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# FREQUENCY OF FLOODS IN CITY OF LIVERPOOL

by

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Report No. 142
(Reprint of W.R.L. Technical Report 68/13)

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The University of New South Wales

Water Research Laboratory

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## PART I

## FLOOD DISCHARGE - FREQUENCY RELATIONS

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# Table of Contents

## Table of Contents (cont'd.)



## List of Figures

## 1. General Background to this Investigation

Some years ago, the St. George and Sutherland Dredging and Reclamation Committee, acting on behalf of a number of councils, requested the School of Civil Engineering of the University of New South Wales, per medium of Unisearch, to carry out studies of the Georges River estuary, primarily from the point of view of proposed reclamation works.

In carrying out this investigation, the opportunity was taken to illustrate the need for an integrated overall study of the river basin, with due regard to the relationship between pollution, navigation, tidal and flood flows and other phenomena as well as the effects of reclamation, and in this respect it went beyond the basic terms of reference in an endeavour to awaken Local Government Authorities to the need to take a broader and more long term view of these problems.

The results of the investigation were published in Report No. 101 of the Water Research Laboratory of the University of New South Wales entitled "The Georges River Hydraulic, Hydrologic and Reclamation Studies". This report presented a tabulation showing an array in order of magnitude of peak flood levels at Liverpool Traffic Bridge from 1873 to 1968 as follows:-

Table 1: Peak Flood Levels at Liverpool and Milperra

| Year | Estimated R. L. at Liverpool Traffic Bridge ** | Estimated R. L. at Milperra ** | Estimated Discharge at Milperra * cfs x $10^{-3}$ n=.04 | n = .03 | Rank | Re-currence Inverval (years) |
|---|---|---|---|---|---|---|
| 1873 | 134.5 | 121.3 | 80 | 106 | 1 | 95 |
| 1875 | 132.5 | 119.7 | 66 | 90 | 2 | 47 |
| 1889 | 132.0 | 119.2 | 63 | 86 | 3 | 32 |
| 1956 | 128.0 | 116.0 | 41 | 57 | 4 | 24 |
| 1914 | 125.0 | 113.5 | 29 | 39 | 5 | 19 |
| 1950 | 124.8 | 112.6 | 25 | 33 | 8 | 12 |
| 1933 | 124.5 | 113.1 | 27 | 37 | 6 | 16 |
| 1961 | 124.0 | 112.4 | 24 | 32 | 9 | 11 |
| 1900 | 124.0 | 112.7 | 25 | 34 | 7 | 13 |
| 1895 | 123.5 | 112.3 | 24 | 32 | 10 | 9.5 |

* n refers to the Manning roughness coefficient.
** Datum 100 ft. below Std. Datum

However, it must be stressed that the levels in this Table for "historic" floods prior to 1900 were merely copied directly from records in the Department of Public Works, Fairfield Council and Liverpool Council, without any investigation of the accuracy of such records.

This tabulation lists three floods in the 27 year period 1873-1899 inclusive which were greater than the greatest flood (1956) in the 69 year period 1900-1968 inclusive. This is theoretically possible, but points to the obvious need to check the accuracy of the flood records of the nineteenth century.

In May 1966, H. A. Scholer, in an internal report of the New South Wales Department of Public Works entitled "Report on Georges River Flood Mitigation - Floods in the Lower Georges River", (Reference 1) stated that data were inadequate for an accurate estimate of the frequency diagram for Liverpool, but then proceeded by an ingenious (although in the writers' opinion erroneous) method to produce a table showing the relations between recurrence interval in years and height of flood at Liverpool Traffic Bridge. In the authors' opinion, Scholer's analysis is most interesting but is not satisfactory for making an estimate of the array of past floods from which a flood frequency diagram can be constructed.

He did not adopt the most direct and accurate method, which is to study the rainfall of past storms and to apply these rainfalls to a synthetic unit hydrograph for the catchment, to produce an estimated flood hydrograph for historic floods for which there are no reliable records of flood heights or discharges.

R. Stewart, Design Engineer of the Liverpool City Council, subsequently submitted to Mr. Standen, Engineer for the Council, a critical review and evaluation of the available data. He pointed out that Scholer's report led to the conclusion that the 1956 flood was a "once in 9 year flood" (although it clearly is the highest flood since 1900 or earlier). He then plotted five possible flood frequency curves and gave a table showing an estimated array in order of magnitude of floods, with the 1956 flood having a recurrence interval of between 12. 5 and 14 years.

Mr. Standen, City Engineer for Liverpool, in a report to a Special Meeting of Council on 11. 9. 68, (Reference 2), deduced that the 1956 flood would have a recurrence interval of 15 years and a flood level of 27. 5 at Liverpool Bridge and 15. 5 at Milperra. At this Council Meeting it was decided that the Council, through Unisearch, would request the School of Civil Engineering of the University of New South Wales to make a thorough investigation of the question of flood frequencies and levels in the City of Liverpool.

The terms of reference suggested by Professor C. H. Munro and approved by Mr. Standen were:-

" (i) <u>Preparation of Flood Frequency Diagram</u>

(a) Check the validity of reputed flood levels of 1806, 1809, 1817, 1860, 1867, 1873, 1875, 1883, 1887, 1889, 1897, 1900 and 1908 by interviews and library searches and critical evaluation of the available evidence regarding the reliability of the original source of the reputed level.

(b) Collect rainfall data on the dates of these floods and preceding seven days at as many stations as possible on or near the catchment from Weather Bureau Records and library searches.

(c) Synthesize, by correlation, missing rainfall data where available records are not adequate.

(d) For all those floods for which adequate rainfall data can be obtained, apply this rainfall data and the 1956 flood rainfall data to the synthetic unit hydrograph for Georges River catchment upstream of Liverpool Bridge and plot the flood hydrograph for these floods.

(e) Make a tabulation of peak flood discharge for all floods equal to or greater than the 1956 flood and plot a flood frequency diagram for these floods.

(f) Calculate confidence limits and plot them on the graphs.

(g) Writing and publication of report.

(ii) Flood Levels for Floods of Various Frequencies

(a) Check, by interview and library research, the levels reached by the 1956 flood, and perhaps other recent floods, in the area shown in Mr. Standen's report Drawing No. 33/66B, in Report to Special Council Meeting on 11.9.68.

(b) By hydraulic calculations and possibly some model studies prepare map similar to Drawing No. 33/66 showing flood levels for recurrence intervals of 10 years, 20 years and forty years."

This report presents a summary of these investigations.

Figure 1 shows a locality plan, and Figure 2 the isohyets of mean annual rainfall on the catchment.

## 2. Accuracy of Reported Historic Flood Levels

(a) Professor Munro has had considerable experience in investigating flood levels in the period 1800-1900, particularly in Tasmania. There is one lesson that stands out clearly from his experience and this is that one must look with great suspicion upon such reputed flood levels. If one can find a brick or concrete building with a flood level mark and the date of flood inscribed upon it, and if one is certain that this mark and inscription was made shortly after the flood, then it can be accepted. However, if the flood level evidence comes from such reports as "the flood rose 38 feet" or "the highest flood ever recorded" or "reached the top of the bar counter of the Royal Hotel" then these cannot be accepted unless some confirmation is available. If rainfall records exist, these provide an obvious means of checking the level. A major flood could not have occurred unless the rainfall was heavy. Even flood marks on buildings with dates inscribed can be misleading. Sometimes it has been found that the building was later jacked up to be above flood level and no one bothered to alter the flood marks.

(b) Immediately after a flood, human psychology is such that exaggerated reports, perhaps made by a semi-intoxicated or over excited person, are accepted as gospel truth by people who never observed the flood. This level is enshrined in the folklers of the district. Often investigation has shown the obvious absurdity of such evidence.

(c) Levels taken by a surveyor twenty years or so after the flood occurred have no value unless there is clear evidence from more than one source that the level upon which he placed his measuring staff is in actual fact the level reached by the water.

The 'Sydney Morning Herald' writer of 3rd May 1860, in discussing floods generally in New South Wales, commented that some reported flood levels "rather sounds problematical as "a tale of the times of old' ".

Even for the recent flood of 1956, a critical evaluation of reported flood levels in some areas reveal obvious errors of 4 to 5 feet, and similar errors could well have occurred in reported historic flood levels.

3. Frequency of Flooding in Period 1900-1968 compared with 1800-1900.

There has been some suggestion that the period 1900 - 1968 was abnormal in that unusually few major floods occurred. The authors would dispute this. Over many parts of New South Wales we experienced an extraordinary period of floods between 1949 and 1964, and one might well "have a hunch" that this was the worst period since 1800. We quote a few examples:

(i) In his paper, "The Flood Problem" (Reference 3) presented at the 1955 University of New South Wales Symposium on "The Water Resources of Australia, Their Control and Development", R. A. Young, (then Commissioner for Irrigation) presents a graph of floods in the

Hunter Valley from 1855 to 1955 and comments:- "From the commencement of white settlement on the Hunter until 1949 there were only three major floods exceeding 35 feet on the Belmore Bridge gauge. However, since 1949 there have been six such floods".

(ii) The widespread cyclonic storms of February 1955 and January 1956 are used by hydrometeorologists in estimating "maximum possible precipitation", because they were the most efficient storm mechanisms on record.

(iii) There is reliable evidence that the 1961 flood on the Hawkesbury at Windsor has been exceeded by only one flood since 1799 - that of 1867.

(iv) The behaviour diagram of Burrendong Dam on the Macquarie River from 1894 to 1960 shows almost continuous flooding in the periods 1950-1952 and 1954-1956 inclusive, and this did not occur in any other part of the record.

## 4. Rainfall and Flood Level Reports for Historic Floods

Newspaper reports, historic documents, Weather Bureau records, Fairfield and Liverpool Council files, and other sources were studied in order to summarise and compare:-

(i) various reports of flood levels prior to 1900;
(ii) daily (9 a.m.)rainfall records at the time of floods;
(iii)the time pattern of such rainfalls during each 9 a.m. to 9 a.m. period.

The information regarding (i) above obtained is summarised in Appendix A.

It was concluded that the results of (i) above were in general not to be relied upon.

Quite satisfactory records of rainfalls enabled isohyetal maps to be drawn for all storms from 1873 onwards, and average rainfalls over the catchments to be computed for each day of rain.

In regard to time patterns of rainfall during each day, these were readily obtainable for the period 1900 - 1968, and were plotted for the major storms for this period.

From the total volume of rain in each storm, and also from observers' reports of flood heights, it was quickly obvious that the floods of 1873, 1898 and 1956 were the three greatest since 1860 or possibly even earlier.

As all of these storms occurred in February, and C. J. Wiesner, an authority on hydrometeorology in the University of New South Wales, gave it as his opinion that the time pattern of most February cyclonic storms should be fairly similar over the Georges River catchments, it was felt that it would be reasonable to assume that the percentage rain-percentage duration of storm curves for 1873 and 1898 would be the same as the known patterns for 1956. At a late stage in the investigations further rainfall observers' reports were found for 1873 and 1898, enabling the actual time pattern for 1873 to be plotted with a high degree of confidence, and that of 1898 with fair confidence. These patterns were of the same general nature as the 1956 pattern.

