Bermuda Meteorological Office

Technical Note No. 8

The Rainfall of Bermuda

By

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CONTENTS

1. INTRODUCTION

Bermuda is a very isolated group of islands with a total area of less than 20 square miles situated near latitude 32 N., longitude 65 W, at a distance of 570 miles East-South-East of Cape Hatteras, North Carolina which is the nearest land, and 770 miles North-East of the Bahamas the nearest point in the West Indies.

The islands are the eroded remnants of a layer of aeolian limestone several hundred feet thick resting on the top of the rocks of an ancient volcano which rises steeply from the ocean bed so that ocean depths well over 5000 feet are reached within a mile or so of the shore. No point on Bermuda is as much as 300 feet above sea level and most of the land is below 100 feet, while the islands average less than one mile wide and are nowhere more than two miles across. There is, therefore, no large scale orographic effect on rainfall.

The soil and subsurface layers are extremely porous so that rain water rapidly soaks back to sea level and there are no fresh water streams or lakes. The top layers of ground water are tapped by sinking wells almost to sea level and shortly after heavy rains the water in some wells is almost fresh, but the salinity increases as water is pumped and the water is generally not usable for human consumption. For this reason all fresh water must be obtained by collecting rain in special catchments, usually on the roof and storing it in tanks. The provision of adequate catchments and storage tanks is, therefore, an essential part of any building scheme and for this an exact knowledge of the amount and distribution of rainfall is necessary.

In a previous publication (Technical Note No. 1, 1944), the rain records for 1891-1942 were analysed, these being the only ones available in the Meteorological Office at that time. Since then older records have been found which give data for 3 years in the 1830s and a continuous record since 1852 except for a gap of $2\frac{1}{2}$ years from 1863 to 1865. Unfortunately, the Meteorological Office was destroyed by fire in 1955 and all the original records since 1891 were lost. It has been possible to reassemble much of this data from printed records and it is the purpose of this paper to present and discuss all the data available which now covers more than 100 years.

2. SOURCES OF DATA

The earliest records available are for the period November, 1836 to April, 1839. These were taken at St. George's by the Royal Engineers and monthly rainfall totals were printed in Bermuda newspapers. No daily values were given and the original records have not been found.

There is no record of any observations from 1839 to 1851, but in 1852 regular observations were instituted at many British military and naval bases and in Bermuda observations were begun by the Royal Navy at Ireland Island and by the Royal Engineers at St. George's. None of the original Ireland Island

record sheets have been found. However, daily values were published in newspapers from January, 1852 with no gaps except March, 1863, until the series ends with September, 1863. Monthly totals were also published in the Bermuda Almanac. Monthly record sheets giving daily observations at St. George's are filed in the British Meteorological Office, London, and photostat copies were obtained. There are many gaps in the records and the series ends with March, 1862. Monthly summaries of these readings are included in Observations at Overseas Stations of the Royal Engineers. The Ireland Island series has been adopted here for the reasons given later in section 15.

No rain records of any kind have been found for October, 1863 to December, 1865.

A new set of observations at St. George's by the Army Medical Department began in January, 1866 and continued until November, 1869 when the hospital was moved to Prospect Camp, the new military headquarters in Devonshire Parish. The monthly tabulations of daily values are filed in the British Meteorological Office and are the only source for these years. After a gap of four months a new observatory was opened at Observatory Cottage, Prospect, in March, 1870 and this continued as the main site of official observations under control of the Army Medical Department until March, 1932. The earlier monthly tabulations are filed in London but there are many months missing and after 1880 the records appear erratic and cease entirely in 1885.

In the latter part of 1869 observations were begun by Mr. William Gosling in Paget and daily values were published in the newspapers until the end of 1886 and after that monthly totals until 1900. There are no gaps from December 1st, 1869 to December 30th, 1890, and these figures are preferred to the intermittent Prospect data for these years.

In the latter part of 1890 daily synoptic weather reports from Prospect to Canada were begun and from that date the station was under the supervision of the Canadian Meteorological Office to whom the daily observation sheets were forwarded. These sheets were returned to the Bermuda Meteorological Office after 1932 and were the source for Technical Note No. 1. All these records were lost in the 1955 fire. From 1894 to 1900 monthly summaries giving daily observations were prepared and forwarded to London where they now are filed in the Meteorological Office.

The newspapers printed daily rainfall totals from Prospect with few gaps until 1903 and intermittently until 1922.

Daily values for Prospect for some years were also printed in the Registrar General's Blue Book. It was found previously, however, that these Blue Book figures had many errors when compared with the original Prospect records, but for some months and years the Blue Books are now the only source of daily values.

From 1916 to 1931, with the exception of 1924, daily rainfall totals are printed in Canadian records.

The Meteorological Office began rainfall observations at Fort George in May, 1932, and these have been continued up to the present. All records and tabulations were lost in the fire and we now have only such data

as had been printed. Hourly values are now available for only 1949 to 1953, and 1956 in addition to figures given for 1933 to 1942 in Technical Note No. 1. There are now no Fort George records for 1954 and 1955.

Daily rainfall figures for Hamilton are published in newspapers and given to various other authorities so for 1954 and 1955 we have the values deduced from these sources.

In calculating averages only figures since 1852 have been used and the averages are therefore based on the following:

January, 1852 — September, 1863. Ireland Island.
Observer, Royal Navy.
Source, Bermuda Newspapers and Almanacs.

January, 1866 — November, 1869. St. George's.
Observer, Army Medical Department.
Source, Original Monthly Summaries.

December, 1869 — December, 1890, Clermont, Paget.
Observer, Mr. W. Gosling.
Source, Bermuda Newspapers and Almanacs.

January, 1891 — April, 1932, Observatory, Prospect.
Observer, Army Medical Department.
Source, Original Monthly Summaries, Canadian Annual Summaries, Newspapers, Tech. Note No. 1.

May, 1932 — December, 1953, Fort George.
Observer, Meteorological Service.
Source, Annual Summaries of Observations.

January, 1954 — December, 1955, Hamilton.
Observer, Meteorological Service.
Source, Newspapers and private records.

January, 1956 — December 1956, Fort George.
Observer, Meteorological Service.
Source, Original records.

3. SITES AND INSTRUMENTS

The earliest observations taken at St. George's by military personnel were presumably in the barrack area just east of the town but the exact locations are unknown. The 1852-1862 series were at an altitude of 122.6 feet probably close to the Royal Engineer office, and the earliest 1836-1839 observations may well have been at the same site. In 1836-1839 the gauge was 8 feet above ground and in 1852-1862 "on the ground." The 1866-1869 observations were at an altitude of 61 feet and being taken by the medical staff, were probably close to the hospital. The gauge was "on the ground."

There is no definite information as to the Ireland Island site but from the notes in the Registrar-General's reports observations were probably taken near the hospital by medical staff.

The observations by Mr. Gosling were made at his residence, Highwood, on the south side of Hamilton Harbour about one mile due south of Prospect Observatory. The gauge is understood to have been located on the ground some 50 feet to the west of the house at an altitude of about 60 feet. The site was covered with cedar trees in 1943 which probably had grown since observations ended. The site was variously refered to as Clermont, Highwood, or the North Side of Paget.

Prospect military camp is a mile North-east of Hamilton and covers a number of ridges from 100 to 150 feet above sea level. The Observatory was at the southern edge of the camp where the rain gauge was 147 feet above mean sea level, and the barometer at 151 feet. Up to August, 1873, the altitude was given as 120 feet but this was later stated to be an error, and the rain gauge is believed to have remained in the same position until observations ceased in 1933 although the barometer was moved to the hospital in 1927.

The instrument enclosure at Fort George is on the western slope of Fort George Hill some 25 feet below the parapet of the fort which is 100 feet from the enclosure. The gauges are at a height of 164 feet above mean sea level and except on the side towards the fort, the ground outside the enclosure falls rapidly to sea level. The site is an exposed one and the windbreak of cedars died in the period 1946-1947, and have been removed. As was shown elsewhere this produced a change in the temperature and humidity observations at the site.

The observations at Hamilton were taken from June, 1946 to January, 1955, on a site near the Washington Street edge of the former Hamilton Hotel site midway between Church and Victoria Streets, an area which has since been levelled as a site for the new City Hall. Since February, 1955 observations have been taken on a bluff some 200 yards to the west on Church Street overlooking the car park and Par-la-Ville gardens. This bluff is also scheduled for demolition.

Little is known of the older gauges but they were presumably all of standard type when installed.

The gauges at Fort George and Hamilton are standard five-inch gauges, meeting British specifications. The autographic gauges at Fort George and Hamilton are also standard type with eight-inch funnels.

4. TIME OF OBSERVATION

In the 1836 to 1839 series observations were taken at 6 a.m. and 6 p.m. and there is no indication what constituted a day for record purposes.

In the Ireland Island and St. George's observations from 1852 to 1869, and the Clermont 1869 to 1890 series, the observations were made at 9 or 9.30 a.m. and entered to the day of observation. In all cases where this was done and where we have daily values, monthly totals have been recalculated with morning observations entered to the preceding day.

At Prospect from 1891 rain was measured twice daily and although the official figures gave totals for 24 hours from 8 or 9 a.m. on the morning of each day, the values in newspapers often were for 24 hours up to 8 p.m., and this was the case with the Canadian records. It is consequently not now possible to recalculate all the monthly totals for this period on the basis of 8 a.m. observations entered to preceding day, which produces some minor differences from data given in Technical Note No. 1.

Observations at 24-hour intervals are available for the whole period but those for 1887-1890 are for Gibbs Hill, a site which is very poor and gives values between one-half and three-quarters of elsewhere. Twelve hourly readings are available since 1891 and shorter periods are obtained from the autographic records since 1932.

Hourly values were not included in published annual summaries until 1949, and extremes in shorter periods only in 1953. Consequently we now have only the data available for 1933-42 in Technical Note No. 1 and the figures since 1949 as a basis for the tables giving rainfall in less than 12 hours.

5. ANNUAL FALL

Table 1 gives some of the chief data relative to the annual fall.

Average Fall	57.64 inches
Maximum Fall	89.64 inches - 156% of average. Recorded in 1902.
Minimum Fall	39.38 inches - 68% of average. Recorded in 1861.
Range	50.26 inches - 87% of average.
Mean Deviation	6.95 inches
Percentage Variability	12%
Standard Deviation	8.72

TABLE 1. Total Annual Rainfall.

The average of 57.64 inches is a considerable rainfall and is approximately equal to that of the wettest places on the Eastern Seaboard of the United States and nearly three times the average in London.

The fluctuation of 87 per cent of the average between the recorded extremes is also noteworthy in view of the average fall, but even the absolute minimum of 39.38 inches provides ample water for any normal purpose. This minimum fall equals over 20 gallons per square foot, and nearly 900,000 gallons per acre.

Table 2 gives the percentage of years in which the total fall was in each successive one-inch range, and Table 3 gives the percentiles from 5 to 95%, while Figure 1 gives the cumulative frequency.

Fall Inches	Per Cent of Years	Fall Inches	Per Cent of Years	Fall Inches	Per Cent of Years	Fall Inches	Per Cent of Years
39	2	49	3	59	8	69	1
40	–	50	5	60	6	70	1
41	1	51	4	61	2	71	2
42	–	52	4	62	2	72	–
43	1	53	4	63	4	73	2
44	2	54	6	64	5	74	–
45	4	55	3	65	2	75	2
46	1	56	5	66	6		
47	2	57	5	67	2		
48	3	58	2	68	1	89	1

TABLE 2. Percentage of years with total fall in inches within limits of stated value to 0.99 inch higher.

The data shows that the maximum fall was well separated from the next highest value and consequently that 1902 was an unusually wet year, whose total fall is unlikely to be exceeded for many years. There were two years, 1861 and 1911, with total falls between 39 and 40 inches and with this frequency of once in 50 years, a year with less than 40 inches may occur before long.

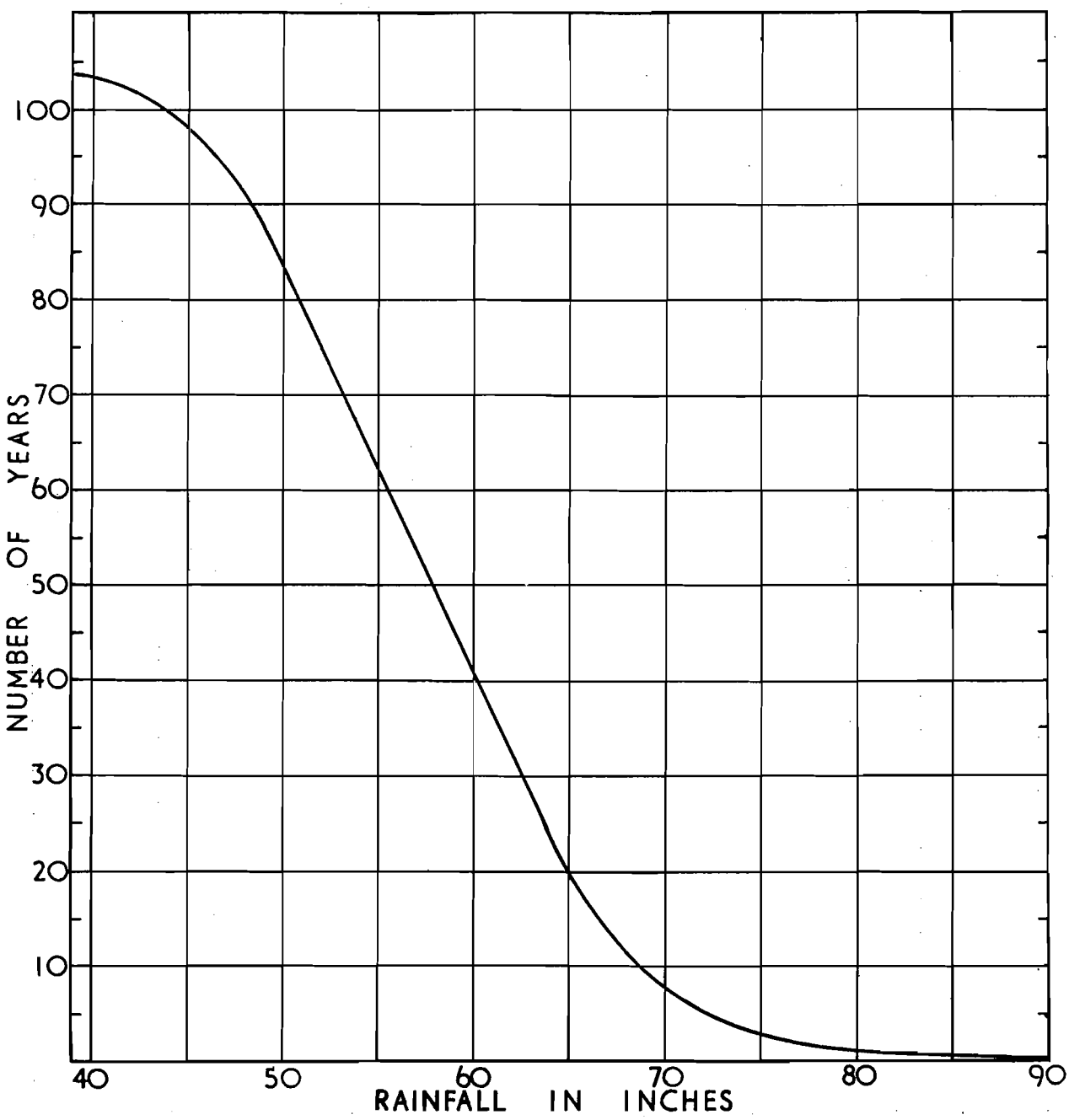

FIGURE 1. Ogive of Total Annual Rainfall.

Percentiles	Inches
5	44.57
10	45.97
20	50.25
30	52.62
40	54.79
50	57.50
60	59.68
70	61.87
80	64.80
90	68.31
95	72.83

TABLE 3. Percentiles of Total Annual Rainfall.

5.1. EXTREME FALLS IN SERIES OF CONSECUTIVE YEARS

The driest and wettest series of consecutive years up to 50 are given in Table 4, and Figure 2 shows the percentage of normal which fell in the same periods.

No. of Years	MAXIMUM				MINIMUM			
	Average per Year Inch	Percent of Normal	Total Excess Inch	Occasion	Average per Year Inch	Percent of Normal	Total Deficit Inch	Occasion
1	89.6	156	32	1902	39.4	68	18	1861
2	76.1	132	37	1901–02	41.9	73	31	1861–62
3	72.9	126	46	1900–02	46.6	81	33	1911–13
4	70.2	122	50	1900–03	48.2	84	38	1910–13
5	67.7	118	51	1899–03	50.8	88	34	1910–14
6	66.1	115	51	1900–05	51.5	89	37	1949–54
7	65.8	114	57	1885–91	51.6	90	42	1907–13
8	65.9	114	66	1885–92	52.8	92	39	1906–13
9	65.6	114	72	1885–93	53.6	93	36	1948–56
10	65.1	113	75	1884–93	53.4	93	42	1907–16
15	64.3	112	100	1889–03	53.6	93	61	1910–24
20	64.0	111	127	1884–03	54.7	95	59	1904–23
25	63.0	109	133	1882–06	55.9	97	44	1903–27
30	62.4	108	143	1877–06	56.0	97	50	1911–40
35	62.0	108	153	1872–06	55.6	96	71	1907–41
40	61.0	106	134	1871–10	56.2	97	59	1907–46
45	60.2	104	115	1874–18	56.0	97	73	1910–54
50	59.8	104	106	1872–21	56.1	97	79	1907–56

TABLE 4. Extreme falls in 1 to 50 consecutive years.

