Wisconsin.—The month was the coldest February in the central and southern portions of the State since 1885, and probably the coldest February on record in the northwestern counties. Although extremely low temperatures were recorded throughout the State, it is generally believed that no damage to crops resulted, as winter grains and grasses were protected by an ample covering of snow. Stock were reported as wintering in good condition.—*W. M. Wilson.*

Wyoming.—The temperature throughout the State for the month was in excess of the normal and there were no severe storms. As a result stock continued in excellent condition and very little feeding had to be done. The mild weather started the grass in some sections, so that a green tinge was given to the low places. A good supply of snow accumulated in the mountains of the western and northern portions of the State, but a marked deficiency existed at the close of the month over the southeastern portion.—*W. S. Palmer.*

SPECIAL ARTICLES.

DISPOSITION OF RAINFALL IN THE BASIN OF THE CHAGRES.

By Gen. H. L. ABBOT, U. S. A., retired, dated Cambridge, Mass., March 4, 1904.

The question of what becomes of the precipitation falling from the clouds upon a given catchment basin—what part escapes through the channels of the streams, what part is evaporated, what is absorbed by plant life, and finally what part sinks into the earth as ground water—has received much attention from hydraulic engineers by reason of its important bearings upon the water supply of cities, the irrigation of arid regions, and the development of water power. To be of utility, such studies must be based upon long-continued measurements of the rainfall at localities suitable to afford a true estimate of the average precipitation upon the region in question during each of the different seasons of the year, together with accurate gagings of the outflowing streams during the same periods. For a complete solution, further observations to determine the evaporation from land and water surfaces and the absorption of moisture by plants are desirable to furnish a check upon the values found for the other and more important elements, but the extreme difficulty of such studies has usually proved a bar to undertaking them. It must not be forgotten, however, that a portion of the water apparently lost by infiltration into the earth may ultimately find its way into the streams as ground water, and as such may be detected, at least approximately, by a careful investigation of the ratio between downfall and drainage in different seasons of the year. Even in this simplified form the labor and expense involved in the needful measurements have restricted their application to a few localities, and those generally situated in populous and temperate districts.

In connection with their other technical investigations the engineers of the New Panama Canal Company found it obligatory to study some of these questions with considerable attention, and this paper is written in the hope that the resulting facts and figures may prove useful in throwing light upon the more general problem of the ultimate disposition of rainfall.

The Isthmus of Panama is a locality specially favorable to studies of this character. Ice and snow, which have usually complicated such investigations, are here unknown. The region is practically in its natural condition, densely covered with the luxuriant growth of the Tropics. The temperature of the air, which largely influences evaporation, hardly varies from month to month and from year to year, thus in a great measure eliminating one important element of relative uncertainty. Finally, the rainfall is excessive, and is sharply divided between a dry season of three months and a rainy season of seven months, with two intermediate months of less marked character. This fact, as will appear later, has greatly favored the analysis. It seems not improbable that results obtained under so favorable conditions may not only be applicable to similar regions in the Tropics but may also throw light upon certain elements common to more northern latitudes.

The district covered by these measurements is the basin of the Chagres above Bohio, at which locality will be placed the lower reservoir dam creating a large lake to be traversed by shipping as part of the canal route. Under present conditions all outflow from above passes Bohio. The catchment basin is naturally divided into three subbasins, the lower extending to Gamboa, where the Chagres first joins the canal route; the middle extends thence to Alhajuela, where a second dam should be placed; the upper includes the valley above this point. The surveys of the Panama Railroad, supplemented by those of the two Panama Canal companies, have well defined the watershed of the two lower subbasins, as well as the western and much of the southern boundaries of the upper subbasin; but a gap exists on the northern and eastern boundary of the latter where the line of demarcation is somewhat uncertain for a distance of about 35 miles. One point nearly in the middle of the unknown portion was determined by a reconnaissance made by a party of the Isthmian Canal Commission coming from the San Blas district to the head of the eastern branch of the upper Chagres, and this point together with the well known general character of the district, low ridges separated by narrow gorges, have enabled the ill-defined part of the boundary to be laid down on the map with fair precision. All the rest of the entire watershed of the basin being accurately determined, no error can exist in the estimated area large enough to sensibly affect any practical conclusions to be based on the study. The following table exhibits, in statute miles, the dimensions of the basin, which is a hilly rather than a mountainous district, and much of it is covered with a dense tropical growth. The highest summits rarely if ever rise more than about 1500 feet above sea level:

Subbasin.	Basin above Bohio.				Length of bed.	Number of affluents.
	Area.	Per cent.	Length.	Width.		
Upper	320	46	18	18	31	?
Middle	130	18	7	18	11	15
Lower	250	36	11	23	20	17
Total	700	100	.....	.....	70	.....

Before stating the general conclusions resulting from the study it will be well to consider in some detail the several important elements upon which they are based.

RAINFALL IN THE BASIN ABOVE BOHIO.

So many data have been collected respecting rainfall upon the Isthmus of Panama that the monthly and yearly precipitation is well understood. The records kept by the Panama Railroad Company at Colon are nearly continuous since 1862, and those kept on the Pacific coast and at various intermediate points by the two Panama Canal companies are nearly continuous since 1881. The figures were published in the MONTHLY WEATHER REVIEW for May, 1899, and March, 1903. Those specially valuable in the present study date from 1895, when the daily measurements of discharge were extended to include Alhajuela, near the site of the projected upper dam. Unfortunately, they were discontinued at this post in 1897 and 1898, but were resumed in 1899 and are still in progress. All rain gages are read and recorded daily. The respective heights above the ground in their vicinity are the following: At Colon, 30 feet; at Alhajuela, 8 feet; at Gamboa, 36 feet; at Bohio, 6 feet; and at La Boca, 2.5 feet.

What is needful in the present study is a knowledge of the average monthly rainfall in each of the three subbasins, from which that in the entire basin may be deduced. Bohio and Gamboa are near each other and at the extremities of the lower subbasin; Gamboa and Alhajuela are also near each other and at the extremities of the middle subbasin; finally, from the fact that the Pequeni, the largest and most important

branch of the upper Chagres, heads near Porto Bello only about five miles from the Atlantic coast, where the conditions as to rainfall are similar to those at Colon, it may be assumed that a mean between the recorded rainfall at Alhajuela and at Colon will fairly represent the precipitation in the upper subbasin. Introducing the areas of the subbasins, and reducing, the following expressions result for the rainfall, in millimeters, in the entire basin and for that above Gamboa as well; in them B, G, A, and C denote rainfall, in millimeters, at Bohio, Gamboa, Alhajuela, and Colon, respectively:

(1) Rainfall above Bohio $= 0.323\ (0.6\ B + 0.9\ G + A + 0.7\ C)$.

(2) Rainfall above Gamboa $= 0.5\ (0.3\ G + A + 0.7\ C)$.

The following table presents the rainfall, in millimeters, computed as above indicated for the several basins under consideration during the entire period of these studies. As rain records at Alhajuela were lacking in 1898 and in the first six months of 1899, the figures for those months have been found by assuming that the rainfall in the upper subbasin is represented by that noted at Colon. Similar check comparisons for subsequent months have shown that no important errors are thus introduced. Bold-face figures for May, 1902, indicate interpolations, all records being lacking for this month.

TABLE 1.—*Average rainfall, in millimeters, in the basin of the Chagres.*

Month.	Basin above Bohio.							Basin above Gamboa.						
	1898.	*1899.*	*1900.*	*1901.*	*1902.*	*1903.*	Means.	*1898.*	*1899.*	*1900.*	*1901.*	*1902.*	*1903.*	Means.
January	140	156	89	19	464	16	147	99	152	81	15	232	14	99
February	11	96	24	15	12	5	27	6	104	4	9	10	5	23
March	27	56	12	37	52	17	34	20	33	11	38	42	15	27
April	108	27	74	43	163	32	75	78	24	71	48	148	22	65
May	238	267	234	320	**266**	271	266	230	285	264	298	**270**	273	270
June	283	236	383	270	183	263	270	267	193	377	280	201	273	265
July	579	403	432	279	268	400	394	512	431	451	225	336	450	401
August	532	305	311	428	241	350	361	395	303	320	391	204	376	332
September	198	304	330	370	270	273	291	182	302	337	340	267	149	263
October	301	334	372	455	341	356	361	255	584	360	454	317	340	385
November	363	285	416	655	388	487	432	341	299	390	637	405	504	429
December	133	118	57	173	119	455	176	131	114	54	135	132	456	170
Year	2,913	2,587	2,734	3,064	2,767	2,925	2,834	2,516	2,824	2,720	2,870	2,564	2,877	2,729

