Hydrologic Budget of the Beaverdam Creek Basin Maryland

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1472

Prepared in cooperation with the Maryland Department of Geology, Mines and Water Resources

Hydrologic Budget of the Beaverdam Creek Basin Maryland

By WILLIAM C. RASMUSSEN *and* GORDON E. ANDREASEN

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1472

Prepared in cooperation with the Maryland Department of Geology, Mines and Water Resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1959

UNITED STATES DEPARTMENT OF THE INTERIOR

FRED A. SEATON, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U. S. Geological Survey Library has cataloged this publication as follows:

Rasmussen, William Charles, 1917–

Hydrologic budget of the Beaverdam Creek basin, Maryland, by William C. Rasmussen and Gordon E. Andreasen. Washington, U. S. Govt. Print. Off., 1958.

v, 106 p. illus., maps. 25 cm. (U. S. Geological Survey. Water-supply paper 1472)

Part of illustrative matter folded in pocket.

"Prepared in cooperation with the Maryland Dept. of Geology, Mines, and Water Resources."

Bibliography: p. 101–104.

1. Water, Underground—Maryland—Beaverdam Creek basin. 2. Water-supply—Maryland—Beaverdam Creek basin. I. Andreasen, Gordon Ellsworth, 1924– joint author. II. Title. (Series)

TC801.U2 no. 1472 551.490976225 G S 59–168

—— ——— Copy 2. GB1025.M3R3

†

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C.

CONTENTS

ILLUSTRATIONS

[All plates, except plates 2, 8, and 9, are in pocket]

TABLES

HYDROLOGIC BUDGET OF THE BEAVERDAM CREEK BASIN, MARYLAND

By William C. Rasmussen and Gordon E. Andreasen

ABSTRACT

A hydrologic budget is a statement accounting for the water gains and losses for selected periods in an area. Weekly measurements of precipitation, streamflow, surface-water storage, ground-water stage, and soil resistivity were made during a 2-year period, April 1, 1950, to March 28, 1952, in the Beaverdam Creek basin, Wicomico County, Md. The hydrologic measurements are summarized in two budgets, a total budget and a ground-water budget, and in supporting tables and graphs.

The results of the investigation have some potentially significant applications because they describe a method for determining the annual replenishment of the water supply of a basin and the ways of water disposal under natural conditions. The information helps to determine the "safe" yield of water in diversion from natural to artificial discharge. The drainage basin of Beaverdam Creek was selected because it appeared to have fewer hydrologic variables than are generally found. However, the methods may prove applicable in many places under a variety of conditions.

The measurements are expressed in inches of water over the area of the basin. The equation of the hydrologic cycle is the budget balance:

$$P = R + ET + \Delta SW + \Delta SM + \Delta GW$$

where P is precipitation; R is runoff; ET is evapotranspiration; ΔSW is change in surface-water storage; ΔSM is change in soil moisture; and ΔGW is change in ground-water storage. In this report "change" is the final quantity minus the initial quantity and thus is synonymous with "increase." Further, $\Delta GW = \Delta H \cdot Yg$, in which ΔH is the change in ground-water stage and Yg is the gravity yield, or the specific yield of the sediments as measured during the short periods of declining ground-water levels characteristic of the area. The complex sum of the revised equation $P - R - \Delta SW - ET - \Delta SM$, which is equal to $\Delta H \cdot Yg$, has been named the "infiltration residual"; it is equivalent to ground-water recharge.

Two unmeasured, but not entirely unknown, quantities, evapotranspiration, (ET) and gravity yield, (Yg), are included in the equation. They are derived statistically by a method of convergent approximations, one of the contributions of this investigation.

On the basis of laboratory analysis, well-field tests, and general information on rates of drainage from saturated sediments, a gravity yield of 14 percent was assumed as a first approximation. The equation was then solved, by weeks, for evapotranspiration, ET. The evapotranspiration losses were plotted against the calendar week. Using the time of year as a control, a smooth curve was fitted to the evapotranspiration data, and modified values of ET were read from the curve. These were used to compute weekly values of the infiltration residual, which were plotted against ground-water stage. The slope of the line of best fit

gave a closer approximation of gravity yield, Yg. The process was repeated. The approximations converged, so that a fourth and final approximation resulted in a close grouping of all the points along a line whose slope indicated a Yg of 11.0 percent, and a slightly asymmetric bell-shaped curve of total evapotranspiration by weeks was obtained that is considered representative of this area.

Check calculations of gravity yield were made during periods of low evapotranspiration and high infiltration, which substantiate the computed average of 11.0 percent.

Refinements in the method of deriving the ground-water budget were introduced to supplement the techniques developed by Meinzer and Stearns in the study of the Pomperaug River basin in Connecticut in 1913 and 1916. The hydrologic equation for the ground-water cycle may be written $Gr = D + \Delta H \cdot Yg + ETg$, in which Gr is ground-water recharge (infiltration); D is ground-water drainage; ΔH is the change in mean ground-water stage (final stage minus initial stage); Yg is gravity yield (taken as 11.0 percent in computations here); and ETg is ground-water evapotranspiration.

The ground-water recharge is derived from the hydrograph of mean water level of the 25 wells, plotted weekly. The ground-water decline during periods of no rain (no recharge) is called a recession curve, and has a characteristic shape. This curve is extrapolated during periods when water levels rise in response to rain, so that the difference between peak stage and extrapolated recession stage may be determined. This difference, multiplied by the gravity yield, is the ground-water recharge, Gr.

The ground-water drainage, D, is calculated from a base-flow rating curve obtained by plotting the average water level in the 25 wells against the base flow obtained from the stream hydrograph. From this curve a close approximation of true weekly base flow was obtained and plotted as ground-water runoff on the stream hydrograph. This method is a second contribution of this investigation to statistical hydrology.

The difference between the mean ground-water stage of any two periods, ΔH, multiplied by the gravity yield, Yg, gives the net change in ground-water storage. When the final stage is less than the initial stage the difference becomes $-\Delta H$. With these factors known, the ground-water equation was solved for ground-water evapotranspiration, ETg. Comparison of ETg and total evapotranspiration, ET was thus possible, for individual periods and on an annual basis.

Abundant rainfall and high infiltration rates provide this portion of the Atlantic Coastal Plain with large quantities of ground water, which are discharged about equally by runoff and evapotranspiration. Recovery of water lost to nonbeneficial plants, or by unused streamflow, would permit large expansion of ground-water facilities such as wells, dug ponds, and collection galleries, for irrigation, industry, or municipal supply.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this report is to present a method for statistically solving the equation of the water cycle: Precipitation = runoff + evapotranspiration + final storage − initial storage. The drainage basin in which the study was made is that of Beaverdam Creek, east of Salisbury, Wicomico County, Md.

The broad purpose of the study was to measure and examine the various factors of the water cycle in a small, homogeneous drainage basin in an area of humid climate to obtain quantitative knowledge of the movement and storage of water under natural conditions. Observations were made of all measurable hydrologic phenomena for a period of 2 years; the data are summarized in a hydrologic budget, table 1. A hydrologic budget is a statement of the water gains and losses of an area for periods of time. It is kept in balance by equating precipitation, as water gained, to runoff and evaporation-transpiration, as water lost, plus any water saved, or less any water deficit, in basin storage. The hydrologic budget is discussed in relation to the conditions of climate and geology characteristic of the area of study.

The specific aim of the study was a ground-water budget showing the apportionment of precipitation within a given time of observation among ground-water recharge, subsurface runoff to ponds and streams, ground-water evapotranspiration, and ground-water storage. The ground-water budget is summarized in table 10 (p. 97).

TABLE 1.—*Hydrologic budget of the Beaverdam Creek basin, April 1950 through March 1952*

All measurements and calculations given in inches are taken as inches over the entire Beaverdam Creek basin, 19.5 square miles.

The change in ground-water storage, $\Delta H \cdot Yg$, or the "infiltration residuals," as it is called in this report, is derived from the weekly differences in ground-water stage, in feet, converted to inches, multiplied by the gravity yield, Yg, taken as 11 percent. Yg was derived by the method of convergent approximations (p. 86).

The soil-moisture deficiency, SM, has been calculated from electrical-resistivity measurements (p. 66). It was used only in the first approximation of ET.

The soil-moisture change has been computed from the hydrologic equation, using Yg as 11 percent and ET from the curve (fig. 17 and p. 75). Columns of measurement of stage marked α, β, γ indicate measurements at end of week.

	Precipitation P (in)	Runoff R		Parker Pond S_p			Schumaker Pond S_s			Channels ΔS_c (in)	Ground water H		Calculated soil moisture deficiency SM—mean (in)	Computed soil-moisture change (in)	Total evapotranspiration from graph (fig. 17) (in)
		(cfs)	(in)	Stage α (ft)	Δ Stage (ft)	Δ Storage (in)	Stage β (ft)	Δ Stage (ft)	Δ Storage (in)		Mean stage γ (ft above msl)	Δ Storage ($\Delta H \cdot Yg$, in)			
1950															
Apr. 1–7	0.23	24.4	0.326	1.30			10.30	−0.08	−0.0023		46.74	−0.09		−0.40	0.40
Apr. 8–14	.07	20.0	.267	1.22	−0.08	−0.0029	10.25	−.05	−.0014		46.21	−.70		+.05	.46
Apr. 15–21	.73	18.1	.242	1.25	+.03	+.0011	10.30	+.05	+.0014		45.99	−.29		+.27	.51
Apr. 22–28	.80	20.6	.275	1.29	+.04	+.0015	10.30	.00	.0000		45.90	−.12		+.08	.56
Apr. 29–May 5	.69	24.4	.326	1.30	+.01	+.0004	10.28	−.02	−.0006		46.01	+.14	6.78	−.41	.63
May 6–12	.76	22.0	.294	1.28	−.02	−.0007	10.27	−.01	−.0003		45.94	−.09	6.47	−.12	.68
May 13–19	.89	22.4	.299	1.34	+.06	+.0022	10.28	+.01	+.0003		45.95	+.01	6.26	−.15	.73
May 20–26	1.38	28.6	.382	1.75	+.41	+.0150	10.39	+.11	+.0031		46.55	+.79	5.52	−.59	.78
May 27–June 2	.38	22.6	.302	1.65	−.10	−.0037	10.23	−.16	−.0045	−0.0116	46.08	−.62	5.68	−.10	.82
June 3–9	.29	17.6	.235	1.38	−.27	−.0099	10.20	−.03	−.0008	−.0015	45.65	−.57	7.53	−.23	.86
June 10–16	.54	15.4	.206	1.36	−.02	−.0007	10.19	−.01	−.0003	−.0019	45.34	−.41	8.42	−.16	.91
June 17–23	.37	13.4	.179	1.32	−.04	−.0015	10.17	−.02	−.0006	−.0018	44.84	−.66	8.64	−.10	.95
June 24–30	.06	10.4	.139	1.27	−.05	−.0018	10.15	−.02	−.0006	−.0009	44.40	−.58	9.22	−.47	.98
July 1–7	2.06	14.8	.198	1.56	+.29	+.0106	10.22	+.07	+.0020	+.0039	44.36	−.05	7.52	+.90	1.00
July 8–14	1.26	15.1	.202	1.30	−.26	−.0095	10.23	+.01	+.0003	−.0013	44.37	+.01	7.73	+.05	1.01
July 15–21	1.15	17.4	.232	1.17	−.13	−.0048	10.24	+.01	+.0003	−.0005	44.73	+.48	7.72	−.57	1.02
July 22–28	.13	10.6	.142	1.10	−.07	−.0026	10.14	−.10	−.0028	−.0031	44.31	−.55	8.08	−.48	1.03
July 29–Aug. 4	1.67	11.5	.154	1.26	+.16	+.0059	10.24	+.10	+.0028	+.0018	44.14	−.22	6.79	+.72	1.01
Aug. 5–11	.21	11.0	.147	1.05	−.21	−.0077	10.12	−.12	−.0034	−.0054	43.81	−.44	6.18	−.47	.99
Aug. 12–18	.06	8.6	.115	1.02	−.03	−.0011	10.13	+.01	+.0003	−.0011	43.50	−.41	8.81	−.60	.96
Aug. 19–25	.07	9.3	.124	1.03	+.01	+.0004	10.11	−.02	−.0006	−.0021	43.27	−.30	8.98	−.68	.93
Aug. 26–Sept. 1	.01	11.5	.154	.98	−.05	−.0018	8.73	−1.38	−.0390	−.0040	42.92	−.46	11.07	−.53	.89
Sept. 2–8	.44	10.9	.146	.99	+.01	+.0004	8.51	−.22	−.0062	+.0028	42.66	−.34	10.35	−.21	.85
Sept. 9–15	2.01	7.6	.101	1.13	+.14	+.0051	9.87	+1.36	+.0384	+.0026	42.68	+.03	10.45	+1.04	.80
Sept. 16–22	2.26	10.9	.146	1.32	+.19	+.0070	10.17	+.30	+.0085	+.0123	43.01	+.44	9.64	+.93	.72
Sept. 23–29	.06	9.2	.123	1.07	−.25	−.0092	10.11	−.06	−.0017	−.0116	43.07	+.08	7.35	−.77	.65
Sept. 30–Oct. 6	.11	6.1	.081	.95	−.12	−.0044	10.09	−.02	−.0006	−.0004	42.91	−.21	7.07	−.30	.55
Oct. 7–13	.42	6.7	.089	1.06	+.11	+.0040	10.10	+.01	+.0003	+.0001	42.75	−.21	6.96	+.09	.45
Oct. 14–20	.08	5.4	.072	1.05	−.01	−.0004	10.10	.00	.0000	+.0004	42.63	−.16	7.41	−.21	.38
Oct. 21–27	.61	7.5	.100	1.06	+.01	+.0004	10.10	.00	.0000	+.0001	42.45	−.24	7.26	+.45	.30
Oct. 28–Nov. 3	.05	6.3	.084	1.05	−.01	−.0004	10.10	.00	.0000	+.0008	42.36	−.12	7.76	−.14	.22

Nov. 4–10	.50	7.1	.095	1.04	−.01	−.0004	10.10	.00	.0000	+.0004	42.25	−.15	7.76	+.38	.17
Nov. 11–17	.04	6.3	.084	1.04	.00	.0000	10.10	.00	.0000	+.0004	42.16	−.12	7.90	−.05	.12
Nov. 18–24	.61	7.7	.103	1.08	+.04	+.0015	10.12	+.02	+.0006	−.0004	41.98	−.24	7.95	+.67	.07
Nov. 25–Dec. 1	2.33	20.3	.271	.59	−.49	−.0180	10.14	+.02	+.0006	−.0021	43.62	+2.16	7.15	−.14	.05
Dec. 2–8	1.79	13.9	.186	1.05	+.46	+.0169	10.30	+.16	+.0045	+.0247	44.34	+.95	4.04	+.57	.04
Dec. 9–15	.77	21.7	.290	1.20	+.15	+.0055	10.22	−.08	−.0023	−.0129	45.24	+1.19	3.81	−.74	.04
Dec. 16–22	.11	14.0	.187	1.05	−.15	−.0055	10.18	−.04	−.0011	−.0040	45.04	−.26	4.07	+.16	.04
Dec. 23–29	.27	11.9	.159	1.20	+.15	+.0055	10.18	.00	.0000	−.0004	44.86	−.24	4.30	+.30	.04
Dec. 30–Jan. 5, 1951	.50	12.9	.172	1.98	+.78	+.0286	10.22	+.04	+.0011	+.0086	44.78	−.10	4.28	+.36	.04
1951															
Jan. 6–12	.62	16.7	.223	1.90	−.08	−.0029	10.22	.00	.0000	−.0001	45.08	+.40	4.90	−.04	.04
Jan. 13–19	.34	16.4	.219	1.67	−.23	−.0084	10.22	.00	.000	−.0019	45.13	+.07	4.86	+.03	.04
Jan. 20–26	.39	10.7	.143	2.14	+.47	+.0172	10.17	−.05	−.0014	+.0037	45.03	−.13	4.08	+.32	.04
Jan. 27–Feb. 2	.63	11.9	.159	2.25	+.11	+.0040	10.24	+.07	+.0020	+.0065	44.98	−.07	4.16	+.48	.04
Feb. 3–9	.89	20.3	.271	1.48	−.77	−.0282	10.38	+.14	+.0040	+.0002	45.52	+.71	4.20	−.12	.05
Feb. 10–16	.01	15.7	.210	1.75	+.27	+.0099	10.15	−.23	−.0065	−.0071	45.56	+.53	3.64	−.31	.06
Feb. 17–23	.89	18.5	.247	1.84	+.09	+.0033	10.30	+.15	+.0042	+.0062	45.86	+.39	3.79	+.14	.09
Feb. 24–Mar. 2	.08	16.9	.226	1.84	.00	.0000	10.22	−.08	−.0023	−.0073	45.68	−.24	3.20	−.03	.13
Mar. 3–9	.18	15.9	.212	1.78	−.06	−.0022	10.20	−.02	−.0006	−.0022	45.38	−.40	2.89	+.20	.17
Mar. 10–16	.75	16.6	.222	1.97	+.19	+.0070	10.24	+.04	+.0011	+.0073	45.46	+.10	3.12	+.19	.22
Mar. 17–23	1.33	34.1	.455	1.98	+.01	+.0004				+.0047	46.25	+1.04	2.91	−.44	.27
Mar. 24–30	.21	20.1	.268	1.84	−.14	−.0051				−.0074	46.08	−.22	2.34	−.15	.33
Mar. 31–Apr. 6	1.02	23.6	.315	2.08	+.24	+.0088	10.32			+.0055	46.13	+.07	2.48	+.22	.40
Apr. 7–13	.22	18.9	.252	1.85	−.23	−.0084	10.24	−.08	−.0023	−.0129	45.92	−.28	1.80	−.19	.46
Apr. 14–20	.45	16.3	.218	1.87	+.02	+.0007	10.24	.00	.0000	+.0023	45.56	−.48	2.42	+.19	.51
Apr. 21–27	.77	15.7	.210	1.81	−.06	−.0022	10.24	.00	.0000	+.0057	45.36	−.26	1.16	+.26	.56
Apr. 28–May 4	.50	16.4	.219	1.69	−.12	−.0044	10.22	−.02	−.0006	−.0027	45.33	−.04	1.20	−.30	.63
May 5–11	.37	11.3	.151	1.84	+.15	+.0055	10.17	−.05	−.0014	+.0005	45.08	−.33	8.18	−.14	.68
May 12–18	.65	14.3	.191	2.08	+.24	+.0088	10.18	+.01	+.0003	−.0022	44.89	−.25	8.80	−.03	.73
May 19–25	2.70	28.9	.386	1.72	−.36	−.0132	10.38	+.20	+.0057	+.0252	46.19	+1.72	8.99	−.20	.78
May 26–June 1	.02	24.3	.324	1.42	−.30	−.0110	10.22	−.16	−.0045	−.0278	45.72	−.62	9.07	−.46	.82
June 2–8	1.37	13.6	.182	2.12	+.70	+.0257	10.33	+.11	+.0031	+.0068	45.39	−.44	6.46	+.73	.86
June 9–15	3.12	65.3	.872	1.96	−.16	−.0059	10.32	−.01	−.0003	+.0079	47.32	+2.55	6.37	−1.21	.91
June 16–22	.01	20.6	.275	2.19	+.23	+.0084	10.22	−.10	−.0028	−.0085	46.53	−1.04	7.49	−.17	.95
June 23–29	.52	16.6	.222	2.22	+.03	+.0011	10.26	+.04	+.0011	−.0041	45.88	−.86	7.60	+.18	.98
June 30–July 6	1.20	21.7	.290	1.95	−.27	−.0099	10.14	−.12	−.0034	−.0036	45.73	−.20	7.64	+.12	1.00
July 7–13	.10	10.8	.144	2.08	+.13	+.0048	10.17	+.03	+.0008	+.0004	45.15	−.77	8.61	−.29	1.01
July 14–20	1.46	27.7	.370	1.98	−.10	−.0037	10.25	+.08	+.0023	+.0049	45.79	+.84	7.55	−.78	1.02
July 21–27	.54	16.1	.215	1.46	−.52	−.0191	10.17	−.08	−.0023	−.0069	45.17	−.82	7.08	+.14	1.03
July 28–Aug. 3	.63	13.3	.178	1.34	−.12	−.0044	10.16	−.01	−.0003	−.0042	44.75	−.55	7.52	+.01	1.01
Aug. 4–10	1.95	16.1	.215	1.50	+.16	+.0059	10.22	+.06	+.0017	+.0053	44.78	+.04	7.48	+.69	.99
Aug. 11–17	.38	13.3	.178				10.16	−.06	−.0017	−.0035	44.52	−.34	6.50	−.41	.96
Aug. 18–24	1.77	18.0	.240	1.27	−.23	−.0084	10.20	+.04	+.0011	+.0018	44.63	+.15	6.25	+.46	.93
Aug. 25–31	.16	10.0	.134	1.20	−.07	−.0026	10.13	−.07	−.0020	−.0022	44.23	−.53	6.52	−.33	.89
Sept. 1–7	.71	9.6	.128	1.36	+.16	+.0059	10.14	+.01	+.0003	+.0014	43.92	−.41	6.30	+.13	.85
Sept. 8–14	T	8.1	.108	1.32	−.04	−.0015	10.12	−.02	−.0006	+.0002	43.91	−.01	7.56	−.89	.80
Sept. 15–21	1.96	16.4	.219	1.08	−.24	−.0088	10.16	+.04	+.0011	−.0020	43.66	−.33	6.80	+1.36	.72
Sept. 22–28	.84	9.1	.121	1.28	+.20	+.0073	10.14	−.02	−.0006	+.0001	43.46	−.26	6.26	+.33	.65
Sept. 29–Oct. 5	.76	9.2	.123	1.30	+.02	+.0007	10.16	+.02	+.0006	+.0036	43.25	−.28	6.12	+.36	.55
Oct. 6–12	1.47	10.7	.143	1.51	+.21	+.0077	10.17	+.01	+.0003	+.0024	43.65	−.53	6.01	+.34	.45
Oct. 13–19	.69	9.4	.125	1.35	−.16	−.0059	10.12	−.05	−.0014	−.0021	43.70	+.07	5.90	−.47	.38
Oct. 20–26	.34	7.0	.093	1.74	+.39	+.0143	10.13	+.01	+.0003	+.0028	43.60	−.13	5.30	+.06	.30

TABLE 1.—*Hydrologic budget of the Beaverdam Creek basin, April 1950 through March 1952*—Continued

	Precipitation P (in)	Runoff R (cfs)	Runoff R (in)	Parker Pond S_p Stage α (ft)	Parker Pond S_p Δ Stage (ft)	Parker Pond S_p Δ Storage (in)	Schumaker Pond S_s Stage β (ft)	Schumaker Pond S_s Δ Stage (ft)	Schumaker Pond S_s Δ Storage (in)	Channels ΔS_c (in)	Ground water H Mean stage γ (ft above msl)	Ground water H Δ Storage ($\Delta H \cdot Yg$, in)	Calculated soil moisture deficiency SM—mean (in)	Computed soil-moisture change (in)	Total evapotranspiration from graph (fig. 17) (in)
1951—Continued															
Oct. 27–Nov. 2	1.01	9.8	0.131	1.91	+0.17	+0.0062	10.21	+0.08	+0.0023	+0.0043	43.56	−0.05	6.33	+0.70	0.22
Nov. 3–9	3.25	36.4	.486	2.30	+.39	+.0143	10.54	+.33	+.0093	+.0274	46.31	+3.63	5.08	−1.09	.17
Nov. 10–16	.28	24.7	.330	2.20	−.10	−.0037	10.27	−.27	−.0076	−.0138	46.27	−.05	6.08	−.09	.12
Nov. 17–23	.08	19.1	.255	2.06	−.14	−.0051	10.24	−.03	−.0008	−.0029	45.76	−.64	----	+.44	.07
Nov. 24–30	.86	22.6	.302	2.28	+.22	+.0081	10.30	+.06	+.0017	+.0010	45.98	+.29	5.93	+.21	.05
Dec. 1–7	.47	21.6	.288	1.89	−.39	−.0143	10.26	−.04	−.0011	−.0012	45.79	−.25	6.21	+.41	.04
Dec. 8–14	.02	19.7	.263	1.66	−.23	−.0084	10.24	−.02	−.0006	−.0072	45.52	−.36	6.32	+.09	.04
Dec. 15–21	3.36	40.7	.543	2.12	+.46	+.0169	10.82	+.58	+.0164	+.0518	47.59	+2.73	3.81	−.04	.04
Dec. 22–28	.43	59.1	.789	1.84	−.28	−.0103	10.40	−.42	−.0119	−.0375	47.52	−.09	1.00	−.25	.04
Dec. 29–Jan. 4, 1952	.04	29.3	.391	1.55	−.29	−.0106	10.33	−.07	−.0020	−.0089	46.98	−.71	6.04	+.34	.04
1952															
Jan. 5–11	1.57	37.9	.506	1.88	+.33	+.0121	10.46	+.13	+.0037	+.0191	47.31	+.44	5.78	+.55	.04
Jan. 12–18	.64	35.0	.467	1.68	−.20	−.0073	10.42	−.04	−.0011	−.0044	47.36	+.07	5.51	+.08	.04
Jan. 19–25	.88	40.4	.539	2.08	+.40	+.0147	10.48	+.06	+.0017	−.0013	47.54	+.24	7.65	+.05	.04
Jan. 26–Feb. 1	1.73	89.7	1.198	2.11	+.03	+.0011	10.55	+.07	+.0020	+.0008	48.30	+1.00	7.92	−.52	.04
Feb. 2–8	1.34	64.0	.854	1.68	−.43	−.0158	10.50	−.05	−.0014	−.0027	48.35	+.07	7.63	+.39	.05
Feb. 9–15	.03	36.1	.482	1.32	−.36	−.0132	10.36	−.14	−.0040	−.0127	47.69	−.87	7.52	+.39	.06
Feb. 16–22	1.34	48.6	.649	1.54	+.22	+.0081	10.44	+.08	+.0023	+.0066	47.91	+.29	7.64	+.29	.09
Feb. 23–29	.48	34.6	.462	1.52	−.02	−.0007	10.42	−.02	−.0006	+.0021	47.76	−.20	7.80	+.09	.13
March 1–7	1.83	86.3	1.152	1.60	+.08	+.0029	10.48	+.06	+.0017	+.0040	48.48	+.95	7.66	−.45	.17
March 8–14	1.25	52.3	.698	1.82	+.22	+.0081	10.58	+.10	+.0028	+.0099	48.48	.00	7.75	+.31	.22
March 15–21	.67	47.7	.637	1.74	−.08	−.0029	10.52	−.06	−.0017	−.0072	48.24	−.32	7.87	+.09	.27
March 22–28	2.10	99.6	1.330	1.64	−.10	−.0037	10.66	+.14	+.0040	+.0019	48.83	+.78	7.98	−.34	.33

In some respects this report is a sequel to that of a quantitative study made in the Pomperaug River drainage basin of Connecticut (Meinzer and Stearns, 1929) in the humid eastern part of the United States by the Geological Survey more than 30 years ago. The investigations in the Pomperaug River basin and the Beaverdam Creek basin were similar in many respects: both were areas selected for hydrologic reasons and not because the water resources were either intensively developed or of especial value; both have ground-water conditions representative of a much larger area; both were convenient units for quantitative study with fewer complications than are found in most areas; both were by-products of regular ground-water investigations by the State; and in both investigations, allotments for carrying on the work were relatively small. Profiting by the study in the Pomperaug River basin, the number of observations in the Beaverdam Creek basin study was multiplied several fold. In the Pomperaug investigation "the number of observations made were inadequate to yield very accurate results" (Meinzer and Stearns, 1929, p. 73). As concluded by Meinzer and Stearns, the authors believed "that a presentation of the methods used will be of value to others who make quantitative studies of ground water in humid regions."

This research was prompted by an essay of a French hydrologist, Diénert (1935), who pointed out that too frequently hydrologists theorize on the water cycle but do not adequately measure the factors involved. Few realize that its components remain inadequately measured, and that, practically, the equation is unsolvable. But, the solution may be approached by a method of convergent approximations, thus revealing synoptic pictures of this important phenomenon.

The results of the investigation have some potentially significant applications because they describe a method for determining the annual replenishment of the water supply of a basin and the ways in which the water is disposed of under natural conditions. This information provides a large part of the data needed for determining how much of the water can be taken from wells without excessive depletion of surface water for economic uses or of soil moisture needed for the growth of plants—hence, it helps in determining the "safe" yield of ground water in the basin. The unused ground-water potential is one of the principal assets of a Nation that is demanding more water each passing year. When properly used, this water will help assure adequate municipal supplies and provide the need of growing industry. Also, even here in the humid East where complete crop failures are almost unknown, drought-reduced crop yields are becoming distressingly frequent, and some of the water doubtless will be used profitably for supplemental irrigation.

ACKNOWLEDGMENTS

The investigation described in this report was under the general supervision of A. N. Sayre, chief, Ground Water Branch, and C. G. Paulsen, chief, Water Resources Division, U. S. Geological Survey. To them, and to the following groups and individuals, the authors express their appreciation:

J. T. Singewald, Jr., Director of the Maryland Department of Geology, Mines and Water Resources, who encouraged the proposed study as a cooperative Maryland-Federal project in connection with the overall study of ground-water reservoirs in the Eastern Shore of Maryland; G. N. Brancato and R. K. Linsley, U. S. Weather Bureau, who contributed technical advice on measuring precipitation and pan evaporation, and loaned several Weather Bureau instruments; the district office of the Surface Water Branch, U. S. Geological Survey, College Park, Md., under the supervision of F. F. LeFever, which assisted in collection and analysis of streamflow records in the Beaverdam Creek basin; A. E. Hulme, engineer of the Surface Water suboffice at Dover, Del., who assisted in surveying Schumaker Pond; V. J. Kilmer and C. S. Slater, U. S. Department of Agriculture, Beltsville, Md., for helpful advice on measurement of soil moisture; Penn P. Livingston, hydraulic engineer, U. S. Geological Survey, Austin, Tex., who offered many useful suggestions in regard to instrumentation, particularly concerning the installation of observation wells; the Quality of Water Branch, U. S. Geological Survey, which collected and analyzed several water samples; T. H. Slaughter, assistant geologist, Maryland Department of Geology, Mines and Water Resources, who supervised the test-hole augering, assisted in geologic interpretation of the upper sedimentary rocks, and calibrated the soil-moisture units; W. B. Langbein of the Geological Survey, who developed the statistical solution, guided the project with technical advice, and supervised the computation and analyses of the hydrologic budget; M. I. Rorabaugh, district engineer of the Ground Water Branch in Florida, who gave a helpful critical analysis of the rough draft of the statistical data; and D. H. Boggess, J. W. Brookhart, O. J. Coskery, I. W. Marine, B. S. Sumner, R. P. Bailey, and Ethel W. Coffay, all of the Water Resources Division, U S. Geological Survey, for help in the installation of equipment, surveying, routine measurements, compilation of data, and manifold computations.

The coauthors of this report contributed the following phases: W. C. Rasmussen began and supervised the project, studied the geology, and brought the manuscript to final form; G. E. Andreasen was in charge of the project for 2 years during both collection and analysis of data, and prepared the manuscript in rough draft.

GEOGRAPHY

LOCATION, EXTENT, AND RELIEF OF THE DRAINAGE BASIN

The Beaverdam Creek basin is in Wicomico County, Md., between latitudes 38°18′ and 38°26′ north and longitudes 75°28′ and 75°34′ west, approximately at the center of the Delmarva Peninsula. It is shown in regional setting in figure 1, and in detail in plate 1. The western boundary is 1 mile east of Salisbury and the eastern boundary passes through the town of Parsonsburg, which is 6 miles from Salisbury. The northern part of the basin lies 2 miles south of the Delaware-Maryland State line.

The basin has an area of 19.5 square miles. It is 8.5 miles long (from north-northeast to south-southwest) and averages a little more than 2 miles in width. The basin is on the Coastal Plain, yet the relief is considerable for this low-lying region. The elevation above mean sea level, which at the lower end of the basin is about 10 feet, increases to about 85 feet in the northern headwater area.

PONDS

The outlet of the basin is at Schumaker dam, behind which lies Schumaker Pond (pl. 2–A), a shallow body of fresh water about 4,000 feet long and 200 to 400 feet wide occupying an area of about 0.046 square mile. The altitude of the spillway is 17 feet, and the base of the dam is at about 10 feet. The greatest depth of water is about 10 feet.

About 1 mile upstream from Schumaker Pond is Parker Pond (pl. 2–B), also formed by a dam on the creek. The pond is about 1 mile long, ranges in width from 100 to 200 feet, and has an area of about 0.050 square mile.

VEGETATION

About 40 percent of the Beaverdam Creek basin is covered by trees and brush; the remainder is cleared and cultivated. Evergreen and hardwood trees are about equal in number. Plate 1 shows the forest boundaries traced from aerial photographs made in 1952 for the Production and Marketing Administration, U. S. Department of Agriculture. The cleared land is used for such crops as watermelons, strawberries, cantaloupes, cucumbers, tomatoes, sweet potatoes, corn, and peaches, and to pasture.

CLIMATE

According to the classification of Trewartha (1943), the Eastern Shore of Maryland has a humid-subtropical climate. The summers are hot and sultry, and the winters are usually mild.

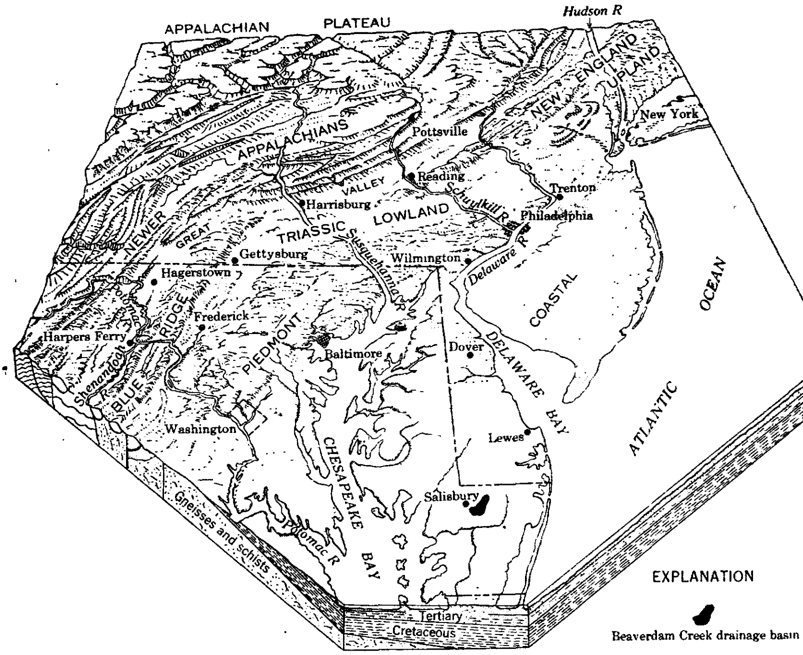


FIGURE 1.—Block diagram showing the regional physiographic provinces and location of the Beaverdam Creek basin. Adapted from an original by Raisz (Stephenson, Cooke, and Mansfield, 1933).

Climatological data of the U. S. Weather Bureau indicate an average annual temperature in the area of about 56° F. January is generally the coldest month, with a mean temperature of 35.6° F. The lowest recorded temperature for this area since 1906 was 9° below zero. July is usually the warmest month, with a mean temperature of 76.9° F. The highest recorded temperature is 106° F. The average growing season is 184 days from the last killing frost about April 20 to the first killing frost about October 21. The mean annual precipitation is about 43 inches and is distributed fairly uniformly thoughout the year. The mean annual snowfall is about 14 inches, the snow generally melting shortly after falling.

The Civil Aeronautics Authority maintain a weather station at the Salisbury Airport in the center of the basin. The following tables showing daily precipitation and the mean daily air temperatures were compiled from its records. The U. S. Geological Survey maintained a Class A weather station, with evaporation pan and anemometer, at Salisbury during this investigation. Table 2, showing evaporation and wind-movement data, was compiled from the records of this station.

A. STREAMFLOW-GAGING STATION AT THE OUTLET OF SCHUMAKER POND

B. PARKER POND, VIEW UPSTREAM

Daily precipitation, in inches, at the Salisbury municipal airport, April 1950 to March 1952

[Adapted from Climatological Data, monthly, U. S. Weather Bureau. Tr. signifies a trace.]