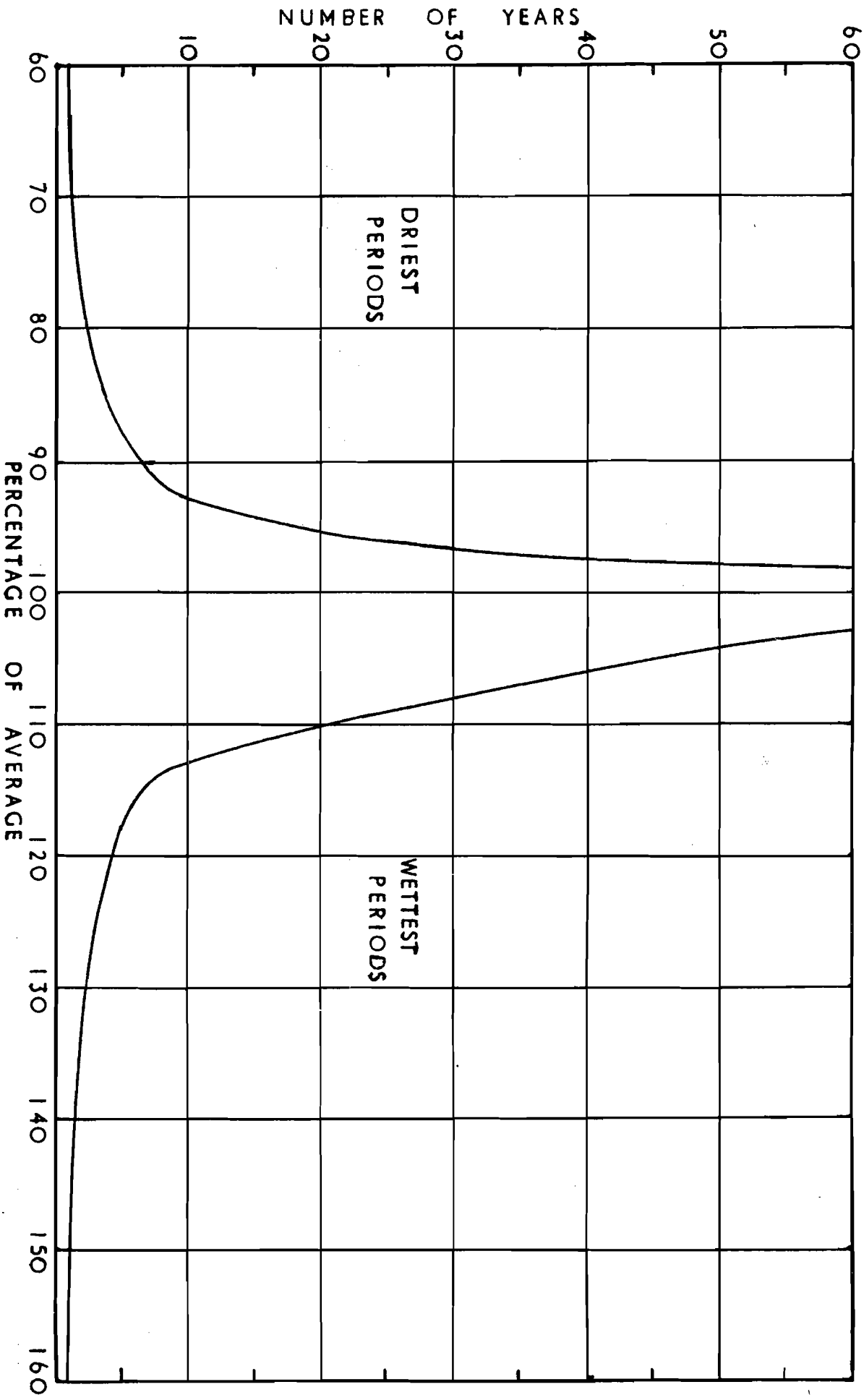

FIGURE 2. Percentage of average fall which was recorded in Driest and Wettest series of consecutive years.

As was noted earlier the extreme wettest year with 156% of normal was a very exceptional year and consequently the wettest 2-year period is much nearer normal with 132% and as length of period is increased the percentage decreases until it is only 115% of normal in 6 years after which the rate of decrease becomes less and less and the wettest 50 years have only 4% above normal.

Since the driest year with 68% of normal was not as exceptional as the wettest year, the dry series does not show as great a change from 1 to 2 years as does the wet, but there is at first a similar rapid approach to more normal values with longer periods so that the driest 6 years have 89% of normal. Thereafter the percentage gradually rises to 97% by 25 years at which value it remains almost steady up to 50 years.

The wettest 2 to 6 years are grouped about 1902, the wettest year, while the wettest 7 to 10 years occurred in the decade beginning 1885, due to over 75 inches in both 1885 and 1891 and 71 inches in 1889. The longer wet periods extended over both these series.

The driest one and two years are centered on the driest year 1861, but as the following three years, 1863 to 1865, are missing this series is broken. With the exception of the driest 6 and 9 years which were between 1948 and 1956, all other series are grouped about 1911 the second driest year which had little more rain than 1861.

6. MONTHLY RAINFALL

The main data for each month are summarised in Table 5.

April with just under 4 inches has the smallest average and October with over $6\frac{1}{4}$ inches, the greatest.

Month	AVERAGE	MAXIMUM			MINIMUM			Mean Deviation	Standard Deviation	% Variability	Range
	Inch	Inch	% Average	Year	Inch	% Average	Year	Inch			Inch
Jan.	4.46	10.77	241	1839	1.08	24	1937	1.57	1.94	35	9.69
Feb.	4.54	11.03	242	1877	1.11	26	1883	1.62	2.08	36	9.92
Mar.	4.62	10.05	218	1920	1.19	26	1898	1.66	2.00	36	8.86
Apr.	3.96	13.17	333	1902	0.73	18	1931	1.75	2.33	44	12.44
May	4.60	13.13	285	1889	0.80	17	1918	2.10	2.53	46	12.33
June	4.19	10.98	262	1915	0.43	10	1943	1.87	2.30	45	10.55
July	4.44	19.44	438	1886	0.78	18	1855	2.15	2.84	48	18.66
Aug.	5.40	21.33	395	1902	0.64	12	1910	2.07	2.91	38	20.69
Sept.	5.27	16.28	309	1915	1.15	22	1837	2.07	2.69	39	15.13
Oct.	6.37	17.42	273	1917	1.34	21	1915	2.69	3.44	42	16.08
Nov.	5.12	12.70	248	1885	0.99	19	1940	1.93	2.54	38	11.71
Dec.	4.67	12.11	259	1930	0.55	12	1932	1.78	2.24	38	11.56

TABLE 5. Monthly Rainfall.

The months may be divided into three groups. The first, the "wet season," is from August to November, where the rainfall is above the yearly average. The second group in which the months are all near the yearly average consists of December to March with February slightly above and the other three slightly below average. The third group is the "dry season," April to July, in which all months have less than average although April and June are the only two with more than 0.5 inches below average.

October is the only month which exceeds the yearly mean by more than an inch, its rainfall being partly due to tropical depressions, but mainly to the extra tropical storms which develop as the first severe cold fronts of autumn reach Bermuda from the north. The relative dryness in April is due to the reduction in intensity of winter fronts while sea temperatures are still low and local convection action not so developed as in summer.

All months have had over 10 inches and more than twice normal on occasion, with the maximum of 21.33 inches in August, 1902, while July, 1886, with 19.44 inches had nearly $4\frac{1}{2}$ times normal for the month. The 4 months, July to October, have each had over 16 inches.

Except October, which has a minimum of 1.34 inches, each month has had less than $1\frac{1}{4}$ inches and the 5 months, April to September, as well as November and December, have had less than one inch. June, 1943, with a fall of 0.43 inches, is the only month which has had less than half-an-inch.

April to July are the most variable months with the average departure in July almost half the mean for the month.

The winter months show the least variability, with January the most regular.

The variability of the fall is also shown in Table 6 which gives the percentages of occasions in which each month's fall lay between various limits, while Table 7 and Figure 3 give the total rainfall each month reached in 5% to 95%

Inches	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.50 - 0.99				3	3	5	2	3			1	2
1.00 - 1.99	12	10	8	14	11	10	13	6	7	6	9	5
2.00 - 2.99	10	12	16	24	22	23	24	8	15	11	8	16
3.00 - 3.99	23	21	19	22	13	15	11	18	14	7	18	24
4.00 - 4.99	20	21	16	13	8	15	11	18	19	18	20	12
5.00 - 5.99	14	18	18	11	14	10	16	15	11	12	14	14
6.00 - 6.99	10	7	12	4	10	7	9	11	12	10	13	14
7.00 - 7.99	6	4	4	2	9	7	5	7	8	9	8	6
8.00 - 8.99	1	3	4	3	5	5	1	8	6	6	1	2
9.00 - 9.99	3	3	2	2	3	1	3	2	4	10	1	1
10.00 - 11.99	1	2	1	2	–	2	4	2	2	7	7	3
12.00 - 13.99				1	2		–	2	–	3	1	1
14.00 - 15.99							–	–	1	1		
16.00 - 17.99							–	–	1	3		
18.00 - 19.99							1	–				
20.00 - 21.99								1				

TABLE 6. Percentage of occasions on which monthly rainfall was within limits stated, 1836 - 1956.

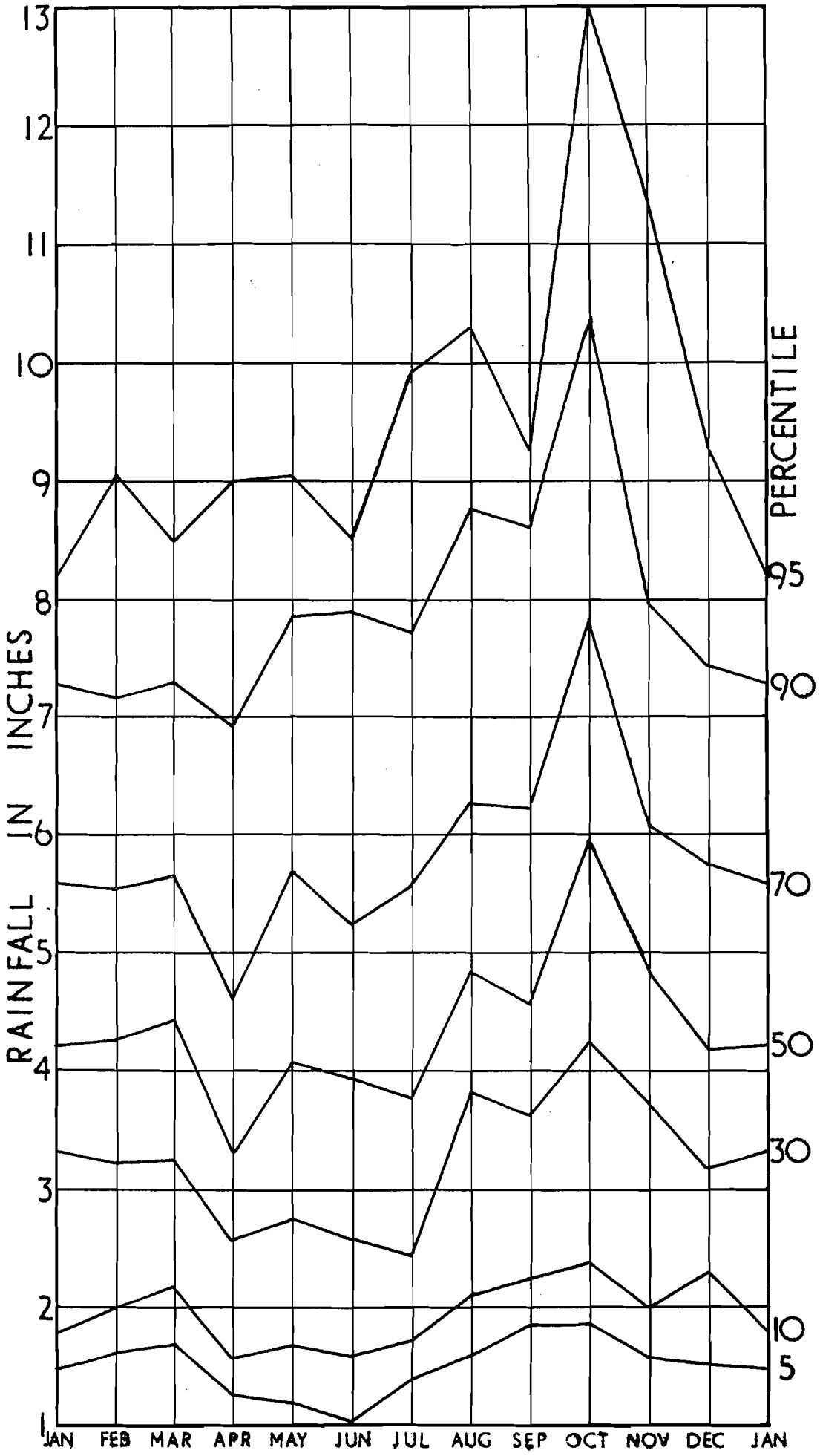

FIGURE 3. Monthly Rainfalls not exceeded in stated percentages of years.

of occasions. Table 6 shows that 12 inches or more has fallen in only 18 months over the whole period, seven of these occasions being in October.

The values for 50% in Table 7 are the medians, the values which actual observations in each month are as often above as below. Owing to the skewness of distribution, the median is in each case less than the average monthly rainfall given in Table 5. In April the rainfall is as often below 3.30 inches as it is above and in June and July also the median is less than 4 inches. Only in August, September, October and November is it above $4\frac{1}{2}$ inches.

Although April has the lowest median, Table 7 shows that the 5 percentiles for May and June are lower than for April; in other words, in the driest 5% of occasions for each month the rainfall is less in May and June than in April.

%	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5	1.48	1.61	1.69	1.25	1.19	1.03	1.39	1.59	1.84	1.86	1.58	1.51
10	1.78	1.98	2.17	1.56	1.68	1.59	1.71	2.09	2.23	2.37	1.99	2.29
20	2.92	2.87	2.76	2.22	2.35	2.09	2.22	3.35	2.92	3.83	3.24	2.91
30	3.32	3.22	3.24	2.57	2.74	2.58	2.43	3.82	3.62	4.24	3.72	3.17
40	3.82	3.74	3.79	2.97	3.50	3.17	3.08	4.45	4.19	4.92	4.16	3.64
50	4.21	4.26	4.43	3.30	4.06	3.93	3.78	4.82	4.58	5.94	4.81	4.18
60	4.65	4.80	5.11	3.81	5.18	4.65	4.53	5.52	5.68	6.84	5.21	5.07
70	5.59	5.53	5.64	4.60	5.68	5.22	5.56	6.25	6.22	7.81	6.07	5.74
80	6.07	5.88	6.28	5.48	6.83	6.09	6.35	7.19	7.12	9.39	6.79	6.50
90	7.27	7.16	7.29	6.92	7.85	7.89	7.71	8.76	8.60	10.38	7.95	7.42
95	8.17	9.05	8.49	8.99	9.03	8.50	9.90	10.29	9.26	13.00	11.34	9.28

TABLE 7. Percentiles of Total Monthly Rainfall.

In every month the driest 5% of occasions have less than 2 inches, the percentiles varying from 1.03 inches in June to 1.86 inches in October.

At the other extreme on the wettest 5% of occasions every month has over 8 inches varying from the lowest limit of 8.17 inches in January to 13.00 inches in October.

The range or distance between extreme values is least in March where it is less than 9 inches, and greatest in August where it is almost 21 inches, due to the exceptionally high maximum.

Table 8 gives the number of occasions on which each month was either the wettest or the driest in the year. The uncertainty of annual rainfall is shown by the fact that every month has been the wettest or driest month of the year on

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
High	4	6	3	5	9	5	9	10	11	25	11	6
Low	7	8	6	19	13	12	9	6	4	5	10	5

TABLE 8. Number of years in which each month had highest or lowest monthly fall for the year.

at least 3 occasions for each. October and April, which have the highest and lowest average falls, respectively, are the highest and lowest months on more occasions than any others, but October has the highest on only one year in four and April the lowest on only one year in five. On more than half the occasions the wettest month is from August to November, and the driest from April to July.

6.1 DRIEST AND WETTEST SERIES OF CONSECUTIVE MONTHS

The extreme falls which have been recorded in series of consecutive months are given in Tables 9 and 10.

No. of Months	Total Fall Inch	Mean per Month Inch	Percent of Normal	Total Deficit Inch	Occasion
1	0.43	0.43	9	4.4	June, 1943
2	1.41	0.71	15	8.2	June - July, 1855
3	2.64	0.88	18	11.8	June - Aug. 1910
4	6.55	1.64	34	12.7	April - July 1941
5	9.85	1.97	41	14.2	April - Aug. 1941
6	13.24	2.21	46	15.6	Jan. - June 1939
7	17.58	2.51	52	16.0	Nov. 1910 - May 1911
8	21.24	2.65	55	17.2	Dec. 1912 - July 1913
9	24.10	2.68	56	19.1	Sept. 1912 - May 1913
10	26.20	2.62	55	21.8	Sept. 1912 - June 1913
11	28.42	2.58	54	24.4	Sept. 1912 - July 1913
12	31.28	2.61	54	26.4	June 1910 - May 1911
15	44.44	2.96	62	27.6	May 1910 - July 1911
18	56.02	3.11	65	30.4	May 1910 - Oct. 1911
21	69.28	3.30	69	31.6	Jan. 1861 - Sept. 1862
24	80.94	3.37	70	34.3	June 1910 - May 1912
36	127.02	3.53	73	45.9	June 1910 - May 1913
48	188.26	3.92	82	42.3	Nov. 1909 - Oct. 1913
60	240.14	4.00	83	48.1	June 1910 - May 1915
120	530.23	4.42	92	46.2	May 1907 - April 1917

TABLE 9. Lowest Falls in Consecutive Months.

The driest month on record is June, 1943. The extremes of 2 to 6 months occurred in various years, but for 7 months and longer the driest periods were with one exception in the dry period of 1910 to 1913.

Similarly the wettest periods, with four exceptions, included 1902 in which year, August with 21.33 inches, was the wettest month on record.

On the driest occasions on record less than a normal year's rain fall in 18 months, while in the wettest occasions more than a year's fall was recorded in 7 months.