Month.	Basin above Alhajuela.							Basin Alhajuela–Gamboa.						
January	.....	151	100	19	254	15	108	.....	151	36	7	180	11	77
February	.....	104	5	13	12	6	28	.....	104	3	4	7	3	24
March	.....	33	15	44	35	18	29	.....	33	2	25	60	9	26
April	.....	24	62	51	128	27	58	.....	24	93	42	192	12	73
May	.....	285	285	280	**284**	287	284	....	285	215	340	**270**	240	270
June	.....	193	374	293	204	273	267	.....	193	381	250	195	275	259
July	.....	500	464	227	376	462	406	.....	269	421	218	242	421	314
August	.....	317	351	386	193	381	326	.....	269	247	403	227	363	302
September	.....	313	337	353	275	254	306	.....	273	337	309	248	224	278
October	.....	342	376	443	322	325	362	.....	252	322	463	307	374	344
November	.....	321	427	689	399	567	480	.....	247	305	515	420	358	369
December	.....	138	67	131	152	463	190	.....	58	25	147	86	439	151
Year	.....	2,721	2,863	2,929	2,634	3,078	2,844	.....	2,158	2,387	2,723	2,414	2,731	2,487

Month.	Basin Gamboa–Bohio.						
January	192	182	102	25	453	52	168
February	17	79	8	24	14	5	25
March	39	59	15	33	67	19	39
April	152	32	77	33	186	48	85
May	253	240	180	353	**258**	265	258
June	310	299	389	251	151	244	274
July	687	346	396	367	152	312	377
August	743	304	291	484	212	304	390
September	221	284	314	412	271	316	303
October	469	346	388	447	276	352	380
November	462	243	453	677	349	417	434
December	112	113	61	233	95	415	171
Year	3,657	2,527	2,674	3,339	2,464	2,749	2,904

OUTFLOW FROM THE BASIN ABOVE BOHIO.

Although measurements to determine the discharge of the Chagres at Gamboa and at Bohio were by no means neglected by the engineers of the old company, they have been made with much more system since the work devolved upon the receiver, and later upon the new company. The chief stations have been Gamboa and Bohio and finally Alhajuela. As a result, a definite knowledge has been secured of the monthly discharges at the two first-named stations since January, 1890, and at Alhajuela since January, 1895, except for a few months when the work was suspended.

These measurements have been made carefully by the method of floats, supplemented by self-registering water gages recording continuously the water level of the river. The discharge measurements have been made sometimes daily and sometimes on every third day, with frequent additions during freshets. Nevertheless, in a stream so subject to frequent oscillations involving excessive variations in the volume transported, the only satisfactory mode of estimating the continuous discharge is to study the relation between the height of the water surface and the corresponding volumes, and thus deduce rating tables from which the discharge at short intervals, every two hours, can be determined. This has been done with great care at each of the three stations, and at each the result has been to show that two rating scales should be framed, one applicable to the river when the surface is sensibly unchanging in level, and the other applicable to sudden freshets when a huge wave sweeps down the channel. All rivers under such conditions carry at any fixed level a much larger volume when rising than when falling, and this difference must be taken into account by adjusting the rating tables to indicate the average volume at each level. The great number of actual gagings has rendered this adjustment a simple matter, and rating tables wholly independent of each other have thus been derived for the three stations. They are shown by the following formulæ, that for Alhajuela based on 1599 gagings; that for Gamboa on 2147 gagings; and that for Bohio on 1854 gagings. They have been framed either by the method of least squares or by an algebraic study of the platted curves representing the observations. The latter method has generally proved to be the most satisfactory, since it recognizes the general law of continuity while the former tends to follow the accidental departures from it of the observations themselves, often giving a slightly wavy curve. No arbitrary drawing of any part of the scale has been employed. In these formulæ Q denotes the discharge in cubic meters per second, and C the height of water surface above mean sea level.

(3) Alhajuela, $Q = -6 + 52\ (C - 27.5)^2 - 1.6\ (C - 27.5)^3$; level sensibly unchanging.

(4) Alhajuela, $Q = -7 + 110\ (C - 28) + 40\ (C - 28)^2 - 1.8\ (C - 28)^3$; rapid changes of level.

(5) Gamboa, $Q = -24 + 24\ (C - 13) + 18\ (C - 13)^2 - 0.5\ (C - 13)^3$; sensibly unchanging.

(6) Gamboa, $Q = -26 + 40\ (C - 13) + 18\ (C - 13)^2 - 0.5\ (C - 13)^3$; rapid changes of level.

(7) Bohio, $Q = 47C + 5C^2 + C^3$; level sensibly unchanging.

(8) Bohio, $Q = 62C + 5C^2 + C^3$; rapid changes of level.

A comparison of the volumes thus computed from day to day at the three stations leaves no doubt as to the precision of this method of determining the relative and hence, probably, the absolute discharge. Based on wholly independent data these volumes are found to be in perfect accord with each other, showing during quiet stages discharges slightly increasing from station to station as the intermediate tributaries enter, and during freshets indicating the passage of the wave in a clear and natural manner. Of late years this method by rating tables and automatically recorded river stages has been uniformly followed in estimating the average monthly volumes; but for some of the months prior to 1898, when hourly water height records are lacking, the estimated volumes represent the means of the actual gagings, or in a few rare instances discharges measured at the adjacent station and transferred by well established ratios, for determining which the data are ample. The Engineering Magazine for December, 1902, gives the volumes since 1890. The following table exhibits in cubic meters per second the average monthly discharges for which

corresponding rain records are available. The outflowing volumes from the three subbasins are estimated from those measured at the three gaging stations, or rather from the differences between them.

TABLE 2.—*Outflow, in cubic meters per second, from the basin of the Chagres.*

Month.	Basin above Bohio.							Basin above Gamboa.						
	1898.	1899.	1900.	1901.	1902.	1903.	Means.	1898.	1899.	1900.	1901.	1902.	1903.	Means.
January	160	109	60	42	318	46	122.5	122	99	48	29	148	46	82.0
February	48	49	30	28	59	29	40.5	42	27	23	19	45	26	30.0
March	31	28	21	20	36	18	25.7	29	27	15	13	29	20	22.2
April	57	31	20	16	61	16	33.5	52	30	16	13	55	20	31.0
May	76	58	46	65	58	43	57.6	70	54	38	50	51	43	51.0
June	95	89	81	79	90	72	84.3	81	70	55	58	82	61	67.8
July	186	112	159	90	86	114	124.5	120	80	95	62	85	94	89.3
August	150	162	149	122	96	155	139.0	117	120	101	81	79	123	103.5
September	91	120	135	164	111	161	130.3	72	90	87	103	83	133	94.7
October	143	140	198	179	168	158	164.3	98	96	128	105	125	112	110.7
November	222	150	187	375	189	236	226.5	147	106	115	191	134	162	142.5
December	81	102	106	130	85	297	133.5	65	75	76	89	62	199	94.3
Means	112	96	99	109	113	112	106.8	85	73	66	68	81	87	76.6
	Basin above Alhajuela.							Basin Alhajuela-Gamboa.						
January	.....	*90	45	28	120	32	63.0	.....	9	3	1	28	14	11.3
February	.....	*24	23	19	36	24	25.2	.....	3	0	0	9	1	2.6
March	.....	*24	15	13	23	14	17.8	.....	3	0	0	6	6	2.8
April	.....	25	16	13	48	16	23.6	.....	5	0	0	7	4	3.2
May	.....	45	38	44	40	37	40.1	.....	9	0	6	5	5	5.0
June	.....	61	44	49	62	55	54.2	.....	9	11	9	20	7	11.2
July	.....	63	62	56	60	88	65.8	.....	17	33	6	25	5	17.2
August	.....	93	80	69	66	90	79.6	.....	27	21	12	13	33	21.2
September	.....	68	61	83	67	79	71.6	.....	22	26	30	16	54	27.6
October	.....	75	91	78	91	78	82.6	.....	21	37	27	34	34	30.6
November	.....	83	84	135	89	139	106.0	.....	23	31	56	45	23	35.6
December	.....	64	65	86	52	155	84.4	.....	11	11	3	10	44	15.9
Means	.....	60	52	56	63	67	59.5	.....	13	14	12	18	19	15.3
	Basin Gamboa-Bohio.													
January	38	10	12	13	170	0	40.5							
February	6	22	7	9	14	3	10.2							
March	2	1	6	7	7	0	3.8							
April	5	1	4	3	6	0	3.2							
May	6	4	8	15	7	0	6.6							
June	14	19	26	21	8	11	16.5							
July	66	32	64	28	1	20	35.2							
August	33	42	48	41	17	32	35.5							
September	19	30	48	61	28	27	35.5							
October	45	44	70	74	43	46	53.7							
November	75	44	72	184	55	74	84.0							
December	16	27	30	41	28	98	40.0							
Means	27	23	33	41	32	26	30.4							

*Outflow for January, February, and March, 1899, estimated from that measured at Gamboa, the ratio being well known. Black figures for May, 1902, indicate interpolations.

A comparison of these figures with those for the preceding years will make it apparent that the river has recently been passing through a phase of minimum discharge, and it becomes a matter of interest to push the inquiry further in order to fully understand the regimen. Fortunately, this can be done from the fluviograph record of water heights at Gamboa.

