A study of ground water in the Pomperaug Basin, Conn., by Oscar Edward Meinzer and Norah Dowell Stearns.[1]—In this paper the authors have made a quantitative study of the intake and discharge of water on the basin of Pomperaug River, Conn. The drainage basin of that river is situated in the central part of the western highland of Connecticut. It is about 17 miles in length and 8 miles in maximum width and has an area of about 89 square miles and comprises nearly all of the towns of Bethlehem and Woodbury and a large part of the town of Southbury, and small parts of the towns of Roxbury, Washington, Morris, Watertown, and Middlebury.

The highest point in the basin 1,150 feet above sea level, is at the northern extremity, near the village of Morris; the lowest point, only 100 feet above sea level, is at the mouth of Pomperaug River. The basin consists chiefly of rather rugged uplands, but in the south-central part there are extensive valley areas.

Inasmuch as this is one of the few efforts that have been made in the humid east to determine, month by month what becomes of the precipitation that occurs over a basin, the summary and conclusions of the authors are reproduced in full.—*A. J. H.*

SUMMARY

The water in the drainage basin of Pomperaug River is nearly all derived from precipitation—that is, from the rain and snow which fell on the basin. It is nearly all disposed of as run-off or by evaporation—that is, it is either carried out of the basin by Pomperaug River or else is evaporated directly or through the agency of plants. In the three full years covered by this investigation, October, 1913, to September, 1916, according to the data that were obtained, the precipitation averaged 44.48 inches, the run-off 20.66 inches, and the evaporation 23.20 inches a year (plus or minus a slight unknown difference in stream and soil storage). Moreover, there was during the 3-year period a net increase in ground-water storage (that is, in the quantity of water stored in the zone of saturation) which amounted to 1.85 inches, or an average of 0.61 inch a year, as is shown by the higher position of the water table at the end than at the beginning of the period.

During the 3-year period the ground-water recharge, or quantity of water that percolated from the surface to the water table and entered the zone of saturation, averaged 15.58 inches a year. Of this amount, an average of 8.76 inches seeped into Pomperaug River and its tributaries and was carried out of the basin by the river, 6.21 inches evaporated either directly or through the agency of plants, and 0.61 inch remained in storage in the zone of saturation.

According to these results, in the 3-year period the total run-off amounted to about 46½ per cent and the total evaporation to about 52 per cent of the precipitation, about 1½ per cent of the precipitation being stored in the zone of saturation. The ground-water recharge amounted to about 35 per cent of the precipitation, of which somewhat more than half was disposed of as run-off and somewhat less than half by evaporation. More precisely, the ground-water run-off amounted to about 19½ per cent of the precipitation, the ground-water evaporation to about 14 per cent, and the net increase in ground-water storage to about 1½ per cent.

There was no marked seasonal distribution of the precipitation but a very pronounced seasonal distribution of the evaporation. Consequently, each year was divided into a replenishing and a depleting season. In the replenishing season, from late fall to early spring, an average of approximately 7 inches of water was stored in the zone of saturation, over and above the withdrawals as run-off and by evaporation; in the depleting season, from late spring to early fall, nearly a like average amount was withdrawn from storage, in addition to the contributions that were occasionally received by the zone of saturation during this season. Most of the water withdrawn from storage during the depleting season was utilized by the vegetation or otherwise evaporated; only a small part ran off through Pomperaug River. In any long period of years the average seasonal depletion will, of course, be very nearly equal to the average seasonal replenishment.