No. of Months	Total Fall Inch	Mean per Month Inch	Percent of Normal	Total Excess Inch	Occasions
1	21.33	21.33	444	16.5	Aug. 1902
2	25.50	12.75	265	15.9	Sept. - Oct. 1943
3	36.57	12.19	254	22.2	Aug. - Oct. 1902
4	40.71	10.18	212	21.5	Aug. - Nov. 1902
5	47.64	9.53	198	23.6	April - Aug. 1902
6	52.11	8.69	181	23.3	March - Aug. 1902
7	62.88	8.98	187	29.3	April - Oct. 1902
8	67.35	8.42	175	28.9	Mar. - Oct. 1902
9	75.44	8.38	175	32.2	Feb. - Oct. 1902
10	79.58	7.96	166	31.5	Feb. - Nov. 1902
11	86.46	7.86	164	33.6	Feb. - Dec. 1902
12	90.83	7.57	158	33.2	Feb. 1902 - Jan. 1903
15	111.25	7.42	154	39.2	Oct. 1901 - Dec. 1902
18	121.98	6.78	141	35.5	Oct. 1901 - Mar. 1903
21	135.00	6.43	134	34.1	Nov. 1884 - July 1886
24	154.39	6.43	134	39.1	Feb. 1902 - Jan. 1904
36	218.67	6.07	126	45.7	Jan. 1900 - Dec. 1902
48	281.59	5.87	122	51.0	Aug. 1900 - July 1904
60	349.05	5.82	121	60.9	June 1888 - May 1893
120	658.27	5.49	114	81.9	Sept. 1883 - Aug. 1893

TABLE 10. Largest Falls in Consecutive Months.

The fall of 31.28 inches in the driest 12 months is 8.10 inches or 21% less than the fall in the driest calendar year, but the wettest 12 months with 90.83 inches gave only 1.19 inches or 1% more than the wettest calendar year.

The wettest 3 calendar years are also the wettest 36 months, but there was 13 inches, about 10% less in the driest 36 months than the driest 3 years. There was a difference of about 1% in each case between extremes in 10 calendar years and 120 months.

7. QUARTER MONTHLY RAINFALLS

To determine the falls in periods close to a week, each month was divided as follows:

Months with 31 days — 1st-8th; 9th-16th; 17th-23rd; 24th-31st.

Months with 30 days — 1st-8th; 9th-15th; 16th-23rd; 24th-30th.

February — 1st-7th; 8th-14th; 15th-21st; 22nd-29th.

The average daily fall in each of these periods is given in Table 11 and plotted in the ~~top~~ MIDDLE graph of Figure 4.

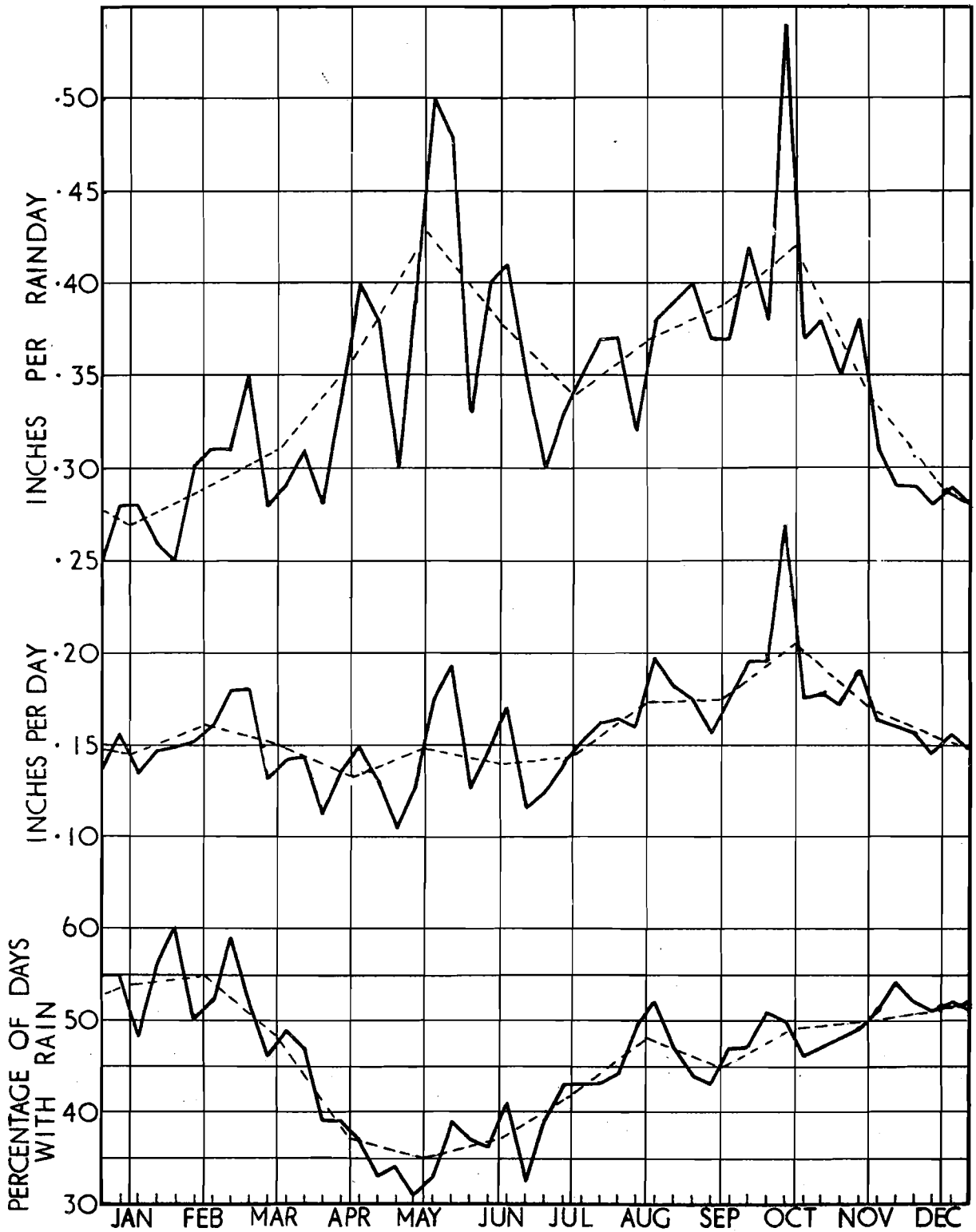

FIGURE 4. Percentage of Rain Days and fall per Day and per Rain Day in each month and quarter month.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1st.	.136	.148	.181	.112	.104	.125	.119	.164	.175	.195	.172	.157
2nd.	.156	.152	.130	.136	.126	.147	.141	.158	.156	.269	.191	.143
3rd.	.135	.160	.142	.149	.173	.170	.152	.196	.175	.174	.162	.156
4th	.147	.180	.144	.130	.193	.116	.162	.182	.196	.178	.159	.147

TABLE 11. Average daily rainfall in each Quarter Month in Inches.

The driest week of the year is the first quarter of May with an average daily fall of just over one-tenth of an inch which is only 66% of the daily average over the whole year. The first week of April has only 0.112 of an inch per day, 71% of average, while the last week of June and the first of July have 75% of year's average.

The wettest week is the second quarter of October with 0.269 of an inch a day, which is 170% of the year's average, while the two weeks preceding each have nearly 0.2 of an inch per day, so that the period consisting of the last week in September and the first half of October has 139% average.

Beginning with the second quarter of March each interval until mid-May has less than average, while from mid-September to the end of November each period has above average.

A noticeable change from the figures in Technical Note No. 1, which covered only half the period of this note, is that April becomes the driest month instead of July, and the figures show that the change is due to a reduction in the second half of April and an increase in the last three quarters of July.

Probably the September-October maximum is due to three factors, that local convection showers are still frequent as in summer, that some cold fronts push south and reach Bermuda while still of considerable intensity as in winter, and that tropical storms come nearest at this period.

8. NUMBER OF RAINDAYS

A rain day is defined as one on which at least 0.01 of an inch is recorded, and Table 12 gives the average and extreme numbers in each month, while Table 13 gives the percentage of raindays in each quarter month.

February is the wettest month with rain on 55% of days, although January with an average of 16.6 days has the greatest number, and the five months from October to February each average above 15 rain days. May with under 11 days has the smallest average but April and June are only slightly greater.

The first and last weeks of February with 60% and 59% of raindays, respectively, are the wettest, and except for the third quarter of January, which has 48% of rain days, each interval from mid-November to the first quarter of March has rain on more than half the days.

The driest weeks are the second quarter of May with rain on 31% of days and the last quarter of June with 32%. The period from the fourth quarter of April to the third quarter of May has rain on less than one day in three.

The average percentage of rain days in each month and quarter month are plotted in the bottom graph of Figure 4.

	AVERAGE		MAXIMUM			MINIMUM		
	Number	Percent	Number	Percent	Year	Number	Percent	Year
Jan.	16.6	54	27	87	1857	9	29	1950
Feb.	15.7	55	25	89	1855, 1942	6	21	1903
Mar.	14.9	48	26	84	1866	7	23	1921
Apr.	11.1	37	21	70	1884	4	13	1867, 1931
May	10.8	35	18	58	1856	4	13	1918
June	11.1	37	21	70	1897	4	13	1943
July	12.9	42	23	74	1904	5	16	1861
Aug.	14.8	48	28	90	1902	5	16	1861
Sept.	13.5	45	22	73	1950	7	23	4 years
Oct.	15.1	49	28	90	1857	7	23	1911,1916
Nov.	15.1	50	22	73	1935	9	30	7 years
Dec.	15.9	51	24	77	1935	8	26	1956
Year	168	46	210	58	1930	128	35	1861

TABLE 12. Raindays - Days with 0.01 inch or more.

Quarter	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
First	55	60	52	39	34	37	39	44	44	51	48	52
Second	55	50	46	39	31	36	43	49	43	50	49	51
Third	48	52	49	37	33	41	43	52	47	46	51	52
Fourth	56	59	47	33	39	32	43	47	47	47	54	51

TABLE 13. Percentage of Raindays (0.01 inch or more) in each Quarter Month.

8.1 FREQUENCY OF MONTHS WITH A GIVEN NUMBER OF RAINDAYS

Table 14 gives the percentage of occasions on which each month had a given number of raindays, while Table 15 gives the percentiles of frequency as the number of raindays which is not exceeded on the stated percentages of occasions.

No month has had less than four raindays which minimum has been recorded in April, May and June, while January and November have not had less than 9 days, and December, February and March have had less than 9 on only one or two occasions each.

At the other end of the scale May has the smallest maximum number with 18 days, followed by April and June which have not had an occasion with more than 21 raindays.

The highest number of 28 raindays in the month has been recorded twice, in August, 1902 and October, 1857.

No. of Days	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
4				2	1	1						
5					2	2	1	1				
6		1		1	4	5	2					
7		1	1	7	9	7	6	2	4	2		
8			1	12	15	11	3	2	2	5		1
9	1	2	5	12	11	10	8	1	4	4	7	3
10	5	3	6	13	6	10	8	6	9	4	5	
11	4	4	5	15	14	11	13	9	5	8	5	4
12	4	8	9	8	9	11	10	6	16	7	7	12
13	6	10	15	11	9	10	8	11	15	7	4	6
14	7	10	9	6	8	10	11	9	11	8	14	8
15	7	4	10	6	5	6	8	16	8	10	12	11
16	15	18	8	2	5	4	3	7	6	6	9	10
17	16	12	9	4	4	2	7	12	8	10	8	17
18	5	10	7		1	1	8	5	10	7	15	11
19	10	6	6	1		1	2	5	2	7	8	1
20	10	3	4	1			1	4	1	11	3	9
21	6	2	2	1		1	3	3		1	3	3
22	2	3	2					2	1	2	1	2
23	3	1	1				1	1		1		3
24	1	1	2									1
25		2								1		
26			1									
27	1											
28								1		1		

TABLE 14. Percentage of occasions when each month has a given number of rain days. (Days with 0.01 inch or more.)

%	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5	10	10	9	7	6	6	7	9	8	8	9	11
10	12	11	10	8	7	7	8	10	10	9	10	12
20	14	13	12	8	8	8	10	11	11	11	12	13
30	15	14	13	9	9	9	11	13	12	13	14	14
40	16	15	13	10	9	10	12	14	13	14	14	15
50	17	16	15	11	11	11	13	15	13	15	15	16
60	17	17	16	11	12	12	14	15	14	17	16	17
70	19	17	17	13	13	13	15	17	15	18	18	18
80	20	18	18	14	14	14	17	18	17	19	18	18
90	21	20	20	15	16	15	18	20	18	20	19	20
95	23	22	22	17	17	17	20	21	18	22	20	22

TABLE 15. Number of raindays per month which is not exceeded in stated percentages of occasions.

8.2 AVERAGE FALL PER RAINDAY

It is of interest to combine the data given above on total falls and number of raindays to determine the average fall per day on the days when it does rain, and the value for each month and quarter month are given in Table 16 and plotted in the ~~middle~~ top graph of Figure 4.

It is seen that the fall per rainday is least in the winter, with lowest value of 0.27 of an inch in January, and rises to two peaks, one of 0.43 of an inch in May and a second of 0.42 of an inch in October both more than 50% above the January rate.

The quarter monthly figures show that the first week of January and the first week of February with an average of $\frac{1}{4}$ of an inch per rainday, have the lowest rates, while the third quarter of May and the second quarter of October have the highest with more than $\frac{1}{2}$ inch per rainday.

	Whole Month	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
Jan.	.27	.25	.28	.28	.26
Feb.	.29	.25	.30	.31	.31
Mar.	.31	.35	.28	.29	.31
Apr.	.36	.28	.34	.40	.38
May	.43	.30	.39	.50	.48
June	.38	.33	.40	.41	.35
July	.34	.30	.33	.35	.37
Aug.	.37	.37	.32	.38	.39
Sept.	.39	.40	.37	.37	.42
Oct.	.42	.38	.54	.37	.38
Nov.	.34	.35	.38	.31	.29
Dec.	.29	.29	.28	.29	.28

TABLE 16. Average fall per rainday.

8.3 PERCENTAGE OF DAYS WITH FALLS EXCEEDING VARIOUS LIMITS

Table 17 gives for each month the percentage of days with total rainfalls equalling or exceeding various amounts from 0.04 of an inch to 12 inches, and data for 6 major amounts are plotted in Figure 5.

A day with 0.04 of an inch fall is a "Wet Day" and the data shows that the number of wet days varies from month to month in the same manner as the number of raindays as given in Table 12, with the maximum frequency of 44% in February and minimum of 28% in May. The percentage of wet days is less than 30% in April, May and June and above 40% only in January and February. The percentage falls rapidly from February to April and rises steadily from May to February except that August shows a secondary maximum.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
.04	41.7	44.3	39.5	28.9	28.1	29.2	32.5	39.0	36.4	38.8	39.5	39.5	36.4
.10	30.5	32.3	29.3	22.1	20.9	21.6	24.9	29.8	28.4	29.8	29.9	29.1	27.3
.20	20.0	22.0	20.0	16.3	15.7	16.1	17.7	21.7	20.5	22.1	20.4	20.2	19.4
.30	15.0	16.6	14.6	12.5	12.9	12.9	13.6	17.1	15.8	17.4	15.7	14.4	14.8
.40	11.0	12.4	11.3	9.8	10.1	10.6	11.0	13.8	12.4	14.1	12.6	11.1	11.7
.50	8.4	9.7	9.2	7.9	8.7	8.7	8.9	11.1	10.5	11.7	10.1	8.6	9.5
.60	6.8	8.1	7.3	6.6	7.6	7.5	7.4	9.1	9.1	10.3	8.5	7.1	8.0
.80	4.0	5.2	5.1	4.7	5.7	5.1	4.8	6.3	6.7	7.5	6.0	4.8	5.5
1.00	2.8	3.3	3.4	3.6	4.2	3.8	3.6	4.5	4.6	5.7	4.2	3.1	3.9
1.20	2.0	2.5	2.3	2.5	3.3	2.8	2.6	3.7	3.4	4.7	2.9	2.3	2.9
1.60	.98	1.1	1.3	1.2	2.2	1.4	1.4	1.8	1.9	2.9	1.8	1.4	1.6
2.00	.55	.55	.65	.61	1.3	.71	.81	.99	1.4	2.0	1.1	.76	.95
3.00	.03	.18	.16	.27	.46	.27	.29	.23	.51	.95	.34	.20	.33
4.00		.04	.07	.14	.16	.10	.10	.13	.31	.39	.07	.10	.13
5.00			.07	.07	.07	.07	.03	.07	.10	.10	.03		.05
6.00				.07		.03			.10		.03		.02
7.00				.03		.03			.03		.03		.01
8.00				.03		.03							.006
9.00				.03									.003
10.00				.03									.003
11.00				.03									.003

TABLE 17. Percentage of days with total fall equalling or exceeding amounts stated.

As we consider days with progressively higher falls the form of the distribution curve gradually changes. February has the highest percentage of days with at least 0.10 of an inch, but for all values from 0.20 of an inch to 5 inches October has the highest percentage of occurrences. May has the lowest percentage of days with falls up to 0.30 of an inch, April the lowest from 0.40 to 0.60 of an inch, and January the lowest for all the highest values. January has a day with an inch or more less frequently than once a year whereas October has almost 2 a year.

8.4 MAXIMUM DAILY FALLS RECORDED

Table 17 shows that daily falls of 5 inches or more have been recorded on only 18 days in the period.