The instrument was established there in 1882, and a nearly complete record has been kept since that date. It is lacking for the year 1889, when the old canal company ceased operations, and for some months in 1896 and 1897, for which the sheets were, unfortunately, lost. This leaves available three 6-year epochs (1883–1888, 1890–1895, and 1898–1903), for which have been accurately noted for each month the number of freshets and the total number of hours when the river rose above a level about 10 feet above the low-water stage (17 meters above mean tide). This level is the standard from which freshets are estimated. Below it the Chagres at Gamboa is a quiet stream, with a volume ranging from about 500 to about 11,500 cubic feet per second; above it the discharge often attains 30,000 or 35,000 cubic feet, and in great floods a maximum of nearly 80,000 cubic feet. A knowledge of the number and duration of the freshets gives, therefore, a good general idea of the relative discharge in different months and years.

The following table presents this information consolidated in 6-year groups, together with the corresponding local rainfall at Gamboa. These 6-year epochs are all complete, except for the river data in October, 1887, and May, 1902, and the local rainfall for the year 1895; for January and February, 1883; for January, 1884, and for May, 1902. The sign + following a figure in the table indicates that one month is missing, and, hence, that approximately one-fifth part should be added when comparing it with other months. This correction has been made in the averages.

TABLE 3.—*Number and duration of freshets at Gamboa, with corresponding local rainfall.*

Month.	Totals in 1883–1888.			Totals in 1890–1895.			Totals in 1898–1903.			Average freshet hours in 6 yrs.
	Freshets.	Hours.	Rainfall.	Freshets.	Hours.	Rainfall.	Freshets.	Hours.	Rainfall.	
January	0	0	3.0+	3	27	8.0+	7	108	23.3	45
February	0	0	2.7+	0	0	2.3+	0	0	2.5	0
March	1	9	1.7+	0	0	6.1+	0	0	6.3	3
April	3	19	21.4	3	28	18.5+	2	21	16.7	23
May	10	201	74.2	17	136	60.4+	3+	23+	42.6+	122
June	27	206	76.8	7	54	49.0+	3	5	50.8	88
July	22	179	54.2	20	161	56.5+	6	35	70.3	125
August	33	299	93.7	16	101	54.6+	11	67	75.1	156
September	31	322	63.6	6	47	58.5+	2	10	53.5	126
October	26+	217+	79.8	13	108	80.0+	7	52	70.0	126
November	25	423	82.8	12	158	55.4+	18	183	79.4	255
December	20	810	53.1	21	465	46.5+	8	51	28.7	442
Totals	203	2,728	608.5	118	1,285	595.0	68	560	527.7	1,511
Annual	34	455	101.6	20	214	99.2	11	93	88.0	252

It should not be forgotten in comparing these three groups that the first includes two flood years (1885 and 1888) and the second two flood years (1890 and 1893), while the third has none, but as these floods affect only the months of November and December, the evidence is still conclusive that the present is a period of exceptionally low water, caused by a rainfall below the general average. The investigations of the Isthmian Canal Commission have demonstrated that similar variations covering several years have occurred in Nicaragua, but there seems to be no annual correlation between the two districts. The fact, however, that the present is a low-water epoch for the Chagres should be borne in mind in considering the following analysis.

EVAPORATION, PLANT ABSORPTION, AND PERCOLATION.

There being no natural lakes in the basin of the Chagres, no attempt has been made to measure evaporation from exposed water surfaces. A study of all available records where the conditions are approximately similar led the Comité Technique of the New Panama Canal Company to adopt, as the probable evaporation from the projected artificial lakes and the water surface of the canal, 6 millimeters (0.24 inches) per twenty-four hours, adding for possible infiltration an equal amount.

In Nicaragua, where evaporation is an important element in the problem of water supply for a canal, careful measurements were made by the Isthmian Canal Commission, both by the methods of pans floating in the lake and by comparative studies of lake level as affected by rainfall, inflow, and outflow through the channel of the San Juan River. The conclusions are thus summed up by Mr. A. P. Davis, the hydrographer of the commission:

Observations by the pan method were made in 1898, 1899, and 1900, some of them covering an entire year. The results ranged from a maximum of 8.13 inches in April, 1898, to a minimum of 2.02 inches in September, 1899, the grand average for ninety-four months being 4.28 inches per month, or about 0.18 inch in twenty-four hours. He notes that the results were rather discordant, and, moreover, that the conditions affecting the pans did not duplicate those affecting the lake, where: "Except along the eastern shore the surface of the lake is thrown into billows, the waves often attaining a considerable height and being crowned with whitecaps, and the total water surface in contact with the wind is much greater

than the level surface of the lake. Most of the lake surface must, therefore, lose by evaporation a greater depth of water than the pan." Recourse was therefore had to the second method, based during the dry seasons of 1900 and 1901 on the observed lake level, the rain records at eight stations, the estimated inflow, and the measured outflow by the San Juan River. The results in inches per twenty-four hours were as follows: For February, 1900, 0.21; for March, 0.22; for April, 0.18; for first half of May, 0.21. For the second year (1901) the figures were, in February, 0.12; in March, 0.13; in April, 0.26. The grand mean was thus found to be 0.19 inch in twenty-four hours, which, it will be noted, is slightly less than that assumed by the Comité Technique for the basin of the Chagres, but is in good accordance therewith.

What is specially involved in the present problem is not evaporation from exposed water surfaces, but that from the general surface of the basin. Existing data in tropical regions are insufficient to permit a numerical estimate of the latter, but it is well known that the essential elements upon which it depends are the relative volume of aqueous vapor already held in suspension in the atmosphere, the capacity for which is largely increased as the temperature rises, the greater or less agitation due to winds, the absolute atmospheric pressure acting inversely, and the nature of the surfaces presented to the air. The known conditions existing in the basin of the Chagres render it fair to assume that evaporation there must be extremely uniform throughout the rainy months of the year, and that it can not be excessive in amount. Thus, the hygrometric observations at Colon made by the old canal company in 1881, and those by the United States Weather Bureau in 1898, concur in indicating a relative humidity ranging within narrow limits from 0.80 in the dry months to 0.87 in the rainy season. The winds of the Isthmus are gentle, rarely attaining a velocity of 10 miles an hour. The surface of nearly the entire region is covered by a dense tropical growth impenetrable to the rays of the sun or to rapid movements of the atmosphere. The barometric pressure is so nearly uniform that continuous observations covering the last four and a half years at Alhajuela show an extreme variation of only 0.43 inch, of which about 0.1 of an inch is represented by the normal diurnal oscillation. Finally, the temperature of the air hardly varies from month to month, or from place to place, throughout the entire Isthmus, as is shown by the following 5-year records at Alhajuela and La Boca, confirmed by the aggregate records of about twenty-six years at Colon, Gamboa, Alhajuela, Panama, La Boca, and Naos, ending December, 1902:

TABLE 4.—*Observed air temperatures on the Isthmus.*

Month.	Alhajuela, 51 months.			La Boca, 53 months.			General average, 308 months.		
	Months.	° *F.*	° *C.*	*Months.*	° *F.*	° *C.*	*Months.*	° *F.*	° *C.*
January	4	78.01	25.56	4	79.34	26.30	25	78.28	25.71
February	3	79.74	26.52	4	80.37	26.87	24	78.51	25.84
March	3	80.10	26.72	4	80.94	27.19	25	79.21	26.23
April	4	81.25	27.36	4	81.77	27.65	26	80.31	26.84
May	3	79.00	26.11	3	80.19	26.77	24	80.33	26.85
June	4	79.67	26.48	4	80.74	27.08	24	81.01	27.23
July	5	79.18	26.21	5	79.92	26.63	26	80.44	26.91
August	5	79.65	26.47	5	78.89	26.05	26	79.93	26.63
September	5	79.51	26.39	5	79.34	26.30	26	80.28	26.82
October	5	78.78	25.99	5	78.53	25.84	27	79.38	26.32
November	5	78.62	25.90	5	77.97	25.54	27	79.12	26.18
December	5	78.93	26.07	5	79.11	26.17	28	79.11	26.17
Year	.....	79.37	26.32	.....	79.76	26.53	.....	79.66	26.48

These facts, confirmed by the above measurements of evaporation from water surfaces in Nicaragua, which do not materially differ from similar series under like rainfall in temperate regions, support the assumption that whatever influence may be exerted by evaporation in the catchment basin of the Chagres, it must be sensibly constant throughout the rainy months of the year and, therefore, will not exert any considerable disturbing influence upon the ratio between downfall and drainage in those months. The same may be affirmed respecting the influence of plant life as it exists on the Isthmus. As already stated, these advantages, together with the absence of ice and snow, greatly facilitate the study of ground water as a function of this ratio, which became one of the special objects of these investigations from its bearing upon possible percolation from the artificial lakes.