In the following tables are given a summary of the monthly and annual inventories of the water supply of this basin during the period covered by the investigation:

Inventory of the water supply of the Pomperaug Basin, July, 1913, to December, 1916, in depth in inches over the drainage area

	Precipitation	Increase or decrease of ground water in storage	Ground-water run-off	Ground-water recharge	Ground-water evaporation	Total run-off	Total evaporation plus increase or minus decrease in surface and soil storage	Principal changes in surface and soil storage or other conditions that make the figures given in last column greater or less than total evaporation
1913								
July	2.07							
August	3.35		0.13			0.25		
September	3.43		.17			.35		
October	9.21	+4.30	.52	5.67	[1] 0.85	2.57	2.34	Increase in stream and soil storage.
November	2.72	+1.38	1.73	3.11	(2)	2.73	−1.39	Decrease in soil storage.
December	2.58	−.23	1.42	1.19	(2)	2.24	.57	
1914								
January	3.01	−.77	1.00	.23	(2)	1.33	2.45	Estimate of total run-off probably too low.
February	3.10	−.31	[3] .40	.09	(2)	.58	2.83	Increase in snow storage; estimate of total run-off probably too low.
March	6.01	+.23	.86	1.09	(2)	4.32	1.46	
April	4.29	+1.69	1.03	2.72	(2)	2.94	−.43	Decrease in snow storage.
May	3.66	−.08	.85	[4] 1.84	1.07	2.35	.79	Decrease in soil and stream storage.
June	3.11	−2.30	.39	(5)	1.91	.63	4.78	
July	5.68	−1.46	.38	[4] .45	1.53	.70	6.44	
August	3.67	−.77	.29	[4] .45	.93	.45	3.99	
September	.31	−1.23	.18	(5)	1.05	.20	1.34	Decrease in soil storage.
October	3.35	+.31	.22	1.38	[1] .85	.31	2.73	Increase in soil storage.
November	2.50	+.15	.34	.49	(2)	.51	1.84	
December	4.10	−.08	[3] .50	.42	(2)	[3] .62	3.56	Increase in soil storage and perhaps in snow storage; estimate of total run-off may be too low.
1915								
January	6.49	+2.00	[3] .95	2.95	(2)	[3] 3.41	1.08	
February	5.63	+1.69	[3] 1.20	2.89	(2)	[3] 3.58	.36	
March	.10	−.38	1.19	.81	(2)	1.61	−1.13	Decrease in stream and snow storage.
April	1.88	−.614	.90	.29	(2)	1.60	.89	
May	3.15	−.23	.67	1.61	[1] 1.17	1.21	2.17	
June	1.88	−1.00	.28	(5)	.72	.45	2.43	
July	5.77	−.15	.24	[4] .60	.51	.78	5.14	
August	7.87	+1.84	.60	3.34	[1] .90	1.79	4.24	
September	2.56	−.31	.44	1.05	[1] .93	.92	1.95	Decrease in soil storage.
October	2.61	−.92	.55	[4] .50	.87	1.01	2.52	
November	2.51	−.15	.36	.21	(2)	.92	1.74	
December	4.86	+2.30	.73	3.03	(2)	2.90	−.34	Records for precipitation probably too low.
1916								
January	1.48	+.61	1.34	1.95	(2)	3.00	−2.13	Decrease in snow storage.
February	4.77	+1.60	.99	1.99	(2)	2.71	1.06	Increase in snow storage; records for precipitation probably too low.
March	2.43	+.38	1.16	1.54	(2)	3.66	−1.61	Decrease in snow storage; records for precipitation probably too low.
April	2.20	+.31	1.90	2.21	(2)	4.45	−2.56	Decrease in snow storage.
May	3.83	−.31	.89	[4] 1.84	1.26	1.76	2.38	
June	4.27	−1.84	.69	[4] .40	1.55	1.68	4.43	
July	4.49	−1.06	.54	[4] .40	.86	1.05	4.44	
August	4.67	−1.15	.29	(5)	.86	.56	5.26	
September	3.38	−1.06	.25	(5)	.81	.45	3.99	
October	1.29	−.77	.25	[4] .30	.82	.44	1.62	
November	2.65	+.08	.32	.40	(2)	.56	2.01	Increase in soil storage.
December	3.52	+.84			(2)			

[1] Unsatisfactory estimate based on average of corresponding months in other years.
[2] Ground-water evaporation is regarded as negligible.
[3] Estimated on inadequate data.
[4] Estimated from irregularity in water-table curve in Plate 19.
[5] Ground-water recharge was apparently negligible in amount.

