 3.6 gpm/ft, or appreciably lower than indicated by the 10-minute test when the hole was 84 feet deep. However, 12 minutes after bailing began in the final test, which is approximately the same length of time as the test at shallower depth, a specific capacity of 5.3 was computed. This would indicate that no significant water-bearing material was penetrated below 84 feet.

In summary, the producing zone in this test hole is between about 16 and 84 feet below the land surface. However, the upper part of this zone is unstable and required casing, probably reducing the capacity of the test hole appreciably. It is unlikely that the capacity could have been increased significantly by drilling below 99.5 feet. The specific capacity of this hole for short periods of pumping and small pumping rates is about 3.6 gpm/ft. If, for the purpose of comparison with the other test holes, it is assumed that the specific capacity would decline with consecutively increasing pumping increments at the same rate as determined for public-supply well 2 (fig. 3), then with a drawdown of the water level nearly to the bottom of the producing zone, this test hole would yield about 130 gpm for short periods of pumping, and the specific capacity would be about 2.2 gpm/ft.

Well Characteristics and Well Interference

Knowledge of the hydraulic characteristics of existing wells drilled in the crystalline rocks aids in understanding the geo-hydrology of the crystalline-rock aquifers. This knowledge is valuable also as a guide for the proper construction of wells in the crystalline rocks. The construction of rock wells generally is simple in comparison with wells in sand and gravel, as are found in the Maryland Coastal Plain, for generally no screen or gravel pack is used, the casing is short, and little development occurs with pumping. Crystalline-rock well characteristics are governed chiefly by the nature of the rock in the vicinity of the well and the extent to which the producing zone (aquifer) is exposed, or uncased, in the well. It is important to keep in mind that the well characteristics revealed by brief pumping tests may not be applicable for long periods of pumping because of lateral changes in geology and hydrology as the pumped water is derived from areas some distance from the wells and because of substantial withdrawal of water from storage.

Public-Supply Well 2

On May 30, 1955 a step-drawdown and interference test was made on Mount Airy public-supply wells 1 and 2; water-level measurements were made in both wells, and in test hole 1 and 4. (See fig. 2). The data for test holes 1 and 4 are not included in this memorandum. Discharge water was pumped through a 4-inch fire hose to Prospect Road. Public-supply well 2 was pumped for 84 minutes at an average rate of 87 gpm with a drawdown of 19 feet. Thus, the specific capacity at the end of 84 minutes was 4.6 gpm/ft.

The pumping rate was increased 84 minutes after discharge began by opening the discharge valve completely, and pumpage averaged 93.3 gpm for the next 105 minutes. An additional drawdown of 4 feet was measured, or a total of 23 feet. The specific capacity, after the increase in pumping rate, is 4.1 gpm/ft. This well reportedly yields 127 gpm, for short periods of pumping, when it discharges into the municipal system. The lower discharge through the fire hose is attributed to greater friction loss.

After 189 minutes (3.15 hours) of pumping it was necessary to direct the discharge water through another fire hose upwards into the municipal supply tanks for a period of 44 minutes to satisfy a municipal requirement for water. The increased pumping head and friction reduced the discharge to 60 gpm. One water-level measurement in public-supply well 2 during this period of pumping suggests that the specific capacity would be approximately 8 gpm/ft, based on an extrapolated drawdown estimate of 7.5 feet a few hours after the change in pumping rate. When the discharge was again directed through the hose to Prospect Road, the discharge rapidly increased to about its prior rate, averaging 91.8 gpm for a period of 14 minutes.