GROUND-WATER FLOW.

The study of the flow of water in natural channels involves no slight difficulties, as is well known to hydraulic engineers, but the problems offered by the passage through the soil of that part of the rainfall that ultimately finds its way to the sea by that route is rendered far more complex by the variety of the materials to be traversed, and by the addition of two new motive forces to the action of gravity when the laws governing transmission are to be considered. These two forces are capillarity and thermal pressure as affecting both the fluid itself and the more or less compressible materials through which it finds its devious route. Much progress has recently been made by experimental researches on the rate of flow through different materials, but the difficulty of certainly ascertaining the nature of these materials, and the possible existence of fissures impossible to take into account, render too hazardous any attempt to make a practical application of these researches in any particular case. The general fact that water penetrates to depths of perhaps two miles and is in constant movement through the earth's crust has been established beyond question by different lines of investigation, and notably by the fact that some streams increase very sensibly their volume in traversing districts where they receive no visible contributions; but the application of any theory of motion to particular cases has hardly yet been reached in engineering practise.

In the case of the Panama Canal the question of ground water was raised by the claim of the opponents of this route that the creation of artificial lakes by damming the stream might be rendered futile by reason of excessive percolation through the soil to be submerged. The same objection might be raised a priori against any proposed reservoir; and the geological formation of the Valley of the Chagres offers every reason for believing that no such result is to be apprehended. Nevertheless, since stream flow is a function of rainfall, evaporation, plant absorption, and ground water, and since two of these variables must have nearly constant values in the Valley of the Chagres, it seemed possible that a prolonged study of the ratio between the rainfall and the volume flowing in the valley of the stream might throw further light upon the problem. If the result indicated that little or no ground water found its way to the river the possible existence of an underground flow dangerous to an artificial lake would be suggested. If, on the contrary, the volume received through the earth should prove to be considerable, there would remain little or no danger of serious escape from the lakes. The sharp division of the year into rainy and dry seasons would render the study of the ratio decisive on this question. Careful investigations have been in progress since January, 1898, and the preliminary results appeared in the MONTHLY WEATHER REVIEW for June, 1900. Since that date the measurements have been continuous, and have now reached a point where it is believed that the evidence is conclusive that no important loss of water from the lakes is to be feared. Ground water has been demonstrated to be a very important element of the volume carried by the river.

RATIO BETWEEN DOWNFALL AND DRAINAGE.

The available data, contained in Tables 1 and 2, have allowed the ratio between downfall and drainage to be studied during a period of six years for the entire basin, for the two subbasins above Gamboa jointly, and for the lower subbasin, and separately during five years for the two upper subbasins. The general formula for the entire basin, taking into account the areas of the three subbasins, is the following, in which the

letters A, C, G, and B denote, in meters, the rainfall at the four observing stations of which they are the initials, Q denotes the outflow in cubic meters per second at Bohio, D denotes the number of days for which rainfall and outflow are considered, and R denotes the desired ratio.[1] The numerical constant correlates the mile and meter units. The computations have been made for calendar months, periods sufficiently long to usually eliminate discrepancies resulting from the time elapsed between precipitation and direct outflow, which observation has shown to vary from twenty-four to forty-eight hours according to the locus of the rainfall. The formulæ for the separate subbasins are easily derived from the general expression which is the following:

$$(9) \qquad R = \frac{Q \times 3600 \times 24 \times D}{1610^2 \left(\frac{250\,(B+G)}{2} + \frac{130\,(G+A)}{2} + \frac{320\,(A+C)}{2} \right)}$$

For making the computations this general expression may be placed under the following more convenient form, in which the unit for A, C, G, and B remains the meter, and n represents unity for a month of thirty days, 1.034 for one of thirty-one days, and 0.934 for one of twenty-eight days.

$$(10) \qquad R = \frac{n\,Q}{125\,(B+G) + 65\,(G+A) + 160\,(A+C)}$$

Similar reductions may be made for computing the ratio for the separate subbasins. The following table represents the results of these several computations applied to the foregoing data. It should be stated that the columns of "means" are not the numerical averages of the ratios for the different years, but are the quotients found by dividing the sums of the corresponding values of the numerator of formula (10) by the sums of the corresponding values of its denominator. The "general average" in like manner is computed from the "means" of the five basins, upon the same principle.

Figs. 1–5 have been designed to present clearly to the eye the relative values of the more important data of Tables 1, 2, 4, and 5 as exhibited in each of the five basins under consideration. Their general conformity is manifest throughout the entire catchment area.

TABLE 5.—*Ratio between downfall and drainage in the basin of the Chagres.*

Month.	Above Bohio, six years.							Above Gamboa, six years.						
	1898.	1899.	1900.	1901.	1902.	1903.	Means.	1898.	1899.	1900.	1901.	1902.	1903.	Means.
January	1.79	0.99	1.00	3.28	1.10	4.38	1.26	2.83	1.50	1.35	4.29	0.82	7.46	1.91
February	6.33	0.67	7.13	2.50	6.89	7.94	2.33	14.52	5.36	11.12	3.98	8.96	10.66	2.69
March	1.72	0.97	3.50	0.81	1.04	1.62	1.24	3.83	1.88	3.06	0.77	1.59	3.04	1.90
April	0.75	1.26	0.39	0.53	0.54	0.75	0.65	1.48	2.83	0.50	0.60	0.83	1.93	1.06
May	0.47	0.32	0.29	0.30	.....	0.24	0.32	0.70	0.29	0.33	0.39	.....	0.36	0.43
June	0.48	0.55	0.30	0.42	0.70	0.39	0.44	0.12	0.96	0.33	0.43	0.90	0.50	0.57
July	0.48	0.41	0.54	0.47	0.47	0.42	0.46	0.49	0.42	0.48	0.64	0.58	0.48	0.51
August	0.44	0.81	0.71	0.43	0.59	0.65	0.58	0.68	0.95	0.72	0.48	0.89	0.75	0.72
September	0.66	0.58	0.59	0.64	0.59	0.85	0.65	0.88	0.66	0.57	0.67	0.69	1.21	0.80
October	0.65	0.63	0.79	0.59	0.73	0.68	0.68	0.88	0.70	0.82	0.54	0.90	0.76	0.66
November	0.84	0.77	0.65	0.83	0.70	0.71	0.75	0.96	0.79	0.65	0.67	0.74	0.71	0.74
December	0.96	1.32	2.74	1.13	1.05	0.99	1.14	1.14	1.50	3.18	1.51	1.07	1.00	1.16
	Above Alhajuela, five years.							Alhajuela-Gamboa, five years.						
January	.....	1.90	1.45	4.76	0.94	6.80	1.89	.....	0.53	0.66	1.14	0.54	10.20	1.14
February	.....	0.67	13.42	4.43	8.75	14.24	2.63	.....	0.21	*	*	9.94	1.87	0.79
March	.....	2.35	3.23	0.95	2.15	2.66	2.06	.....	0.72	*	*	0.79	4.97	0.86
April	.....	3.32	0.81	0.80	1.17	1.80	1.27	.....	1.64	*	*	0.13	2.61	0.33
May	.....	0.51	0.43	0.51	.....	0.44	0.46	.....	0.25	*	0.14	.....	0.16	0.15
June	.....	0.99	0.37	0.52	0.95	0.63	0.63	.....	0.36	0.23	0.28	0.79	0.19	0.33
July	.....	0.41	0.43	0.79	0.52	0.62	0.52	.....	0.50	0.62	0.22	0.81	0.10	0.44
August	.....	0.95	0.74	0.58	1.10	0.76	0.79	.....	0.80	0.67	0.22	0.47	0.72	0.56
September	.....	0.68	0.57	0.74	0.76	0.98	0.73	.....	0.62	0.60	0.50	0.50	1.85	0.76
October	.....	0.71	0.78	0.57	0.91	0.76	0.74	.....	0.59	0.91	0.46	0.88	0.72	0.71
November	.....	0.81	0.62	0.61	0.70	0.77	0.69	.....	0.72	0.78	0.84	0.92	0.49	0.74
December	.....	1.49	3.13	2.13	1.00	1.08	1.44	.....	1.51	3.57	0.16	0.93	0.79	0.83
	Gamboa-Bohio, six years.							General average of the five basins.						
January	0.82	2.26	0.48	2.15	1.55	*	1.00	.....	.....	.....	.....	.....	.....	1.38
February	1.28	1.04	3.27	1.40	3.96	2.49	1.53	.....	.....	.....	.....	.....	.....	1.94
March	2.22	0.07	1.71	0.88	0.44	*	0.40	.....	.....	.....	.....	.....	.....	1.20
April	0.12	0.02	0.21	0.36	0.28	*	0.15	.....	.....	.....	.....	.....	.....	0.51
May	0.10	0.07	0.18	0.18	.....	*	0.11	.....	.....	.....	.....	.....	.....	0.30
June	0.18	0.25	0.27	0.34	0.21	0.17	0.24	.....	.....	.....	.....	.....	.....	0.44
July	0.40	0.38	0.67	0.31	0.03	0.27	0.39	.....	.....	.....	.....	.....	.....	0.47
August	0.18	0.57	0.68	0.35	0.23	0.44	0.38	.....	.....	.....	.....	.....	.....	0.59
September	0.34	0.42	0.61	0.59	0.41	0.35	0.47	.....	.....	.....	.....	.....	.....	0.69
October	0.40	0.52	0.75	0.68	0.47	0.55	0.59	.....	.....	.....	.....	.....	.....	0.67
November	0.65	0.73	0.64	1.11	0.63	0.71	0.78	.....	.....	.....	.....	.....	.....	0.74
December	0.59	0.99	2.03	0.73	1.00	0.98	0.94	.....	.....	.....	.....	.....	.....	1.14

* No outflow from basin, reducing the ratio to zero.

