RAINFALL DATA OF BERKELEY, CAL.[1]

By WILLIAM GARDNER REED.

[Author's abstract, Washington, D. C., Mar. 10, 1916.]

Engineers are of necessity paying more and more attention to rainfall data, particularly to data of heavy falls of rain in short intervals of time, because of the importance of a knowledge of such heavy falls in connection with the designing of storm sewers and other structures which must carry off the rain water. The records kept by the University of California as a cooperative station of the Weather Bureau since 1886, and by the sanitary engineer and the department of civil engineering of the university since 1910, have been tabulated and studied. These data are the only records available for the east shore of San Francisco Bay, and the study is of interest because it modifies and extends the previous work.[2]

Measurements of precipitation, using a standard 8-inch raingage, have been made at least once each day since October, 1886. Until 1892 measurements were made regularly at 2 p. m. (Pacific time); since 1892 the measurements have been made at 8 a. m. and 8 p. m. Measurements have frequently been made at the end of the rain and during rain, although the practice has varied from time to time. Since 1910 records from a Friez tipping-bucket gage, electrically recording, are available; but these records are more or less fragmentary because of gage failure. The exposures of the gages are shown by Table 1.

TABLE 1.—*Raingage exposures at Berkeley, Cal.*[3]

8-inch raingage.

Date.	Description of exposure.	H.	h.	Read at—
		Ft.	*Ft.*	*Pac. St. T.*
October, 1886, to September, 1892.	Framework over a portion of the observatory building.	347	21	2 p. m.
September, 1892, to September, 1899.	On the ground north of observatory building.	320	1	8 a. m. 8 p. m.
Since September, 1899..	Roof of extension of observatory building.	334	15	8 a. m. 8 p. m.

12-inch tipping-bucket gage.

Date.	Description of exposure.	H.	h.	Read at—
Since January, 1911.....	Roof of 6 feet × 12 feet shed 12 feet above roof of civil engineering building, 60 feet square.	410	70	Electrically recording each 0.01 inch rain.

Although roof exposure is not to be recommended, conditions at Berkeley have made such exposure necessary and this exposure is fairly satisfactory.[4] A careful examination of the rainfall record of the Students' Observatory shows no break in continuity when the position of the gage was changed in 1892 and in 1899.

TABLE 2.—*Summary of rainfall data, Berkeley, Cal., July, 1887–June, 1915.*

[Compiled from observations by the University of California in cooperation with the U. S. Weather Bureau.]

Month.	Total precipitation.					Number of days with 0.01" or more.				
		Greatest.		Least.			Greatest.		Least.	
	Average.	Amount.	Year.	Amount.	Year.	Average.	Number.	Year.	Number.	Year.
	In.	*In.*		*In.*		*Days.*	*Days.*		*Days.*	
January......	6.02	15.99	1911	0.78	1889	12	25	1909	4	1889
February.....	4.16	10.68	1891	0.22	1899	9	25	1915	1	1898
March........	4.59	13.19	1899	0.31	1898	10	18	{1904, 1907}	3	{1898, 1901, 1914}
April.........	1.43	6.72	1896	0.02	1909	6	14	1896	1	{1898, 1909}
May..........	1.27	3.43	1905	0	1909	5	14	1915	0	1909
June.........	0.21	1.24	1907	0	8 yrs.	1	5	1888	0	12 yrs.
July..........	0.02	0.44	1891	0	18 yrs.	0	2	{1891, 1913}	0	24 yrs.
August.......	0.04	0.90	1896	0	14 yrs.	0	2	{1896, 1898, 1906}	0	20 yrs.
September....	05.8	4.44	1904	0	6 yrs.	2	6	{1891, 1901}	0	8 yrs.
October......	1.43	5.80	1889	0	{1887, 1890}	4	12	1889	0	4 yrs.
November....	2.68	5.89	1903	0	1890	7	17	1913	1	{1890, 1894, 1907}
December....	4.29	12.63	1894	1.22	1898	10	24	1889	3	1910
Year (July-June).....	26.72	46.00	1889-90	14.40	1897-98	66	104	1889-90	52	1897-98

TABLE 3.—*Maximum precipitation in 1 day for each rainfall year, July, 1887–June, 1915, Berkeley, Cal.*

[Compiled from observations by the University of California in cooperation with the U. S. Weather Bureau.]