None of these days occurred in the three winter months December to February, and only once each in July and November, while there were three

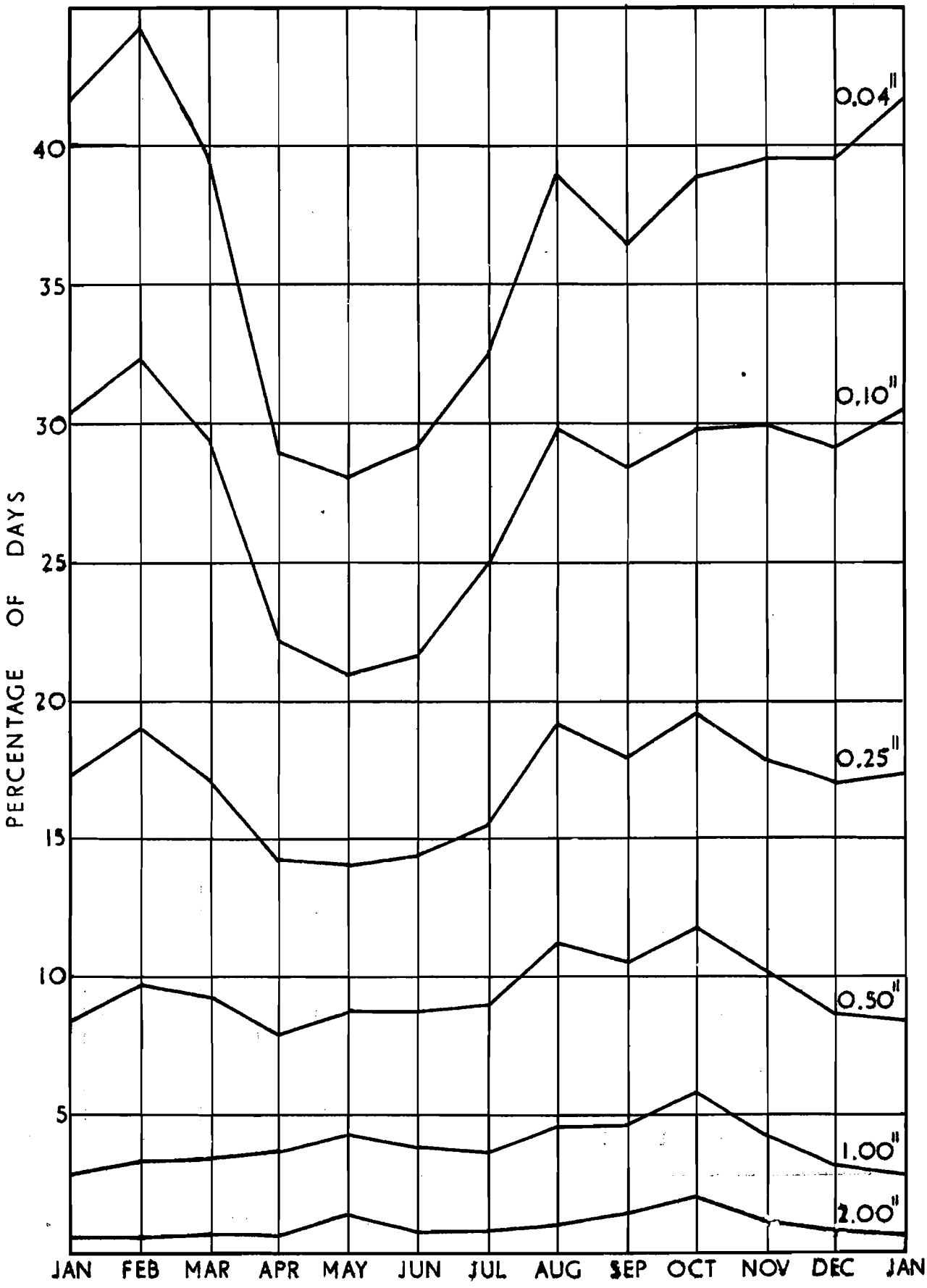

FIGURE 5. Percentage of Days each month on which total fall reaches amounts stated.

each in September and October. Because of their special interest, the exact dates and falls are given below.

11.38 inches on 20th April, 1902
8.81 inches on 14th June, 1922
7.53 inches on 4th September, 1947
7.18 inches on 9th November, 1885
6.53 inches on 16th April, 1889
6.20 inches on 8th September, 1909
6.12 inches on 3rd September, 1915
5.88 inches on 25th August, 1902
5.84 inches on 24th October, 1860
5.70 inches on 13th October, 1892
5.64 inches on 20th August, 1891
5.50 inches on 27th May, 1921
5.48 inches on 27th July, 1943
5.40 inches on 23rd June, 1902
5.32 inches on 3rd March, 1908
5.16 inches on 14th October, 1858
5.09 inches on 23rd May, 1920
5.08 inches on 2nd March, 1901

The extreme fall of 11.38 inches actually fell chiefly between midnight on the 20th April, 1902, and 6 a.m. on the 21st April. Heavy rain was reported as being continuous with heavy lightning most of the time, and hail about 2 a.m. There was widespread flooding, and roads everywhere were much damaged.

A fall of 12.50 inches was recorded on this date at Clermont, Paget.

9. DIURNAL VARIATION OF RAINFALL

Hourly values of rainfall are available for only 16 years from 1933 to 1942, 1949 to 1953, and 1956, and in this short period individual heavy falls have an undue effect on the average hourly values. Consequently the data was analysed for 2 hourly intervals and Table 18 gives the percentage of the total rain recorded in each two hours per day over the period but even here the figures are somewhat erratic.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
0- 2	11.7	6.0	9.0	8.3	3.8	7.6	9.4	8.7	7.5	7.2	7.9	9.0	8.0
2- 4	9.2	8.9	9.3	10.4	8.7	8.4	9.4	8.8	8.5	7.5	11.0	8.3	8.9
4- 6	6.6	10.0	6.5	14.4	12.0	11.5	12.8	6.4	11.7	6.9	8.1	9.5	9.5
6- 8	7.3	9.2	12.0	10.0	9.5	14.6	8.0	9.5	10.7	9.1	6.3	8.0	9.4
8-10	7.4	10.6	10.8	6.4	12.1	10.9	8.7	10.6	6.2	9.6	8.3	8.6	9.1
10-12	9.2	5.5	9.5	8.4	8.8	12.8	11.8	11.6	8.3	9.2	9.3	11.4	9.6
12-14	6.8	6.2	5.8	5.2	8.4	9.8	9.9	8.7	8.1	11.4	9.7	9.2	8.4
14-16	5.7	8.8	6.5	6.2	11.4	8.1	10.0	13.1	7.0	7.5	9.5	8.4	8.5
16-18	6.1	8.7	9.1	5.5	7.5	3.4	4.7	7.3	6.1	8.3	6.3	6.4	6.8
18-20	10.4	9.0	6.8	10.6	8.3	4.4	5.4	6.6	8.9	7.5	5.2	8.2	7.7
20-22	10.7	10.9	6.8	7.9	4.4	5.2	4.8	4.7	8.8	7.1	8.6	7.1	7.3
22-24	8.8	6.1	8.0	6.8	5.1	3.5	5.0	3.8	8.3	8.6	9.8	6.1	6.8

TABLE 18. Percentage of total rain which fell in each two hours of the day.

The figures for the whole year show a minimum rate of fall from 4 p.m. to midnight with a maximum about 30% greater from 4 a.m. to noon.

The individual monthly values also show a minimum between 4 p.m. and midnight from June to December but between 10 a.m. and 4 p.m. from January to April.

In six months from March to September (omitting August) the maximum is between 4 a.m. and 10 a.m. and in January and November between midnight and 4 a.m.

From September to March the maximum each day was twice the minimum while in the summer half-year, the maximum was three times the minimum.

The difference was least in October where the maximum was 60% greater than the minimum, and greatest in June where the maximum was four and one-third times the minimum.

Working from the monthly means in Table 5 and the percentages in Table 18, it appears that over the years most rain falls between noon and 2 p.m. in October, and least between 4 and 6 p.m. in June with more than 5 times as much in the October period as in the June.

10. DURATION OF RAIN

The total duration in hours each month and the average per day and per rain day are given in Table 19, while Table 20 gives the total monthly duration not exceeded on 5 to 95% of occasions.

The data is deduced from records of the automatic gauge, on which the minimum detectable rate of fall is about .005 inch per hour.

	Average	Maximum Hours	Maximum Year	Minimum Hours	Minimum Year	Average per Day	Average per Rainday
Jan.	39.7	76.0	1955	9.0	1950	1.3	2.3
Feb.	37.8	84.1	1942	13.2	1939	1.3	2.4
Mar.	36.2	68.7	1947	9.9	1938	1.2	2.6
Apr.	27.6	68.1	1933	5.9	1947	0.9	2.5
May	29.0	57.6	1942	10.2	1953	0.9	2.8
June	22.3	50.0	1947	1.3	1943	0.7	2.0
July	18.8	48.7	1946	3.3	1937	0.6	1.4
Aug.	24.0	55.6	1935	7.9	1937	0.8	1.6
Sept.	24.8	50.3	1943	7.1	1952	0.8	1.7
Oct.	36.9	70.7	1956	12.3	1949	1.2	2.2
Nov.	30.7	67.5	1932	12.6	1952	1.0	2.2
Dec.	32.9	67.6	1947	8.7	1932	1.1	2.0
Year	360.7	480.4	1942	214.3	1953	1.0	2.1

TABLE 19. Total Duration of Rain each Month in Hours.

Percentile	5	10	30	50	70	90	95
Jan.	10	14	26	38	51	65	74
Feb.	13	16	25	38	46	61	80
Mar.	11	17	24	32	48	65	69
April	6	9	19	28	34	45	65
May	10	11	20	28	37	52	56
June	3	9	16	20	29	35	47
July	3	6	11	19	23	35	46
Aug.	8	10	18	21	27	41	53
Sept.	8	12	18	22	28	47	50
Oct.	13	16	26	33	45	67	70
Nov.	13	14	20	30	34	53	65
Dec.	10	15	21	31	43	59	66
Year	223	276	320	367	386	437	474

TABLE 20. Percentiles of Total Monthly Duration of Rain in Hours.

There is a marked seasonal variation with a maximum of 1.3 hours for January and February, subsidiary maximum of 1.2 hours in October, and minimum of 0.6 hours in July, less than half the maximum.

When duration per rain day is considered, we find the maximum has moved to the spring months with the highest value of 2.8 hours per rain day in May. The minimum is still in July which has 1.4 hours, half the May maximum.

Except for July which has had a maximum duration of 48.7 hours, all months have had at least 50 hours on some occasion, and each from October to April has had 67 hours or more with a maximum of 84 hours total, over three hours per day, in February, 1942.

All months have had an occasion with a total of less than 14 hours with a minimum of 1.3 hours in June, 1943.

Table 20 shows that in 4 years out of five, July has between 6 and 35 hours while February has between 16 and 61.

An average duration of one hour per day is exceeded in 2 years out of 3 in February, but only once in 7 years in July. An average of one and a half hours a day is exceeded only once in 20 years in July, but once in three years in February.

10.1. FREQUENCY OF DAYS WITH VARIOUS DURATIONS OF RAIN

Table 21 gives the average number of days in each month on which rain fell for certain specified times, while Figure 6 gives the same data compressed into five curves which give the percentage of days with duration in the more significant intervals.

Duration Hours	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
0.0	13.1	11.6	16.5	18.2	19.8	18.3	17.1	15.1	13.8	13.1	14.7	13.5	184.8
0.1- 0.4	4.9	4.1	3.6	3.2	3.5	4.5	6.0	5.9	6.6	6.6	5.1	5.3	59.3
0.5- 0.9	3.7	2.9	2.5	2.0	1.9	2.2	2.6	3.5	2.9	2.3	3.7	3.7	33.9
1.0- 1.9	3.6	3.5	2.9	2.3	1.6	1.5	2.1	2.5	2.7	3.4	1.9	3.0	31.0
2.0- 2.9	1.7	1.7	1.9	1 0	1.0	.95	1.4	1.5	1.2	1.5	1.3	1.8	17.0
3.0- 3.9	1.0	1.5	1.0	.95	.55	.86	.68	.91	.95	1.4	1.0	1.3	12.0
4.0- 4.9	.59	.95	.41	.55	.64	.55	.45	.45	.68	.77	.59	.50	7.1
5.0- 5.9	.55	.64	.36	.59	.64	.32	.09	.50	.45	.45	.41	.45	5.5
6.0- 6.9	.59	.55	.32	.23	.27	.18	.14	.23	.14	.55	.18	.36	3.6
7.0- 7.9	.32	.32	.27	.18	.14	.27	.18	.18	.14	.18	.32	.27	2.8
8.0- 8.9	.14	.18	.27	.14	.23	.05	.09	.05	.09	.09	.32	.27	1.9
9.0- 9.9	.18	.09	.05	.05	.09	.14	.05	.14	.09	.09	.05	.09	1.1
10.0-11.9	.18	.05	.36	.23	.23	.18	.09	–	.09	.32	.14	.14	2.0
12.0-13.9	.05	.18	.14	.18	.09	.05		.05	.05	.14	.05	.18	1.2
14.0-15.9	.18	.05	.09	.14	.05	–		.05	.05	.09	.14	.05	0.9
16.0-17.9	.14		.09		.14	.05			–	–	–	.05	0.5
18.0-19.9	.05		.09		.05				–	.05	.05		0.3
20.0-24.0					.05				.05	.05			0.1

TABLE 21. Average number of days per month and year with duration of rain between limits stated .1933-56.

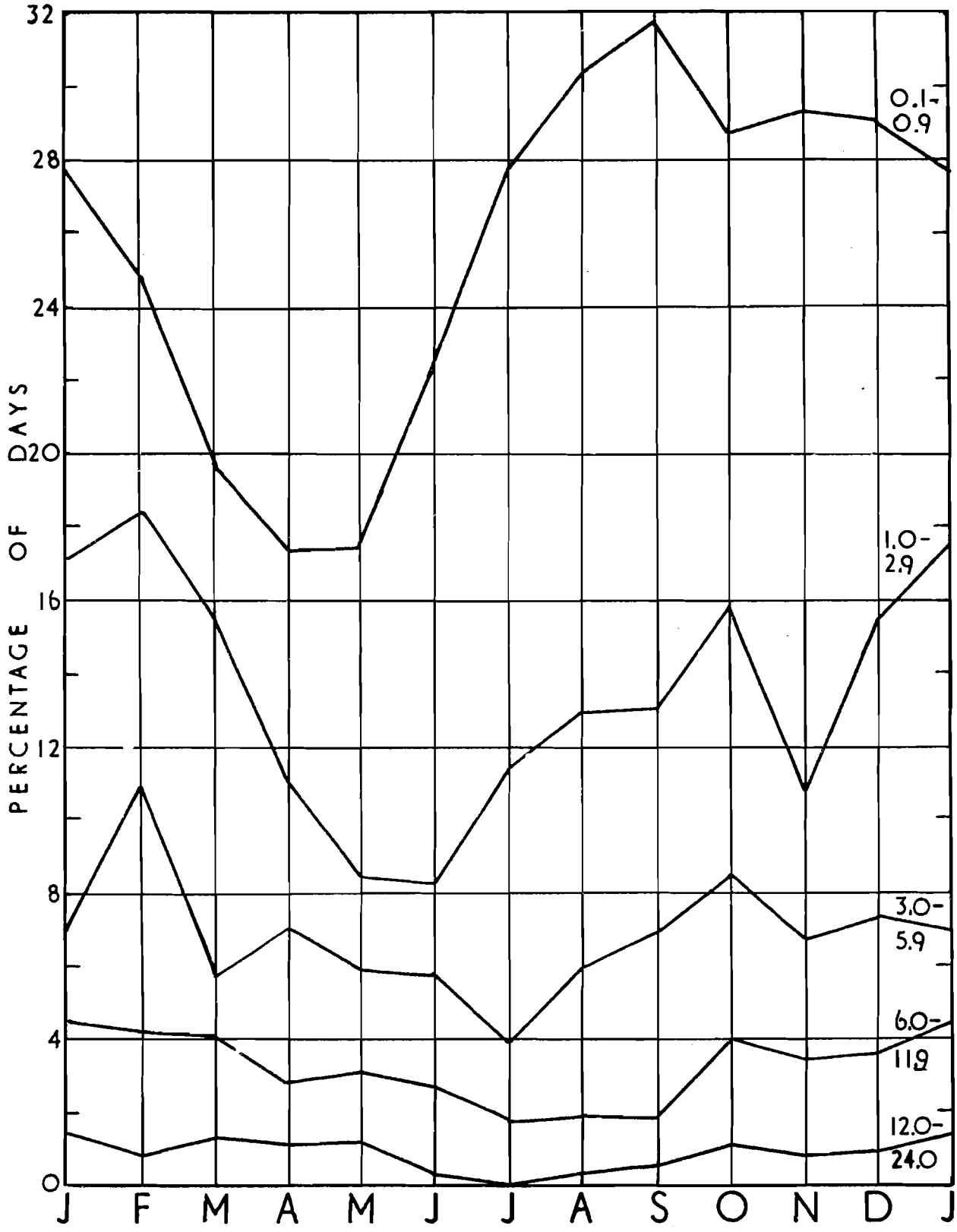

FIGURE 6. Percentage of Days each month with Total Duration of Rainfall between limits stated in hours.

The table shows that April, May and June have the highest percentage of days without rain with the highest normal of 20 days in May. February with an average number under 12, has the smallest number of rainless days of any month.

Days with some rain, but less than one hour, are most frequent from August to December where nearly one day in three is in this range, with the highest frequency in September. This range is least frequent in April and May with one day in six.

The other four curves for longer durations each show the general form of maximum frequency in January or February and a minimum in summer, which is progressively later with increased durations.

In each of these longer durations there is a subsidiary maximum in October and minimum in November.

Days with from one to six hours duration are most frequent in February, and days with six to twenty-four hours in January.

10.2. MAXIMUM DURATION OF RAIN ON INDIVIDUAL OCCASIONS

Table 22 gives the maximum duration of rain on individual occasions in the years available.

The figures for consecutive hours in Columns 1 and 2 are taken from tabulations of hourly values, and cover years 1933 to 1942, 1949 to 1953, and 1956.