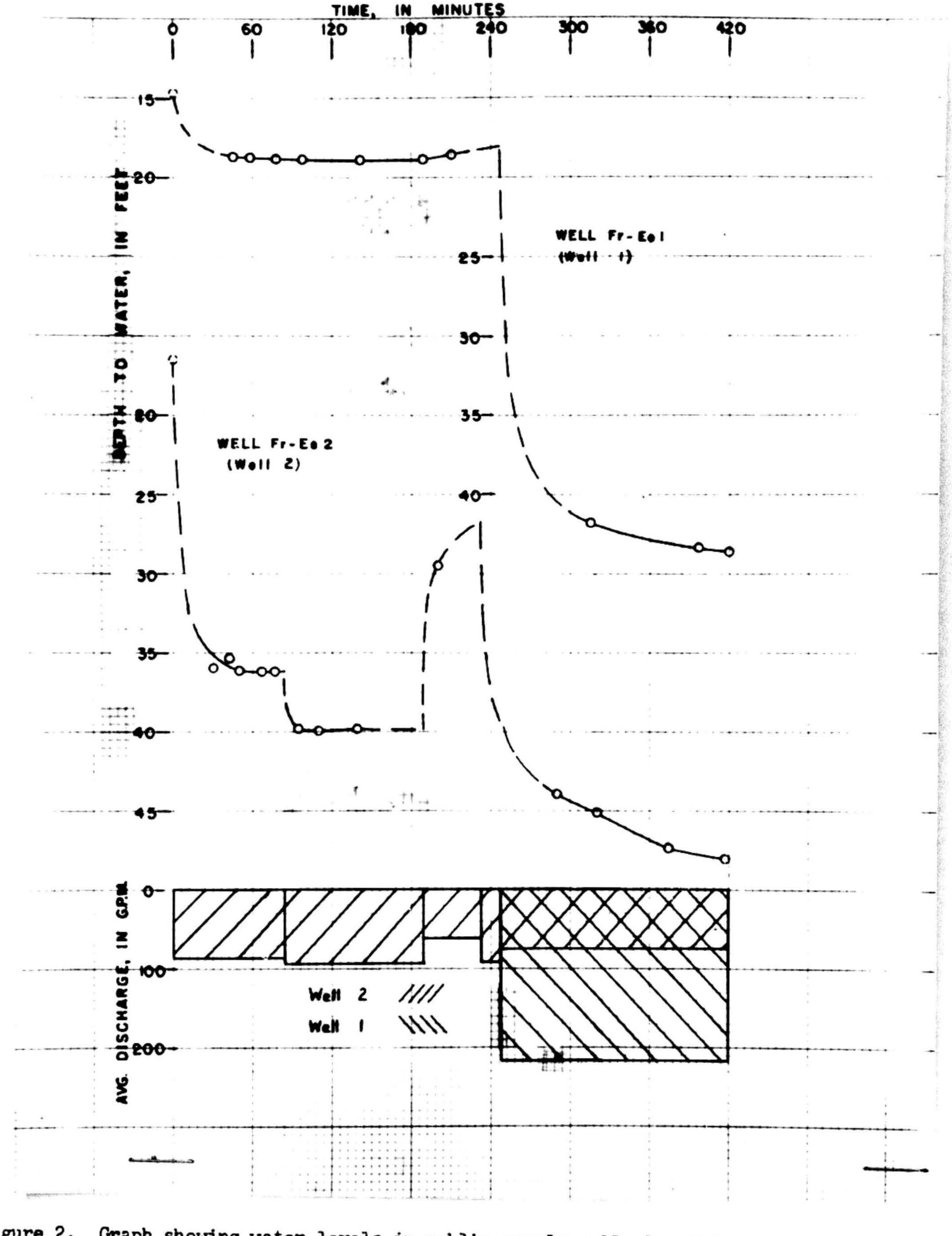

Figure 2. Graph showing water levels in public-supply wells 1 and 2 and pumpage during step-drawdown and interference test. Dashed lines indicate estimated water levels where no measurements were made.

