THE DISTRIBUTION OF RAINFALL OVER RESTRICTED AREAS.

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A correspondent has recently raised the question, What is the variation in intensity of rainfall in all directions from the center of a rainstorm?

The rains of eastern United States naturally fall into two great groups, first, cold-weather or cyclonic rains and, second, warm-weather rains, comprising for the most part convective and thunderstorm rains. It is quite probable that a further distinction should be made to take account of the latitude effect or distance inland from a large body of water. Rains of the first group, as a rule, are rather widely distributed and of rather uniform intensity, but rains of the second group are, on the other hand, largely local in character and may vary greatly in intensity with distance from the geographical center of the storm.

The distribution of precipitation about the center of a barometric depression has been studied by a number of meteorologists, but the results of their studies refer, almost exclusively, to the geographic distribution about the center rather than to the intensity of the rainfall in different parts of the storm.

It is not known with any degree of certainty whether or not the rainfall at the geographical center of a rainstorm is greater than at some distance from the center. It is a matter of common observation that the rainfall increases from zero at the margin of the storm to what may be called the average intensity at some unknown distance therefrom. In the absence of observational material little progress can be made toward a satisfactory solution of the problem. What is needed is a close network of gaging stations placed at uniform distances apart so as to cover completely some restricted area.

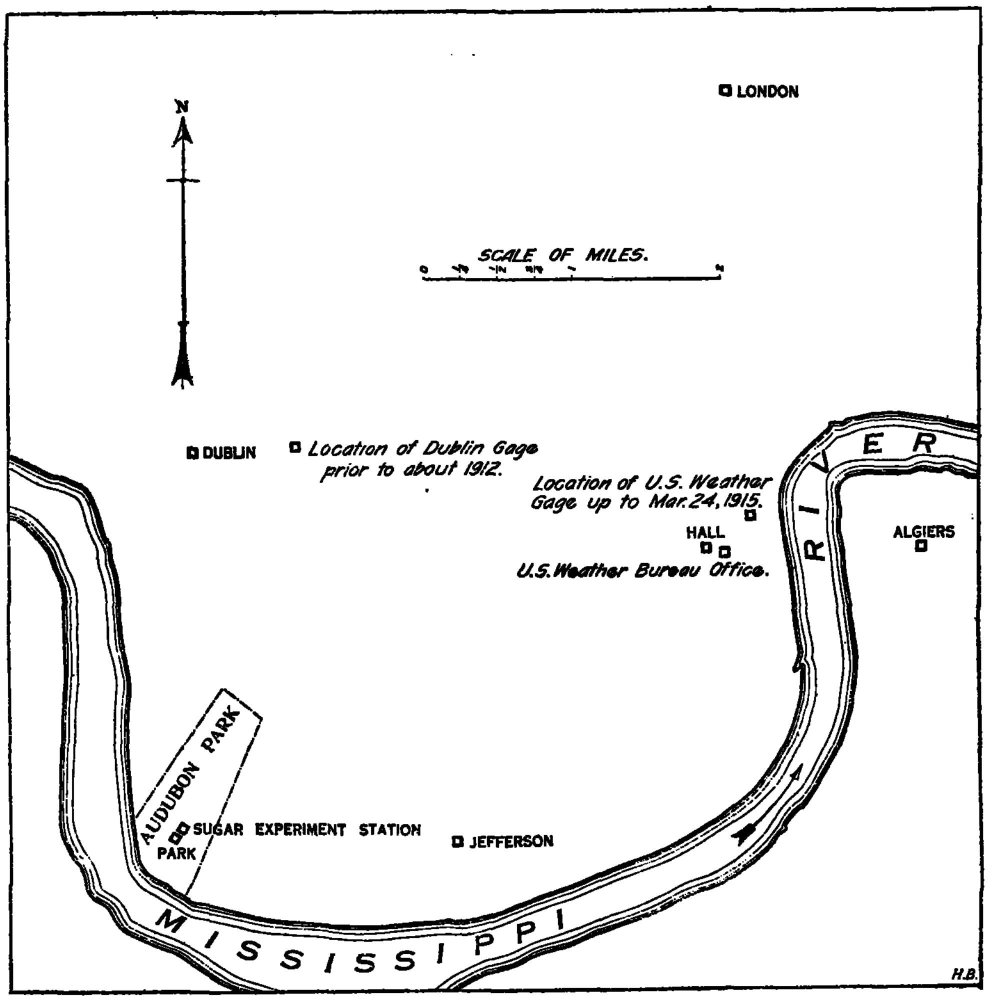

FIG. 1.—Distribution of rain gages, New Orleans, La.