	Consecutive Hours with rain recorded in each		Continuous Rainfall .005 inch per hour	
Month	Average Maximum	Extreme Maximum	Average Maximum	Extreme Maximum
Jan.	11.7	21	6.4	12.1
Feb.	10.8	20	5.7	8.9
Mar.	12.2	23	8.1	22.3
April	10.0	19	6.4	10.3
May	10.6	15	6.1	14.5
June	10.6	20	4.9	18.5
July	7.1	18	3.5	7.2
Aug.	9.1	21	4.0	7.5
Sept.	11.0	46	6.9	22.9
Oct.	16.4	46	7.4	22.1
Nov.	10.0	20	5.3	13.6
Dec.	9.5	19	5.1	9.0
Year	23.3	46	15.5	22.9

TABLE 22. Maximum duration of Rainfall on separate occasions. 1933-42, 1949-53, 1956.

They give the maximum number of consecutive hours with a rain amount entered, but take no account of whether the rain lasted for all or only part of the hour.

The figures for continuous rainfall in columns 3 and 4 were determined directly from the records of the automatic gauge and give the duration of continuous recorded falls. The lowest rate detectable on the chart is about .005 of an inch per hour. As these figures were not published in the annual summaries of observations, we now have available only the 1933 to 1942 data in the Technical Note 1 and the charts for 1956.

Both tables show that in general periods of rainfall are shortest in midsummer and longest in early spring and early autumn.

In the wettest period in July continuous rain normally does not last more than $3\frac{1}{2}$ hours nor are there more than 7 consecutive hours with rain in each. On the other hand, October normally has one period of $7\frac{1}{2}$ hours continuous rain with 16 consecutive hours in which rain fell, and March a period over 8 hours of continuous rain and 12 consecutive hours with rain. Neither July nor August has had 8 continuous hours of rain, but March, September and October have each had over 22 hours.

There is normally each year one period with 15 hours of continuous rain and one of 23 consecutive hours with rain.

The extreme values recorded were in September, 1941 when there was one period of 23 hours of continuous rain, while for 46 hours rain fell at some time in each hour. In October, 1956 there was another period of 46 consecutive hours of rain.

10.3. LONGEST RAIN PERIODS

Figures relating to the longest rain periods, when a day is the unit of time, are given in Table 23 which gives the largest number of consecutive days with at least 0.01 of an inch rain on each.

The differences from month to month are not as great as those in Table 22 for hourly falls, the average maximum in February, the month with longest periods, being only 50% greater than in April and May which have the shortest periods.

February has the longest normal maximum of 6.0 days, but January, August and October are only slightly less with 5.7 days.

The lowest values of just under 4 days are in April and May, considerably earlier than the minimum of consecutive hours which Table 22 showed is in July.

Each month has had at least 11 consecutive days with rain on some occasion and the two greatest were 28 days from August 3rd to 30th, 1902 and 22 days from February 11th to March 4th, 1942.

There have been occasions in May, June and, rather surprisingly, October, when there was not rain on any two consecutive days, but all other months have never passed without at least one period of two consecutive days with rain. There has not been a year without at least one period of 5 consecutive rainy days and the average maximum per year is 10 days.

	Average Monthly Maximum	Absolute Monthly Maximum		Shortest Monthly Maximum	
		Days	Date	Days	Date
Jan.	5.7	14	1857, 1940	2	3 years
Feb.	6.0	22	1942	2	3 years
Mar.	5.4	19	1866	2	3 years
Apr.	3.9	11	—	2	10 years
May	3.9	11	1899	1	1956
June	4.3	13	1949	1	1943
July	5.2	14	1946	2	3 years
Aug.	5.7	28	1902	2	5 years
Sept.	5.2	15	1950	2	3 years
Oct.	5.7	15	1857	1	1911
Nov.	5.4	16	1885	2	4 years
Dec.	5.2	14	1934	2	5 years
Year	10.2	28	1902	5	

TABLE 23. Duration of longest rain periods; number of consecutive days each with 0.01 inch or more.

11 MAXIMUM FALLS IN PERIODS FROM 1 TO 28 DAYS

The absolute maximum falls observed in 1 to 28 days in each month are given in Table 24. As these extremes are due to exceptional conditions, they

No. of Days	1	2	3	7	14	21	28
Jan.	3.84	7.10	7.44	8.10	9.12	10.12	11.66
Feb.	5.44	5.80	6.92	7.68	12.16	13.76	14.42
Mar.	5.86	7.66	7.66	8.24	10.32	12.02	12.92
Apr.	11.44	11.54	11.66	12.36	13.16	13.51	14.31
May	5.50	6.60	6.95	8.11	8.80	11.90	12.70
June	8.81	9.51	9.51	9.75	10.02	12.78	13.44
July	5.47	6.18	7.35	14.87	17.00	18.60	19.37
Aug.	6.88	9.24	10.76	14.09	18.26	19.76	21.33
Sept.	7.53	8.56	9.80	14.64	14.90	17.44	18.12
Oct.	6.18	7.50	8.07	12.24	16.02	19.03	20.39
Nov.	7.18	7.18	7.18	9.26	10.26	14.92	16.66
Dec.	4.74	6.18	6.66	8.05	8.84	10.93	12.13
Year	11.44	11.54	11.66	14.87	18.26	19.76	21.23

TABLE 24. Highest falls recorded in periods of 1 to 28 days.

are somewhat erratic, but in general lowest values are in December and January and highest in August and September.

The absolute maxima up to 3 days are all due to a thunderstorm in the early morning hours of April 21st, 1902, when in a period of only 8 hours a total of 11.36 inches was recorded at Prospect, the official station, and 12.50 inches was measured at Clermont.

The wettest 7 days were the last week of July, 1886, making it the wettest July, while the extreme falls in 14, 21 and 28 days all occurred in the wettest month on record, August, 1902, which had rain on 28 consecutive days and, in the second half of the month, one day with over 5 inches, 3 days with 2 inches, 2 days over one inch, and three days over 0.7 of an inch.

11.1 MAXIMUM FALLS IN PERIODS OF 1 TO 12 HOURS

Table 25 gives figures relative to falls in short periods as determined from the recording gauge which has been operating since 1933 but only 16 years records are now available owing to the fire loss.

The maximum falls in 60 and 180 minutes were scaled from the charts but not published in the annual summaries until 1953 so that such figures are now available only for 1953 and 1956 and the years 1933 to 1942 which were covered in the Technical Note No. 1. From 1949 to 1952 values scaled between exact hours are available which are however likely to be less than the extremes, especially for shorter periods.

	AVERAGE MAXIMUM IN				ABSOLUTE MAXIMUM IN			
	1 Hour	3 Hours	6 Hours	12 Hours	1 Hour	3 Hours	6 Hours	12 Hours
Jan.	0.51	0.79	0.98	1.16	1.13	1.37	2.00	2.80
Feb.	0.53	0.81	0.91	0.99	0.87	1.95	2.68	4.34
Mar.	0.71	1.05	1.20	1.41	1.28	2.26	2.51	3.66
Apr.	0.77	1.17	1.37	1.55	1.40	4.25	8.50	11.36
May	0.64	1.01	1.25	1.45	1.07	1.98	2.34	3.46
June	0.73	1.00	1.17	1.37	1.63	2.16	4.00	8.00
July	0.79	1.03	1.15	1.29	2.20	2.96	2.96	3.12
Aug.	1.06	1.29	1.45	1.53	2.66	3.14	3.17	5.78
Sept.	0.92	1.35	1.60	1.77	2.22	4.25	4.76	6.12
Oct.	0.91	1.23	1.54	1.88	1.92	2.50	3.11	4.54
Nov.	0.66	0.91	1.21	1.45	1.74	2.03	3.01	4.09
Dec.	0.90	1.19	1.32	1.51	3.51	3.60	3.73	4.64
Year	1.64	2.27	2.71	3.16	3.51	4.25	8.50	11.36

TABLE 25. Maximum Falls in one to twelve hours.

The list of Absolute Maxima in 12 hours includes readings obtained between 1891 and 1932 from twice daily readings and the figures for 3 and 6 hours in April and for 6 hours in June are each based on the 12 hourly reading.

The table shows that each month normally has an hour with more than $\frac{1}{2}$ inch rain, 3 hours with 0.8 of an inch, 6 hours with 0.9 of an inch, and 12 hours with 1.0 inch. Each year there is an hour with over $1\frac{1}{2}$ inches, 3 hours with over 2 inches, 6 hours with over $2\frac{1}{2}$ inches, and 12 hours with over 3 inches.

Except for February each month has had at least one hour with an inch or more and except for January each month has had 3 hours with close to 2 inches.

The wettest hour was on December 1st 1953 when 3.51 inches were measured.

The wettest 3, 6 and 12 hours all occurred with the exceptional rainfall of the early morning of 21st April 1902 when 11.36 inches was recorded at Prospect in a period stated to be 8 hours. The newspaper of the following day reports 12.50 inches at Clermont and states that almost all the rain fell between midnight and 6 a.m. We may safely assume, therefore, that the maximum falls in 3 and 6 hours were not less than three-eighths and three-quarters respectively of the 12 hour total and these are the figures entered in Table 25.

11.2. MAXIMUM FALLS IN PERIODS OF 5 TO 60 MINUTES

Although the extreme falls each month in periods of 60 minutes or less were extracted from the records since 1932, the figures were not published until 1953 and following the fire, there is now available only the 1953 and 1956 data plus an analysis of the 20 heaviest hourly falls between 1933 and 1942. From this data Table 26 has been deduced, giving the maximum falls in 5 to 60 minutes which may be expected to occur at intervals of 1 to 12 years.

	Interval in Minutes						
Frequency	60	45	30	20	15	10	5
1 in 12 years	3.5	3.1	2.6	2.1	1.7	1.4	0.9
1 in 6 years	2.7	2.3	1.9	1.5	1.4	1.2	0.8
1 in 4 years	2.3	2.0	1.7	1.3	1.1	1.0	0.7
1 in 3 years	2.1	1.9	1.5	1.2	1.1	0.9	0.6
1 in 2 years	1.8	1.6	1.4	1.1	1.0	0.8	0.5
1 in 1 year	1.4	1.3	1.1	0.9	0.8	0.6	0.4
2 in 1 year	1.2	1.1	0.8	0.6	0.5	0.4	0.2

TABLE 26. Maximum rainfall, in inches, which occurs with stated frequencies in from 5 to 60 minutes. (1933-1942, 1953, 1956.)

The greatest values in all periods were recorded between 9 and 11 a.m. on December 1st, 1953, when 3.51 inches fell in 60 minutes, and the falls in shorter periods were estimated as 3.10 inches in 45 minutes, 2.57 inches in 30 minutes, 2.06 inches in 20 minutes, 1.75 inches in 15 minutes, 1.38 inches in 10 minutes, and 0.90 inches in 5 minutes.

Table 26 shows that every year we may expect one-half inch in 10 minutes, three-quarters of an inch in 15 minutes, and one inch in about 30 minutes, while once in 4 years there will be a fall of an inch in about 10 minutes and 2 inches in 45 minutes.

These maximum falls occur mainly in the summer with greatest frequency in June and August and lowest in January and February.

12. DRY PERIODS

Although as shown earlier there has never been a calendar month without rain, marked dry periods do occur and data on these are given in Table 27.

The two left hand columns give figures relative to days without recorded rain, i.e., less than 0.005 inch while the two right hand columns give the average and extreme lengths of periods in which less than 1 inch fell. The figures are given for each month but in each case the maximum period was measured and when it extended over two months, it was credited to the month which it covered the more.

Month	Maximum Periods with Total Falls Less than			
	0.01 inch		1.00 inch	
	Average	Extreme	Average	Extreme
January	4.4	10	17.4	39
February	4.3	9	15.2	30
March	5.7	17	17.0	41
April	7.0	17	19.9	44
May	8.1	22	21.7	40
June	7.6	15	21.1	50
July	7.6	21	22.1	54
August	6.5	21	18.1	50
September	6.6	15	17.7	58
October	6.0	17	17.4	37
November	4.9	13	17.1	35
December	4.6	11	17.1	38
Year	12.3	22	33.0	58

TABLE 27. Length of Longest Dry Periods in days.

The longest dry periods occur in early summer with usually a rainless period of 8 days in May and 7 to 8 days in June and July. In each of these 3 months there is normally a 21-day period with a total fall of less than one inch. Dry periods are shortest in winter with lowest values in February when 4 days are normally the longest rainless period and 15 days the longest period with less than one inch.

There have not been more than 9 consecutive rainless days in February or more than 10 in January, but May has had 22 and July and August each 21 days.

There have been periods covering the 4 summer months, June to September, when less than an inch fell in 50 days with a maximum of 58 days in September. The five months, October to February, have never had 40 days with less than an inch while 30 days is the longest period covering February.

There is every year, on the average, one rainless period of 12 days and one period of 33 days in which less than one inch of rain falls.

The longest rainless period which has been observed is 22 days in May, 1908 while 58 days ending in September, 1910 had a total fall of less than one inch.

12.1. DRIEST PERIODS OF 1 TO 24 WEEKS PER YEAR

Table 28 gives the minimum falls recorded in 1 to 24 consecutive weeks each year, and Table 29 gives the percentiles for the same periods.

The normal year has 4 weeks with under three-quarters of an inch, 8 weeks under $3\frac{1}{2}$ inches, 12 weeks under 7 inches, and 24 weeks under $19\frac{1}{2}$ inches.

Number of Weeks	1	2	3	4	6	8	12	16	20	24
Average Minimum	0.00	0.05	0.30	0.72	1.88	3.41	6.88	10.56	14.75	19.45
Absolute Minimum	0.00	0.00	0.00	0.07	0.64	0.98	2.04	3.14	7.06	10.03
Highest Minimum	0.01	0.26	0.98	1.86	4.20	6.09	13.21	17.10	28.91	32.97

TABLE 28. Rainfall in driest 1 to 24 weeks (7 to 168 days) per year.

There have been occasions with only one-tenth of an inch in 4 weeks, 1 inch in 8 weeks, 2 inches in 12 weeks, and 10 inches in 24 weeks.

From Table 29 the deficits from average falls at a yearly rate of 57.64 inches were computed and Figure 7 gives the deficit from normal fall which occurs up to 24 weeks in from 2% to 98% of occasions.

In Figure 7 the 2% curve which shows the driest occasions which occur once in 50 years, the total deficit increases in almost a straight line as the period increases from 1 to 14 weeks when it reaches a value of over 12 inches. With still

Percent	1	2	3	4	6	8	12	16	20	24
2	.00	.00	.00	.11	0.7	1.2	2.5	4.4	7.9	11.6
5	.00	.00	.02	.20	0.8	1.7	3.4	5.9	9.1	12.6
10	.00	.00	.07	.30	1.1	2.2	4.3	6.8	10.3	13.8
20	.00	.00	.12	.43	1.3	2.6	5.0	8.3	11.6	15.5
30	.00	.01	.16	.53	1.4	2.8	5.7	9.1	12.8	17.1
40	.00	.02	.21	.61	1.6	3.1	6.3	9.7	13.9	18.1
50	.00	.04	.28	.68	1.8	3.3	6.9	10.4	14.8	19.2
60	.00	.04	.32	.77	2.0	3.6	7.4	11.2	15.7	20.3
70	.00	.07	.36	.85	2.2	4.0	7.9	12.0	16.3	21.8
80	.00	.09	.46	1.00	2.5	4.3	8.7	13.0	17.6	23.3
90	.00	.14	.62	1.26	2.7	4.9	9.6	14.4	19.4	24.9
95	.00	.19	.78	1.40	3.2	5.3	10.7	15.5	20.5	26 0

TABLE 29. Rainfall in driest 1 to 24 weeks (7 to 168 days) of the year which s recorded in from 2 to 95 per cent of years.

longer periods the rate of increase in deficits slows down, but reaches 15 inches in 24 weeks and is still increasing.

As a larger percentage of years are included, the curves become flatter, i.e., there is a smaller increase in total deficit as the period is lengthened, but even in 98% of years the deficit increases up to periods of 6 weeks so that in 49 years out of 50, each year has a deficit of at least 3 inches.

The median, the curve for 50% of cases, is almost horizontal from 20 to 24 weeks with a maximum of 7.3 inches deficit, indicating that longer periods would have more than average fall and thus reduce the deficit.

The curve for 60% shows a definite decline in deficit from 20 to 24 weeks, and this decline becomes pronounced with 70% and 80%. The 80% curve shows almost a steady value of deficit from 8 to 20 weeks. The curves for 90% of occasions and above, show a decrease from 7 to 8 weeks onward, and in 95% of cases the maximum deficit in one week is greater than in 22 weeks.

13. DROUGHTS

The word drought is likely to bring to mind dry parched lands with vegetation all withered, but this is a condition which fortunately never occurs in Bermuda. However, although as shown above there have never been more than 22 consecutive days without rain, there are an appreciable number of occasions when although some rain falls, it is not sufficient to maintain garden crops nor to replenish the house water supply and in effect a state of drought exists.

Owing to the dependence of water supply on rain collected and stored in individual tanks the rate of use over a long period cannot exceed the 29.9 gallons per square feet of catchment per year given by the average rainfall of 57.64 inches. If water is used at this rate then, whenever the daily fall is below this average, the reserve is drawn upon and the longer the deficit continues the greater the drain on the accumulated supply.