Day of month	1950									1951												1952		
	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	Tr.	0.05	Tr.	Tr.	Tr.	0.03	0	0	0	0	0.41	0.06	0	0	0	0.76	0.05	0	Tr.	0.30	0	0	0	1.14
2	0	.02	0	.69	.38	.11	0	0	0	0	0	0	.14	0	0	0	0	1.16	0	.38	0	0	0	.10
3	0	.01	Tr.	.25	1.05	.37	0	0	0	0	.02	.04	.45	Tr.	0	0	.43	Tr.	0	1.04	0	Tr.	.43	.53
4	0	Tr.	.17	1.00	0	0	.01	.44	.74	.17	0	.11	0	0	.48	Tr.	0	0	.67	0	.10	.68	.63	.03
5	.18	.15	0	.21	0	0	Tr.	0	.01	0	0	.01	Tr.	Tr.	.50	0	0	0	Tr.	0	.33	.19	0	0
6	0	.07	0	.35	.29	0	0	0	Tr.	0	0	0	0	0	0	0	.07	.31	0	Tr.	0	Tr.	0	0
7	0	.03	0	0	0	0	Tr.	0	1.00	.63	.82	.04	0	0	0	0	.50	0	.47	1.45	0	0	0	Tr.
8	Tr.	0	0	0	0	0	.09	0	.01	Tr.	0	0	Tr.	0	1.98	0	.93	0	.02	0	Tr.	Tr.	0	0
9	0	.03	0	.19	0	Tr.	.14	0	0	0	0	0	0	0	Tr.	0	0	0	0	0	Tr.	0	0	0
10	0	.08	.53	0	0	.09	.01	.01	.76	0	.02	0	.29	0	1.71	0	Tr.	0	.30	0	0	.64	0	0
11	Tr.	.20	.02	0	0	.04	0	.02	.01	.01	0	0	0	.93	0	0	0	0	.26	0	Tr.	0	.03	.74
12	0	.39	0	.87	.03	.11	.02	0	0	0	0	0	Tr.	0	Tr.	.06	.34	0	0	0	0	0	0	0
13	.01	Tr.	0	.28	0	1.75	0	0	0	0	0	.46	Tr.	0	.31	0	0	0	0	0	0	0	0	.16
14	0	0	.10	.27	0	Tr.	0	0	0	.17	0	.27	0	0	0	Tr.	0	0	0	.06	.82	0	0	.06
15	0	.59	Tr.	1.22	Tr.	.03	0	0	.09	.15	Tr.	Tr.	.02	0	0	Tr.	0	1.92	0	.12	.23	0	0	0
16	0	.01	Tr.	0	Tr.	.09	0	0	Tr.	0	0	0	.34	0	0	2.00	0	0	0	.08	0	0	.43	Tr.
17	0	0	0	0	0	0	0	0	0	0	.47	0	0	0	0	Tr.	Tr.	Tr.	.01	0	0	.19	.68	0
18	0	.16	0	0	0	0	0	0	0	0	0	Tr.	0	Tr.	0	Tr.	0	0	.01	Tr.	.73	.42	0	Tr.
19	0	.03	.26	0	Tr.	.30	0	0	0	0	.03	.81	.01	.53	0	.30	.29	0	Tr.	Tr.	0	Tr.	0	.53
20	.11	Tr.	0	.95	Tr.	0	.13	.59	0	0	Tr.	.37	0	Tr.	0	0	.80	0	0	0	.99	.05	.04	0
21	.55	0	.07	Tr.	0	1.47	0	.09	0	Tr.	.34	Tr.	0	.06	0	Tr.	.05	0	0	0	.82	0	.09	0
22	0	0	0	0	0	.48	.03	0	Tr.	0	0	.08	.05	0	0	0	.15	0	0	0	0	.67	0	Tr.
23	.10	.30	0	0	.03	Tr.	.92	Tr.	0	0	0	0	.28	1.80	0	.33	0	.07	0	0	0	.04	0	.70
24	.04	.56	0	0	Tr.	Tr.	.03	.25	.02	.39	0	.05	0	.23	Tr.	.06	0	0	.29	.10	0	0	.05	1.34
25	Tr.	Tr.	0	0	0	0	0	1.65	0	Tr.	0	0	0	0	0	Tr.	0	.73	0	.26	.33	0	Tr.	0
26	.04	Tr.	0	.16	0	0	0	0	Tr.	0	0	0	.36	Tr.	.27	0	0	0	0	.50	.06	.07	.16	0
27	0	0	.06	0	0	0	0	0	0	0	0	0	0	0	.23	0	0	0	0	0	0	.43	.26	0
28	.43	Tr.	0	0	0	0	Tr.	Tr.	.17	0	0	0	0	Tr.	0	0	.07	0	.05	.05	0	1.47	0	Tr.
29	.24	.27	Tr.	0	Tr.	.10	.03	Tr.	.16	.02	......	.02	.49	0	.68	.40	0	0	0	.01	0	0	0	0
30	.13	0	Tr.	0	0	Tr.	0	Tr.	.40	.07	......	.39	0	0	0	.20	0	0	.02	0	Tr.	0	......	0
31	......	0	......	0	0	......	0	......	.05	.07	......	0	......	0	......	0	0	......	.27	......	0	0	......	0
Total	1.83	2.95	1.21	6.44	1.78	4.97	1.41	3.05	3.42	1.68	2.11	2.71	2.43	3.55	6.16	4.13	3.68	4.19	2.37	4.35	4.41	4.85	2.80	5.33

Mean daily air temperatures at the Salisbury municipal airport January 1950 to March 1952, in degrees Fahrenheit

Day of month	1950												1951												1952		
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	39.0	41.5	44.0	41.5	59.0	65.5	74.0	81.5	82.5	64.5	71.5	34.5	31.5	51.5	43.0	58.0	58.0	74.0	77.0	81.0	80.0	64.5	56.0	43.5	57.0	40.5	34.5
2	51.5	45.0	25.0	52.0	56.0	68.0	72.5	81.5	82.0	65.0	68.5	41.5	34.0	33.5	50.0	51.5	64.0	78.5	75.5	70.0	79.0	70.5	52.0	44.5	49.0	47.5	33.0
3	58.5	35.5	22.5	61.0	54.5	74.5	80.0	77.5	79.5	71.5	64.0	60.0	55.5	20.5	45.0	47.0	62.5	76.0	73.0	71.0	76.0	67.0	44.5	45.0	35.0	46.5	36.5
4	64.5	32.5	28.0	70.0	62.5	62.0	77.0	70.0	75.0	57.0	68.0	50.0	52.5	25.0	48.5	45.5	56.0	77.0	77.0	68.5	70.0	68.0	38.5	54.0	32.5	55.0	45.0
5	64.5	36.5	41.0	55.0	69.0	64.5	78.5	67.5	64.0	53.0	51.5	36.5	40.5	33.0	43.5	46.5	55.5	65.0	79.0	64.0	68.0	73.5	37.0	55.5	39.0	46.0	37.5
6	65.0	42.0	42.5	38.5	76.5	71.5	70.5	67.5	65.0	55.5	44.5	38.0	45.5	34.0	42.0	52.0	52.5	62.0	70.5	66.5	66.0	74.0	43.5	58.0	32.5	38.5	36.0
7	49.5	41.0	37.5	38.5	69.0	73.0	69.5	65.5	64.5	63.0	54.5	53.5	44.0	38.0	54.5	54.0	55.0	67.0	70.5	72.0	69.0	67.5	58.0	60.0	29.5	34.5	34.0
8	28.5	34.0	55.5	46.5	51.0	70.5	70.5	67.5	66.0	68.5	60.5	45.5	27.5	17.0	46.0	50.5	61.5	67.0	72.5	78.5	60.5	55.5	40.5	60.5	30.5	36.0	33.5
9	30.5	50.0	34.5	40.5	52.0	72.0	68.5	73.5	73.0	67.5	63.0	37.0	25.0	17.5	40.5	54.5	64.5	65.0	75.0	79.0	64.0	49.0	40.5	58.0	39.5	38.5	35.0
10	59.0	45.0	32.0	42.0	70.5	77.0	78.5	77.0	79.5	61.5	54.0	39.0	33.5	25.5	34.0	49.0	65.0	59.5	77.0	81.5	65.5	50.0	46.5	37.0	38.5	40.5	45.0
11	48.0	42.5	38.5	57.5	67.5	66.0	78.5	78.5	70.5	60.0	41.5	36.0	41.0	30.0	36.0	51.5	66.0	60.0	75.5	81.5	72.5	48.5	47.5	35.5	30.5	47.0	55.0
12	39.0	42.5	54.5	47.5	54.5	61.0	75.5	66.5	67.0	62.0	37.0	32.0	35.0	45.0	38.5	55.0	57.0	61.5	79.5	80.5	74.0	52.5	45.0	33.0	38.0	36.5	42.5
13	48.0	47.5	51.0	37.5	60.0	61.0	78.5	66.0	66.5	52.5	38.0	29.0	31.5	54.0	38.0	50.0	57.0	63.5	76.0	76.5	76.5	50.5	53.0	29.0	39.0	35.5	46.5
14	56.0	52.5	35.0	36.0	59.5	68.0	75.5	67.0	65.0	51.0	38.5	29.0	40.0	52.5	41.5	52.0	57.0	68.0	76.5	78.0	76.0	56.0	65.5	36.0	55.0	30.5	40.0
15	41.5	53.0	42.0	39.5	65.5	67.5	72.0	70.0	68.0	61.0	42.5	40.0	48.5	34.0	39.5	61.0	62.0	66.5	78.0	78.0	69.5	64.0	58.5	42.0	58.5	30.5	35.0
16	48.5	40.0	36.0	43.5	55.0	74.0	78.5	69.0	65.5	55.0	58.5	31.5	35.0	35.5	42.0	48.0	66.0	69.0	80.0	83.0	70.5	65.5	60.0	20.5	42.0	43.0	33.5
17	34.5	35.0	34.0	54.5	60.0	74.0	80.5	75.5	60.5	67.5	51.5	29.5	37.0	45.5	40.5	43.0	68.5	67.0	80.0	81.0	68.5	61.5	42.0	18.0	41.0	46.5	38.0
18	46.5	37.5	38.5	65.5	58.5	62.5	82.0	74.5	60.5	64.0	38.5	26.0	52.0	43.0	39.0	44.5	54.0	66.5	76.5	76.0	65.5	62.0	35.0	36.0	49.0	40.5	39.5
19	38.0	39.5	33.5	67.5	51.5	72.5	77.5	76.5	68.5	63.0	41.0	23.5	55.0	38.0	47.0	57.5	54.0	69.5	76.0	72.5	65.0	61.5	30.0	25.5	39.5	38.0	51.5
20	26.5	25.5	35.0	51.0	48.0	78.0	82.5	74.5	67.5	62.0	55.0	23.5	57.5	47.0	46.0	48.0	60.5	72.5	76.5	73.5	68.0	57.0	31.0	39.0	51.5	36.0	47.5
21	33.5	25.5	46.5	45.0	56.0	75.0	65.5	68.5	71.0	56.5	37.5	25.5	45.0	49.0	43.0	50.5	66.5	76.0	74.5	79.0	68.0	56.0	30.5	55.0	34.5	43.0	68.0
22	42.0	46.0	45.5	48.5	60.5	67.0	69.0	68.0	65.5	57.5	35.5	29.0	26.5	46.0	34.0	58.0	75.0	76.0	81.0	71.5	69.0	57.5	41.5	36.0	45.0	33.5	59.0
23	54.5	43.5	42.5	56.5	66.0	71.5	68.0	71.5	65.5	58.5	45.5	38.0	37.0	40.0	47.5	51.0	70.0	80.5	85.5	68.5	68.5	59.0	56.5	32.0	44.5	34.0	57.5
24	59.0	40.0	50.0	52.0	68.5	80.0	70.5	71.0	49.5	56.0	44.0	47.0	47.5	38.5	51.0	51.0	54.5	84.0	76.5	65.5	64.0	70.0	50.0	40.0	29.5	34.0	49.5
25	67.0	32.5	44.0	47.5	66.0	82.5	78.5	71.0	46.5	56.0	41.5	31.5	37.0	48.5	41.5	61.5	61.0	80.0	72.0	65.5	69.5	52.5	33.5	39.5	34.5	38.5	44.0
26	66.5	24.0	41.5	59.0	63.5	79.0	73.0	71.0	50.0	46.5	27.5	36.0	30.5	51.0	34.5	71.5	70.0	75.5	76.0	66.0	62.0	55.0	44.0	37.0	56.0	32.0	44.0
27	45.0	24.5	61.5	55.0	64.5	79.0	72.0	70.0	53.0	47.5	33.0	19.0	32.0	57.5	37.5	52.0	64.5	77.0	81.5	71.0	67.0	61.0	34.5	27.0	59.0	36.0	45.0
28	37.5	30.0	62.5	64.5	60.5	71.0	75.0	75.0	60.5	57.5	33.0	26.0	45.5	42.5	51.0	50.5	64.0	80.5	81.0	72.0	59.0	61.5	35.0	24.5	44.5	41.0	45.0
29	50.0	----	49.0	51.5	63.5	70.5	76.5	81.5	58.0	64.5	32.5	38.5	44.0	----	62.0	70.0	61.5	79.0	76.5	72.5	52.0	48.5	38.5	42.0	26.0	42.0	45.5
30	46.0	----	37.0	48.0	67.5	73.5	78.5	80.5	64.5	67.0	34.0	34.0	28.5	----	56.0	58.5	65.5	78.5	77.5	74.5	53.5	53.0	40.5	51.5	17.5	----	45.5
31	38.5	----	37.5	----	71.0	----	81.0	81.0	----	68.5	----	37.0	31.5	----	49.0	----	71.0	----	79.0	72.0	----	60.0	----	48.0	23.5	----	49.5
Average	48.0	38.8	41.2	50.5	61.6	71.1	75.1	72.8	65.8	60.1	46.9	35.4	39.6	39.0	44.0	53.2	62.0	71.4	76.9	73.9	67.9	59.8	44.3	40.8	40.1	39.4	43.6
Annual	----	----	----	----	----	----	----	----	----	----	----	55.6	----	----	----	----	----	----	----	----	----	----	----	56.1	----	----	----

TABLE 2.—*Pan evaporation and wind movement at the U. S. Geological Survey station, Salisbury, Md., April 1950 through March 1952*

Week ending	Evaporation (inches)	Wind (miles)	Week ending	Evaporation (inches)	Wind (miles)	Week ending	Evaporation (inches)	Wind (miles)
1950			*1950*—Con.			*1951*—Con.		
Apr. 7	1.306	871	Dec. 15	0.256	254	Aug. 10	1.420	224
14	1.215	598	22	.110	334	17	1.235	221
21	1.338	[1] 533	29	.244	450	24	1.662	252
28	1.102	[1] 398	*1951*			31	1.350	196
May 5	.639	402				Sept. 7	1.194	167
12	1.843	482	Jan. 5	Ice	[1] 408	14	1.334	202
19	1.835	[1] 379	12	do	[1] 445	21	.842	104
26	2.565	273	19	do	544	28	1.032	309
une 2	1.921	[1] 262	26	do	[1] 556	Oct. 5	1.034	467
9	1.736	285	Feb. 2	do	[1] 578	12	.782	427
16	2.298	333	9	do	[1] 393	19	.613	504
23	1.864	401	16	do	[1] 352	26	.647	206
30	2.722	330	23	.418	521	Nov. 2	.688	316
July 7	1.699	343	Mar. 2	.950	417	9	.920	482
14	1.399	394	9	.562	344	16	.316	229
21	1.708	334	16	.742	697	23	.584	529
28	1.328	182	23	.683	502	30	.576	467
Aug. 4	2.356	255	30	1.040	527	Dec. 7	.187	213
11	1.620	384	Apr. 6	1.160	490	14	.344	361
18	[2] 1.108	233	13	.799	210	21	.626	530
25	1.970	258	20	1.334	480	28	.320	256
Sept. 1	1.934	308	27	1.510	528	*1952*		
8	1.400	358	May 4	1.688	370			
15	.822	327	11	1.594	363	Jan. 4	.283	319
22	.938	217	18	1.698	319	11	.358	665
29	[2] .742	226	25	1.022	435	18	[2] .349	336
Oct. 6	.885	228	June 1	1.732	[1] 350	25	.538	[1] 485
13	.592	378	8	1.474	226	Feb. 1	.084	501
20	.677	204	15	.835	388	8	[2] .648	435
27	.578	220	22	1.680	219	15	[2] .598	526
Nov. 3	.690	189	29	1.948	315	22	[2] .562	[1] 538
10	.830	[1] 348	July 6	1 897	357	29	.410	395
17	.446	327	13	2.088	236	Mar. 7	.480	591
24	.623	433	20	1.208	207	14	.678	539
Dec. 1	.308	346	27	1.596	274	21	.764	552
8	.312	585	Aug. 3	1.618	249	28	.765	342

[1] Approximate.
[2] Doubtful data.

POPULATION AND CULTURE

The population of the Beaverdam basin is chiefly rural. The population density is about 70 persons per square mile. The town of Parsonsburg, population 725 in the U. S. Census of 1950, is on the headwater divide between Beaverdam Creek and tributaries of the Pocomoke River.

Chicken farming is the major occupation, broiler chickens being raised in houses of 1,000 to 20,000 capacity. Crop farming, by normal methods with little irrigation, is the second major occupation.

The basin is served by many primary and secondary roads and by one railroad, the Baltimore and Eastern spur line. The Salisbury airport, which has concrete runways, occupies about three-eighths of a square mile in the central part of the basin.

GEOLOGY

The Beaverdam Creek drainage basin is on the Atlantic Coastal Plain approximately 90 miles east of the Fall Line, the boundary between the Coastal Plain and the Piedmont. The Coastal Plain is underlain by unconsolidated or semiconsolidated sedimentary rocks consisting chiefly of sand, silt, clay, greensand, and shell marl, which stretch like a huge apron or fan away from the Piedmont, on an old eroded surface of crystalline rock, as shown in figure 1 and plate 3. The sedimentary rocks thicken in a short distance in a southeasterly direction. They also dip southeast at gradients between 10 and 100 feet to the mile, the dip generally increasing with depth.

Correlation from the outcrop to wells in this area indicates that the sedimentary rocks range in age from Triassic(?) to Recent. The regional geology has been described by Stephenson, Cooke, and Mansfield (1933), Spangler and Petersen (1950), and Richards (1945, 1948, 1953).

In a deep oil test, Wi–Cg 37 (see pls. 3 and 4), drilled 1 mile east of the Beaverdam Creek drainage basin, weathered crystalline rock was penetrated at 5,498 feet (Anderson, 1948, p. 10). This rock was schist, similar to some of the rocks of the Piedmont province, and it is the basement complex, from which no appreciable amount of water can be obtained. Hard crystalline rock was found at 5,529 feet, and the hole was drilled in it to 5,568 feet. Thus the well log shows more than a mile of sedimentary rock below the land surface at this site.

The structure and texture of the earth materials in a drainage basin affect the land portion of the hydrologic cycle. Such factors as stream development, capacity of the soil to absorb water, rate of groundwater flow, yield of wells, nature of the vegetation, type and distribution of forest growth, and the pattern of cultivation are determined in part by the character of the rocks and their weathered byproduct, the soil. Therefore, the local geology of the Beaverdam Creek basin is considered here in some detail. An earlier brief description of the geology of Wicomico County, in which this area is located, was made by Berry (Clark, Mathews, and Berry, 1918, p. 310–323). A more detailed description has been given by Rasmussen and Slaughter (1955). The geology is considered in three parts: the geomorphology, or surficial land features (including soils), which controls the entry and discharge of ground water; the stratigraphy, which controls the storage and transmission of ground water; and special features of the Beaverdam basin that affect the hydrologic cycle there. Plates 4 and 5 illustrate the formations and landforms described.

GEOMORPHOLOGY

The landforms of the Beaverdam Creek basin are all of low relief, yet they affect the hydrologic regimen significantly. The broadest landforms are marine terraces. The narrowest landforms are the valleys of Beaverdam Creek and its tributaries, formed during four cycles of rejuvenation coincident with lowered sea levels. Both terraces and valleys are festooned with the sandy rims of peculiar oval depressions called "Maryland basins," which partly control the catchment of rainfall, the retention of runoff, and the maintenance of a high rate of evapotranspiration in the boggy centers. Low, stabilized sand dunes cap some of the rims and are marginal to parts of the marine terraces. These geomorphic features are described in sequence, from those formed first to those formed later.

TERRACES

The physiography of the Beaverdam Creek basin is that of a recently emerged submarine plain of low relief, with gentle slopes interrupted by low sandy ridges. Studies of the Atlantic Coastal Plain from New Jersey to Florida have shown that this plain is actually composed of several terraces, each representing a stand of the sea higher than that at present. Using criteria developed by Shatuck (1901, 1906) and Cooke (1930 to 1952), five terraces are recognized in this area. These terraces, illustrated in figures 2 and 3, represent successive high

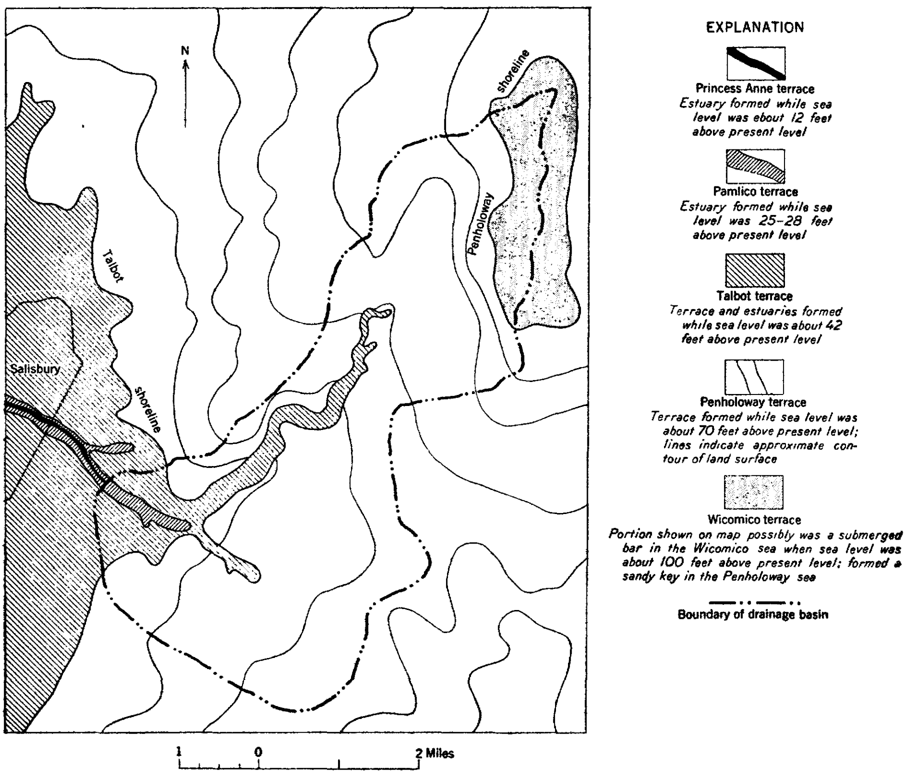


FIGURE 2.—Map of the Pleistocene terraces in Beaverdam Creek basin.

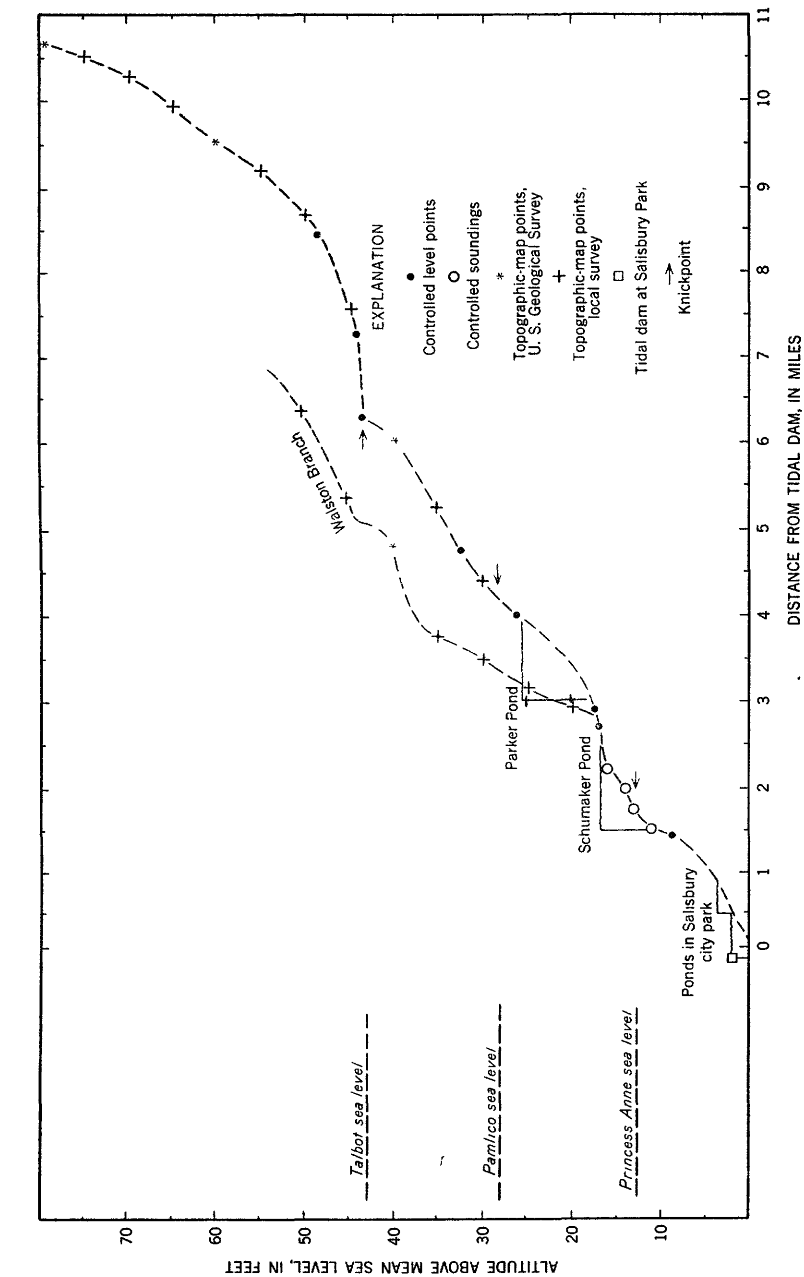


FIGURE 3.—Profile of Beaverdam Creek showing knickpoints.

stands of the ocean. They are shown in the following table, from highest to lowest (oldest to youngest).

Terraces in Beaverdam Creek basin

Terrace name	Altitude, in feet above sea level	
	Lowest remnant unmodified by later terrace development	Highest reach in Beaverdam Creek basin
Wicomico	70	84
Penholoway	42	70
Talbot	25	42
Pamlico	12	25
Princess Anne	0	12

In the areas where these terraces were originally defined, their upper limit, or the ancient sea level, was represented by the toe of a scarp, or at least by an observable change in the slope of the land. Elsewhere the evidence for a terrace shoreline has been found in a linear arrangement of topographic features, such as low dunes, barlike mounds and ridges, or elongated swales, some of them marshy. Black organic soils, now cultivated, lie in low areas behind the barlike ridges, and suggest back-bay marsh deposits.

So far as is indicated by the fieldwork of the writers in Kent, Queen Annes, Caroline, Talbot, Dorchester, and Wicomico Counties, the evidence for the Talbot beach line, at about 40 feet, is well founded. Evidence for the Pamlico shoreline at 25 feet is obscure. Evidence for the Penholoway shoreline at 70 feet is vague. The divide area north of Parsonsburg would have been a low sandy island, capped by dunes, in the Penholoway sea. The Wicomico shoreline is described as standing 90 to 100 feet above present sea level. This entire area would have been under the waters of the Wicomico sea, with a shoreline far to the north in Cecil County. The area of the Parsonsburg divide may have been a shallow bar in this ancient sea.

STREAM DEVELOPMENT

Beaverdam Creek is a stream in the mature phase of development—that is, one along which downcutting of the channel and reduction of the valley walls are progressing at about the same rate. The creek occupies a U-shaped valley in much of its course, with an adequate flood plain commensurate with the size and runoff capacity of the drainage basin. The tributaries to Beaverdam Creek—Walston Branch, Halloway Branch, Perdue Creek, and the headwaters of Beaverdam Creek—are, in general, youthful, still developing on the terrace plains and completing the drainage of the "Maryland basins." They have V-shaped valleys and no flood plain. The valleys are not deep because the sands and silts have a low angle of repose and slump readily when undercut.

Although Beaverdam Creek is mature, with an average gradient of only 8 feet per mile, the profile (fig. 3) shows the results of at least 4 cycles of erosion, indicated by 4 concave segments separated by 3 knickpoints. The first (highest) and most pronounced segment has a knickpoint at an altitude of 43 feet, above which the gradient is 5 feet per mile and increases upstream to 17 feet per mile. The next concave segment, not so pronounced, has a gradient of about 7 feet per mile above a knickpoint at 28 feet. A third segment has a gradient of 6.7 feet per mile above a knickpoint at 12 feet. The lowest profile has an average gradient of 7.5 feet per mile to sea level. These profiles presumably correspond to stream grades down to the terrace strands: the profile above 43 feet, the grade formed during Talbot time; the profile from 28 to 43 feet, that during Pamlico time; the profile from 12 to 28 feet, that during Princess Anne time (Wentworth, 1930, p. 31); and the profile from sea level to 12 feet, which is downstream from the basin outlined for this study, probably represents a new grade formed by headward erosion in Recent time.

The most gentle stream grade is that associated with the Talbot sea level, suggesting that a longer time, or more intensive erosion, or both, were instrumental in producing it. The drainage basin above the 40-foot altitude is underlain predominantly by the Walston silt, which does not have as high an infiltration rate as the Beaverdam sand that underlies most of the basin below the 40-foot contour. Consequently, direct runoff may be higher, and therefore stream erosion greater, in the upper part of the drainage basin.

MARYLAND BASINS

The areal geologic map (pl. 4) shows the land surface of the Beaverdam Creek basin festooned with the sandy rims of oval basins. The rims are composed of material correlated as the Parsonburg sand. The poorly drained basins enclosed by the rims were named "Maryland basins" by Rasmussen and Slaughter (1955). In the interior of these basins earlier formations that appear as fensters in the veneer of Parsonsburg sand are exposed (see p. 41).

These sandy rims are of low relief: the maximum relief, rim to center, is found in the basin in which the Salisbury airport is situated, where the sandhill on the eastern rim is 22 feet higher than the head of drainage near the airport entrance. The average relief of many basins is slightly less than 10 feet. The rims of the basins are not horizontal, except for those deposited on level ground; most of them lie on the gentle terrace slopes. The rims are highest where two or more basins coalesce.

In the field, the oval outline can be seen only in the smaller basins because woods and distance hamper observation of the encircling rims of the larger ones. The outline of the basins has been sketched by means of aerial photographs, the topographic map, the soils map, and field reconnaissance. It is possible that a few basins of vague outline have been overlooked in mapping, but an attempt was made to record all basins.

The areal map shows 57 "Maryland basins" entirely or partly in the Beaverdam Creek drainage basin. The basins range in long diameter from 0.08 mile to 3.08 miles and average 0.71 mile. The short diameter ranges from 0.06 mile to 1.55 miles and averages 0.49 mile. Calculated as ellipses, the areas range from about 2.4 to 2,400 acres. In shape, the basins range from a few which are nearly circular to those which are very elliptical. A few ellipses have a ratio of long to short axes of almost 2 to 1, but the average is closer to 1.5 to 1. The average elliptical eccentricity is 0.7 (eccentricity is the ratio of the distance between the foci of an ellipse to the length of the long axis).

The rims of the basins range in width from less than 50 to more than 1,000 feet. Where the rims have been breached by erosion of recent streams, or where their slopes are gentle, they are obscure. There appears to be no predominant direction in which the rims become thicker; rather, rim thickness appears to be random. However, the rims of basins that lie below an altitude of 55 feet appear to be thicker, and the basins themselves average larger, than those in the higher reaches of the drainage area.

Moreover, like the "Jersey basins" in New Jersey, the "Maryland basins" do not appear to have a prevailing orientation. There are smaller basins of diverse trend within larger basins. The long axes appear to be oriented at random. In this respect the "Maryland basins" differ markedly from the classic bays of the Carolinas, for "Carolina bays" generally have a northwest alinement of long axes.

The mode of origin of the "Maryland basins" must be considered because some of the processes of origin that have been proposed, if valid and if operative today, would invalidate the calculations of the hydrologic budget made in this report. The same hypotheses for the origin of the "Carolina bays" and for the "Jersey basins" are considered here. Many of the basins of both Maryland and New Jersey are much less distinct than, smaller than, and lacking in the preferred orientation of, the classic bays of North Carolina, South Carolina, and Georgia. Nevertheless, they bear so much resemblance in shape, soil, rim, and relief that it is possible they are all of the same origin and can be explained by a single theory.

It has now been shown that there is an almost continuous chain of these bay or basin landforms on the Atlantic Coastal Plain from New Jersey to Florida (Rasmussen, 1953), and similar forms on the Coastal Plain of Alaska (Black and Barksdale, 1949). If these landforms on the Atlantic Coastal Plain are of two modes of origin, then it is necessary to demonstrate wherein they differ, and to draw the lines, geographically, between the bays and basins. It would not be objective to reject some basin forms merely because they did not meet preconceived notions of axial orientation or of perfection in shape. The poorly formed basins must be considered with those of regular or well-defined outline. In fact, the less regular or exceptionally irregular basins might provide clues to origin which otherwise would be overlooked.

Basins in the Coastal Plain were first recognized in writing in 1848 by Michael Tuomey, the first State Geologist of South Carolina, who attributed them to springs rising to the surface of the sandy plain. Glenn, in 1895, described two small bays near Darlington, S. C., and attributed them to the action of shoreline winds and waves. Smith, in 1931, showed that the solution of aluminum and iron could account for the volume loss of the depressed areas in South Carolina.

In 1933 Melton and Schriever declared that the "Carolina bays" were formed by an infall of thousands of meteorites, and claimed the northwest alinement of the long axes as a major point in their theory. Cooke (1933) questioned this extraterrestrial origin, and stated that the bays were formed as crescent-shaped keys and lagoons under the influence of a prevailing southeasterly wind, which set up rotating currents having an elliptical orbit. In subsequent years Cooke (1940, 1954) modified his theory by suggesting that the rotating currents were created and controlled in elliptical motion by gyroscopic effects of the earth's rotation, which caused a northwest elongation because of the Coriolis force.

Johnson (1936) at first advocated solution as the chief cause of bays, and the rims being explained as due to deposition of windblown sand, but later (1942) he proposed a complex hypothesis that depends upon huge volumes of ground-water leakage. This hypothesis is called the artesian-solution-lacustrine-eolian hypothesis. It contends that the artesian formations of the Coastal Plain leaked water through fissures in their confining beds up into the surficial Pleistocene sands. Solution activity and sapping by these artesian springs created depressions containing lakes. Because the artesian beds, and, in general, the land surface, sloped southeasterly, the sinkhole became elongated in a southeastern direction. The lakes overflowed at the southeastern end, and created rim deltas. Wind activity at the lake shore formed marginal rim dunes.

Raisz (1934) studied rounded lakes and lagoons on the Coastal Plain of Massachusetts and advanced the first periglacial interpretation—that the elongation was in the direction of maximum wind velocity, and that the strongest winds blew off the continental ice mass during glacial time.

Grant (1945) held that shoals of fish formed the bays while swimming around artesian springs in nearshore marine areas.

Prouty (1934, 1935, 1952) revised the meteoritic theory by asserting that the elliptical, shallow sand-rimmed depressions were formed by air-shock waves associated with the falling meteorites. MacCarthy (1936, 1937) and McCampbell (written communication, dissertation, University of North Carolina, 1943; 1945) cited magnetic anomalies in the Coastal Plain, which they believe are related to the bays and presumably to buried meteorites.

LeGrand, in 1953, revived the solution hypothesis by indicating that most if not all of the Coastal Plain areas in which the bays and basins are found are underlain by marls and shell beds at moderate depth—that is, 100 to 200 feet. He believed that the solution of limy material would develop a normal sinkhole karst topography, the long axes of the sinkholes being controlled by the southeast dip of the beds. He suggested that the sinkholes would be reflected in the overlying Pleistocene sands.

Wolfe (1953) described the depressions on the Coastal Plain of New Jersey and related them to periglacial activity. He considered the "Jersey basins" a phenomenon distinct from the "Carolina bays" because of the less regular shape and the general lack of a preferred orientation. Rasmussen (1953), in a discussion of Wolfe's article, pointed to the more or less continuous scatter of basins or bays from New Jersey through Delaware, the eastern shores of Maryland and Virginia, to the Carolinas, Georgia, and Florida, as an objection to considering them separately.

Kelly (1951) and Kelly and Dachille (1953) noted the resemblance of the basins to kettle holes left by blocks of melting ice in the outwash plains derived from a melting glacial ice mass. He suggested that the "Carolina bays" were caused by icebergs carried to shore by tidal waves. The preferred orientation was explained as controlled by a uniform current against a relatively uniform, southeasterly slope.

Rasmussen and Slaughter (1955) discussed the basins of Wicomico County, Md., which includes the Beaverdam Creek area, and recognized that the hypothesis of stranded icebergs could account for both the northwestern orientation of "Carolina bays" and the random orientation of "Maryland basins." The Carolina coastal plain presents an almost uniform southeastern slope to the sea, so icebergs would be stranded with almost uniform alinement if they were beached by a uniform onshore wave. The Delmarva Peninsula, however, is open to the water from two sides, by way of the Atlantic Ocean and Chesapeake Bay. This would permit icebergs to come together from both directions. The presence of larger basins at lower altitudes also finds an explanation in the iceberg theory, inasmuch as bigger icebergs would run aground in deeper water, and thus be stranded at lower altitudes when the water receded.

Rim formation may be ascribed to sedimentation around the icebergs, either by the continued surge of high tides or by runoff from the higher land, and some eolian deposition. The basin-in-basin nesting, and the coalescent rims, may be due to the shifting of the icebergs, through progressive melting or through subsequent high tides.

A further explanation that may have merit lies in treating the basins and bays as a periglacial phenomenon similar to the "pingos" of Siberia, but on a scale larger than any observed heretofore. Poiré (written communication, 1950) says that Russian scientists have described hydrolaccoliths or "pingos" on the spotted tundra of Siberia as large swelling hummocks, commonly 250 feet or more in diameter and 26 to 130 feet high, each formed by a huge, convex, lens-shaped mass of ground ice overlain by a relatively thin soil, less than 10 feet thick, composed of peat, sand, and clay. The ice cupolas are said to be formed by hydrostatic pressure of ground water, under artesian head, from below the permafrost layer. In melting away the "pingos" leave black peaty depressions. Only in their dimensions do they fail to approach the grandness of "Carolina bays" or "Maryland basins." In the papers examined by Poiré, no mention is made of shape or preferential orientation of the basins.

It is not within the scope of this report to resolve the problem of the origin of "Carolina bays" or "Maryland basins," beyond the brief discussion given. It is appropriate, however, to discard as improbable two hypotheses that call upon movements of ground water, which presumably would be continuing today.

In order to demonstrate whether solution of underlying beds containing lime carbonate was the major cause in producing the basins, Rasmussen and Slaughter (1957) had 4 test holes drilled along the long axis of a prominent basin 1 mile north of East New Market, Dorchester County, about 28 miles northwest of the Beaverdam Creek drainage area. This basin has the shape and orientation of a classic "Carolina bay." It is outlined by the hachured 40-foot contour line on the East New Market quadrangle, Maryland (Corps of Engineers, 7½-minute series, 1942) and is shown well on aerial photo ANJ–7K–

10K of the U. S. Department of Agriculture, 1952. The long axis of this basin is about 2,800 feet long, bearing about N. 35° W. The relief from the center (altitude 35 feet) to the south rim (altitude 52 feet) is 17 feet, and to the north rim (altitude 45 feet), 10 feet. The holes were drilled to depths ranging from 126 to 210 feet. The section penetrated included about 55 feet of gravelly sand, 55 feet of light-gray silt, 50 feet of gray sandy silt with shell fragments, and 50 feet of gray fine sand. The top of the bed containing shell fragments had a uniform dip of 17 feet to the mile southeastward. The subsurface structure so far as shown by the test holes did not reflect in any manner the pronounced basin on the surface. Consequently, it is concluded that this basin, at least, is not a sinkhole structure produced by solution of underlying artesian beds, or aquicludes.

The complex process of Johnson, involving artesian springs, seems not to be hydrologically sound. In order to produce the many thousands of bays and basins, the artesian beds would have had to leak water like a sieve, and under high head. There is no reason to believe that the upward leakage of water into the permeable sands of Pleistocene age would form a depression immediately above the point of maximum leakage, or that an oval depression would form at all. Rather, the blanket of sand would diffuse the pressure, and, at points where springs emerged, normal stream runoff would occur. The random orientation and great number of basins in the Beaverdam area make the artesian hypothesis untenable.

Rasmussen (written communication, dissertation, Bryn Mawr College, 1958) has developed new evidence in Delaware that the bays, a regular landform, are derived from the basins, an irregular landform, by a type of sinkhole formed under water-table conditions. In the basin phase, removal of colloids and clays in suspension is regarded as the principal method of deepening and enlargement in most areas, where iron and aluminum are the chief cations. Solution is probably the principal method in other areas where calcium and magnesium are the important cations. The bay phase is initiated when the basin is deep enough to hold a water-table pond during much of the year. The wind generates waves which round the basin, and eventually elongate it, into a bay, in the direction of the dominant wind vector.

In any event, there is no evidence that the artesian sand underlying the area, the Manokin aquifer, is leaking any water upward through the confining bed, the lower aquiclude, to the sands of Pliocene(?) and Pleistocene age of the Beaverdam Creek drainage basin today. Moreover, the water table in the major part of the intake area of the Manokin aquifer in northwestern Wicomico County is at a lower altitude than the water table in most of the Beaverdam Creek drainage basin.

The present effect of the "Maryland basins" on the drainage basin is to restrain runoff and increase opportunity for infiltration, particularly in the higher part of the basin and to promote evapotranspiration, particularly in the lower part of the basin.

DUNES

In the Beaverdam Creek drainage basin, sand dunes or barlike sandhills are marginal to Schumaker Pond at a general elevation of 40 feet, and to Parker Pond at an elevation of about 50 feet. Others are marginal to Beaverdam Creek along the road south of Walston at an elevation of about 60 feet. Finally, low dunes cap the divide north of Parsonsburg at a general elevation of 80 feet.

The dunes of this area are all stabilized by vegetation. No blowouts or migrating dunes are known. The dunes have a low relief, 5 to 10 feet; high dunes are unknown. In general, the dunes below an altitude of 70 feet show no compass alinement, and no predominant facing of gentle and steep sides. Only the dunes on the crest of the Parsonsburg divide have a linear development, in general north to south, parallel to the broad divide.

A peculiarity of some of the dunes is that they have a clay base and a sand cap. One clay-based dune is a mile east of the airport. Two explanations are offered, and both may apply. Near Corpus Christi, Tex., dunes composed of clay pellets are formed on the flood plain of a river during the dry season (Huffman and Price, 1949). Scattered sand grains in a clay-silt matrix found in several dunes in the Beaverdam basin seem to favor such an interpretation. However, test augering indicates that the clay base may be an erosional remnant of the Walston silt. These remnants may have served as windbreaks, on which a cap of dune sand was deposited.

It is possible that the dunes of random orientation, found at almost all altitudes in the Beaverdam Creek area, represent an interstadial time of great wind activity and sparse vegetation, perhaps under semifrigid desert (tundra) conditions during or immediately after the Wisconsin glaciation. Formation of the dunes may be related to the formation of the Peorian loess deposits of the Mississippi Valley. However, the interpretation favored by the authors is that most of the dunes, particularly those of apparently random orientation, mark the rim of a "Maryland basin," where loose sand has been sorted by the wind and anchored by vegetation. Little tendency of the dunes to migrate off the crest onto the basin floor is indicated.