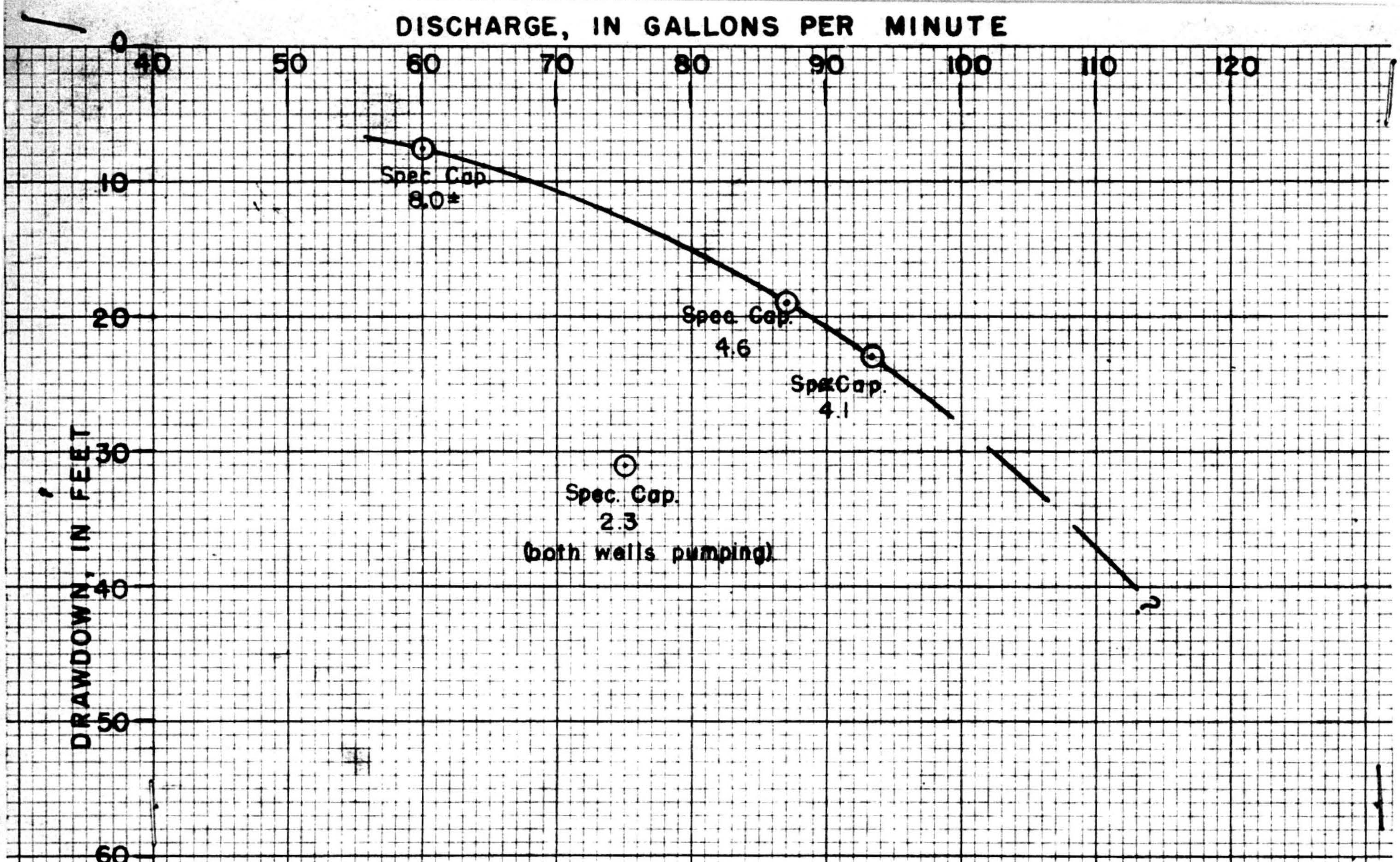

Figure 3. Graph showing relation between discharge and drawdown for public-supply well 2.