## 5. Synthetic Unit Hydrograph for Catchment Upstream of Liverpool Bridge

Due to the past neglect of the need for a national hydrologic network, no streamflow measurements have ever been made at Liverpool Bridge and therefore there is no stage-discharge curve for this site.

Therefore the unit hydrograph had to be synthesized from catchment parameters. This was done by the Clark-Johnstone procedure, as recommended by the Institution of Engineers, Australia in "Australian Rainfall and Runoff" 1958 (Reference 4), but with the modification of coefficients put forward by Cordery (Reference 5 - Internal Weather Bureau Report). These coefficients were based on studies of New South Wales catchments.

The unit hydrograph so derived is shown in Figure 3.

## 6. Estimation of Flood Discharges Assuming Uniform Rate of Rainfall During Each Daily Period

For a preliminary estimate, the rainfalls were applied to the unit hydrograph to obtain the actual flood hydrograph, on the assumption that the rainfalls during each 24 hour period ending 9 a.m. were at a uniform rate during this period. The results are summarised in Table II of Section 7. Estimates of initial loss were based on the studies of 14 New South Wales catchments by Cordery (Reference 6 -

"Initial Loss for Flood Design and Flood Forecasting." Civil Eng. Trans. Inst. Engrs. Australia - in press).

7. Estimation of Flood Discharges for Varying Rates of Rainfall During Each Daily Period

Although the analysis described in Section 6 above might rank the floods correctly in order of magnitude, the peak discharge so computed would be too low, because inadequate allowance is made for the effects of very intense bursts of rainfall within the 24 hour periods.

Therefore, for the nine floods for which the time patterns of rainfall was known (1873, 1898, 1914, 1916, 1949, 1950, 1956, 1961 and 1964) the actual rainfall pattern was applied to the unit hydrograph to re-compute the flood hydrographs. The percentage increases over the results obtained in Section 6 above were somewhat similar except for 1873, 1961 and 1964 and the average percentage increase was 42 pc. For storms for which the time patterns are not known, the true discharges can be approximately estimated by adding 42 pc. to the peak discharges obtained by the uniform daily rainfall assumption of Section 6. The results are given in Table II. In this table the recurrence intervals have been computed by the so-called "California" method, which suffices for this study.

On 23rd June 1967, the "highest ever" flood level of 63 ft. $2\frac{1}{2}$ inches occurred at Windsor and the investigators searched diligently to find references to high floods at that time in the Georges River, but the only reference is Moriarty's passing reference to "big floods" in 1857 and 1867 (see Standen's report page 5, Reference 2).

The 1873 flood is reported as the greatest in living memory, and if living memory is deemed to be 55 years, the estimated return period of this flood would be 150 years.

The authors have studied the "Notes on Floods" included in the Bureau of Meteorology 1948 publication "Results of Rainfall Observations Made in New South Wales" (Reference 7) . These cover the period 1789-1945. Floods in Georges River or Cordeaux are mentioned in 1800, 1809 and 1873. There were really disastrous floods in the Windsor region in 1806, 1809 and 1867, but during the period 1811-1860 only minor flooding is reported in all regions.

Table II

Estimation of Flood Frequencies

| 1 Date | 2 Daily Rainfalls | | | | | 3 Initial Loss | 4 Total Excess Rain | 5 Peak Disch. Uniform Daily Rain | 6 Peak Disch. Non-Uniform Daily Rain | 7 Pc. Increase from 5 to 6 | 8 Return Period | 9 Flood Heights Liverpool Bridge (Scholer) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Ins. | Ins. | Cusecs | Cusecs | | Years | ft. S. D. |
| 22-27/2/1873 | 0.10 | 0.92 | 1.20 | 5.00 | 8.00 | 2.55 | 12.67 | 31200 | 57100 | 83 | 168 | 34.5 |
| 13-17/2/1898 | 2.15 | 7.70 | 0.74 | 0.85 | - | 2.50 | 8.94 | 27800 | 41400 | 49 | 50 | |
| 9-11/2/1956 | 0.40 | 6.90 | 4.60 | - | - | 1.51 | 10.39 | 25500 | 41300 | 62 | 33 | 27.5 |
| 23-25/3/1890 | 0.20 | 1.80 | 6.10 | - | - | 1.30 | 6.80 | 23500 | 33300 | 42 | 25 | - |
| 25-29/5/1889 | 1.10 | 2.50 | 4.70 | 4.90 | 1.63 | 3.06 | 11.77 | 19900 | 28200 | 42 | 20 | - |
| 4-6/10/1916 | 1.10 | 4.45 | 0.68 | - | - | 1.20 | 5.03 | 16900 | 25400 | 50 | 17 | - |
| 4-7/7/1900 | 0.95 | 4.65 | 4.55 | 0.65 | - | 1.11 | 9.69 | 17700 | 25100 | 42 | 14 | - |
| 17-19/6/1949 | 1.48 | 3.95 | 2.32 | - | - | 1.00 | 6.75 | 15200 | 24900 | 64 | 12 | 25.10 |
| 17-20/11/1961 | 0.40 | 3.38 | 5.74 | 2.90 | - | 2.40 | 10.02 | 22100 | 24400 | 10 | 11 | 23.50 |
| 19-23/1/1895 | 0.40 | 0.30 | 0.50 | 1.15 | 4.40 | 0.70 | 6.05 | 17000 | 24100 | 42 | 10 | - |
| 23-24/3/1914 | 1.75 | 4.20 | - | - | - | 0.64 | 5.31 | 16200 | 24100 | 49 | 9 | 24.00 |
| 15-17/6/1950 | 0.90 | 4.60 | 1.70 | - | - | 0.80 | 6.40 | 17700 | 23000 | 30 | N. R. | 24.41 |
| 10-13/6/1964 | 3.50 | 4.20 | 4.80 | 1.80 | - | 0.84 | 13.46 | 18500 | 22400 | 21 | N. R. | 23.63 |
| 29-31/8/1963 | 1.35 | 5.30 | 0.15 | - | - | 2.10 | 4.70 | 18000 | 21300 | 18 | N. R. | 21.80 |
| 10-14/5/1883 | 0.50 | 0.61 | 0.60 | 3.70 | - | 1.60 | 3.81 | 14200 | 20200 | 42 | N. R. | - |
| 1-3/2/1908 | 0.10 | 0.05 | 2.30 | 3.40 | 0.40 | 2.52 | 4.03 | 13100 | 18700 | 42 | N. R. | - |
| 18-22/3/1894 | 0.10 | 0.44 | 3.25 | 0.70 | 0.58 | 0.29 | 4.78 | 12500 | 17800 | 42 | N. R. | - |
| 22-26/1/1887 | 0.90 | 0.30 | 0.10 | 0.20 | 2.90 | 0.70 | 3.70 | 11150 | 15800 | 42 | N. R. | - |
| 3-7/6/1875 | 0.14 | 0.05 | 0.38 | 2.11 | 2.22 | 0.37 | 4.53 | 8500 | 12200 | 42 | N. R. | - |
| 23-27/7/1897 | 0.30 | 1.89 | 2.03 | 1.68 | 0.52 | 2.23 | 4.19 | 7900 | 11300 | 42 | N. R. | - |

From the study of available historic evidence given in Section 10 below, the authors concluded that the best estimate of the recurrence interval of the 1873 flood is 168 years. It is quite possible also that the 1898 and 1956 floods were greater than those of 1860 and 1809, in which case their recurrence intervals would be respectively 84 and 56 years.

However, in Table II the authors assumed that we have no knowledge of flood levels prior to 1868, except that none exceeded the 1873 flood, and decided to base recurrence intervals on this 100 year period of record (except for the 1873 flood). With this assumption the results of the rainfall-loss rate - unit hydrograph studies may be summarised as shown in Table II.

## 8. Discussion of Results

In considering Table II, it must be realised that the peak discharge depends mainly on the most intense rate of rainfall over 6 to 12 hours or so during the storm. Therefore one flood may have a greater amount of total excess rainfall than another (see Col. 4 of Table II) and yet cause a smaller peak discharge, because its rate of rainfall may be more uniform. Broadly speaking, the floods would be expected to be ranked in order of magnitude according to the highest daily rainfall after initial loss has been satisfied.

For example, the 1873 flood had a one day excess rain of 8.00 inches as compared with 7.35 inches for the heaviest day in 1898, so that one would expect the 1873 flood to exceed the 1898 flood, but not by a large margin. However, in Sydney in 1873 a burst of 8.2 inches was reported in 7 hours, and Appin reported 10 inches between 9 a.m. and 4.0 p.m. When the rainfall pattern is adjusted to these figures, which are abnormal, the peak discharge in 1873 is computed as 57100 cusecs, compared with 41100 for 1898. As a matter of interest, if we used the 1956 time pattern for 1873, on the argument that long period cyclonic rains in February should be generally similar in time patterns, the peak discharge becomes 44,700, which is 44 pc. above the 1873 peak discharge computed on the assumption of uniform rate of rainfall throughout each day.

Consider now the comparison of the 1956 and 1898 floods. Although the total excess rain in 1956 was 10.39 inches, as compared with 8.94 inches in 1898, the heaviest day of excess rain in 1956 was 5.19 inches, as compared with 7.35 inches for 1898. Considering 7.35 against 5.19, one would expect quite a difference between the peak discharges of these two storms, and yet the computed peak discharge in 1898 is only 100 cusecs greater than in 1956. The reason is that the heaviest day's rain is only a rough guide, and one must look at the shorter period bursts also. In 1956, the heaviest 6 hour burst on the heaviest day was 3.90 inches, which was practically the same as the 4.00 inches in the heaviest 6 hours on the heaviest day in 1898. Hence the peak rate of discharge of the two storms are nearly equal.

An apparent discrepancy in Table II will be noted in that the peak discharge of the 1916 flood is given as 25400 cusecs with a heaviest day of excess rain of 4.65 - (1.20 - 1.10) = 4.55 inches, whereas the 1900 flood is credited with a lower peak discharge of 25100 cusecs, although its heaviest day of excess rain was also 4.55. It must be realised that details of the time pattern of the 1900 flood were not known, and the value of 25100 was obtained by adding 42 pc. to the peak discharge computed when assuming a uniform rate of rainfall each day, and this 42 pc. is an average value obtained as described in Section 7. The true percentage increase for any particular storm could be greater or less by an amount of 15 pc. or more.

Similar discrepancies between the heaviest day - peak discharge relations for 1949 and 1961 are readily explained by the fact that the daily time patterns of the 1961 flood showed an unusually uniform rate of rainfall.

Similarly the 1914 discharge was higher than the 1950 discharge because its rainfall was more variable.

In considering reported peak flood heights near the Liverpool Bridge, it must be remembered that until 1958 there existed, just upstream of the existing Liverpool Road Bridge, a "low level" road bridge. Observers aged about 14 years in 1898 now state that their memory of the 1898 flood was that the flood height was up to the deck of the low level bridge, whereas they remember clearly (and correctly) that the peak level of the 1956 flood was three or four feet lower than the deck of this bridge, and one might at first thought conclude that the 1898 peak discharge should be more than 100 cusecs greater than the 1956 peak discharge.