The significance of the dunes in the hydrologic budget is the high infiltration rate they offer to rainfall—that is, their ability to absorb and store water for transmission to the underlying Walston silt or Beaverdam sand. Where saturated, they feed water laterally to the basin centers and to the areas outside the basins.

STRATIGRAPHY

The sedimentary formations beneath the Beaverdam Creek basin range in age from Triassic(?) to Recent and compose a sedimentary column about 5,500 feet thick. However, this study is concerned chiefly with the shallow sedimentary rocks—that is, those within a few hundred feet of the land surface, including the sediments of the shallow ground-water reservoir and the sediments below that might leak water upward into the reservoir or might receive water from it by downward percolation. Therefore those formations below 1,000 feet are not described, and the reader is referred to Rasmussen and Slaughter (1955) for a description of them.

The basic well data are summarized in table 3. The drilled wells, which have a prefix Wi– and a letter coordinate, followed by a number, are numbered in accordance with location on a grid of 5-minute rectangles covering Wicomico County. The logs of these wells are given in the report by Rasmussen and Slaughter (1955). The logs of the augered test holes and wells numbered between 100 and 200, are presented in table 4.

TERTIARY SYSTEM

The Tertiary system beneath the Beaverdam Creek drainage basin includes rocks of the Paleocene, Eocene, Miocene, and Pliocene series, but the rocks discussed are all Miocene or younger.

MIOCENE SERIES

The Miocene series in this area is illustrated in plate 6, a composite log of Wi–Cf 61, drilled to 1,025 feet in the Beaverdam Creek basin, almost to the base of the Miocene series. The Miocene strata in this area belong to the Chesapeake group, of middle and late Miocene age, and to an overlying unit tentatively identified as the Cohansey sand, which cannot be distinguished from the uppermost formation of the Chesapeake group, the Yorktown.

TABLE 3.—*Characteristics of wells and test holes*

Well No.	Contractor	Owner	Depth below land surface (feet)	Altitude (feet)	Diameter (inches)	Date drilled	Method of construction	Geologic unit	Use	Remarks
101	Cooperative Ground-Water Survey.	Cooperative Ground-Water Survey.	23	37.3	1	Jan. 1950	Hand auger and driving.	Pleistocene	Observation well.	
102	do	do	23	41.5	1	Jan. 1950	do	do	do	
103	do	do	20	46.1	1	Jan. 1950	do	do	do	
103a	Delaware Geological Survey.	do	28.5	44.6	3	May 1952	Power auger	do	Test hole	
104	Cooperative Ground-Water Survey.	do	14.2	47.7	1	Jan. 1950	Hand auger and driving.	do	Observation well.	
104a	Delaware Geological Survey.	do	33	46.6	3	June 1952	Power auger	do	Test hole	
104b	do	do	30	47.7	3	June 1952	do	do	do	
104c	do	do	24	52.8	3	June 1952	do	do	do	
105	Cooperative Ground-Water Survey.	do	27.5	55.3	1	Jan. 1950	Hand auger and driving.	do	Observation well.	
105a	Delaware Geological Survey.	do	39	56	3	June 1952	Power auger	do	Test hole	
105b	do	do	39	54.4	3	June 1952	do	do	do	
106	Cooperative Ground-Water Survey.	do	20	48.4	1	Jan. 1950	Hand auger and driving.	do	Observation well.	
106a	Delaware Geological Survey.	do	29	48.8	3	May 1952	Power auger	do	Test hole	
106b	do	do	29	49.1	3	May 1952	do	do	do	
106c	do	do	28.5	44.5	3	May 1952	do	do	do	
106d	do	do	28	43.3	3	May 1952	do	do	do	
107	Cooperative Ground-Water Survey.	do	16.2	47.7	1	Jan. 1950	Hand auger and driving.	do	Observation well.	
107a	Delaware Geological Survey.	do	24	48.1	3	June 1952	Power auger	do	Test hole	
107b	do	do	29	58	3	June 1952	do	do	do	
107c	do	do	29	52.6	3	June 1952	do	do	do	
107d	do	do	28	49.1	3	May 1952	do	do	do	
108	Cooperative Ground-Water Survey.	do	23	45.4	1	Jan. 1950	Hand auger and driving.	do	Observation well.	
108a	Delaware Geological Survey.	do	29	44.9	3	May 1952	Power auger	do	Test hole	
108b	do	do	29	44.5	3	May 1952	do	do	do	

108c	do	do	29	44.9	3	May 1952	do	do	do	
108d	do	do	54	47.5	3	May 1952	do	Pliocene(?)	do	
109	Cooperative Ground-Water Survey.	do	20.5	41.0	1	Jan. 1950	Hand auger and driving.	Pleistocene	Observation well.	
109a	Delaware Geological Survey.	do	28.5	41.4	3	May 1952	Power auger	do	Test hole	
109b	do	do	28	39.3	3	May 1952	do	do	do	
109c	do	do	29	39	3	May 1952	do	do	do	
110	Cooperative Ground-Water Survey.	do	26.2	46.8	1	Feb. 1950	Hand auger and driving.	do	Observation well.	
110a	do	do	23	48	1	Jan. 1950	do	do	do	Well casing pulled.
111	do	do	16.2	49.3	1	Feb. 1950	do	do	do	
111a	do	do	15	50	1	Jan. 1950	do	do	do	Do.
112	Cooperative Ground-Water Survey.	do	21.5	45.5	1	Jan. 1950	Hand auger and drilling.	do	do	
113	do	do	21	42.5	1	Jan. 1950	do	do	do	
114	do	do	22	37.0	1	Jan. 1950	do	do	do	
115	do	do	16.2	40.8	1	Jan. 1950	do	do	do	
116	do	do	18	51.6	1	Jan. 1950	do	do	do	
117	do	do	21.5	49.7	1	Jan. 1950	do	do	do	
118	do	do	16.7	50.7	1	Jan. 1950	do	do	do	
119	do	do	25.8	68.0	1	Feb. 1950	do	do	do	
119a	do	do	21	60	1	Jan. 1950	do	do	do	Well casing pulled.
120	do	do	13.7	84.1	1	Jan. 1950	do	do	do	
121	do	do	20.5	54.4	1	Feb. 1950	do	do	do	
121a	do	do	16	55	1	Jan. 1950	do	do	do	Do.
122	do	do	11.5	78.8	1	Jan. 1950	do	do	do	
123	do	do	11	77.6	1	Jan. 1950	do	do	do	
124	do	do	10.7	73.4	1	Jan. 1950	do	do	do	
125	do	do	18.7	58.6	1	Jan. 1950	do	do	do	
126	do	do	22	58.3	1	Jan. 1950	do	do	do	
127	do	do	14	47.5	1	Feb. 1950	do	do	do	
128	do	do	16.5	53.1	1	Jan. 1950	do	do	do	
129	do	do	15.7	52.6	1	Jan. 1950	do	do	do	
130	do	do	16.7	45.9	1	Jan. 1950	do	do	do	
131	do	do	21.6	42.2	1	Jan. 1950	do	do	do	
132	do	do	11.5	45.2	1	Apr. 1950	do	do	do	
133	do	do	10	66.7	1	Apr. 1950	do	do	do	
Wi-Cf 3	J. H. Rulon	City of Salisbury	109	45	16	1942		do	Observatation well.	Well never used for water supply. Converted to automatic-recording observation well.
Wi-Cf 28	A. C. Schultes	do	92	41	6	Mar. 1948	Cable-tool drill	Pliocene(?)	Test well	Specific capacity 10 gpm/ft drawdown.
Wi-Cf 29	do	do	72	30	2	Mar. 1948	do	do	Observation well.	
Wi-Cf 30	do	do	82	39	6	Mar. 1958	do	do	do	
Wi-Cf 31	do	do	94	43	2	Mar. 1948	do	do	do	

TABLE 3.—*Characteristics of wells and test holes*—Continued

Well No.	Contractor	Owner	Depth below land surface (feet)	Altitude (feet)	Diameter (inches)	Date drilled	Method of construction	Geologic unit	Use	Remarks
Wi-Cf 54	E. Cusick	J. Smith	202	42	1.5	Mar. 1950	Jet	Miocene	Domestic	Top of Miocene 94 feet (?).
Wi-Cf 55	R. B. White	Cooperative Ground-Water Survey.	139	46	2	Sept. 1950	do	do	Test hole	Top of Miocene 107½ feet (?).
Wi-Cf 58	L. Rude & Son	City of Salisbury	107	50	5	Jan. 1950	do	Pliocene (?)	Airport use	Well abandoned owing to high iron content of water.
Wi-Cf 61	Survey Drilling Co.	Transportation Pipe Line Corp.	1,025	42	6	May 1951	Rotary drill	Miocene, Calvert formation.	Test hole	Exploration for subsurface gas reservoir. Top of Miocene 110 feet (?).
Wi-Cf 62	do	do	1,024	48	6	May 1951	do	do	do	Exploration for subsurface gas reservoir. Top of Miocene 128 feet (?).
Wi-Cf 63	do	do	1,004	38	6	May 1951	do	do	do	Exploration for subsurface gas reservoir. Top of Miocene 92 feet (?).
Wi-Cf 67	R. C. Scott	W. Toadvine	64	39	2	May 1952	Jetting	Pliocene (?)	Domestic	
Wi-Cg 35	Shannahan Artesian Well Co.	Hastings Hatchery.	685	75	6	1938–1940	Rotary drill	Miocene	Cooling	Top of Miocene 157 feet (?).
Wi-Cg 37	Ohio Oil Co	Ohio Oil Co	5,568	70		Oct. 1949	do	Basement complex.	Test hole	Oil exploration. Top of Miocene 130 feet (?).
Wi-Cg 38	Delaware Geological Survey.	Cooperative Ground-Water Survey.	79	80	3	Nov. 1952	Power auger	Pleistocene	do	
Wi-Cg 40	do	do	79	79	3	Aug. 1952	do	do	do	
Wi-Df 25	R. B. White	do	104	40	2	Sept. 1950	Jetting	Miocene	do	Top of Miocene 90 feet (?).

TABLE 4.—*Logs of auger holes in the Beaverdam Creek basin*

[Depth intervals are below land-surface datum]

Well or hole	Altitude (ft above msl)	First stratum		Second stratum		Third stratum		Fourth stratum		Fifth and sixth strata	
		Depth (ft)	Description	Depth (ft)	Description	Depth (ft)	Description	Depth (ft)	Description	Depth (ft)	Description
101	37.3	0–18	Buff sand								
102	41.5	0–4	do	4–12	Gray silt	12–14	Buff sand				
103	46.1	0–1	Gray loam	1–2	Buff sand	2–12	Mottled silt	12–14	Buff sand		
103a (1,650 ft. W of 103.)	44.7	0–1	Black loam	1–9	Sandy silt	9–14	Mottled clay	14–16	Silty sand	16–28½	Medium-grained sand.
104	47.7	0–1	Sandy loam	1–9	Mottled clay	9–12	Fine sand				
104a (70 ft. E of 104.)	46.7	0–1	Gray loam	1–7½	Silty clay	7½–12½	Silty sand	12½–33	Buff sand		
104b (980 ft. E of 104.)	47.7	0–1	Black loam	1–3½	Silty sand	3½–12½	Pastel clay	12½–30	Medium-grained sand.		
104c (3,055 ft. SE of 104.)	52.8	0–1½	Gray loam	1½–4	Tan sand	4–19	Silt and clay	19–24	do		
105	55.3	0–2	Black loam	2–7	Brown sand	7–11	Gray sand	11–20½	Mottled clay	20½–21	Medium-grained sand.
105a (15 ft. NW of 105.)	56.0	0–1½	Gray loam	1½–8½	Silty sand	8½–18½	Silty clay	18½–39	Medium-grained sand.		
105b (3,000 ft. NE of 105.)	54.5	0–1	do	1–9	Silt and sand	9–15½	Brown clay	15½–24	Silty sand	24–29 29–39	Sandy silt. Medium-grained sand.
106	48.4	0–2	do	2–11	Sandy silt	11–13	Medium-grained sand.				
106a (7 ft. SE of 106.)	48.8	0–1½	Black loam	1½–8	Silty sand	8–10	Silty clay	10–13½	Brown clay	13½–18 18–29	Sandy silt. Medium-grained sand.
106b (427 ft. NW of 106.)	49.2	0–2	Gray sand	2–4½	Sand and silt	4½–5½	White clay	5½–9	Silty sand	9–14 14–29	Silty clay. Fine sand.
106c (947 ft. NW of 106.)	39.0	0–3	Silty sand	3–5½	Sandy silt	5½–9	Clayey silt	9–10	Sandy silt	10–28½	Medium-grained sand.
106d (1,590 ft. NW of 106.)	43.4	0–4	Sandy silt	4–8½	Light silt	8½–28	Medium-grained sand.				
107	47.7	0–3	Black loam	3–7	Sand and silt						
107a (9 ft. NW of 107.)	48.2	0–2	do	2–8	do	8–13	Silt and clay	13–24	Medium-grained sand.		
107b (1,500 ft. NW of 107.)	58.1	0–2½	Brown loam	2½–8½	Clayey silt	8½–14	Light silt	14–17½	Silty sand	17½–24 24–29	Clayey silt. Medium-grained sand.

TABLE 4.—*Logs of auger holes in the Beaverdam Creek basin*—Continued

Well or hole	Altitude (ft above msl)	First stratum		Second stratum		Third stratum		Fourth stratum		Fifth and sixth strata	
		Depth (ft)	Description	Depth (ft)	Description	Depth (ft)	Description	Depth (ft)	Description	Depth (ft)	Description
107c (2,370 ft. NW of 107.)	52.7	0–1½	Gray loam	1½–4	do	4–10	Sand and silt	10–16	Silty clay	16–21 21–29	Sand and silt. Medium-grained sand.
107d (3,470 ft. NW of 107.)	49.2	0–1	Dark gray loam.	1–8	Sandy silt	8–12	Silty clay	12–28	Medium-grained sand.		
108	45.4	0–2	Brown loam	2–13	Medium-grained sand.						
108a (5 ft. N of 108.)	44.9	0–½	Gray loam	½–10	Sandy silt	10–17	Sand and silt	17–29	Medium-grained sand.		
108b (640 ft. SE of 108.)	44.5	0–2½	do	2½–7½	Silty sand	7½–14	Fine sand	14–29	do		
108c (1,490 ft. SE of 108.)	44.9	0–2½	Silty sand	2½–5	Sand and silt	5–13½	Silty sand	13½–29	do		
108d (2,933 ft. SE of 108.)	47.5	0–2½	do	2½–8	do	8–11	do	11–55½	do		
109	41.0	0–2	Gray sand	2–4	Brown clay	4–13	Medium-grained sand.				
109a (2,476 ft. S of 109.)	41.4	0–1	Gray loam	1–7½	Sandy silt	7½–28½	do				
109b (1,000 ft. N of 109.)	39.3	0–2	do	2–4	do	4–28½	do				
109c (2,036 ft. N of 109.)	39.0	0–3	Tan sand	3–7½	do	7½–13	Sand and silt	13–29	Medium-grained sand.		
110	46.8	0–7	Silty sand	7–9	Mottled clay	9–14½	Silty sand	14½–19	do		
110a (2,000 ft. E of 110.)	48±	0–2	Gray loam	2–16	Gray clay	16–18	Medium-grained sand.				
111	49.3	0–3	Black loam	3–4	Medium-grained sand.	4–13	Buff clay	13–14	Medium-grained sand.		
111a (2,500 ft. SE of 111.)	58±	0–1	do	1–9	Gray silt	9–13	Medium-grained sand.				
112	45.5	0–3¼	Brown sand	3¼–6	Silty sand	6–10¼	Sand and silt	10¼–11¾	Silty sand		
113	42.5	0–5	Sand and silt	5–9¾	do	9¾–12	Sandy silt				
114	37.0	0–8	Brown sand	8–10	Sand and silt	10–18	Coarse sand				
115	40.8	0–2½	do	2½–5¾	Coarse sand	5¾–6	Silty sand	6–6¾	Sandy silt	6¾–10 10–12	Sand and silt. Medium-grained sand.

116	51.6	0– 1¾	Brown sand	1¾– 4¼	Silty sand	4¼– 9¾	Sandy silt	9¾–12¼	Silty sand		
117	49.7	0– 4	do	4–16	Brown clay	16–20	Silty sand				
118	50.7	0– 5	do	5– 8	Coarse sand	8–10	do	10–11	Coarse sand		
119	68.0	0– 3½	Brown silt	3½–10	Silty clay	10–16	Gray clay				
119a (600 ft. N of 119.)	63±	0– 4	Medium-grained sand.	4–10	do	10–14	do	14–16	Medium-grained sand.		
120	84	0–6	Brown sand	6–9	Medium-grained sand.						
121	54.4	0–10	Sandy silt								
121a (1,200 ft. S of 121.)	56±	0– 5	Medium-grained sand.	5–10	Sandy silt	10–11	Coarse sand	11–13½	Medium-grained sand.		
122	78.8	0– 6	Brown sand	6–10	Coarse sand						
123	77.6	0– 4	do	4–10	do						
124	73.4	0– 5	do	5– 7	do						
125	58.6	0– 5	do	5– 8	Silty sand	8–12	Medium-grained sand.	12–12½	Brown clay	12½–16	Medium-grained sand.
126	58.3	0– 6	do	6– 7½	Sandy silt	7½– 8½	do	8½–15	Sandy clay	15–17	Coarse sand.
127	47.5	0– 4	Sandy silt	4–12	Buff sand						
128	53.2	0– 7	Coarse sand	7–12½	Sandy clay	12½–13½	Coarse sand				
129	52.6	0– 7	Medium-grained sand.	7–10	Silty sand	10–11	Sandy clay	11–13	Coarse sand		
130	45.9	0–15	Coarse sand								
131	42.2	0–17	do								
132	45.2	0– 3	Medium-grained sand.	3– 7½	Mottled clay	7½–11½	Sand and silt				
133	66.7	0– 3	do	3– 5	Coarse sand						

CHESAPEAKE GROUP BELOW YORKTOWN FORMATION

The Chesapeake group is composed of the Calvert, Choptank, St. Marys, and Yorktown formations, which are well exposed in cliffs along the western shore of Chesapeake Bay, in Calvert and St. Marys Counties. In Wi–Cf 61 the portion of the group below the Yorktown formation is logged as a gray very fine sand and silt, containing shells of macrofossils and Foraminifera. The unit does not yield much water to wells, and shows only two thin aquifers in more than 700 feet of thickness. The average permeability of the unit is very low, suggesting that it will neither yield nor take much water.

YORKTOWN FORMATION AND COHANSEY(?) SAND

Underlying the Beaverdam Creek basin at depths ranging from 100 to 200 feet is a unit, 175 to 230 feet thick, composed of gray shale, fine sand, and medium- to coarse-grained sand, containing few fossils. It is correlated with the Yorktown formation of Virginia and tentatively with the Cohansey sand of New Jersey. The lowest part of this unit has been called the Manokin aquifer by Rasmussen and Slaughter (1955) because it yields water to many wells in the vicinity of the Manokin River in Somerset County, and also to many wells in Wicomico and Worcester Counties. The piezometric surface of this aquifier is lower than the water table in most of the Beaverdam Creek basin. Hence, if there were a hydraulic connection between the two, the water-table sands would leak water to the Manokin aquifer.

Fortunately for the purpose of this study, the Manokin aquifer is confined by a tough gray silty shale, which prevents or impedes water movement. This unit, called the lower aquiclude, is regarded as an effective confining unit beneath the water-table sands.

South and east of the Beaverdam Creek basin the Yorktown and Cohansey(?) unit includes an aquifer above the lower aquiclude, the Pocomoke aquifer, which in turn is confined by an upper aquiclude. These units in the Miocene above the lower aquiclude are not recognized in wells beneath the Beaverdam Creek basin. The intake belt of the Pocomoke aquifer, with the upper aquiclude at its western edge, is believed to pass a few miles to the east of the basin. The stratigraphic and structural relations of the formations in the Beaverdam basin are illustrated in the block diagram, plate 5. This shows the southeastern dip of the formations of Miocene age, and the unconformity at the base of the red gravelly sand of Pliocene(?) age.

PLIOCENE(?) SERIES

The basal part of the unconfined ground-water reservoir of the Beaverdam Creek drainage basin is a red, orange, and brown gravelly sand that is correlated, on lithology alone, with the Pliocene series. It was correlated by Rasmussen and Slaughter (1955) with the Brandywine, Bryn Mawr, and Beacon Hill(?) formations, and it is possible that it is related to all of these. However, in this report it is considered part of the Brandywine formation. Campbell (1931) described the Brandywine as an alluvial fan—"sand and gravel brought down by the Potomac River during a period of downcutting"—which spread out from the present site of Washington, D. C., as a center, sloping from an altitude of 300 feet to below 100 feet. Hack (1955) considers the Brandywine formation to be a channel deposit of a degrading and laterally cutting stream such as the ancestral Potomac River.

Beneath the Beaverdam basin the top of the gravelly sand is more than 80 feet below sea level at Parsonsburg, but it is at sea level beneath Schumaker Pond. The sand does not crop out in the basin area of this study, but it is within a few feet of the land surface in several of the wells of the city of Salisbury along the Park Ponds. Tests of the well field at Salisbury indicate a high coefficient of transmissibility, 100,000 gpd (gallons per day) per foot, and field coefficient of permeability, 1,600 gpd per square foot, for the gravelly sands (Rasmussen and Slaughter, 1955, p. 104).

The Brandywine formation lies unconformably on an erosion surface on the Miocene series. The upper surface of the Brandywine formation was eroded before deposition of the tan and buff sands of the Pleistocene series. One well at Melson, north of the Beaverdam basin, indicates that the Pleistocene series extends very deep, so the Brandywine formation has been interpreted as wedging out in that direction. Control in the northern part of the basin is based on regional structure maps (Rasmussen and Slaughter, 1955), whereas that in the southern part is based on data from wells. Structurally, the red gravelly sand with its southeastern dip is related to the Tertiary system more closely than it is to the deposits of the Quaternary system, which have relatively horizontal attitude, although lithogically the sand appears more like the deposits of the Pleistocene series of the Quaternary system. In a structural sense, the sand is transitional.

The significance of the Brandywine formation in the Beaverdam Creek drainage basin, with respect to the hydrologic budget, lies in the reservoir storage it provides. The formation is saturated with water and the storage is latent at the present. Should large-capacity wells be drilled to it, the discharge may be an important item in future water calculations. However, well discharge was not a factor in this area during this 2-year budget study.

QUATERNARY SYSTEM

The Quaternary system is composed of the Pleistocene and Recent series. The description and subdivision of the Quaternary system is given on pages 36–37. The areal geology is shown on plate 4, and a block diagram (pl. 5) indicates the stratigraphic and structural relationships.

PLEISTOCENE SERIES

The Pleistocene series comprises all the surficial yellow, buff, and tan deposits of sand, silt, and clay from the soil zone to the top of the red gravelly sand of the Pliocene(?) series, or, where the Pliocene(?) is absent, to the top of the gray sand and green and gray silt of the Miocene series. Medium-grained sand and sandy silt are the predominant deposits of the Pleistocene series, but there are scattered pebbles, pockets of sandy gravel, a few cobbles, and, rarely, boulders, among the minor admixtures on the coarse end of the grade scale, and there are a few beds of clay, particularly in the upper units, as a minor admixture on the fine end. No fossils have been found in the Pleistocene deposits in the Beaverdam Creek drainage basin.

The Pleistocene epoch is popularly called the Ice Age because the Pleistocene deposits record the four successive advances and recessions of continental ice sheets in the northern half of the Northern Hemisphere. The ice sheets did not reach as far south as the Beaverdam Creek drainage basin; their nearest approach was 150 to 200 miles to the north, in northern Pennsylvania and New Jersey. In the Beaverdam Creek area, deposits associated with the advances of the ice are few and thin. The ice maxima were associated with greatly lowered sea levels, the acceleration of stream erosion, huge runoff from the ice front, and possibly rainy conditions. Valley cutting occurred in the Beaverdam Creek area.

The long interglacial stages, between the ice maxima, were times of rising sea level, culminating in levels several tens of feet higher than the modern level of the sea along the Atlantic Coast. In the Beaverdam Creek drainage basin, these were times of deposition, in fluviatile, lagoonal, swamp, deltaic, estuarine, and marine environments. Material that accumulated in outwash plains in front of the ice margin was redistributed during the interglacial warm spells, and deposited by streams and wind and wave action at lower altitudes on the Coastal Plain. The geologic sequence in the preceding table is an attempt to fit the deposits of this area into the glacial-interglacial chronology. It is based upon erosion cycles, as shown by disconformities, and upon lithology.

BEAVERDAM SAND

The basal formation of the Pleistocene series is the Beaverdam sand, an unconsolidated white to buff medium-grained sand that crops out in the lower half of the Beaverdam Creek drainage basin. It was named by Rasmussen and Slaughter (1955) from a type well, Wi-Cf 63, in this area. It is poorly exposed because the material is incoherent. It appears as fensters within the rims of the Parsonsburg sand.

Study of many samples from test holes in Wicomico County indicates that the Beaverdam sand is relatively homogeneous in composition, texture, and color. In composition, it is a quartz sand with a small percentage of dark heavy minerals. Its characteristic texture is shown by the following grade classification:

	Percent
Granules and small pebbles	20
Very coarse sand	5
Coarse sand	10
Medium-grained sand	26
Fine sand	24
Very fine sand	7
Silt	8
	100

In color it ranges from light gray to tan and buff.

The Beaverdam sand beneath the basin rests on the eroded surface of the Brandywine formation and possibly, in the northern part of the basin, directly on the so-called blue clay, or lower aquiclude, of the Miocene series.

The Beaverdam sand is overlain disconformably in the upper half of the basin by the Walston silt (p. 38), from which it is distinguished by color and texture. Much of the Walston silt is tough, whereas the Beaverdam sand is incoherent and easily drilled. In the lower half of the basin, the Beaverdam sand is overlain disconformably by the Parsonsburg sand (p. 40), from which it is distinguished by color and sorting. The Beaverdam sand is light in color and relatively homogeneous and well sorted, whereas the Parsonsburg sand is darker brown, more heterogeneous, and poorly sorted. Also the Beaverdam sand probably is overlain by the Talbot and Pamlico formations, which in this area are silts, in the narrow flood plains of the lower valley and by Recent alluvium in the main valley and lower courses of the tributaries of Beaverdam Creek.

The Beaverdam sand ranges in thickness from 30 to 70 feet beneath the basin, being thinnest at low altitudes beneath Schumaker and Parker Ponds and thickest beneath the Parsonsburg divide. Structurally, it appears to be almost horizontal, but it may dip eastward at a rate of 1 to 3 feet to the mile, along an initial sedimentary slope.

Formations of the principal ground-water reservoir and confining bed of the Beaverdam Creek basin

System	Series	Stage	Formation (and possible correlatives)	Approximate thickness (feet)	General character
Quaternary	Recent	Postglacial		0–10	Alluvium in the mature valleys, dunes of low relief, soil, and small accumulations of peat. Material has a high infiltration rate and a high rate of discharge by evapotranspiration.
	Pleistocene (Columbia group).	Wisconsin glacial	Parsonsburg sand	0–25±	A stratified drift, composed predominantly of sand, in bar-like ridges and dunes that form the rims and part of the floors of "Maryland basins." The formation ranges in altitude from below sea level to 85 ft. above sea level. Infiltration capacity is high and drainage is rapid. Storage is relatively low because of the thinness and narrowness of the deposit.
		Sangamon interglacial	Talbot and Pamlico formations (Cape May formation of New Jersey; Gardiners clay of Long Island; Suffolk scarp of Virginia).	0–10±	A terrace deposit of sandy silt and clay that forms a narrow tongue in the Beaverdam Creek valley beneath the alluvium, at altitudes ranging from sea level to 25 ft. above sea level. Forms a semipermeable layer in the bottom of Schumaker and Parker Ponds, and the lower flood plain of Walston Branch.
		Illinoian glacial	None	0	Beginning of present valley erosion. Lower portion of Beaverdam Creek valley excavated.
		Yarmouth interglacial	Walston silt. Possibly formed during a period beginning with the rise of sea level toward the Wicomico stage and extending through Penholoway time. (Pensauken formation of New Jersey).	0–60±	Lenticular beds of fine sand, silf, clay, and peat. General altitude about 40 ft. above sea level; range from 10 to 67 ft. above. Presumably a remnant of the deposits forming a low, marshy plain that extended from the western shore of Maryland to Worcester County. Infiltration rate is low to moderate; gravity yield is low; specific retention is high. Functions in part as an aquiclude. Has yielded marsh gas (methane) used to illuminate homes in the Parsonsburg area.
		Kansan glacial	None	0	Scouring of the Beaverdam sand.
		Aftonian interglacial	Beaverdam sand. Possibly an early deposit of the rising sea that formed the Coharie terrace at 215 ft. above sea level, and then fell to 170 ft. and formed the Sunderland terrace. (Bridgeton formation of New Jersey).	30–70±	Unconsolidated white to buff medium-grained sand, with small quantities of coarse to fine sand, occasional pebbles and granules, and a lesser admixture of white silt. Altitudes range from 48 ft. below sea level to 55 ft. above. Infiltration rate is high; gravity yield is relatively high; specific retention is low. Yields moderate to large quantities of water to properly developed wells, and small but adequate quantities of water to many driven wells. In much of the Beaverdam Creek drainage basin the water table lies in the Beaverdam sand.

		Nebraskan glacial	None	0	Trenching of the red gravelly sand.
Tertiary	Pliocene(?)	An alluvial fan, continental deposition.	Brandywine formation (Bryn Mawr gravel of Pennsylvania; Beacon Hill gravel of New Jersey).	0–70±	Slightly cemented red, orange, and brown gravelly sand. In conjunction with the Beaverdam sand, yields moderate to very large quantities of water to wells at Salisbury. Forms lower part of the unconfined ground-water reservoir; filled with latent stored water beneath the Beaverdam Creek drainage basin.
	Miocene	Marine sedimentation	Upper unit (lower aquiclude) of the Yorktown and Cohansey(?) formations.	100±	Gray and green clayey silt; blue clay of drillers. An aquiclude, forming the confining bed beneath the water-table reservoir of the Beaverdam Creek drainage basin.

The few exposures of the Beaverdam sand show truncated high-angle bedding, suggestive of the foreset beds of a delta, overlain by low-angle crossbeds. Wentworth (1930, p. 104) stated that "Fluvial materials of fine matrix are generally buff to dark red, whereas marine materials vary from white to cream yellow." On the basis of color, texture, and structure the Beaverdam sand probably is estuarine in part and possibly marine littoral in part. It has no fossils, however, to substantiate a marine origin.

Stratigraphically, the Beaverdam sand was deposited during the first interglacial stage, the Aftonian. It may be an early estuarine or marine phase of deposition in the rising sea that later formed a terrace (the Coharie) along the South Atlantic coast, 215 feet above the present sea level.

Hydrologically, the Beaverdam sand contains the water table, the fluctuations of which were measured in the driven observation wells in this study. Most of the wells used for observation tap the Beaverdam sand, in spite of the rather extensive covering of Walston silt in the drainage basin. The silt is thin in many places, and the wells were driven through it to the Beaverdam sand. The infiltration rates, gravity yield, and other ground-water properties determined in the budget are principally expressive of the Beaverdam sand. Beneath 2 or 3 square miles in the area of the Parsonsburg divide the Beaverdam sand is confined and its water is artesian. A few wells in the vicinity of Parsonsburg yield water from the Parsonsburg sand or sands in the Walston silt.

WALSTON SILT

The Walston silt is a lenticular silty sand, silt, and clayey-silt unit, containing some organic matter that covers the upper half of the Beaverdam Creek drainage basin, disconformably overlying the Beaverdam sand. It was named by Rasmussen and Slaughter (1955, p. 116) from its outcrop in Walston Branch, but, because exposures are poor, it was described in test hole Wi-Cg 40 as the type well. This well, whose altitude is 79 feet and which is 2 miles north of Parsonsburg, records the Parsonsburg sand, the Walston silt, and the Beaverdam sand, in closely spaced samples. The Walston silt is logged as 57 feet thick, between 10 and 67 feet above sea level. It is overlain unconformably by 12 feet of the Parsonsburg sand. The log of a second test hole that gives a detailed section of the Walston silt, 43 feet thick, is that for well Wi-Cg 38, altitude 80 feet, at Parsonsburg. In the environs of Walston Branch the silt ranges in thickness from 4 to 30 feet, as determined from many boreholes in the area. It occurs at a general altitude of 40 feet above sea level, in contact with the Beaverdam sand.

The Walston silt contains layers of dark organic clay and peat in the area of the Parsonsburg divide. Clark, Mathews, and Berry (1918, p. 320) report that wells drilled to a depth of 30 to 40 feet in the Parsonsburg-Pittsville area discovered marsh gas (methane) which was used for a time to illuminate homes.

Cooke (1952, p. 48, 49) cites a carbonaceous clay containing cypress stumps at the base of the Wicomico formation at an altitude of 30 feet in the excavation for the Mayflower Hotel in Washington, D. C. Diatoms found in this clay are correlative with others found in Pleistocene bog ponds from Massachusetts and Alabama. The bog deposits in the Walston silt beneath the Parsonsburg divide in Wicomico County could have been formed at the same time as the other carbonaceous deposits mentioned.

It is possible that the Walston silt is the remnant of a swamp deposit that was once extensive. That a low, flat land surface existed in Walston time at altitudes of 10 to 67 feet above present sea level may mean that Chesapeake Bay did not then exist. The swamp deposits are believed to have accumulated at the end of the second glaciation—that is, in the early phase of rising sea level, which reached a maximum of 100 feet above present sea level in Wicomico time.

The Walston silt yields small quantities of water to domestic wells driven in the sand lentils of the formation. A water table exists in places where the formation is sufficiently permeable, but in the clayey silt no free water surface has been recognized.

TALBOT AND PAMLICO FORMATIONS

The Talbot and Pamlico formations have not been positively identified in the Beaverdam Creek drainage basin, but it is probable that sediments of these formations compose narrow tongues of sandy silt in the valley of Beaverdam Creek, beneath Schumaker and Parker Ponds and portions of Walston Branch, at altitudes below 42 and 28 feet above sea level, respectively. These deposits, if they exist, are covered by Recent alluvium and so do not appear on the areal map (pl. 4). If present, they represent the interglacial stage, the Sangamon, just prior to the last great glaciation. However, it is possible that all the deposits were removed by rejuvenated streams, cutting valleys during Wisconsin time. The Pamlico formation has distinctive marine fossils (Richards, 1936) that have been found at Federalsburg, Md., and Lewes, Del., and if similar fossils were found in the lower valley of Beaverdam Creek they would indicate the presence of remnants of the deposits in ancient tidal estuaries of the Pamlico sea. Until drilling and collection of samples are warranted in these narrow valleys, the evidence for these formations will remain conjectural.

PARSONSBURG SAND

The Parsonsburg sand is the name assigned by Rasmussen and Slaughter (1955) to the deposits forming the rims and veneering a part of the floors of the "Maryland basins." The formation is named for Parsonsburg, a village on the highest part of the gentle divide between the Beaverdam Creek basin and the headwaters of the Pocomoke River.

The Parsonsburg sand is composed predominantly of poorly sorted brown medium-grained sand. The materials range in size from small boulders (rare) through cobbles, gravel, very coarse to very fine sand, and silt to clay. The texture of the Parsonsburg commonly is similar to that of the directly underlying material, but more heterogeneous. It is buff, tan, orange, or brown, but inclined to be dirty—that is, speckled with heavy minerals and clay aggregate. It has been modified in many places by soil-forming processes.

In composition the Parsonsburg sand consists of quartz grains in sand and silt sizes, and small quantities of clay, believed to have been derived chiefly from the earlier formations of the nearby area. The cobbles and boulders are chiefly of sandstone and small-pebble conglomerate, well cemented and approaching quartzite. In some pieces the cement is mainly silica; it some others it is ferruginous. The rocks resemble sandstone and ironstone from the nonmarine Cretaceous sedimentary rocks of the Western Shore of Maryland and northern Delaware and may have been derived, at least in part, from those areas.

No fossils have been found in the Parsonsburg sand in this area, although it is possible that the vertebrate remains reported by Cope (1869, p. 178) from Oxford Neck in nearby Talbot County came from the rim of one of the basins. Cope reported *Elephas primigenius*, *E. columbi*, *Cervas canadensis*, *Odocoileus virginianus*, *Chelydra serpentina*, and *Terrapene eurypygia*.

The Parsonsburg sand is distinguishable from the Walston silt by its coarser texture, and from the Beaverdam sand by its darker color. It resembles somewhat the red gravelly sand of the Brandywine formation, but in general it is not as gravelly, and the two are not in contact.

The Parsonsburg sand is a veneer deposit, strewn upon the older formations at all ranges in altitude from below sea level to the crest of the Parsonsburg divide. In different places it rests unconformably on each of the earlier formations of Pleistocene age. It is overlain only by soil, alluvium, peat, and possibly dune sand, all of the Recent series.

The Parsonsburg sand has been logged in many wells. It is easily recognized in a geologist's sample log but is overlooked in drillers' logs. The maximum logged thickness is 26 feet (Wi–Cd 34), but the average in 23 wells is 12 feet. The thickest sections are on the rims of Maryland basins. There are many fensters, or "windows," in the surface of the Parsonsburg sand, in the central parts of the larger "Maryland basins," in which the older formations, or their weathered soils, are exposed. The Parsonsburg, therefore, is logged as absent in some wells for which detailed sample descriptions are available.

The mapping of the Parsonsburg sand shown in plate 4 was based in large part on topographic expression, but the interpretation was assisted by information from aerial photographs, auger holes, and soil maps. There is no sharp line of demarcation in the field between the Parsonsburg sand and the earlier Pleistocene materials, so that the boundaries shown are somewhat arbitrary. The boundaries of the Parsonsburg sand in the rims of the depressions must be considered interpretive, and general rather than detailed. However, there is a fairly sharp break between the Parsonsburg sand and underlying formations, which can be seen readily in well logs that are based on closely spaced samples. Therefore the distribution of the Parsonsburg in any locality can be worked out in detail, should the occasion warrant, by careful and fairly closely spaced test borings to depths of at least 35 feet.

The genesis of the Parsonsburg sand is a part of the same mystery as that of the "Maryland basins." The presence of erratic boulders and cobbles indicates that ice rafting played some part in the sedimentation, but their rarity indicates that it was a small part. In age the Parsonsburg sand is Sangamon or post-Sangamon, because in nearby areas it rests on members of the Pamlico formation.

Part of the deposition of the rim could have occurred during the temporary rise of sea level accompanying the deposition of the Peorian loess (deposited in early Wisconsin time and named for exposures of loess near Peoria, Ill.). The rise would have had to be great enough to bring deposits up to 85 feet in altitude.

The stranding of icebergs, as sea level fell with the advent of Wisconsin glaciation, is suggested as the mode of deposition. The hypothesis of stranded icebergs as the result of a tidal flood has been advanced by Kelly and Dachille (1953), but this implies a cataclysm, an implication which is not necessary in the view of the author. The deposit is regarded as a stratified drift, and the "Maryland basins" as kettleholes on a marine plain. The authors are uncertain whether the low, dunelike hills that cap the rims in places represent an episode of wind activity in latest Pleistocene or in Recent time or represent overlapping original deposits.

Hydrologically, the Parsonsburg sand is generally unsaturated and so lies in the zone of aeration, or vadose zone. In places, however, the water table lies in the Parsonsburg. The sand is porous and permeable, and admits infiltration readily. Where the Walston silt immediately underlies the Parsonsburg sand, subdrainage is usually slow, and ground-water discharge occurs to the centers of the "Maryland basins," and to the areas outside the basins and their rims. Because many of the "basins" are fairly well drained by Recent streams, ground water discharges by seeping to the heads of the streams.