[1] Water-Supply Paper 597 B, U. S. Geological Survey, 1929.

Inventory of the average monthly water conditions in the Pomperaug Basin, July, 1913, to December, 1916, in depth in inches over the drainage area

[Based on all data in the preceding table]

Month	Precipitation [1]	Increase or decrease of ground water in storage	Ground-water run-off	Ground-water recharge	Ground-water evaporation	Total run-off	Total evaporation plus increase or minus decrease in surface and soil storage
October	4.12	+0.73	0.39	1.96	0.85	1.08	2.38
November	2.60	+.33	.69	1.05	----------	1.18	1.05
December	3.77	+.71	.88	1.55	----------	1.92	1.26
January	3.66	+.61	1.10	1.71	----------	2.58	.47
February	4.50	+.79	.86	1.66	----------	2.29	1.42
March	2.85	+.08	1.07	1.15	----------	3.20	−.43
April	2.76	+.46	1.28	1.74	----------	3.00	−.70
May	3.35	−.21	.80	1.76	1.17	1.77	1.78
June	3.09	−1.71	.45	.13	1.39	.92	3.88
July	4.50	−.87	.39	.48	.96	.84	5.34
August	4.89	−.03	.33	1.27	.90	.76	4.50
September	2.42	−.87	.26	.35	.93	.48	2.43

1 Based on monthly precipitation during the period; not Waterbury normal.

Inventory of the annual water supply of the Pomperaug Basin, October, 1913, to September, 1916, in depth in inches over the drainage area

[Based on all data in the preceding table]

Month	Precipitation	Increase or decrease of ground water in storage	Ground-water run-off	Ground-water recharge	Ground-water evaporation	Total run-off	Total evaporation plus increase or minus decrease in surface and soil storage
October, 1913, to September, 1914	46.66	+0.45	9.05	16.84	7.34	21.04	25.17
October, 1914, to September, 1915	45.28	+3.23	7.53	15.83	5.07	16.79	25.26
October, 1915, to September, 1916	41.50	−1.83	9.69	14.07	6.21	24.15	19.18
Average	44.48	+.61	8.76	15.58	6.21	20.66	23.20

DISCUSSION OF METHODS AND RESULTS

In arid regions so many quantitative investigations of ground-water supplies have been made that the methods of work are relatively well understood. In humid regions, however, much less quantitative work has been done, the methods that are employed in arid regions are largely inapplicable, and the problem of making quantitative estimates is inherently more difficult. The method used in this investigation is a composite of several available methods and has doubtless led to more reliable results than could have been obtained by the application of any single method. The observations made, however, were not adequate in number nor sufficiently refined to lead to very accurate results, and the period of observations was too short to give average conditions. With the same general method much more accurate results can be obtained if sufficient funds and time are available to make more numerous and more detailed observations.

The precipitation records show that many of the rains and snows are local or vary in intensity within short distances, and that an accurate measure of the quantity of water that falls upon an area so large as the Pomperaug Basin can not be obtained from three rain gages, even though they are well distributed and there are no gaps in the records. Where so few gages are used the daily records are the most likely to be unrepresentative, but even the monthly and annual records may show considerably more or less precipitation than the true average for the basin. It should be noted, however, that with the method that was used the records of precipitation do not enter directly into the ground-water estimates.

In such an investigation the record of total run-off, as determined by the gaging station near the mouth of the trunk stream, is very important, and more money should be spent than was available for the station at Bennetts Bridge, to make this record accurate and complete. Instead of a staff gage read by a local observer once or twice a day, an automatic gage, or water-stage recorder, should be installed. In winter, when the relation of discharge to stage is disturbed by ice in the river, a sufficient number of current-meter measurements should be made to obtain a complete and reliable record.