However, the authors consider that measured rainfall records are a better guide to the estimation of peak discharges than the human memory extending back over 69 years. More importantly, it must be remembered that in major floods such low level bridges often trap large floating trees and the waterway area under the bridge becomes almost completely blocked up, so that the bridge becomes a dam, and artificially raises the flood level in its vicinity. It is known that this did not happen in 1956, but it is quite likely that it happened in 1898. In fact, the memories of these same observers are that although the peak height at Liverpool Bridge in 1889 was higher than in 1956, the flood heights in the Chipping Norton area were higher in 1956 than in 1898. This is what one might expect if the low level bridge acted as a dam. It could be argued,from the reported Chipping Norton levels, that the real truth of the matter is that the 1956 flood had in reality a greater discharge than the 1898 flood and has a return period of 50 years or even more.

As against this, flood levels downstream of the confluence of Cabramatta Creek and Georges River depend somewhat upon the relative floods of the two catchments, and perhaps the flood flow of Cabramatta Creek was less in 1898 than in 1956 and this accounts for the fact that levels in the Chipping Norton area were greater in 1956 than 1898 although levels at the bridge were greater in 1898 than 1956.

But the flood peaks from Cabramatta Creek arrive in the Chipping Norton area long before those from the main stream of the Georges River, as also do the flood peaks from Prospect Creek. Therefore, the authors have a shrewd suspicion that the peak discharge in 1956 may well have been greater than in 1898.

The preceding discussion regarding the low level bridge acting as a dam and artificially raising flood levels leads to another word of caution regarding reports of historic flood levels. Firstly, there is always the possibility that the course of the river has been changed over the years, causing a change in the flood height at Liverpool for a given discharge, although a quick look for geomorphological evidence of this by F. C. Bell was unsuccessful.

Also in some of the rivers in New South Wales huge "rafts" of trees and logs have been built up by successive floods, forming dams which alter the flow of the river. Before the activities of man had cleared country for grazing, the number of uprooted floating trees in Georges River during flood periods may have been much greater than in recent years and such rafts may have been built up in some sections in the earlier floods.

In column 8 of Table II the comment "N. R." stands for "not ranked in order of return period". The reason is that there may be some other minor flood rains in the period 1868-1968 which the authors have not studied, which should be in the list. In any case, the return periods important for the Liverpool Town Plan are those in the range 10 years to 40 years.

Attention is also drawn to the percentages given in Column 7 of Table II. Where the percentage is shown as 42 pc., the computed discharge is only approximate, because the time pattern of the rain during each day is not known, and the peak discharge for uniform rate of daily rainfall has been arbitrarily increased by 42 pc., which is the average such percentage increase for floods for which the daily time patterns are known. Omitting the floods of 1961 and 1964, which seem to have an unusually uniform time pattern and omitting 1873, which had one abnormally long heavy burst, it is clear from a study of column 7 that this 42 pc. could in reality range from about 30 pc. to 60 pc. in any individual case.

Some comments are necessary regarding the recurrence intervals listed in column 8 of Table II. If we have a record of 100 years, we may estimate that the greatest flood in this period will be equalled or exceeded 10 times in 1000 years. A better way of stating this is to say that in any given future year there is one chance in 100 that this flood will be equalled or exceeded. However, we have only one sample of a 100 year period, and such a conclusion is akin to selecting one orange from a shipload of oranges and concluding that all the other oranges are of the same size and quality. Hence not much faith can be held in the statement that the highest flood in a period of 100 years has a recurrence interval of 100 years. The period 1868-1968 may have been a relatively flood free period. On the other hand, the highest flood of this period may in reality be the 1000 year flood, which just happened to occur in the period 1868-1968.

We have two 50 year samples, so that our estimate of 50 year recurrence interval is a little moreaccurate, but still subject to a wide margin of error.

We have three 33 year samples, so that we can have a little more confidence in the estimate that the 1956 flood has a return period of 33 years.

We have five 20 year samples, so that we can be quite confident that the flood levels reached in 1889 can be expected to be equalled or exceeded in the average in the long run 50 times in 1000 years, and also that a discharge round about 28000 cusecs will be equalled or exceeded with the same frequency.

We have ten 10 year samples so that we can feel very confident that the flood level reached in 1914 will be equalled or exceeded 100 times in 1000 years, and that a discharge of about 24000 cusecs will be equalled or exceeded with the same frequency.

Even though the estimates of return periods for the larger floods are subject to wide error, they are the best estimates that can be made from the available data. It is unwise to "play safe" and assume that the 1956 flood is really, say, the 25 year flood and to inflict perhaps unnecessary economic loss on the community by decreeing that the land flooded by the 1956 flood should be zoned as open space.

It would be just as reasonable to go the other way and assume that the 1956 flood is really, say the 65 year flood.

Mr. Standen, City Engineer of Liverpool, in his report to the Special Council Meeting of 11th September 1968, recommended that the Council permits development or subdivision only when land has been filled to the levels hereunder:

(i) Existing zoning
   (a) Residential and commercial - 20 year
   (b) Industrial - 15 year

(ii) Proposed new zoning
   (a) Residential and commercial - 40 year
   (b) Industrial - 20 year

Hence in this particular town planning problem, the true value of the 100 year flood is only of academic interest, and the most important values are the estimated discharges for the 15 year and 20 year floods. For the 20 year flood, we have in the period 1868-1968 five 20 year samples, so that an estimate of 28200 cusecs in Table II is accurate enough for practical town planning purposes, and for the 15 year flood we are still better off with nearly seven 15 year samples.

In Table II, Col. 9, except for 1873.the only heights listed are for floods of this century, because it is considered that reports of historic flood heights are unreliable. Furthermore, it has been assumed that the levels given by Scholer, in Appendix 2 of his May

1966 report entitled "Report on Georges River Flood Mitigation" are correct. Presumably flood levels since 1900 are reasonable reliable. In any case, time did not permit investigations of the source and accuracy of the 1900-1968 levels listed by Scholer.

It should be stressed that the discharges calculated in Table II, even for storms whose rainfall time pattern is known, could be in error by 10 pc. or 15 pc. up or down. However, the authors feel confident that the ranking in order of magnitude is correct. Even if the computed discharges of the 1873, 1898 and 1956 floods are say 4000 cusecs too low, it seems likely from the rainfall records that the 1898 flood would be a little higher than the 1956 flood, and clearly the 1873 flood was the largest.

## 9. Flood Frequencies Computed by the Gumbel Theory

The literature on flood-frequency analysis is voluminous. Linsley and Franzini, in the First Edition of "Water Resources Engineering" (Reference 8, McGraw Hill 1964) discuss in Chapter 5, "Probability Concepts in Design", the question of flood frequency analysis and give as the only example the method put forward by Gumbel (Reference 9, "Floods Estimated by the Probability Method" Eng. News Record Vol. 134 pp. 833-837, 1945), and comment thus:-

"The Gumbel method is based on sound statistical principles and has been checked with data from stations having very long periods of record. Figure 5-3 is typical of frequency plots in that the computed line conforms well to most of the data but diverges sharply from the three or four largest values. This divergence has led many people to adopt distributions which can be adjusted to better fit the plotted points. The discussion of recurrence interval in Section 5-2 points out, however, that these higher points may be incorrectly plotted. Hence, to force a distribution to conform to these plots may only perpetuate the error. Until much longer records are available, there is no absolute proof of the adequacy with which the theoretical distribution fits the actual distribution of floods. Recent studies confirm the belief that the Gumbel method is as sound as any of the methods now in use." (Reference 10, D.M. Hershfield, "An Empirical Comparison of the Predictive Value of Three Extreme-value Procedures", J. Geophys. Res., Vol. 67, pp. 1535-1542, 1962).

A Gumbel plot of Table II is given in Fig. 4. If the Gumbel theory is accepted, the return period of the 1956 flood would be about 45 years, and the straight line represents the best estimate of the discharge-recurrence interval relationship. Many authorities have little faith in the Gumbel or any other distribution being universally applicable to flood series and prefer to use a smooth curve through the plotted points in a discharge-recurrence interval diagram. Furthermore, the U. S. Weather Bureau has concluded that while the Gumbel theory may apply to recurrence intervals of more than 20 years, it is not applicable to the lower values.

In this report, in Part II, the authors have used a smooth curve drawn through the data as plotted, as shown in Fig. 5 of Part II of this report.

## 10. Frequency of the 1956 Flood Based on Various Assumptions Regarding Historic Floods.

The "Notes on Floods" given in the Weather Bureau 1948 publication "Results on Rainfall Observations Made in New South Wales" (Reference 7) gives the impression that the whole of populated New South Wales was free from large floods during the period 1818-1859 inclusive, except for the Hunter in 1820, 1832 and 1840, and hence the use of the period 1868-1968 as the period of analysis may be misleading.

It is worthwhile to endeavour to piece together all the available historic evidence for the period 1800-1872, in an endeavour to compare the historic floods on Georges River during this period with the floods of 1873, 1898 and 1956. The evidence of available historic documents suggests that notable floods may have occurred on the Georges River in the years 1809, 1817, 1860, 1864 and 1867. There are some references to a flood on the Georges River in 1806 but the "Sydney Gazette" in 1809 states: "At the same time as the Hawkesbury flood, May 26th 1809, the water in Georges River was 12 feet higher than in the memorable flood of 1806: at 6.30 a.m. it was at its highest, 34 feet above its usual level".

Clearly, the 1806 flood was a minor one and would be smaller than the 1873, 1898 and 1956 floods. The reliability of the level of 34 feet in 1809 is questionable. Was it measured, or was it merely an estimate by eye by someone standing on the bank? If it was measured, how was the measurement made - by tape or dumpy level? What is the datum, and how is it related to our present standard datum? The Librarian of the Lands Department can find no record of the staff of the Surveyor General of the time taking any levels.

Scholer gives R. L. 33.00 on standard datum for the level of the 1873 flood at the treatment works, which would be about 34.5 or 35.00 at the bridge. If this is correct the 1873 flood exceeded the 1809 flood.

The only justification for assuming a major flood occurred on the Georges River in 1817 is the statement in the "Sydney Morning Herald" of 12th May 1860 (page 10) as follows: "Worst flood (at Liverpool) for more than forty three years--------Georges River, at Liverpool, in a most extraordinary manner, made itself a fresh bed, so that the dam there (erected at a cost of some thousands of pounds) is now practically useless". However, the newspapers of 1817 describe large floods around Windsor, but make no mention of Georges River, although there are a number of items of other local news from Liverpool. In view of the phrase "more than 43 years" it is reasonable to conclude that no major flood occurred at Liverpool in 1817.

Newspaper reports on the 1873 flood imply that it was the highest ever known. Memories of the floods of 1860 and 1867 would be still fresh in 1873 and this would lead to the conclusion that the 1873 flood had a higher peak than the 1860 flood. This conclusion disagrees with the following extract from Standen's report (Reference 2): "On page 136 of the Transactions of the Royal Society for 1869, Mr. Mayes stated: "While an engineer of the Australian Paper Co. in 1865, I ascertained the highest known flood level (1860) near the dam at Liverpool to be 32 feet above the high level of Spring Tides" and Standen comments that this would mean 35 feet on standard datum at the weir. Perhaps the ground level or other mark pointed out to Mr. Mayes as the level reached in 1860 was wrong, or perhaps it was at a point of local disturbance by an obstruction which raised the water level in a small local area.