Rainfall year.	Amount.	Month.	Rainfall year.	Amount.	Month.
	Inches.			*Inches.*	
1887-88..............	1.94	January.	1901-02..............	1.79	February.
1888-89..............	3.43	March.	1902-03..............	2.01	November
1889-90..............	3.63	January.	1903-04..............	*4.75	February.
1890-91..............	4.16	February.	1904-05..............	2.75	September.
1891-92..............	1.56	December.	1905-06..............	1.78	March.
1892-93..............	2.96	December.	1906-07..............	2.31	March.
1893-94..............	3.70	January.	1907-08..............	1.85	January.
1894-95..............	2.20	January.	1908-09..............	2.34	January.
1895-96..............	2.48	April.	1909-10..............	1.66	December.
1896-97..............	2.21	November.	1910-11..............	2.88	January.
1897-98..............	2.19	December.	1911-12..............	1.20	March.
1898-99..............	3.20	March.	1912-13..............	2.39	November.
1899-00..............	3.22	October.	1913-14..............	2.28	January.
1900-01..............	2.06	April.	1914-15..............	1.72	December.

*This amount fell between 1 p. m. Feb. 11, 1904, and 3:45 p. m. Feb. 12, 1904; the 24-hour amount is not available.

TABLE 4.—*Maximum precipitation in 1 day for each month, Berkeley, Cal.*

[Based on records July, 1887–June, 1915, compiled from observations by the University of California in cooperation with the U. S. Weather Bureau.]

Month.	Amount.	Year.	Month.	Amount.	Year.
	Inches.			*Inches.*	
January..................	3.70	1894	July..................	0.44	1891
February................	*4.75	1904	August..................	0.84	1896
March..................	3.43	1889	September..............	2.75	1904
April..................	2.48	1896	October..................	3.22	1899
May..................	2.16	1905	November..............	2.47	1903
June..................	0.62	1894	December..............	2.96	1892

* Maximum in any one day, 4.75 inches February, 1904.

[1] A revised summary by the author of the material contained in the following papers: Rainfall data of Berkeley, Cal. Univ. Cal. publ. in engin., 1: 69–81. Berkeley, 1915. Rainfall data of Berkeley, Cal., II. Univ. Cal. publ. in engin., 1: 83–116. Berkeley, 1916.

[2] The principal papers dealing with heavy falls of rain for the region are as follows: *Grunsky, C. E.* The sewer system of San Francisco, and a solution of the storm-water flow problem. Trans., Am. soc. c. e., New York, 1909, 65: 294–422.
Hyde, C. G. Report on Richmond, Cal., sewers, 1910.
Le Conte, L. J. Intensity of rainfall at San Francisco, Cal. Trans., Am. soc. c. e., New York, 1905, 54: 197–198, in discussion of *C. W. Sherman*, Maximum rates of rainfall at Boston.
McAdie, A. G. The rainfall of California. Univ. Cal. publ. geog., Berkeley, 1914, 1: 127–240.
McAdie, A. G. The climate of San Francisco, Cal. Washington, 1913. 8°. (U. S. Weather Bureau. Bul. 44.)

[3] The exposures are discussed at length in "Rainfall of Berkeley, Cal.," Univ. Cal. publ. geog. Berkeley, 1913, 1:63–79. Report of the meteorological station, 1912–13. *ibid.*, Berkeley, 1914, 1:247–306. Report, 1913–14. *ibid.*, Berkeley, 1916, 1:373–439.

[4] *Marvin, C. F.* The measurement of precipitation. U. S. Weather Bur. Instrument Div. Circular "E," 3d edition, p. 15. Washington, 1913.

TABLE 5.—*Precipitation of 2.50 inches or more in 24 hours at Berkeley, Cal., July, 1887–June, 1915.*

[Compiled from observations by the University of California in cooperation with the U. S. Weather Bureau.]

Month.	Year.	Amount.
		Inches.
September	1904	2.75
October	1899	3.22
November		None.
December	1892	2.96
January	1890	3.63
Do	1894	3.70
Do	1911	2.88
February	1891	4.16
Do	1904	4.75
March	1889	3.43
Do	1899	3.20
Do	1904	2.91

From a statistical and graphic study of all 12-hour periods for which records of intensity are available from the recording gage, the following have been deduced:

(*a*) When 0.80 inch falls in 12 hours, there is a chance that the maximum intensity for 1 hour exceeds 0.50 inch.

(*b*) When 0.80 inch falls in 12 hours, it is probable that 0.30 inch for 1 hour has been exceeded; this is half the maximum shown by the Grunsky curve for San Francisco. (See fig. 1.)

(*c*) When 0.80 inch falls in 12 hours, there is a chance that 0.15 inch in 5 minutes has been exceeded; this is the maximum shown by the Grunsky curve.