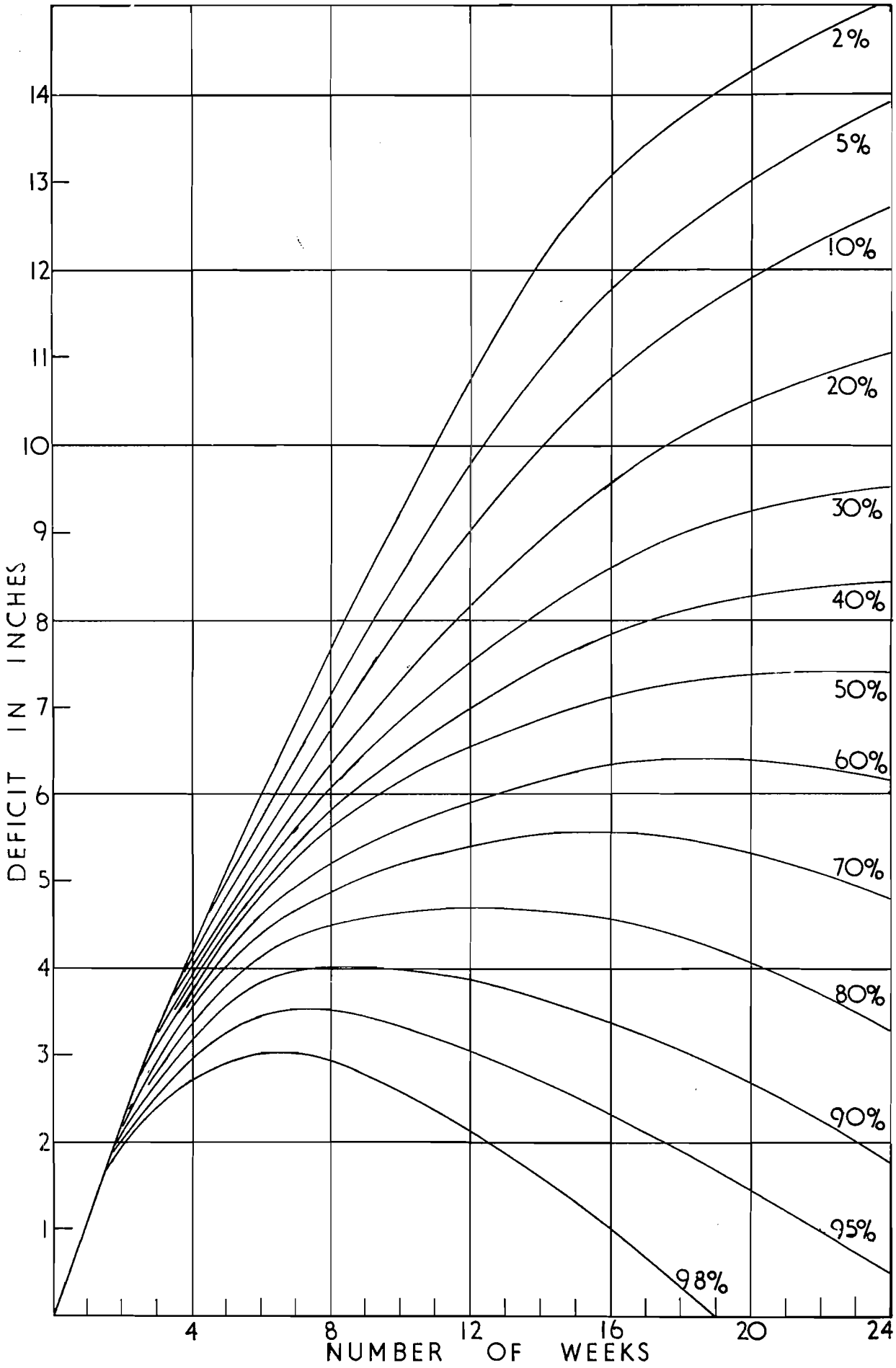

FIGURE 7. Maximum Deficits in Rainfall observed in 1 to 24 weeks in stated percentages of years.

In a period in which each month had its average fall the reserve would decrease from the beginning of December until the end of July and be replenished from August to November. At the end of July the deficit would be 2.9 inches which is 7% of the average fall for 8 months. Such a deficit may, therefore, be expected each year and droughts will be marked as periods with a greater reduction in the water reserve. The extent of this reduction in water reserve is probably the most useful criterion of a Bermuda drought.

To detect drought periods the average falls in 28 to 31 days at the yearly rate of 57.64 inches were determined, then the departure of each actual month's rainfall from these values, and finally the cumulative value at the end of each month of the excesses and deficits from January, 1852 onwards, taking the months missing in 1863 to 1865 as normal. These cumulative values were then plotted against the date giving a graph on which the dry periods show up as a sharp decrease in the accumulated supply. The exact length and intensity of each drought was then determined from the daily records.

Figure 8 gives the highest and lowest points on this curve each year. These graphs could be considered as giving the water level in a tank which received and retained all the rain which fell on a catchment equal in area to the tank's cross section and from which the average rainfall was steadily withdrawn.

It is seen that the whole period consists of three main divisions. Fror 1852 until 1871 there was a decline in the accumulated water to a level of abou 78 inches below the 1852 level. From 1871 to 1906 there was a rise of about 160 inches bringing the level 80 inches above the 1852 level. Since 1906 there has been a decline. 85

The major deficit is 89.7 inches from 1906 to 1956, but this deficit is only 3% of average fall. The deficit, from 1854 to 1871, of 85.6 inches is just under 10% of average but even this cannot be classed as a drought.

The intensity of a drought is given by the ratio of the actual deficit to the normal for the period and expressed as a percentage.

Table 30 gives the greatest deficits which occured with intensity at least 10%, 20%, etc. The largest, 100% deficit, absolutely no rain, is only

Intensity Per cent	Maximum Deficit Inch	Duration Days	Actual Intensity Per cent
100	3.5	22	100
90	7.5	53	90
80	14.9	115	82
70	14.9	115	82
60	17.9	185	61
50	17.9	185	61
40	25.5	361	46
30	32.5	570	36
20	45.5	1328	22
10	78.8	3108	16

TABLE 30. Maximum deficits observed with intensity at least 10, 20, etc., per cent.

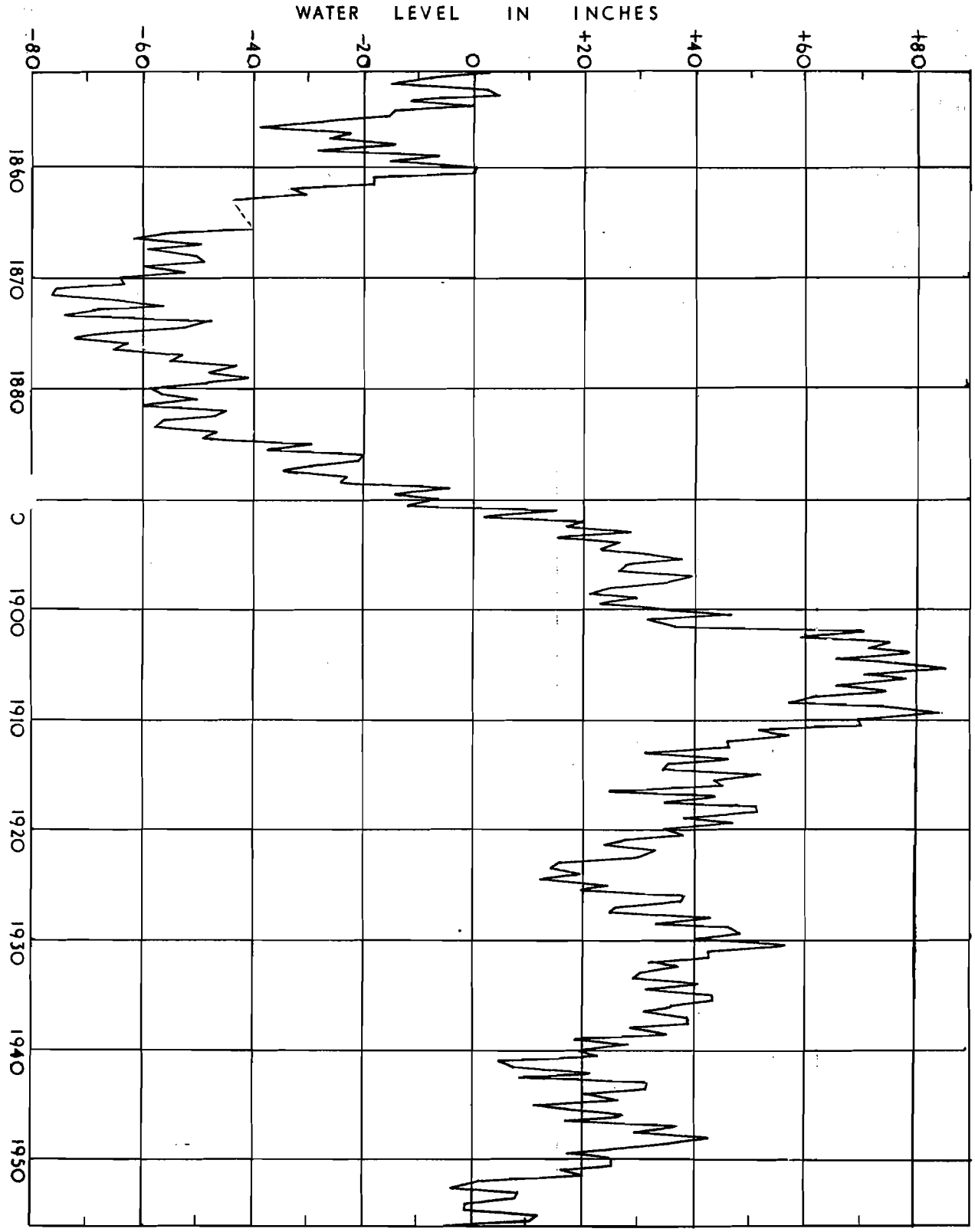

FIGURE 8. Highest and Lowest water levels each year from 1852 in a tank which received all the rain which fell on its area and from which water was withdrawn steadily at a rate of 57.64 inches a year.

3.5 inches with duration of 22 days, while at the other end of the table the maximum 10% was 78.8 inches extending over 3,108 days or $8\frac{1}{2}$ years.

The intensity which makes a deficit noticeable will depend on the conditions with which the particular water user is concerned, but it is unlikely that less than 25%, that is three-quarters normal rain, will usually be significant. General observations over recent years indicate that droughts are noted more rapidly when there is less than half normal fall, that is when intensity is 50% or above.

Tbe greatest deficits with intensity of 25%, 50% and 75%, were therefore deduced from the curve and daily values, and Figure 9 gives the frequency of these deficits over the 103 years available.

Table 31 gives the 25 greatest deficits with at least 50% intensity, while Tables 32 and 33 give the ten greatest with 25% and 75% intensity.

Deficit Inches	Duration Days	Intensity Per cent	Date
17.9	185	61	Mar. 1941-Sep. 1941
16.8	192	56	Dec. 1938-July 1939
15.9	152	67	Dec. 1910-May 1911
15.3	184	53	Feb. 1859-Aug. 1859
15.3	172	56	Jan. 1956-July 1956
15.2	183	53	Nov. 1861-May 1862
14.9	116	82	May 1910-Sep. 1910
14.8	157	60	Apr. 1901-Oct. 1901
14.1	167	54	Aug 1912-Feb. 1913
13.6	158	55	Sep. 1915-Feb.1916
13.5	150	57	Feb. 1913-July 1913
13.4	159	53	Nov. 1874-Apr. 1875
13.0	135	61	Apr. 1906-Aug. 1906
11.7	145	51	Mar. 1931-Aug. 1931
11.6	106	70	Nov. 1931-Feb. 1932
11.6	95	77	June 1861-Sep. 1861
11.2	117	61	May 1908-Sep. 1908
11.0	113	61	Mar. 1886-July 1886
10.8	129	53	Jan. 1929-May 1929
10.3	117	56	May 1923-Aug. 1923
10.3	94	70	Dec. 1870-Mar. 1871
10.3	113	58	Jan. 1917-May 1917
10.0	123	52	Oct. 1889-Feb. 1890
10.0	74	86	May 1855-Aug. 1855
9.9	126	50	Mar. 1874-July 1874

TABLE 31. Greatest droughts with less than half normal fall.

The drought from March to September, 1941, was probably the worst drought experienced. The six months with only 39% of normal rain, came after several years of subnormal rainfall so that reserves were low. Beginning early

in spring, when gardens are in great need of regular water, and continuing through the summer, this drought was felt more than any other by farmers and the community generally.

The most intense drought occurred from May to September, 1910, when less than one-fifth of normal rain fell. Coming as it did in the heat of summer, this was felt particularly by its effect on the water supply, and a great many houses were entirely without fresh water in the latter part of the period.

In questions of water supply it is important to know the frequency with which various deficits occur and from the ogives of 25%, 50% and 75% deficiencies in Figure 9 we can deduce Table 34, which gives the maximum deficits with 25%, 50% or 75% intensity which can be expected in periods of 1 to 100 years.

Deficit Inches	Duration Days	Intensity Per cent	Date
44.4	970	29	Dec. 1860-Sep. 1863
37.8	864	28	May 1855-Sep. 1857
25.5	361	45	Aug. 1912-Aug. 1913
24.5	487	32	Mar. 1931-July 1932
21.2	531	25	May 1870-Oct. 1871
20.0	310	41	July 1949-May 1950
19.2	305	40	Dec. 1951-Sep. 1952
17.9	185	61	Mar. 1941-Sep. 1941
17.5	389	29	Sep. 1879-Oct. 1880
17.0	227	47	Oct. 1910-June 1911

TABLE 32. Greatest droughts with less than three-quarters normal fall.

Deficit Inches	Duration Days	Intensity Per cent	Date
14.9	116	82	May 1910-Sep. 1910
13.5	106	80	Apr. 1941-July 1941
11.6	95	77	June 1861-Sep. 1861
10.0	74	86	May 1855-Aug. 1855
8.9	75	75	Mar. 1956-June 1956
7.5	55	86	Mar. 1954-May 1954
7.4	62	76	Dec. 1949-Feb. 1950
7.1	51	88	July 1857-Aug. 1857
7.0	54	82	Apr. 1892-June 1892
6.7	54	79	Apr. 1957-June 1957

TABLE 33. Greatest droughts with less than one quarter of normal fall.

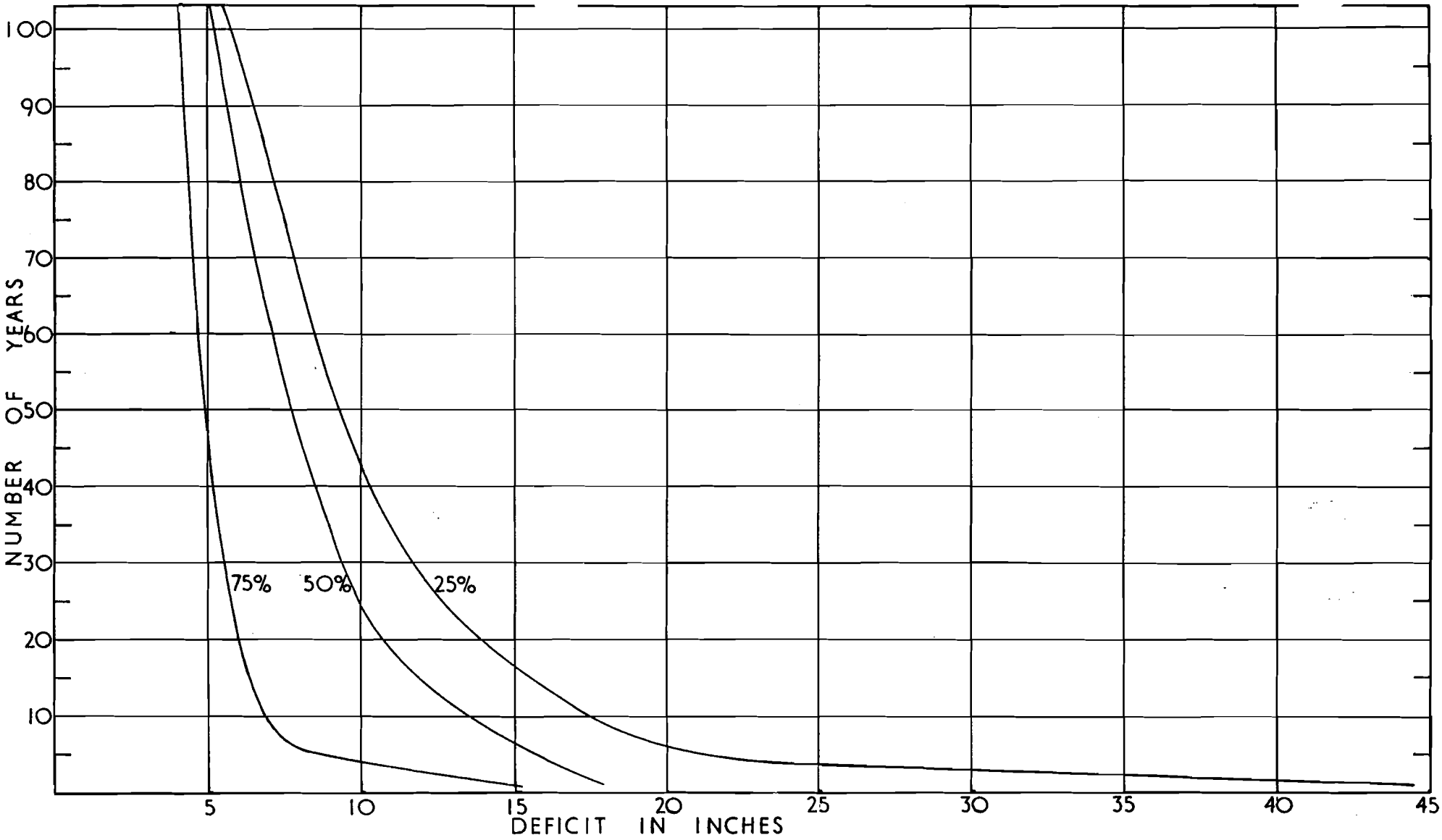

FIGURE 9. Ogives of Rainfall Deficits of at least 25%, 50% and 75% Intensity observed in 103 years.

Frequency	Deficits in Inches with Intensity of		
	25%	50%	75%
Once in 1 year	5.3	5.1	4.0
Once in 2 years	9.1	7.5	4.9
Once in 3 years	11.0	9.0	5.3
Once in 5 years	13.8	10.5	5.9
Once in 10 years	17.2	13.4	6.8
Once in 20 years	20.5	15.3	8.4
Once in 30 years	25.8	16.2	11.3
Once in 50 years	35.0	16.8	13.4
Once in 100 years	44.4	17.8	14.9

TABLE 34. Maximum deficits to be expected.

14. VARIATION OF RAINFALL WITH WIND DIRECTION

The rainfall has been correlated with wind direction for the 6 years since 1949 for which hourly rainfall and hourly wind values are available, and the results are tabulated in Tables 35 and 36.