RECENT SERIES

The Recent series of sediments in the Beaverdam Creek drainage basin consists of thin deposits whose water-bearing capacity is limited. The only unit of the Recent series shown on the geologic map is the alluvium that occupies the narrow valleys of Beaverdam Creek and its tributaries (with the exception of their headward extensions, which are actively eroding the Pleistocene deposits, and have not aggraded their channels). The Recent series includes also soils, peat, manmade fill, and, possibly, dunes.

The alluvium rests unconformably on the formations of Pleistocene age and probably is not more than 10 feet thick, although wells have not been drilled in the valleys to determine the maximum thickness. Presumably the alluvium rests upon, and masks completely, the Talbot and Pamlico formations, but this presumption is based on geological reasoning, not on observation.

The possibility that some of the low dunelike features in the Beaverdam Creek drainage basin are of Recent origin was mentioned in the previous section, but the authors consider it more likely that they are features of the Pleistocene epoch.

The soils of the Beaverdam Creek drainage basin are the most important units of the Recent series. They are thin, the zone affected by soil-forming processes ranging in thickness from 1 to 4 feet. They are predominantly sandy and silty loams of good infiltration capacity but relatively low fertility. Some peaty soils are found near the centers of the "Maryland basins." In places the soils have been waterlogged, chiefly in the lower parts of "basins" on the broad divides, but many of these sites have been drained by creeks or canals.

Manmade fill is of slight but increasing importance as a part of the Recent series. The Salisbury airport was constructed by grading, and in the process the rims of small "Maryland basins" have been smoothed over, and their material scraped into the heads of the gullies that once drained the area. The highway grades in the last few years also have tended to obliterate basin and rim features. No attempt to map fill was made in this study because it still forms such an insignificant part of the total, and once vegetation is established, detailed test boring is required to outline it.

INFLUENCE OF GEOLOGIC FEATURES ON THE HYDROLOGIC BUDGET

The Beaverdam Creek drainage basin was selected for hydrologic study for several reasons: Its sandy soil promised a high infiltration rate; its homogeneous sediments facilitated observations of fluctuations of ground-water level; it was underlain by a sizable ground-water reservoir with sufficient vertical relief to permit ready discharge of ground water; and the bed of Miocene age, called blue clay by drillers, that underlay the water-table sands provided an adequate confining bed to impede downward leakage from the basin.

The first requisite, a sandy surface soil and subsoil, is abundantly fulfilled. Table 5 shows the texture of sediments representing the zone within about the first 20 feet below the land surface. These percentages are based on samples from 58 holes in and on the borders of the Beaverdam Creek drainage basin, comprising 1,144 feet of hole.

The ratio of sandy to clayey sediments in the sedimentary deposits of the world has been variously estimated at 1:1 to 1:6 (Pettijohn, 1949, p. 3–6). In the Beaverdam Creek drainage basin, however, the sand outweighs the silt and clay deposits by a ratio of 3:2.

TABLE 5.—*Texture of surficial sediments in the Beaverdam Creek basin*

	Percent	Class	Percent
Loam	3.4	Soil	3.4
Coarse sand	6.5		
Medium-grained sand	33.0		
Fine sand	2.1	Sand	61.5
Silty sand	8.6		
Unclassified sand	11.3		
Sand and silt	5.5		
Sandy silt	8.4	Silt	21.5
Clayey silt	4.1		
Unclassified silt	3.5		
Silty clay	4.0	Clay	13.6
Clay	9.6		
Total	100.0		100.0

The second requisite, that the sediments be homogeneous, may appear on first glance not to be fulfilled, in view of the presence of gravelly sand (Brandywine), medium-grained sand (Beaverdam), silty sand, silt, and clayey silt (Walston), and dirty sand (Parsonsburg). However, in comparison with the sedimentary rocks of the world as a whole, these sediments of the Beaverdam Creek basin are fairly homogeneous. The veneer of Parsonsburg sand gave the impression, during the initial geological reconnaissance, that all the sediments above the Miocene were a single formation. Only detailed study by means of test boring and soil mapping revealed the departures from homogeneity that finally were recognized. These differences are not trifling, and yet they are not serious. Study of other localities of comparable size indi-

468445—59——4

cates that most are much more complex, and that there are relatively few ground-water basins as homogeneous at this one.

The third requisite, for an adequate ground-water reservoir beneath an area of sufficient topographic relief, is fulfilled by the Beaverdam sand in combination with the Brandywine formation. The relief of the Beaverdam Creek drainage basin, about 65 feet (from 85 feet along the Parsonsburg divide to 20 feet at the spillway of Schumaker Pond), is exceptionally large for a small basin in the central Coastal Plain, and it provides ample avenues for the discharge of excess ground water.

The fourth requisite, an effective lower confining bed, is satisfied by the lower aquiclude, a silt-clay bed in the unit identified as the Yorktown and Cohansey(?) formations of Miocene age.

THE HYDROLOGIC BUDGET

The measurement of "water gains," "water losses," and storage changes in a hydrologic basin involves several important considerations. These are: (1) density of precipitation gages, (2) stream-gaging control, (3) fluctuations of surface-water levels and changes in surface storage, (4) changes in soil-moisture content, (5) density of observation wells, and (6) measurement of pan evaporation. These items, in relation to the Beaverdam Creek basin, are described separately in the following sections.

The purpose of the budget, as mentioned previously, is to equate the water gains to the water losses, plus or minus the changes in storage of water in all forms, for each period of measurement.

INSTRUMENTATION

The instrumentation for this water-budget study was designed to be adequate but simple, because of restrictions on personnel and funds. The instruments may be grouped into nine categories according to use: topographic mapping and surveying, observation wells, geologic exploration, water-temperature and water-quality investigation, precipitation measurement and other weather observations, surface-water measurement, soil-moisture measurement, transportation, and computation.

For topographic mapping and surveying, the following were used: compass, hand level, telescopic level and rod, planetable, alidade and stadia rod, aerial photographs, 2 stereoscopes, topographic maps of 4 quandrangles, an aerial camera, drafting equipment, a planimeter, and a map measurer.

For installation of the 25 observation wells, about 600 feet of 1-inch pipe, well points, pipe vise, cutter and threader, well-driving sleeve and cap, 8-, 10-, and 12-inch wrenches, and 2 hand augers were used. A pitcher pump and portable air compressor with 30 feet of ½-inch rubber hose were used for well development. For measurement of the water levels, 25- and 50-foot steel tapes and 1 weekly float-type automatic water-stage recorder were used.

For geologic exploration, a truck-mounted auger capable of boring 100 feet in unconsolidated materials was used. A hand lens and a binocular microscope were used to study samples. And a thermohm meter and resistance bridge were used to measure water temperature. Large water samples were collected in gallon bottles, and small samples in citrate bottles (about 13 ounces).

Precipitation was measured with 12 rain gages. Daily weather observations were made with a U. S. Weather Bureau 4-foot class-A evaporation pan fitted with a point gage, an anemometer, an aneroid barometer, a wet-dry-bulb thermometer pair for humidity, a hand-cranked fan for use in the humidity measurements, and a maximum-minimum thermometer pair. Soil moisture was determined with 9 plaster Bouyoucos blocks containing electrodes and lead wires, set at 3 different depths at each of three sites and measured weekly with a Wheatstone bridge and an audio-amplifier; soil temperatures were measured at each site by means of a buried thermistor. Samples of soil were calibrated with 9 similar blocks, each set in inner and outer cans, weighed with a precise scale and weights.

Surface-water outflow was measured at the lower end of Schumaker Pond by calibrating the sharp-crested weir at the outlet, a Price current meter being used to measure the flow and a gage in the pond to measure the stage. A continuous record of stage in the pond was obtained by using a recording gage. Channel storage was computed from the stage readings at the Schumaker Pond and from readings on stage gages at Parker Pond and at four points in the stream channel upstream. The survey of the capacity of the two ponds was made by using two rowboats, an outboard motor, sight poles, 300 feet of beaded wire cable, and sounding leads.

Transportation was provided by an automobile and a half-ton pickup truck. A light airplane was chartered for two flights. Computation was aided by an adding machine, a calculator, and slide rules.

Not all the equipment used would be necessary in every similar investigation, but the same purposes would have to be met.

Personnel who used this equipment at various stages of the investigation included a geologist-surveyor, a geologist auger operator and well driver, a hydraulic engineer, a mathematician, an engineering aide, two hydrologic field assistants, and two laborers, none of them employed full time. Minimum personnel for a similar operation, assuming no time limit, would consist of one professional hydrologist and one subprofessional aide.

SURVEYING

The hydrologic budget depends upon a fairly precise calculation of the area of the drainage basin. This calculation requires recognition of the divides, both surface and ground-water. These divides must be delineated on maps, so that the area can be plotted and measured.

The Beaverdam Creek basin has been mapped by the U. S. Corps of Engineers, on scales of 1: 24,000 and 1: 31,680, from U. S. Coast and Geodetic Survey control by photoplanimetric and planetable methods. The contour interval is 20 feet, which in this relatively flat area is too large to permit selection of the stream divides with accuracy. In the field, the land is so nearly flat in many of the divide areas that it is difficult to place the position of the divide by eye, within a margin of ¼ to ½ mile. To assist in defining the divides, third-order level profiles were run over several lines. Secondary control was developed at many intermediate points by field reconnaissance with a hand level from known bench marks, or road traverses. Using aerial-photographic control, maps of the basin were drawn with contours on a 5-foot interval, and the interstream divides were marked.

Third-order level lines were run also between observation wells and staff gages to establish the elevations of the measuring points to the nearest hundredth foot; about 33 miles of third-order leveling was done. These fiducial points served as control for preparing maps of the water table.

OBSERVATION WELLS

Twenty-five observation wells were driven within the Beaverdam Creek basin, each well thus representing an average of slightly less than 1 square mile. The wells, ranging in depth from 9 to 26 feet, were constructed of 1-inch galvanized pipe with a 2-foot sand-point screen. The pipes, with sand points attached, were placed in holes augered to the water table and then driven several feet. Each well was developed by introducing compressed air and later pumped with an ordinary pitcher pump. To help protect the wells from damage, the pipes were provided with caps, through which breather holes were drilled to permit normal ground-water fluctuation. Also, the exposed pipes were painted a bright yellow and were provided with identification plates so that they were clearly visible to operators of vehicles and farm equipment.

Good areal distribution and accessibility generally dictated the choosing of well sites, but when accessibility conflicted with good distribution, the accessible site was nearly always chosen in order to keep the cost of measurement down. Plate 1 shows the location and distribution of the observation wells and fig. 4 shows the hydrograph of the average ground-water level.

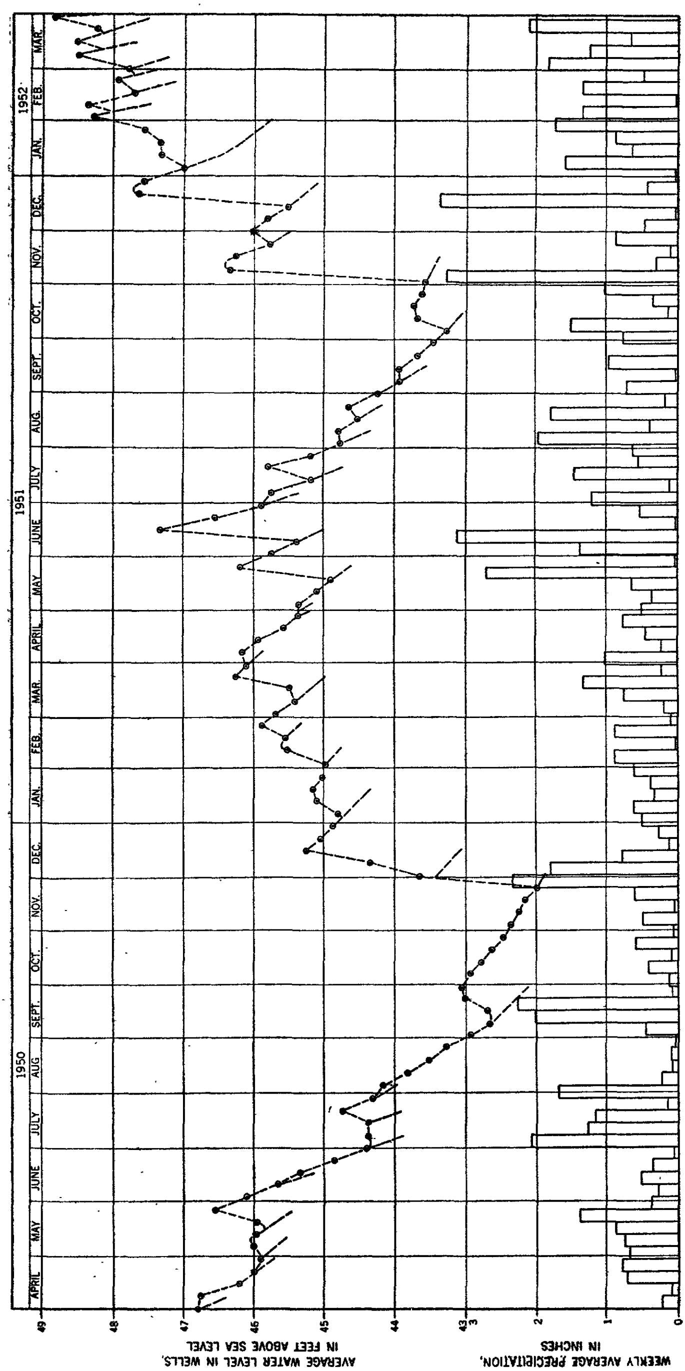


FIGURE 4.—Hydrograph of average ground-water level and bar graph of weekly average precipitation.

In general, the wells farthest from the central stream channel and highest in the basin had to be driven deepest. Greater water-level fluctuations occur in the upper reaches of the basin; the smallest fluctuations occur near the basin outlet. The highest average water level (a simple arithmetic average for the 25 wells) during the two years was 48.83 feet above mean sea level and the lowest average water level was 41.98 feet. The average depth to the water table below the land surface fluctuated from about 4.5 feet (on March 28, 1952) to about 11.5 feet (on November 24, 1950), a range of approximately 7 feet. The greatest depth to water was 18.83 feet (well 119, November 24, 1950) and the shallowest depth to water was 0.33 foot (well 118, March 28, 1952). (See table following.)

In addition to the 25 observation wells within the basin, 8 wells were driven outside the basin for the purpose of detecting any migration of the ground-water divide. However, these wells proved to be too few and too far apart to define the ground-water profile adequately.

WATER LEVELS AND BAROMETRIC PRESSURE

In addition to the small-diameter observation wells, one 16-inch well 109 feet deep at the Salisbury municipal airport was equipped with an 8-day automatic water-level recorder and a continuous record obtained during the 2-year period. This deeper well is 6 feet from observation well 132, which is only 11.5 feet deep. The recorded fluctuations of the water level in the deeper drilled well were essentially the same as those in the shallow driven observation well; however, the trace made by the pen of the recording instrument on well 132 indicated some response to changes in barometric pressure.

Because it appeared likely that some of the shallow observation wells were responding in some degree to barometric changes, owing to variation in the texture of sediments penetrated in the wells that permitted transient semiartesian conditions to exist, six wells were selected for brief tests of the water-level behavior. The water levels in these wells (nos. 104, 105, 106, 107, 109, 132) were measured twice an hour for 8 hours; at the same time, pressure readings from an aneroid barometer were noted.

The plots of the barometric pressures, inverted and expressed in feet of water, were superimposed upon the individual hydrographs. The graphs of wells 104 and 109 indicated a small degree of influence of barometric pressure upon the water levels, but in the other four wells no water-level response to pressure was apparent. The barometric effect in wells 104 and 109 was not large enough to warrant use of a factor to correct for extremes of pressure.

Water levels in observation wells in the Beaverdam Creek basin

[In feet above mean-sea-level datum]

Well No.	1950																				
	April				May				June					July				August			
	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25
102	30.51	30.38	30.33	30.27	30.05	30.04	29.97	30.25	30.19	30.20	30.26	29.89	29.76	29.65	29.57	29.89	29.64	29.54	29.42	29.37	29.15
103	38.14	37.44	37.02	36.80	37.09	36.85	37.36	38.79	37.61	37.01	36.81	36.19	35.86	35.81	36.96	36.87	36.28	35.91	35.67	35.37	35.13
104	43.76	42.84	42.27	42.11	43.08	42.51	42.95	44.44	42.87	41.92	41.49	40.68	39.96	40.91	41.70	42.67	41.45	41.16	40.46	39.79	39.21
106	45.08	44.25	43.65	43.49	44.24	43.67	43.89	45.04	44.02	42.97	42.44	41.42	40.70	41.22	41.84	43.56	42.25	41.62	41.02	40.41	40.23
108	35.72	35.13	34.87	34.72	34.92	34.73	35.10	36.08	35.18	34.77	34.69	34.20	33.94	33.91	33.92	34.25	34.22	33.99	33.79	33.61	33.42
109	28.30	28.25	28.33	28.22	27.99	28.03	27.99	28.13	28.21	28.28	28.10	28.01	27.88	27.84	27.69	27.81	27.68	27.65	27.51	27.41	27.37
110	43.28	42.66	42.42	42.22	42.67	42.37	42.47	43.31	42.48	41.78	41.57	40.85	40.28	40.44	40.74	41.96	41.21	40.74	40.28	39.91	39.56
111	46.76	46.11	45.88	45.82	45.91	45.71	45.73	46.54	45.92	45.19	44.81	43.96	43.39	43.40	43.58	45.00	44.38	43.76	43.29	42.83	42.54
112	36.30	35.84	35.49	35.23	35.06	35.01	34.96	35.45	35.45	35.28	35.24	34.77	34.56	34.52	34.39	34.80	34.55	34.60	34.22	34.06	33.89
113	29.93	29.79	29.68	29.35	29.40	29.33	29.30	29.45	29.55	29.58	29.64	29.25	29.14	29.04	28.95	29.15	29.02	28.95	28.85	28.75	28.87
114	20.59	20.50	20.48	20.44	20.39	20.38	20.31	20.35	20.25	20.29	20.33	20.11	20.04	20.28	19.94	20.05	19.96	20.05	19.90	19.85	19.79
116	46.25	45.33	44.84	44.58	44.66	44.91	44.70	46.22	45.22	44.53	44.18	43.39	42.89	42.91	42.72	43.32	42.83	42.64	42.31	41.97	41.65
118	49.10	48.49	48.21	48.37	48.30	48.27	48.20	48.88	48.33	47.70	47.38	46.61	45.96	45.77	45.57	45.84	45.49	45.31	44.97	44.65	44.61
119	57.82	56.82	56.04	56.13	56.58	56.23	56.01	56.90	56.22	55.38	54.84	53.83	53.17	53.43	53.24	54.04	53.56	53.07	52.56	51.94	51.35
120	78.18	77.85	77.76	77.66	77.51	77.53	77.47	77.75	77.67	77.46	77.44	77.07	76.85	76.00	76.69	76.70	76.44	76.60	76.19	75.98	75.75
121	50.22	49.83	49.51	49.48	49.67	49.69	49.66	49.97	49.72	49.16	48.58	48.09	47.49	47.18	46.96	47.05	46.71	46.43	46.07	45.69	45.32
122	77.57	77.18	77.32	77.42	77.37	77.16	77.19	77.53	77.15	76.89	75.91	76.50	76.12	76.09	75.98	76.16	75.75	76.13	75.63	75.27	74.95
123	74.90	74.53	74.69	74.73	74.74	74.56	74.59	74.63	74.30	74.09	74.19	73.63	73.21	73.42	73.22	73.20	72.69	72.98	72.35	72.02	71.74
125	51.93	51.35	50.89	50.75	51.07	51.25	51.16	51.23	51.08	50.62	50.19	49.38	48.53	47.98	47.63	47.44	47.09	46.74	46.43	46.04	45.63
126	50.59	50.17	50.70	50.63	49.92	50.14	50.04	50.12	49.95	49.42	49.05	48.18	47.38	46.88	46.51	46.36	46.03	45.73	45.39	45.01	44.63
128	47.51	46.88	46.42	46.19	46.29	46.66	46.40	47.07	46.76	46.12	45.57	45.15	44.74	44.45	44.25	44.16	43.93	43.78	43.57	43.36	43.16
129	48.02	47.59	47.22	47.16	47.29	47.48	47.45	48.07	47.59	47.14	46.60	46.18	45.63	45.31	45.07	45.05	44.76	44.56	44.21	43.87	43.60
130	36.57	36.15	35.76	35.63	35.49	35.52	35.39	35.92	36.03	35.72	35.00	35.27	34.97	34.78	34.62	34.60	34.45	34.39	34.25	34.11	34.01
132	38.60	37.50	37.88	37.76	37.93	37.75	37.86	38.81	38.01	37.73	37.65	37.21	36.94	37.40	37.42	38.11	37.47	37.30	36.98	36.78	36.97
133	62.92	62.43	62.21	62.44	62.59	62.61	62.58	62.87	62.36	61.92	61.58	61.09	60.69	60.34	60.20	60.18	59.95	59.99	59.84	59.56	59.25
Average	46.74	46.21	45.99	45.90	46.01	45.94	45.95	46.55	46.08	45.65	45.34	44.84	44.40	44.36	44.37	44.73	44.31	44.14	43.81	43.50	43.27

Water levels in observation wells in the Beaverdam Creek basin—Continued

Well No.	1950																	1951		
	September					October				November				December				January		
	1	8	15	22	29	8	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19
102	29.03	28.86	28.79	28.75	28.56	28.49	28.39	28.29	28.16	28.08	27.96	27.87	27.70	27.82	27.83	28.12	28.16	28.15	27.97	28.02	29.76
103	34.86	34.59	34.67	35.85	35.77	35.40	35.00	34.58	34.28	33.99	33.73	33.50	33.34	34.03	34.36	35.56	35.61	35.54	35.45	35.80	35.87
104	38.89	38.48	38.47	39.03	38.76	38.38	38.14	37.97	37.80	37.67	37.50	37.34	37.18	39.87	41.35	34.39	42.43	41.95	42.15	42.72	42.47
106	39.38	38.94	38.92	39.87	39.54	39.06	38.75	38.58	38.36	38.24	38.07	37.97	37.74	41.14	42.59	44.52	43.71	43.05	43.24	43.93	43.39
108	33.22	33.03	32.98	33.06	33.14	33.76	32.90	32.81	32.77	32.70	32.64	32.58	32.49	33.30	33.54	34.63	34.56	34.36	34.30	34.68	34.59
109	27.14	27.00	26.87	26.78	26.72	26.88	26.61	26.54	26.47	26.38	26.30	26.22	26.10	26.14	26.16	26.26	26.39	26.43	26.43	26.48	26.51
110	39.13	38.80	38.93	39.70	39.55	39.30	39.12	38.96	38.84	38.72	38.60	38.53	38.40	40.60	41.99	42.71	42.17	41.87	42.07	41.49	42.29
111	41.93	41.53	41.55	41.92	42.38	42.10	41.82	41.59	41.39	41.28	41.16	41.03	40.82	44.10	45.21	46.26	45.71	45.28	45.33	45.72	45.46
112	33.72	33.54	33.40	33.43	33.32	33.26	33.19	33.12	33.04	32.98	32.92	32.86	32.75	33.22	33.38	34.10	34.28	34.30	34.11	34.28	34.33
113	28.54	28.44	28.35	28.33	28.29	28.26	28.24	28.19	28.15	28.11	28.07	28.04	27.97	28.17	28.22	28.52	28.69	28.74	28.68	28.74	28.79
114	19.47	19.38	19.18	19.37	19.47	19.48	19.49	19.48	19.44	19.41	19.39	19.38	19.31	19.41	19.43	19.55	19.64	19.69	19.60	19.68	19.67
116	41.34	41.03	40.89	41.26	41.45	41.16	41.25	40.81	40.70	40.61	40.51	40.42	40.26	42.33	43.46	45.17	44.32	43.80	43.66	44.23	44.11
118	43.99	43.68	43.68	44.22	44.11	43.97	43.80	43.63	43.51	43.44	43.34	43.26	43.13	45.66	47.01	48.33	47.80	47.48	47.53	48.66	47.86
119	50.88	50.38	50.49	51.88	52.78	52.23	51.68	51.39	51.08	50.92	50.62	50.47	49.20	55.74	57.95	57.81	57.10	56.70	57.13	57.47	57.30
120	75.51	75.25	75.45	75.65	75.74	75.58	75.42	75.28	75.16	75.06	74.98	74.90	74.82	76.06	76.41	76.85	76.86	76.82	76.00	76.91	76.86
121	44.97	44.62	44.71	44.79	44.92	44.89	44.80	44.62	44.47	44.42	44.28	44.18	43.99	46.02	47.00	48.30	48.22	48.06	48.08	48.37	48.44
122	74.63	74.44	74.93	75.15	75.57	74.34	75.18	75.98	74.88	74.75	74.68	74.58	74.53	76.63	76.98	77.02	76.82	76.79	76.01	76.94	76.92
123	71.38	71.15	71.75	72.23	72.36	72.18	72.04	71.82	71.76	71.59	71.58	71.48	71.50	73.14	73.84	74.04	73.90	73.89	73.89	74.03	74.07
125	45.31	44.93	44.82	44.88	45.18	45.24	45.11	44.96	44.70	44.62	44.45	44.36	44.15	45.75	46.65	48.46	48.59	48.48	48.28	47.68	47.88
126	44.28	43.92	43.82	43.76	43.95	43.88	43.75	43.65	43.45	43.36	43.21	43.12	42.96	44.23	45.08	46.86	46.98	46.84	46.74	47.17	47.36
128	42.98	42.78	42.79	42.74	42.64	42.55	42.49	42.39	42.31	42.28	42.26	42.12	42.07	42.84	43.27	44.45	44.59	44.46	44.28	44.55	44.62
129	43.21	42.93	42.84	43.04	42.94	42.77	42.67	42.54	42.44	42.34	42.26	42.18	42.06	43.55	44.55	46.06	45.89	45.67	45.47	45.82	45.86
130	33.89	33.76	33.66	33.63	33.63	33.60	33.56	33.51	33.43	33.38	33.33	33.27	32.97	33.70	33.81	34.47	34.54	34.42	34.23	34.30	34.34
132	36.41	36.23	36.29	36.92	36.44	36.23	36.14	36.04	35.96	35.92	35.84	35.74	35.67	36.81	37.97	38.18	37.75	37.53	37.46	37.85	37.75
133	58.95	58.73	58.80	58.91	59.56	59.69	59.17	58.95	58.82	58.71	58.62	58.55	58.46	60.28	60.54	61.42	61.26	61.12	61.32	61.54	61.59
Average	42.92	42.66	42.68	43.01	43.07	42.91	42.75	42.63	42.45	42.36	42.25	42.16	41.98	43.62	44.34	45.24	45.04	44.86	44.78	45.08	45.13

Well No.	1951																				
	January	February				March					April				May				June		
	26	2	9	16	23	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15
102	28.06	28.02	28.16	28.29	28.40	28.50	28.57	28.62	28.82	28.89	28.90	28.99	28.93	28.93	28.96	28.89	28.75	28.95	29.16	29.18	29.39
103	35.82	35.73	36.45	36.45	36.97	36.66	36.37	36.35	37.74	37.49	37.42	37.05	36.51	36.39	36.41	36.16	35.89	38.16	37.08	36.70	40.15
104	42.40	42.15	43.56	43.03	43.68	42.70	42.10	42.58	44.42	43.44	43.51	42.80	41.97	41.66	41.93	41.37	41.07	44.50	42.47	41.83	44.93
106	43.32	43.03	44.33	44.03	44.56	44.92	43.32	43.47	45.19	44.51	44.62	43.66	43.39	42.90	43.05	42.39	42.18	44.62	43.63	42.81	45.71
108	34.49	34.38	34.99	34.74	35.19	34.94	34.67	34.66	34.72	35.34	35.33	35.05	34.71	34.53	34.54	34.38	34.23	35.40	34.99	34.63	36.35
109	26.56	26.55	26.62	26.72	26.82	26.97	27.08	27.15	27.22	27.27	27.37	27.47	27.49	27.37	27.49	27.42	27.30	27.38	27.51	27.56	27.76
110	42.16	41.95	42.89	42.57	42.96	42.46	42.11	42.41	43.37	42.86	43.02	42.63	42.26	41.96	41.97	41.58	41.40	43.40	42.27	41.87	43.78
111	45.37	45.16	45.80	45.78	46.15	45.74	45.32	45.47	46.57	46.08	45.89	45.93	45.52	45.18	45.13	44.63	44.41	46.27	45.65	45.11	47.25
112	34.39	34.32	34.50	34.70	34.97	35.10	34.95	34.85	35.32	35.50	35.44	35.42	35.06	34.94	34.80	34.69	34.56	35.13	35.49	35.32	38.81
113	28.86	28.87	28.96	29.01	29.14	29.27	29.31	29.32	29.38	29.47	29.51	29.58	29.51	29.44	28.99	29.26	29.20	29.46	29.62	29.64	30.43
114	19.72	19.68	19.73	19.77	19.82	19.89	19.89	19.90	19.99	20.06	20.06	20.08	20.06	20.04	20.07	19.99	19.96	20.06	20.17	20.17	20.69
116	43.91	43.56	44.83	44.81	45.18	44.73	44.16	44.06	45.93	45.31	45.31	44.88	44.27	43.92	43.95	43.61	43.52	47.08	45.69	44.76	47.99
118	47.64	47.62	48.33	48.41	48.56	48.16	47.82	47.87	48.86	48.49	48.67	48.33	47.93	47.61	47.58	47.20	47.11	48.98	48.18	47.62	49.52
119	57.22	57.11	57.52	57.63	58.02	57.35	56.84	57.19	58.25	57.77	57.85	57.68	56.57	55.95	55.84	55.12	54.85	56.82	56.38	55.51	58.51
120	76.95	76.84	77.12	77.22	77.35	77.35	77.21	77.25	77.61	77.59	77.54	77.57	77.36	77.27	77.16	77.08	76.99	77.68	77.53	77.40	78.29
121	48.42	48.33	48.80	49.00	49.35	49.16	48.89	48.92	49.61	49.57	49.70	49.53	49.18	48.89	48.75	48.53	48.31	49.19	49.09	48.58	50.36
122	76.85	77.07	77.18	77.22	77.30	77.10	76.94	77.11	77.46	77.30	77.33	77.14	77.01	77.03	76.83	76.73	76.60	77.53	76.98	76.93	77.67
123	74.12	74.21	74.33	74.33	74.46	74.32	74.16	74.35	74.67	74.56	74.61	74.43	74.31	74.37	74.21	74.21	73.98	74.84	74.33	74.36	74.96
125	47.90	48.73	49.23	49.73	50.16	50.11	49.77	49.74	50.66	50.79	50.90	50.72	50.26	49.98	50.15	49.65	49.33	49.83	49.14	49.55	51.88
126	47.43	47.24	47.87	48.42	48.86	48.84	48.51	48.44	49.41	49.49	49.66	49.43	49.05	48.75	48.90	48.32	48.04	48.63	49.04	48.36	50.86
128	44.67	44.59	45.32	45.62	46.06	45.91	45.52	45.45	46.60	46.56	46.64	46.44	45.81	45.53	45.50	45.24	44.92	45.94	45.85	45.41	48.41
129	45.89	45.82	46.57	46.74	47.02	46.80	46.44	46.49	47.59	47.41	47.53	47.28	46.80	46.61	46.61	46.37	46.06	47.46	47.01	46.53	48.60
130	34.37	34.26	34.49	34.77	34.89	35.06	34.93	34.87	35.28	35.52	35.45	35.59	35.21	35.07	35.01	34.89	34.71	34.88	36.39	35.23	37.70
132	37.65	37.67	38.41	38.06	38.48	38.03	37.72	37.84	38.96	38.36	38.42	38.11	37.72	37.57	37.61	37.45	37.24	39.68	38.17	37.99	40.05
133	61.60	61.61	62.00	62.04	62.27	62.00	61.82	62.03	62.64	62.32	62.63	62.31	62.16	62.11	61.81	61.78	61.74	62.79	62.11	61.64	62.94
Average	45.03	44.98	45.52	45.56	45.86	45.68	45.38	45.46	46.25	46.08	46.13	45.92	45.56	45.36	45.33	45.08	44.89	46.19	45.72	45.39	47.32

Water levels in observation wells in the Beaverdam Creek basin—Continued

Well No.	1951																				
	June		July				August					September				October				November	
	22	29	6	13	20	27	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9
102	29.89	29.89	29.85	29.72	29.54	29.45	29.37	29.22	29.11	29.06	28.95	28.83	28.70	28.65	28.58	28.45	28.35	28.47	28.30	28.23	28.50
103	37.98	37.68	36.86	36.40	37.06	36.48	36.23	36.01	35.77	36.49	35.95	35.57	35.58	35.19	35.00	34.84	34.75	33.66	34.58	34.57	37.00
104	43.16	42.16	41.94	41.04	43.21	41.82	41.42	41.39	40.67	43.53	40.95	40.67	40.04	39.60	39.40	39.09	39.63	39.30	39.15	38.88	44.54
106	44.40	43.18	43.08	41.83	43.99	42.71	41.83	40.64	41.28	42.38	41.30	40.69	40.90	40.06	39.76	39.42	39.88	39.83	39.60	39.45	45.28
108	35.35	34.82	34.59	34.20	34.74	34.37	34.14	34.05	33.91	34.39	34.07	33.83	33.74	33.64	32.70	33.13	33.44	33.42	33.37	33.30	35.26
109	28.01	28.14	28.10	27.96	30.88	28.14	27.64	27.54	27.44	26.59	27.44	27.32	27.15	27.26	27.15	27.69	27.03	26.97	26.90	26.81	27.01
110	42.66	41.79	41.63	40.90	42.02	41.27	40.76	40.79	40.71	40.60	40.17	38.95	39.80	39.51	39.26	39.09	39.50	39.45	39.59	39.38	43.05
111	46.31	45.43	45.45	44.41	45.64	44.79	44.05	44.01	43.79	43.46	43.10	42.61	42.59	42.23	41.85	41.76	42.19	42.15	42.17	42.02	46.56
112	37.41	36.52	36.41	35.90	37.05	35.93	35.52	35.20	34.94	34.80	34.59	34.38	34.19	34.17	34.13	34.11	33.88	33.90	33.51	33.77	35.70
113	30.58	30.45	30.29	30.05	30.34	30.09	29.84	29.67	29.50	29.42	29.37	29.24	29.13	29.12	29.08	29.09	28.87	28.84	28.87	28.79	29.52
114	20.81	20.76	20.66	21.35	20.49	20.36	20.29	20.17	19.08	19.73	20.01	19.92	19.77	19.83	19.78	19.76	19.75	19.79	19.45	19.66	19.90
116	46.86	45.65	46.18	44.86	46.68	44.79	44.01	43.77	43.31	43.42	43.15	42.48	42.83	42.42	42.25	42.09	42.60	42.41	42.06	41.99	47.12
118	48.68	47.88	48.21	47.21	47.62	47.05	46.50	46.37	46.17	46.15	45.73	45.47	45.68	45.02	44.82	44.78	45.24	45.14	45.01	45.10	49.23
119	57.15	55.93	56.27	55.00	56.03	55.34	54.49	54.73	54.37	53.85	53.17	52.57	52.82	51.74	51.57	51.50	51.76	52.05	51.84	51.79	57.75
120	78.03	77.73	77.62	77.29	78.71	77.39	77.14	77.60	77.38	77.12	76.94	76.70	76.57	76.53	76.09	76.06	76.61	76.66	76.81	76.64	77.81
121	49.84	49.10	49.00	48.16	48.25	47.96	47.46	47.79	47.70	47.43	46.77	46.55	46.64	46.19	46.05	46.02	46.26	46.58	46.50	46.42	49.24
122	77.12	76.81	76.73	76.26	76.43	76.77	76.33	76.95	76.61	76.42	76.08	75.81	75.73	75.93	75.72	75.62	76.45	76.39	76.45	76.54	77.60
123	74.75	74.09	73.79	73.34	73.61	73.66	73.24	73.72	73.30	73.13	72.74	73.25	72.71	72.61	71.72	71.76	73.33	73.24	73.23	73.49	74.66
125	51.14	50.19	49.55	48.77	48.96	48.72	48.26	48.34	47.85	47.84	47.41	46.94	46.95	46.49	46.37	46.47	46.59	47.33	47.33	46.93	50.13
126	50.12	49.15	48.55	47.72	47.59	47.43	46.96	47.30	47.12	46.79	46.34	45.53	45.87	45.52	45.45	45.23	45.27	45.43	45.62	45.51	48.92
128	47.33	46.42	46.05	45.42	45.04	44.73	44.46	44.29	44.16	44.75	44.20	44.04	44.07	43.89	43.84	43.73	43.63	43.83	43.74	43.57	46.78
129	47.80	47.11	46.84	46.21	46.02	45.77	45.36	45.73	45.38	45.60	45.10	44.80	44.71	44.62	44.61	44.63	44.74	44.83	44.66	44.60	47.78
130	36.90	36.37	36.06	36.19	35.39	35.45	35.09	34.91	34.77	34.92	34.70	34.59	34.49	34.60	34.47	34.41	34.28	34.47	34.32	34.29	36.21
132	38.79	38.17	38.12	37.70	38.01	37.73	37.52	37.72	37.72	37.19	37.02	36.89	36.73	36.43	36.65	37.12	36.99	37.77	36.55	36.58	59.71
133	62.20	61.52	61.32	60.74	61.39	61.12	60.81	61.50	61.08	60.81	60.49	60.32	60.27	60.19	60.23	55.45	60.28	60.65	60.49	60.71	62.42
Average	46.53	45.88	45.73	45.15	45.79	45.17	44.75	44.78	44.52	44.63	44.23	43.92	43.91	43.66	43.46	43.25	43.65	43.70	43.60	43.56	46.31

Well No.	1951							1952												
	November			December				January				February					March			
	16	23	30	7	14	21	28	4	11	18	25	1	8	15	22	29	7	14	21	28
102	28.67	26.63	28.59	28.55	28.51	29.03	29.26	29.47	29.60	30.03	30.34	31.63	32.50	32.20	32.62	32.66	34.40	34.68	34.46	36.34
103	37.02	36.55	36.63	36.36	36.17	39.50	40.95	38.63	38.51	39.24	40.00	42.03	41.77	40.12	40.52	39.92	42.12	41.78	41.32	42.63
104	43.78	42.68	44.02	42.59	41.91	45.57	44.89	44.11	43.85	44.53	44.98	45.26	45.13	44.06	44.66	44.66	45.28	45.14	45.02	45.33
106	44.73	43.91	44.06	43.67	43.61	46.21	45.91	45.37	45.90	45.69	45.94	46.25	46.13	45.41	45.75	45.72	46.19	46.15	45.95	46.26
108	35.36	34.89	34.96	34.74	34.61	36.85	36.50	35.78	36.22	35.97	36.54	38.60	37.06	36.08	36.35	36.00	37.21	36.89	36.68	37.57
109	27.43	27.54	27.52	27.54	27.41	28.92	27.97	28.29	28.64	28.61	28.76	29.52	30.20	30.34	30.34	30.29	30.78	30.98	30.98	31.61
110	42.60	42.08	42.37	42.23	41.93	44.48	43.86	43.38	43.94	43.72	43.91	44.21	44.09	43.48	43.73	43.69	44.13	44.09	43.93	44.21
111	46.29	45.73	45.90	45.75	45.35	47.48	47.36	46.94	47.41	47.34	47.48	47.81	47.75	47.27	47.54	47.52	47.91	47.98	47.77	48.03
112	36.09	35.70	35.49	35.30	35.14	36.78	37.83	37.16	37.32	37.52	37.72	39.94	39.88	38.55	38.43	37.85	39.60	39.27	38.71	40.39
113	29.87	29.91	29.86	29.75	29.62	30.03	30.61	30.70	30.94	30.87	30.86	32.00	32.35	31.97	31.71	31.47	32.18	32.15	31.90	32.81
114	20.13	19.98	20.13	20.10	20.09	20.82	20.49	20.57	20.64	20.74	20.81	21.25	21.61	21.55	21.60	21.51	21.82	21.86	21.81	22.16
116	46.18	45.20	45.13	44.78	43.49	48.47	48.25	46.95	47.42	47.18	47.58	48.46	48.61	47.75	48.02	47.77	48.65	48.69	48.32	48.94
118	48.98	48.44	48.61	48.48	48.09	50.31	49.75	49.39	49.92	49.98	49.86	50.24	50.24	49.67	49.94	49.98	50.21	50.33	50.12	50.33
119	58.03	57.03	57.49	57.48	56.73	59.59	58.46	58.00	58.56	58.64	58.46	58.59	58.58	57.68	58.30	58.47	58.66	58.81	58.52	58.76
120	77.92	77.65	77.62	77.58	77.42	78.43	78.65	78.38	78.58	78.60	78.66	79.13	79.28	78.92	79.03	78.85	79.26	79.31	79.17	79.47
121	49.71	49.42	49.57	49.54	49.28	53.12	50.78	50.53	50.90	50.92	50.92	51.33	51.46	50.94	51.18	51.17	51.48	51.59	51.36	51.59
122	77.21	77.10	77.23	77.25	77.03	78.24	77.83	77.55	77.97	77.94	77.89	78.16	78.21	77.78	77.94	77.91	78.16	78.29	78.06	78.28
123	74.55	74.29	74.38	74.40	74.23	75.40	74.99	74.80	75.09	75.10	75.04	75.35	75.35	74.98	75.06	75.06	75.32	75.40	75.16	75.37
125	51.04	50.68	50.83	50.67	50.46	51.98	52.50	52.21	52.55	52.70	52.69	53.36	53.49	52.87	53.14	53.01	53.45	53.58	53.35	53.64
126	59.62	49.29	49.45	49.28	49.00	50.95	53.68	51.03	51.38	51.54	51.59	52.31	52.39	51.73	52.02	51.91	52.41	52.63	52.32	52.63
128	46.86	46.28	46.27	45.95	45.79	48.60	48.54	47.97	48.38	48.36	48.61	49.77	49.70	48.90	49.07	48.79	49.61	49.56	49.33	49.98
129	47.69	47.17	47.29	47.06	46.86	48.71	49.52	48.39	48.78	48.94	48.95	48.59	49.62	49.03	49.37	49.11	49.67	49.71	49.55	49.91
130	36.20	35.85	35.59	35.40	35.34	36.19	37.45	37.02	36.99	37.25	37.62	39.75	39.59	38.56	38.53	38.02	39.46	39.14	38.94	40.35
132	38.64	38.15	38.27	38.07	37.82	40.52	39.86	39.08	39.88	39.56	39.94	40.67	40.40	39.35	39.68	39.59	40.46	40.27	39.97	40.75
133	62.25	61.86	62.18	62.25	62.00	63.58	62.10	62.76	63.35	63.15	63.25	63.43	63.46	62.98	63.21	63.15	63.47	63.67	63.40	63.53
Average	46.27	45.76	45.98	45.79	45.52	47.59	47.52	46.98	47.31	47.36	47.54	48.31	48.35	47.69	47.91	47.76	48.48	48.48	48.24	48.83

TEMPERATURE OF THE GROUND WATER

Ground-water temperatures were measured three times in each well in order to determine whether changes in water viscosity due to the seasonal temperature cycle would be great enough to affect noticeably the rate of movement of the ground water.