(*d*) When 0.80 inch falls in 12 hours, it is probable that 0.07 inch in 5 minutes has been exceeded; this is the lower limit of practical importance; it is half the maximum shown by the Grunsky curve.

TABLE 6.—*Precipitation of marked intensity at Berkeley, Cal., Jan. 1, 1911, to Apr. 30, 1915.*

12-hour period ending at—	Total rain in 12 hours.			5-minute period.		1-hour period.
	Obs.*	C. E.*	Ratio C. E.÷Obs.	Maximum total rain.	Corresponding intensity.	Maximum total rain and intensity.
1911.	*In.*	*In.*		*In.*	*In. per hr.*	*In. per hr.*
Jan. 12, 8 a. m.	0.98					
Jan. 13, 8 p. m.	0.88	0.86	0.98	0.13	1.56	0.15
Jan. 14, 8 a. m.	2.00	1.96	0.98	0.06	0.72	0.39
Jan. 20, 8 a. m.	1.76	1.69	0.96	0.05	0.60	0.35
Jan. 24, 8 a. m.	1.42	1.43	1.01	0.05	0.60	0.30
Jan. 24, 8 p. m.	0.82	0.74	0.90	0.04	0.48	0.36
Jan. 28, 8 a. m.	1.27	1.18	0.93	0.05	0.60	0.33
Jan. 29, 8 a. m.	1.03	0.91	0.88	0.05	0.60	0.19
Jan. 30, 8 a. m.	0.78	0.65	0.83	0.09	1.08	0.32
Mar. 5, 8 a. m.	0.65	0.57	0.88	0.09	1.08	0.23
Mar. 6, 8 p. m.	1.13			0.06	0.72	0.46
Mar. 7, 8 a. m.	1.14	1.23	1.08	0.29	3.48	0.51
Apr. 5, 8 a. m.	1.45 in 24 hrs.					
1912.						
Jan. 26, 8 a. m.	0.77	0.73	0.95	0.10	1.20	0.38
Mar. 12, 8 a. m.	1.02	0.96	0.94	0.04	0.48	0.26
Apr. 10, 8 p. m.	0.45	0.41	0.91	0.09	1.08	0.18
May 22, 8 p. m.	0.12	0.08	0.67	0.08	0.96	0.08
Nov. 6, 8 a. m.	1.44	1.25	0.88	0.03	0.36	0.19
Nov. 6, 8 p. m.	0.95	0.85	0.87	0.04	0.48	0.21
Dec. 14, 8 p. m.	0.50	0.49	0.98	0.10	1.20	0.26
1913.						
Jan. 8, 8 p. m.	0.58	0.55	0.95	0.08	0.96	0.30
Jan. 16, 8 p. m.	0.41	0.35	0.85	0.08	0.96	0.23
Mar. 17, 8 p. m.	0.52	0.49	0.94	0.09	1.08	0.20
Nov. 18, 8 p. m.	0.89	0.78	0.88	0.05	0.60	0.33
Nov. 20, 8 a. m.	0.59	0.57	0.97	0.08	0.96	0.35
Nov. 27, 8 a. m.	1.00					
Dec. 22, 8 a. m.	0.82					
Dec. 30, 8 p. m.	1.54			0.06	0.72	0.33
Dec. 31, 8 p. m.	1.14	0.85	0.75	0.07	0.84	0.27

* Obs.=8-inch gage at Students' Observatory.
C. E.=12-inch gage, electrically recording, at Civil Engineering Building.

TABLE 6.—*Precipitation of marked intensity at Berkeley, Cal., Jan. 1, 1911, to Apr. 30, 1915*—Continued.