The city of New Orleans, La., through its sewerage and water board maintains a network of six rain-gaging stations within the city limits and to this number two additional gages may be added, viz, those maintained by the Weather Bureau and the sugar experiment station, although the latter gage is exposed within a few feet of one of the sewerage and water board gages. There is available, therefore, in reality but seven gages within an area of, say, roughly 50 to 60 square miles, or one gage to about 8 square miles. Details as to exposure of these gages will be found in the table next below and the position of the gages may be seen from figure 1.

TABLE 1.—*Rainfall stations in New Orleans, La. Nos. 1 to 6 are maintained by the Sewerage and Water Board of New Orleans.*

No. and name of station.	Elevation above ground, feet, in—		Location and exposure of gage.	Distance from U. S. Weather Bureau gage.
	1895	1918		*Miles.*
U. S. Weather Bureau.	78.0	71.0	Roof old customhouse	....
Sugar experiment station.	3.4	3.4	On ground in Audubon Park	4.5
1. Dublin	9.2	21.5	On retaining wall at water purification plant.	3.8
2. Park	3.8	3.6	On ground in Audubon Park	4.5
3. Jefferson	20.6	15.3	Top of shed, Gen. Pershing Street and Jefferson Market.	2.9
4. City hall	77.1	91.0	Roof of city hall	0.4
5. London	7.0	8.5	On small platform at London pumping station.	2.9
6. Algiers	19.8	19.6	Top of shed in Algiers, right bank Mississippi.	1.1

The sewerage and water board stations, except No. 4, city hall, are equipped with an 8-inch gage of a pattern designed by the board. It is regretted that a description of the gage is not available. The city hall gage is one of the tipping-bucket form manufactured by Friez; it is the only self-recording gage in the network except that of the U. S. Weather Bureau.

The data afforded by this network of stations while serving to delimit local rains so far as the city itself is concerned do not answer the question of the variation of the intensity of the storms.

Our first step in the analysis was to summarize the results by computing monthly and annual averages for each station. This work was done several years ago; at that time the year 1916 was the latest available and consequently the averaged considered are for the 22 years, 1895–1916.

The group mean for the seven stations is 55.80 inches for the year. The stations having averages in excess of, or below that of the group mean are shown in the following exhibit:

	Inches.
Stations above the mean:	
Weather Bureau gage	0.50
Sugar experiment station	3.03
Park gage	.31
Jefferson gage	.21
London gage	.20
Stations below the group mean:	
Dublin gage	2.07
Algiers gage	1.44
Hall gage	.72

From the above it appears that sewerage and water board stations, London, Jefferson, and Park, agree very closely with the group mean. The roof exposed gage of the Weather Bureau also agrees closely, being half an inch above the group mean. The Hall gage, the other characteristic roof exposure, gives an annual mean 0.72 inch below the group mean.

Sugar experiment station (New Orleans, No. 2), exposed side by side with sewerage and water board gage No. 2, catches the greatest amount of precipitation of any of the stations in the group the excess above the group mean being 3.03 inches. The excess above the mean of the monthly amounts is of course much greater, as will appear later. The catch of the Dublin gage is least of all.

On the whole the discrepancies are not greater than was to be expected, the greatest excess being a little more than 5 per cent, and the greatest deficit being a little less than 4 per cent, so that we may conclude that the probable error in the catch of an individual gage as compared with the group mean will not exceed plus or minus 5 per cent.