CONCLUSIONS RESULTING FROM THE ANALYSIS.

To facilitate a study of these data it has seemed to be desirable to consolidate them, and to present the outflow and rainfall in English units, giving the former in the double form both of cubic feet per second and of the height in inches to which 1 square mile would be flooded by the flow. Under the latter form a direct comparison between the figures for outflow and rainfall, and between the different divisions of the basin can be made, since varying areas are eliminated. This arrangement is carried out in Table 6, to which is added for comparison the outflow for as many months as have been well determined, together with the ratios as given in Table 5.

Table 6 reveals numerous important facts as to the regimen of the Chagres. Thus, a comparison between the outflow, expressed in inch-miles, during the period for which corresponding rainfall records are available and during the longer periods for which the outflow only is known, shows a well-marked correspondence throughout the entire year, the only discrepancy being for the month of May, and this variation is explained by exceptional freshets which occurred in 1890, 1891, 1892, and 1896. Furthermore, it confirms the inference suggested by Table 3 that this region is now passing through an epoch of minimum rainfall and outflow, since the longer periods indicate a larger outflow.

Again, on comparing month by month the known rainfall and outflow in inch-miles, all five basins are in accord in showing a normal variation. To present this more clearly to the eye, it is illustrated by two curves in fig. 6. The rainfall is at its minimum in February; begins to increase rapidly in April, when the sun is passing the zenith, moving northward; experiences a slight reduction in June, when at the summer solstice the northern limit is reached; passes a first maximum in July or August, about the time of the second zenith passage; and, finally, after a slight reduction in September, when the ascending current of air moves southward from the Isthmus, attains the maximum for the year in November, when the sun is lingering near the winter solstice and the moisture-laden winds from the Gulf of Mexico are sweeping over the Isthmus. The outflow curve on fig. 6 demonstrates that this annual sequence is by no means reproduced in the outflow from the basin of the Chagres. The minimum for the year occurs in February or March, and the volume steadily increases until November, with only a slight augmentation to mark the July-August epoch. The explanation of this clearly-defined difference between the two curves must be sought in the ground-water flow revealed by a study of the monthly ratios between downfall and drainage, as will appear below.

Before leaving this important Table 6, it is well to note that the annual average rainfall in the three subbasins shows a maximum of 114.54 inches in the lower, a next larger figure of 111.91 inches in the upper, and a minimum of 98.08 inches in the middle or Alhajuela-Gamboa division. Such differences are naturally to be expected from their geographical positions relative to the Atlantic coast and the well-known reduction in rainfall as the Pacific is approached; but on comparing the corresponding outflow, another variation is apparent. The three values of the outflow corresponding to the above rainfall are, respectively, 4.88 inch-miles, 7.46 inch-miles, and 4.73 inch-miles. This matter will also be considered below.

The ratio between downfall and drainage will now be studied in detail. Except during the dry season, when ground water

[1] i. e. the ratio of the volume of rainfall to that of outflow.

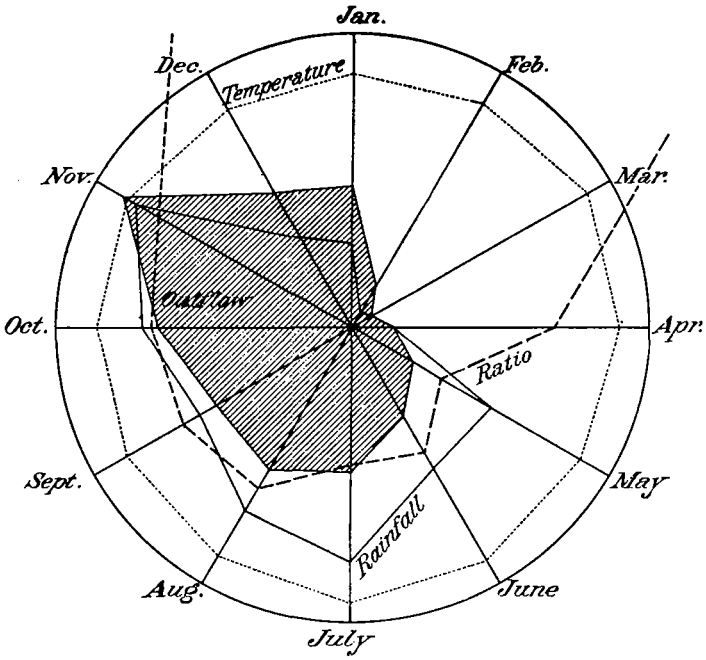

FIG. 1.—Basin above Bohio, six years.

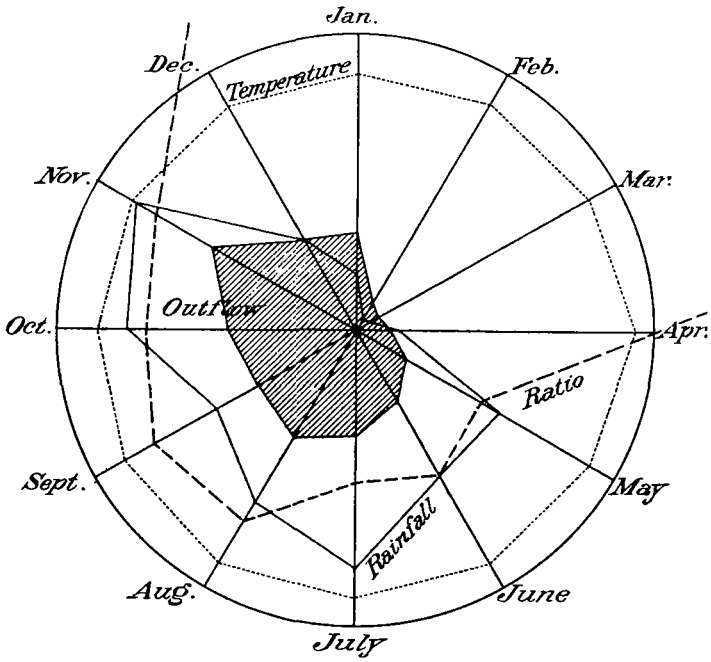

FIG. 2.—Basin above Gamboa, six years.

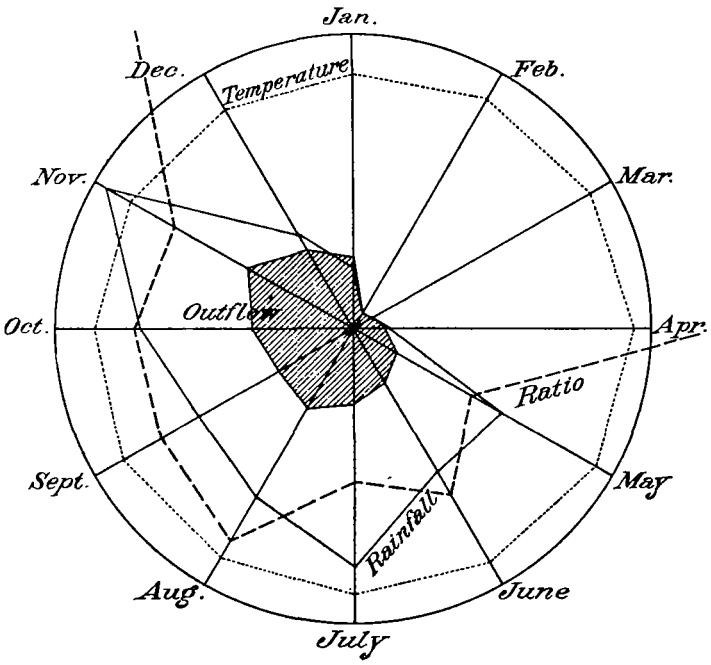

FIG. 3.—Basin above Alhajuela, five years.