On December 14, 1950, observation wells 122, 123, and 125 were hand pumped for several minutes before the water temperatures at the discharge spouts were recorded. On July 15, 1952, water temperatures in observation wells 104, 106, 113, 114, 126, and 130 were measured in the same manner. Each time, pumping was carried on long enough to remove the water originally standing in the wells. The water temperatures represent the temperature of the ground water at about the depth of the well points. On December 30, 1952, temperature profiles from the water surfaces to the bottoms of the wells were obtained by use of the thermohm meter and resistance bridge. Temperature readings were made at 1-foot intervals. The temperature profiles for the 9 wells on December 30, 1952, are shown graphically in figure 5, and the temperature data for the bottoms of the wells on the 3 dates are presented in the following table.

Ground-water temperatures at the bottoms of several wells in the Beaverdam Creek basin

Well	Depth of well (ft)	Dec. 14, 1950		July 15, 1952		Dec. 30, 1952	
		Depth to water (ft below land surface)	Temperature (°F)	Depth to water (ft below land surface)	Temperature (°F)	Depth to water (ft below land surface)	Temperature (°F)
122	11.5	1.8	57	----------	----------	1.4	57.5
123	11	3.4	57	----------	----------	2.8	55.2
125	18.7	11.2	55	----------	----------	7.6	59.2
104	14.2	----------	----------	8.51	64	4.0	59.6
106	20	----------	----------	8.86	66	3.75	59.5
113	21	----------	----------	12.79	63.5	12.6	59.7
114	22	----------	----------	16.48	59	16.5	62.2
126	22	----------	----------	11.98	65	7.3	57.1
130	16.7	----------	----------	10.89	61	9.1	58.8

The mean annual air temperature in this region is about 56° F. In general, the deviations of ground-water temperature from the mean air temperature were slight. The greatest deviation from the mean air temperature was 10° F. in well 106 on July 15, 1952. It is recognized, however, that seasonal low ground-water temperatures are not reached until February or March, nor is the maximum temperature reached until late August or early September. Also, the temperature profiles (fig. 5) show a considerable range from the water surface to the bottom of the well. Tables show that in this temperature range the kinematic viscosity varies roughly 1.4 percent per degree Fahren-

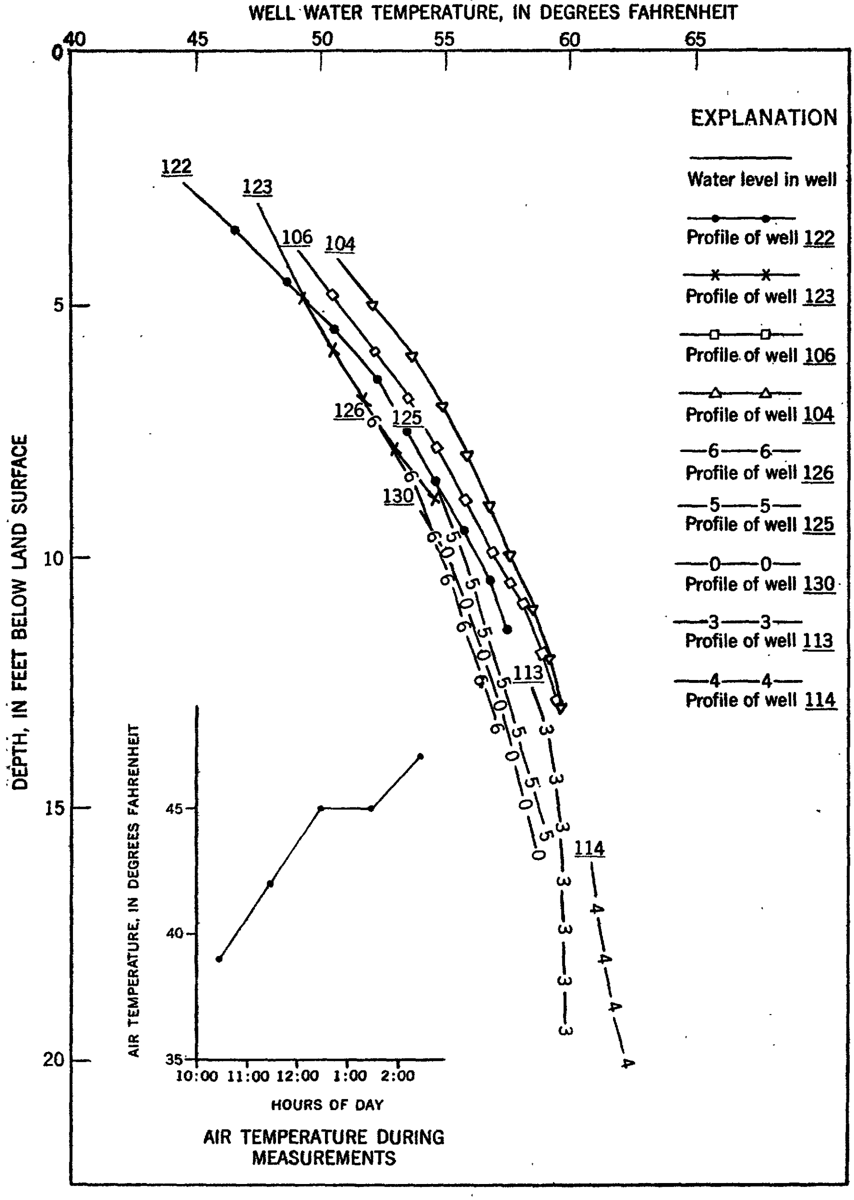


FIGURE 5.—Profiles of ground-water temperature in nine selected wells in the Beaverdam Creek basin on December 30, 1952.

heit. Thus, a temperature change of 10° F. would mean a change in the rate of flow of about 14 percent.

No conclusions on the change in rate of ground-water flow due to temperature changes could be reached from the scant data available.

The data do indicate, though, that at depths in excess of 15 or 20 feet temperature changes probably are not great enough to alter the rate of flow significantly. In areas where the water table is near the land surface, the movement of water in the upper fringe of the saturated zone is likely to be retarded during the winter, decreasing the rate of recession due to ground-water runoff. Diffusion of colder water into the warmer water would result in mixed temperatures which would adjust the rate of discharge and movement commensurate with temperature and head.

RAIN GAGES

Twelve rain gages maintained in the basin area were spaced so as to represent the basin adequately (pl. 1). The density of gages, as recommended by R. K. Linsley of the U. S. Weather Bureau, was established on the basis of a study of storm rainfall over a small area near Wilmington, Ohio (Linsley and Kohler, 1951). Three of the rain gages were U. S. Weather Bureau 8-inch can-type gages and eight were U. S. Signal Corps 4-inch plastic gages. Care was taken to place the rain gages so that no object protruded above an imaginary line drawn 45° from a level line resting on the lip of the gage, according to standard Weather Bureau practice. In addition to these gages, the Civil Aeronautics Administration office at the Salisbury municipal airport within the basin made hourly weather observations, including observations of precipitation. The weekly precipitation is summarized in the following table and shown graphically in figure 4.

Snow measurement was no problem, inasmuch as snowfall occurred seldom and then in small amounts. However, rainfall followed by freezing temperatures presented difficulty. The basin tour of measurements required a full day for one man when ideal weather conditions prevailed. During freezing weather, an additional man was usually assigned to thaw out the chunks of ice in the gages and measure the precipitation with the gaging stick.

The plastic gages were not completely satisfactory because high winds sometimes blew the funnels away, and the plastic tended to fracture easily. Four of the plastic gages deteriorated to such an extent that they had to be replaced by U. S. Weather Bureau 8-inch gages.

Early in the investigation it was thought that a denser network of rain gages might be desirable, if the additional cost could be kept low. An attempt was made to construct a satisfactory and inexpensive rain gage from tin cans of two sizes. The larger diameter tin can, approximately the size of a coffee can, served as a holder for the smaller diameter collector can (size no. 8). The holder can was nailed to a stake driven into the ground. Both cans were coated with olive-drab paint. The supporting stake was creosoted to retard decay.

Weekly precipitation recorded at 12 rain gages in the Beaverdam Creek basin, April 1950 to March 1952

[Tr. = trace]

Week ending—	Precipitation station											
	102	104	107	114	118	120	123	125	127	130	132	133
1950												
Apr. 7	0.27	------	------	------	0.23	------	------	0.23	------	------	0.18	------
14	Tr.	------	------	------	Tr.	------	------	.27	------	------	.01	------
21	.68	------	------	------	.79	------	------	.69	------	------	.76	------
28	.80	------	------	------	.88	------	------	.92	------	------	.61	------
May 5	.45	0.83	0.82	0.53	.32	0.34	0.98	1.10	1.10	------	.60	0.52
12	.85	.72	.62	.78	.99	1.03	.59	.55	.60	0.47	.80	1.11
19	.95	1.14	.93	1.00	.75	.79	.83	.77	.87	.99	.79	.88
26	1.90	1.75	1.33	1.77	1.60	1.66	1.05	.97	1.09	1.65	.56	1.22
June 2	.32	.30	.29	.37	.35	.37	.55	.62	.56	.17	.27	.43
9	.23	.21	.20	.23	.30	.25	.41	.53	.35	.23	.17	.33
16	.67	.70	.72	.44	.62	.66	.45	.44	.34	.40	.65	.43
23	.28	.32	.48	.37	.38	.38	.40	.39	.35	.33	.33	.38
30	.12	.18	.22	.03	.02	Tr.	------	Tr.	.01	Tr.	.06	.02
July 7	2.59	2.99	2.72	2.25	1.95	2.11	1.47	1.46	1.52	1.99	2.50	1.16
14	1.62	1.86	2.00	1.46	1.00	.88	.82	.94	.93	1.10	1.58	.99
21	1.46	1.77	1.20	.87	1.27	1.13	1.04	.83	.78	.23	2.07	1.10
28	.10	.13	.17	.10	.12	.12	.14	.14	.12	.11	.16	.13
Aug. 4	2.04	1.41	1.76	1.91	1.70	1.59	1.80	1.70	.78	1.93	1.43	1.99
11	.28	.42	.37	.33	.15	.04	.07	.11	.16	.21	.29	.11
18	.06	.10	.10	.06	.04	.06	.08	.07	.08	.00	.03	.03
25	.04	.08	.05	.08	.03	.06	.07	.06	.12	.14	.03	.04
Sept. 1	.01	Tr.	Tr.	.02	.01	.02	.02	.00	.02	.02	.03	.00
8	.48	.32	.33	.64	.44	.21	.45	.43	.25	.44	.48	.76
15	1.75	1.83	1 84	1.92	1.82	2.20	2.56	1.98	2.11	2.06	2.02	2.04
22	2.31	2.67	2.25	2.04	2.89	2.04	1.99	2.24	2.07	2.41	2.34	1.90
29	.11	.06	.06	.02	.06	.05	.06	.05	------	.03	.10	.06
Oct. 6	.13	.17	.13	.15	.09	.09	.08	.10	.15	.12	.01	.09
13	.52	.59	.42	.50	.30	.30	.45	.44	.48	.42	.26	.35
20	.16	.16	.16	.08	.05	.04	.03	.03	.04	.06	.13	.03
27	.60	.73	.87	.53	.73	.59	.44	.37	.48	.46	.98	.48
Nov. 3	.05	.08	.06	.07	.06	.04	.03	.03	.06	.06	.03	.03
10	.52	.40	.31	.68	.46	.41	.55	.59	.56	------	.45	.52
17	.04	.05	.05	.05	.04	.04	.05	.05	.05	.04	.02	.05
24	.63	.60	.62	.56	.61	.58	.57	.53	.58	.55	.93	.58
Dec. 1	2.50	2.23	1.94	2.53	2.64	2.75	2.16	2.62	2.57	1.91	1.65	2.45
8	1.54	1.60	1.81	1.51	1.83	1.96	1.89	1.87	1.38	2.51	1.76	1.81
15	.83	.91	.85	.82	.80	.68	.60	.70	.76	------	.78	.70
22	.00	.11	.11	.13	.14	.15	.10	.11	.11	.14	.09	.10
29	.25	.27	.29	.36	.27	.30	.23	.23	.23	.15	.35	.30
1951												
Jan. 5	.55	.60	.65	.46	.58	.52	.38	.42	.43	.50	.45	.43
12	.62	.63	.66	.59	.62	.63	.65	.63	.61	------	.64	.59
19	.34	.33	.32	.33	.31	.33	.39	.38	.36	.33	.32	.34
26	.43	.41	.39	.44	.42	.38	.37	.36	.35	.40	.39	.33
Feb. 2	.80	.62	.49	.57	.72	.72	.64	.58	.55	.75	.57	.51
9	1.36	.89	.73	.91	.94	.80	.85	.99	.95	.82	.84	.64
16	.01	.02	.02	.01	.01	.01	.01	.01	.02	.02	.02	.01
23	.97	.87	.92	.96	.86	.86	.88	.91	.86	.87	.86	.87
Mar. 2	.06	.07	.08	.07	.08	.09	.08	.08	.09	.08	.06	.10
9	.19	.20	.22	.17	.17	.18	.16	.13	.13	.19	.20	.17
16	.59	.78	.81	.73	.75	.81	.81	.80	.73	.80	.53	.84
23	1.39	1.44	1.47	1.30	1.34	1.36	1.25	1.40	1.20	1.15	1.26	1.36
Mar. 30	.13	.12	.19	.16	.21	.22	.22	.20	.17	.19	.46	.20
Apr. 6	1.15	.75	1.02	1.07	1.02	1.05	1.14	1.21	1.14	.99	.59	1.08
13	.18	.22	.21	.23	.22	.26	.23	.20	.23	.19	.29	.22
20	.41	.41	.37	.45	.42	.49	.51	.48	.45	.51	.37	.54
27	.69	.64	.65	.83	.63	.71	.91	.93	.95	.73	.69	.84
May 4	.51	.62	.69	.47	.43	.41	.45	.42	.33	.76	.49	.43
11	.41	.40	.37	.46	.38	.38	.46	.34	.36	.41	.00	.41
18	.53	.63	.58	.71	.81	.73	.51	.55	.52	.74	.93	.59
25	3.06	2.55	2.51	3.06	3.05	2.63	2.47	2.51	2.47	2.56	2.62	2.95
June 1	.01	.01	Tr.	.04	Tr.	.04	.05	.02	.06	.01	.00	.01
8	1.30	1.87	1.55	1.73	1.40	1.07	1.13	1.01	1.15	1.31	1.72	1.24
15	2.93	2.59	2.73	3.25	3.26	3.47	3.30	3.43	3.15	2.90	3.26	3.21
22	Tr.	.00	.02	.03	.01	.02	.02	Tr.	.02	.01	.00	.01
29	.90	.95	.76	.60	.32	.43	.44	.32	.31	.38	.50	.36
July 6	1.20	1.17	1.39	1.32	2.30	1.41	.81	.99	.34	1.91	.68	.82
13	.07	.07	.08	.10	.08	.10	.16	.13	.13	.07	.06	.12
20	.86	.00	.95	.56	1.94	1.00	2.50	1.58	1.32	1.98	2.32	2.45
27	.40	.59	.75	.56	.66	.91	.24	.73	.27	.10	.39	.89

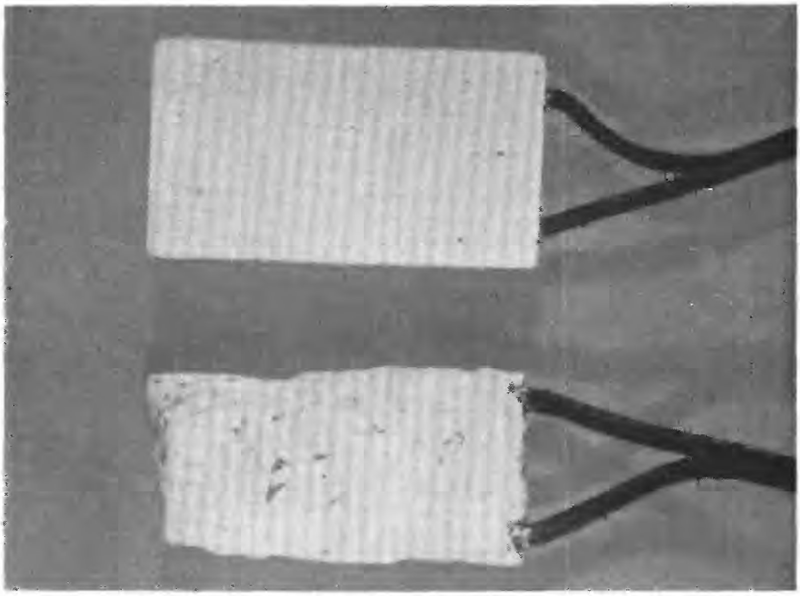
Weekly precipitation recorded at 12 rain gages in the Beaverdam Creek basin, April 1950 to March 1952—Continued

Week ending—	Precipitation station											
	102	104	107	114	118	120	123	125	127	130	132	133
1951—Con.												
Aug. 3	-------	1.05	0.46	0.44	0.22	0.34	0.47	0.72	0.61	0.84	1.08	0.75
10	1.76	1.43	1.47	1.72	1.95	2.56	1.68	2.24	2.42	1.79	1.93	2.39
17	.30	.45	1.24	.26	.30	.29	.28	.27	.27	.23	.34	.27
24	2.14	2.09	1.32	2.94	1.73	.96	1.91	1.28	1.64	2.97	1.29	1.01
31	.09	.15	.17	.08	.16	.28	.27	.12	.25	.09	.07	.19
Sept. 7	.86	.87	.52	.97	.67	.32	.30	.35	.66	1.11	1.47	:36
14	Tr.	Tr.	Tr.	.01	Tr.	Tr.	Tr.	Tr.	.00	.01	.00	.00
21	2.30	1.52	-------	2.40	1.97	1.61	1.79	2.06	1.83	2.35	1.92	1.79
28	.72	1.01	-------	.79	.77	.84	1.08	.99	.75	.70	.80	.79
Oct. 5	.56	.67	.73	.67	.84	.86	.87	.85	.85	.73	.67	.85
12	1.43	1.40	1.49	1.46	1.53	1.40	1.62	1.64	1.48	1.50	1.05	1.60
19	.08	.11	.10	.10	.08	.07	.12	.13	.08	.08	.02	.08
26	.30	.35	.43	.33	.38	.35	.32	.33	.30	.31	.29	.34
Nov. 2	1.03	.86	.86	.91	.99	1.08	1.17	1.08	.98	1.06	1.02	1.09
9	3.12	3.10	-------	3.05	3.33	3.43	3.42	3.32	-------	3.09	-------	3.40
16	.23	.22	.52	.27	.21	.22	.24	.32	.31	.25	.26	.25
23	.10	.06	.07	.11	.08	.08	.09	.08	.09.	.10	.00	.10
30	.87	.88	.80	.90	.92	.87	.90	.90	.86	.90	.66	.89
Dec. 7	.49	.38	.44	.36	.49	.54	.54	.50	.50	.37	.43	.60
14	.02	.01	.02	.02	.01	.02	.03	.04	.01	.02	.02	------
21	3.14	3.18	3.30	3.42	3.58	3.52	3.40	3.58	3.20	3.12	3.57	------
28	.60	.68	.67	.47	.35	.18	.36	.38	-------	.34	.39	.36
1952												
Jan. 4	.04	.04	.03	.03	.04	.04	.03	.04	-------	.04	.04	.03
11	1.59	1.57	1.42	1.50	1.63	1.63	1.63	1.71	-------	1.61	1.37	------
18	.60	.65	.75	.60	.65	.65	.66	.61	-------	.59	.61	.62
25	.74	1.05	1.04	.87	.86	.92	.88	.83	.83	.83	.76	.91
Feb. 1	1.63	1.92	-------	2.11	1.53	1.80	1.82	1.44	1.61	1.43	1.97	------
8	1.08	1.10	-------	1.00	1.92	1.75	1.72	1.38	1.23	1.14	1.06	------
15	-------	.01	-------	.03	.05	.00	.07	.03	.06	.03	.03	------
22	1.51	1.47	-------	1.21	1.36	1.34	1.30	1.39	1.33	1.28	1.24	1.37
29	.34	.39	.63	.50	.64	.47	.45	.37	.56	.34	.47	.65
Mar. 7	1.95	1.87	1.95	1.73	1.92	1.98	1.62	1.79	1.82	1.65	1.79	1.92
14	1.21	1.17	1.13	1.25	1.20	1.21	1.52	1.48	1.40	1.14	.96	1.34
21	.68	.70	.70	.72	.68	.68	.68	.68	.68	.65	.53	.69
28	2.17	2.03	2.09	2.00	2.15	2.15	2.06	2.14	2.09	2.12	2.04	2.20

Twelve of these units were assembled, and to check their performance one was placed near each of the standard rain gages. A few drops of oil were placed in the collector can to reduce evaporation. The amount of rain water was measured by pouring the contents of the collector can into a metal cylinder of such size that 1 inch of water was equivalent to 0.1 inch of rain. Rainfall determined by the makeshift cans showed rather poor agreement with the standard gages when readings were spaced a week apart. The agreement was satisfactory, however, when readings were made daily, or for individual storms. Loss of rainwater by evaporation and splashing was presumed to account for the deviations. It is likely that taller cans would reduce splash and the use of more oil would minimize evaporation.

A. STAFF GAGE 115 ON BEAVERDAM CREEK BRIDGE, MOUNT HERMAN ROAD

B. SOIL-MOISTURE STATION AND WELL 132, AT SALISBURY AIRPORT



UNUSED BOUYOUCOS BLOCK COMPARED WITH ONE AFTER 2 YEARS IN THE SOIL

STREAMFLOW-MEASUREMENT STATION

Since 1929 the Geological Survey has maintained a continuous record of streamflow and gage height at Schumaker dam (see pl. 2*A*), which is the outlet for the basin of Beaverdam Creek as used in this investigation. The daily mean discharge plotted on semilog hydrograph paper appears in plate 7. The altitude of the water surface at the dam is about 17 feet—that is, about 60 feet below the altitude at the headwaters of the creek.

It is assumed that all the water that flows out of the basin does so at this dam. The exception occurs where the headwaters of a small tributary to Beaverdam Creek are joined to the headwaters of Horsebridge Creek by means of a ditch constructed by the Soil Conservation Service as part of a land-drainage program. This breach of the divide was made in the vicinity of observation wells 117 and 118. The runoff in this section of the artificial creek will flow either southeast into the Pocomoke River basin or west into the Beaverdam Creek basin, depending upon the position and intensity of storm rainfall. As this section of the creek is dry much of the year, the water exchange is likely to be small, and the ground-water runoff seems not to be affected.

STAFF GAGES

In addition to the staff gage at Schumaker Pond, staff gages were installed at Parker Pond and at four locations along Beaverdam Creek and its tributaries, near observation wells 109, 115, 120, and 129 (pl. 1), for the purpose of measuring weekly changes in surface storage. The gage at the bridge on the Mount Hermon Road (State Route 350) is between wells 115 and 112. The water-surface areas represented by the Schumaker Pond gage and the Parker Pond gage are measured 0.046 square mile and 0.050 square mile, respectively. The remaining gages represent about 34 miles of channel ranging in width from 3 to 18 feet. The weekly changes in gage height were expressed in equivalent inches of water over the basin and appear in the central column of the budget, table 1. The staff-gage readings are shown in table 6. A picture of staff gage 115 is shown in plate 8*A*.

468445—59——5

Table 6.—*Gage heights at four staff gages on Beaverdam Creek and Walston Branch*

[Figures are elevation of water surface, in feet above mean sea level. The station number is the same as that of a nearby observation well]

Date	109 (Walston Branch)	115 (Beaverdam Creek above Parker Pond)	126 (Beaverdam Creek near head)	129 (Beaverdam Creek at Walston)
1950				
May 26	19.65	27.40	49.27	45.69
June 2	19.24	27.07	48.89	45.38
9	19.15	26.79	49.06	45.52
16	19.15	26.75	(1)	45.14
23	19.07	26.71	(1)	44.99
30	19.09	26.64	(1)	44.87
July 7	19.20	26.90	(1)	44.98
14	19.25	26.68	(1)	44.98
21	19.29	26.57	(1)	44.98
28	19.17	26.47	(1)	44.76
Aug. 4	19.17	26.64	(1)	44.82
11	19.03	26.42	(1)	44.36
18	19.03	26.41	(1)	44.11
25	18.97	26.25	(1)	(1)
Sept. 1	18.55	26.33	(1)	43.86
8	18.77	26.37	(1)	(1)
15	18.88	26.53	(1)	(1)
22	19.69	26.90	(1)	44.03
29	19.00	26.44	(1)	(1)
Oct. 6	18.97	26.43	(1)	(1)
13	18.97	26.44	(1)	(1)
20	19.00	26.45	(1)	(1)
27	19.00	26.46	(1)	(1)
Nov. 3	19.00	26.55	(1)	(1)
10	19.01	26.59	(1)	(1)
17	19.00	26.65	(1)	(1)
24	19.01	[2] 26.59	(1)	(1)
Dec. 1	19.06	26.27	(1)	(1)
8	20.09	26.91	49.20	45.64
15	19.25	26.78	48.99	45.44
22	19.14	26.57	48.91	45.35
29	19.17	26.69	48.74	45.25
1951				
Jan. 5	19.28	27.37	[2] 48.88	[2] 45.37
12	19.19	27.29	49.02	45.49
19	19.18	27.11	49.00	45.47
26	19.14	27.53	49.04	45.51
Feb. 2	19.26	27.65	49.42	45.81
9	19.47	27.35	49.46	45.84
16	19.12	27.18	49.30	45.72
23	19.39	27.37	49.44	45.83
Mar. 2	19.19	27.24	49.08	45.54
9	19.18	27.19	48.92	45.42
16	19.26	27.41	49.34	45.74
23	19.49	27.55	49.42	45.82
30	19.27	27.27	49.20	45.63
Apr. 6	19.41	27.53	49.35	45.76
13	18.63	27.29	49.15	45.64
20	18.86	27.28	49.13	45.64
27	19.23	27.23	49.29	45.80
1951—Con.				
May 4	19.19	27.09	49.25	45.62
11	19.23	27.33	49.09	45.42
18	19.11	27.42	48.98	45.20
25	19.79	27.94	50.10	46.28
June 1	19.23	26.84	48.96	45.50
8	19.47	27.51	48.81	45.40
15	19.56	27.59	49.36	45.89
22	19.27	27.56	48.96	45.47
29	19.22	27.57	(1)	45.19
July 6	19.12	27.31	(1)	45.12
13	19.12	27.45	(1)	44.93
20	19.31	27.61	(1)	45.27
27	19.19	26.83	48.79	45.26
Aug. 3	19.13	26.72	(1)	44.91
10	19.20	26.59	[2] 49.05	45.51
17	19.10	26.49	(1)	45.14
24	19.14	26.67	(1)	45.12
31	19.08	26.59	(1)	44.92
Sept. 7	19.11	26.73	(1)	44.90
14	19.13	26.73	(1)	44.91
21	19.10	26.47	(1)	45.02
28	19.13	[2] 26.52	(1)	44.88
Oct. 5	19.23	26.69	(1)	45.01
12	19.25	26.91	(1)	45.08
19	19.20	26.77	(1)	45.01
26	19.21	27.11	(1)	44.96
Nov. 2	19.39	27.31	(1)	45.10
9	20.07	28.13	49.75	46.14
16	19.57	27.61	49.39	45.92
23	19.35	27.94	49.15	[2] 45.59
30	19.41	27.68	49.34	45.82
Dec. 7	19.37	27.39	49.52	45.88
14	19.26	27.13	49.15	45.66
21	21.29	28.17	[2] 51.10	46.88
28	19.81	27.55	49.53	45.90
1952				
Jan. 4	19.55	27.15	49.29	45.71
11	20.01	27.75	50.17	46.18
18	19.99	27.43	50.01	46.10
25	19.89	27.77	49.71	45.92
Feb. 1	20.15	27.53	49.73	45.88
8	19.93	27.57	49.69	45.84
15	19.53	27.05	49.31	45.64
22	19.69	27.33	49.55	45.78
29	19.71	27.35	49.73	45.86
Mar. 7	19.89	27.57	49.75	45.84
14	20.07	27.73	50.43	46.14
21	19.89	27.69	49.93	45.90
28	20.13	27.67	49.89	45.84

[1] Dry.
[2] Interpolated data.

SOIL-MOISTURE STATIONS

The ability of the sediments in the soil zone to hold water is an important factor in basin storage. Although changes in soil-moisture storage from year to year are not great, seasonal changes can be considerable. Deficiencies in soil moisture occur when evaporation and water demands of the plants exceed the water gain. In this area, soil-moisture deficiencies are greatest during the summer and are zero or very low during the winter.

The resistance-block method developed by Bouyoucos and Mick (1940) was used in an attempt to measure soil moisture. Weekly changes in soil-moisture storage are shown by variations in the electrical resistance of moisture-sensitive elements buried in the soil. The moisture-sensitive elements consist of two tinned electrodes embedded in plaster-of-paris blocks (see pl. 9). The resistance is measured with a Wheatstone bridge, balanced when the audible signal is no longer heard. The plaster-of-paris blocks were placed in the soil at depths of 4, 12, and 39 inches (10, 30, and 100 cm) at three locations, stations 118, 132, and 133 (see pls. 1, 8*B*). The procedure followed for the installation, calibration, and operation of the Bouyoucos-type soil-moisture stations was that published by the U. S. Weather Bureau (1949).

EVAPORATION STATION

Daily measurements of evaporation were made during the 2-year period at the U. S. Geological Survey office in Salisbury, where a U. S. Weather Bureau class A evaporation pan was installed. The evaporating pan was 4 feet in diameter and 10 inches deep, and the water level was restored to within 2 inches of the top of the pan at 9 : 00 a. m. each day. The anemometer, placed 9 inches above the water level, indicated the number of miles of wind passage between readings. The construction, installation, and measuring techniques of the station were according to Weather Bureau practice as described by Kadel (1919), except that a fixed-point gage was used in place of the micrometer-hook gage. Weekly totals are given in table 2, and daily records were published monthly for a part of the period in the Climatological Summary by the U. S. Weather Bureau.

The water removed by evaporation during a period of measurement is restored to the point of the gage by pouring from a quart pitcher. The size of the pan is such that 1 ounce of water equals 0.001 inch of evaporation. To the amount poured in to restore the level, the amount of precipitation during the period must be added to determine the total evaporation during the period. If precipitation exceeds evaporation during the period, the water level is above the point of the gage when the measurement is made; in this case water is removed until the level is at the point, and the amount removed is recorded. To determine evaporation, the amount removed is subtracted from the precipitation.

FACTORS OF THE BUDGET

The hydrologic cycle is a continuous natural phenomenon, having no beginning or ending. However, so far as man is concerned, it can be considered to begin when precipitation falls from the sky. The phases of the cycle useful to man are marked by the immediate runoff of surplus water, the revived growth of plants, the rise of water levels in wells, the restoration of soil moisture, and the filling of ponds and streams. The end of the cycle is marked by the subsequent return of the water to the atmosphere through evaporation and transpiration, the decline of the water level in wells, the diminished flow of brooks and creeks, and the drying up of soil and ponds. The apportionment of the precipitation between basin storage changes, runoff, and evaporation-transpiration (evapotranspiration) losses expresses a hydrologic budget that is in balance at all times. The water gains are equal to the water losses plus any water saved, or less any water deficit. That is, the precipitation during a given period of observation is balanced by the runoff and evapotranspiration plus any increase in storage or minus any decrease in storage. Stated as an equation,

$$P=R+L+\Delta S \tag{1}$$

where P is the water gain in precipitation, R is the runoff, L is the water loss through evaporation and transpiration, and ΔS is the change in basin storage (final storage minus initial storage).

WATER GAINS

Precipitation and, in some areas, natural inflow from adjacent basins are the principal sources of water gain. Other water sources, in certain places, might include water supplied by irrigation or by disposal of wastes. Artificial importation of water to the Beaverdam basin was negligible during this investigation. The aquiclude at the top of the Miocene is sufficiently thick and impermeable to make any material leakage from the deeper artesian sands unlikely and study of the water-table contours indicates that the ground-water divides are reasonably congruous with the topographic divides. In this basin, therefore, precipitation is the dominant source of water supply, and the only one that is considered in the hydrologic budget. Precipitation, considered herein, includes rain and snow.

WATER LOSSES

Water losses include runoff from the basin, evapotranspiration to the sky, and leakage from the basin. The aquiclude underlying the permeable sand and gravelly sand of the basin prevents substantial downward leakage just as it prevents upward leakage. Also, as the ground-water and topographic divides were essentially congruous, lateral leakage was assumed to be negligible during the period of this study.

RUNOFF

Runoff is water that flows from the land, either directly over the surface or from temporary or permanent zones of saturation of the subsurface. From the Beaverdam basin, runoff water flows over Schumaker dam and down through the city park ponds to the tidal Wicomico River, thence to Tangier Sound and Chesapeake Bay, and finally past Cape Charles to the Atlantic Ocean.

Runoff, as measured at the Beaverdam gaging station, is of two types: direct runoff and ground-water runoff or base flow. Direct runoff appears in the stream channels promptly, during and after a storm. It has its origin in overland flow and, in part, in the movement of water in the upper soil layers, which discharge from temporary saturated zones as wet-weather seeps, into the numerous rills that dissect the land surface. Direct runoff is the cause of the sharp rise in streamflow as recorded on the hydrograph. Ground-water base flow, the low flow recorded on a hydrograph, is derived from sustained discharge of ground water as the water table declines from high stage to low. Base flow sustains the stream after direct runoff has ceased. In this report base flow will be referred to as ground-water runoff or as ground-water drainage, depending on the emphasis desired.

The hydrograph in plate 7 shows the daily mean runoff at the outlet of the Beaverdam Creek basin. In the past, the separation of a stream hydrograph into direct runoff and ground-water runoff has been qualitative. One of the earliest attempts at separation was made by Houk (1921) in a study of the rainfall and runoff in the Miami Valley, Ohio. Houk connected the low points on a stream hydrograph, forming a line intended to represent ground-water runoff.

Use of data on water levels in observation wells in the Beaverdam basin has permitted good definition of the ground-water runoff on the stream hydrograph. The weekly average of ground-water levels measured in 25 wells within the basin are plotted in figure 4, with weekly precipitation averaged from 12 rain gages in the basin. The mean ground-water stages corresponding to periods when it was obvious from the stream hydrograph and precipitation records that only base flow was present in the creek were then used to construct a ground-water rating curve, figure 6. From this curve, a close approximation to the true weekly base flow was obtained and plotted on the stream hydrograph, plate 7.

This operation is based upon the following logic: ground-water storage during rainless periods is depleted by drainage into stream channels and by evaporation and transpiration (p. 64). During these periods the channel flow is supported solely by ground-water drainage. Associated with a particular mean ground-water stage (above the mean channel stage) there is a related gradient and a consequent drainage of ground water into the channels. The relationship between ground-water stage and ground-water runoff in this basin becomes evident when, during rainless or low-rainfall periods, the ground-water stages are plotted against the stream-discharge rates on corresponding dates (fig. 6).

For example, one such period, noticeable both on the ground-water hydrograph and precipitation bar graph (fig. 4) and on the runoff hydrograph (pl. 7) was April 7–14, 1950. On April 7 the mean ground-water stage was 46.74 feet above mean sea level, receding to 46.21 feet by April 14. The daily mean streamflow on these dates was 23 and 18 cfs, respectively. These two points are represented along the curve, figure 6, by the two dots with the numeral 4, indicating April 1950, beside them. About 20 additional rainless periods occurred during the 2 years of measurement.

A ground-water runoff, or base flow, corresponding to each mean ground-water stage during the 2-year measurement was read directly from this rating curve, and plotted beneath the runoff hydrograph, plate 7. A dashed line connecting the weekly points represents the hydrograph of ground-water runoff.

EVAPOTRANSPIRATION

Some water is returned to the atmosphere as a vapor through evapotranspiration, a term combining direct evaporation from the soil and other moist surfaces and plant transpiration. The amount of water returned through evapotranspiration depends upon the amount of water available, the solar energy supplied, and the temperature and humidity of the air. Heat, water, and carbon dioxide combine in the process of photosynthesis to manufacture plant matter. Heat, in excess of that needed for optimum photosynthesis, is dissipated by the plant through conduction and radiation, but principally by transpiration. Much of the water required by plants is used to regulate their temperature, which otherwise would rise to a point that would cause them to wither and die.

The Beaverdam Creek basin loses large quantities of water by evapotranspiration during the warm summer. These losses decrease rapidly as the growing season closes in the autumn and are nearly zero in the winter. As the weather warms in the spring, the growing resumes, and evapotranspiration increases, reaching a high again in the summer. This variation in evapotranspiration loss with the time of the year is approximately the same from year to year, providing the vegetative cover is not significantly altered.