Variations in monthly means.—It is assumed without definite proof that the catch of any number of gages properly exposed and situated in close proximity to each other will show the greatest variation in times of frequent and heavy precipitation.

I have therefore selected from the record of the Weather Bureau gage for each month of the year, the greatest precipitation recorded in the 22 years, and present the totals of those months on the top line of the table next below. Immediately below are given the monthly totals for the corresponding months at each of the sewerage and water board stations.

The following-named arrangement enables us to consider 12 months of heavy precipitation as recorded at each of the seven stations. Only two of the months in the table are consecutive, but that is not material to our purpose. The group mean for the seven stations is 133.74 inches. An examination of the results in table shows that the variation during times of heavy precipitation is very little greater, about 2 per cent, than under all conditions of rainfall combined. It should be emphasized, however, that averages should be used cautiously. The records for September, 1898, show how greatly the individual gages may vary from the mean. The greatest catch during that month was 121 per cent of the mean, while the least was only 74 per cent, or a range of 47 per cent.

TABLE 2.—*Months of maximum precipitation at New Orleans, La.*

Stations.	January (1915).	February (1903).	March (1903).	April (1911).	May (1912).	June (1895).	July (1908).	August (1914).	September (1898).	October (1915).	November (1898).	December (1905).	Total.
U. S. Weather Bureau	8.42	10.20	14.61	13.76	16.80	9.74	11.03	8.47	13.90	12.07	5.17	14.43	138.60
Sugar experiment station	6.28	10.53	9.08	13.09	11.95	11.06	12.16	9.75	19.55	12.52	7.09	13.64	136.70
Dublin	6.88	10.44	14.73	11.54	10.99	12.14	11.06	11.23	15.88	11.15	6.70	13.50	136.24
Park	7.33	10.33	8.96	12.31	11.66	11.40	11.43	9.29	18.16	12.46	9.14	13.62	136.09
Jefferson	7.32	9.44	7.90	12.82	11.29	12.33	11.09	7.81	16.40	12.17	6.80	12.57	127.94
City hall	8.20	9.21	12.59	13.57	16.91	8.35	10.91	8.70	16.73	12.40	6.03	12.73	136.33
London	7.16	10.02	13.68	11.41	12.61	7.68	9.74	7.30	16.97	10.37	6.56	12.68	126.18
Algiers	7.62	9.45	12.76	12.36	14.43	8.04	11.36	10.90	11.94	14.30	4.71	13.97	131.84
Average	7.40	9.95	11.79	12.61	13.33	10.09	11.10	9.18	16.19	12.18	6.52	13.39	133.74
Range (inches)	2.26	1.32	6.83	2.35	5.92	4.65	2.42	3.93	7.61	3.93	4.43	1.86	....
Per cent of average	30	13	58	19	44	46	22	43	47	32	68	14	....

It may be interesting to inquire into the circumstances attending the precipitation of the month in question. September, 1898, was a month of phenomenally heavy rain in the entire State of Louisiana due to the fact that three separate barometric depressions from the Gulf of Mexico advanced over the State. These depressions gave at New Orleans three periods of rainfall of two, three, and five consecutive days, respectively, the total precipitation at New Orleans being 1.67, 3.58, and 7.94 inches for each of the periods. Since there is no surface relief in southeastern Louisiana the vertical convection which produced the rains must have been inherent in the cyclonic circulation of the individual storms. The variation at New Orleans amounted to 7.61 inches in a distance of not more than 4 miles in a nearly east-west direction.

Why it should vary within such narrow limits is not apparent. The phenomenon of unusually heavy rainfall over circumscribed areas in the east Gulf States is not new; good examples may be found in the August, 1916, REVIEW. (See Charts 94–99.)

The data of Table 2 afford material for further study. Curiously, the greatest 12-month maximum precipitation was recorded at the U. S. Weather Bureau station—a roof exposure, although the gage at sugar experiment station records the greatest catch on the mean of the year and also during months of minimum precipitation. (See Table 3.) There are, however, months when these conditions are reversed and this fact leads us to suspect that the reasons for a reversal might be discovered by further investigation.