Table 35 shows the percentage of the total rain each month which fell with wind from each of the 8 cardinal directions.

It is seen that over the year, three-quarters of the rain falls with winds between south-east, south and west, with one-quarter each from south and south-west. Least rain falls with northerly winds which give only one-twentyfifth

	N	NE	E	SE	S	SW	W	NW
January	4	8	6	4	16	38	16	8
February	9	2	6	2	21	26	24	9
March	2	2	2	10	17	24	32	10
April	7	4	2	7	29	29	12	10
May	1	6	6	25	25	20	10	6
June	9	1	11	6	47	22	3	1
July	6	6	3	9	25	32	12	7
August	1	10	11	17	20	27	10	6
September	5	8	10	17	28	18	9	7
October	4	18	18	17	21	13	3	6
November	5	4	5	21	35	13	11	5
December	4	3	20	3	21	26	18	6
Year	4	7	9	12	25	23	12	7

TABLE 35. Percentage of total rain which falls with wind from directions stated.

of all rain and in no month does as much as 10% of the rain fall with a northerly wind. Over the year North-easterly and North-westerly each give only 7% of the total rain with North-easterly giving more in Autumn and North-westerly more in Spring.

The greatest falls are with south or south-west winds in each month except March, when the maximum amount falls with west winds. The smallest falls are with north, north-east or east winds in every month except October. when west gives 1% less than north.

In all months the wind direction which gives most rain gives many times as much as the wind direction which gives the least amount. The ratio of the amounts varies from 6 to 7 times in September and October to 11 or more in every month from February to August.

The greatest concentration with direction is in June when almost half the rain falls with a southerly wind and 70% with southerly and south-westerly, while north-easterly and north-westerly each give only 1%. October has rain most widely distributed with wind direction and receives 17% or more of its fall with each of north-east, east, south-east and south winds and 13% with south-westerly.

In general winds from a southerly quarter bring most of the rain at all seasons of the year and winds from the north quarter the least. This is because in summer most rain develops from convection in the prevailing southerly wind flow while in winter the rain falls ahead of the fronts advancing across Bermuda from the west. Winds from the west quadrant give most rain in February and March when fronts are most intense and often follow close behind one another with mainly west or south-west winds between. The east quadrant gives only a small amount of the total rain in winter and is chiefly important in autumn. This is due mainly to the fact that fronts are more likely at this season than any other to lie just south of Bermuda giving both easterly winds and rain but this is also the time of tropical storms which increase the percentage of rain with easterly winds.

Table 36 gives the probability that rain will fall with wind from each separate direction. It gives the number of rain hours in which wind was from each direction as a percentage of all the hours with that wind direction.

The probability of rain is greatest with a south-east wind in May, when rain falls on 18% of occasions. The next highest probability is 15% with north-east in October, south in February, south-west in August, and west in February. The lowest probability of 2% is with north in August, north-east in June, east in April, July and November, south-east in April and west in June.

In September and October the probability of rain is at least 7% with every wind direction while in July the probability does not exceed 7% with any direction. In every month, except July, there is at least one wind direction with which the probability of rain is 11% or more.

Over the year the probability of rain is lowest with north and east wind and greatest with north-east, south and south-west winds.

	N	NE	E	SE	S	SW	W	NW
January	5	9	7	6	8	14	12	10
February	10	6	11	4	15	9	15	7
March	3	11	9	14	9	8	12	8
April	5	8	2	2	8	11	6	6
May	3	10	6	18	11	6	3	5
June	6	2	8	7	11	5	2	6
July	6	7	2	6	5	7	6	6
August	2	6	4	6	7	15	9	8
September	8	13	7	8	7	13	10	10
October	8	15	11	14	11	12	9	8
November	5	8	2	9	14	10	12	7
December	8	8	5	3	10	9	13	7
Year	6	10	6	8	9	9	8	7

TABLE 36. Probability of rain with wind from directions stated. Table gives percentage of total hours with each wind in which rain fell.

15. VARIATION WITHIN BERMUDA

As there are numerous occasions when rain falls in one part of the Islands and not at others, the question arises whether there is any local variation in the normal average rainfall.

In his Memorials of the Bermudas, Lefroy states that rainfall is greater at the west end than at the east, and also it is greater in "the central wooded district" than at either end. His views regarding the east and west ends were probably based on the observations at Ireland Island and St. George between 1852 and 1862 and as was stated earlier, it is probable that the two sets were not comparable.

In comparing the rainfall at two sites, it is essential that the rain gauges be exposed in a similar manner, at each site, and records from gauges set at the British standard 12 inches above ground level are not comparable with records of gauges set on a roof.

The records now available for St. George's between 1852 and 1869 contain two rainfall entries, one "On the Ground," the other "20 feet above Ground." During the 6 years, 1856-61, for which records are complete at St. George's and which can be compared with Ireland Island, the yearly totals at ground levels were respectively 107, 151, 98, 109, 103 and 93% of the totals at 20 feet. It seems, therefore, that except in one year the two gauges must have had similar exposures. However, during the 1866-69 observations when the gauges were presumably set up in a new site the ground level gauge averaged 53% more than the gauge at 20 feet and in no year was the ground level less than 35% more than the total at 20 feet. This range of difference is reasonable for the two exposures and also in these 4 years the ground level figures were within the normal range as found over the 100 years.

During the 1856-61 period, moreover, the "ground level" values at St. George's averaged only 42.16 inches per year, a value which is 20% lower than the driest 6 consecutive years anywhere else in the records and very little more than in the driest 2 years. Also, if the "20 feet above ground" figures for 1856-61 are increased by the ratio found in 1866-69 we get a value of 59.7 inches for ground level, well within the normal range.

During the 6 years, 1856-61, the annual falls at Ireland Island varied from 127% to 147% of the St. George's ground figures with a mean of 134%. The Ireland Island mean for the years of 57.08 is close to the accepted long period average.

It is concluded, therefore, that the St. George's ground level gauge from 1852 to 1862 did not have a standard exposure and its readings are not comparable with other locations. Hence the Ireland Island figures were adopted for these years.

For comparisons between different parts of Bermuda we have, therefore, only modern readings and the longest comparison is between the gauge at Fort George and that at Hamilton. The gauge at Fort George in on the western slope of the hill while that at Hamilton is on a roughly rectangular flat area, about 50 feet across, left by quarrying surrounding stone. It is not an ideal site but might be expected to give lower values rather than higher.

Simultaneous values are available for 9 years, between 1946 and 1957, and the mean values are given in Table 37. The average yearly fall was 56.19 inches at Hamilton and 54.59 inches at Fort George, most of this difference being in October, when Hamilton, with an average 8.10 inches had 1.29 inches more than Fort George. This difference was largely due to Octobers in 1946, 1947 and 1953 in each of which there was about 3 inches more at Hamilton than at Fort George.

	Hamilton 1946–56	Fort George 1946–56	Hamilton-Fort George	Belmont 1941–44	Fort George 1941–44	Belmont-Fort George
January	3.77	3.85	−.08	6.45	5.90	.55
February	2.97	3.17	−.20	6.22	5.96	.26
March	5.01	4.48	.53	4.68	3.95	.73
April	2.77	2.74	.03	3.66	3.86	− .20
May	4.67	4.58	.09	5.55	4.42	1.13
June	4.20	4.49	−.29	3.63	3.10	.53
July	4.36	4.63	−.27	4.02	5.02	−1.00
August	5.94	6.03	−.09	4.82	5.13	− .31
September	6.32	6.13	.19	6.78	8.43	−1.65
October	8.10	6.81	1.29	6.33	7.69	−1.36
November	3.74	3.63	.11	5.85	5.32	.53
December	4.34	4.05	.29	5.00	4.40	.60
Year	56.19	54.59	1.50	62.99	63.18	− .19

TABLE 37. Variation of fall within Bermuda.

Hamilton had the greatest fall in March on 8 occasions but the average difference was only 0.53 of an inch.

In the remaining 10 months the averages agreed within 0.30 of an inch being greater at Hamilton in five months and at Fort George in five months.

Of the whole 108 months the fall was greater at Hamilton in 63 months.

Another shorter comparison is available between Fort George and the observations taken from 1941 to 1946 at Belmont for 36 months and at Darrell's Island for 22 months.

In the Belmont series 11 months agreed with Fort George within 10%, while Belmont was greater in 15 months and Fort George in 10. The yearly means were 62.99 inches and 63.18 inches a close agreement.

The monthly means were greater at Fort George in April and July to October, with a maximum difference of 1.65 inch in September. In May Belmont averaged 1.13 inches above Fort George.

In the Darrell's Island series where the site was about a mile south-west of Belmont and close to sea level, the difference was less than 10% in 8 months, eater at Darrell's Island in 3, and greater at Fort George in 11. The yearly average was 5 inches greater at Fort George.

Throughout these comparisons there are many cases where heavy rainfalls were very local, giving daily totals of an inch or two more at one station than the other, with sometimes the heavy fall at one, and sometimes the other. The major differences are due to exceptional local falls on very few days. Consequently the evidence may be considered as showing that there is no difference as great as 5% between east, west and central parts.

Much longer comparisons are necessary before we could say conclusively that there is a local variation in rainfall, but perhaps the figures, in particular the Hamilton-St. George data, show that St. George has slightly more rain in summer and winter, and less in spring and autumn, giving Hamilton 1 to 2 inches more over the year.

16. LONG PERIOD VARIATIONS IN RAINFALL AND THE SUNSPOT CYCLE

Although the observations since 1852 have been at several sites, any local variation in average fall is very small, as was shown in Section 15 and the series may be regarded as one in so far as possible long period variations are concerned.

Figure 10 gives the departure of each individual year's fall from the accepted average of 57.64 inches. It shows that 4 out of the first 5 years were below average, while the next 4 years were all above. There was a very low fall in 1861 which made it the driest year in the whole period and in the following 10 years, which includes the missing years, only one year was above normal. The next 12 years to 1883 were irregular but with positive departures greater than negative. In 1884 a wet period set in so that for the next 23 years until 1906 only 3 years had less than the normal fall and the average for the 23 years was 63.3 inches. This was followed by a dry period lasting 18 years until 1924 in which only 5 years were above normal and the average was 54.0 inches. From 1925

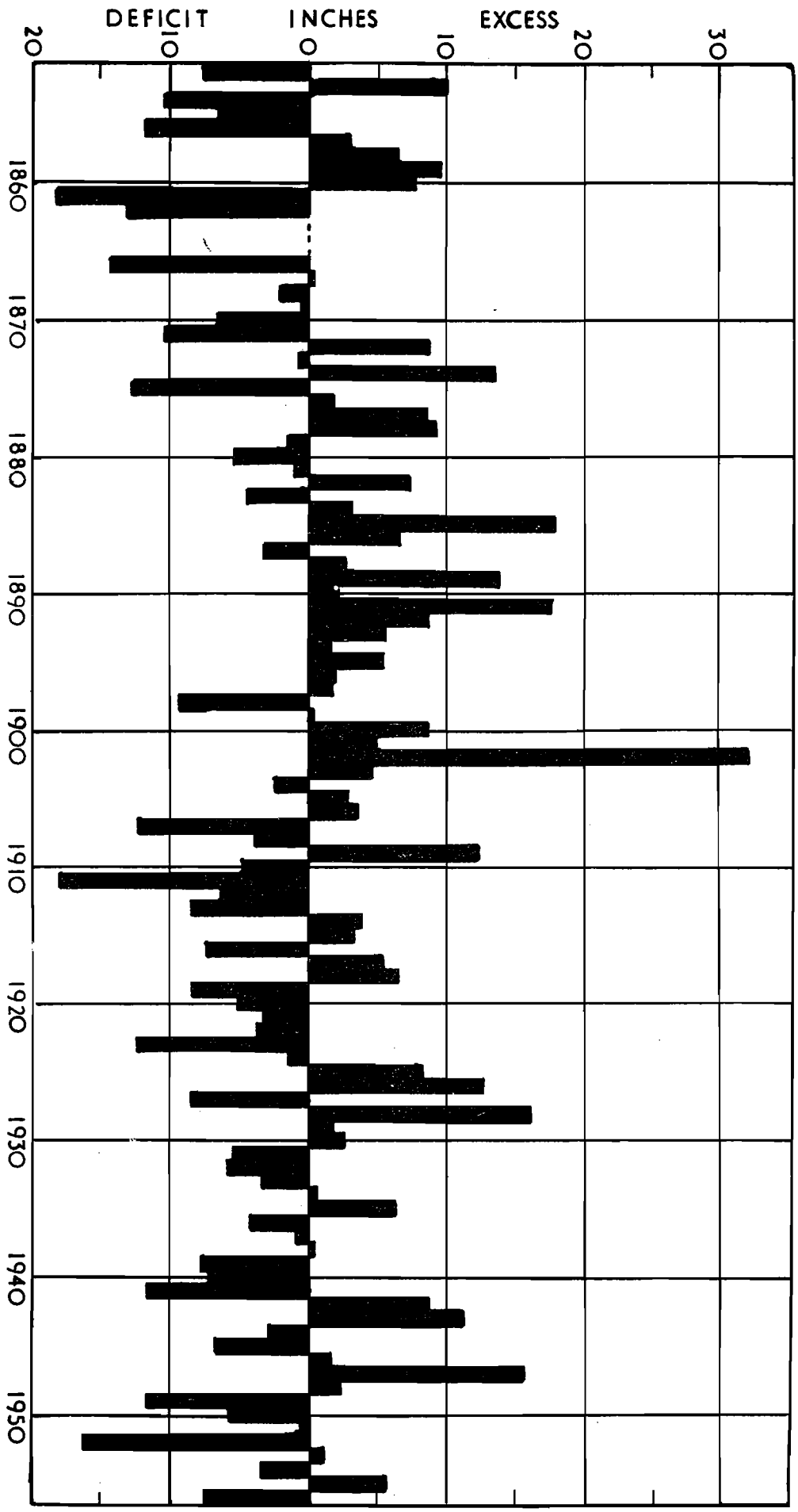

FIGURE 10. Departure of Rainfall in each year from the average of 57.64 inches for the whole period.

to 1930, 5 years were above normal and in the 11 years, 1931-1941, eight years were below and only one appreciably above normal. The following 7 years had 5 above normal while in the last 8 years of the record 6 years were below normal.

Figure 11 gives the running 10-year means as a percentage of 57.64 and also the median for each 10 years as a percentage of 57.50, the median for the whole period.

These curves each show two broad maxima, one from 1887 to 1905 and the other 1926 to 1947. The curves have similar shapes over these two periods with extreme points 13% above average in 1889 and 3% above average in 1930. There is a minimum from 7 to 9% below average about 1909 to 1916 and probably another minimum about ~~1876~~ 1866 when the 10-year mean was 9% and median 2 ~~3~~% below average.

Ten-year means of monthly rainfalls show that the form of the yearly curve in Figure 11 has been largely determined by April, May, June and October, each of which shows minima about 1866 and 1911-16, one maximum between 1886 and 1906 and except for October another maximum between 1924-32. July shows a well marked maximum 1882-86 due to over 19 inches in 1886 and less marked minimum 1906-16. December and January have signs of the the 1886 ıd 1897-1902 extremes but the winter months, December to March, do not show very regular variation. November shows a marked maximum 1881-86 which was due to very large falls in 1884 and 1885. September is the month least in phase with the yearly variation having minima in 1886 and 1931 when the year showed maxima and maxima in 1911 and 1946 when the year has minima.

While, therefore, the evidence of a regular long period variation of rainfall is not conclusive there are indications that 1951-55 is near the low point of an oscillation in yearly and in particular spring rainfall which has a period of about 40 years.

To determine any variation of Rainfall in phase with the sunspot cycle the mean annual rainfall was determined for the four sets of years at sunspot maxima and minima and when sunspot numbers were rising and falling from one to the other. At each epoch 2 or 3 years were taken as seemed most appropriate in view of the actual variations in sunspots.

Table 38 gives the results and shows that rainfall is least when sunspots are decreasing and greatest when sunspots are increasing or at a maximum. There is

Sunspot Number	Rainfall Per Cent Departure from Normal	Per Cent of Years with Rainfall		
		Above Normal	Below 50 Ins.	Above 65 Ins.
Decreasing	−3.7	36	32	18
Minimum	−0.1	50	19	23
Increasing	+4.5	58	0	21
Maximum	+3.3	70	15	20

TABLE 38. Variation of Annual Rainfall with Sunspot Cycle.