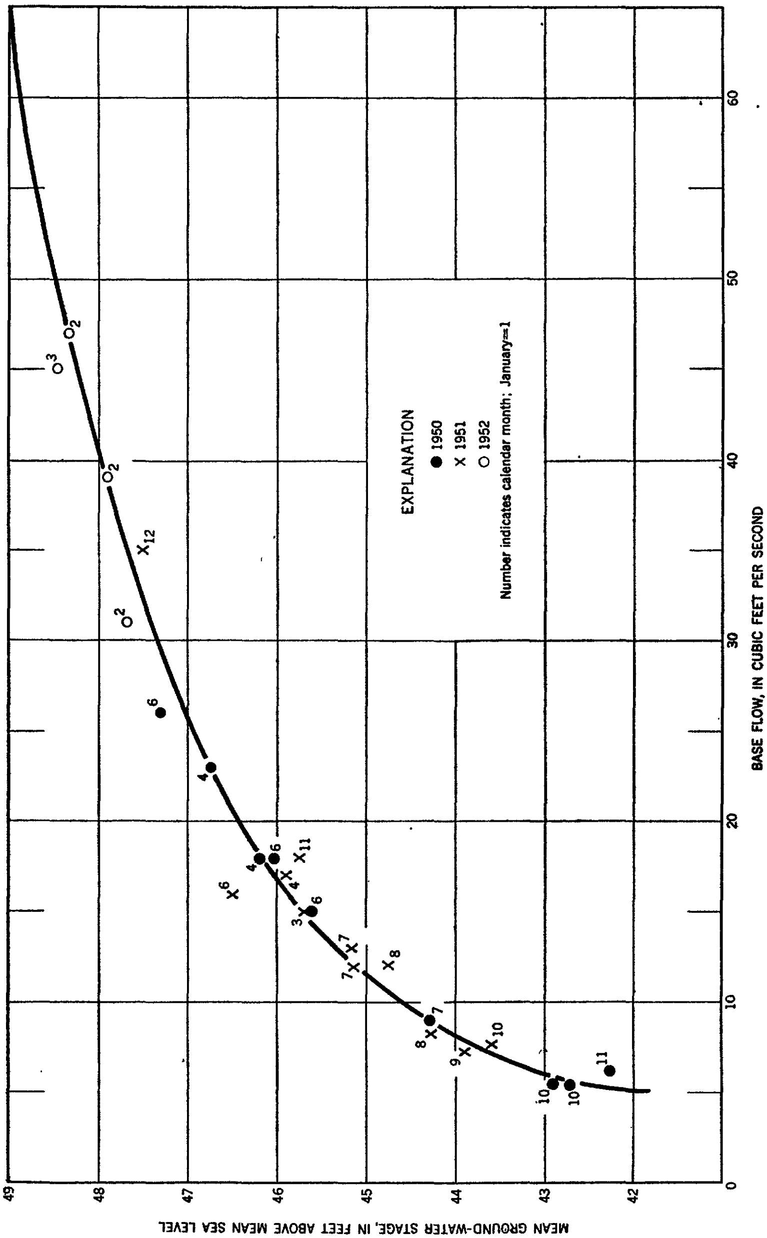


FIGURE 6.—Rating curve of mean ground-water stage compared with base flow of Beaverdam Creek.

BASIN STORAGE

Any excess of precipitation over runoff and evapotranspiration results in an increase in storage. Water is stored on the basin surface in lakes, ponds, and stream channels, and beneath the surface in the soil and subsoil and in the saturated rocks, or ground-water zone.

SURFACE-WATER STORAGE

The Beaverdam Creek basin drainage system consists of about 34 miles of stream channels and two ponds, Schumaker and Parker (p. 9). Some water is held temporarily in surface storage immediately after periods of precipitation before flowing from the basin. Weekly changes in stage at Schumaker and Parker Ponds and at four other points along the channels were converted to equivalent inches of storage change over the basin. The basic data appear in tables 1 and 6 and the converted data in the central columns of table 1.

SOIL-MOISTURE STORAGE

Except during wet periods, when the soil is already at field capacity, some of the water filtering down from the surface replenishes the soil moisture that has been depleted by evaporation and transpiration. In the Beaverdam Creek basin the soil moisture is generally at a maximum during the winter, when evaporation and transpiration demands are low. During the growing season the soil moisture is depleted by evapotranspiration, and there is a deficiency except during very wet periods.

The soil-moisture deficiencies, in inches deficiency per inch of depth, were measured by the Bouyoucos resistance-block method. The deficiency registered by each block was multiplied by the average thickness of soil which the moisture blocks were presumed to represent. Since the blocks were set at 4, 12, and 39 inches, the midpoints were at 8 and 25.5 inches. The 4-inch block thus represented the soil moisture from 0 to 8 inches; the 12-inch block represented the soil moisture for 17.5 inches, from 8 to 25.5 inches; and the 39-inch block represented the soil moisture for 13.5 inches, from 25.5 to 39 inches. The blocks were not used to calculate vadose moisture below 39 inches, which was assumed to remain constant.

The total soil-moisture deficiency for one station is an arithmetical sum of the deficiencies in each layer. The basic data are given in tables 7, 8, and 9, and the curves necessary to convert resistivity to moisture deficiency are given in figures 7 to 15. Figure 16, the calibration curve of a thermistor, was used to compute soil temperature at a depth of 12 inches. Soil temperatures at other depths were derived by the method of Langbein (1949, p. 543–547).

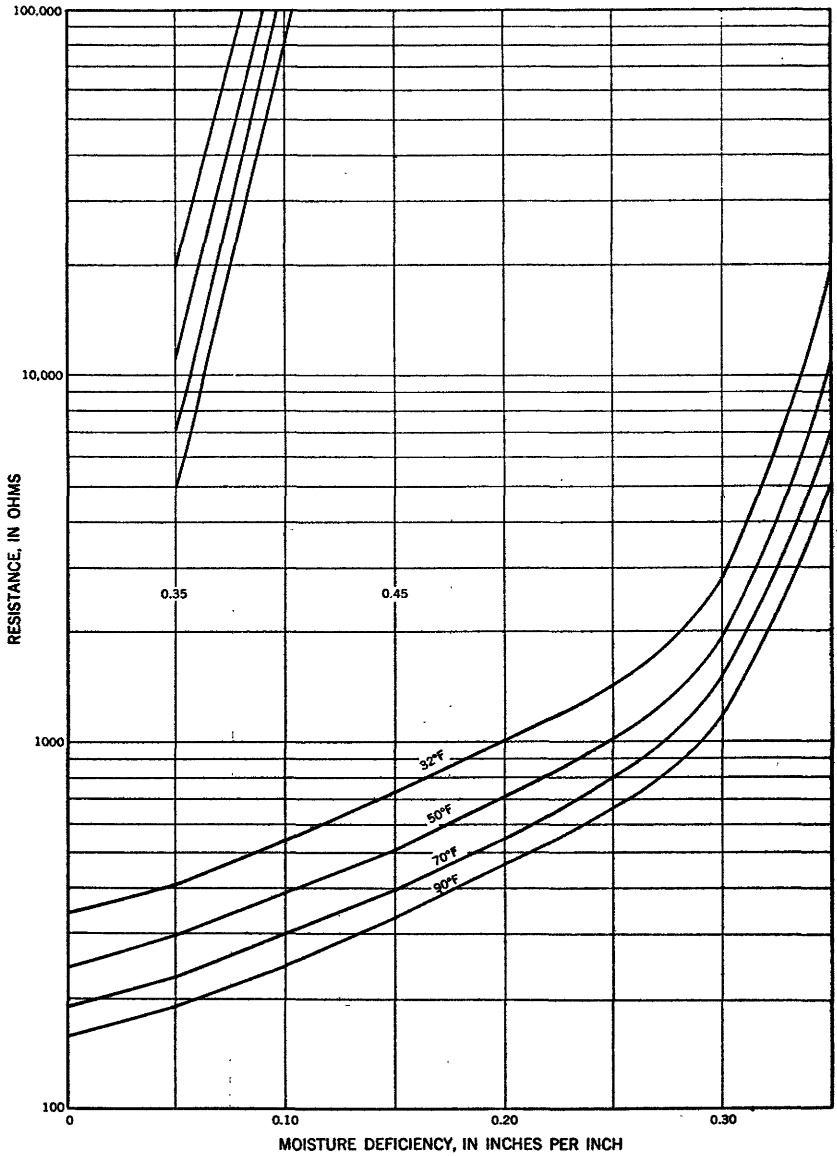


FIGURE 7.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 4 inches, station 118.

The soil-moisture deficiencies for the basin were taken as the end-of-week averages of soil-moisture deficiency at the three stations. For example, on May 5, 1950, the soil-moisture deficiency at station 118 was 4.565 inches (table 7), at station 132 it was 8.040 inches (table 8), and at station 133 it was 7.740 inches (table 9). The computed average

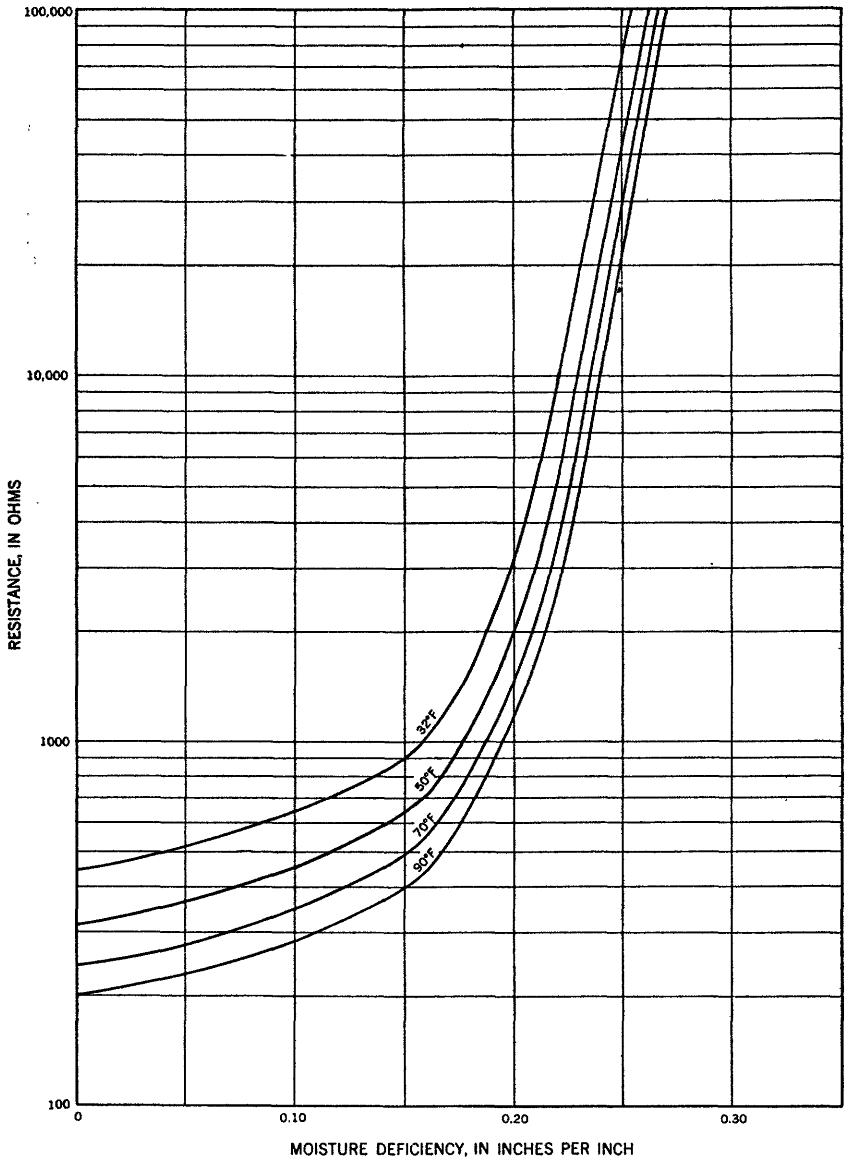


FIGURE 8.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 12 inches, station 118.

deficiency for the basin was then 6.78 inches. This average is recorded in the budget, table 1, in the column headed "Calculated soil-moisture deficiency."

The soil-moisture measurements were generally unsatisfactory. Direct measurements of moisture content of samples taken in the field

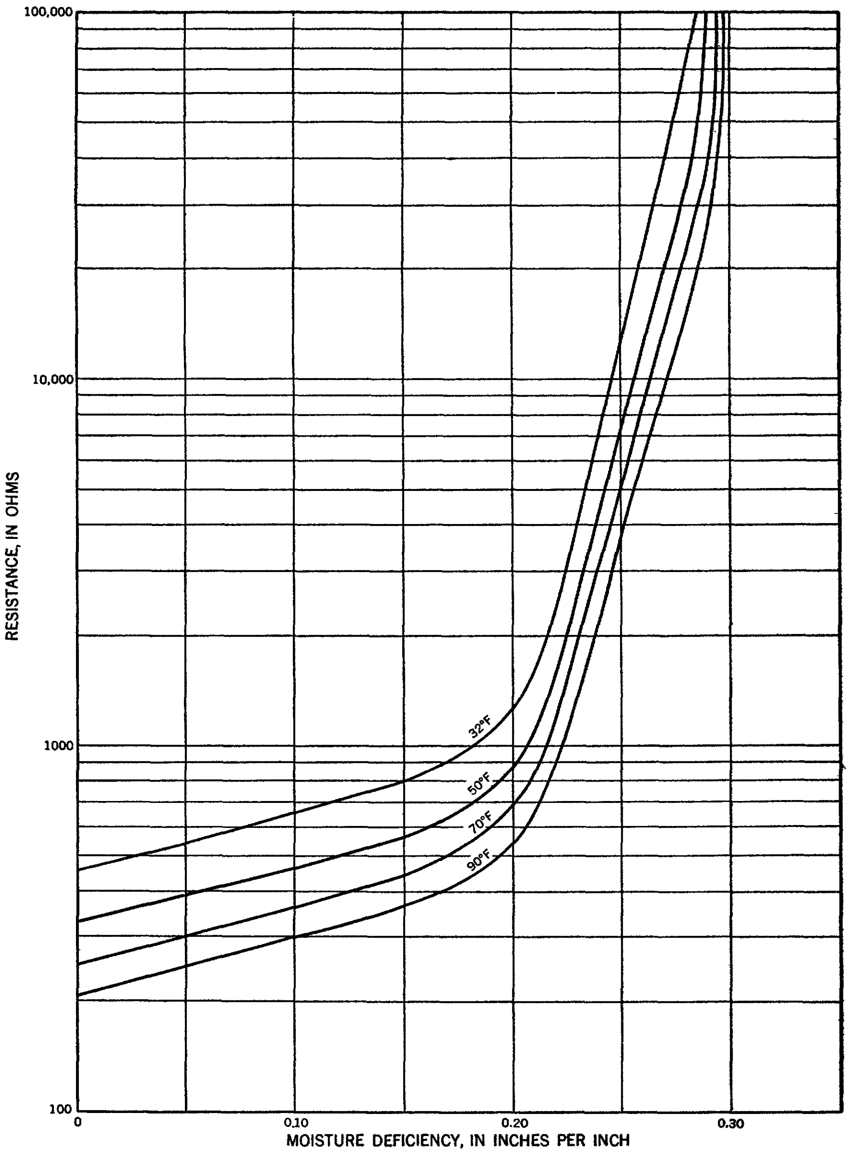


FIGURE 9.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 39 inches, station 118.

showed that the performance of blocks in the ground differed from performance during calibration in the sample cans. The shape of the calibration curves may not have altered, but the curves were shifted (or manifested hysteresis). (Periodic recalibration by measuring soil moisture in samples taken near the installed blocks may

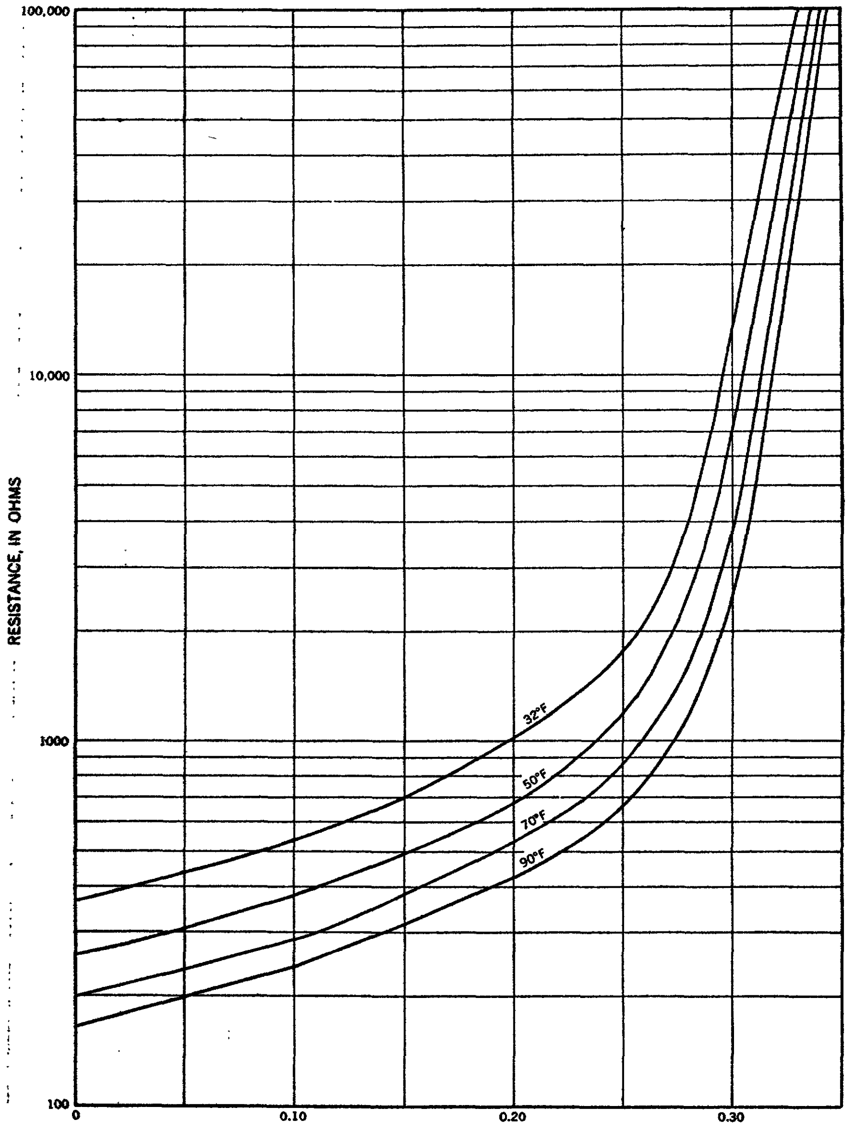


FIGURE 10.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 4 inches, station 132.

eliminate this disturbance.) Moreover, the three stations demonstrated that in this basin the soil moisture is variable from place to place. Data from many more stations would be needed to give dependable results in a basin as large as that of Beaverdam Creek.

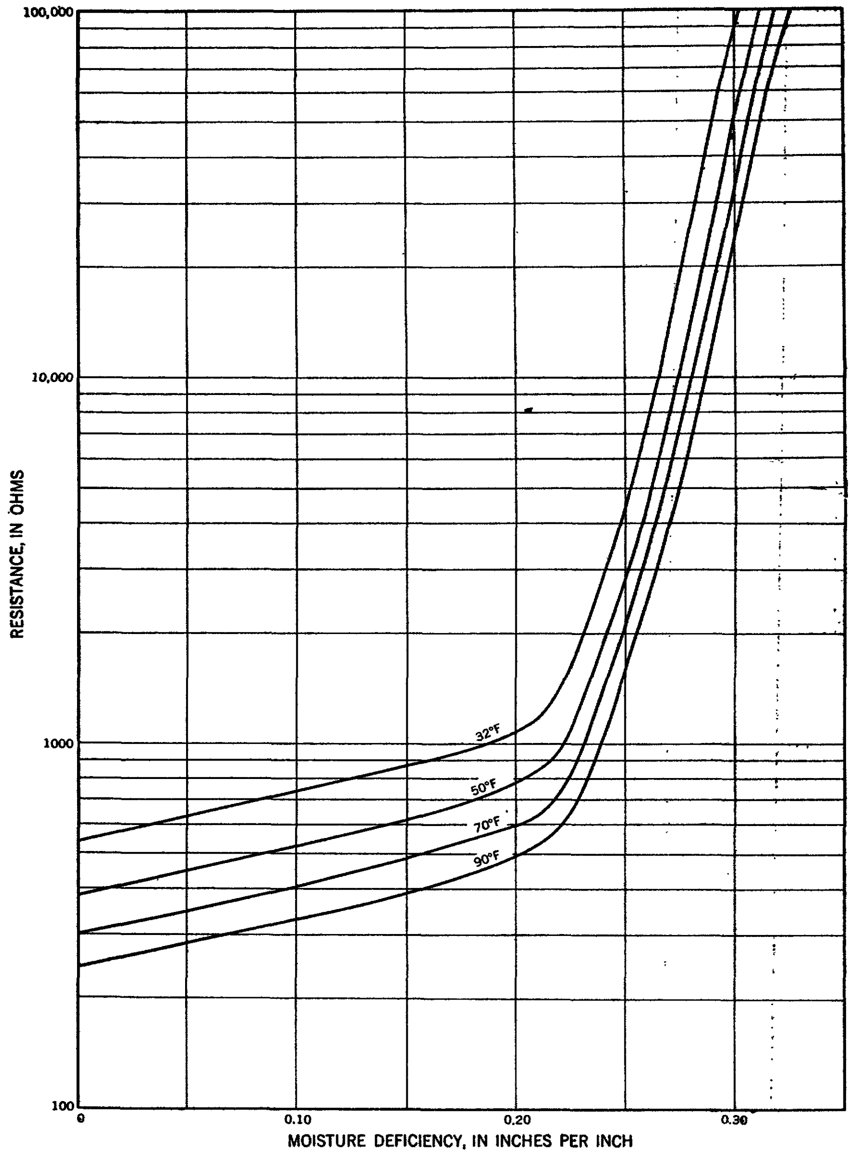


FIGURE 11.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 12 inches, station 132.

Calibration curves (figs. 7 to 16) show that the resistance-deficiency curves are insensitive for the lower resistance (higher moisture) readings. Small changes in resistance in the lower readings correspond to very large changes in soil-moisture deficiency.

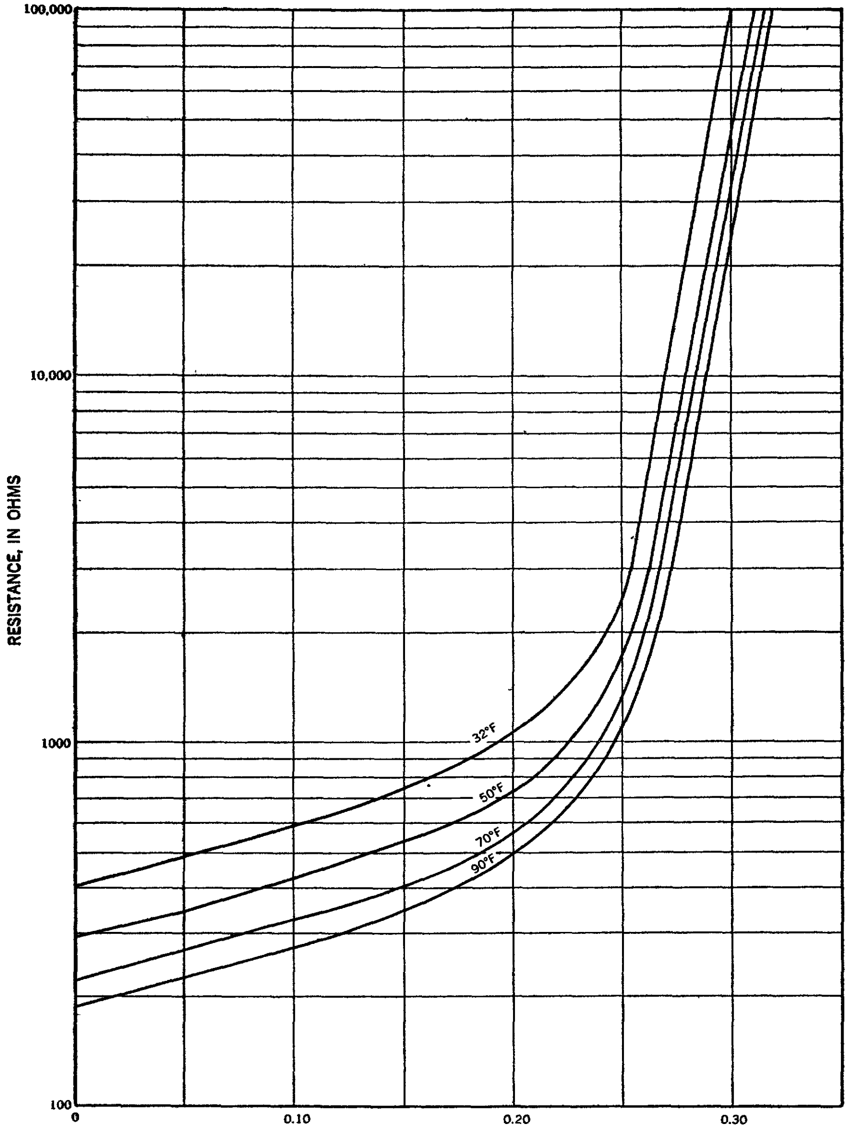


FIGURE 12.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 39 inches, station 132.

The plaster-of-paris blocks did not hold together satisfactorily. A picture of one block before installation and after 2 years in the soil is shown in plate 9. Most of the blocks dissolved to such an extent that the electrodes were exposed to the soil.

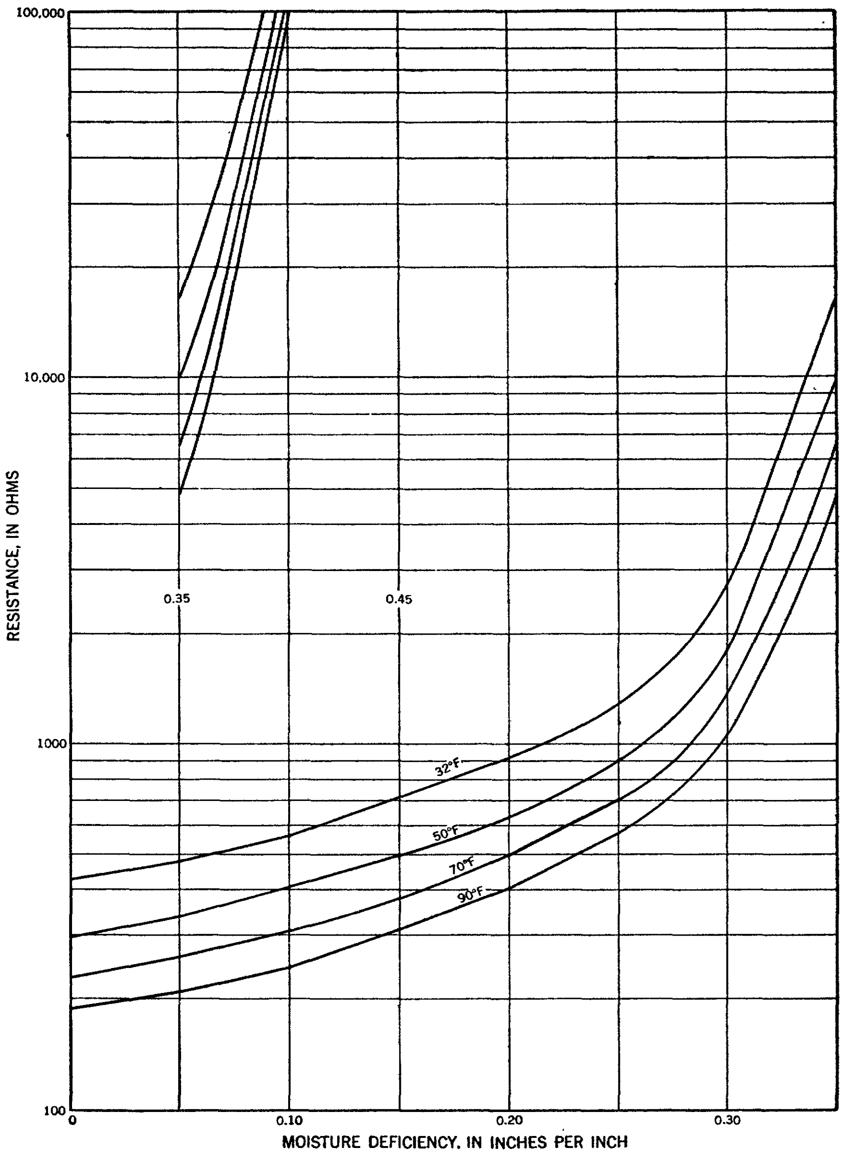


FIGURE 13.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 4 inches, station 133.

On a few occasions when ground-water levels were high, soil-moisture deficiencies were measured at the 39-inch level when ground-water levels in the adjacent wells indicated that the block should have been within the saturated zone. It is not unlikely, in these cases, that the lower blocks were in sediments whose permeability was far less than

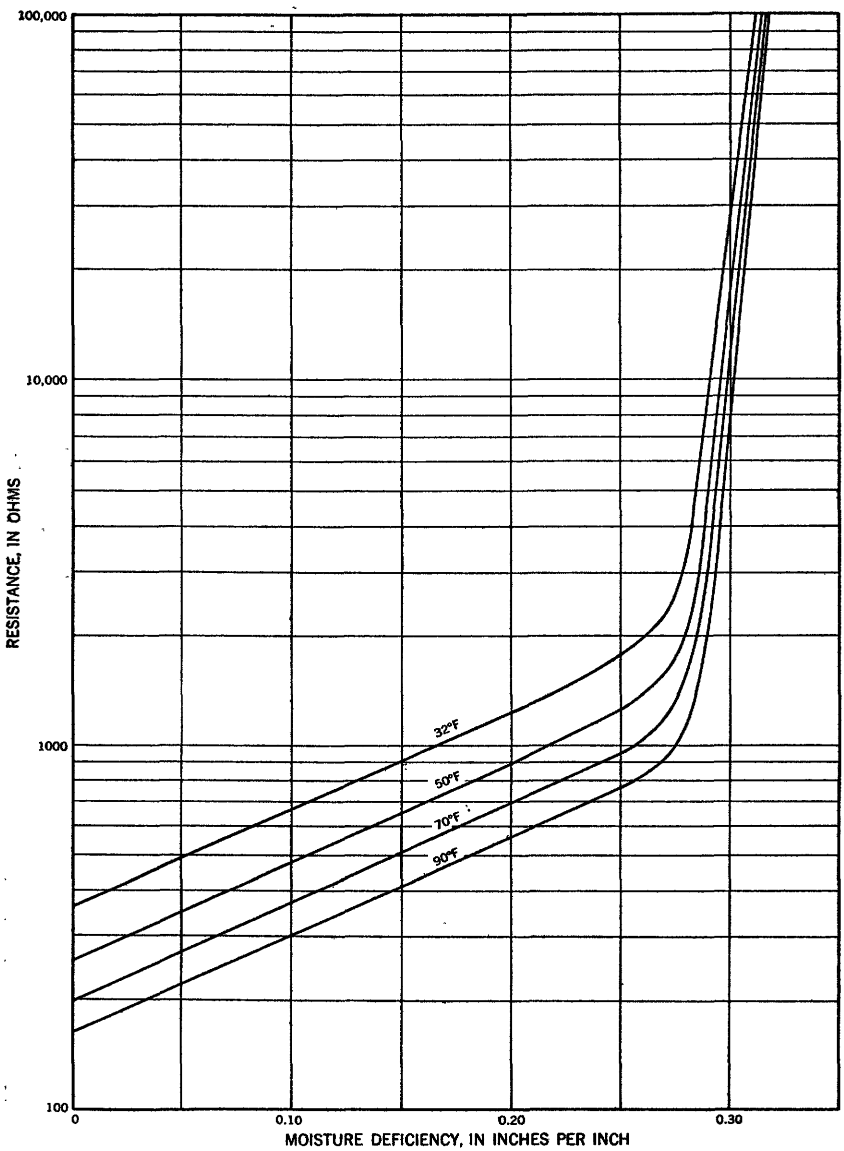


FIGURE 14.—Calibration curves for computing soil moisture deficiency from electrical resistance at a depth of 12 inches, station 133.

the surrounding sediments, so that with a fast-rising water table there would be a time lag before complete saturation took place. In a complementary fashion, the 39-inch block frequently remained at the low resistivities calibrated as indicating saturation long after normal re-

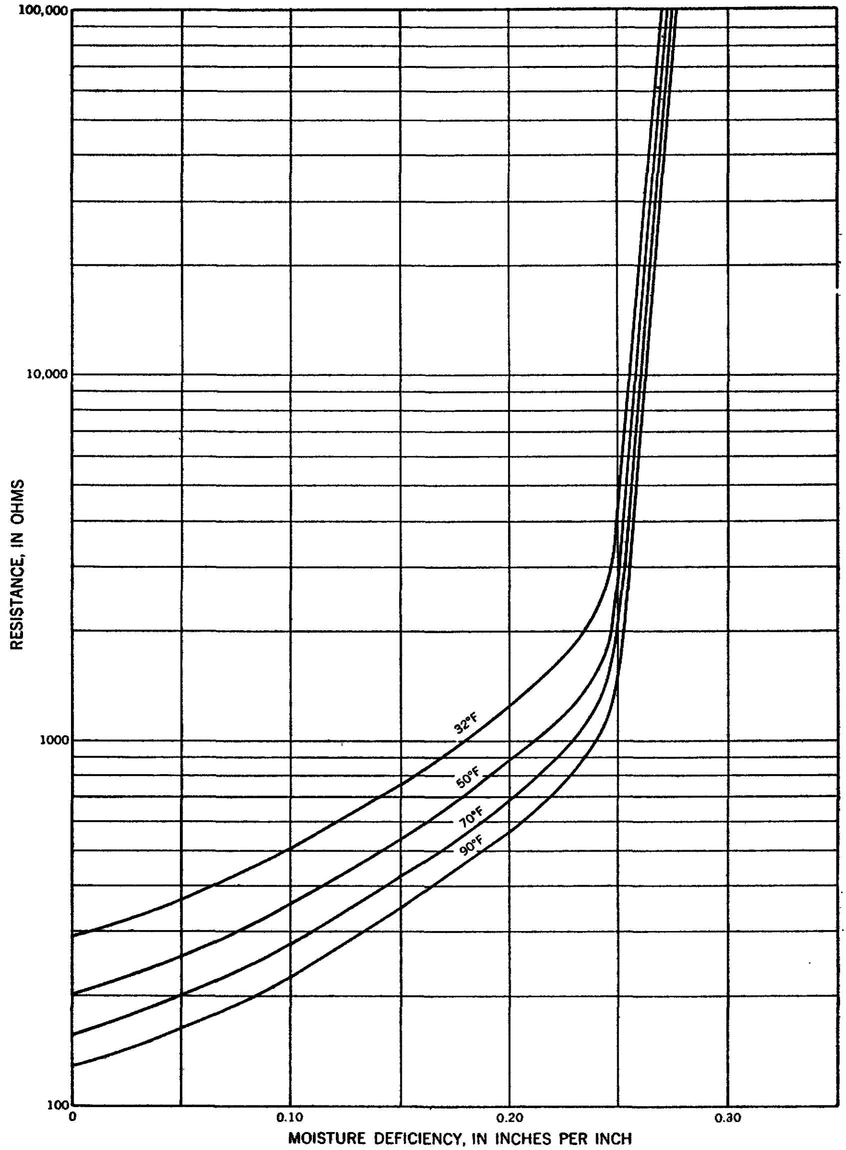


FIGURE 15.—Calibration curves for computing soil-moisture deficiency from electrical resistance at a depth of 39 inches, station 133.

cession had carried the ground-water level below the block, indicating that the block was still in an extended capillary fringe.

As a consequence of these difficulties, the soil-moisture changes determined by the deficiencies from the resistance-block method were used only in the first approximation in the budget, to obtain approxi-

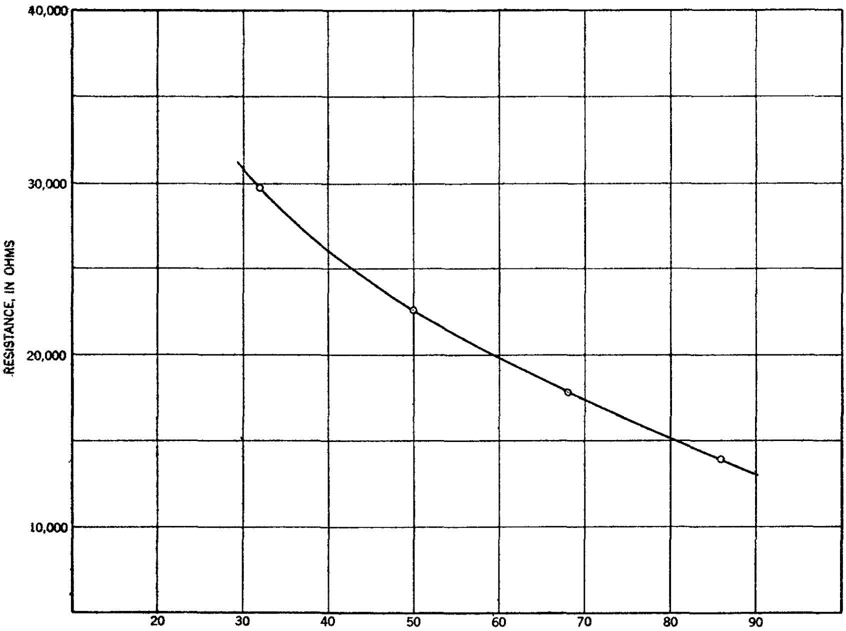


FIGURE 16.—Calibration curve for a thermistor used to compute temperature from electrical resistance at a depth of 12 inches.

mate values for evapotranspiration. A smooth line was drawn between the evapotranspiration values and the weekly changes in soil moisture were then calculated from the hydrologic equation. These weekly computed soil-moisture changes are listed in the budget, table 1.

Comparison from table 1 of the differences of calculated soil-moisture deficiencies and the computed soil-moisture changes shows that there is only a crude relationship between the two, and that the changes even differ frequently in sign.

For example (see table 1), during the week May 20 to 26 inclusive, 1.38 inches of rain fell, 0.38 inch ran off, surface-water storage gained 0.02 inch (0.0150+.0031 inch), the change in ground-water storage was a gain of 0.79 inch (0.60 foot x 12 inches/foot x 0.11 gravity yield), and the evapotranspiration derived from the graph (fig. 17) was 0.78 inch. Thus the computed water discharge (R+ET) plus the gain in storage equaled 1.97 inches (0.38+0.78+0.02+0.79 inch), whereas the rainfall was only 1.38 inches. The difference, −0.59 inch, if it was real, was derived from the soil and the intermediate vadose zone.