In this investigation the estimates of ground-water run-off were based on the discharge of the Pomperaug at Bennetts Bridge—that is, on the discharge during the periods between rains, when there was virtually no direct run-off left in the stream system. Much better results could be obtained by basing the estimates on periods beginning as soon after rains as all of the direct run-off has reached the streams. With this method the ground-water run-off during any particular day would be the total run-off minus the decrease in stream storage. The decrease in stream storage could be estimated by maintaining gages at several points on the trunk stream and on selected tributaries and making surveys of the stream system showing the approximate water areas of different parts of the system at different gage heights. Calculations show that in a drainage basin which is not larger than the Pomperaug the total quantity of water stored in the stream system at any time is rather small compared with the rate of discharge and hence that errors in the measurement of decrease in storage will introduce relatively small errors in the estimates of ground-water run-off. The proposed method would have the advantage over the method used in this investigation in that the record would cover a much larger part of each period between rains and that the entire process would be one of observation and measurement without the intangible feature of the present method. It would not be necessary to make current-meter measurements to develop rating curves at the subsidiary stations, as only change in storage, indicated by change in gage height, is involved, not rate of discharge.

Records should be obtained in regard to snow storage and soil storage. The precipitation records should show whether the precipitation occurred as rain or snow, and there should be a record of the days when the snow contributed to the direct run-off, when it did not thaw sufficiently to contribute to the run-off, when the ground was virtually free of snow, and when the ground was frozen. Soil storage is an important item in the monthly inventory and could be estimated on the first of each month by making a number of moisture determinations of soil samples collected in fairly typical locations. Large numbers of moisture determinations are made in connection with dry-farming and irrigation investigations, and some are now made in the laboratories of the Geological Survey in connection with hydrologic investigations.

There should be a larger number of observation wells, they should be more widely distributed over the basin, and so far as possible they should be equipped with automatic water-stage recorders. Much more work should be done to determine the specific yield of the different kinds of material in which the water table occurs, because the specific yield is a factor in the estimates of ground-water recharge and ground-water evaporation. In recent investigations it has been found feasible to obtain columns of the undisturbed materials and to make direct tests of the specific yield of these materials in their natural state. The columns are taken directly above the water table at a low stage.

Records of evaporation from a free water surface should be obtained for the entire period covered by the investigation. Work could also be done in determining transpiration and soil evaporation by tank experiments and from daily fluctuations of the water table shown by water-stage recorders over wells. Indeed, with the methods that have been outlined, the accuracy of the results in a quantitative study of the water resources of an area will be largely a function of the funds and time available for making the investigation.

W. Peppler on characteristic features of air currents on coasts (*Meteorologische Zeitschrift, February, 1929*).—The remarks of W. Georgii and H. Koschmeider in *Heft* 8, *Meteorologische Zeitschrift*, 1928, lead me to make a few statements relative to the air currents on the coast of Flanders. In the course of the two years during which I was engaged in the work of the naval kite station at Breedene near Ostend, I had abundant opportunity to become acquainted with the interesting conditions of the current as it came from the open sea upon the land and also with the effect of the dunes upon the current. Although there was no opportunity to undertake special investigations of definite individual problems, the characteristic features of the coast as related to aerology forced themselves into notice at the times of the daily kite flights.

Especially with stormy west winds there was plainly observed the influences of the coast and the dunes in producing an intensification of disturbances in the air. For this reason and on account of the well known stormy character of the weather on the coast of the channel, the kite station suffered considerably until a certain adaptation of kite technique was taken up, and with a specially strong kite, constructed according to instructions from Herman John, there came success, even in a heavy storm, in launching and landing it for the most part undamaged. One can hardly imagine the terific wind velocities and the extraordinary turbulence that often prevail in the wind currents of the channel.

