R.O.T.M. 2

ROYAL OBSERVATORY, HONG KONG.

A STATISTICAL SURVEY OF HONG KONG RAINFALL

By

L. STARBUCK, B.Sc. (Lond.), A.U.C.N., F.Inst.P., F.R.Met.S.

Assistant Director.

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FOREWORD

Water shortage in Hong Kong is annually a matter of some concern if not actual danger. The present survey of the Colony's rainfall is designed to give the maximum information in as concise a form as possible. Emphasis has deliberately been placed on diagrammatic representation for easy reference.

My acknowledgments are gratefully tendered to numerous observers of the staff of the Royal Observatory, who through the years have kept careful and complete records, and to the Director, Mr. G.S.P. Heywood, for much encouragement in connection with a not inconsiderable amount of "donkey-work" upon which this analysis is necessarily based.

L. STARBUCK

A STATISTICAL SURVEY OF HONG KONG RAINFALL.

Sections

A STATISTICAL SURVEY OF HONG KONG RAINFALL.

1. SOURCES OF INFORMATION.

For the period 1853 to 1883, that is before the foundation of the Observatory, the results were collected from various reports in the Colony and Observatory library records containing observations made by several different institutions. It is believed that their values are approximately applicable to the later Observatory determinations, and they are included here for interest and completeness. The values for the period of the Japanese occupation of Hong Kong, 1941 to 1945, were compiled from records made at Shum Shui Po and Argyle Street Prisoner-of-War Camps and again can only be considered as approximate. Statistical determinations have therefore been confined to the 55 year period 1884 to 1938, the records of which were all made at the Observatory under similar conditions.

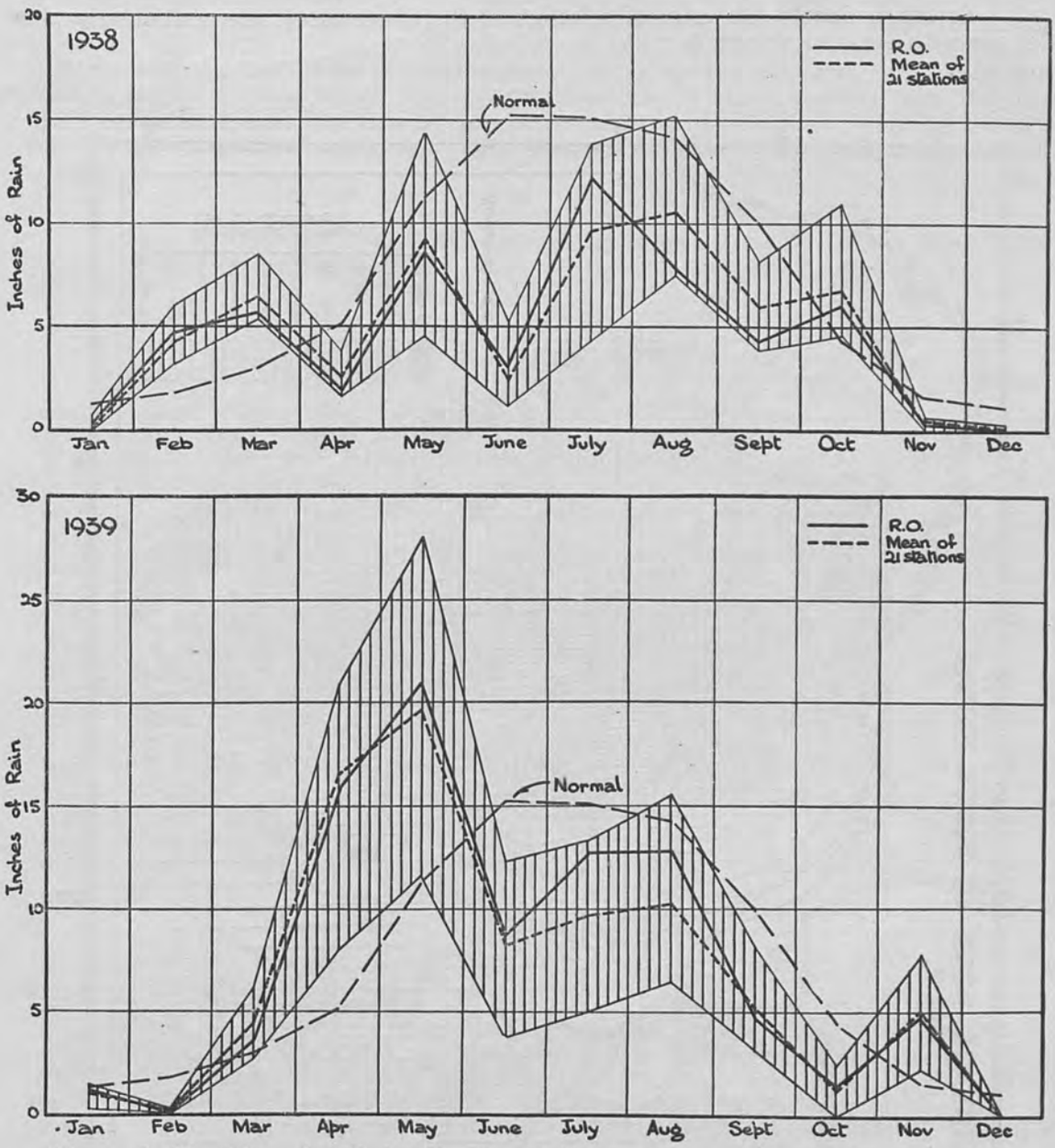


Figure 1. Monthly rainfall for the Royal Observatory and Mean, Maximum and Minimum values for 21 rain-recording stations.

2. APPLICABILITY OF THE DETERMINATIONS.

A comparison of monthly returns from the pre-war rainfall stations of Hong Kong shows that wide variations in the amount of rain occur within the Colony limits. The returns also show, however, that the Observatory values represent a fair average of all the amounts. Of four rain-recording stations operating from 1914 to 1929, the Observatory values were never more than 10% different from the mean of all the stations except on one occasion (1919, 12.9% low). The overall percentage from the

mean was less than 3% (low). Of five stations operating from 1930 to 1939, the average deviation from the mean was only 2%, and of 21 stations operating in the years 1938 and 1939, the difference was less than 1% from the mean value (low). It seems fair to suppose therefore that the Observatory records do not differ by more than $2\frac{1}{2}$% from the mean of widely spread stations, and the Observatory figures can be taken as representative of the Colony's rainfall to that approximation. To illustrate how closely the Observatory figures give a representative value, the actual monthly amounts for the two years 1938 and 1939, when there were 21 stations in operation, are plotted in Figure 1 together with the maximum and minimum values from all the stations. It will be seen that the Observatory figures follow the mean curve remarkably closely and everywhere fall within the area bounded by the maximum and minimum curves. In general, the reservoir gauges record rather more rainfall than does the Observatory gauge, so that any discrepancy is definitely on the right side, i.e. the present survey tends to underestimate rather than overestimate actual quantities of rain effective in maintaining the water supply.

Credit is due to the original selectors of the Observatory site, particularly in a district with such an uneven terrain.