However, the difference between the soil-moisture deficiency of 6.26 inches on May 19 and 5.52 inches on May 25 indicates a gain in soil moisture of 0.74 inch, rather than a loss of 0.59 inch. If there actually was a gain, it would have been necessary to derive 0.74− (−0.59) =

TABLE 7.—*Soil-moisture data for station 118*

Date	4-inch depth			12-inch depth			39-inch depth			Total deficiency (in)
	Resistance (ohms)	Mean air temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Thermistor temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Derived temperature (°F)	Deficiency (in/in)	
1950										
Apr. 28	600	64.5	0.200	580	57.0	0.170	430	47.8	0.070	--------
May 5	520	69.0	.185	500	60.0	.130	400	50.3	.060	4.565
12	550	54.5	.180	480	64.0	.130	400	54.0	.070	4.66
19	620	51.5	.185	450	62.0	.120	400	55.2	.070	4.525
26	500	63.5	.175	420	65.0	.120	360	56.1	.060	4.310
June 2	420	68.0	.150	410	67.0	.115	310	58.6	.020	3.4825
9	650	72.0	.230	600	67.0	.160	500	61.8	.150	6.665
16	640	74.0	.230	600	67.0	.160	500	63.7	.150	6.665
23	700	71.5	.240	650	69.0	.170	510	65.2	.160	7.055
30	25,100	73.5	.380	555	72.0	.160	480	67.8	.150	7.865
July 7	700	69.5	.230	600	73.0	.170	450	69.5	.150	6.84
14	700	75.5	.240	600	75.0	.170	520	70.8	.180	7.325
21	680	65.5	.220	573	78.0	.160	540	72.2	.180	6.990
28	680	75.1	.240	630	73.0	.170	560	72.5	.185	7.3925
Aug. 4	700	70.0	.230	500	77.0	.150	560	73.3	.190	7.03
11	600	78.5	.225	400	76.0	.130	300	73.2	.100	5.425
18	2,600	74.5	.320	700	75.0	.175	560	72.4	.190	8.1875
25	26,500	71.0	.390	4,200	74.0	.220	320	72.2	.085	8.1175
Sept. 1	129,000	82.5	.400	42.000	80.0	.250	570	73.5	.190	10.14
8	3,800	66.0	.330	25,000	73.0	.240	620	73.2	.200	9.54
15	7,200	68.0	.350	6,800	68.0	.220	5,900	71.8	.255	10.0925
22	6,200	65.5	.340	5,700	68.0	.220	4,300	70.1	.250	9.945
29	720	58.0	.215	600	63.0	.160	440	65.6	.130	6.275
Oct. 6	610	55.5	.190	530	65.0	.150	410	65.2	.130	5.9
13	640	52.5	.195	580	64.0	.155	430	64.0	.125	5.96
20	690	62.0	.210	600	65.0	.160	460	64.0	.140	6.37
27	760	47.5	.200	610	58.0	.150	500	61.8	.155	6.3175
Nov. 3	700	64.0	.220	600	63.0	.160	540	62.0	.170	6.855
10	800	54.0	.225	620	60.0	.160	560	60.3	.170	6.895
17	820	51.5	.225	700	56.0	.165	600	55.9	.170	6.9825
24	1,020	44.0	.230	750	50.0	.165	620	51.9	.170	7.0225
Dec. 1	1,080	34.5	.220	800	43.0	.155	560	46.6	.140	6.3625
8	450	45.5	.115	160	54.0	.100	460	46.4	.080	3.75
15	590	40.0	.140	400	45.0	.050	450	43.5	.040	2.535
22	750	29.0	.140	450	42.0	.070	460	38.8	.040	2.885
29	600	38.5	.140	450	42.0	.060	500	37.4	.050	2.845
1951										
Jan. 5	600	40.5	.140	450	47.0	.080	530	38.4	.070	3.465
12	500	35.0	.105	500	42.0	.080	680	38.2	.140	4.13
19	450	55.0	.140	440	46.0	.080	500	39.0	.060	3.33
26	660	30.5	.120	380	44.0	.040	500	39.9	.060	2.47
Feb. 2	610	33.6	.130	400	47.0	.050	490	39.0	.060	2.725
9	810	17.8	.100	450	40.0	.050	510	35.3	.060	2.485
16	410	35.3	.060	400	45.0	.050	490	35.9	.040	1.895
23	380	40.0	.060	500	51.0	.120	520	38.5	.070	3.525
Mar. 2	290	50.0	.040	290	52.0	.000	500	41.3	.070	1, 265
9	280	40.5	.020	240	50.0	.000	470	42.5	.075	1.1725
16	350	42.1	.040	300	49.0	.000	480	41.4	.060	1.13
23	320	46.5	.050	280	51.0	.000	490	41.4	.075	1.4125
30	250	56.0	.030	200	60.0	.000	450	43.1	.050	0.915
Apr. 6	210	52.0	.000	200	55.0	.000	480	45.6	.080	1.08
13	200	50.0	.000	120	59.0	.000	460	47.14	.075	1.0125
20	220	48.0	.000	190	59.0	.000	440	48.14	.060	0.810
27	50	52.0	.000	130	65.0	.000	420	50.2	.080	1.08
May 4	170	56.0	.000	90	65.0	.000	410	53.3	.090	1.215
14 [1]	780	57.0	.225	820	60.0	.175	500	55.2	.140	6.7525
18	1,180	54.0	.270	940	65.0	.170	680	56.7	.185	7.6325
25	1,300	61.0	.290	1,100	58.0	.180	890	58.4	.205	8.2375
June 1	1,180	74.0	.290	1,000	64.0	.180	780	61.9	.200	8.17
8 [2]	850	65.0	.240	620	67.0	.160	460	64.4	.000	4.72
15	660	66.5	.210	540	72.0	.160	400	63.9	.000	4.48
22	710	76.0	.240	550	69.0	.155	310	64.4	.000	4.6325
29	650	79.0	.230	600	75.0	.170	410	69.9	.000	4.815
July 6	710	70.5	.230	550	72.0	.165	370	71.6	.000	4.7275
13	730	76.0	.240	650	75.0	.170	400	72.4	.140	6.785
20	620	76.5	.230	580	76.0	.165	400	73.8	.140	6.6175

[1] Bridge repaired on May 11 by D. H. Boggess.
[2] Bridge recalibrated at Weather Bureau Laboratory on June 6.

TABLE 7.—*Soil-moisture data for station 118*—Continued

Date	4-inch depth			12-inch depth			39-inch depth			Total deficiency (in)
	Resistance (ohms)	Mean air temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Thermistor temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Derived temperature (°F)	Deficiency (in/in)	
1951—Con.										
27	460	81.5	0.190	400	84.0	0.140	190	74.7	0.140	5.86
Aug. 3	680	71.0	.230	480	81.0	.160	280	75.5	.140	6.53
10	590	81.5	.220	410	78.0	.140	390	74.5	.140	6.10
17	560	81.0	.220	400	79.0	.140	310	76.2	.080	5.29
24	520	65.5	.180	420	75.0	.140	300	75.4	.080	4.97
31	580	72.0	.210	500	74.0	.160	350	73.5	.110	5.965
Sept. 7	600	69.0	.210	450	74.0	.140	350	73.4	.100	5.48
14	740	76.0	.250	840	74.0	.180	450	72.4	.140	7.04
21	700	68.0	.230	510	69.0	.150	400	71.6	.130	6.22
28	600	59.0	.200	450	70.0	.140	400	69.7	.120	5.67
Oct. 5	500	73.5	.190	450	69.0	.140	400	68.0	.120	5.59
12	750	52.5	.210	420	62.0	.110	400	65.6	.110	5.09
19	600	61.5	.200	450	66.0	.130	300	63.4	.040	4.415
26	400	55.0	.110	500	64.0	.140	450	62.2	.120	4.95
Nov. 2	700	52.0	.200	460	62.0	.130	410	60.7	.100	5.225
9	820	40.5	.200	400	55.0	.090	130	55.8	.000	3.175
16	130	60.0	.000	400	59.0	.100	600	55.0	.170	4.045
30	1,000	40.5	.220	550	48.0	.130	110	47.8	.000	4.035
Dec. 7	780	60.0	.230	560	53.0	.140	140	48.6	.000	4.29
14	1,220	36.0	.240	610	48.0	.140	190	47.4	.000	4.37
21	510	54.5	.160	480	46.0	.090	200	42.7	.000	2.855
28	450	24.5	.020	30	44.0	.000	50	40.4	.000	.16
1952										
Jan. 4	1,000	32.5	.200	620	45.0	.130	510	41.4	.070	4.82
11	820	30.5	.160	640	40.0	.120	500	39.6	.060	4.19
18	700	49.0	.200	620	43.0	.120	500	41.3	.070	4.645
25	1,230	34.5	.240	820	42.0	.160	510	41.0	.070	5.665
Feb. 1	1,380	40.5	.260	900	42.0	.160	590	39.7	.110	6.365
8	1,290	36.0	.250	800	43.0	.150	550	40.2	.100	5.975
15	1,450	30.5	.240	800	40.0	.150	530	39.3	.070	5.49
22	1,390	33.5	.250	800	41.0	.150	520	39.2	.070	5.57
29	1,380	42.0	.270	800	42.0	.150	600	38.6	.110	6.27
Mar. 7	1,420	34.0	.260	800	43.0	.150	520	37.9	.080	5.785
14	1,200	51.0	.270	750	43.0	.150	520	40.0	.080	5.865
21	1,190	50.0	.270	730	44.0	.150	530	42.0	.090	6.00
28	1,090	51.0	.260	690	51.0	.160	500	45.0	.100	6.23

TABLE 8.—*Soil-moisture data for station 132*

Date	4-inch depth			12-inch depth			39-inch depth			Total deficiency (in)
	Resistance (ohms)	Mean air temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Thermistor temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Derived temperature (°F)	Deficiency (in/in)	
1950										
Apr. 28	800	64.5	0.230	800	58.0	0.210	840	47.8	0.205	---------
May 5	700	69.0	.230	700	60.0	.200	700	50.3	.200	8.04
12	750	54.5	.220	650	65.0	.200	680	54.0	.200	7.96
19	700	51.5	.210	680	62.0	.200	650	55.2	.200	7.88
26	570	63.5	.200	600	67.0	.190	380	56.1	.100	6.275
June 2	620	68.0	.210	600	82.0	.210	470	58.6	.150	7.38
9	130,000	72.0	.350	850	71.0	.220	700	61.8	.210	9.485
16	100,000	74.0	.340	2,400	70.0	.280	700	63.7	.210	10.455
23	107,000	71.5	.340	24,000	72.0	.300	700	65.2	.210	10.805
30	130,000	73.5	.350	130,000	75.0	.320	640	67.8	.210	11.235
July 7	600	69.5	.210	750	76.0	.220	550	69.5	.195	8.1625
14	580	75.5	.220	680	79.0	.215	600	70.8	.205	8.29
21	650	65.5	.215	710	81.0	.220	600	72.2	.210	8.405
28	840	75.0	.250	780	80.0	.220	600	72.5	.210	8.685
Aug. 4	600	70.0	.220	600	80.0	.210	300	73.3	.180	7.865
11	900	78.5	.260	500	80.0	.190	400	73.2	.160	7.565
18	100,000	74.5	.340	1,320	78.0	.236	580	72.4	.200	9.55
25	165,000	71.0	.350	21,500	77.0	.290	610	72.2	.210	10.71
Sept. 1	760,000	82.5	.350	168,000	84.0	.350	620	73.5	.210	11.76
8	95,000	66.0	.340	55,000	76.0	.305	600	73.2	.210	10.8925
15	7,500	68.0	.300	6,000	73.0	.270	500	71.8	.195	9.7575
22	610	65.5	.205	4,000	73.0	.260	310	70.1	.100	7.54
29	800	58.0	.230	800	66.0	.220	460	65.6	.160	7.85
Oct. 6	820	55.5	.225	720	65.0	.210	500	65.2	.175	7.8375
13	820	52.5	.220	700	66.0	.205	500	64.0	.170	7.6425
20	1,390	62.0	.315	710	66.0	.205	550	64.0	.180	8.5375
27	950	47.5	.225	800	60.0	.210	550	61.8	.180	7.905
Nov. 3	1,200	64.0	.315	760	64.0	.210	570	62.0	.190	8.76
10	1,100	54.0	.310	800	62.0	.210	600	60.3	.190	8.72
17	2,230	51.5	.320	860	57.0	.215	620	55.9	.190	8.8875
24	1,200	44.0	.305	1,000	49.0	.220	660	51.9	.195	8.9225
Dec. 1	1,200	34.5	.300	1,060	43.0	.210	350	46.6	.140	7.965
8	400	45.5	.100	100	54.0	.170	480	46.4	.100	5.125
15	700	40.0	.180	670	45.0	.150	410	43.5	.070	5.01
22	900	29.0	.180	800	41.0	.180	400	38.8	.050	5.265
29	750	38.5	.180	800	42.0	.180	480	37.4	.080	5.67
1951										
Jan. 5	700	40.5	.185	650	51.0	.180	440	38.4	.050	5.305
12	790	35.0	.180	840	44.0	.190	540	38.2	.100	6.115
19	600	55.0	.190	740	48.0	.180	580	39.0	.125	6.3575
26	800	30.5	.160	730	45.0	.170	590	39.9	.125	5.9425
Feb. 2	620	33.6	.130	700	48.0	.170	488	39.0	.135	5.8375
9	810	17.8	.130	850	43.0	.190	610	35.3	.130	6.12
16	590	35.3	.120	700	48.0	.170	550	35.9	.110	5.42
23	400	40.0	.070	530	51.0	.120	580	38.5	.120	4.28
Mar. 2	380	50.0	.100	580	53.0	.140	500	41.3	.100	4.6
9	420	40.5	.080	540	52.0	.130	500	42.5	.100	4.265
16	490	42.0	.110	590	50.0	.140	540	41.4	.110	4.815
23	430	46.5	.100	570	51.0	.140	400	41.4	.080	4.33
30	420	56.0	.140	450	63.0	.110	410	43.1	.060	3.855
Apr. 6	340	52.0	.080	540	58.0	.140	610	45.6	.040	3.63
13	310	50.0	.050	400	62.0	.100	430	47.1	.025	2.4875
20	410	48.0	.100	430	62.0	.090	460	48.1	.100	3.725
27	390	52.0	.110	300	71.0	.000	360	50.2	.060	1.69
May 4	2,200	56.0	.280	300	69.0	.000	280	53.3	.010	2.375
14 [1]	1,130	57.0	.250	1,320	63.0	.230	900	55.2	.220	8.995
18	11,230	54.0	.310	1,940	67.0	.240	1,220	56.7	.235	9.8525
25	1,600	61.0	.280	1,610	61.0	.240	790	58.4	.210	9.275
June 1	2,040	74.0	.290	1,400	66.0	.230	1,380	61.9	.245	9.6525
8 [2]	920	65.0	.245	580	71.0	.205	310	64.4	.065	6.425
15	1,030	66.5	.250	980	70.0	.225	300	63.9	.050	6.6125
22	2,610	76.0	.300	920	73.0	.225	1,100	64.4	.240	9.5775
29	4,100	79.0	.300	1,160	80.0	.230	1,100	69.9	.240	9.665
July 6	2,500	70.5	.290	1,000	76.0	.230	1,200	71.6	.245	9.6525
13	20,500	76.0	.320	3,000	78.0	.250	1,200	72.4	.245	10.2425
20	820	76.5	.250	990	80.0	.230	200	73.8	.235	9.1975
27	860	81.5	.260	690	82.0	.220	800	74.7	.230	9.035

[1] Bridge repaired on May 11 by D. H. Boggess.
[2] Bridge recalibrated at Weather Bureau Laboratory on June 6.

TABLE 8.—*Soil-moisture data for station 132*—Continued

Date	4-inch depth			12-inch depth			39-inch depth			Total deficiency (in)
	Resistance (ohms)	Mean air temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Thermistor temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Derived temperature (°F)	Deficiency (in/in)	
1951—Con.										
Aug. 3	2,140	71.0	0.290	720	84.0	0.220	960	75.5	0.240	9.41
10	650	81.5	.240	670	82.0	.215	2,450	74.5	.265	9.26
										Partial
17	1,190	81.0	.280	590	84.0	.220	--------	--------	--------	6.09
24	820	65.5	.240	590	78.0	.220	--------	--------	--------	5.77
31	1,500	72.0	.280	650	78.0	.220	--------	--------	--------	6.09
Sept. 7	800	69.0	.240	650	78.0	.220	--------	--------	--------	5.77
14	10,000	76.0	.320	1,000	78.0	.230	--------	--------	--------	6.585
21	800	68.0	.240	750	73.0	.220	--------	--------	--------	5.77
28	700	59.0	.220	650	76.0	.220	--------	--------	--------	5.61
Oct. 5	700	73.5	.240	650	74.0	.220	--------	--------	--------	5.77
12	810	52.5	.220	890	67.0	.220	--------	--------	--------	5.61
19	800	61.5	.240	700	70.0	.220	--------	--------	--------	5.77
26	1,800	55.0	.280	700	66.0	.210	--------	--------	--------	5.915
Nov. 2	790	52.0	.220	640	66.0	.200	--------	--------	--------	5.26
9	1,000	40.5	.220	860	61.0	.220	--------	--------	--------	5.61
16	3,300	60.0	.290	800	63.0	.220	--------	--------	--------	6.17
30	1,200	40.5	.240	1,050	48.0	.220	--------	--------	--------	5.77
Dec. 7	1,000	60.0	.250	950	59.0	.230	--------	--------	--------	6.025
14	1,580	36.0	.250	1,120	49.0	.220	--------	--------	--------	5.85
21	500	54.5	.160	400	53.0	.030	--------	--------	--------	1.805
28	300	24.5	.000	500	44.0	.040	--------	--------	--------	.7
1952										
Jan. 4	120	32.5	.000	1,000	45.0	.210	--------	--------	--------	3.675
11	1,200	30.5	.220	700	40.0	.150	--------	--------	--------	4.385
18	850	49.0	.220	600	43.0	.100	--------	--------	--------	3.51
25	1,750	34.5	.250	1,480	42.0	.210	--------	--------	--------	5.675
Feb. 1	1,920	40.5	.260	1,780	42.0	.230	--------	--------	--------	6.105
8	1,800	36.0	.260	1,890	43.0	.230	--------	--------	--------	6.105
15	1,920	30.5	.250	1,780	39.0	.230	--------	--------	--------	6.025
22	1,890	33.5	.260	1,690	43.0	.230	--------	--------	--------	6.105
29	1,700	42.0	.260	1,630	43.0	.230	--------	--------	--------	6.105
Mar. 7	1,900	34.0	.260	1,790	43.0	.230	--------	--------	--------	6.105
14	1,490	51.0	.260	1,380	48.0	.230	--------	--------	--------	6.105
21	1,490	51.0	.260	1,450	49.0	.230	--------	--------	--------	6.105
28	1,580	51.0	.270	1,420	49.0	.230	--------	--------	--------	6.185

TABLE 9.—*Soil-moisture data for station 133*

Date	4-inch depth			12-inch depth			39-inch depth			Total deficiency (in)
	Resistance (ohms)	Mean air temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Thermistor temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Derived temperature (°F)	Deficiency (in/in)	
1950										
May 5	750	69.0	0.260	750	59.0	0.200	590	50.3	0.160	7.740
12	680	54.5	.220	680	63.0	.180	500	54.0	.140	6.800
19	650	51.5	.210	640	61.0	.160	450	55.2	.140	6.37
26	550	63.5	.200	550	65.0	.150	420	56.1	.130	5.98
June 2	500	68.0	.180	590	68.0	.170	410	58.6	.130	6.17
9	760	72.0	.060	750	69.0	.210	560	61.8	.170	6.45
16	800	74.0	.270	750	68.0	.210	550	63.7	.170	8.13
23	790	71.5	.260	760	71.0	.210	540	65.2	.170	8.05
30	4,200	73.5	.340	720	73.0	.210	460	67.8	.160	8.555
July 7	820	69.5	.270	680	71.0	.200	400	69.5	.140	7.55
14	750	75.5	.260	610	74.0	.190	460	70.8	.160	7.565
21	720	65.5	.240	700	76.0	.210	450	72.2	.160	7.755
28	840	75.0	.270	760	75.0	.220	460	72.5	.160	8.17
Aug. 4	600	70.0	.230	500	78.0	.170	200	73.3	.050	5.49
11	700	78.5	.260	500	75.0	.160	200	73.2	.050	5.555
18	2,370	74.5	.320	760	74.0	.220	500	72.4	.170	8.705
25	14,500	71.0	.370	700	73.0	.210	300	72.2	.110	8.120
Sept. 1	148,000	82.2	.460	3,850	77.0	.290	540	73.5	.190	11.32
8	70,000	66.0	.400	6,200	71.0	.300	450	73.2	.160	10.61
15	8,100	68.0	.360	8,700	70.0	.300	4,200	71.8	.250	11.505
22	7,100	65.5	.350	7,300	70.0	.300	4,700	70.1	.250	11.425
29	850	58.0	.260	830	63.0	.210	500	65.6	.160	7.915
Oct. 6	800	55.5	.250	730	63.0	.190	480	65.2	.160	7.485
13	840	52.5	.240	750	63.0	.190	480	64.0	.150	7.27
20	690	62.0	.240	730	67.0	.200	420	64.0	.140	7.31
27	940	47.5	.260	810	57.0	.190	500	61.8	.160	7.565
Nov. 3	820	64.0	.250	750	62.0	.200	500	62.0	.160	7.66
10	840	54.0	.250	800	60.0	.200	530	60.3	.160	7.66
17	900	51.5	.250	900	55.0	.210	560	55.9	.160	7.835
24	1,020	44.0	.240	950	49.0	.210	600	51.9	.170	7.89
Dec. 1	1,160	34.5	.240	1,000	44.0	.190	550	46.6	.140	7.135
8	440	45.5	.100	460	54.0	.140	100	46.4	.000	3.25
15	700	40.0	.180	570	43.0	.140	100	43.5	.000	3.89
22	850	29.0	.180	650	43.0	.150	150	38.8	.000	4.065
29	780	38.5	.200	700	42.0	.160	200	37.4	.000	4.40
1951										
Jan. 5	690	40.5	.180	530	49.0	.150	220	38.4	.000	4.065
12	790	35.0	.190	710	44.0	.160	260	38.2	.010	4.455
19	590	55.0	.200	650	44.0	.150	300	39.0	.050	4.9
26	700	30.5	.150	600	46.0	.150	250	39.9	.000	3.825
Feb. 2	670	33.6	.140	600	49.0	.160	240	39.0	.000	3.92
9	890	17.8	.150	690	42.0	.160	220	35.3	.000	4.0
16	530	35.3	.100	600	47.0	.160	190	35.9	.000	3.6
23	570	40.0	.140	490	50.0	.140	220	38.5	.000	3.57
Mar. 2	480	50.0	.140	500	52.0	.150	200	41.3	.000	3.745
9	510	40.5	.120	440	51.0	.130	180	42.5	.000	3.235
16	530	42.0	.120	510	48.0	.140	210	41.4	.000	3.41
23	450	46.5	.110	430	49.0	.120	200	41.4	.000	2.98
30	300	56.0	.020	360	60.0	.120	220	43.1	.000	2.26
Apr. 6	380	52.0	.080	390	56.0	.120	180	45.6	.000	2.74
13	320	50.0	.020	310	58.0	.100	200	47.1	.000	1.91
20	390	48.0	.080	400	57.0	.120	210	48.1	.000	2.74
27	200	52.0	.000	210	65.0	.040	80	50.2	.000	0.7
May 4	200	56.0	.000	140	62.0	.000	80	53.3	.000	0
14[1]	950	57.0	.260	1,140	60.0	.230	780	55.2	.200	8.805
18	1,200	54.0	.280	1,120	62.0	.220	900	56.7	.210	8.925
25	1,310	61.0	.290	1,260	58.0	.230	1,100	58.4	.230	9.45
June 1	1,230	74.0	.300	1,200	63.0	.230	1,020	61.9	.220	9.395
8[2]	900	65.0	.270	790	66.0	.200	690	64.4	.190	8.225
15	860	66.5	.260	750	67.0	.200	630	63.9	.180	8.01
22	800	76.0	.270	750	73.0	.210	650	64.4	.180	8.265
29	880	79.0	.280	730	73.0	.200	620	69.9	.190	8.305
July 6	900	70.5	.270	810	71.0	.210	630	71.6	.200	8.535
13	1,440	76.0	.300	800	78.0	.220	600	72.4	.190	8.815
20	590	76.5	.240	500	76.0	.180	340	73.8	.130	6.825
27	600	81.5	.240	450	75.0	.160	320	74.7	.120	6.34

[1] Bridge repaired on May 11 by D. H. Boggess.
[2] Bridge recalibrated at Weather Bureau Laboratory on June 6.

TABLE 9.—*Soil-moisture data for station 133*—Continued

Date	4-inch depth			12-inch depth			39-inch depth			Total deficiency (in)
	Resistance (ohms)	Mean air temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Thermistor temperature (°F)	Deficiency (in/in)	Resistance (ohms)	Derived temperature (°F)	Deficiency (in/in)	
1951—Con.										
Aug. 3	590	71.0	0.230	500	78.0	0.180	300	75.5	0.120	6.61
10	580	81.5	.240	500	78.0	.180	390	74.5	.150	7.095
17	500	81.0	.218	450	79.0	.150	300	76.2	.118	5.962
24	580	65.5	.215	480	73.0	.150	300	75.4	.117	5.9245
31	550	72.0	.217	450	73.0	.140	250	73.5	.085	5.3335
Sept. 7	680	69.0	.245	450	73.0	.140	250	73.4	.085	5.5575
14	680	76.0	.255	520	73.0	.160	330	72.4	.125	6.5275
21	640	68.0	.230	530	69.0	.160	300	71.6	.112	6.152
28	570	59.0	.197	500	75.0	.160	250	69.7	.077	5.4155
Oct. 5	550	73.5	.222	500	(?)	.150	200	68.0	.042	4.968
12	700	52.5	.225	550	63.0	.150	240	65.6	.067	5.3295
19	600	61.5	.217	500	67.0	.140	300	63.4	.100	5.536
26	600	55.0	.202	600	67.0	.170	300	62.2	.099	5.9275
Nov. 2	700	52.0	.225	590	63.0	.160	400	60.7	.132	6.382
9	840	40.5	.210	500	52.0	.110	300	55.8	.085	4.7525
16	350	60.0	.092	600	60.0	.160	680	55.0	.182	5.993
30	930	40.5	.225	710	47.0	.150	400	47.8	.118	6.018
Dec. 7	810	60.0	.253	660	49.0	.150	400	48.6	.119	6.2555
14	1,100	36.0	.230	820	49.0	.180	450	47.4	.121	6.6235
21	900	54.5	.292	500	47.0	.100	420	42.7	.104	5.49
28	50	24.5	(?)	400	44.0	.050	300	40.4	.044	1.469
1952										
Jan. 4	890	32.5	.260	990	45.0	.200	640	41.4	.150	7.605
11	850	30.5	.175	950	40.0	.190	700	39.6	.156	6.831
18	850	49.0	.240	740	43.0	.140	700	41.3	.160	6.53
25	1,450	34.5	.260	1,600	42.0	.260	840	41.0	.180	9.06
Feb. 1	1,510	40.5	.280	1,200	42.0	.220	890	39.7	.190	8.655
8	1,390	36.0	.270	1,120	42.0	.210	900	40.2	.180	8.265
15	1,470	30.5	.260	1,300	39.0	.230	890	39.3	.180	8.535
22	1,400	33.5	.260	1,230	48.0	.240	850	39.2	.180	8.71
29	1,460	42.0	.270	1,220	42.0	.220	900	38.6	.180	8.44
Mar. 7	1,460	34.0	.260	1,300	42.0	.230	910	37.9	.180	8.535
14	1,280	51.0	.280	1,090	43.0	.230	840	40.0	.180	8.695
21	1,180	50.0	.280	1,200	47.0	.240	850	42.0	.180	8.87
28	1,290	51.0	.280	1,150	48.0	.240	800	45.0	.180	8.87

1.33 inches of water from the intermediate vadose zone, and discharge it by evapotranspiration at a rate that much in excess of the computed rate. This explanation is admittedly conjectural, and improbable. The anomaly and many others like it, which may be found by study of the budget data (table 1), emphasize the need for accurate basinwide measurements of soil moisture and possibly for the development of methods of instrumentation to determine moisture interchanges in the vadose zone.

GROUND-WATER STORAGE

The infiltrated water that reaches the ground-water zone is the most significant factor in the present basin study. The amount of water that may be stored in a rock or soil is limited by the porosity of the rock or soil. However, the amount of water that a saturated material will yield when allowed to drain by gravity is somewhat less than the porosity because some of the stored water will be held by capillarity. The ratio of the volume of drained, or gravity, water to the total volume of the rock or soil is called the specific yield (Meinzer, 1923), a term that is in wide use. The [redacted] stage and Y is [redacted].

The same expression represents ideally the amount of water entering storage with a rising water level. However, in a sand that is fairly homogeneous except that a silt or few clay lenses are within the zone of ground-water fluctuation, a rise of the water table from below to above one of these lenses would not result immediately in complete saturation of it. Though the silt or clay might be considerably more porous than the surrounding sand, its permeability might be so low that a rather long time would be required for the water to penetrate the lens, and even then some air would be trapped. Conversely, when the water table receded, leaving a partly or completely saturated silt-clay lens somewhere within the capillary fringe, the lens would not yield its gravity water as readily as the surrounding sand. Rather, there would be a leakage from the silt-clay lens down to the lowered water table. Further, the water table responds quickly to every sizable rainfall, and a rapidly rising water table entraps air in even the coarser sediments. Trapping of air results in a decrease in porosity and permeability, until the air is dissolved in the water.

Because of these considerations, a new term, gravity yield, will be defined here in such a way that the definition will include length of drainage time. The gravity yield of a rock or soil after saturation or partial saturation is the ratio of (1) the volume of water it will yield by gravity to (2) its own volume, during the period of ground-water recession. Gravity yield, in effect is a "field" specific yield; it is a function of time and of previous fluctuations of infiltering water, as well as of the character of the rock or soil, whereas specific yield is the end point that may be reached only after a history of complete saturation and a sustained drought or a prolonged period of pumping. The specific yield is seldom attained under field conditions because of the length of time required for complete draining.

QUALITY OF WATER

A factor that affects the hydrologic cycle, although sometimes to a minor extent only, is the quality of the surface and ground waters moving over and within a drainage basin. In basins adjacent to salt water, there is a zone of contact between fresh water and salt water that fluctuates with the water table. In semiarid basins a layer of calcium carbonate (caliche) is often left by evaporating soil moisture and ground waters. In arid basins, alkali residues may be left by surface and ground water evaporating from playa lakes. The porosity and permeability of the soil are altered by the precipitated solids. Moreover, dissolved solids may have a coagulating, or a dispersing, effect on the clays, according to the character of the water in relation to the ion-exchange properties of the clays; thus they can alter the porosity and permeability of the rock both in the vadose zone and in the ground-water reservoir.

To determine what effect, if any, the quality of water may have on the hydrologic budget in this study, 3 water samples were taken from wells in the headwaters of the basin, 1 sample was taken from a ditch on the south side of the airport, and another sample was taken from Beaverdam Creek. The analyses are given in the following table. Both the surface and ground waters are low in dissolved solids and iron and are soft. The pH (4.8) of the surface water is in the acid range of the pH scale; that of the well waters (6.1 to 6.3) is higher but still on the acid side. The water has no recognizable chemical property that may be considered to have an appreciable effect on the water budget.

Analyses of water from Beaverdam Creek basin

[Collected December 14, 1950. Chemical constituents in parts per million by weight]

	Well 122	Well 125	Well 123	Ditch near well 110	Beaverdam Creek near staff gage 129
Silica (SiO_2)	9.6	6.4	11	8.6	7.8
Iron (Fe)	.3	.2	.3	.01	.03
Calcium (Ca)	2.8	4.1	3.2	1.6	9.3
Magnesium (Mg)	.7	1.0	.3	.9	2.3
Sodium (Na)	5.9	1.6	3.7	3.7	6.3
Potassium (K)	2.8	3.3	1.6	1.5	2.0
Carbonate (CO_3)	0	0	0	0	0
Bicarbonate (HCO_3)	9.2	12	6.9	1.4	1.2
Sulfate (SO_4)	1.7	1.3	.2	12	26
Chloride (Cl)	12	7.6	5.4	6.2	12
Nitrate (NO_3)	.1	2.2	.2	.3	4.3
Dissolved solids (sum)	40	33	32	36	71
Hardness as $CaCO_3$	10	14	9	8	33
Specific conductance (micromhos at 25°C)	98.1	76.6	51.1	53.7	127
pH	6.1	6.3	6.1	4.8	4.8
Temperature (°F)	57	55	57	33	38
Depth (feet below land surface)	11.5	18.7	11.0	----------	----------
Altitude (feet above sea level)	78.8	58.6	77.6	42	42

The samples were taken on December 14, 1950, when the mean ground-water stage was about 45.1 feet above mean sea level. This is about the midpoint of the range of fluctuation, so the quality of the waters sampled may be regarded as representing average conditions for the year at the sites sampled. At a low ground-water stage in the summer, the concentrations of dissolved solids may be slightly higher; and at the highest stage in early spring, the mineralization probably is somewhat less owing to the diluting effect of recharge from precipitation.

If the maximum agricultural production is to be attained, it will be necessary to supplement the precipitation by means of irrigation. The source of the irrigation water might be either surface or ground water. However, determination of the quantity of water available for irrigation is not all that must be done. The quality of the irrigation water also is of great importance.

It can be seen from an inspection of the analyses that the water sampled is of good quality for most purposes. The rather low pH would perhaps make the water undesirable without prior treatment for use where corrosiveness is a factor. However, water of the quality shown in the analyses would be suitable for irrigation. According to Magistad and Christiansen's standards (1944) for irrigation waters, the above samples would be placed in class 1—water that is excellent to good, and suitable for most plants under most conditions. Likewise in the interpretation of irrigation waters by Wilcox (1948) in which the percent sodium and dissolved-solids content (as indicated by electrical conductivity) are considered, these waters would be classified as excellent to good.

DETERMINATION OF EVAPOTRANSPIRATION AND GROUND-WATER STORAGE

For any given period of observation, the water gain may be set equal to the runoff and water losses through evapotranspiration, plus or minus net changes in basin storage. For a given period of time, equation (1), page 62 may be expressed in greater detail as

$$P=R+ET+\Delta H\cdot Yg+\Delta SM+\Delta SW \qquad (2)$$

where P=precipitation

R=runoff

ET=evapotranspiration

ΔH=change in mean ground-water stage (final stage minus initial stage)

Yg=gravity yield

ΔSM=change in soil moisture (final soil moisture minus initial soil moisture)

ΔSW=change in surface-water storage (final storage minus initial storage)

The hydrologic budget for the Beaverdam Creek basin includes weekly measurements of P, R, ΔH, ΔSM, and ΔSW. Gravity yield, needed for computing the mean changes in ground-water storage (see p. 95), was unknown. Evapotranspiration, although not measured, was not entirely unknown, for it is a cyclic function of the time of the year and is assumed to approximately repeat itself each year. Furthermore, the annual evapotranspiration is essentially equal to the excess of annual precipitation over annual runoff, the change in basin storage from one year to the next being small. Although it would be possible to devise a second equation for evapotranspiration, permitting a formal solution for ET and Yg, the equation would be involved and the nature of the data lends itself more readily to a solution by convergent approximations.

METHOD OF CONVERGENT APPROXIMATIONS

If a value of Yg is assumed, equation (2) can be solved for the weekly evapotranspiration losses. These losses may then be plotted against the calendar week using, in effect, the time of year as a control. The double-integration method (Langbein, written communications) of fitting a smooth curve to the computed weekly evapotranspiration was used.

Using the ET figures from the graph, the equation can then be solved for the expression $(P-R-\Delta SW-ET-\Delta SM)$, for each week. These increments, called here the infiltration residuals, are accumulated, week by week, and plotted against H, the mean elevation of the water table. The infiltration residual $(P-R-\Delta SW-ET-\Delta SM)$ is identical to $H \cdot Yg$, so that the slope of the curve drawn through the plotted data is Yg. Using this estimate of Yg, the above procedure is repeated, resulting in a further refinement of the evapotranspiration graph and of the gravity-yield estimate. The process is repeated until there is no further significant change in Yg. The final evapotranspiration graph is shown in figure 17. The final calculated weekly evapotranspiration, in inches, derived from this graph is shown in the last column of table 1.

A gravity yield of 14 percent was assumed initially for the first approximation. In the third approximation Yg ranged from 10 to 12.5 percent, depending upon the mean ground-water stage as shown in figure 18, which illustrates the scatter of weekly points. The fourth and final approximation of Yg, shown in plate 10, resulted in a close grouping of all points along a line slope that gives a Yg of 11.0 percent, although individual increments ranged from 8.3 to 16.7 percent.

The scattering of data evident in figure 18 is due to errors in the basic soil-moisture data, short-period variations in the gravity yield, and the assumption of evapotranspiration as primarily a function of the time of year. For example, the hydrologic budget includes several weeks when obviously anomalous readings of soil moisture and ground-water fluctuations occurred. During the week of September 23–29, 1950, a gain in soil moisture of 2.29 inches was recorded, even though rainfall in that week amounted to only 0.06 inch. During the week of November 3–9, 1951, ground-water levels rose an average of

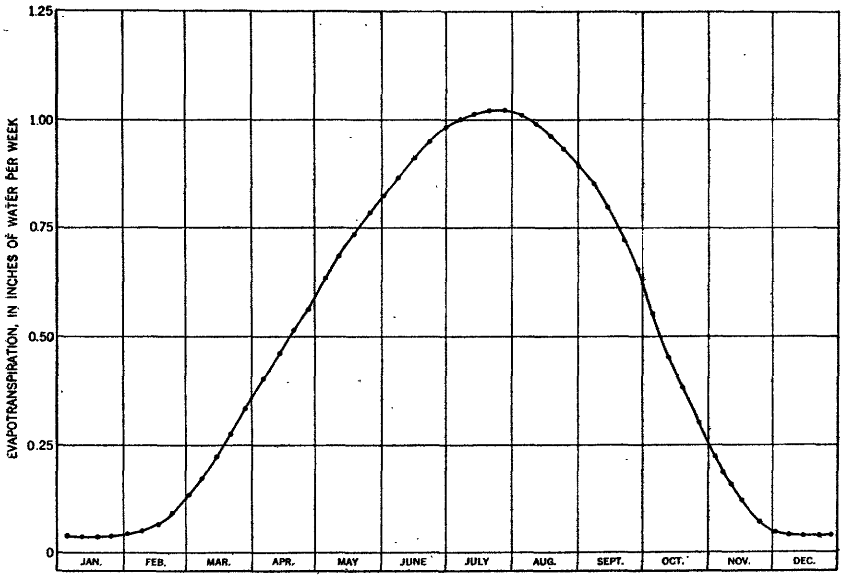


FIGURE 17.—Curve of weekly evapotranspiration in Beaverdam Creek basin.

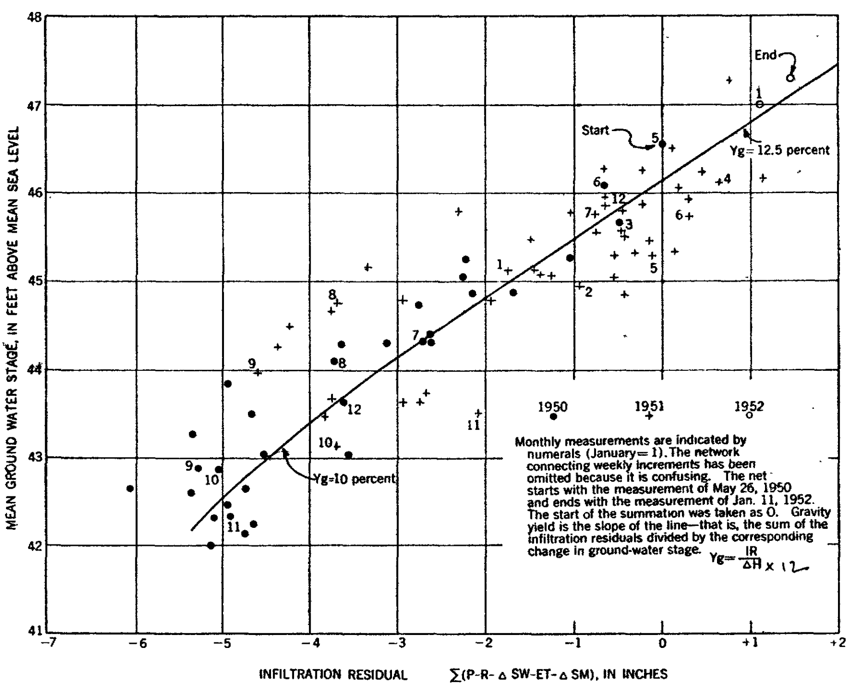


FIGURE 18.—Third approximation of gravity yield derived from a plot of mean ground-water stage and the sum of infiltration residuals.

2.75 feet, although there was only 3.25 inches of precipitation, an obvious inconsistency in view of the concurrent increases in runoff and soil-moisture storage.

These apparent anomalies remain unexplained because of a lack of understanding of the flow of water in the vadose zone, that zone between the surface and the water table. The storage in the part of the vadose zone below the soil has been assumed to be a constant, that part of the zone functioning presumably as a uniform transmitter of water from the soil to the water table. This presumption may not be justified. Air undoubtedly plays a part in moisture changes in the vadose zone. Condensation of water vapor may occur when air temperatures drop below the dew point, and this may account for a part of the apparent gain in soil moisture during the last week in September 1950. Such condensation could, theoretically, increase storage somewhat throughout the vadose zone.