Treating the months of least rainfall in the same way, it is found that the group mean for the 12 months is 15.82 inches. Sugar experiment station gage consistently records the greatest precipitation, the total for the 12 months of minimum rainfall being 124 per cent of the group—meanwhile the Weather Bureau record for the same 12 months was but 83 per cent of the group mean, a range of 41 per cent, or not quite so great as in case of the months of maximum rainfall. The monthly amounts for each station are shown in the subjoined table:

as an inch or more were recorded. Some examples of irregular distribution follow:

On August 13, 2.38 inches of rain fell at the London station, 0.61 at the United States WEATHER BUREAU, 1.52 at Algiers, and 0.54 at city hall. These stations are in a north-south line, approximately within an area 2 miles wide by 3 miles long. No rain fell at the other stations within the city limits.

On August 5 the rainfall was confined to the two stations, Jefferson and Park, 0.47 falling at the former and 1.56 at the latter. Both stations are in the same part of the city in a nearly east-west line and distance from each other not quite 2 miles. The heaviest rain was at the western station shading off to zero in a little more than 2 miles. The record contains many cases of light rains generally less than 0.04 inch at one station and none at the others. This is especially true of the warm season.

Below will be found a table giving the dates used to illustrate the distribution of local rains at New Orleans. The group mean has been computed for each date and the departures therefrom are given for each station. A departure equaling the groups mean signifies no rainfall at the station.

Finally I may mention a series of rain-gage measurements made at Ithaca, N. Y., under the direction of Prof. Wilford M. Wilson in charge of that station. The two gages used were the regular 8-inch station gage and a similar gage exposed at the evaporation station, 374 yards distant from the station gage in a practically east-west line. Daily measurements May to October for three seasons are available for comparison.

In general the differences in catch of the two gages are quite small and of little practical importance. In but one of the 18 months considered did the accumulated differences amount to as much as half an inch; in this case the total of the small daily differences amounted to 0.74 inch. It is only on rare occasions that the daily amounts differed by as much as a quarter of an inch. On no date during the three seasons was there substantial rain (one-fourth inch) at one station without a like

TABLE 3.—*Months of minimum precipitation at New Orleans, La.*

Stations.	January (1902).	February (1911).	March (1916).	April (1910).	May (1898).	June (1907).	July (1896).	August (1899).	September (1899).	October (1898).	November (1903).	December (1913).	Total.
U. S. Weather Bureau	0.97	1.35	0.64	0.90	0.02	0.98	2.92	2.31	0.35	0.78	0.18	1.78	13.18
Sugar experimental station	1.44	1.46	1.91	1.15	.05	2.83	4.44	1.74	.30	1.90	.23	2.14	19.59
Dublin	.41	.97	.58	1.28	.00	1.08	3.17	3.26	.29	1.65	.29	1.36	14.34
Park	.76	1.33	.78	1.08	.02	2.70	4.35	1.94	.32	1.93	.24	1.92	17.37
Jefferson	1.06	1.07	.91	.98	.17	1.62	4.20	3.32	.49	1.98	.15	1.82	17.77
City hall	.85	1.17	.73	.88	.00	.75	3.29	2.42	.36	1.21	.12	1.87	13.65
London	.68	1.48	.68	.88	.65	1.73	3.25	4.46	.44	1.09	.17	1.40	16.91
Algiers	.71	1.72	.36	1.07	.28	.62	3.13	2.64	.44	1.17	.28	1.34	13.76
Average	.86	1.32	.82	1.03	.15	1.54	3.59	2.76	.37	1.46	.21	1.70	15.82
Range	1.03	.75	1.55	.40	.65	2.21	1.52	2.72	.20	1.20	.17	.80	....

Before concluding this study I have made a short examination of the variations in the 24-hour catch at the various gaging stations, using for this purpose the records of 1919 only. It would be desirable to extend the examination to other years but time was not available.