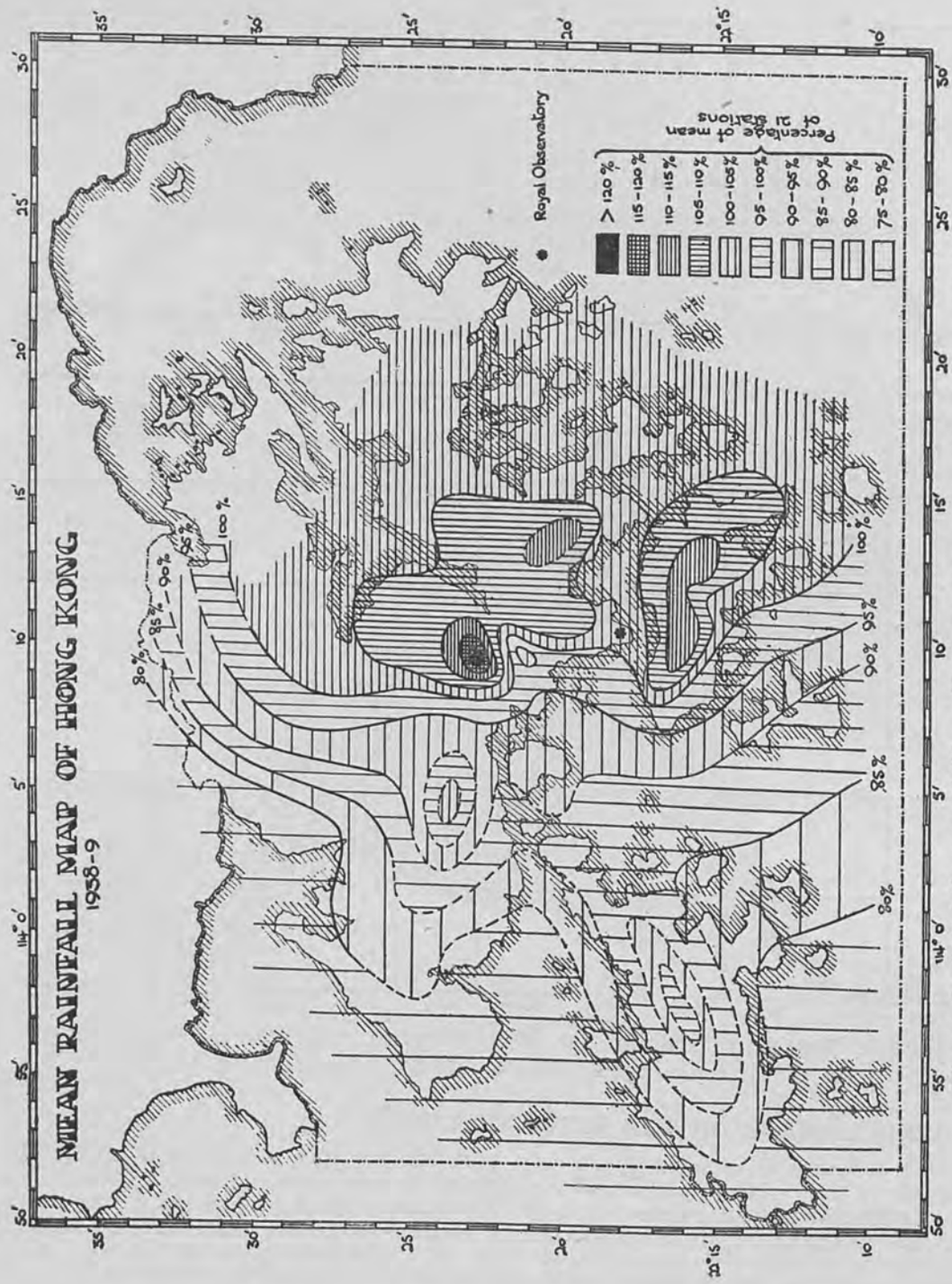


Figure 2. Rainfall map of Hong Kong based on 21 rain-recording stations.

3. DISTRIBUTION OF RAINFALL.

Unfortunately an adequate network of rain-recording stations was not in operation for a sufficient period of time for a mean rainfall map of the Colony to be drawn up. However, a mean map for the years 1938-9, when there were 21 stations recording rainfall, is included here in Figure 2 for interest and because it is probable that even on two years' observations the main features of rainfall distribution are evident. Where the extrapolations are doubtful owing to paucity of records the percentage lines are broken. A true picture of rainfall conditions over the Colony would undoubtedly show greater detail in the matter of small dry or wet areas.

As would be expected in a territory where orographic rain plays an important part, the hill stations have high rainfall. The other major feature of the map is that the east side of the Colony is generally wetter than the west. The prevailing wind direction for the whole year is easterly, and by far the most predominant direction of typhoon winds is also easterly. At first sight it might be supposed that stations with a southern exposure would have high rainfall. That they do not is a fair indication of the frequent interruptions of the southerly monsoon during the summer and the fact that rainfall resulting from tropical storms occurs by far the most frequently with easterly winds in Hong Kong. Finally, for moderate or heavy summer rain, the most likely pressure distribution is a low pressure area over the Gulf of Tongking giving a fairly marked pressure gradient WSW from the Colony and consequently easterly winds.

Listed in order of annual amounts the stations appear as in the table below. These amounts, expressed as percentages of the mean of the 21 stations, are given alongside.

Station	*Percentage of Mean*		*Average*
	1938	*1939*	
1. Shing Mun No. 1. (Water Works)	120.0	133.1	126.5
2. Shing Mun No. 2. (Water Works)	117.0	116.2	116.6
3. Tytam (Water Works)	112.8	118.5	115.7
4. Wong Nei Chong (Water Works)	111.3	109.4	110.3
5. Victoria Peak	104.4	110.3	107.3
6. Kowloon Reservoir (Water Works)	101.0	110.4	105.7
7. Tytam Tuk (Water Works)	106.2	104.4	105.3
8. Tai Po (Police Station)	104.1	105.3	104.7
9. Sai Kung (Police Station)	102.8	105.7	104.3
10. Botanical Gardens	97.6	106.0	101.8
11. **Royal Observatory**	94.0	106.4	100.2
12. Shing Mun No. 3. (Water Works)	103.0	97.0	100.0
13. Aberdeen (Water Works)	102.0	97.9	99.9
14. Fanling (R.H.K. Golf Club)	109.0	85.4	97.2
15. Pokfulam (Water Works)	97.3	91.6	94.5
16. Shek Li Pui (Water Works)	88.7	99.0	93.9
17. Mount Kellett (Matilda Hospital)	90.3	92.1	91.2
18. Ping Shan (Police Station)	88.1	77.3	82.7
19. Cheung Chau (Police Station)	85.3	79.5	82.4
20. Un Long (Water Works)	84.0	76.5	80.3
21. Lok Ma Chau (Police Station)	81.2	77.8	79.5

4. ANNUAL RAINFALL.

Annual amounts of the rainfall in Hong Kong for the period 1853 to 1948 are represented in Figure 3. The amounts vary widely from a record low of 45.8 inches in 1895 to a record high of 119.7 inches in 1888, i.e. 54% and 142% of the normal amount (84.26 inches) respectively. If the annual amounts be twice Bloxamised* on ten-year periods, a fairly symmetrical curve emerges with definite peaks at 1889 and 1922, i.e. separated by 33 years. Curve fitting has frequently proved a doubtful procedure with meteorological elements, but it is significant that the ten wettest years of the 55-year period all fell within 5 years of these two dates, five between 1885 and 1894 and five between 1918 and 1927. On this basis the period 1950-1960 should contain several (about 5) very wet years.

**Bloxamisation*—a method of "smoothing" frequently used with scattered values in climatology in order to reveal possible periodic or cyclic changes. Running means of ten consecutive years, *e.g.* 1884-1893, 1885-1894, 1886-1895 and so on, were first calculated, and the means subjected to the same process to give running means of the consecutive means.

Twice Bloxamised values of Macao's annual rainfall for 40 years, and of Swatow's annual rainfall for 55 years are plotted in the same diagram for comparison. Macao has a normal rainfall of 68.92 inches (81.8% of Hong Kong's normal) and Swatow has 58.55 inches (69.5% of Hong Kong's normal). Hong Kong's greater rainfall, probably due to the mountainous nature of its territory, is an important factor for water supply in so densely populated a district. The Swatow curve shows a remarkably similar trend to that of Hong Kong, but out of phase by about 7 years. The Macao curve is similarly out of phase and also appears to have a shorter period, but the time interval is insufficiently long to allow theorising on what may be a mere coincidence.