12-hour period ending at—	Total rain in 12 hours.			5-minute period.		1-hour period.
	Obs.*	C. E.*	Ratio C. E.÷Obs.	Maximum total rain.	Corresponding intensity.	Maximum total rain and intensity.
1914.	*In.*	*In.*		*In.*	*In per hr.*	*In per hr.*
Jan. 2, 8 a. m.	0.99					
Jan. 12, 8 p. m.	2.01	2.08	1.04	0.08	0.96	0.52
Jan. 14, 8 a. m.	0.72	0.61	0.65	0.05	0.60	0.31
Jan. 17, 8 a. m.	1.02					
Jan. 17, 8 p. m.	0.57			0.07	0.84	0.21
Jan. 22, 8 a. m.	1.16	1.05	0.90	0.05	0.48	0.28
Jan. 24, 8 a. m.	1.32	1.05	0.80	0.03	0.36	0.27
Feb. 20, 8 p. m.	1.15	1.06	0.92	0.05	0.60	0.28
Mar. 29, 8 a. m.	0.82	0.90	1.10	0.10	1.20	0.44
Apr. 4, 8 a. m.	0.42	0.39	0.93	0.06	0.72	0.32
Dec. 2, 8 p. m.	0.71	0.69	0.97	0.06	0.72	0.33
Dec. 6, 8 p. m.	0.25	0.25	1.00	0.10	1.20	0.22
Dec. 16, 8 p. m.	1.40	1.20	0.86	0.05	0.60	0.43
1915.						
Jan. 6, 8 a. m.	0.65	0.56	0.86	0.09	1.08	0.26
Jan. 8, 8 a. m.	0.87	0.82	0.94	0.13	1.56	0.52
Jan. 11, 8 p. m.	0.41	0.43	1.05	0.03	0.36	0.30
Feb. 2, 8 a. m.	0.83	0.74	0.89	0.07	0.84	0.21
Feb. 7, 8 p. m.	1.06	0.96	0.91	0.05	0.60	0.31
Feb. 16, 8 p. m.	0.62	0.51	0.82	0.17	2.04	0.31
Feb. 22, 8 p. m.	0.99					
Feb. 24, 8 a. m.	0.34	0.32	0.94	0.08	0.96	0.24
Apr. 26, 8 a. m.	0.33	0.34	1.03	0.10	1.20	0.33

Table 6 is a summary of the data of heavy rainfall from which the study was made to determine the occurrence of precipitation of marked intensity. It includes all 12-hour periods from January 1, 1911, to April 30, 1915, during which the amount indicated important intensities. Interesting intensities for Berkeley are:

≥ 0.80 inch in 12 hours.
≥ 0.30 inch in 1 hour.
≥ 0.07 inch in 5 minutes.

The table indicates that the 5-minute or 1-hour periods with precipitation of approximately half the maximum intensity will occur at Berkeley about as often as the 12-hour amount equals or exceeds 0.80 inch.

A study of the records of heavy continuous downpours has made it possible to estimate with a moderate degree of accuracy the probabilities of the maximum intensity when we know the total fall of rain and the duration of the downpour. The results are given in Table 7.

TABLE 7.—*Ratio of average intensity to maximum intensity for short periods of heavy continuous downpour, Berkeley, Cal., January, 1911, to February, 1915.*

	Continuous downpour.			Maximum intensity.		Ratio: maximum÷average intensity.	
	Total rain.	Duration.	Average intensity.	5 minutes.	10 minutes.	5 minutes.	10 minutes.
Average of all downpours	*Inches.* 0.56	*Min.* 139	*In./hr.* 0.25	*In./hr.* 1.00	*In./hr.* 0.73	4.00	2.92
Maximum	[1] 2.08	[1] 360	[2] 0.51	[3] 3.48	[3] 1.92	[3] 8.50	[3] 4.68

[1] Jan. 12, 1914. [2] Jan. 26, 1912. [3] Mar. 7, 1911.

In the consideration of the run-off of rainfall of marked intensity, the condition of the ground at the time of maximum intensity is important. At Berkeley frozen ground does not affect the problem, but the amount and duration of rainfall immediately preceding the maximum intensity are of considerable importance.[5] These data are presented in Tables 8, 9, 10, and 12.

TABLE 8.—*Percentage of cases at Berkeley, Cal., 1911–1915, in which the maximum intensity of rainfall for 5 minutes occurred within a given period from the beginning of continuous heavy rain.*

Maximum intensity for 5 minutes occurred within—	Per cent of cases.
5 minutes from the beginning of heavy rain	29
10 minutes do. do.	40
20 minutes do. do.	52
30 minutes do. do.	61
40 minutes do. do.	63
60 minutes do. do.	66
90 minutes do. do.	77
120 minutes do. do.	86
180 minutes do. do.	91
240 minutes do. do.	95
300 minutes do. do.	97
360 minutes do. do.	98
420 minutes do. do.	99
480 minutes do. do.	100

TABLE 9.—*Percentage of cases at Berkeley, Cal., 1911–1915, in which the maximum intensity of rainfall for 5 minutes was preceded by continuous rain for a given amount.*

Maximum intensity for 5 minutes occurred after a fall of—	Per cent of cases.
1.80 inches or less	100
1.00 inch or less	99
0.60 inch or less	96
0.40 inch or less	93
0.30 inch or less	86
0.20 inch or less	81
0.10 inch or less	60