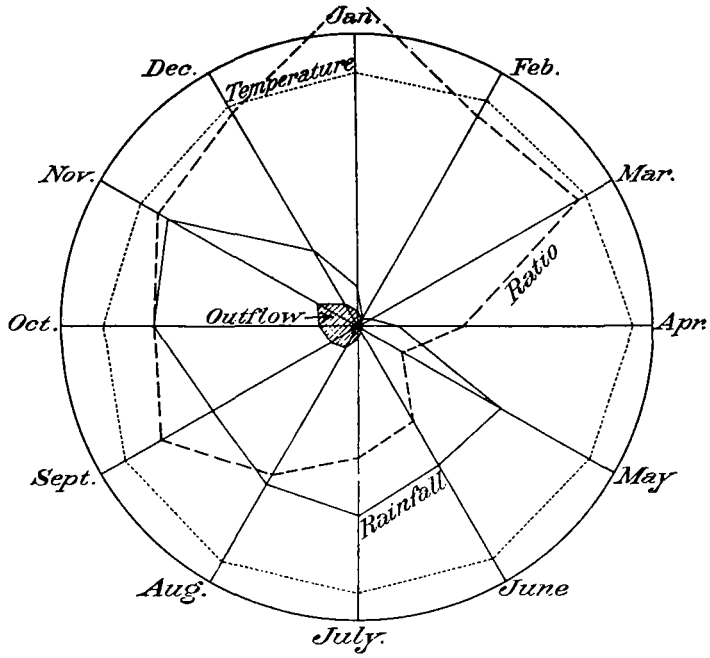

FIG. 4.—Basin between Alhajuela and Gamboa, five years.

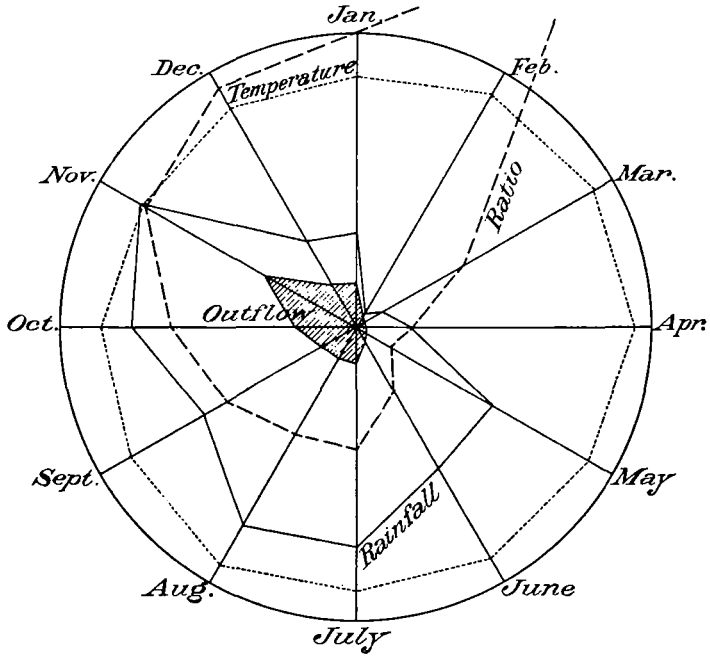

FIG. 5.—Basin between Gamboa and Bohio, six years.

FIGS. 1–5.—Hydrology of the basin of the Chagres at Alhajuela, Gamboa, and Bohio. Annual variation in average temperature, rainfall, outflow, and ratio between the two latter. The radius of the circle indicates 30° C. of temperature; 500 millimeters of rainfall; 250 cubic meters per second of outflow and a ratio of unity between the rainfall and outflow, both expressed in cubic meters. The figures here plotted are as follows: Temperatures, from Table 4, column 4; rainfall, from Table 1, column of means; outflow, from Table 2, column of means; ratio, from Table 5, column of means.

TABLE 6.—*Average rainfall and outflow in the Valley of the Chagres.*

Month.	Outflow in foot-seconds.			Outflow in inch-miles.			Rainfall, inches.		Mean ratio.
	5 years.	6 years.	14 yrs.	5 years.	6 years.	14 yrs.	5 years.	6 years.	
Basin above Bohio, 700 square miles.									
January	4,061	4,327	4,065	6.69	7.13	6.70	5.85	5.78	1.26
February	1,377	1,430	1,546	2.05	2.09	2.30	1.34	1.06	2.33
March	869	908	986	1.43	1.50	1.63	1.37	1.34	1.24
April	1,020	1,183	1,391	1.63	1.89	2.22	2.67	2.95	0.65
May	1,906	2,034	3,986	3.14	3.35	6.56	10.69	10.47	0.32
June	2,903	2,977	4,001	4.63	4.74	6.38	10.51	10.63	0.44
July	3,979	4,397	5,484	6.55	7.24	9.04	14.03	15.51	0.46
August	4,831	4,909	6,160	7.95	8.08	10.15	12.87	14.21	0.58
September	4,877	4,602	5,860	7.77	7.33	9.34	12.18	11.45	0.65
October	5,961	5,802	7,028	9.82	9.56	11.58	14.63	14.21	0.68
November	8,032	8,000	8,592	12.79	12.76	13.70	17.57	17.01	0.75
December	5,086	4,717	7,445	8.38	7.77	12.26	7.26	6.92	1.14
Year	3,742	3,774	4,712	72.83	73.44	91.86	110.97	111.54	.....
Basin above Gamboa, 450 square miles.									
January	2,611	2,896	2,657	6.70	7.43	6.80	3.89	3.90	1.91
February	987	1,059	1,228	2.28	2.45	2.26	1.04	0.91	2.69
March	734	784	842	1.88	2.01	2.16	1.09	1.06	1.90
April	943	1,095	1,215	2.34	2.71	3.01	2.46	2.56	1.06
May	1,670	1,801	2,913	4.28	4.61	7.46	10.94	10.63	0.43
June	2,305	2,394	2,907	5.81	5.93	7.21	10.42	10.43	0.57
July	2,935	3,154	3,808	7.52	8.08	9.76	14.90	15.79	0.51
August	3,806	3,655	3,971	9.75	9.36	10.17	12.54	13.07	0.72
September	3,506	3,344	3,757	8.69	8.29	9.32	10.98	10.35	0.80
October	3,989	3,909	4,304	9.95	10.02	11.04	16.18	15.16	0.66
November	5,001	5,033	5,082	12.40	12.48	12.62	17.60	16.89	0.74
December	3,539	3,330	4,873	9.06	8.53	12.49	7.01	6.69	1.16
Year	2,670	2,705	3,130	80.66	81.90	94.30	109.05	107.44	.....
Lower subbasin (Gamboa-Bohio), 250 square miles.									
January	1,450	1,430	1,408	6.69	6.60	6.49	6.40	6.61	1.00
February	390	360	318	1.62	1.50	1.33	1.02	0.98	1.53
March	135	134	144	0.62	0.62	0.68	1.52	1.54	0.40
April	77	113	176	0.35	0.50	0.78	2.96	3.35	0.15
May	236	233	1,073	1.08	1.07	4.90	10.20	10.15	0.11
June	598	583	1,094	2.67	2.60	4.89	10.50	10.84	0.24
July	1,044	1,243	1,676	4.82	5.73	7.74	12.38	14.82	0.39
August	1,025	1,254	2,189	4.73	5.79	10.10	12.56	15.35	0.38
September	1,371	1,254	2,103	6.12	5.60	9.39	12.57	11.93	0.47
October	1,963	1,896	2,724	9.06	8.75	12.57	14.24	14.96	0.59
November	3,031	2,967	3,510	13.51	13.25	15.68	16.84	17.09	0.78
December	1,547	1,413	2,572	7.13	6.52	11.57	7.22	6.92	0.94
Year	1,072	1,074	1,582	58,40	58.53	86.42	108.41	114.54	.....
Middle subbasin (Gamboa-Alhajuela), 130 square miles.									
	5 years.	7 years.	14 yrs.	5 years.	7 years.	14 yrs.	5 years.	6 years.	Ratio
January	388	293	.....	3.44	2.59	.....	3.03	.....	1.14
February	92	133	.....	0.74	1.07	.....	0.94	.....	0.79
March	99	129	.....	0.88	1.14	.....	1.02	.....	0.86
April	113	96	.....	0.97	0.76	.....	2.97	.....	0.33
May	177	764	.....	1.57	6.78	.....	10.63	.....	0.15
June	396	746	.....	3.39	6.40	.....	10.19	.....	0.33
July	607	697	.....	5.39	6.18	.....	12.36	.....	0.44
August	749	778	.....	6.64	6.90	.....	11.89	.....	0.56
September	975	993	.....	8.37	8.53	.....	10.94	.....	0.76
October	1,081	1,049	.....	9.59	9.31	.....	13.54	.....	0.71
November	1,257	1,145	.....	10.80	9.84	.....	14.53	.....	0.74
December	558	873	.....	4.95	7.74	.....	5.94	.....	0.83
Year	541	641	.....	56.73	67.24	.....	98.08	.....	.....
Upper subbasin (above Alhajuela), 320 square miles.									
January	2,225	2,395	.....	8.02	8.58	.....	4.25	.....	1.89
February	890	945	.....	2.89	3.07	.....	1.10	.....	2.63
March	629	643	.....	2.27	2.32	.....	1.10	.....	2.06
April	833	931	.....	2.90	3.25	.....	2.28	.....	1.27
May	1,416	1,646	.....	5.11	5.93	.....	11.18	.....	0.46
June	1,914	1,945	.....	6.67	6.79	.....	10.51	.....	0.63
July	2,324	2,257	.....	8.37	8.15	.....	15.99	.....	0.52
August	2,811	2,679	.....	10.14	9.65	.....	12.83	.....	0.79
September	2,529	2,384	.....	8.82	8.32	.....	12.05	.....	0.73
October	2,917	2,896	.....	10.51	10.44	.....	14,25	.....	0.74
November	3,744	3,389	.....	13.06	11.82	.....	18.90	.....	0.69
December	2,981	2,926	.....	10.75	10.55	.....	7.47	.....	1.44
Year	2,101	2,086	.....	89.51	88.87	.....	111.91	.....	.....