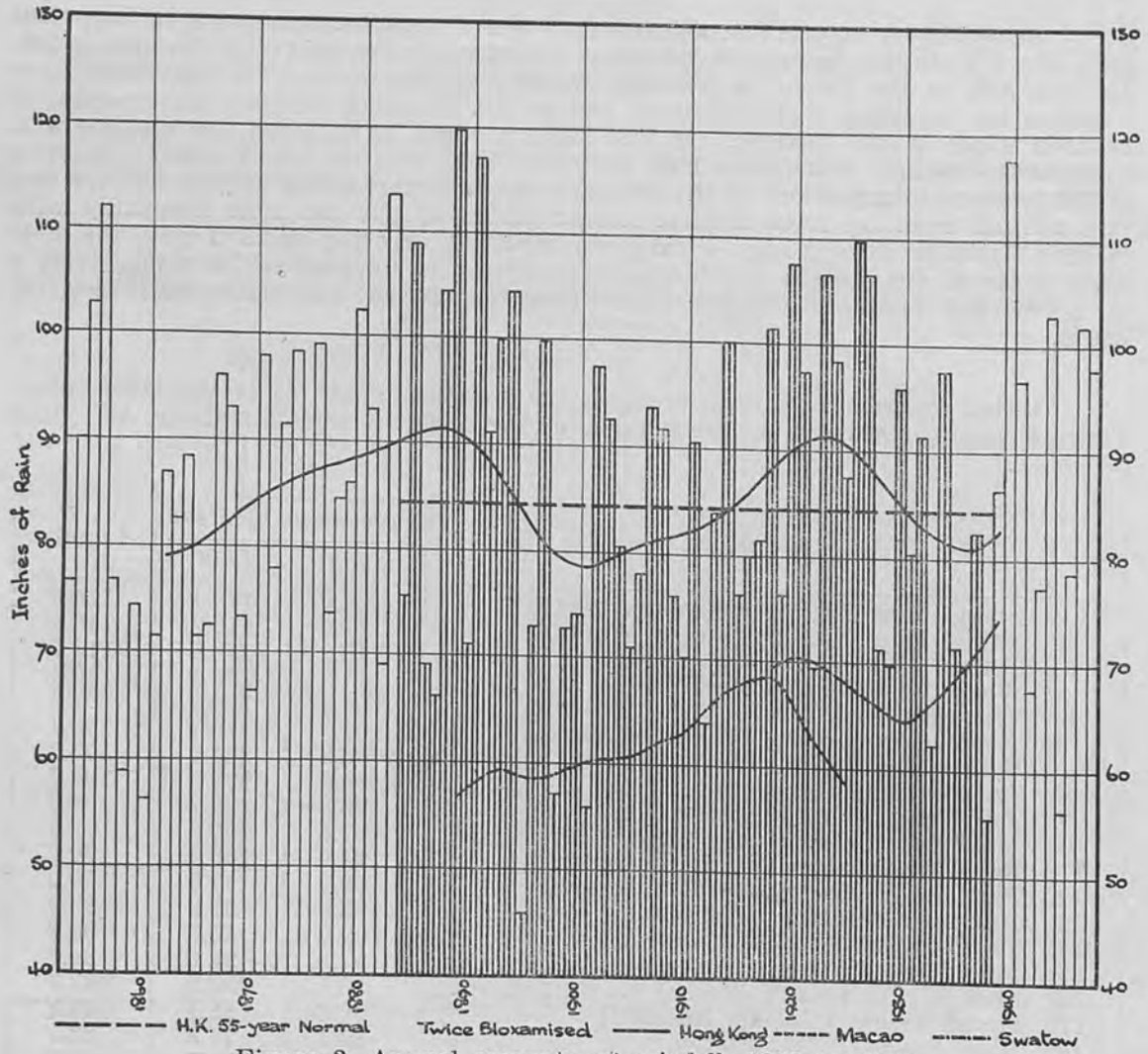


Figure 3. Annual amounts of rainfall, 1853 to 1948.

5. FREQUENCIES OF ANNUAL VALUES.

Frequency curves of the distribution of the annual values about the mean are drawn in Figure 4. The actual annual amounts are plotted separately below the graphs as percentage deviations from normal. The three rows of figures at the base of the diagram give the numbers of annual values falling in successive ranges of $2\frac{1}{2}$%, 5%, and 10%, the central range being symmetrical about the normal value in each case. The curves show a remarkable double maximum of equal value and approximately equally spaced at 20% above and below the normal. The probability that rainfall for any year will be 15-25% below or above normal is almost twice as high as the probability that within 5% of the normal amount of rain will fall. The divergence of probabilities for smaller ranges of percentages is even more impressive. This is important from the point of view of the Colony's water supply. In above-normal years a considerable amount of additional water, the greater part of it occurring in the form of heavy rain, is lost in overflow from the reservoirs. Moreover, only 25 years registered more than normal rainfall against 30 years below normal, so that for every 5 wet years there are on average 6 dry years. On this argument it would appear preferable to use 20% less than the statistical normal value as a basis for computing water supply, i.e. 67 inches rather than 84 inches per year.

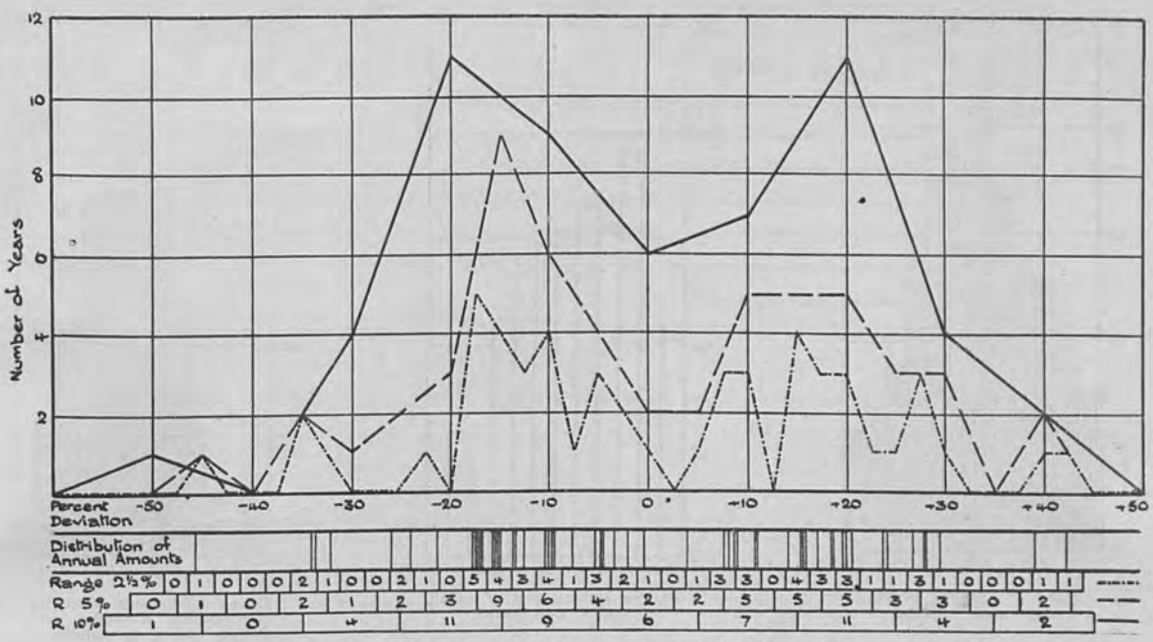


Figure 4. Frequencies of annual amounts of Hong Kong rainfall.

6. MONTHLY RAINFALL.

The climate of the Colony is characterised by hot, wet summers and cool, dry winters, the major influences being a southerly monsoon in the summer which, however, is very frequently interrupted, and a much more consistent northeast monsoon in winter. Mean monthly values of rainfall are given in Figure 5 together with the absolute maxima and the absolute minima recorded for each month. They range from a normal minimum of 1.09 inches in December to a normal maximum of 15.23 inches in June. The highest rainfall recorded in one calendar month was 48.84 inches, more than half the normal yearly total, in May 1889. It will be seen that May has the largest proportional variation of rainfall and July the smallest. Very wet Mays are not infrequent—434% of the normal amount fell in 1889—whereas either very dry or very wet Julys are rare. A complete absence of rain has never been recorded for the months March to October inclusive, but the minimum amounts for the months March, September and October are very small. More than half the annual rainfall on average falls during the three months June, July and August. Two-thirds of the annual fall occurs in the one-third of the year, May to August. About four-fifths of the annual rainfall is confined to the five-months period May to September, and nine-tenths to the seven-months period April to October. The percentage contributions of the wettest periods are given in Figure 6.