TABLE 10.—*Percentage of cases at Berkeley, Cal., 1911–1915, in which the maximum intensity of rainfall for 1 hour occurred within a given period from the beginning of the storm.*

Maximum intensity for 1 hour occurred within—	Per cent of cases.
1 hour from the beginning of the storm	20
2 hours do. do.	32
3 hours do. do.	35
4 hours do. do.	38
5 hours do. do.	44
6 hours do. do.	47
12 hours do. do.	58
18 hours do. do.	67
24 hours do. do.	76
30 hours do. do.	82
36 hours do. do.	86
42 hours do. do.	87
48 hours do. do.	89
54 hours do. do.	93
60 hours do. do.	95
72 hours do. do.	98
108 hours do. do.	100

TABLE 11.—*Percentage of cases at Berkeley, Cal., 1911–1915, in which the maximum intensity of rainfall for 1 hour was preceded by a storm of given amount.*

Maximum intensity for 1 hour after a fall of—	Per cent of cases.
3.00 inches or less	100
2.50 do. do.	94
2.00 inches or less	90
1.80 do. do.	88
1.60 do. do.	84
1.40 do. do.	82
1.20 do. do.	77
1.00 inch or less	71
0.90 do. do.	70
0.80 do. do.	66
0.70 do. do.	65
0.60 do. do.	61
0.50 inch or less	55
0.40 do. do.	51
0.30 do. do.	46
0.20 do. do.	34
0.10 do. do.	25

TABLE 12.—*Comparison of intensities of rainfall obtained from various curves for San Francisco and vicinity and observed maximum at Berkeley, Cal.*

Reference No.	Formula.	Intensities in inches per hour for periods of—												
		5 min.	10 min.	15 min.	20 min.	30 min.	45 min.	1 hr.	$1\frac{1}{2}$ hrs.	2 hrs.	3 hrs.	4 hrs.	5 hrs.	10 hrs.
1	$i=3.68\div\left[\frac{2t}{t+60}+t^{0.4}\right]$	1.79	1.31	1.10	0.97	0.81	0.68	0.60	0.51	0.45	0.38	0.34	0.32	0.25
2	None	2.16	1.50	1.20	1.02	0.83	0.68	0.60	0.51	0.45	0.38	0.34	0.32	0.25
3	$i=7\div t^{0.5}$	3.14	2.21	1.81	1.57	1.27	1.05	0.91	0.74	0.64	0.52	0.45	0.41	0.28
4	$i=5\div t^{0.5}$	2.24	1.58	1.29	1.12	0.91	0.75	0.65	0.53	0.46	0.37	0.32	0.29	0.20
5	None	2.60	2.00	1.65	1.41	1.12	0.88	0.74	0.60	0.51	....	....	....	....
6	None	3.48	2.00	1.65	1.41	1.12	0.88	0.74	0.60	0.51	....	....	....	....
7	$i=5.25\div[t^{0.5}-0.75]$	3.52	2.18	1.68	1.41	1.11	0.88	0.75	0.60	0.52	0.39	0.36	0.32	0.22
8	Automatic record	3.48	2.00	....	1.41	1.10	....	0.74	....	0.43	....	....	....	....

AUTHORITY.

1. *Grunsky, C. E.*, in Trans., Am. soc. c. e., 1908, **65**, 316. Data from all sources for San Francisco before 1899.
2. *Grunsky, C. E.*, in Trans., Am. soc. c. e., 1908, **65**, 316. Data from U. S. W. B., San Francisco, 1899–1908.
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4. *Metcalf & Eddy*, in American Sewerage Practice, v. 1, 1914, p. 230.
5. *Hyde, C. G.*, in Report on Richmond Sewers, 1910. Data from City Engineer, Oakland, 1906.
6. *White, M. K.*, in "Rainfall data of Berkeley, Cal., II, by W. G. Reed and M. K. White." Univ. Cal. publ. engin., Berkeley, 1916, 1: 83–116. Data from the recording gage at the university, 1911–1915.
7. *White, M. K.*, in Mathematical form of No. 6.
8. Tipping-bucket gage record at Berkeley, 1911–1915.

[5] *Henry, A. J.*, Rainfall of the United States, United States Weather Bureau Bull. D (Washington, 1897), p. 53, also published in Annual Report of the Chief of the Weather Bureau, 1896–97 (Washington, 1897), p. 363.
Correspondence from A. J. Henry in Journ. Western Soc. Engrs., vol. 4 (Chicago, 1899), pp. 165–166, in discussion (pp. 147–194) of *E. Duryea, jr.*, "Tables of excessive precipitations of rain at Chicago, Ill., from 1889 to 1897, inclusive," pp. 73–105.
Metcalf and Eddy, American sewerage practice, vol. 1, p. 268.