In a storm the following conditions were characteristic: If the west storm was from the open sea against the coast the wind velocities on the shore in front of the dunes were considerably greater than those at the kite station situated on a level plot of ground 300 meters behind the dunes. Despite the relatively slight elevation of the dunes (about 30 meters) their windbreak effect stretched inland at least 400 meters. Of course, it is to be taken into consideration that even on a flat shore the wind force decreases rapidly toward the interior on account of the sudden and marked increase in friction with the passage of the current from sea to land. There forms, so to speak, a pillow of air over which the succeeding masses of air must mount. Behind the dunes in the space where the conditions were affected by the windbreak there was an extraordinary increase in wind velocity, usually from 10 to 30 meters per second, from the ground to about 60 meters elevation, where in some cases 35 meters per second must have prevailed in so far as could be determined with any certainty from the course of the small storm kites. Generally it was observed that the kite entered more or less suddenly into an extremely turbulent current when it came to the elevation of the crests of the dunes. This stratum of turbulence had a thickness of about 100 meters. Above it the flow of air became somewhat more steady and in many cases the mean velocity decreased to increase again above some 500 meters. In the stratum of turbulence above the elevation of the crests of the dunes there pass in rapid succession over the relatively calm, lower stratum very strong whirls that bring marked oscillations in the readings of the dynamograph. These whirls evidently originate through friction and the damming of the current on the dunes.

In the current behind the dunes the following strata can be differentiated:

1. Relatively calm, less turbulent ground stratum that reaches to the height of the crests of the dunes. Here there is very marked increase in wind force upward from the ground.
2. Stratum of greatest turbulence between about 40 and 100 meters elevation. The lower and upper limits of this stratum are more or less plainly marked.
3. Stratum of moderate turbulence with wind velocity frequently decreasing upward.

In flights during stormy west winds the vertical temperature was such that up to from 50 to 100 meters above the ground (upper limit of the second stratum) there prevailed marked decrease in temperature (frequently 1° C. per 100 meters). In another paper [1] I have shown that for the average of many flights the vertical temperature gradient of the ground stratum increases in proportion to the wind velocity. As is well known, the cause is mechanical intermixing. Striking and unexpected to me, however, was the frequent observation that the temperature gradient decreased above the ground stratum and that there lay at from 50 to 100 meters elevation a slight inversion or then isothermacy. At first I thought this discontinuity the remnant of a nocturnal ground inversion; however, this view was not tenable since with cloudy weather and storm from the west inversions could neither form nor maintain themselves. Moreover, these discontinuities occurred with the afternoon flights also.

The fact that these discontinuities are not always present with westerly winds is explainable when they occur in the same manner as the mountain inversions cited by W. Georgii, occurring, thus, only when the lapse rate in the undisturbed current is less than 1° C. per 100 meters. In the storm the lapse rate in the ground stratum is often equal to or greater than 1° C. per 100 meters. The fact that this discontinuity, originating in the obstruction presented by the dunes, lies not directly at the crests of the dunes, but at a higher elevation is explained by the stratum of turbulence. One can conceive of the boundary between this and the upper undisturbed current as a kind of glide surface, although it is of a kind other than the glide surface between different bodies of air. In conclusion, I may mention that the upward wind over the dunes occasionally makes itself evident in fracto-nimbus cloudlets that form in strong wind over the dunes (and only there) at elevations of from 100 to 200 meters.

It is regrettable that the individual flights and the numerous interesting meteorological, aerological, and cloud observations contained in my war journal of over 5,000 pages could not be published on account of lack of funds. They contain, among other things, many interesting notes and observations on the air current and temperature conditions on coasts.—*Translated by W. W. Reed.*

Nile silt does not enrich the soil.—It has been held since the ages of the Pharaohs that silt enriches the soil and the classical example given is the Nile Valley. Comes along now Dr. E. McKenzie Taylor, of the School of Agriculture, University of Cambridge, England, who holds that the age-worn view is fallacious.[2] The editor of that journal in commenting upon the article rightly

[1] Aerologische und hydrographische Beobachtungen der deutschen Marine-Stationen während der Kriegzeit 1914 bis 1918. Die Beobachtungen der Marine-Drachenstationen Breedene Meer und St. Michel bei Brügge in den Jahren 19 15bis 1918. Heft 3 und 4. Deutsche Seewarte, Hamburg, 1922.

[2] E. McKenzie Taylor, Engineering News-Record, June 20, 1929.