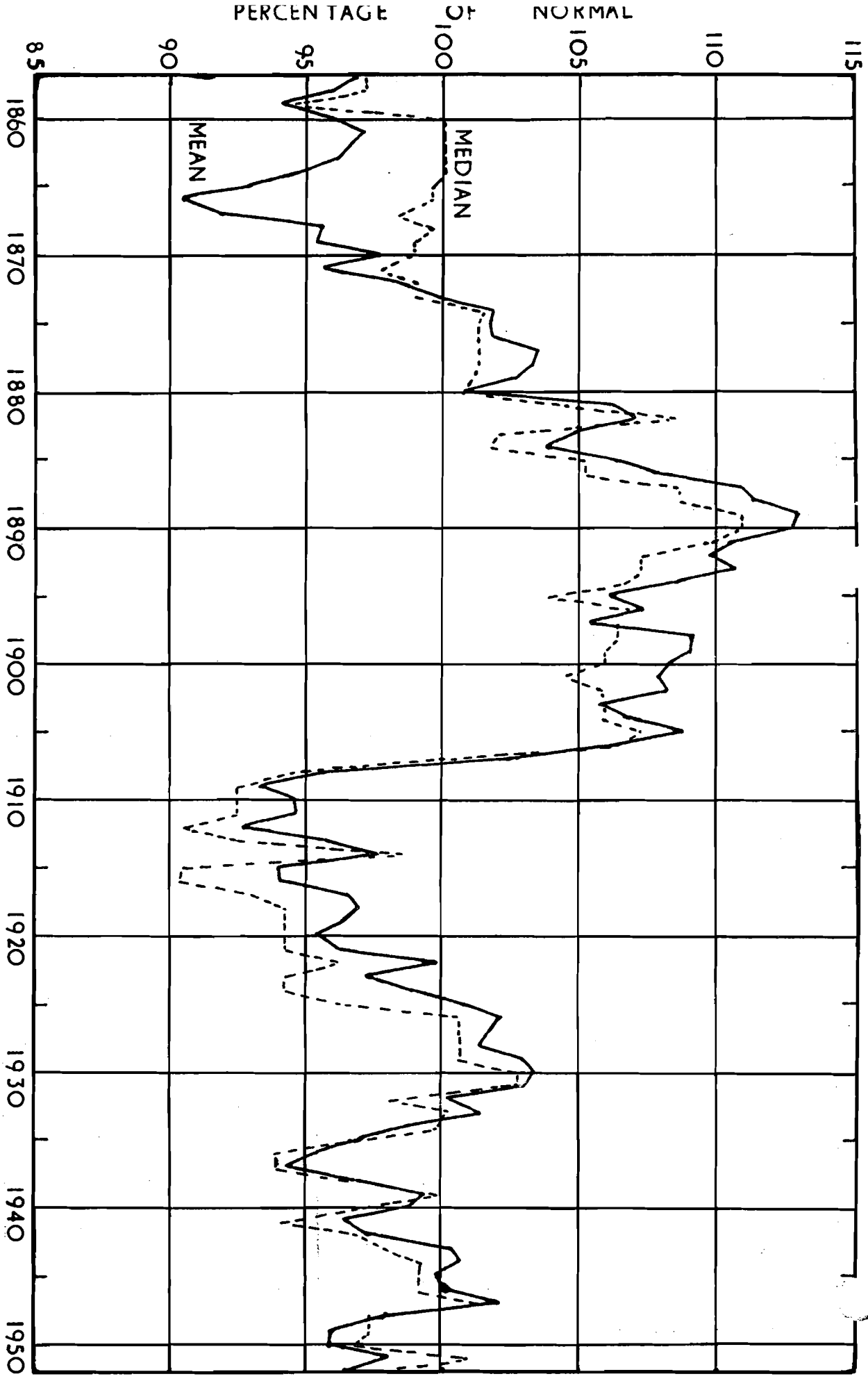

FIGURE 11. Ten year Means and Medians of Annual Rainfall. Figures are entered under sixth year of periods.

a range of 8% between the rainfall in the two cases. When sunspots are decreasing two-thirds of the years have less than normal rainfall while with sunspots increasing or at a maximum two-thirds of the years have more than normal rainfall.

The percentage of wet years does not show much variation through the cycle but when sunspots are decreasing one year in three is dry, with less than 50 inches rainfall, while when sunspots are increasing there were no years with less than 50 inches. Of the 25 major droughts listed in Table 31, 12 occurred at times of decreasing sunspots, 6 at sunspot minima and only 2 at times of increasing sunspots.

The data was also examined to see if any greater correlation than above existed with the double sunspot cycle, by taking means at alternate sunspot maxima and minima, etc.

These rainfall observations were begun at a time of decreasing sunspot numbers with a sunspot minimum in 1856 followed by a maximum in 1860. The rainfall data for the alternate sunspot minima, etc., beginning with these years are entered in Table 39 under Dec A, Min A, etc., while Dec B, Min B, etc.,

Sunspot Number	Rainfall Per Cent Departure from Normal	Per Cent of Years with Rainfall		
		Above Normal	Below 50 Ins.	Above 65 Ins.
Dec A	−3.7	37	37	19
Min A	+5.0	54	15	40
Inc A	+4.4	64	0	18
Max A	+5.4	75	17	33
Dec B	−3.8	33	25	17
Min B	−5.2	46	23	8
Inc B	+4.7	50	0	25
Max B	+0.3	63	13	0

TABLE 39. Variation of Annual Rainfall with Double Sunspot Cycle. Series A alternate cycles beginning with 1852-60. Series B alternate cycles beginning with 1861-71.

apply to the alternate series beginning with the decrease from 1862-65. The table shows that rainfall was below normal with both series of decreasing sunspots and above normal with both series of increasing sunspots the differences being of the same magnitude as in Table 38. However, the means of rainfall at the two sets of sunspot maxima do not agree nor do the means at the two sets of sunspot minima. The years at the two sets of sunspot minima give rainfall departures of equal magnitude but opposite sign while of the two sets of sunspot maxima, the one gives an increase in rainfall and the second close to normal values.

This analysis, therefore, shows a broad maximum of rainfall covering the first sunspot minimum and maximum and the years between, i.e. the series of which the 1944 Minimum and 1947 Maximum are the latest.

There is a narrower maximum in the alternate series of increasing sunspot numbers of which this present year, 1957, is the latest The rainfall minimum

occurs with the second set of decreasing sunspots and immediately following minimum of which the 1954 minimum is the most recent There is a subsidiary minimum with the first period of decreasing sunspots.

The winter temperature at Stockholm, Sweden, has been correlated with the double sunspot cycle by Simojoki (Geophysica, Vo 6, p25) and he found that the two series of sunspot minima gave departures of opposite sign while one series of sunspot maxima gave an appreciable departure and the other almost average values. These are the effects shown in Bermuda rainfall. However, while lower temperatures at Stockholm occur with higher rain in Bermuda and higher temperatures with lower rainfall in the two series of sunspot minima, with the sunspot maxima lower Stockholm temperature occurs with lower Bermuda rainfall.

The yearly rainfall was also analysed over a quadruple sunspot cycle which would approximate to the major cycle of 40 to 45 years shown in Figure II The results showed that the highest falls with mean 12% above normal occurred at the periods of rising sunspot numbers centered 1891 and 1935 and the lowest falls with the periods of decreasing sunspots and sunspot minima 1861-67, 1908-13 and 1951-54, when the mean rainfall was 12% below normal.

There is, therefore, reasonable evidence that annual rainfall varies wit' sunspot numbers being greater when the number of sunspots is increasing an lower when the number is decreasing with a greater variation extending over four sunspot cycles. The long period minimum having passed in 1954-55 the trend of rainfall will be upward during the next two sunspot cycles until the period of increasing sunspot numbers immediately before the sunspot maximum which may be expected about 1980.

17. WATER SUPPLY

Using the data above we may deduce the requirements of a water supply system in Bermuda as regards catchment and storage capacity.

The volume of fresh water needed daily is determined by the operations of the particular user. In a home this depends mainly on the amount used for flushing and baths and more care will be taken over conservation during dry periods so that the daily rate of use is lowered. It is certain that the average rate of consumption in a Bermuda home is much smaller than in many other countries which are less water conscious and water is piped to the houses from a public supply. After discussion with many persons concerned in such matters it is concluded that 20 gallons per person per day is a generous allowance in Bermuda so that with an average household of 5 persons the requirement is 100 gallons. We, therefore, consider the catchment and storage necessary to give 100 gallons a day throughout the year.

The size of tank and area of catchment are interdependent, for the greater the area of catchment, the smaller the storage necessary, so long as the catchment is large enough to collect the required volume with the rainfall expected.

The area of catchment necessary is directly proportional to the average rainfall which it is considered desirable to rely on. Thus to average 100 gallons per day we would need 1,219 square feet with 57.64 inches a year and with 3 inches, the driest 12 months on record, we need 2,268 square feet.

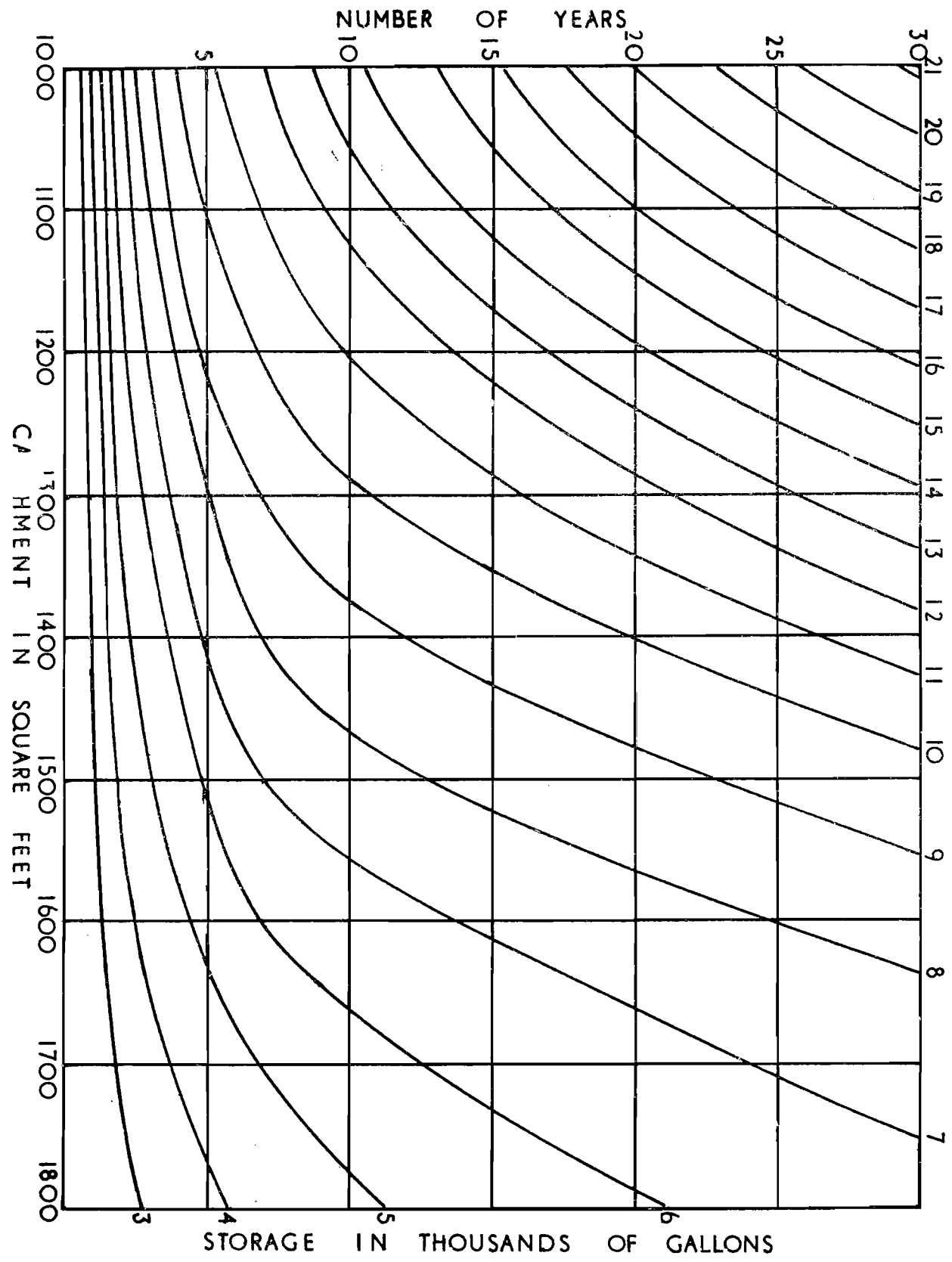

FIGURE 12. Rain Catchment and Water Storage needed to cover the maximum shortages expected in periods of 1 to 30 years when 100 gallons is used daily.

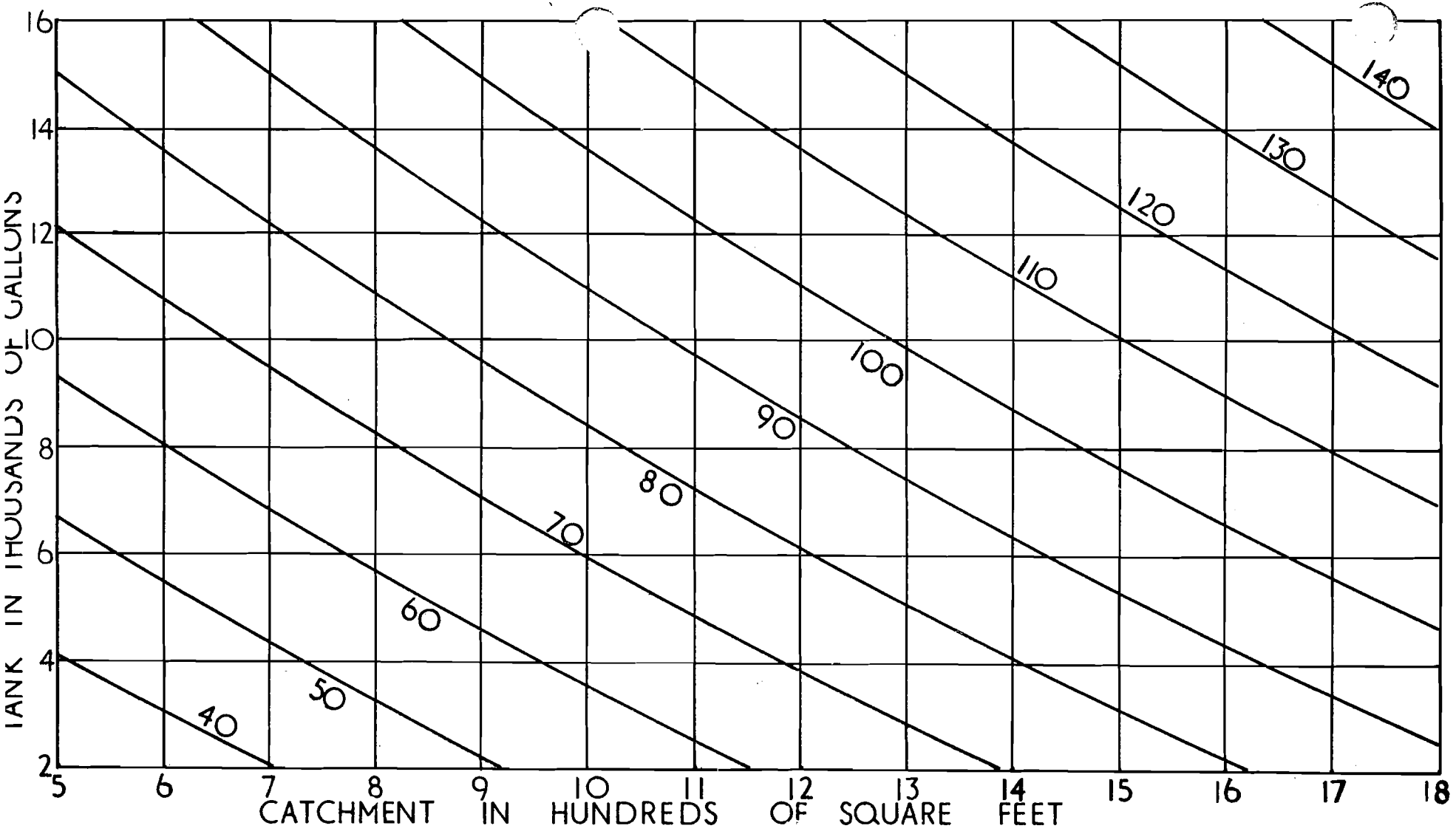

FIGURE 13. Maximum Daily consumption in gallons which is possible with stated Catchment Area and Tank Capacity if shortages are not to be more frequent than once in ten years.

The storage depends on the area of the catchment and on the maximum deficit for which we have to provide. This deficit will itself depend directly upon the rainfall for which calculations are made, decreasing as the estimated rate of rainfall decreases and hence the deficit varies inversely as the catchment.

The average annual fall of 57.64 inches is the greatest amount which it can be planned to use over an extended period and to do this requires a catchment of 1,219 square feet as stated above, and storage to meet the deficits discussed in Section 13. For the deficits listed in Table 34 and a catchment of 1,219 square feet it is seen that a storage of 4,026 gallons will meet the deficit of 5.3 inches rainfall to be expected every year while 13,067 gallons is needed to cover the 10 yearly maximum deficit and 33,730 gallons to meet the extreme occurring once a century.

Usually it will be preferred to provide a larger catchment which would give the required supply with less than average fall and in this case as the deficits will be smaller, the storage needed will also be smaller.

To enable comparisons to determine the most satisfactory combination of catchment and storage, the deficits in section 13 with 25% intensity were recalculated as they would be with different annual rates of use in inches of rainfall. The rates of annual rainfall were selected as the ones which would require catchments of the even areas 1,000, 1,200, etc., square feet to give 100 gallons per day. From the set of deficits for each rate of rainfall a frequency table such as Table 34 was determined up to a limit of 30 years as it is unlikely that it would be economic to provide for less frequent deficits. The data was then plotted in Fig. 12 which gives the combinations of catchment and storage which will cover the maximum deficits to be expected in 1 to 30 years when 100 gallons are used per day.

The curves show that the maximum deficit to be expected increases rapidly at first with the length of period considered but the rate of increase decreases and is fairly steady after 10 years. It appears, therefore, that for many purposes it would be satisfactory to design the water system to cope with the maximum deficit normally experienced in 10 years.

From Fig. 12 we can deduce the maximum daily consumption which is possible with specified catchment and storage if a shortage is not to occur more often than once in 10 years, and these rates are given in Fig. 13. The figure shows that with 500 square feet catchment and a tank of 2,000 gallons only 30 gallons a day is available while with 1,800 square feet catchment and 16,000 gallons storage the use of 150 gallons a day will not give a shortage more often than once in ten years.

Meteorological Office,
Hamilton
Bermuda.
October, 1957.

APPENDIX **AVERAGES FOR 30 YEARS 1901 TO 1930.**

	Average Fall		Average Number of Raindays
	Inches	Mms.	
January	4.58	116.3	15.8
February	4.78	121.4	15.1
March	4.63	117.6	14.3
April	4.41	112.0	10.9
May	4.07	103.4	10.3
June	4.50	114.3	10.6
July	3.56	90.4	12.6
August	5.96	151.4	15.2
September	5.23	132.8	13.4
October	6.20	157.5	14.2
November	5.11	129.8	14.5
December	4.97	126.2	15.9
Year	58.00	1473.2	164.8