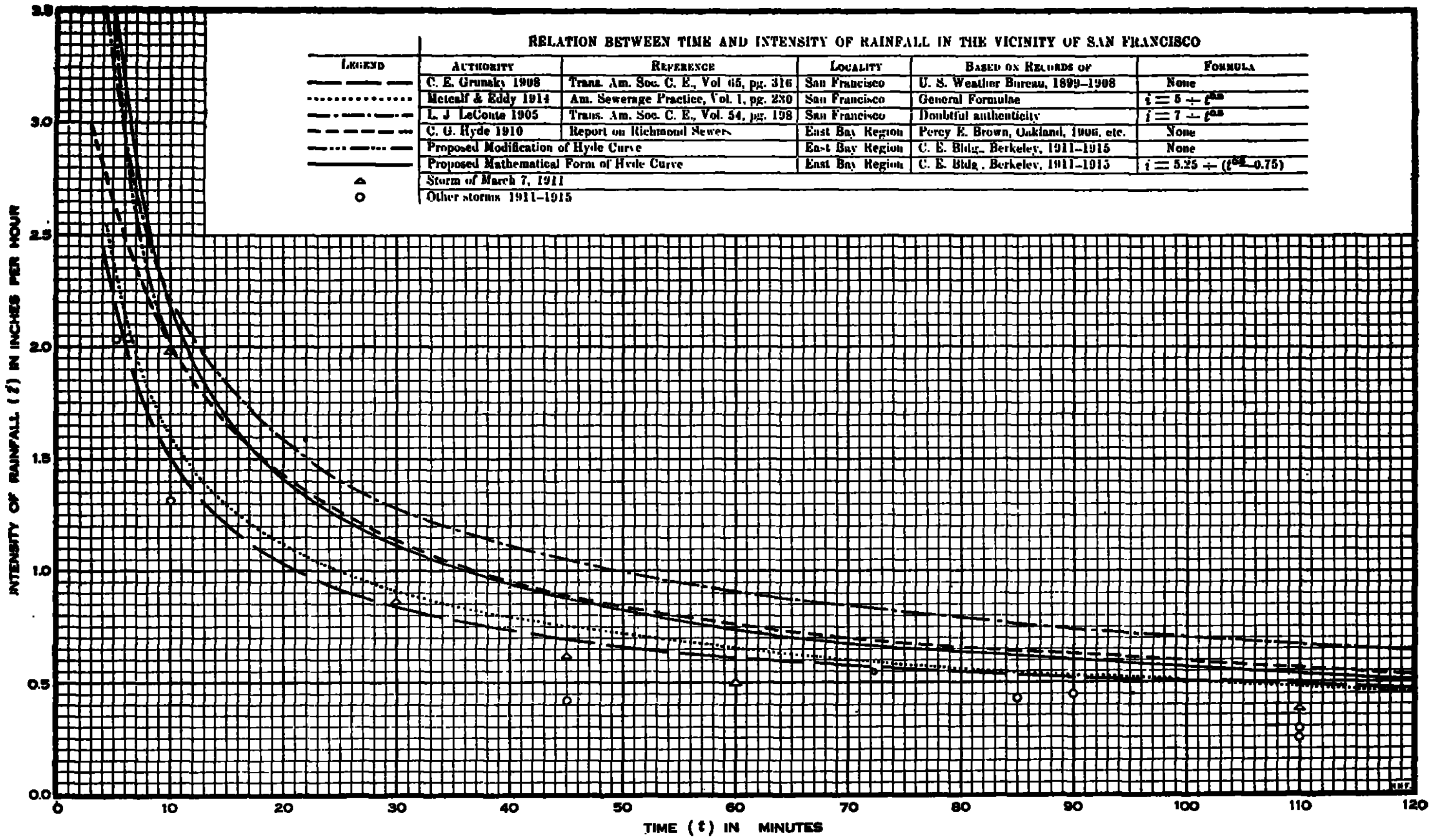

Figure 1.