The Sydney Morning Herald of 13th June 1864 stated: "At Liverpool the river was nearly as high as it was during the great flood of 1860, but yesterday evening it had fallen 16 feet. It is reasonable to conclude that the 1873 flood was higher than that of 1864.

Although the highest flood level ever known occurred at Windsor in 1867, the only reference to floods on Georges River in that year is a comment by Moriarty in a proposal to supply Sydney with water, which refers to floods in 1857 and 1867. (See Reference 2).

If we take the period 1800-1968, we could speculate on the ranking of floods equal to or greater than the 1956 flood as follows:-

Table III

| Assumption No. 1 | | Assumption No. 2 | | Assumption No. 3 | | Assumption No. 4 | |
|---|---|---|---|---|---|---|---|
| Ranking | Recurrence Interval | Ranking | Recurrence Interval | Ranking | Recurrence Interval | Ranking | Recurrence Interval |
| 1873 | 168 | 1873 | 168 | 1873 | 168 | 1873 | 168 |
| 1809 | 84 | 1809 | 84 | 1809 | 84 | 1809 | 84 |
| 1860 | 56 | 1860 | 56 | 1898 | 56 | 1956 | 56 |
| 1898 | 42 | 1864 | 42 | 1956 | 42 | 1898 | 42 |
| 1956 | 33 | 1898 | 33 | 1860 | 33 | 1860 | 33 |
| | | 1956 | 28 | | | | |

Assumption No. 3 assumes that in the 1860 and 1864 floods, the levels reported are misleading because of obstruction by rafts of logs or similar obstacles, as discussed in Section 8. Assumption No. 4 assumes that the 1956 peak discharge was greater than that of 1898, which would well be, in view of the difference of only 100 cusecs in the computed discharges.

## 11. Effect of Urban Development

Figure 1 shows dotted the areas which may be developed in the future. Such development will not increase appreciably the total excess rainfall during the periods of intense rainfall of the storms, which is the governing factor causing the peak rate of flood discharge. As shown in Table II, initial loss is first satisfied before the excess rain has been applied to the synthetic unit hydrograph, so that this rain is falling on a saturated catchment and the infiltration rate on natural soil is negligible during the critical period of excess rain. Further, the truly impervious areas of the catchment - roads and roofs - are very small in area compared with the total area of the catchment, and domestic gardens tend to increase the loss rate.

The stormwater drainage system of urbanized areas will tend to increase the concentration rate of some storm flows, but the effect on the unit hydrograph shape would be minor.

Most important of all, Figure 2 shows that the really high rainfall rates occur in the upstream half of the catchment, which will not be urbanized in the foreseeable future.

## 12. Conclusion Regarding the Frequency of the 1956 Flood

The 1956 flood is of particular importance because great confidence can be felt in the flood levels reached over a wide area.

From the discussions of the preceding sections, it can clearly be stated with a high degree of confidence that the recurrence interval of a flood of the magnitude of the 1956 flood lies between 30 years and 50 years.

Weighing carefully all the evidence, the authors conclude that the best estimate of the recurrence interval of this flood is 38 years.

# Part II

## Flood Stage - Frequency Relation Throughout the City of Liverpool.

by

C. H. Munro

and

D. N. Foster

## 13. Introduction

In Part I of this report the discharge-frequency of floods at the Liverpool gauge was established. This relationship is shown in Figure 5.

The next step in this investigation was to convert the discharge-return period relationships in Fig. 5 into flood height - recurrence - interval relationships, i. e. to compile a stage-discharge relationship at Liverpool Bridge. As no streamflow measurements have ever been made at the bridge (a serious omission by the authorities concerned) this must be estimated by indirect methods.

Having obtained this stage-discharge relation, the final step involves an estimation of the flood gradients throughout the flood plain for floods of various magnitudes.

These two steps are described in Part II of the report hereunder.

## 14. Stage-Discharge Relationships at Liverpool Bridge

### 14. 1 Introduction

In the absence of measurements of discharge at Liverpool Bridge, indirect methods of computing a flood stage - discharge relationship must be used. The authors have used three methods as follows:-

(i) Use of previous hydraulic model studies regarding the effect on flood behaviour of the construction of a lake at Chipping Norton, as reported in Manly Water Research Laboratory Report No. 67/ 7, November 1967 (Reference 11).

(ii) Relating discharges computed in (i) of this report with flood levels at Liverpool Bridge given by Scholer (Reference 1).

(iii) Computing the value of Manning's "n" from the flood levels of the 1956 flood and the estimated discharge for this flood given in Part I and plotting a graph of stage versus discharge with this value of "n".

### 14.2 First Method

When undertaking the model studies on the effect on floods of a proposed lake at Chipping Norton (Reference 11), a relationship between stage at Liverpool Bridge and inflow to the model was estimated using Manning equation with various values of Manning's "n". It was found possible to verify the model over a small range of discharges, and this was used to obtain the best estimate of "n".

The stage-discharge relationship obtained in this manner is given in Figure 19 of Water Research Laboratory report No. 67/7 (Reference 11) and has been reproduced as curve A in Figure 6 of this report. As the inflow to the model included flow from Cabramatta Creek, this must be subtracted to obtain the discharge rating curve at Liverpool Bridge. The curve obtained by doing this is shown as curve B in Figure 6.

### 14.3 Second Method

In Part I of this report the discharge at Liverpool Bridge was estimated for various floods using rainfall-runoff relationships, whilst the flood stage reached by these floods at the Liverpool gauge has been estimated by Scholer 1966 (Reference 1).

A study of the levels reported by Scholer for the Sewage Treatment Works and the site of the wool washing plant reveal some inconsistencies. However, the authors have assumed that Scholer's levels at the Liverpool Bridge, particularly for recent floods, are reasonably accurate.

The discharges and reported flood stages are listed in Table IV.

Table IV

Flood Discharge - Flood Stage Relations at Liverpool Bridge
(Refer to Part I and Scholer (1966) )

| Date | Estimated Discharge cfs (see Part I) | Estimated Stage ft. on S.D. (Scholer, 1966) | Remarks |
|---|---|---|---|
| 1964 | 22,400 | 23.6 | |
| 1963 | 21,300 | 21.8 | |
| 1961 | 24,400 | 23.5 | |
| 1956 | 41,300 | 27.5 | Well documented |
| 1950 | 23,000 | 24.4 | |
| 1949 | 24,900 | 25.1 | |
| 1895 | 24,100 | 23.6 | Time distribution of rainfall not known |
| 1873 | 57,100 | 34.5 | Stage based on level of treatment works + 1.5 ft. |

The stage-discharge relationshipsfor each of these floods have been plotted as specific points directly on Figure 6.

14.4 Third Method

A third approach would be based on computations by the Manning equation in the reach upstream of Liverpool Bridge, using the 1956 flood for estimating the appropriate roughness parameter. In Part I the peak discharge for the 1956 flood was estimated at 41,300 c.f.s. whilst the approximate hydraulic gradient as obtained from reported flood levels is shown in Figure 7. Using these values and measured cross sections of the river, the corresponding value of the Manning roughness parameter "n" was calculated at 0.037. Assuming that the flood gradient does not change with flood level, the stage-discharge curve computed by Manning equation is shown as curve C on Figure 6. The assumption of constant flood gradient in this reach is incorrect because of the presence of Liverpool Weir. The gradient will actually change from a very flat slope at low discharges to the valley slope as the weir is completely drowned out as its backwater effects become negligible. Curve C will therefore tend to over-estimate the discharge at low stage and under-estimate the discharge at high stage.

### 14.5 Best Estimate of Stage-Discharge Curve

All of these three methods are subject to errors and the final relation accepted for the rating curve must be based on subjective judgement. Until the correct relationship is obtained by current meter streamgauging, it is recommended that the curve D shown in Figure 6 be adopted as the best estimate of the stage-discharge relationship at Liverpool Bridge.

## 15. Stage-Frequency Relationship Liverpool Bridge

The stage-frequency relationship at Liverpool Bridge can be computed from the discharge-frequency curve (Figure 5) and Curve D of the stage-discharge curve (Figure 6). This relationship is shown in Figure 7. The estimated flood stages for various flood frequencies is summarised in Table V.

Table V.

Flood Stage-Flood Frequency Estimates at Liverpool Flood Gauge

| Return Period of Flood (yrs.) | Estimated Stage on Standard Datum (ft.) |
|---|---|
| 10 | 23.4 |
| 20 | 24.9 |
| 40 | 27.7 |
| 100 | 31.0 |

## 16. Flood Stage-Frequency Relationships at Various Locations on Flood Plain

### 16.1 Introduction

In Section 15 the stage-frequency relations at Liverpool Bridge were established. To transfer these values to other locations in the flood plain, it is necessary to determine the hydraulic gradients for floods of various magnitudes. Accurate computation of the flood gradients would require a great deal more survey data and information on channel and overbank roughness than is presently available in the Liverpool area. The cost of obtaining this information is beyond the scope of this study. Fortunately, a detail survey of the 1956 flood levels has been made by Standen (1968 - Reference 2) and these can be used to establish the hydraulic gradient for this flood much more accurately than could be achieved by any method of computation. Consequently, the gradient of the 1956 flood can be used with some confidence for estimating flood stage frequency relationship at various locations on the flood plain as discussed below.

### 16.2 1956 Flood Gradient

Flood levels reached in the 1956 flood have been investigated by Liverpool Council and are given in the report on the Georges River by Standen (1968 - Reference 2). Although these levels are generally consistent, there are some that are obviously wrong. For example, in the vicinity of the treatment works there are two reports of flood levels at RL. 20.0 which are more than 5 ft. lower than the levels actually reached. This clearly illustrates the danger of accepting unsupported reports of historic floods as has been discussed in some length in Section 2 of Part I.

In addition to the levels taken by Liverpool Council, some further stages reached by the 1956 flood in the Chipping Norton area were taken by the Water Research Laboratory during studies to investigate the hydraulic effects of a proposed lake in this locality (W. R. L. Report No. 67/7, 1967 - Reference 11). These show general agreement with those obtained by the Council.

To estimate the flood gradient, the mean path of the high velocity flood flows should be considered. During a major flood there is a considerable amount of overbank flow and many of the sharp bends in the river are short circuited. The dry weather flow channel is no longer a suitable delineation of the main flood flow. In estimating the flood channel backwater, areas which carry no flow must be separated and allowances made for topography and the effect of overbank roughness such as trees and houses on the resistance to flow. With the information available in the Liverpool area this can only be done approximately. The position of the mean flood channel has been estimated from an inspection of the available topographical plans and a knowledge of the flood behaviour in Chipping Norton as indicated in the model studies of this area. The estimated location of the flood channel is shown in Figure 8.

Using the flood levels obtained in the 1956 flood and the estimated location of the flood channel, the hydraulic gradient has been plotted as shown in Figure 8.

## 16.3 1956 Flood Stage Contours

Flood levels in the backwater areas which carry no appreciable flow are directly related to those along the main flood channel and estimated contours of flood stage in the Liverpool Municipality for the 1956 flood are shown in Figure 8.