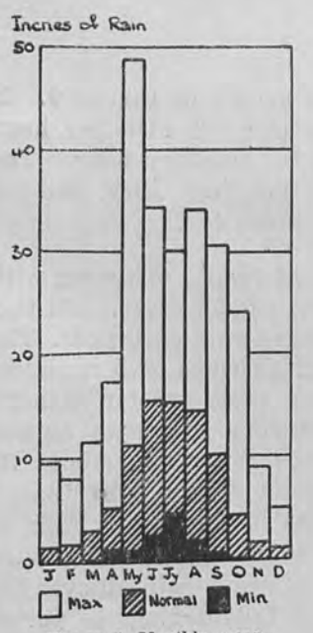
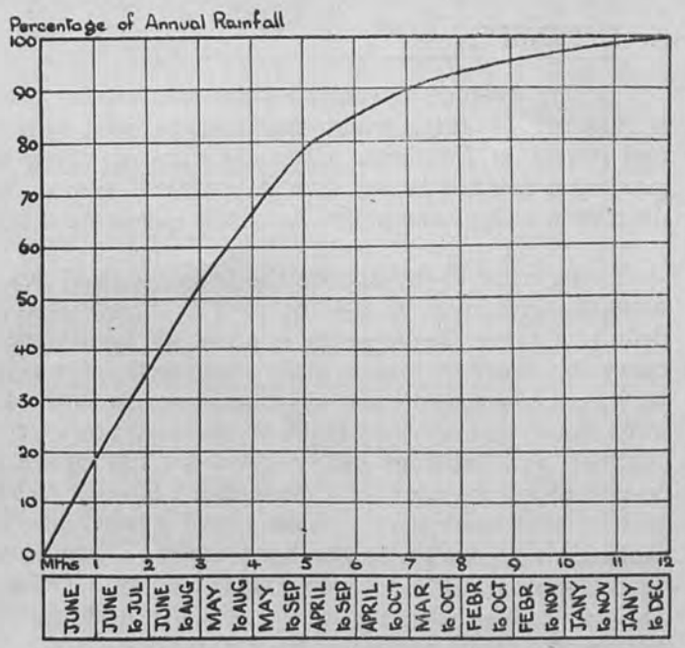


Figure 5. Monthly mean, absolute maximum and absolute minimum amounts of Hong Kong rainfall, 1884 to 1938.



Figue 6. Percentage contributions of the wettest periods for Hong Kong rainfall.

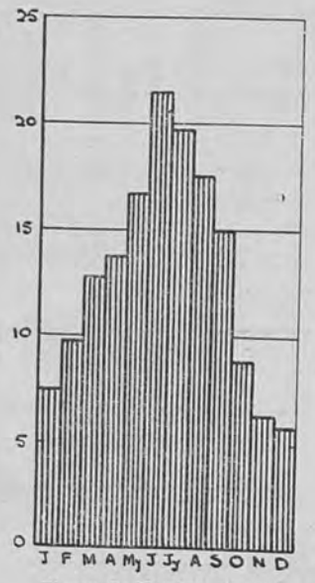


Figure 7. Number of rain days each month.

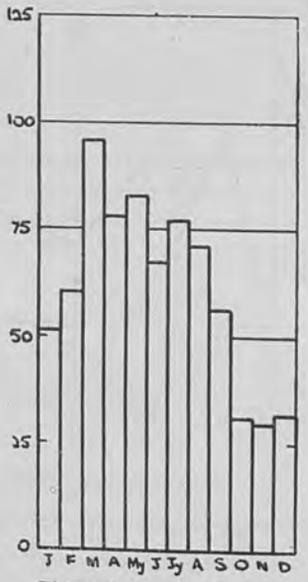


Figure 8. Duration of rain in hours per month.

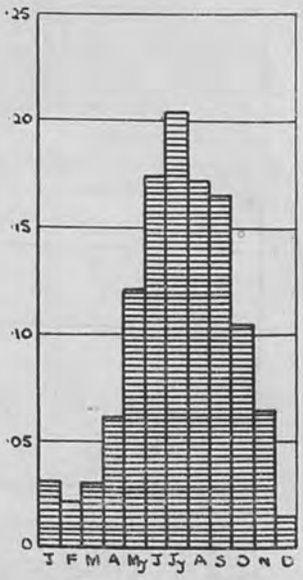


Figure 9. Average intensity of rainfall in inches per hour for each month.

7. RAIN DAYS.

The average number of days on which rain falls each month, excluding unregistered drizzle, are given in Figure 7, a maximum of 21.4 days occurs in June and a minimum of 5.8 in December. It will be seen that there are no reversals in the frequencies of rain days which increase regularly from the dry winter season to the wet summer season and decrease regularly, but more rapidly, back again.

8. DURATION OF RAIN.

Average durations of rain in hours per month are given for each month in Figure 8. The maximum occurs in March which has less than 1/5 of the amounts of rain for June or July, a good indication of the marked difference in the types of summer and winter rain in Hong Kong. A subsiduary minimum duration occurs in June which actually averages the maximum amount of rain for any month in Hong Kong. The transition from winter to summer types of rain undoubtedly accounts for the irregularity in monthly durations during late spring and early summer.

9. INTENSITY.

The average intensity of the rainfall for each month is shown in Figure 9. It is highest in July, when the average rate is a little more than 1/5 inch per hour and lowest in December when the rate averages less than 1/50 inch per hour. The maximum rainfall in one civil day, 21.025 inches, occurred on 19th July, 1926, and the maximum fall in one hour was 3.965 inches at 4 a.m. on the same day.

In order to investigate the frequencies of heavy rainfall, all hourly occasions with amounts in excess of 0.4 inches (10 mms.) were extracted for the 55 years. On this definition there are on average about 47 hourly occasions of heavy rain each year. The curve in Figure 10 was actually constructed for successive rainfall rates at 5 mms. intervals, i.e. greater than 10 mms./hour, greater than 15 mms/hour, greater than 20 mms/hour, and so on. It is so regular, however, that conversions to inches appear justified and rates in inches per hour are shown on the same diagram. About 33 hourly occasions each year have more than $\frac{1}{2}$ inch of rain; about 8 have more than 1 inch; 3 have more than $1\frac{1}{2}$ inches, and 1 has more than 2 inches in the hour. Falls of more than $2\frac{1}{2}$ inches in the hour occur on average only once in two years, and greater than 3 inches in the hour once in five years. The distribution of heavy rainfall over the various months (Figure 11) shows a maximum in June. Heavy falls during the period October to April inclusive are infrequent.

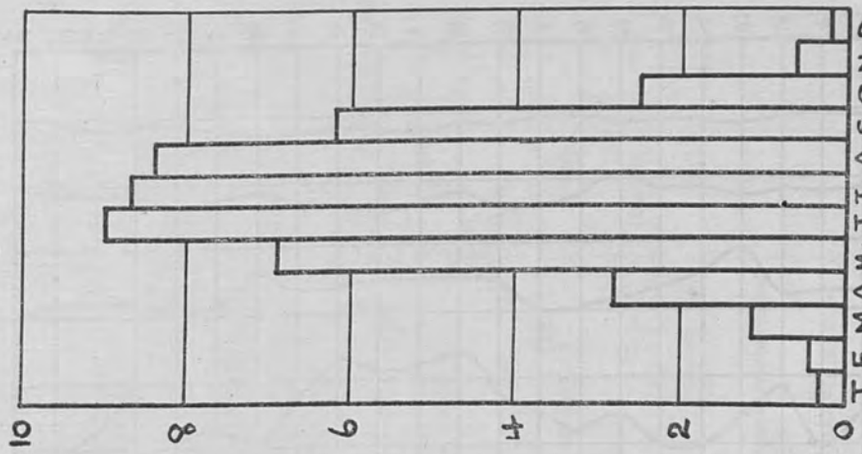


Figure 11. Average number of hourly occasions each month of "heavy" rainfall (rates in excess of 0.4"/hr.)