In the final phase of the test, designed to measure the interference effects on public-supply well 2 caused by pumping public-supply well 1, pumping of well 2 was continued and pumping from well 1 was begun. The water levels in, and discharge of, both wells were measured, as well as the water levels in test holes 1 and 4. This additional discharge, averaging 213 gpm, increased the drawdown in well 2 to 31 feet (formerly 23 feet) and reduced its yield to 75 gpm (formerly 93.3 gpm) after 173 minutes of combined pumping. The computed specific capacity for well 2, with both wells pumping, is only 2.3 gpm/ft.

Figure 3 shows a plot of yields versus drawdowns required to produce those yields measured during the test. Each plotted point represents a specific capacity measurement; the specific capacity of 8 gpm/ft is an approximation. The general pattern of the graph, showing a decrease in specific capacity with increase in drawdown and pumping rate, is normal for wells in crystalline-rock aquifers under water-table conditions. This decrease reflects withdrawal of water from storage and an appreciable decrease in saturated thickness in the vicinity of the pumped well. Assuming 50 to 60 feet of available drawdown in public-supply well 2, extrapolation of the curve suggests that the maximum capacity of this well for short periods of pumping may be between 120 and 130 gpm. Thus, the reported yield for this well of 127 gpm would appear to be its maximum yield for short periods of pumping. The yield of well 1 declined about 25 percent during the 2-day aquifer test, suggesting that perhaps the yield of well 2 would decline to about 95 gpm after 2 days of pumping.

Also plotted on figure 3, for purposes of comparison, is the point representing the yield and drawdown measurements for well 2 after well 1 was turned on. By following a vertical line from this point to the curve it appears that when well 2 is pumped alone it could yield 75 gpm with a drawdown of only about

13 feet, and by following a horizontal line to the curve it appears that, with a drawdown of 31 feet, well 2 could discharge, if pumped alone, about 103 gpm. Reduction in its capacity of approximately 25 percent due to the interference is indicated.

Public-supply well 1

The water level in public-supply well 1 declined about 4 feet during the first part of this test, when well 2 was pumped alone. At the end of the period of combined pumping (173 minutes) its water level had declined 26 feet more, or a total of 30 feet; its discharge averaged 213 gpm, decreasing from 228 gpm near the beginning of the period of combined pumping to 198 gpm near the end.

Using a pumping rate of 250 gpm and a drawdown of 23 feet, which were measured a few hours after pumping started for the 48-hour aquifer test (described later), and assuming that a specific-capacity curve for this well would have about the same shape as that for well 2 (fig. 3), it is estimated that well 1 could discharge for short periods 213 gpm with a drawdown of only 6 feet; or, with a drawdown of 30 feet it could discharge 262 gpm. A reduction in well capacity of about 20 percent due to the interference from well 2 is indicated.

If the available drawdown is assumed to be about 75 feet (based on the driller's log of this well), then extrapolation of the assumed curve indicates a maximum capacity of not more than 290 gallons per minute for short periods of pumping.

Decline in specific capacity during long periods of pumping

Specific capacities of wells, particularly water-table wells, are more meaningful when the length of pumping time is considered. Under water-table conditions the specific capacity generally decreases with continued pumping, because of the decreased depth of flow in the vicinity of the well, or wells, and the withdrawal of water from storage. It appears that in the vicinity of Mount Airy lateral changes in geology and hydrology may also lower the specific capacity with continued pumping. Thus, as pumping time increases, and the cone of depression enlarges, more and more factors affect the yield and drawdown of a well.

Figure 4 shows graphically the changes in specific capacity measured in public-supply well 1 during the 48-hour aquifer test. With the discharge valve completely open throughout the test, the discharge averaged about 223 gpm, declining from about 255 gpm one and one-half hours after the start of pumping to about 190 gpm at the end, a decrease of 65 gallons per minute; the drawdown increased from 22 feet to 33 feet, a lowering of 11 feet. The computed specific capacities range from about 11.6 gpm/ft near the beginning of the test to 6.8 gpm/ft at the end of the test, a decrease of about 40 percent. It should be noted that specific capacities measured for long periods of pumping and with a constant discharge valve setting, such as were determined here, are not entirely comparable to those determined by step-increases in discharge by manual valve adjustments, as described above. In computing the specific capacities for figure 4 the average discharge from the beginning of the test to the particular time being considered was used rather than the discharge that was occurring at that particular time.