The term 'contour' used above is a line of equal flood height reached in 1956 at various sections of the river length. It is in general approximately at right angles to the main flood flow and is quite distinct from the topographical contours.

On Fig. 8 the approximate limits of 1956 flooding are also shown. These are based on the contours of the County of Cumberland series and are known to be inaccurate. Therefore, no reliance should be placed on this line of Fig. 8. When development in various locations shown on the plan is under consideration, it will be essential that the area in question be surveyed, and levels throughout on standard datum be established, and compared with the "flood stage contour" of Fig. 8 for the flood of appropriate recurrence interval.

## 16.4 Flood Stages for Floods of Varying Frequencies

The stage contours shown in Figure 8 will give a close approximation to flood levels at various locations over the flood plain for the 1956 flood, which is estimated to have a recurrence interval of 38 years. For floods having different frequency of occurrence, it is strictly necessary to estimate the flood gradients for the changed discharge. There is insufficient information to do this accurately and it has been assumed that the gradients for all floods will be the same as that in 1956. This will be a reasonable assumption for all major floods provided the flood channel is not materially altered. Along the Georges River near Liverpool the flood channel is controlled by a number of constrictions produced by the natural topography and once significant overbank flow has occurred it could be expected that the flood channel will be essentially constant.

Some data are available from the Department of Public Works to check the gradient of the 1961 flood (the estimated 1 in 11 year flood) with that of the 1956 flood. The differences in flood levels at various locations are shown in Table VI. If the gradients were identical, these differences would be identical and generally this is correct to within ± 0.5 ft. which is well within the accuracy to be expected from a more complete analysis.

Table VI

Comparison of Flood Levels in 1956 and 1961.

| Location | 1956 Flood Level | 1961 Flood Level | Diff. in Level |
|---|---|---|---|
| Liverpool Bridge | 27.5 | 23.5 | 4.0 |
| Sewerage Works | 25.0 | 21.7 | 3.3 |
| Hollywood | 17.5 | 15.0 | 2.5 |
| Milperra Bridge | 16.0 | 12.4 | 3.6 |
| East Hills | 12.4 | 8.8 | 3.6 |
| | Mean Diff. | | 3.5 |

Having accepted that the 1956 gradient applies to all major floods, the stage reached by floods having varying frequency of occurrence can be obtained. From Figure 7, the difference in stage at Liverpool Bridge for the particular flood in question and the 1956 flood (the 1 in 38 year flood) is obtained. The level at various locations over the flood plain is obtained by adding this difference to the flood stage contours of the 1956 flood as shown on Figure 8.

### 16.5 Effect of Proposed Lake at Chipping Norton on Floods

The effect on floods of a lake at Chipping Norton has been previously investigated. The results of this study are described in Water Research Laboratory No. 67/7, November, 1967 (Reference 11). Although the present study does not invalidate any of the results or conclusions reached in this investigation, it does indicate that a different flood frequency should be allocated to the discharges tested. The 1 in 25 year flood referred to in the above report approximately corresponds to the 1956 flood discharge which is now estimated to have a recurrence interval of 1 in 38 years. The 1 in 100 year flood referred to in the above report corresponded approximately with the 1873 flood, which is now estimated to have a recurrence interval of between 150 to 200 years.

The pertinent graphs from the model study (Reference 11) which show the reduction in flood levels for various flood frequencies have been included in this report (Figures 9 and 10) with recurrence intervals altered to accord with the present findings.

## 17. Summary and Conclusions

Part I of this report describes the estimation from rainfall records of the peak flood discharges of all major floods which have occurred in the period 1873-1968 inclusive.

It also reviews the historical evidence of flood peaks for the period 1800-1872 inclusive.

The conclusion is reached that the recurrence intervals of floods equal to or greater than the 1956 flood is between 30 and 50 years, and that the best estimate is 38 years. Furthermore, the recurrence intervals of other flood peak discharges are given in Fig. 5.

Part II of this report first describes the method estimating the peak height reached at Liverpool Bridge for floods of various recurrence intervals. Results are summarised in Fig. 7.

Secondly, in this part, estimates are made of the peak water level gradient down the river system from Liverpool Bridge to Milperra Bridge for floods of various magnitude. From consideration of Fig. 7 and these estimated gradients, peak flood contour levels were computed at various locations in the river system for floods of recurrence intervals of 10, 20 and 40 years. The results are summarised in Fig. 8.

Note: A print of Figure 8 to a scale of 800 ft. to 1 inch is available at a small fee from the Water Research Laboratory.

References

Frequency of Floods in City of Liverpool.

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3. Young, R. A. - "The Flood Problem" Proc. of University of New South Wales Symposium on "The Water Resources of Australia - Their Control and Development" 1955.

4. Institution of Engineers, Australia - "Rainfall and Runoff" 1958.

5. Cordery, I. - Weather Bureau Internal Report.

6. Cordery, I. - "Initial Loss for Flood Design and Forecasting" Civil Eng. Trans. Institution Engineers, Australia - in press.

7. Commonwealth of Australia - Bureau of Meteorology - "Results of Rainfall Observations in Australia" Appendix IV - "Notes on Floods" 1948.

8. Linsley and Franzini - "Water Resources Engineering" - McGraw Hill, 1964.

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10. Herschfield, D.M. "An Empirical Comparison of the Predictive Value of Three Extreme-Value Procedures" J. Geophys. Res. Vol. 67 pp. 1535-1542, 1962.

11. Munro, C.H., Foster, D.N. and Harris, G. - "Effect of Construction of a Proposed Lake at Chipping Norton on Behaviour of Georges River" University of New South Wales Water Research Laboratory Technical Report No. 67/7, November 1967.

The following publication is also relevant.

12. Munro, C. H., Foster, D. N., Nelson, R., and Bell F. C. - "Georges River - Hydraulic, Hydrologic and Reclamation Studies" University of New South Wales Water Research Laboratory Report No. 101, December 1967.

# Appendix A.

## Frequency of Floods in City of Liverpool.

### Brief Notes from Historic Documents etc.

(1) 1800 (March)

"Notes on Floods" (Ref. 7) "Towards the end of the month much damage was inflicted on corn crops by floods in Hawkesbury and Georges Rivers. Some lives were lost".

(2) 1806

"Notes on Floods" say that "from 20th to 30th March very great damage was done in Hawkesbury, levels being 3 to 10 feet higher than any previous flood."

(3) 1809

"Notes on Floods" says "25th to 27th May - Hawkesbury rose rapidly, all lower situations under water. Georges River was 34 feet above normal level".

"Sydney Gazette" says "At the same time as the Hawkesbury flood May 26th 1809, the water in Georges River was 12 feet higher than the memorable flood of 1806; at 6.30 a.m. on 26th it was at its highest, 34 feet above the usual level".

(4) 1817

"Sydney Gazette" 8th March says "Hawkesbury level came within 10 or 12 inches of the flood level of August 1809 at Windsor." There is no mention of Georges River, although there are articles on news at Liverpool and Parramatta.

(5) 1860

"Sydney Morning Herald" 12th May, 1860 (page 10)
Article on floods of 27th and 28th April. Worst flood for more than forty three years. "..... Georges River at Liverpool, in a most extraordinary manner, made itself a fresh bed, so that the dam there (erected at a cost of some thousands of pounds), is now practically useless".

"We have heard of only three or four houses in the whole (Holdsworthy) district which were not dangerously flooded".

Standen (Reference 2) quotes: "In the book entitled "Liverpool" by W. L. Havard it is stated that at the end of April 1960 the most serious floods within living memory of the oldest inhabitants covered miles of country in the district". Also, he quotes: "On p. 136 of the Transactions of the Royal Society of New South Wales for 1869, Mr. Mayes stated 'While engineer of the Australian Paper Co. in 1865, I ascertained the highest known flood level (1860) near the dam at Liverpool to be 32 ft. above the high level of Spring Tides.' ". Standen says this would be 35 ft. on Standard Datum at Weir.

(6) 1864

Reported in "Sydney Morning Herald", June 13th: "At Liverpool the river was nearly as high as it was during the great flood of 1860; but yesterday evening it had fallen sixteen feet".

(7) 1867

All news of floods in "Sydney Morning Herald" is of floods in the Hawkesbury, with no mention of Georges River. Standen (Ref. 2) states that on page 167 of a memorandum by Moriarty on a proposal to supply Sydney with water from Georges River, there are references to big floods which occurred in 1857 and 1867.

"Notes on Floods" by the Weather Bureau in 1948 says "1967 - 23rd June - Disastrous floods on the Hunter, Hawkesbury, Murrumbidgee and other rivers. On 23/6/67 Hawkesbury rose 62 ft. 7 inches above usual level at Windsor. Highest flood on record; caused great destruction of property in Nepean and Hawkesbury basins along lower reaches. (Note: This level of 62 ft. has been authenticated and the highest level since 1867 is 50 ft

(8) 1873 (22-27/2/1873)

1. Newspaper Reports.

Town and Country Journal (March 1st, p. 262: "We have had the highest flood here that, as far as I have been able to ascertain, has ever been known in the district".

Gives detailed description of rise of flood with special reference to conditions at wool washing establishment.

March 8th: Further reports on damage by flood at Liverpool. A breach in the dam "over 8 feet in width" was mentioned.

"Evening News"( Feb. 27th ) :" The flood is the highest known at Liverpool. River began to rise rapidly on Tuesday morning (25th). Mr. Samuel's machinery at woolwashing carried away;seven feet of water in home of Captain Sadlier and family. "

"Sydney Morning Herald"(Feb. 27th, 1873, page 5) : "The highest flood known in the district occurred at Liverpool on Tuesday night (25th)".

"Some idea of the height of the flood may be obtained by those who know the country, when it is stated that Georges River and a creek which runs through Mr. Wooll's farm, met.

2. Rainfall Reports

According to "Monthly Meteorological Observations 1870-73" published by Sydney Observatory, there are monthly rainfall figures for:-

| | Total | Greatest Fall in 24 hours. |
|---|---|---|
| Liverpool | 14.085 | 5.410 (26th) |
| Cordeaux River | 23.770 | 10.980 (26th) |
| Wilton | 18.450 | 9.050 (26th) |
| Parramatta | 9.220 | 3.510 (26th) |
| Sydney | 18.556 | 8.900 (25th) |

Official Weather Bureau records provide daily 9 a.m. readings for Appin, Maryland, Parramatta, Cordeaux River, Wilton, Sydney, Wollongong and Liverpool. Daily isohyetal maps can be drawn for the catchment by linear interpolation between stations. These give the daily 9.00 a.m. rainfalls, averaged over the whole area of the catchment, as shown in Table II of Part I of the report.

This storm has, in recent years, been thoroughly studied by the Weather Bureau and results are available in an internal Weather Bureau report. For example, 8.2 inches fell at Sydney Observatory in 7 hours (time not specified) and also 10 inches of rain fell at Appin between 9.00 a.m. and 4.00 p.m. on 25th February. From such reports the time pattern of rain could be estimated fairly accurately.