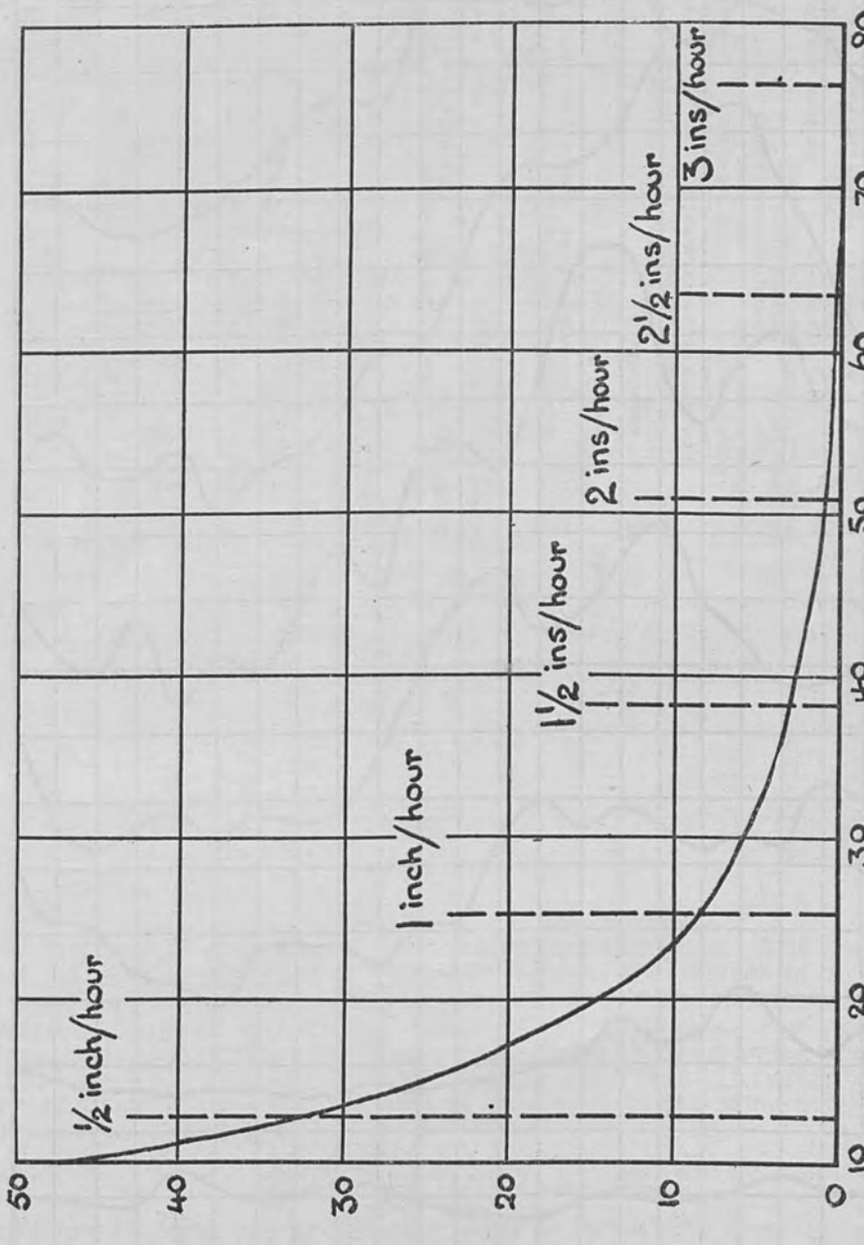


Figure 10. Average number of hourly occasions per year of rainfall rates in excess of the given values

10. DIURNAL VARIATION OF RAINFALL.

Diurnal variation of rainfall for each month of the year is shown in Figure 12. During the driest months there is little or no daily variation. On the other hand all the wet months are characterised by a predominance of morning rain, maximum frequency occurring about 8 or 9 a.m. This feature is most marked in June (the wettest month) after which the diurnal variation becomes progressively less marked until by November, there is little to choose between any of the daily periods.

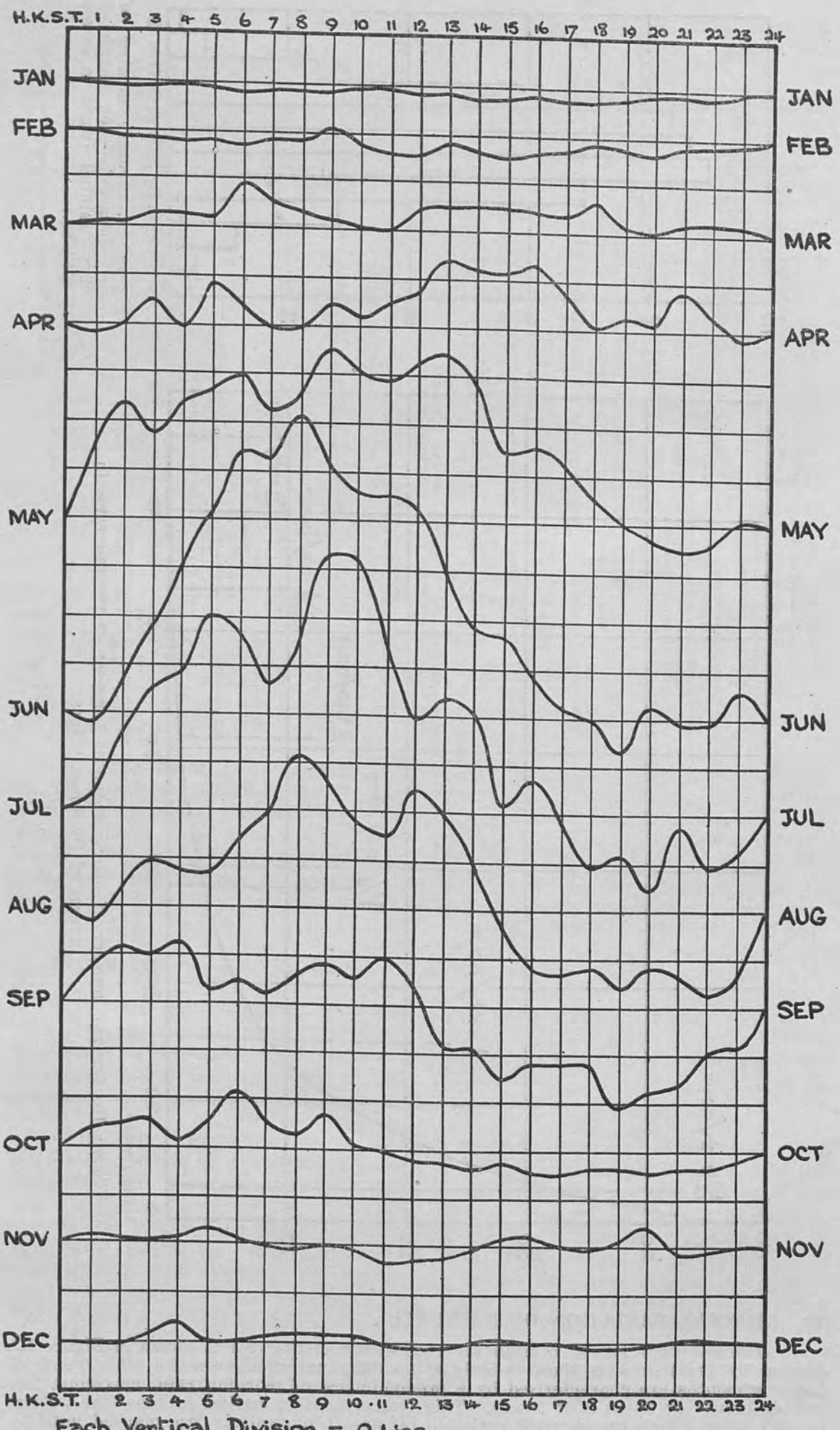


Figure 12. Diurnal variation of rainfall in Hong Kong for each month.