Extrapolation of the decline in yield, assuming the change in rate of decline remains constant, suggests that at the end of 5 days of continuous pumping from well 1 alone the yield would decrease to 145 gpm, at the end of 15 days to 88 gpm, and at the end of 30 days to 52 gpm. Extrapolation of the decline in water level suggests that at the end of 5 days pumping the drawdown would be about 40 feet, at the end of 15 days about 47 feet, and at the end of 30 days about 51 feet. Then, using average yields throughout the test and the extrapolated time, specific capacities of 5.0, 3.7, and 3.0 gpm/ft may be computed respectively for 5, 15, and 30 days of pumping. A reduction in specific capacity of about 75 percent after 30 days of pumping is indicated.

Aquifer Transmissibility

The properties of a water-bearing formation that determine its capacity to transmit water, and to release water from storage, are the coefficients of transmissibility and storage. The coefficient of transmissibility may be expressed as the quantity of water, in gallons a day, that flows through a strip of the aquifer 1 mile wide under a hydraulic gradient of one foot per mile, at the prevailing temperature of the ground water. The coefficient of storage is the volume of water released from, or taken into storage, per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Preliminary analysis of the data from the 48-hour test by means of the Theis nonequilibrium formula[4/] indicates that the coefficient is about 6000 to 7000 gallons per day per foot and the coefficient of storage about 0.02. Deviations from the theoretical curve suggest that both recharge- and barrier-type boundaries may be present. The stream could be recharging the aquifer,

4/ Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., .p. 519-524, 1935.