3. Reported Flood Levels 1873

1. P.W.D. Report (quotes M.W.S. and D.B.) R.L. 33.0 at Sewerage Works ≈ 34.5' at Traffic Bridge

2. P W D. Plans (borrowed in 1965) R.L. 33.1 at Pump House ≈ 34' at Traffic Bridge

3. M.W.S. and D.B. Level Book 3326, folio 14, Surveyor Arkell. During a survey carried out on 5.3.37 a level was taken on a peg near Mill Street, Liverpool, giving R.L. 38.97 ≈ 38' at Traffic Bridge

   In the remarks column the peg was originally noted as the 1860 flood level but 1860 has been crossed out and 1873 placed over it.

4. Sonter's report (Fairfield Council) quotes level marked at Liverpool Sewerage Works has R.L. 33 ≈ 34.5' at Traffic Bridge

(9) 1875 (3-7/6/1875

"Sydney Morning Herald" of 8th and 9th June report floods at Windsor but not Georges River.

(10) 1883 (10-14/5/1883

No newspaper evidence of a major flood.

(11) 1887 (12-14/4/1887

Camden Bridge reported submerged by flood and "Georges River almost in flood at Liverpool".

(12) 1889 (25-29/5/1889

"Town and Country Journal": June 1st 1889: Severe floods reported in Cook's River, Hawkesbury, Hunter, at Kiama and Sydney suburbs but not Liverpool or Georges River.

"Daily Telegraph" May 28th, 29th, 30th : Heaviest 4 day rains on record reported at Sydney and Windsor. Flooding in suburbs but Georges River not mentioned.

Floods at Windsor, Hunter, Castlereagh, but not Georges River.

(13) 1890 (23-25/3/1890

"Town and Country Journal" March 29th: Floods at Windsor but not Liverpool.

"Daily Telegraph" March 26th (p. 5): "At Liverpool, Georges River is in heavier flood than at any time since 1872, when Sir Saul Samuel's woolwashing machinery was swept away. All low lands on the southern bank of the river are covered to a depth of from 3 ft. to 4 ft., judging from the tops of the fences peering above the water".

| | | | | |
|---|---|---|---|---|
| Canley Vale rain: | 24th | 2.46: | 25th | 5.50" |
| Merrylands rain: | 24th | 2.04" | 25th | 5.54" |

(14) 1894 (18-22/3/1894)

No evidence of major flood.

(15) 1895 (19-23/1/1895)

"Daily Telegraph" January 24th, 1895: "Liverpool: Heavy rain has been falling almost continuously since Monday last flooding the low lands and causing the river to rise very rapidly..... river is expected to be exceptionally high."

January 25th, 1895: Reports of floods at Windsor, Grafton and Maitland but not Liverpool. Gives a table of flood heights at Maitland going back to 1826.

(16) 1897 (23-27/7/1897)

Reports of heavy rain at Camden and "moderate floods throughout central coast" Liverpool rain 1/7/1897 = 4.23 inches. No reports of flood damage on Georges River.

(17) 1898 (13-17/2/1898)

(1) Rainfall

Good data on daily rainfalls are available, and also adequate data to estimate approximate time pattern. This rainfall has also been recently studied by the Weather Bureau and results are contained in an internal report.

(2) Newspaper Reports

"Liverpool Herald" reports a violent storm on Sunday night: "Rain fall in torrents and the wind blew with terrific force..... Georges River rose rapidly and the lowlands surrounding Haigh's Woolscouring Works were submerged, the water finding its way to some of the buildings..... Persons residing close to Clinch's Pond, which overflowed, had their premises surrounded with water and in danger of being submerged".

"Campbelltown Herald"

Feb. 16th: Reports second largest flood known at Camden with severe damage. No report of floods in Georges River.

Feb. 23rd: Reports that floods in district were the "most destructive at Camden".

"Town and Country News: Feb. 19th: Reported that portion of Cataract Dam had burst - second largest flood known at Camden - no reports of floods at Liverpool.

(18) 1900 (4-7/7/1900)

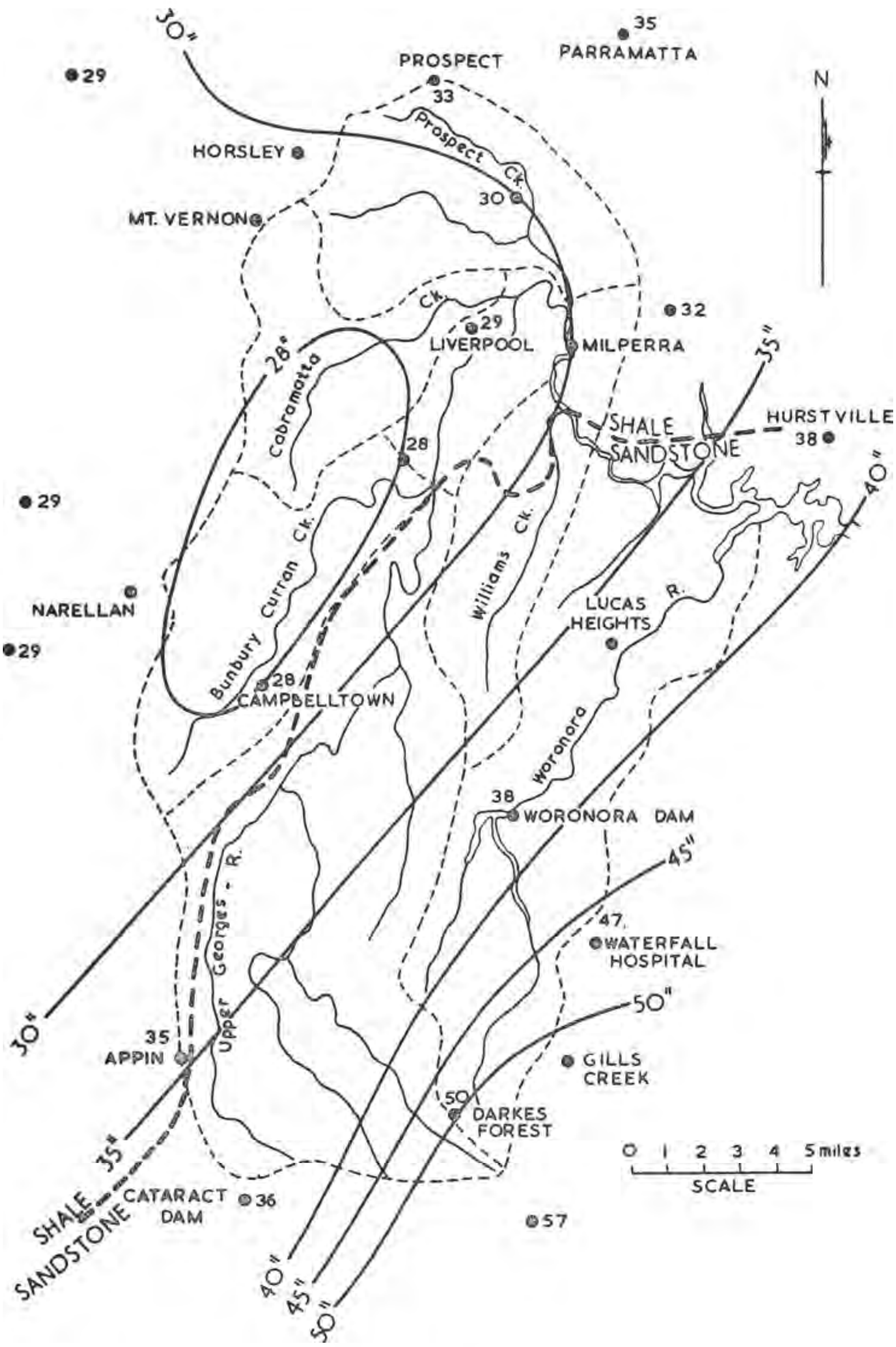
"Campbelltown Herald": Floods not mentioned.

"Liverpool Herald": July 7th says "Heavy and continuous rain has fallen throughout the district since Tuesday evening last, with the result that Georges River and the various creeks are in flood".

July 14th - not mentioned.

"Daily Telegraph" July 7th: Floods at Windsor, Yass and Camden but not Liverpool. Greatest flood in 33 years at Penrith and Windsor.

FIGURE 1 is not in the original print copy.