Twenty-eight dates in that year were selected on each of which the rainfall at one or more stations in the group amounted to an inch or more. A group mean was computed, and departures were tabulated for each date. The results appear in the table next below. In the great majority of cases the variations are small and unimportant. On 15 of the 28 dates the differences at one or more measuring points equaled or exceeded half an inch and on 5 out of the 28 dates differences of as much

rain at the other. In this respect the record differs from that at New Orleans.

TABLE 4.—*Distribution of local rains at New Orleans, La., 1919, and departure from the group mean in each case.*

[Inches and hundredths.]

	January.		February.		March.	April.			
Dates	16	22	20	25	26	3	6	10	15
Group mean	1.02	1.67	1.38	1.37	1.29	1.60	2.42	1.10	1.34
Dublin	− .09	− .27	− .19	.00	+ .18	− .28	− .08	− .44	+ .01
Park	+ .01	+ .13	+ .03	+ .10	+ .41	+ .03	+ .22	+ .06	+ .10
Jefferson	+ .05	+ .04	+ .24	+ .31	− .04	+ .07	− .20	+ .24	− .05
Hall	+ .05	+ .08	+ .08	+ .12	− .13	+ .09	.00	+ .17	+ .03
Algiers	+ .27	+ .05	+ .30	− .18	− .32	+ .05	+ .04	+ .25	− .15
London	− .31	− .03	− .47	− .37	− .13	− .02	.00	− .27	+ .04
Weather Bureau	+ .18	+ .18	.00	+ .19	− .12	+ .17	− .04	+ .12	+ .19

TABLE 4.—*Distribution of local rains at New Orleans, La., 1919, and departure from the group mean in each case*—Continued.

	May.			June.			July.		
Dates	12	26	29	2	13	24	12	20	25
Group mean	1.60	1.62	0.66	0.53	1.72	0.98	1.61	0.62	1.93
Dublin	+ .63	− .51	+ .27	+1.22	− .51	− .11	+ .17	+ .34	− .13
Park	+ .10	+ .20	+ .44	− .46	− .01	− .14	+ .79	+ .39	+ .62
Jefferson	− .46	− .02	+ .52	− .45	+ .16	− .31	+ .46	+ .09	− .55
Hall	− .33	+ .01	− .36	− .36	− .11	+ .21	+ .08	+ .06	− .08
Algiers	+ .19	+ .16	− .29	− .53	− .15	+ .01	− .34	− .33	+ .82
London	− .13	+ .18	− .55	+ .55	− .35	− .16	−1.05	− .54	− .67
Weather Bureau	+ .26	− .23	− .32	− .34	− .39	− .23	− .06	+ .02	− .20

TABLE 4.—*Distribution of local rains at New Orleans, La., 1919, and departure from the group mean in each case*—Continued.

	August.			September.		October.			November.	
Dates	5	13	24	7	13	4	5	16	9	10
Group mean	0.34	0.74	0.99	0.93	1.47	1.10	1.00	0.65	0.94	3.51
Dublin	− .34	− .74	.00	+ .24	− .37	− .03	− .24	+ .44	+ .52	+ .69
Park	+1.22	− .74	− .46	− .24	+ .44	.00	− .66	+ .40	− .40	− .07
Jefferson	+ .13	− .74	− .09	+ .38	+ .36	− .31	+1.32	− .16	+ .01	− .38
Hall	− .34	− .20	+ .66	+ .02	− .19	+ .02	− .19	− .65	− .52	+ .80
Algiers	− .34	+ .78	+ .36	− .12	− .05	+ .29	− .13	− .65	+ .41	− .47
London	− .34	+1.64	− .47	− .29	− .17	+ .01	+ .30	+ .60	− .03	− .57
Weather Bureau	− .34	− .13	+ .66	− .11	− .29	− .10	− .36	− .65	+ .38	− .63

SUBSTANCES DISSOLVED IN RAIN AND SNOW.

551.577 : 551.510.4

By SHERMAN SHAFFER.

[Mount Vernon, Iowa, June 10, 1921.]

The determination of the character and quantities of the substances dissolved in rain and snow is of considerable interest and importance. My work is a continuation of the rain and snow analyses which have been made at Cornell College for a number of years.