gives fictitious values exceeding unity, the monthly curves in the five basins are so nearly parallel that the grand mean given in Table 5, exhibiting the average variations from month to month, affords the best basis for a general discussion of this element. A curve representing the final mean has been added to fig. 6, with dots to show the corresponding values for the entire basin above Bohio, as given in Table 5. This curve, which is well worthy of study, demonstrates that the same conclusions result whether one or all five divisions of the valley are considered.

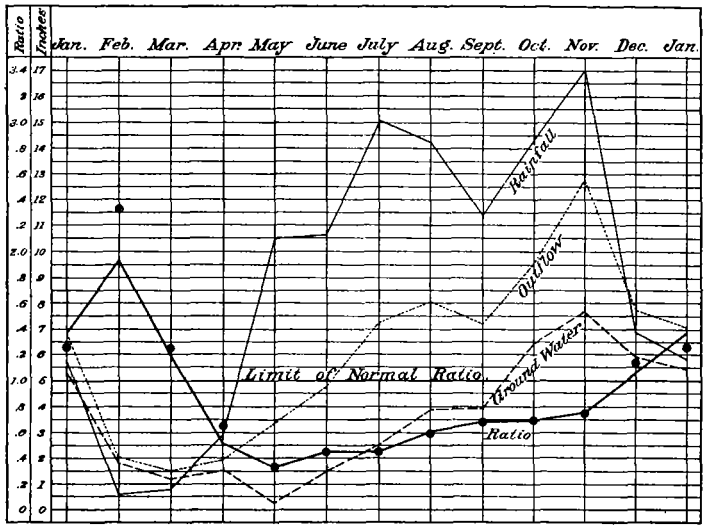

FIG. 6.—Hydrology of the basin of the Chagres River above Bohio. The three curves of mean monthly rainfall, outflow, and ground water are drawn to the scale of inches on the left-hand side, and accord with the data given in Table 7. The heavy curve, showing the ratio between the general average rainfall and drainage for the five basins for the six years is plotted according to the scale of ratios on the left-hand side, and accords with the general average given in Table 5.

Bearing in mind that the maximum normal value of the ratio is unity, corresponding to the hypothetical case that the entire rainfall of each month flows off during that month in the channel of the river, it is at once apparent that ground water plays a most important part in the regimen of the Chagres. The soil of the valley must act like a vast sponge and radically modify the rate of flow. In May, just after the end of the dry season, the ratio has its minimum value, about 0.3, the soil then being probably nearly or quite drained of its reserves. From this date the ratio continues gradually and steadily to increase, indicating a larger and larger volume of ground water escaping to the stream until, in November, when the outflow reaches its maximum, exceeding 12 inch-miles per month, the ratio becomes about 0.75. Then follows the dry season, when the rainfall soon becomes only about 1 inch-mile per month, but the ratio continues to rapidly increase to a maximum, in February, of about two units, indicating that the flow is then maintained almost wholly by ground water. From this maximum the ratio rapidly falls to the minimum, in May, by reason of the gradual failure of the ground-water supply. Incidentally, it may be remarked that nature thus provides an efficient and precious reserve to meet, in part, the needs of the canal. This matter is so important that it merits an analysis in figures.

The first step is to form an estimate as to what is the normal ratio between downfall and drainage when there is no flow of ground water. Table 5 presents 23 independent determinations of this ratio for the minimum month (May), giving an average value of 0.30, with a probable error of 0.03. As this value is not inconsistent with what investigations upon other streams of similar size and character of catchment basin would suggest, it will be adopted for the Chagres. While nothing is better established than that this ratio is subject to considerable variations, even in the same district, dependent upon whether the rainfall is gradual or comes in violent downpours

and upon other causes, it may be hoped that in this case observations have been continued for a period long enough to effect mutual cancelation among the variable elements to an extent sufficient to justify general conclusions from the following computations. Nothing more is claimed for them.

Upon the assumption then that in the Valley of the Chagres the normal value of the ratio between downfall and drainage, when there is no flow of ground water, is 0.30, the portion of each monthly outflow attributable to direct rainfall may be computed, since it is the product of the measured monthly outflow by the quotient obtained by dividing 0.30 by the observed value of the ratio for the corresponding month. The difference between such outflow and that directly measured will represent the volume attributable to ground water. The following table exhibits the results of such a computation applied to the mean outflow past Bohio during the six years recorded in Table 6. If 0.3 should be considered too small a value for the normal ratio when no ground water is flowing, it should be borne in mind that the only effect of an increase would be to reduce the estimated volume of the latter without effecting the essential fact that it constitutes a real and very important element in the regimen of the Chagres. For example, if the normal ratio be assumed as 0.5, which is probably excessive for this heavily wooded region, the computed volume of ground water in November, the maximum month, will only fall from 4800 cubic feet per second to 2666 cubic feet, and the corresponding volume of direct flow will only increase from 3200 cubic feet to 5334 cubic feet. Such a change has no important bearing upon the fundamental fact of the real flow.

TABLE 7.—*Means for six years in the basin above Bohio, 700 square miles.*

Month.	Rainfall.	Measured outflow.		Outflow due direct rainfall.		Outflow due ground water.	
		Foot-seconds.	Inch-miles.	Foot-seconds.	Inch-miles.	Foot-seconds.	Inch-miles.
	Inches.						
January	5.78	4,327	7.13	1,030	1.70	3,297	5.43
February	1.06	1,430	2.09	184	0.27	1,246	1.82
March	1.34	908	1.50	22	0.36	886	1.14
April	2.95	1,183	1.89	231	0.37	952	1.52
May	10.47	2,034	3.35	1,907	3.14	127	0.21
June	10.63	2,977	4.74	2,029	3.24	945	1.50
July	15.51	4,397	7.24	2,873	4.72	1,524	2.52
August	14.21	4,909	8.08	2,540	4.18	2,369	3.90
September	11.45	4,602	7.33	2,124	3.38	2,478	3.95
October	14.21	5,802	9.56	2,501	3.16	3,301	6.40
November	17.01	8,000	12.76	3,200	5.10	4,800	7.66
December	6.92	4,717	7.77	1,241	2.05	3,476	5.72
Year	111.54	3,774	73.44	1,657	31.67	2,117	41.77

On fig. 6 will be found a curve showing from month to month the volume attributed to ground flow as contained in Table 7. It is reasonable to suppose that the gradual and progressive filling and emptying of the subterranean reservoir, as rainy and dry seasons succeed each other, should cause a gradual progressive flow of ground water of like character, and this the curve certainly indicates. It may, therefore, be fairly claimed that it offers intrinsic evidence of its approximate accuracy. A comparison of dates shows that the rainfall during these six years attained its maximum in November and its minimum in February, and that the corresponding values of the ratio between downfall and drainage (Table 5) occurred respectively in February and May, or three months later in each case. Furthermore, the rate of increase of this ratio from month to month is less rapid at first than later, as would naturally be expected to result from the prolonged dry season during which the accumulated supply is slowly finding its way to the river bed. These facts perhaps suggest that the average rate of flow through the earth may be such as to require about three months to attain the river.

Finally the results of the analysis certainly demonstrate how groundless are the apprehensions that serious leakages may occur in the artificial lakes which form a part of the project. Manifestly, if important drains other than the bed of the river existed no such normal flow of ground water throughout the entire region is conceivable. The opinions of the geologists of the company are amply confirmed.

That a moderate percolation exists through the lower part of the tertiary deposit that fills the ancient gorge at and above Bohio is well known, and it is not without interest to consider what light this analysis throws upon its importance. Table 6 supplies the data. By regarding only the annual means, all complications resulting from ground water are eliminated, and as outflow per inch-mile and rainfall in inches are directly comparable conclusions may be formed from a simple inspection of the figures, which are here repeated for convenience of reference.