GEORGES RIVER

FIGURE 2: MEAN ANNUAL RAINFALL

CE-E-7150

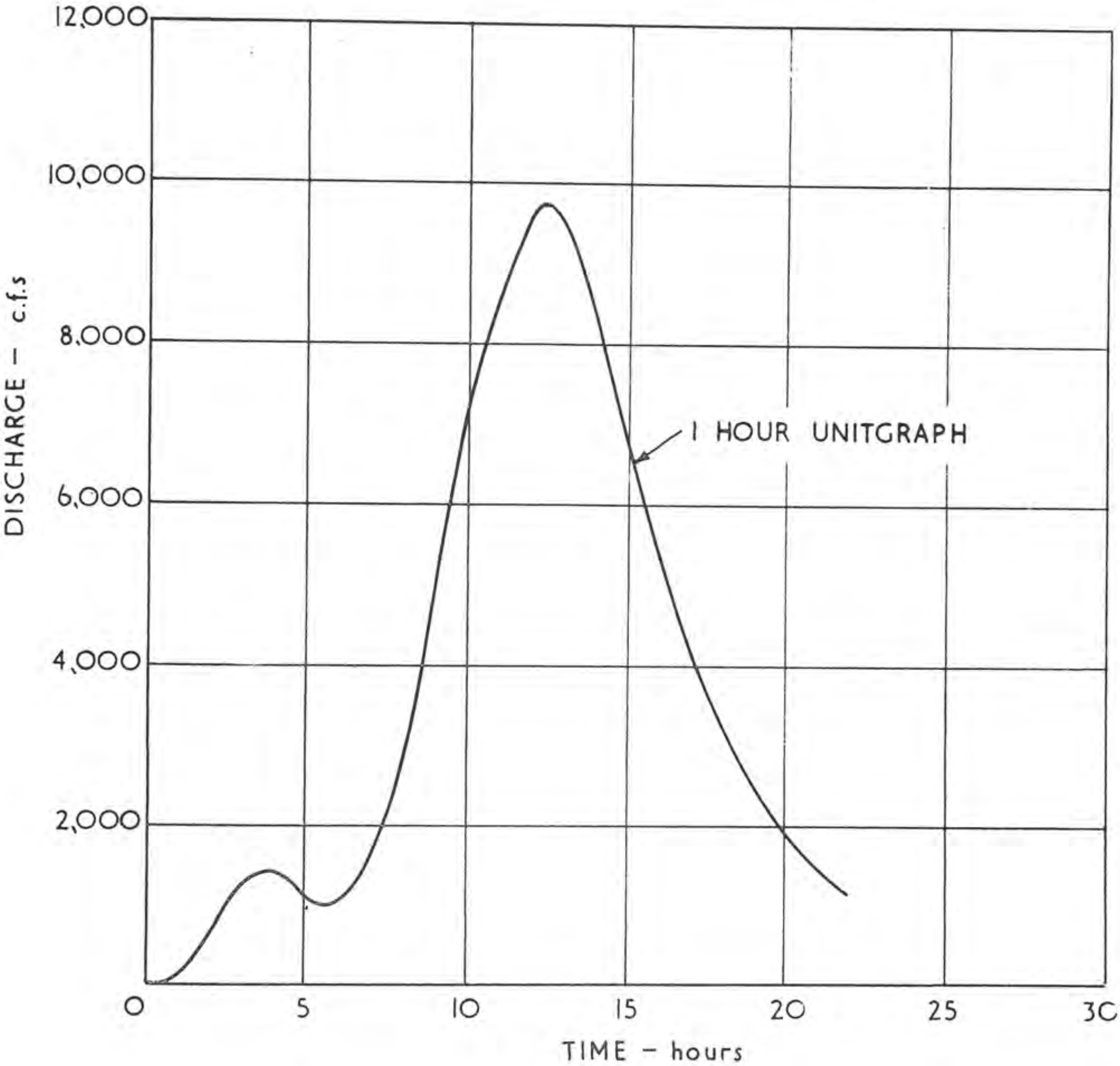



FIGURE 3 : UNITGRAPH FOR GEORGES RIVER AT LIVERPOOL

CE-E-7579

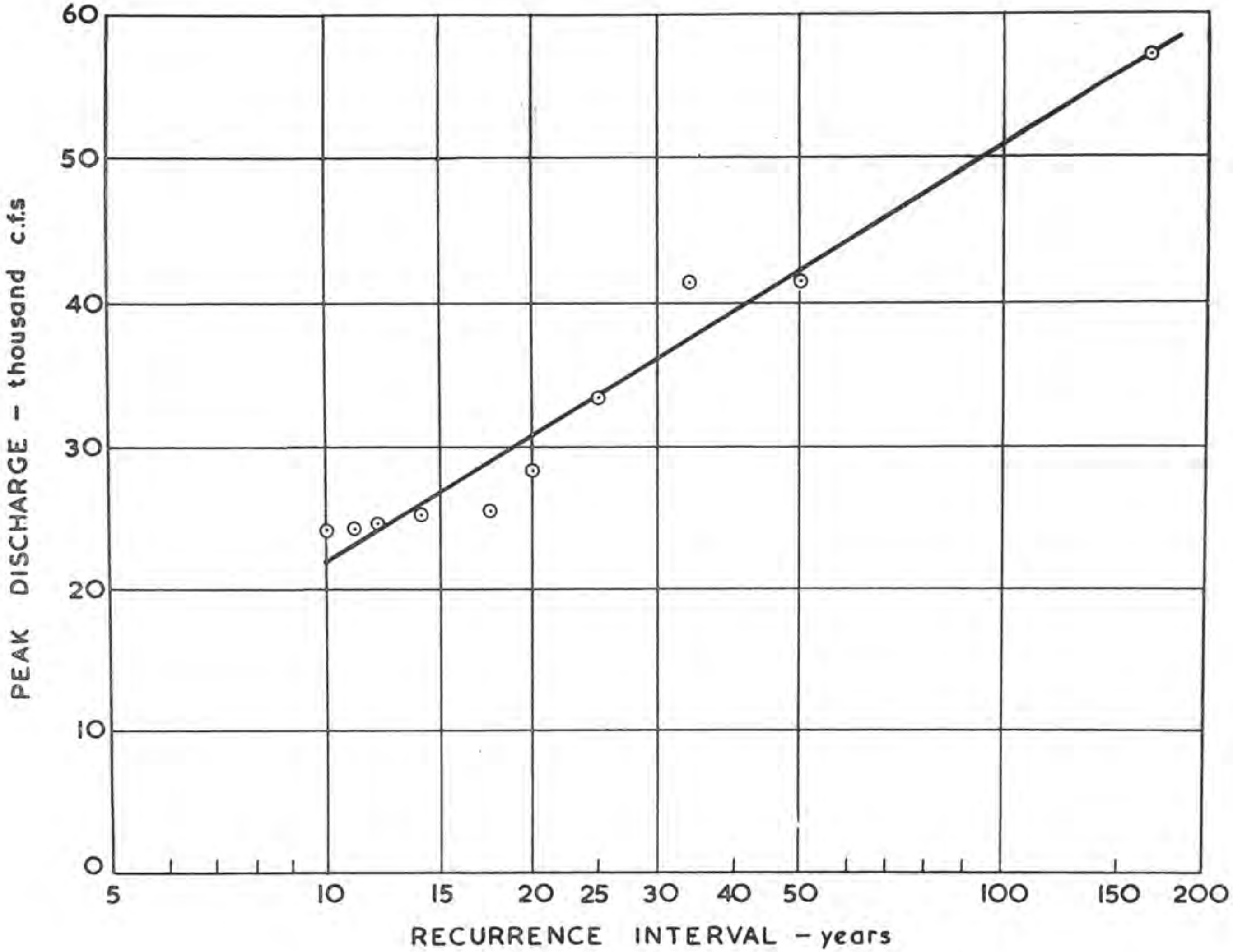



FIGURE 4: GUMBEL DISTRIBUTION OF FLOOD PEAK DISCHARGES

CE-D-7580

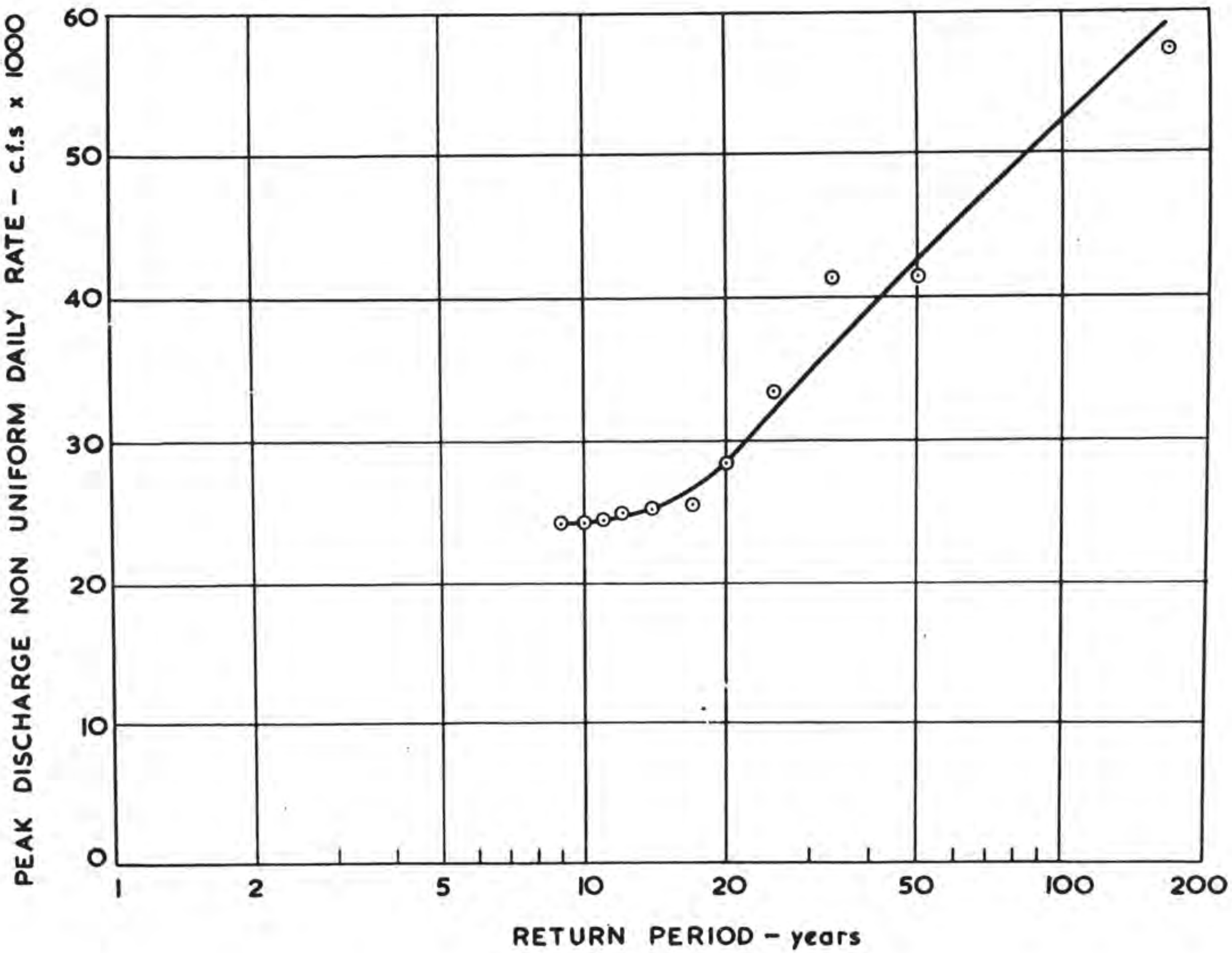



FIGURE 5: DISCHARGE-FREQUENCY RELATIONSHIP
LIVERPOOL BRIDGE

CE-D-7581

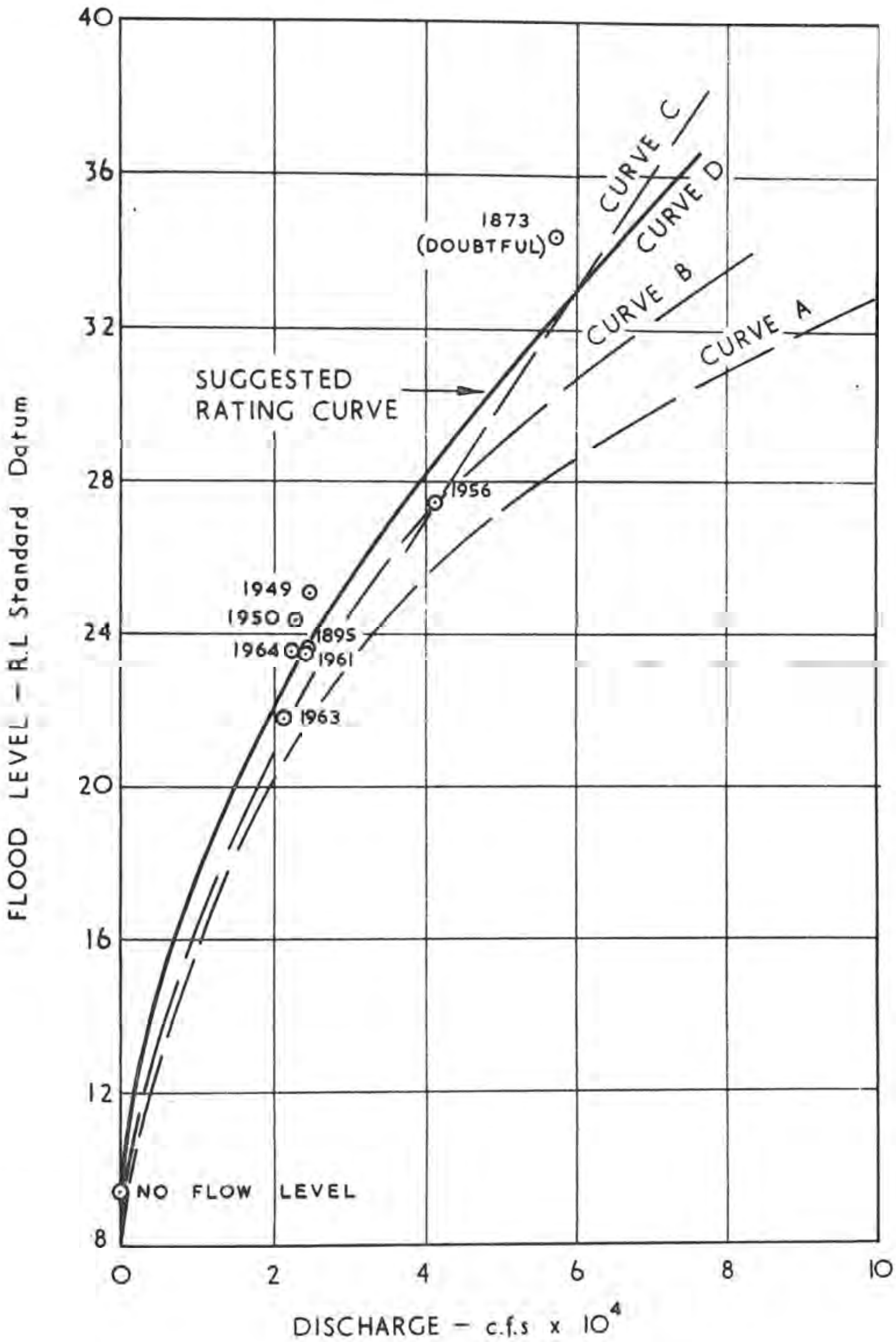



FIGURE 6: RATING CURVE AT LIVERPOOL BRIDGE

CE-E-7582

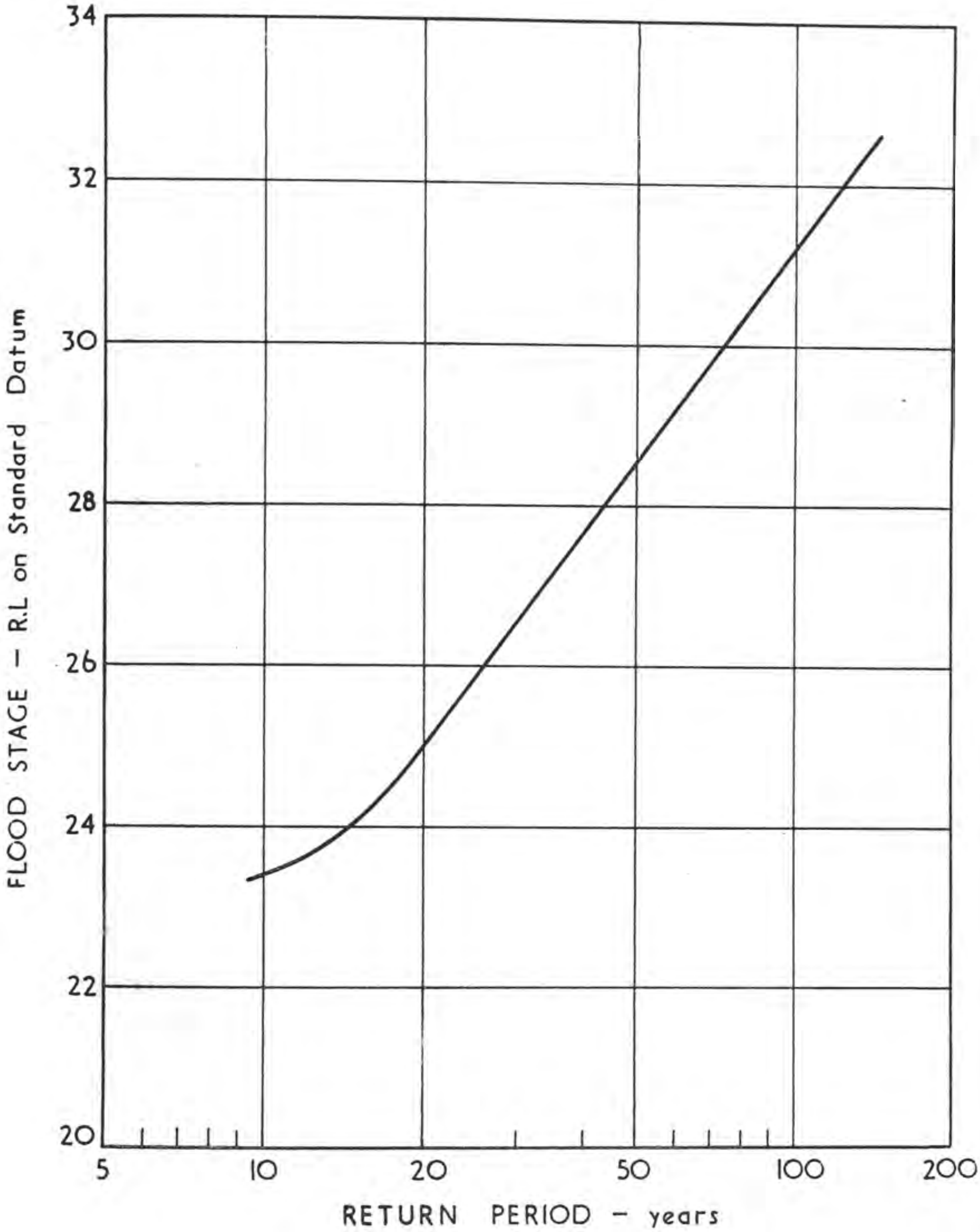
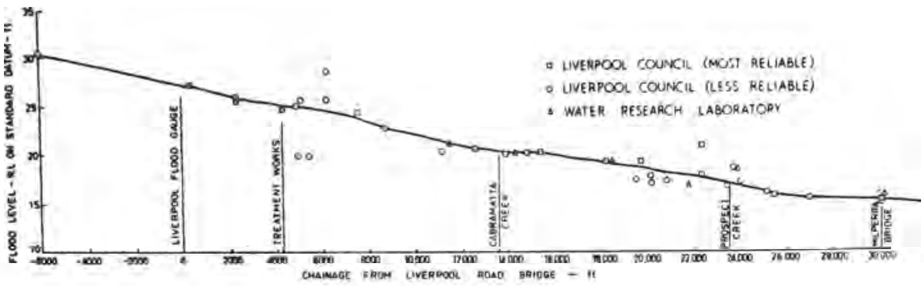



FIGURE 7: STAGE FREQUENCY RELATIONSHIP