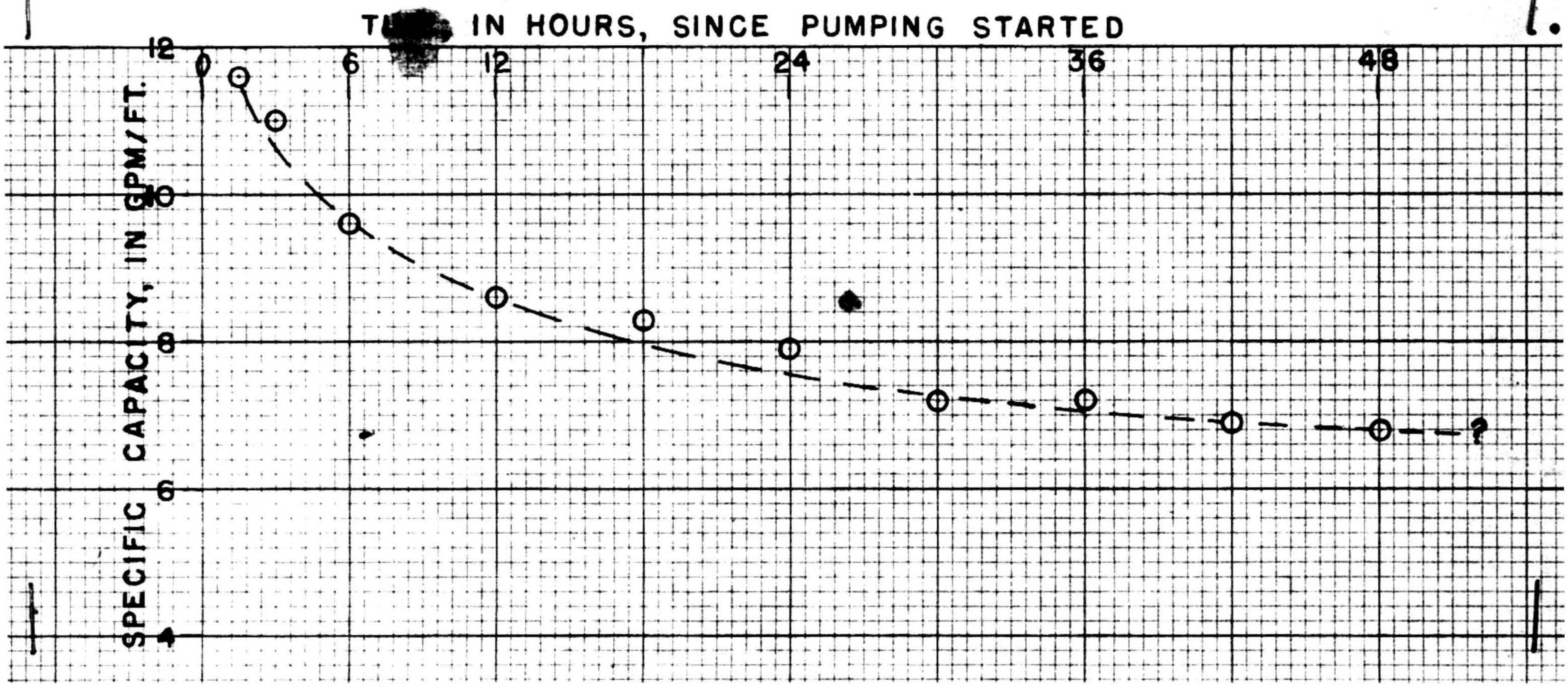

Figure 4. Graph showing the decline in specific capacity of public-supply well 1 during 48 hours of pumping at an average rate of 223 gpm.

and relatively impermeable rocks in the hills on either side of the valley could act as barriers to the flow of ground water. However, additional data and a more detailed analysis of the aquifer test would be necessary before the presence and effect of such boundaries on the flow of ground water could be ascertained.

Relation of Stream to Aquifer

The amount of water moving toward the stream may be roughly estimated, if certain assumptions are made, by using a modified version[5] of Darcy's formula, Q = TIW, where Q is the rate of discharge, in gallons per day, to the stream, T is the coefficient of transmissibility, in gallons per day per foot, I is the hydraulic gradient, in feet per mile, and W is the width, in miles, of the aquifer normal to the direction of ground-water movement. Using a transmissiblity of 6000 gallons per day per foot, a gradient of 22 feet per mile (based on the difference between an assumed annual average water level below the land surface of 9 feet in the vicinity of public-supply well 1, when undisturbed by pumping, and the stream elevation), and an aquifer length equal to the length of the stream, about 1.3 miles, then Q = TIW = 6000 x 22 x 1.3 = 171,600 gallons per day moving westward to the stream, if the water-bearing character of the aquifer and bordering hills were the same throughout the length of the stream on its east side. If an equal amount of water is discharged from the rocks on the west side of the stream, then the total discharge to the stream is 2 x 171,600 or about 340,000 gallons per day. This figure is merely a crude approximation, and presumably is low inasmuch as the value of the coefficient of transmissibility is probably low. However, it is probably of the proper order of magnitude.

5/ Ferris, J. G., in Wisler, C. O., and Brater, E. F., Hydrology; John Wiley and Sons, Inc., New York, p. 266, 1949.

Inasmuch as the area of the stream basin is approximately one square mile, the computed figure checks reasonably close with the figure of 400,000 gallons a day of ground-water discharge per square mile determined by a method of streamflow analysis for the Rock Creek basin in Montgomery County, Maryland 6/ and 500,000 gallons a day per square mile for the Little Gunpowder Falls basin in Harford County, Maryland 7/. It would be necessary to test drill throughout the valley to determine the areal geo-hydrology, and construct seasonal water-table maps of the valley and bordering areas to compute the ground-water discharge to the stream accurately.