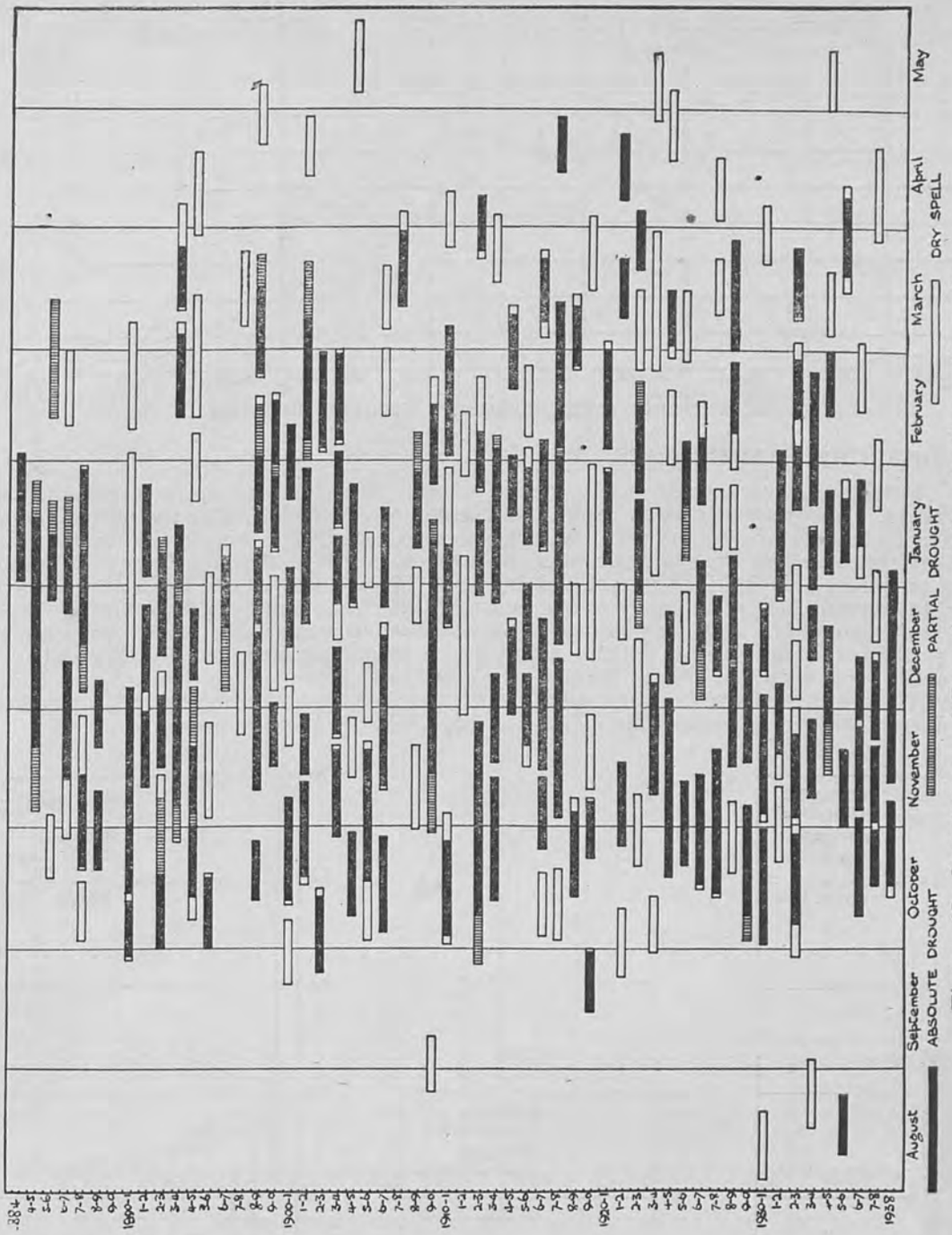


Figure 13. Occurrences of Droughts and Dry Spells in Hong Kong.

11. DROUGHTS.

The sharp fall after September on all four figures 5, 7, 8 and 9 demonstrates the relatively abrupt ending of the wet season in Hong Kong. It is also discernible in the changed slope of the curve in Figure 6 between the periods of 5 and 6 months. Since the Colony has a well-marked dry season, it is not surprising that droughts are of relatively frequent occurrence. The following analysis of drought occurrences is based on certain definitions which have been adopted for comparative statistical purposes. The definitions of Absolute and Partial Droughts were introduced in "British Rainfall" in 1887, and that of Dry Spell in the same publication in 1919. They are as follows:

Absolute Drought—a period of at least 15 consecutive days to none of which is credited .01 inch of rain or more.

Partial Drought —a period of at least 29 consecutive days, the mean daily rainfall of which does not exceed .01 inch.

Dry Spell —a period of at least 15 consecutive days to none of which is credited .04 inch of rain or more.

Occurrences of droughts and dry spells are shown in Figure 13. In the period 1884 to 1938 there were 144 absolute droughts, 50 partial droughts and 199 dry spells. Only one year of the 55 (1889) was entirely free from droughts or dry spells; it had the maximum annual rainfall of 119.7 inches. Only three years had no absolute droughts.

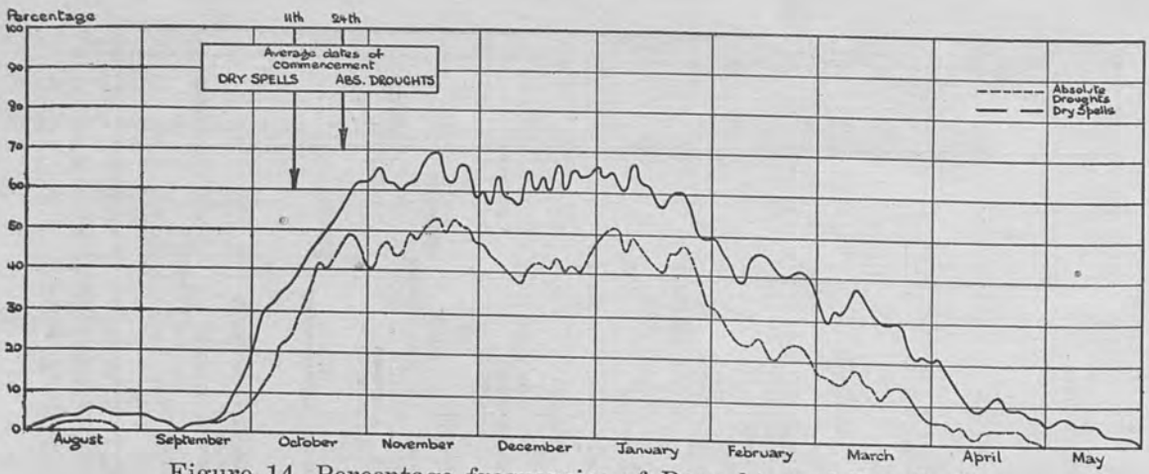


Figure 14. Percentage frequencies of Droughts and Dry Spells.

12. DROUGHT FREQUENCIES.

Percentage frequencies of occurrence of droughts and dry spells are shown in Figure 14. The frequency rises rapidly at the end of September. For the period end of October to middle of January, the chances are very nearly two to one that a dry spell is in progress, and for the same period chances are about even that the Colony is undergoing an absolute drought. Drought and dry spell frequencies fall off, much more slowly, from the second half of January to the end of May. June and July have been entirely free from droughts. Only one drought has occurred in August, in 1935. An isolated dry spell in July occurred in 1919. After the rainy season, only one drought and four dry spells have occurred before the end of September. The average date of commencement of the dry season's first dry spell is 11th October, and of droughts, 24th October. In general, the end of September marks the beginning of the dry season.

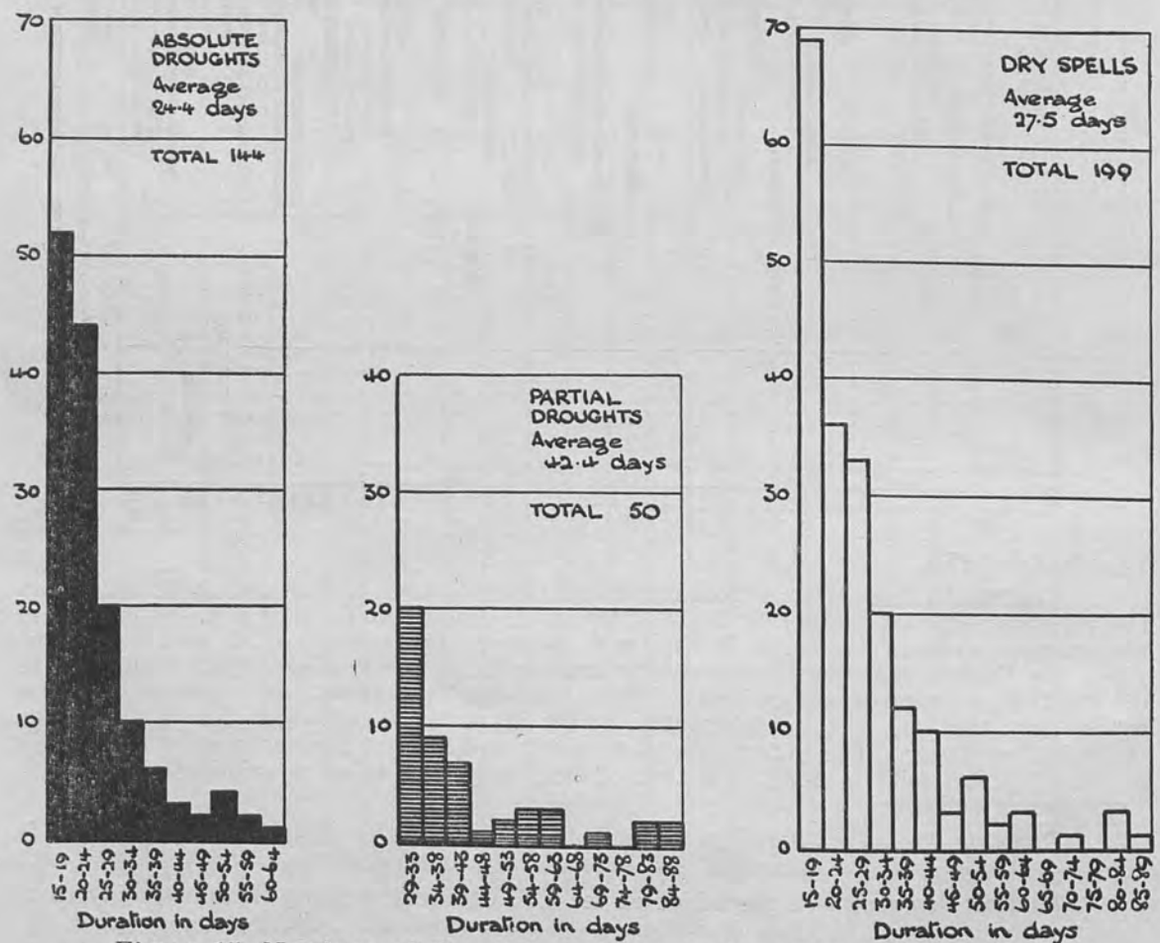


Figure 15. Numbers of Droughts and Dry Spells of different durations.