Another possibility that had to be ignored is the "Lisse" effect, or rise in water level in wells almost immediately after a small rain. This effect has been ascribed to the change in capillary tension created by the increased pressure of air trapped in the vadose zone by the water moving down from the soil zone. This relief of tension allows water stored in the capillary zone to recharge the water table, causing a sudden rise in the water level in wells even though there has been no opportunity for the infiltrated rainfall to reach the water table. Krul and Liefrinck (1946, p. 43), in discussing ground-water replenishment in the dune area of Holland, say:

> A sudden temporary rise in the indications of the phreatic level in standpipes after showers may also occur in cases where the capillary fringe does not reach the surface. This may be explained by the compression of the air volume contained in the interstices, resulting from a downward capillary penetration of the rainwater. A rainfall of a few millimeters may then be accompanied by a rise of the standpipe indications in centimeters. This last phenomenon is termed in Holland, the "Lisse"-effect, after a village in the bulb-growing region, where it was first observed at the Agricultural Experiments Station.

Indeed, our knowledge of the movement of moisture in the vadose zone is so meager that it is still conceivable that a thick vadose zone could store the recharge from one or more rainfalls in the form of belts of infiltrating water slowly percolating downward to the water table. The poor correlation between rise of water levels in wells and rainfall in small amounts could be due to absorption of rainfall at the water table coincident with percolation of water from a downpour saturating the soil zone.

The long-standing idea that the soil-moisture deficiency must be satisfied before any water moves toward the water table has not yet been satisfactorily explained away, even though it can be shown that ground-water recharge has occurred while soil-moisture deficiencies persisted.

The pressure exerted by the tons of rainfall in saturating the soil zone must be transmitted instantaneously through the skeletal structure of the vadose zone to the water table and it may result in rearrangement of the grain packing, producing a rise in water level in wells as a result of the process of dilatancy, described by Reynolds (1885, 1886). Such an effect probably would be very small by this time, however, as the sediments have been exposed to these forces for thousands of years.

The possibility of Chinook (foehn) winds—dry winds of great evaporative capacity—penetrating the open soil pores and removing moisture from the vadose zone has not been evaluated.

The budget summations of a weekly synopsis are not precise, because the measurements themselves, spanning an 8-hour period, are not representative of a single instant of time, even though they are compressed into an interval representing 4.8 percent of the week. Daily measurements doubtless would lead to better weekly precision, but with water in continual transit even such a weekly summation is likely to lead to some statistical anomalies. These problems deserve detailed investigation by hydrologists to explain the aberrations apparent in weekly or other short-period hydrologic budgets. Until these investigations are made, a gross statistical solution must suffice.

CHECK CALCULATION FOR GRAVITY YIELD

A method of estimating gravity yield that serves as an independent check on the foregoing method of convergent approximations is based on a critical selection of periods of ground-water recharge. Conditions for computing gravity yield are best when such troublesome variables as evapotranspiration and soil-moisture change are small, and ground-water recharge is great. These conditions prevail when the following assumptions are valid: the soil-moisture deficiency is zero at times when the mean ground-water stage rises a foot or more, and the evapotranspiration losses are comparatively low. These conditions were met during the following periods: December 2–29, 1950; February 3–23, 1951; November 3–30, 1951; December 1–28, 1951; and January 5–February 1, 1952. The significant rises in ground-water stage are shown in figure 4, and the low evapotranspiration loss at these times of year is indicated by figure 17.

The precipitation during these periods can be set equal to the total runoff plus the net addition to the ground-water and surface-water storages plus a comparatively small amount of evapotranspiration. Stated as an equation, using the symbols defined on page 85,

$$P=R+\Delta H\cdot Yg+\Delta SW+ET \qquad (3)$$

or

$$Yg=\frac{P-R-\Delta SW-ET}{\Delta H}$$

The precipitation and runoff, in inches, are derived as the sum of the weekly increments in table 1. The changes in surface-water storage, given in the budget, table 1, for Schumaker Pond, ΔS_s, Parker Pond, ΔS_p, and the stream channels, ΔS_c, were added together for each period to obtain ΔSW.

$$\Delta SW=\Delta S_s+\Delta S_p+\Delta S_c \qquad (4)$$

The water losses by evapotranspiration were assumed to be relatively small, for these periods occurred during late autumn and winter, and were estimated to be about 0.05 inch a week. The net ΔH for each period can be obtained directly from the mean ground-water stages in the budget, table 1.

A sample computation of gravity yield, based on these assumptions and data, for the period December 2–29, 1950, is presented below:

Source	*Computation*	*Inches*
Table 1	$P=1.79+0.77+0.11+0.27$	= 2.94
Do	$R=0.186+0.290+0.187+0.159$	= .82
Do	$\Delta SW=\Delta S_s+\Delta S_p+\Delta S_c$	= .03
Estimated	$ET=4$ weeks × .05	= .20
Table 1	$\Delta H=(44.86-43.62)\times 12$	=14.88
substituting in equation (3)	$Yg=\frac{2.94-0.82-0.03-0.20}{14.88}$	=0.130
	=13.0 percent	

Hydrologic data for the remaining four periods suitable to this analysis appear in the following table.

Estimates of gravity yield

	Feb. 3–23, 1951	Nov. 3–30, 1951	Dec. 1–28, 1951	Jan. 5–Feb. 1, 1952
P ....inches	1.79	4.47	4.28	4.82
R ....do	.73	1.37	1.88	2.71
ΔSW ....do	−.01	.03	−.01	.04
ET ....do	.15	.20	.20	.20
ΔH ....do	10.6	29.0	18.5	15.8
Yg ....percent	8.7	9.9	11.9	11.8

The above estimates of gravity yield, which range from 8.7 to 13.0 percent, average 11.1 percent, in close but probably coincidental agreement with the final estimate determined by the method of convergent approximations. These check values of gravity yield were obtained under conditions of a rising water table, when the gravity yield percentage would be lower because of entrapped air. That is, the water levels would be too high, and the gravity yield thus would be computed too low. Hydrologists have noted the same phenomenon in the dunes of the Netherlands. Krul and Liefrinck (1946, p. 40) say:

> An observation worth mentioning was that indications of water levels computed during an infiltration period with a rising water table were always found to be too high, a phenomenon which was attributed to compression of the air contained in the sand interstices * * *

In the analyses that follow, a gravity yield of 11 percent will be used as a generalized average.

LABORATORY DETERMINATION OF SPECIFIC YIELD

The specific yield of a rock or soil is the ratio of (1) the volume of water which, after being saturated, it will yield to gravity to (2) its own volume (Meinzer, 1923). Specific yield, as a percentage, may be expressed by the formula

$$Y=100\frac{x}{V}$$

in which Y is the specific yield, x is the volume of gravity water in the rock or soil, and V is the volume of the rock or soil. Saturated rocks or soils that are allowed to drain will not yield all the water occupying the pore spaces. The water that does not yield to gravity is held in final retention, and is expressed by the term "specific retention." The specific yield and specific retention together equal the porosity. The above expression for specific yield may be stated in the form

$$Y=100\left(\frac{V_p-V_r}{V}\right)=100\left(\frac{V_p}{V}\right)-100\left(\frac{V_r}{V}\right) \quad (5)$$

where V_p is the volume of pore space; V_r is the volume of water retained; 100 (V_p/V) is the porosity; and 100 (V_r/V) is the specific retention of the soil.

The specific retention is approximately equal to the moisture content at the moisture equivalent, the latter being expressed by the formula

$$100\frac{c}{W}$$

where c is the weight of the water which the soil, after saturation, will retain against a centrifugal force 1,000 times the force of gravity, and W is the weight of the soil when dry (Meinzer, 1923). The mois-

468445—59——7

ture equivalent can be converted into a volume unit comparable to specific yield and specific retention by multiplying it by the specific gravity of the dry soil.

The procedures for determining porosity were essentially the same as those described by Stearns (1927, p. 131–134). Porosity determinations for sediments from the Beaverdam Creek basin were made by R. W. Stallman at the hydrologic laboratory of the U. S. Geological Survey, as shown below:

Type of material	*Porosity (percent)*
Medium-grained sand	38.0
Sandy silt	38.3
Sandy clay	36.5
Average	37.6

The samples were taken from three pits, which were dug down to the water table at well sites 108, 116, and 133. Duplicate samples were taken for determination of the moisture equivalent. The samples were collected on March 6, 1951, when the mean ground-water stage was about 45.5 feet above mean sea level, which is approximately the mean for the 2-year period. The moisture equivalents were determined by the centrifuge method at the Plant Industry Station of the Department of Agriculture, Beltsville, Md., under the guidance of V. J. Kilmer. The logs of the pits and the moisture equivalent of each sample are shown in the following table.

An inspection of the preceding table shows that the converted moisture equivalents, which range from 2.3 to 39.6 percent, are greatest for the clay and least for the sand. Table 5 shows the predominance of medium-grained sand in the basin. The pit logs also indicate a predominance of sand, so that a single arithmetic average of the converted moisture equivalents, assumed to be equal to the specific retention, is reasonable. Substituting the average porosity and the average converted moisture equivalent in equation (6) gives a specific yield of 21.0 percent (37.6 − 16.6).

It is possible that this high specific yield was due, in part, to inadequate sampling of the basin. Serious errors are apt to be brought in when comparatively large areas are represented by only a few samples. It is reasonable, however, that the specific yield would be higher than the gravity yield, because it is unlikely that ground-water drainage during the period of observation was ever accomplished so completely that all gravity water was released from storage.

Logs of, and moisture equivalent of samples from, test pits in the Beaverdam Creek basin

Depth (ft below land surface)	Thickness (ft)	Description	Average moisture equivalent (percent by weight)	Moisture equivalent times specific gravity of dry soil (percent moisture by volume)
		Pit 1, near well 108		
0.5	0.5	Soil, dark-gray	4.6	7.6
1.0	.5	Sand, clayey, reddish-brown	4.7	7.8
3.0	2.0	Sand, clayey, brown	2.6	4.3
4.0	1.0	Sand, clayey, buff	1.4	2.3
		Pit 2, near well 116		
1.4	1.4	Sand, buff, medium- to fine-grained, little clay	2.2	3.6
2.0	.6	Sand, clayey, dark-grayish	6.0	9.9
2.3	.3	Sand, clayey, dark-grayish	9.8	----
2.7	.4	Sand, clayey, light-tan	4.7	7.8
3.3	.6	Clay and sand, reddish-brown	5.8	9.6
4.8	1.5	Clay and sand, reddish-brown; with coal	10.0	16.5
5.5	.7	Clay, gray; with reddish-brown sandy streaks	18.0	29.7
		Pit 3, near well 133		
0.5	0.5	Soil, gray	2.8	4.6
3.5	3.0	Sand, clayey, buff	4.0	6.6
4.5	1.0	Clay; with iron stains; some sand and gravel (auger samples from 7.0 to 17.5 ft)	22.9	37.8
7.0	2.5	Sand and clay, gray	18.6	30.7
10.0	3.0	Sand, medium- to fine-grained, light-gray; some clay	13.4	22.1
11.0	1.0	Clay, light-gray; with iron stains and some gravel	19.1	31.5
13.0	2.0	Clay, rose-colored	24.0	39.6
17.5	4.5	Sand and clay, gray	16.6	27.4
		Grand average	10.1	16.6

GROUND-WATER BUDGET

A part of the precipitation percolates down through the soil and rock to the water table, the top of the zone of saturation. Some of the water reaching the water table drains into stream channels and is carried from the basin. Still another part of the ground water is lost through evaporation and transpiration. The excess of infiltering water over ground-water drainage and ground-water evapotranspiration results in increased ground-water storage and is manifested by rising ground-water levels. If G_r is the ground-water recharge, D is the ground-water drainage, $\Delta H \cdot Yg$ is the net change in ground-water storage, and ET_g is the ground-water evapotranspiration, then

$$G_r = D + \Delta H \cdot Yg + ET_g \qquad (7)$$

where ΔH is the change in mean ground-water stage and Yg is the gravity yield. Deep leakage is assumed to be insignificant (see p. 62).

GROUND-WATER RECHARGE

The amount of water that reaches the saturated zone can be estimated from figure 4. With each significant rainfall the mean ground-water stage rises sharply. The amount of recharge for each month is nearly equal to the sum of the individual rises within that month multiplied by the gravity yield, which, on the basis of previous calculations, was taken as 11 percent. However, this amount falls short of the true recharge by the amount of ground-water drainage occurring during the rise. To account for this part of the recharge, the hydrograph prior to the rise was projected to the date on which the peak of the rise occurred. This projection, or antecedent hydrograph, represents the recession in ground-water stage had there been no recharge. The difference between the peak stage and recession stage on the day of the peak of the rise, multiplied by the gravity yield, is equal to the ground-water recharge. For example, the ground-water levels during the month of February 1951 rose twice, in response to two rainfalls. The mean changes in stage, recession stages to peaks, were 0.80 and 0.45 foot respectively, or a total change of 1.25 feet. The total recharge for this month was $\Delta H_r \cdot Yg = 1.25 \times 12 \times 0.11 = 1.65$ inches. Recharge calculations for the 24 months of the budget are shown in the following table. This same method of estimating recharge was applied to the Pomperaug River basin in Connecticut (Meinzer and Stearns, 1929).

Ground-water recharge

[Gravity yield, Yg=11 percent]

	Change in water level ΔH (ft)	Ground-water recharge Gr (in)		Change in water level ΔH (ft)	Ground-water recharge Gr (in)
1950			*1951*—Continued		
April	0.7	0.92	April	0.45	0.60
May	1.5	1.98	May	1.65	2.18
June	.2	.26	June	2.2	2.90
July	1.1	1.45	July	1.45	1.91
August	.2	.26	August	.80	1.06
September	.9	1.19	September	.30	.40
October	0	0	October	.70	.92
November	1.5	1.98	November	3.55	4.69
December	2.15	2.84	December	2.35	3.10
1951			*1952*		
January	.80	1.06	January	2.45	3.23
February	1.25	1.65	February	1.6	2.11
March	1.3	1.72	March	3.2	4.22

GROUND-WATER DRAINAGE

The ground-water drainage for each month is calculated from the hydrograph of ground-water runoff (pl. 7 and also p. 63). The amount of drainage in equivalent inches of water over the basin can be computed by use of the simple formula

$$D=\frac{(\Sigma d)\ (0.0372)}{A}\ \text{inches}$$

where Σd is the accumulated day-by-day ground-water runoff for the month, in cfs days; 0.0372 is a conversion factor; and A is the area of the basin, which is 19.5 square miles. The daily drainage is read directly from plate 7. The total monthly drainage from the basin is given in the following table.

The total ground-water drainage for the 2-year period was 21.46 inches, which is 26 percent of the total precipitation and 72 percent of the total runoff carried by Beaverdam Creek. That is, 72 percent of the basin's runoff represented ground-water runoff.

Ground-water drainage from the Beaverdam Creek basin

	Ground-water runoff, in cfs days	Drainage, (in)		Ground-water runoff, in cfs days	Drainage, (in)
1950			*1951*—Continued		
April	567	1.08	May	410	0.78
May	537	1.02	June	548	1.05
June	388	.74	July	428	.82
July	284	.54	August	308	.59
August	223	.43	September	230	.44
September	174	.33	October	217	.41
October	177	.34	November	462	.88
November	154	.29	December	717	1.37
December	331	.63	*1952*		
1951			January	961	1.83
January	356	.68	February	1,081	2.06
February	394	.75	March	1,443	2.59
March	481	.92			
April	465	.89	Total		21.46

GROUND-WATER STORAGE

The difference between the beginning-of-month and end-of-month mean ground-water stage, ΔH, multiplied by the gravity yield, Yg, for the particular range in stage is equal to the net change in ground-water storage. The ΔH in feet each month can be read directly from the hydrograph shown in figure 4. The gravity yield was taken as 11 percent throughout the entire ground-water budget. For example, the mean ground-water stage at the beginning of June 1950 was 46.2 feet and the end-of-month stage was 44.4, a mean change of -1.8 feet or -21.6 inches. The net change in ground-water storage, $\Delta H \cdot Yg$, for this month was -2.38 inches, the negative sign indicating a storage decrease. The change in ground-water storage from beginning to end of the 2-year period amounted to a net gain of 1.7 inches, which is about 2.1 percent of the total precipitation. The data on net ground-water storage, month by month, appear in the following table.

Net changes in ground-water storage in Beaverdam Creek basin

	Mean ground-water stages			Storage change ΔH·Yg (in)
	Beginning (ft)	End (ft)	ΔH (in)	
1950				
April	46.8	45.9	−10.8	−1.19
May	45.9	46.2	+3.6	+.40
June	46.2	44.4	−21.6	−2.38
July	44.4	44.2	−2.4	−.26
August	44.2	43.0	−14.4	−1.58
September	43.0	43.1	+1.2	+.13
October	43.1	42.4	−8.4	−.92
November	42.4	43.4	+12.0	+1.32
December	43.4	44.8	+16.8	+1.85
1951				
January	44.8	45.0	+2.4	+.26
February	45.0	45.75	+9.0	+.99
March	45.75	46.0	+3.0	+.33
April	46.0	45.35	−7.8	−.86
May	45.35	45.8	+5.4	+.59
June	45.8	45.8	0	0
July	45.8	44.9	−10.8	−1.19
August	44.9	44.2	−8.4	−.92
September	44.2	43.4	−9.6	−1.06
October	43.4	43.55	+1.8	+.20
November	43.55	46.0	+29.4	+3.23
December	46.0	47.3	+15.6	+1.72
1952				
January	47.3	48.2	+10.8	+1.19
February	48.2	47.75	−5.4	−.59
March	47.75	48.1	+4.2	+.46
Total				+1.72

GROUND-WATER EVAPOTRANSPIRATION

Loss of ground water in a vapor state through evaporation and transpiration is a function of stage as well as season. Where ground-water levels are near the land surface during the growing season, considerable water is taken up by plant roots and transpired through the leaves to the atmosphere, and water is lost by direct evaporation from the soil also. The combined water losses from the saturated zone through evaporation and transpiration are calculated from the following equation:

$$ETg = G_r - D - \Delta H \cdot Yg$$

The monthly amounts of ground-water recharge, ground-water drainage, net change in ground-water storage, and ground-water evapotranspiration are shown in table 10. Also shown in table 10 are the approximate monthly precipitation and the total evapotranspiration. Figure 19 shows the total evapotranspiration and ground-water evapotranspiration, in inches per month.

$G_r = D + \Delta H \cdot Y_g + ET_g$

TABLE 10.—*Ground-water budget*

[All items expressed in inches]

	Precipitation P	Recharge G_r	Drainage D	Change in ground-water storage $\Delta H \cdot Y_g$	Evapotranspiration	
					Ground-water ET_g	Total ET
1950						
April	2.20	0.92	1.08	−1.19	+1.03	2.07
May	3.73	1.98	1.02	+.40	+.56	3.26
June	1.26	.26	.74	−2.38	+1.90	3.94
July	4.84	1.45	.54	−.26	+1.17	4.49
August	1.77	.26	.43	−1.58	+1.41	4.22
September	4.78	1.19	.33	+.13	+.73	3.23
October	1.27	0	.34	−.92	+.58	1.73
November	3.48	1.98	.29	+1.32	+.37	.49
December	3.34	2.84	.63	+1.85	+.36	.18
1951						
January	1.63	1.06	.68	+.26	+.12	.18
February	2.24	1.65	.75	+.99	−.09	.30
March	2.81	1.72	.92	+.33	+.47	1.03
April	2.69	.60	.89	−.86	+.57	2.07
May	3.75	2.18	.78	+.59	+.81	3.26
June	5.46	2.90	1.05	0	+1.85	3.94
July	3.46	1.91	.82	−1.19	+2.28	4.49
August	4.29	1.06	.59	−.92	+1.39	4.22
September	3.51	.40	.44	−1.06	+1.02	3.23
October	3.00	.92	.41	+.20	+.31	1.73
November	5.14	4.69	.88	+3.23	+.58	.49
December	4.29	3.10	1.37	+1.72	+.01	.18
1952						
January	4.85	3.23	1.83	+1.19	+.21	.18
February	3.19	2.11	2.06	−.59	+.64	.30
March	5.85	4.22	2.59	+.46	+1.17	1.03
Total	82.83	42.63	21.46	+1.72	19.45	50.24

COMPARISON TO THE POMPERAUG RIVER BASIN STUDY

In the introduction to this report the study made in the Pomperaug River basin in Connecticut, by Meinzer and Stearns (1929) was mentioned as a similar investigation involving a water budget, of which the Beaverdam basin study is, in a sense, a sequel. Periodic measurements of precipitation, surface runoff, and ground-water levels were made in the Pomperaug basin from the summer of 1913 to the end of 1916, but measurements of soil moisture and surface-water storage were not made.

The Pomperaug basin is 89 square miles in area and ranges in altitude from 100 to 1,150 feet above sea level. It is underlain by ancient crystalline rocks, such as schist, gneiss, and diorite, except in the south-central part, where volcanic trap rock and sedimentary rocks of Triassic age occur. Spread over these rocks is a mantle of glacial drift, generally thin and absent in places. The average annual precipitation in the basin was 44.48 inches and the mean annual temperature at Waterbury was 48.8° F.

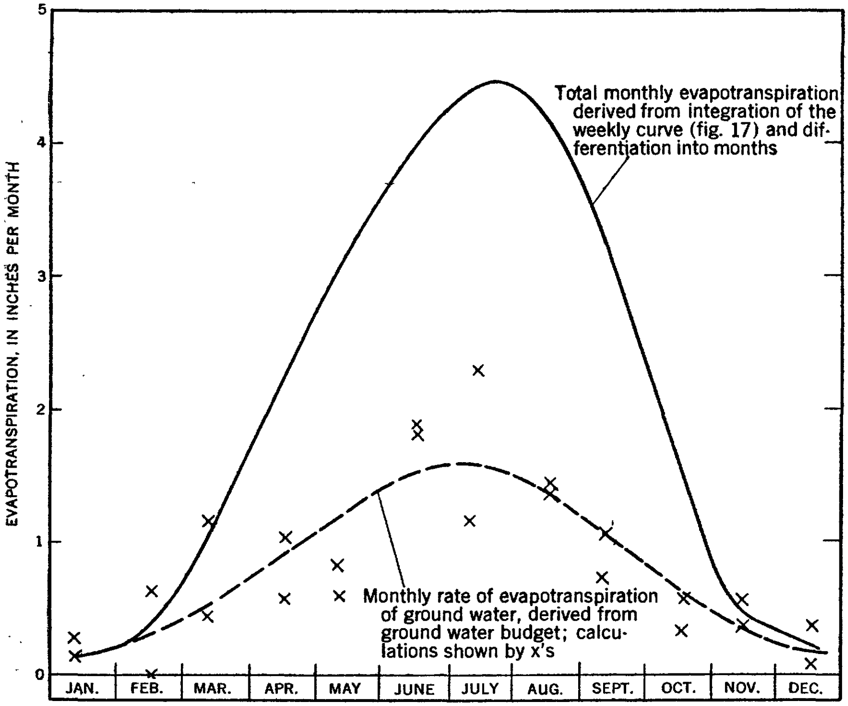


FIGURE 19.—Graph comparing ground-water evapotranspiration to total evapotranspiration by months

Estimates of total evapotranspiration, ground-water evapotranspiration, ground-water recharge, ground-water runoff, and ground-water storage were made for the 3-year period. The comparative results for the Pomperaug and Beaverdam basins are as follows:

Comparison of the hydrologic budgets, in percentage of precipitation, of the Pomperaug River basin, Connecticut, and the Beaverdam Creek basin, Maryland

Budget factors	Pomperaug River basin	Beaverdam Creek basin
Total runoff	46. 4	36. 1
Total evapotranspiration	52. 2	60. 7
Basin storage	1. 4	3. 2
Total budget	100. 0	100. 0
Ground-water runoff (drainage)	19. 6	25. 9
Ground-water evapotranspiration	14. 0	23. 5
Ground-water storage	1. 4	2. 1
Ground-water recharge (infiltration)	35. 0	51. 5

The comparison shows that ground water plays a larger part in the hydrologic cycle in the Beaverdam basin than in the Pomperaug basin. Infiltration was 51.5 percent of precipitation in the Beaverdam basin compared to 35 percent in the Pomperaug basin. The lower percentage in the Pomperaug basin is consistent with the greater relief and lower permeability of rocks there.

Evapotranspiration of ground water was much greater in the Beaverdam basin, owing to the higher water table there, about 9 feet higher than in the Pomperaug basin. The weighted average depth to water in the Pomperaug basin ranged from 14.5 to 19.4 feet and averaged about 17 feet in weekly determinations over a 3-year period. The average depth to water in the Beaverdam basin ranged from 4.5 to 11.5 feet and averaged about 8 feet in weekly measurements over a 2-year period. Consequently, the Beaverdam basin lost about two-thirds again as much ground water to evapotranspiration, percentage-wise. The higher evapotranspiration is due, further, to greater moisture-storage capacity in the soil and to the higher mean air temperature (by 7° F) in the Beaverdam basin.

Conversely, the greater significance of surface water in the Pomperaug basin is shown by the total runoff of 46.4 percent, in contrast to 36.1 percent in the Beaverdam basin. This greater ratio of runoff in the Pomperaug basin is not entirely beneficial, because more than half is direct runoff and only about 42 percent of the total runoff is sustained by ground-water flow. In the Beaverdam basin, almost 72 percent of the total runoff is sustained by ground-water flow, and a greater percentage of the precipitation is available in the form of water in the streams in dry weather than it is in the Pomperaug basin.

Insufficient data on precipitation, runoff, and ground-water levels, and lack of data on soil moisture and on changes in surface-water storage, caused the writers of the Pomperaug basin study to make several recommendations for more detailed observations in similar studies. These recommendations were followed insofar as possible in this present study.

CRITICAL DISCUSSION AND SUMMARY

The Beaverdam Creek drainage basin is fairly representative of many parts of the Atlantic Coastal Plain in topography, soils, ground-water reservoir, and vegetation. The humid, warm climate is regarded as typical of the Eastern Seaboard. The rates of infiltration, 51.5 percent of the rainfall, the total runoff, 36.1 percent, and the total evapotranspiration, 60.7 percent, determined in the 2-year water budget, also are probably reasonably representative, compared in time to the average year and compared in space to the region as a whole.

The average density of observation wells, 1.28 per square mile, of rain gages, 0.62 per square mile, of stream-gaging stations, 1 for the 19.5-square-mile basin, were about adequate for this type of weekly synoptic budget. The 5 staff gages at stations other than Schumaker

Pond could be considered unnecessary, inasmuch as changes in surface-water storage proved to be insignificant; however, this could not have been predicted in advance.

The 3 soil-moisture stations were inadequate—only 0.15 per square mile. A density of 1 per square mile, or perhaps 1 per observation well, might give more adequate data. The use of 3 measurement levels, at 4, 16, and 39 inches (10, 30, and 100 cm.), was sufficient for the soil zone, but some measurement of the underlying part of the vadose zone also is recommended. Temperature elements should be incorporated at each depth instead of at a single depth. The plaster blocks were not durable, and other electrode units, such as fiber-glass wafers, may prove more acceptable. Bouyoucos (1954) has proposed a new type electrode, composed of wire screen, embedded in the plaster.

The resistance method, itself, was not entirely satisfactory because of hysteresis of the resistance-moisture relationship on a seasonal basis. It is possible that periodic moisture tests of samples taken close to the emplaced block could be used to adjust the curves. The use of tensiometers may be warranted in protected installations. A method involving neutron emission has considerable promise (Sharpe, 1953). Horton (1956), finding that laboratory and field calibration did not compare exactly, doubted the wisdom of doing laboratory calibration at all. Olson and Hoover (1954) compared all methods and concluded that nylon soil-moisture units, combined with tensiometers for measuring the wet range, most nearly approach the ideal. They concede that the neutron method has a possibility of matching the ideal.

The soil-moisture storage makes up a significant part of the weekly water balance, and future water budgets must place emphasis on an accurate soil-moisture index. Much of the lack of balance between items of the budget from week to week doubtless was due to the lack of adequate soil-moisture determinations.

The synoptic period of 1 week proved adequate for the purposes of this report. However, a synoptic balance on a daily basis undoubtedly would reveal hydrologic relations that are not yet thoroughly understood. In particular, apparent rise of the water table that occurs before soil-moisture deficiency is completely satisfied might be explained.

A hydrologic budget of an area having a thick vadose zone, if done with proper instruments throughout the vadose zone, may give information on temporary storage above the water table. Fluctuations of the capillary fringe, particularly in response to changes in air pressure in the intermediate vadose zone, appear to be a promising field of investigation. Evaporation and condensation in the vadose zone should be investigated critically, rather than discounting them as negligible except near the surface.

Electrokinetic phenomena in relation to the movement of water need further investigation. Careful recording with sensitive potentiometers and current meters distributed areally and in depth, might indicate the relation of the electrical to the hydraulic parameters. Even such phenomena as the movement of colloidal clay and iron compounds and the plugging of well screens may prove to be electrokinetic or electrochemical in part.

In further hydrologic investigations, as in this one, it is advisable that detailed geologic exploration be done first, to assess the degree of homogeneity of the reservoir materials, and the tightness of the confining beds. Chemical-quality studies, which proved not to be critical in the interpretations involved in this study, are a highly essential part of most detailed hydrologic investigations and should never be neglected (Hem, in preparation).

In conclusion: Abundant rainfall and high infiltration rates provide the portion of the Atlantic Coastal Plain represented by the Beaverdam basin with large quantities of ground water that are discharged about equally by runoff and evapotranspiration. Recovery of water lost to nonbeneficial plants or to unused streamflow will permit expansion of ground-water facilities for irrigation, industry, or municipal supply.

REFERENCES

Anderson, J. L., and others, 1948, Cretaceous and Tertiary subsurface geology: Maryland Dept. Geology, Mines and Water Res. Bull. 2, 456 p.

Black, R. F., and Barksdale, W. L., 1949, Oriented lakes of northern Alaska: Jour. Geology, v. 57, p. 105–118.

Bouyoucos, G. J., 1954, New type electrode for plaster of paris moisture blocks: Soil Sci., v. 78, no. 5, p. 339–342.

Bouyoucos, G. J., and Mick, A. H., 1940, An electrical resistance method for the continuous measurement under field conditions: Michigan Agr. Expt. Sta. Tech. Bull. 172.

Campbell, M. R., 1931, Alluvial fan of Potomac River: Geol. Soc. America Bull. v. 42, p. 825–852.

Clark, W. B., Mathews, E. B., and Berry, E. W., 1918, The surface and underground water resources of Maryland: Maryland Geol. Survey Special Rept. v. 10, pt. 2, 549 p.

Cope, 1869, Am. Philos. Soc. Proc., v. 11, also reported in Hay, O. P., 1923, The Pleistocene of North America and its vertebrated animals from the States east of the Mississippi River and from the Canadian provinces east of longitude 95°: Carnegie Inst. Washington Pub. 322, p. 347.

Cooke, C. W., 1930, Correlation of coastal terraces: Jour. Geology, v. 38, p. 577–589.

——— 1930, Pleistocene seashores: Washington Acad. Sci. Jour., v. 20, p. 389–395.

——— 1931, Seven coastal terraces in the southeastern states: Washington Acad. Sci. Jour., v. 21, p. 503–513.

——— 1932, Geology—Tentative correlation of American glacial chronology with the marine time scale: Washington Acad. Sci. Jour., v. 22, p. 310–312.

Cooke, C. W., 1933, Origin of the so-called meteorite scars of South Carolina: Jour. Geology, v. 42, p. 88–96.

——— 1935, Tentative ages of Pleistocene shore lines: Washington Acad. Sci. Jour., v. 25, p. 331–333.

——— 1936, Geology of the Coastal Plain of South Carolina: U. S. Geol. Survey Bull. 867.

——— 1937, The Pleistocene Horry clay and Pamlico formation near Myrtle Beach, S. C.: Washington Acad. Sci. Jour., v. 27, p. 1–5.

——— 1939, Scenery of Florida: Florida Geol. Survey Bull. 17, 118 p.

——— 1940, Elliptical bays in South Carolina and the shape of eddies: Jour. Geology, v. 48, p. 205–211.

——— 1941, Discussions. Two shore lines or seven?: Am. Jour. Sci., v. 239, p. 457–458.

——— 1943, Geology of the Coastal Plain of Georgia: U. S. Geol. Survey Bull. 941.

——— 1945, Geology of Florida: Florida Geol. Survey Bull. 29, 339 p.

——— 1952, Sedimentary deposits in geology and water resources of Prince Georges County, Md.: Maryland Dept. Geology, Mines and Water Res. Bull. 10, p. 1–53.

——— 1954, Carolina bays and the shapes of eddies: U. S. Geol. Survey Prof. Paper 254–I, p. 195–207.

Diénert, F. V., 1935, Des moyens d'etude du cycle de l'eau dans la nature: Revue générale de l'Hydraulique, no. 2, p. 77–79.

Glenn, L. C., 1895, Some Darlington, South Carolina bays: Science, v. 11, p. 472–475.

Grant, Chapman, 1945, A biological explanation of the Carolina bays: Sci. Monthly, v. 61, p. 443–450.

Hack, J. T., 1955, Geology of the Brandywine area and origin of the upland of southern Maryland: U. S. Geol. Survey Prof. Paper 267–A, 43 p.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U. S. Geol. Survey Water-supply Paper 1473.

Horton, J. S., 1956, Use of electrical soil-moisture units in mountain soils: Proc. Western Snow Conf., 23d Ann. Mtg., Portland, Oreg., p. 20–26.

Houk, I. E., 1921, Runoff and rainfall in the Miami Valley, Ohio: Miami Conservancy District, pt. 7.

Huffman, G. G., and Price, W. A., 1949, Clay dune formation near Corpus Christi, Tex.: Jour. Sed. Petrology, v. 19, p. 118–127.

Johnson, D. W., 1936, Origin of Carolina bays (abs.): Geol. Soc. America Proc., p. 84.

——— 1942, Origin of Carolina bays: New York, Columbia Univ. Press, 341 p.

Kadel, B. C., 1919, Instructions for the installation and operation of class A evaporation stations: U. S. Weather Bur. Circ. L, 30 p.

Kelly, A. O., 1951, The origin of the Carolina bays and oriented lakes of Alaska: Pop. Astronomy, p. 199–205.

Kelly, A. O., and Dachille, Frank, 1953, Target: Earth, the role of large meteors in earth science: Pensacola Engaving Co., Inc.

Krul, W. F. J. M., and Liefrinck, F. A., 1946, Recent ground-water investigations in the Netherlands: Monograph on the progress of research in Holland, New York-Amsterdam, Elsevier Publishing Co., 78 p.

Langbein, W. B., 1949, Computing soil temperatures: Am. Geophys. Union, v. 30, p. 543–547.

LeGrand, H. E., 1953, Streamlining of the Carolina Bays: Jour. Geology, v. 61, p. 263–274.

Linsley, R. K., and Kohler, M. A., 1951, Variations in storm rainfall over small areas: Am. Geophys. Union Trans., no. 2, p. 245–250.

Magistad, O. C., and Christiansen, J. E., 1944, Saline soils: U. S. Dept. Agric. Circ. 207.

McCarthy, G. E., 1936, Magnetic anomalies and geological structures of the Carolina coastal plain: Jour. Geology, v. 44, p. 396–406.

——— 1937, The Carolina Bays: Geol. Soc. America Bull., v. 48, p. 1211–1226.

McCampbell, J. C., 1945, A geomagnetic survey of some Bladen County, N. C., "Carolina Bays": Jour. Geology, v. 53.

Meinzer, O. E., 1923, Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-supply Paper 494.

Meinzer, O. E., and Stearns, N. D., 1929, A study of ground water in the Pomperaug Basin, Conn., with special reference to intake and discharge: U. S. Geol. Survey Water-supply Paper 597–B, p. 73–146.

Melton, F. A., and Schriever, William, 1933, The Carolina bays—Are they meteorite scars?: Jour. Geology, v. 41, p. 52–66.

Olson, D. F., Jr., and Hoover, M. D., 1954, Methods of soil-moisture determination under field conditions: Southeastern Forest Expt. Sta. Paper 38, Asheville, N. C., 29 p.

Pettijohn, F. J., 1949, Sedimentary rocks: New York, Harper & Bros., 526 p.

Prouty, W. F., 1934, "Meteor Craters" of the Carolinas; The Carolina bays: Elisha Mitchell Sci. Soc. Jour., v. 50, p. 48, 59–60.

——— 1935, The Carolina bays and elliptical lake basins: Jour. Geology, v. 43, p. 200–207.

——— 1952, Carolina bays and their origin: Geol. Soc. America Bull., v. 63, p. 167–224.

Raisz, E. J., 1934, Rounded lakes and lagoons of the coastal plains of Massachusetts: Jour. Geology, v. 42, p. 839–848.

Rasmussen, W. C., 1953, Periglacial frost-thaw basins in New Jersey—A discussion: Jour. Geology, v. 61, p. 473–474.

Rasmussen, W. C., and Haigler, L. B., 1953, Ground-water problems in highway construction and maintenance: Delaware Geol. Survey Bull. 1, 24 p.

Rasmussen, W. C., and Slaughter, T. H., 1955, Ground-water resources *in* Water resources of Somerset, Wicomico, and Worcester Counties, Md.: Maryland Dept. Geology, Mines and Water Resources Bull. 16, 533 p.

——— 1957, Ground-water resources *in* Water resources of Caroline, Dorchester, and Talbot Counties, Md.: Maryland Dept. Geology, Mines and Water Resources Bull. 18, 465 p.

Reynolds, Osborne, 1885, On the dilatancy of media composed of rigid particles in contact: Philos. Mag., 5th ser., v. 20, p. 469.

——— 1886, Dilatancy: Nature, v. 33, p. 429.

Richards, H. G., 1936, Fauna of the Pleistocene Pamlico formation of the southern Atlantic Coastal Plain: Geol. Soc. America Bull., v. 47, p. 1611–1656.

——— 1945, Subsurface stratigraphy of Atlantic Coastal Plain between New Jersey and Georgia: Am. Assoc. Petroleum Geologists Bull., v. 29, p. 885–955.

——— 1948, Studies on the subsurface geology and paleontology of the Atlantic Coastal Plain: Acad. Nat. Sci. Philadelphia Proc., v. 100, p. 39–76.

——— 1953, Record of the rocks: New York, Ronald Press Co., 413 p.

Sharpe, J., 1953, Measurement of moisture content by neutron counting: Applied Physics, v. 4, no. 3, p. 93–94.

Shattuck, G. B., 1901, The Pleistocene problem of the north Atlantic Coastal Plain: Johns Hopkins Univ. Circ., v. 20, p. 69–75.

Shattuck, G. B., 1906, The Pliocene and Pleistocene deposits of Maryland: Maryland Geol. Survey, 291 p.

Smith, L. L., 1931, Solution depressions in sandy sediments of the coastal plain of South Carolina: Jour. Geology, v. 39, p. 641–653.

Spangler, W. B., and Peterson, J. J., 1950, Geology of the Atlantic Coastal Plain in New Jersey, Delaware, Maryland, and Virginia: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1–99.

Stearns, N. D., 1927, Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-supply Paper 596–F, p. 121–176.

Stephenson, L. W., 1912, The Coastal Plain of North Carolina—The Quaternary formations: North Carolina Geol. Survey, v. 3, p. 286.

Stephenson, L. W., Cooke, C. W., and Mansfield, W. C., 1933, Chesapeake Bay region: Internat. Geol. Cong. 16th, Washington, D. C., Guidebook 5, 49 p.

Trewartha, G. T., 1943, An introduction to weather and climate: New York, McGraw-Hill Book Co., 545 p.

Tuomey, Michael, 1848, Report on the geology of South Carolina: South Carolina Geol. Survey, p. 143–144.

United States Weather Bureau, 1949, Installation and operation of a soil moisture station: Provisional Paper, 17 p.

Wentworth, C. K., 1930, Sand and gravel resources of the Coastal Plain of Virginia: Virginia Geol. Survey Bull. 32, 146 p.

Wilcox, L. V., 1948, Explanation and interpretation of analyses of irrigation waters: U. S. Dept. Agr. Circ. 784, 8 p.

Wolfe, P. E., 1953, Periglacial frost-thaw basins in New Jersey: Jour. Geology, v. 61, p. 133–147.

INDEX

O