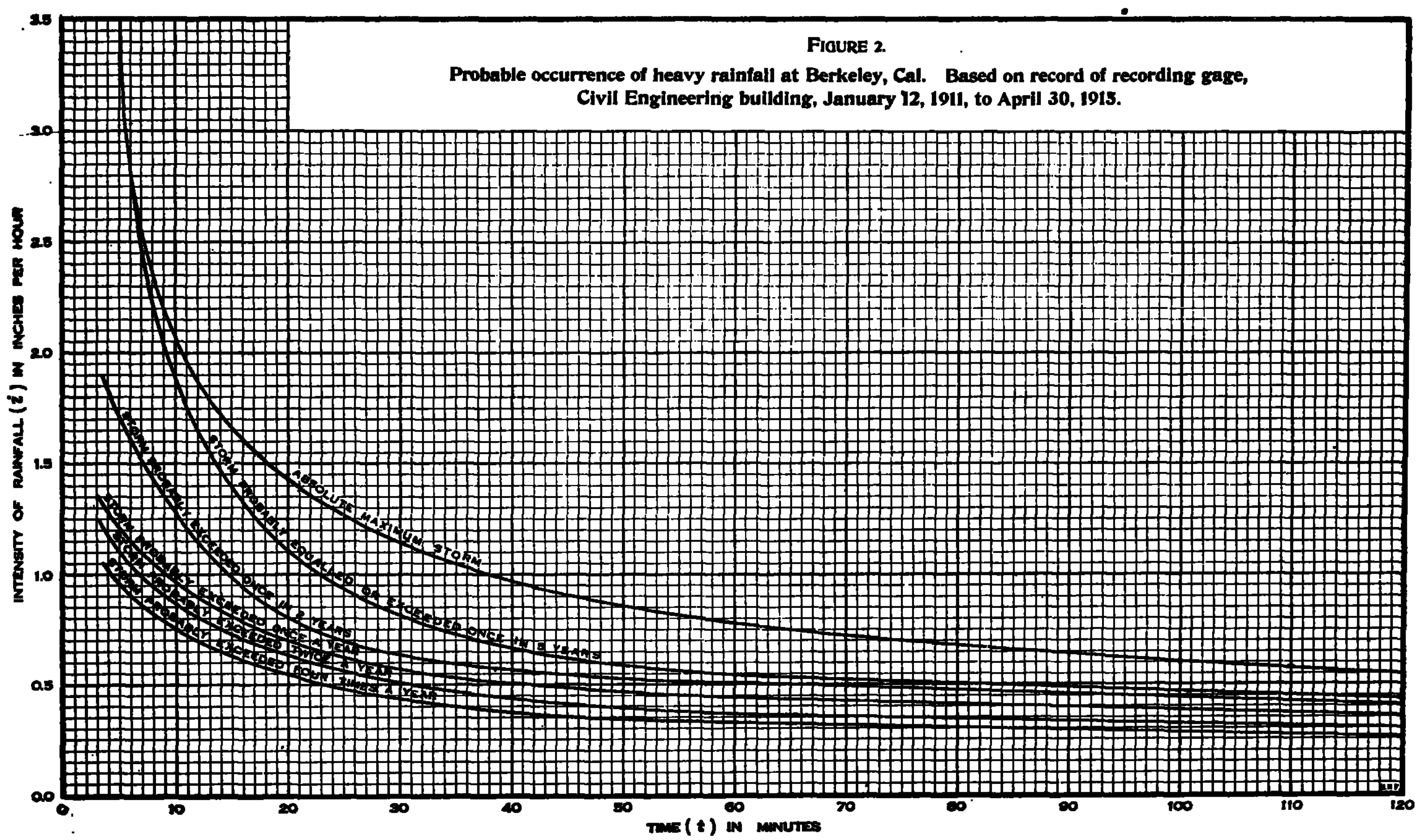

Figure 2.

Table 12 is a comparison of rainfall intensities, indicated by the various curves which have been used in the design of structures to carry off storm water in the San Francisco Bay region, and also the recorded maximum intensities for the five years during which the tipping-bucket gage has been in operation at Berkeley. The curves are shown by figure 1.

Under some conditions it might be unjustifiable to design a structure for the absolute maximum storm; but if the design is made for a storm of less severity, it is well to know how often the structure is likely to be inadequate. For this reason figure 2 was drawn from the data for all storms in which marked intensities were reached. In order to draw the curves it was necessary to make some interpolations for storms for which the intensity records are incomplete. The curves show within the limits of error imposed by the interpolation and the rather short record (five years) what intensities may be expected in the intervals shown.

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DISTRIBUTION OF CYCLONIC PRECIPITATION.[1]

By TORAHIKO TERADA, Rigakuhakushi.