13. DROUGHT DURATIONS.

Frequencies of drought and dry spell durations are given in Figure 15. Maximum durations were an absolute drought of 60 days—1909 13th November to 1910 11th January, a partial drought of 88 days—1917 15th December to 1918 12th March, and a dry spell of 87 days—1917 16th December to 1918 12th March.

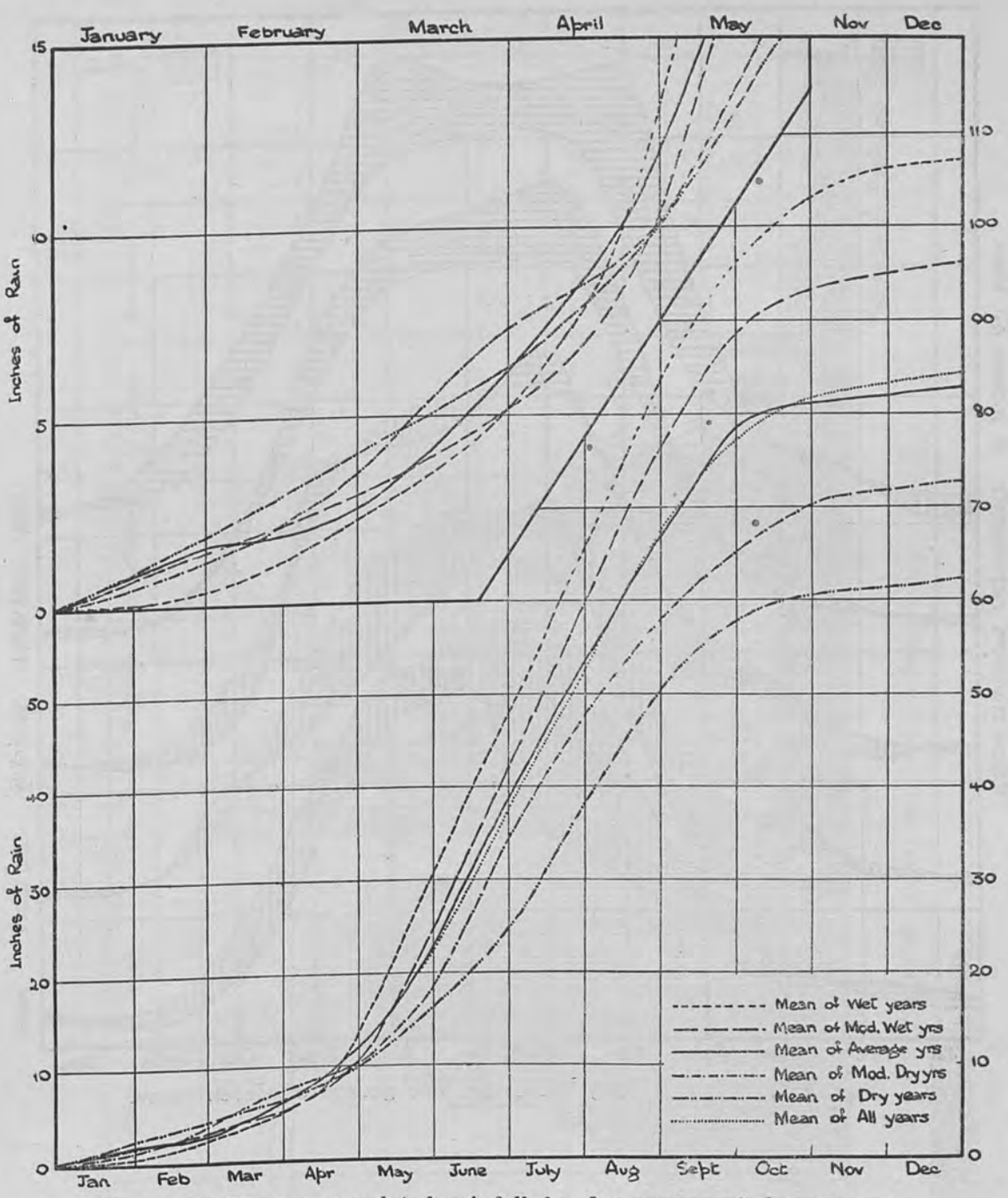


Figure 16. Mean accumulated rainfall for five groups of eleven years.

14. STRUCTURE OF HONG KONG RAINFALL.

In order to investigate the structure of Hong Kong rainfall further, the annual values were divided into five eleven-year groups, Wet, Moderately Wet, Average, Moderately Dry and Dry. Mean curves of accumulated rainfall are shown in Figure 16. By the end of May, i.e. after only about a quarter of the annual amount has fallen, all the curves are in their final order. The form of the curves varies little, the wetter the year the steeper the curve, and all show the rapid flattening out at the end of September. On the same basis mean monthly values for the five groups are compared in Figure 17 with the normal curve. It will be seen that the mean curve for the eleven driest years shows more than average rainfall in the early months, while the eleven wettest years were similarly deficient in rain during the early months. The reversal occurs about March. The curve for the wet years after March shows a fairly uniform proportional increase spread over the rest of the year, with a tendency towards wet autumns. The moderately wet years curve is similar but shows rather less summer rain. The average years curve shows a slight excess in early summer offset by a deficiency in late summer. Moderately dry years appear deficient in spring and late summer. The dry years are generally deficient in rain after March, but particularly so in the early summer. The secondary rainfall peak is only evident in the wettest years, while the primary peak appears to shift to later and later times in the year as the annual rainfall decreases.