The samples for analysis were collected in enameledware pans, at an open spot near the center of the village of Mount Vernon, Iowa. Mount Vernon is a town of about 2,100 population, situated 17 miles from a manufacturing center, and with no industries of its own. The samples were analyzed as soon as possible after they were collected. They were analyzed under ordinary laboratory conditions, but every precaution was taken to avoid contamination.

Forty-five samples of rain and snow were analyzed, during the period from August 18, 1920, to June 1, 1921. The precipitation during this period was 20.97 inches, 18.14 inches of rain and 34 inches of snow. Twelve inches of snow are taken as equal to one inch of rain.

The nitrates which fell during this period amounted to 0.60126 pounds per acre, assuming that 1 inch of water on 1 acre weighs 226,875 [1] pounds. The average [2] content was 0.3 part per million. The highest nitrogen content was 1 part per million on January 4, 1921. The amount of nitrates is influenced by the length of the interval between rains. A curve drawn for intervals between rains as abscissæ and nitrates per inch of rain as ordinates tends to rise as the interval is increased. There is no noticeable variation of the amount of nitrates with the seasons. On the contrary, the average through the year is quite constant. When the amount of nitrate per inch of rain for each month is compared with the rainfall in inches for each month, it is found that the nitrates are greater when the rainfall is less—that is, the solution is more concentrated, as might be expected. When the nitrates are determined by the phenolsulphonic method and no sodium carbonate is added before evaporating the water, no nitrates are found. This would seem to indicate that all the nitrate is in the form of free nitric acid. If this is true, the ammonia present must be united with some other acid radicle, or it would combine with the nitric acid.

The nitrites totaled 0.03985 pound per acre. The highest figure was 0.03 part per million on May 17, 1921. The average was 0.0033 part per million. A curve drawn for intervals between rains as abscissæ and nitrites per inch of rain as ordinates showed an increase with an increasing interval, but the curve was very irregular. The nitrites, like the nitrates, tended to greater concentration when there was less rain, but this tendency was not so marked as in the case of the nitrates.

The total amount of free ammonia was 1.48045 pounds. The highest ammonia was in the snow of November 27, 1920, which tested 2.1 parts per million. The average was 0.47 part per million. On the whole, no difference was found in the amounts of substances dissolved by snow and by rain under the same circumstances. This differs from the results of former investigators, who found that snow did not dissolve as much of the substances as did rain.

The albuminoid ammonia amounted, during the period, to 1.16022 pounds per acre. The highest being 2 parts per million, on December 13, 1920, and the lowest 0 on April 1, 1921. The average was 0.38 part per million, considerably less than the free ammonia. A curve drawn between albuminoid ammonia per inch of rain and number of days between rains showed a very striking increase of ammonia with increase of interval. The albuminoid ammonia remained on the average fairly constant throughout the year, as did the free ammonia. Both were lower in the spring than during the fall and winter.

A total of 34.43179 pounds of chlorides per acre was found. The average chlorine content was 10.1 parts per million. The highest was 49.7 parts per million. The chlorides were higher during the winter and spring than during the fall. They were not found to be present in constant proportion as was reported by former investigators, but varied from 3.5 parts per million to 49.7. The chlorides show the same tendency as the other substances to be more concentrated when the rainfall is less. A curve between chlorides and intervals of time shows a tendency toward increase in chlorides with increase in time interval.

The total sulphates amounted to 327.0619 pounds per acre, figured as SO_3. The average was 29.9 parts per million, and the highest 101.2, on May 17, 1921. The sulphates undoubtedly come from the combustion of the sulphur in coal used for heating. The amounts found rise from none in August, to 4.8 pounds per acre in September, and to 66.2 pounds per acre in February, after which they again decline.

Thirteen determinations of sulphurous acid were made, using N/10 iodine-potassium iodide solution against N/10 sodium thiosulphate solution. Seven of the tests

[1] The latest edition of *Smithsonian Meteorological Tables* gives the weight of an inch of rainfall per acre at a temperature of 62° as 113 short tons or 226,000 pounds.—Ed.

[2] The arithmetical mean of all of the analyses.