[Dated: Physical Institute of College of Science, Tokyo Imperial University, Nov. 20, 1915.]

[Author's abstract.]

The regional distribution of cyclonic rainfall has already been investigated by many meteorologists.[2] The results, however, differ widely according to the localities concerned, and as yet no general theoretical discussion of the principal moments determining the distribution in question seems to have been attempted.

Recently Messrs. T. Yokota and S. Ôtuki, undergraduates in the Physical Institute of the Science College, undertook the statistical investigation of the problem regarding Japan. The chief data used were the daily weather charts of the Central Meteorological Observatory from January, 1905, to December, 1915. The main islands constituting Japan proper, i. e., Kiushu, Shikoku, Honshu, and Hokushu, were divided into 18 districts, 6 each for the Pacific, the Japan Sea, and the axial region. The percentage expectation of precipitation for each of these districts was calculated for different possible positions of the center of a cyclone. The chief results obtained may be summed up as follows:

(1) In front, i. e., on the northeast side of a cyclone, the precipitation is generally more frequent on the Pacific side of the land than on the Japan Sea side. On the rear side of the barometric depression the reverse is the case. The difference is most pronounced in regions remote from the center.

(2) When the center of the depression lies over the Japan Sea far from the land, specially if near the center of curvature of the axial line of Honshu, the lines of equal rainfall expectation have a tendency to run parallel to the axial line. In this case the draining influence of the coastal mountain ranges becomes obvious, in giving birth to a comparatively rainless zone in the axial region of Honshu.

For the case of the center lying over the Pacific, the rainfall is rather concentrated on a limited region of more or less closed shape.

(3) Comparing the depressions lying over the sea but not very far from the coast, the Pacific depression is associated with a more dense and extended precipitation area on the land than the Japan Sea one.

(4) When the depression lies east of Sakhalin the entire Japan Sea coast is affected, and the lines of equal expectation run parallel to the land.

In connection with these investigations a general theoretical discussion of the problem was attempted. It seems convenient to analyze the secondary influences causing the unsymmetrical distribution of cyclonic precipitation into the following three principal moments:

(*a*) Planetary thermal influence, which consists in the change of temperature with latitude. This influence results in shifting the center of rainfall on the southeastern side of the center of depression, in the Northern Hemisphere, provided the other conditions are uniform.

(*b*) Geographical thermal influence, which consists in the thermal contrast between land and water. The results differ widely according to the season, and also according to the humidity of the land in question. For example, in summer in the Northern Hemisphere, provided the land is sufficiently humid, this effect *taken alone* will tend to increase the precipitation on that side of the depression which looked at from the center has the land on the right-hand side.

(*c*) Hydrodynamical topographical influence, which consists in the forced ascending air current brought about by the discontinuity of the horizontal flux of air at the boundary of two regions with different coefficients of friction.[3] According to this influence, the precipitation will be generally abundant, cæteris paribus, on that part of the coast line, or that side of a mountain range, which viewed from the center of a cyclone has the sea or lowlands on the right-hand side. The direction of the greatest rainfall depends on the difference of friction. These relations have been fully discussed in the paper above cited.[3]

These three influences combined properly seem to explain the peculiarities of rainfall distribution in most diverse cases. For example, result (1) above mentioned is the direct outcome of the third influence (*c*). The result (2) may be explained if we consider that the amount of the third influence (*c*) mainly depends on the angle made by the coast line with the radius vector drawn from the center of the cyclone toward the point concerned. Besides, the draining effect of the mountain range may also be interpreted in terms of the same influence, since on the lee side of the range a downward velocity is superposed on the general upward velocity of air proper to the inner region of a cyclone.

Again, result (3) may be elucidated by the combination of influences (*a*) and (*c*), since in our case the supply of the moisture precipitated is mostly from the sea (the

[1] *Terada, Torahiko.* On the distribution of the cyclonic precipitations. (An abstract.) [Read Nov. 20, 1915.] Proc., Tôkyô math.-phys. soc., 1915 (2), 8, no. 12, pp. 382–384. Also separately printed.

[The spelling of place names conforms to the decisions of the U. S. Board on Geographic Names.—C. A. jr.]

[2] *Hildebrandsson, H.* Sur la distribution des éléments météorologiques autour des minimas et des maximas barométriques. Uppsala. 1883.

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Åkerblom, Ph. Sur las distribution à Vienne et à Torshavn des éléments, etc.

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[3] In the sense of the generalized Guldberg & Mohn theory. See *T. Terada*, in Proc. Tôkyô math.-phys. Soc., 1914, 7.