Locality.	Annual outflow, inch-miles.			Annual rainfall.	
	5 years.	6 years.	14 years.	5 years.	6 years.
Above Bohio	72.83	73.44	91.86	110.97	111.54
Above Gamboa	80.66	81.90	94.30	109.05	107.44
Lower subbasin	58.40	58.53	86.42	108.41	114.54
Middle subbasin	56.73	.....	.....	98.08	.....
Upper subbasin	89.51	.....	.....	111.91	.....

While it is to be regretted that the observations at Alhajuela were not begun sooner, this evidence is sufficient to justify the belief that the largest rainfall and the largest outflow per square mile occur in the upper subbasin which nearly approaches the Atlantic coast. In the middle subbasin they appear to be the least, as might be expected since it is the one most remote from this rainy coast. But the lower subbasin, although receiving about the same rainfall as the general average throughout the entire basin, and more than that above Gamboa, has a less outflow per square mile than either. The latter district is the better standard of comparison, since the deficiency of outflow in the lower subbasin affects the average for the entire basin, while the average above Gamboa is not thus reduced, and the slight excess there, in recorded rainfall, indicates that the normal outflow of the lower subbasin should be at least equal. But the 5-year column of the table indicates an annual deficiency in outflow of about 22 inch-miles; the 6-year column, one of about 23 inch-miles, and the 14-year column (for which there are no corresponding rainfall data) one of about 8 inch-miles. The area of the lower subbasin being 250 square miles, these figures respectively correspond to discharges per second of 413 cubic feet, 432 cubic feet, and 195 cubic feet, which appear to be attributable to percolation through the bed of gravel underlying the present bed of the river at Bohio. While admittedly of questionable numerical accuracy, these figures are not alarming. They correspond to percolations of 0.06 and 0.02 inch in twenty-four hours, and the International Commission of Engineers advisory to the New Panama Canal Company estimated 0.24 inch as the probable percolation from the artificial lakes. Still it must not be forgotten that the flow will be increased under the increased head due to the artificial lake, and in my judgment this new data confirms the belief that the level of Lake Bohio should not be raised to the height demanded by the single lake project, and that reserves for the low-water needs of the canal should be stored in an upper lake above Alhajuela, where they will certainly be secured against leakage.

It remains to consider the general problem of what becomes of the rain that falls on the catchment basin of the Chagres, or, in other words, to estimate the volume of the residue after allowance has been made for direct and ground-water flow. This residue is usually classed as evaporation, although it really represents not only evaporation, properly so called, but also water absorbed by plants, much of which is ultimately returned as vapor to the atmosphere, and that part of infiltrated water which penetrates deeply into the earth and is

there consumed in the chemical changes in progress. The data available are insufficient to render it possible to differentiate between these three kinds of loss.

Table 7 is in a form to facilitate this study, and from it are extracted most of the items in the following table, which represents the entire catchment basin above Bohio during the six years for which complete data are available. The residue found by subtracting direct flow and ground water from rainfall is denominated evaporation, which is classed as negative when the rainfall becomes less than the outflow, by reason of ground water.

TABLE 8.—*Disposition of rainfall in the Valley of the Chagres.*

Month.	Rainfall.	Outflow, in inch-miles.		Evaporation.	
		Direct.	Ground water.	Inch-miles.	Per cent of rainfall.
	Inches.				
January	5.78	1.70	5.43	Negative.	.....
February	1.06	0.27	1.82	Negative.	.....
March	1.34	0.36	1.14	Negative.	.....
April	2.95	0.37	1.52	1.06	36
May	10.47	3.14	0.21	7.12	68
June	10.63	3.24	1.50	5.89	55
July	15.51	4.72	2.52	8.27	53
August	14.21	4.18	3.90	6.13	43
September	11.45	3.38	3.95	4.12	36
October	14.21	3.16	6.40	4.65	36
November	17.01	5.10	7.66	4.25	25
December	6.92	2.05	5.72	Negative.	.....
Year	111.54	31.67	41.77	38.10	34

It is to be noted that the monthly estimates for evaporation in Table 8 are subject to the criticism that the ground-water flow due to rain falling in previous months is included in the computations for each month, and must vitiate the results. If the rate of flow through the ground were definitely known this error could be corrected, but this is a refinement too uncertain to be attempted. The steady decrease in the percentage column from month to month in the rainy season is doubtless due to this cause, and the value for June and July, when there is little ground water, is, say, about 55 per cent, which is probably quite closely the average for the entire rainy season. The average value for the year, 34 per cent of the rainfall, is not vitiated by ground water, as it represents a complete cycle, and its small figure is due to the absence of surface water to be evaporated in the dry season. The reduced humidity then observed confirms this view.

It would appear, therefore, from this study of the rainfall above Bohio, that the annual loss by evaporation (as above defined) averages 3.18 inch-miles per month, corresponding to a flow from the entire 700 square miles of 1995 cubic feet per second, to compare with 1657 cubic feet of direct flow and 2117 cubic feet of ground-water flow. In other words, of the entire rainfall about one-third disappears, another third flows off directly by the channel of the Chagres, and the remaining third, after a retardation of perhaps three months by its passage through the soil, ultimately reaches the bed of the river as ground water.

Furthermore, the 3.18 inches lost monthly by evaporation correspond to a daily loss of 0.11 inch; and as this applies to the general surface of the country, not to water surfaces directly exposed to the atmosphere, it is in good accord with the measurements above quoted made by the Isthmian Canal Commission in Nicaragua where the climatic conditions are quite similar. Such figures certainly show that the high humidity observed on the Isthmus is easily explained, notwithstanding the large capacity for moisture in air of such high temperature.

To enable a comparison to be made between these results and those noted in more temperate regions, advantage is taken of the summary for 12 American streams given in the able paper on the "Relation of rainfall to run-off," by George W. Rafter, which forms "Water supply and irrigation paper," No. 80, of the United States Geological Survey, 1903. The available data respecting these streams were not sufficient to permit a quantitative estimate of the ground-water flow, but Mr. Rafter in his general summary of the subject states the following conclusions, which are amply confirmed by the Chagres records: "When rainfall is below the mean for several months ground water may be expected to become continuously lower, with the result that the flow of streams will be less." And, "The ground water must be taken into account in order to understand all the peculiarities of flow. A very important effect of forests is in increasing the ground-water flow." The following table is abstracted from that on page 99 of Mr. Rafter's paper, the unit being inches per square mile of the basin. The figures for the Chagres are repeated for convenience of comparison.

TABLE 9.—*Average annual rainfall, outflow, and evaporation in the catchment basin.*

Streams.	Years observed.	Catchment area.	Rainfall.	Outflow.	Evaporation.
		Sq. miles.	*Inches.*	*Inches.*	*Inches.*
Muskiguni River	8	5,828.0	39.7	13.1	26.6
Genessee River	9	1,070.0	40.3	14.2	26.1
Croton River	23	338.8	49.4	22.8	26.6
Lake Cochituate	38	18.9	47.1	20.3	26.8
Sudbury River	26	78.2	46.1	22.6	23.5
Mystic Lake	18	26.9	44.1	20.0	24.1
Neshaminy Creek	16	139.3	47.6	23.1	24.5
Perkiomen Creek	16	152.0	48.0	23.6	24.4
Tohickon Creek	15	102.2	50.1	28.4	21.7
Hudson River	14	4,500.0	44.2	23.3	20.9
Pequannock River	9	63.7	46.8	26.8	20.0
Connecticut River	11	10,234.0	43.0	22.0	21.0
Chagres above Bohio	6	700.0	111.5	73.4	38.1

In round numbers, therefore, it appears that the valley of this tropical river has about 2.5 times the rainfall, about 3.3 times the outflow, and about 1.5 times the evaporation characteristic of the northeastern portion of the United States, and that ground water probably plays a much more important part in the regimen of the stream.

Now that the Panama Canal is about to pass under the control of the United States it is proper to state that to the wise forethought of Monsieur Maurice Hutin, the Director General, and of Monsieur Louis Choron, the Director of Investigations and of Construction, is due the credit for the exceptionally complete system of observations which renders possible a close study of every element involved in the preparation of the final plans for the completion of the canal. Such data is of vital importance, and could only have been secured by long years of labor.

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Dr. W. F. R. PHILLIPS, Librarian, etc.

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Quarterly Journal of the Royal Meteorological Society. London. Vol. 30.

Marriott, W. Some Account of the Meteorological Work of the late James Glaisher. Pp. 1-22.

—— Currents in the Arctic Ocean. P. 28.

Symons, G. J. Report on the Thunderstorms of 1857. Pp. 29-39.

Gibbs, L. Evaporation from the Land. [Note.] Pp. 39-40.

—— Meteorological Society of Japan. [Note.] P. 40.

Sutton, J. R. On Certain Relationships between the Diurnal Curves of Barometric Pressure and Vapour Tension at Kenilworth (Kimberley), South Africa. Pp. 41-53.

Bourhill, H. Curious Electrical Phenomena. Pp. 55-56.