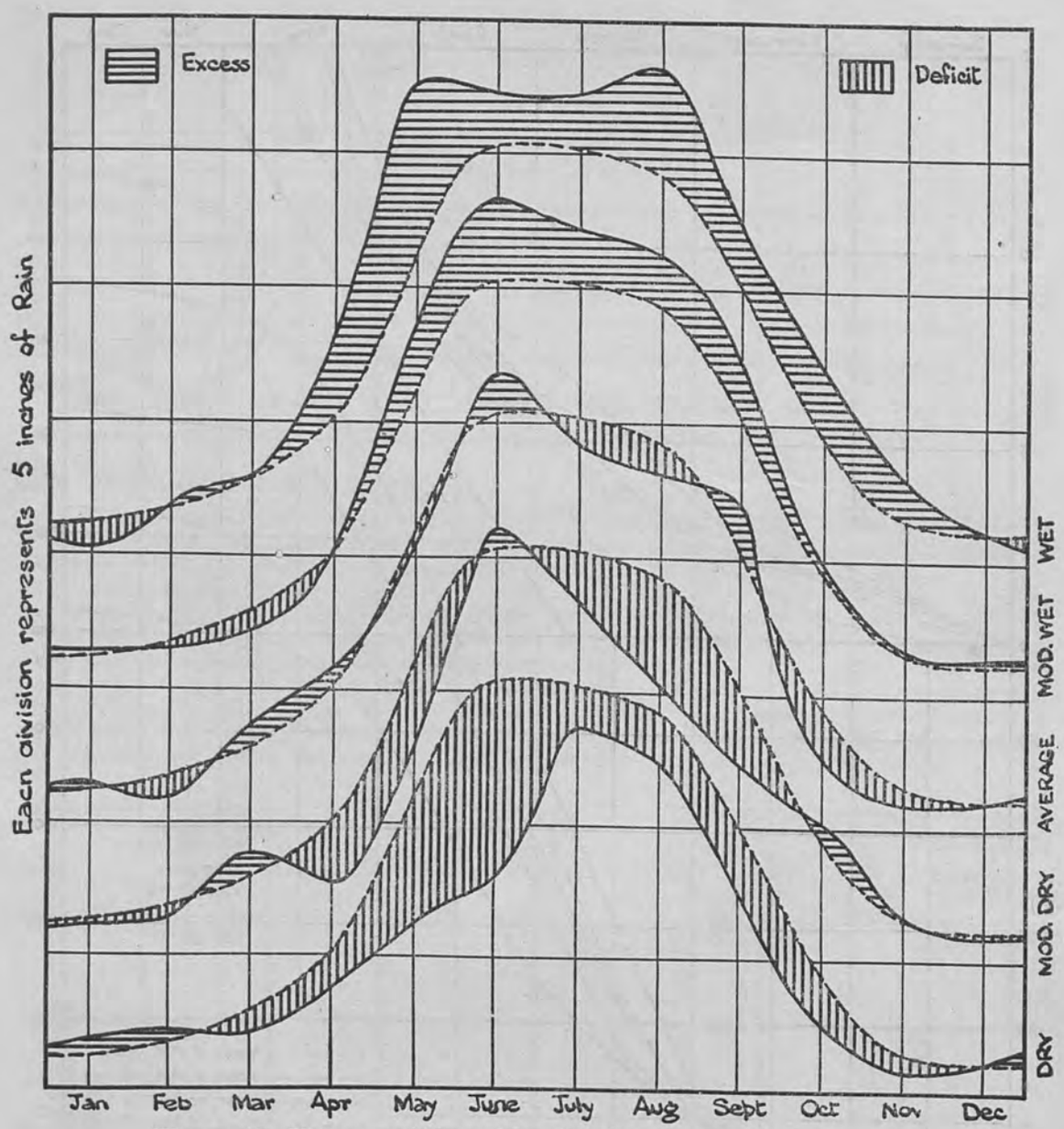


Figure 17. Mean monthly values for five groups of eleven years.

15. TYPHOONS AND RAINFALL.

Typhoons are invariably accompanied by heavy rainfall, the condensation of which provides the energy which they manifest in high winds. Yet a preliminary examination of Hong Kong rainfall and typhoon frequency statistics revealed no apparent correlation. Of the typhoons giving gale force or greater in Hong Kong during the 55 years under consideration, 35 occurred in years having less than average rainfall and 35 in years with more than the average. The wettest and driest years, 1889 with nearly 120 inches and 1895 with less than 46 inches, each had one typhoon. The year with rain amount nearest the average had two typhoons. Four typhoons occurred in each of the years 1923 with 107 inches, 1894 with 104 inches, and 1893 with 100 inches, all of which had above average rainfall; on the other hand three typhoons occurred in each of the years 1906 with 78 inches, 1896 with 73 inches, 1887 with 66 inches, all of which had below average rainfall. It appeared, therefore, that on average the total annual rainfall amount was largely independent of typhoon gale occurrences in Hong Kong. It probably is, in the sense that several typhoon gales in any one year do not mean that the total amount of rain will be excessive.

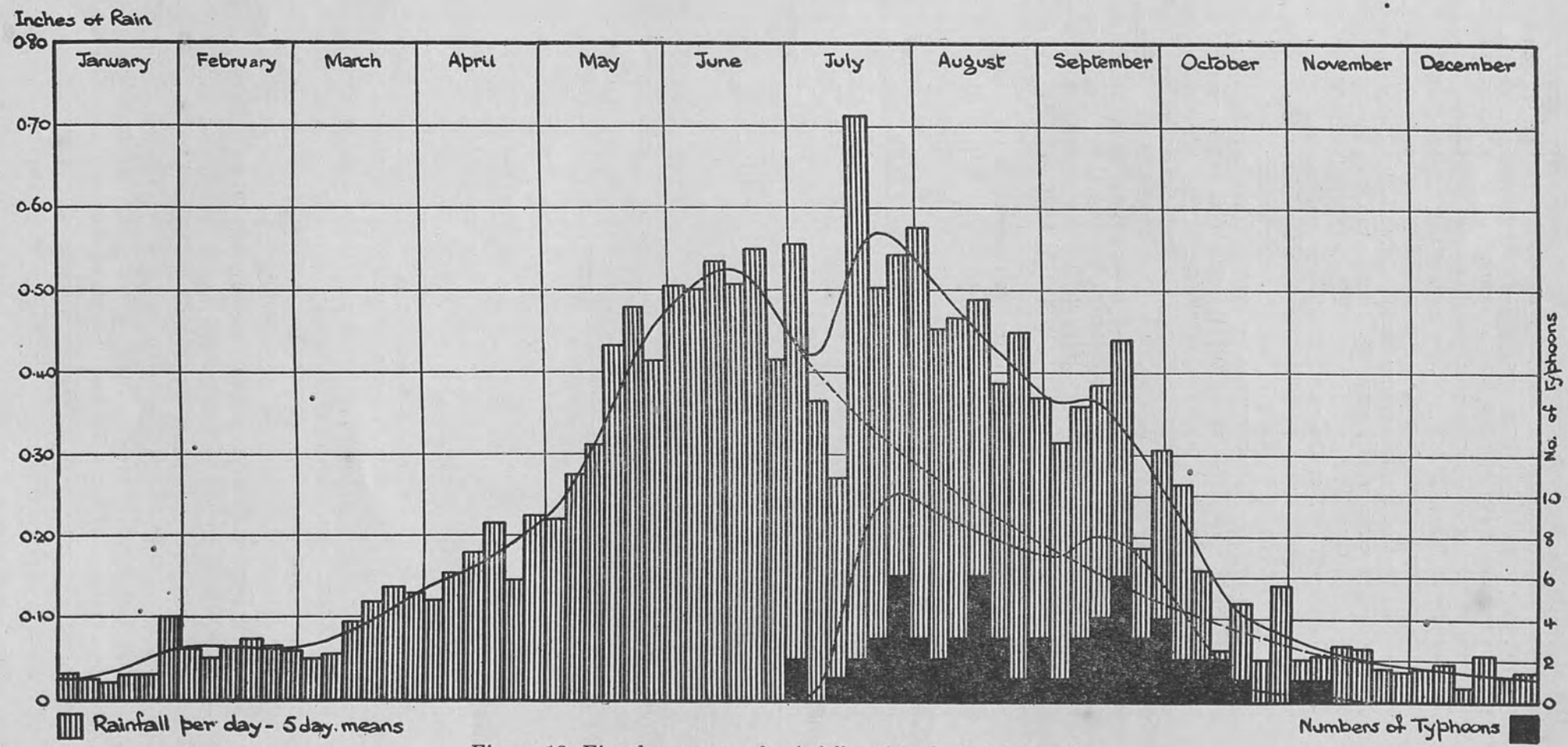


Figure 18. Five-day means of rainfall and typhoon frequencies.

Further investigation, however, shows that although the wide variations in the amount of annual rainfall are sufficient to mask any correlation between it and typhoon occurrences, a part of the rainfall in any year is demonstrably due to tropical storm incidence. The monthly means of rainfall have a normal maximum for June and July (Figure 5), but the 5-day normals reveal a peculiar double maximum, one peak occurring in the middle of June, the other in the second half of July, with a marked subsidiary minimum between them. Rainfall for the 5-day period July 10-14 is considerably less than half that of the succeeding period, July 15-19. 5-day mean values of rainfall in Hong Kong are shown in Figure 18. 5-day mean frequencies of typhoons affecting Hong Kong, shown on the same diagram, have a marked correlation with the rainfall curve in the second half of the year, subsidiary maxima and minima being generally coincident. It appears very probable therefore that the double maximum of the rainfall curve is due to an added contribution of rain resulting from typhoons. It is significant also that of the 17 years when no typhoons affected the Colony to the extent of producing gale force, 14 were proportionately deficient in rainfall for the typhoon months (July to November), while of the seven years that had either three or four typhoons each, 6 had proportionately high rainfall for the typhoon months. From this argument, on the smooth curve of 5-day normals (Figure 18) an extension was drawn from the first maximum in June, extrapolating the normal decrease in the second half of that month and the first half of July through to meet the curve in the latter half of November. By subtraction, the rainfall attributable to typhoons (shown by the dot-dash curve) amounts to about 20% of the annual total. If this indeed be the case, a solitary consoling feature emerges from Hong Kong's susceptibility to typhoon visitations. Without their effect, water supply in the Colony would be a much greater problem.