Availability of Ground Water

Presumably the approximate average recharge to the aquifer is more than 300,000 gallons per day (210 gpm), and this is the approximate rate at which water could be pumped from wells in the valley constantly without depleting storage. A large number of closely spaced wells would be required to divert all the present discharge to the stream toward the wells. The figure indicates that the present municipal pumpage of about 80,000 gallons per day (55 gpm) is considerably below the computed amount theoretically available perennially from water-bearing material underlying the valley. Of course, by depleting storage it would be possible to pump water for short periods at rates much higher than the perennial maximum; and over a period of time the partially emptied aquifer would refill, if the intervals between pumping periods are long. Inasmuch as a static water level of 6 feet below the land surface is reported for public-supply well 1 when pumping began in 1925, and the water levels in the municipal wells now recover to about 10 to 12 feet below the land surface after

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6/ Dingman, R. J., and Meyer, Gerald, The ground-water resources, in The Water Resources of Howard and Montgomery Counties, Md.; Md. Dept. of Geol., Mines and Water Resources Bull. 14, p. 42, 1954.

7/ Dingman, R. J., and Ferguson, H. F., The ground-water resources of the Piedmont part of Baltimore and Harford Counties, Md. Dept. of Geol., Mines and Water Resources Bull.___(manuscript), p. 116.

pumping, no significant dewatering of the aquifer (depletion of storage) has resulted from the past pumpage from the Mount Airy municipal well field.

Well Spacing

Inasmuch as "proper" well spacing invariably involves economic factors as well as geo-hydrologic factors, no hard and fast rules for spacing of wells in the crystalline rocks can be established. The data indicates that the yield of wells drilled to the north of public-supply well 1 would decrease more by pumping from this well than would wells drilled to the west of it, toward the center of the valley and nearer the stream. By the same token, pumping wells located to the north of public-supply well 1 would decrease its yield more than would pumping wells located equal distances to the west of it, with the same pumping rate. A wider spacing of wells drilled near the borders of the valley than those drilled in the center would appear desirable. The center of the valley appears to be more favorable than the borders because of its greater distance from the hills bordering the valley, which may act as partial hydrologic barriers. Also, the transmissibility of the aquifer may be higher in the center of the valley (compare specific capacities of test holes 2 and 3 (pages 9 and 13).

The following table of drawdowns measured after two days of pumping from public-supply well 1 at an average rate of 223 gallons per minute shows the effect of this pumpage, in feet of drawdown, at various distances from the pumped well:

	Distance and direction from pumped well	Measured drawdown
Public-supply well 2	85 feet north	13.01 feet
Test hole 1	158 feet north	6.11 feet
Test hole 2	300 feet north	4.50 feet
Test hole 3	175 feet west	2.96 feet
Test hole 4	58 feet west	14.78 feet

It is seen that the drawdown in test hole 3 is only one-half the drawdown in test hole 1, although the two holes are about equal distance from the pumped well; and the drawdown in test hole 3 is even less than the drawdown in test hole 2, which is 125 feet farther from the pumped well.

The drawdowns in the observation wells are directly proportional to the rate of pumping, so that the drawdowns that would occur at the end of two days, if the pumping rate were only 55 gpm (the approximate pumping rate from the well field for municipal use) can be computed by multiplying the drawdowns in the above table by $\frac{55}{223}$. The computed drawdowns at the smaller pumping rate are, in downward order in the table, 3.20 feet, 1.50 feet, 1.10 feet, 0.72 foot, and 3.64 feet. Extrapolation of these drawdowns with distance from public-supply well 1 suggests that beyond a distance of about 600 to 700 feet from public-supply well 1 in a northerly direction the drawdown would be nearly zero after 48 hours of pumping, and that beyond a distance of about 250 - 300 feet from public-supply well 1 in a westerly direction the drawdown would be nearly zero. With continued pumping, the effects of the pumping would spread farther and farther from the pumped well. Further analysis of the present data may permit rough computation of the long-term effects at various distances caused by pumping, and the interference effects between pumping wells, but additional, areal test-drilling in the valley and bordering hills is needed to evaluate with reasonable accuracy the hydrologic barrier effects and lateral changes in transmissibility suggested by the present data.