LIVERPOOL BRIDGE

CE-E-7583

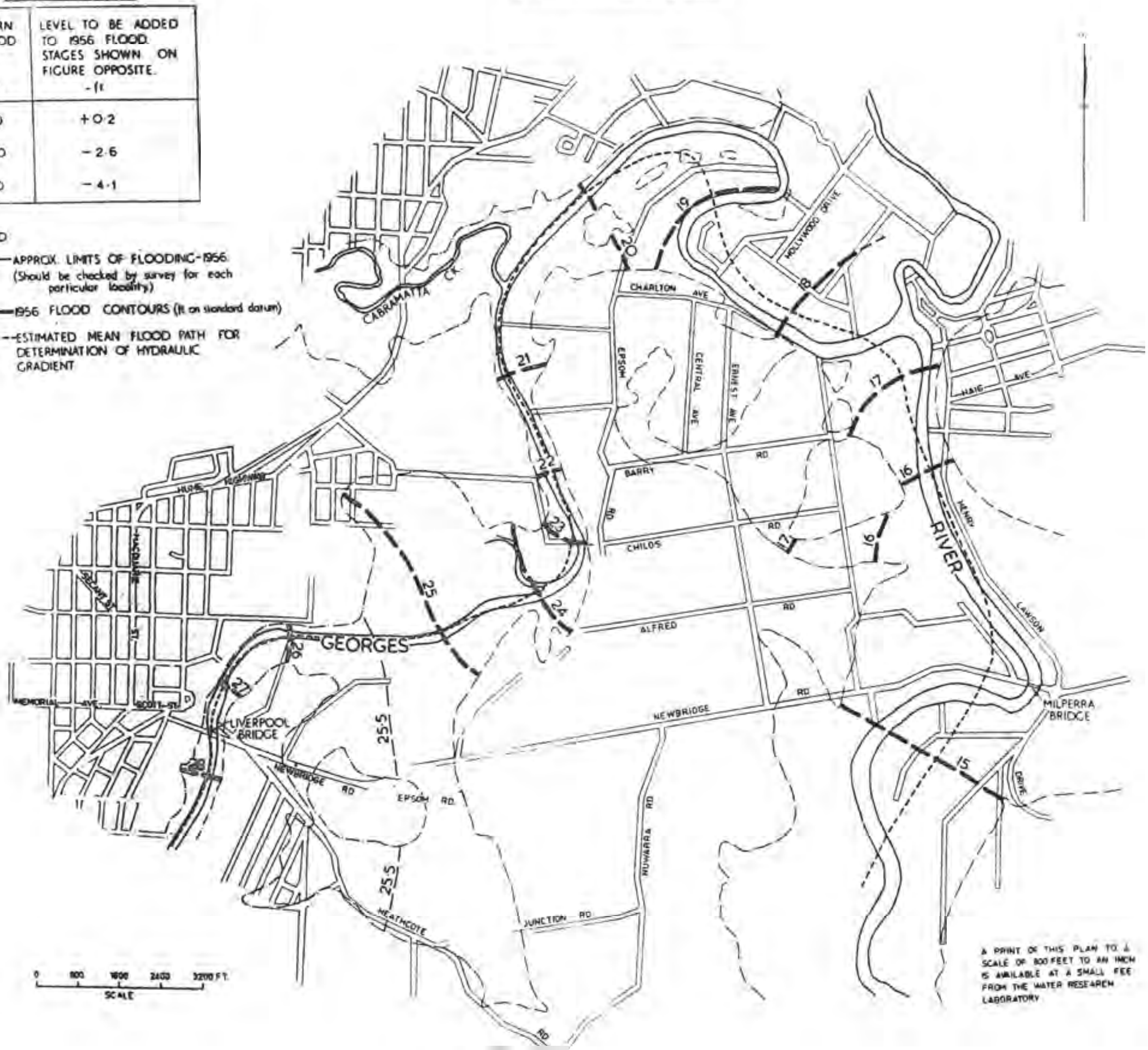



1956 FLOOD GRADIENT

STAGES FOR FLOODS OF VARIOUS FREQUENCIES

| RETURN PERIOD -yrs | LEVEL TO BE ADDED TO 1956 FLOOD. STAGES SHOWN ON FIGURE OPPOSITE. -ft |
|---|---|
| 40 | +0·2 |
| 20 | −2·6 |
| 10 | −4·1 |

LEGEND
- — —APPROX. LIMITS OF FLOODING-1956. (Should be checked by survey for each particular locality)
- ▬ ▬1956 FLOOD CONTOURS (ft on standard datum)
- -----ESTIMATED MEAN FLOOD PATH FOR DETERMINATION OF HYDRAULIC GRADIENT




1956 FLOOD CONTOURS

**FIGURE 8: PEAK STAGES FOR THE 1956 AND OTHER FREQUENCY FLOODS**

CE-A-7584

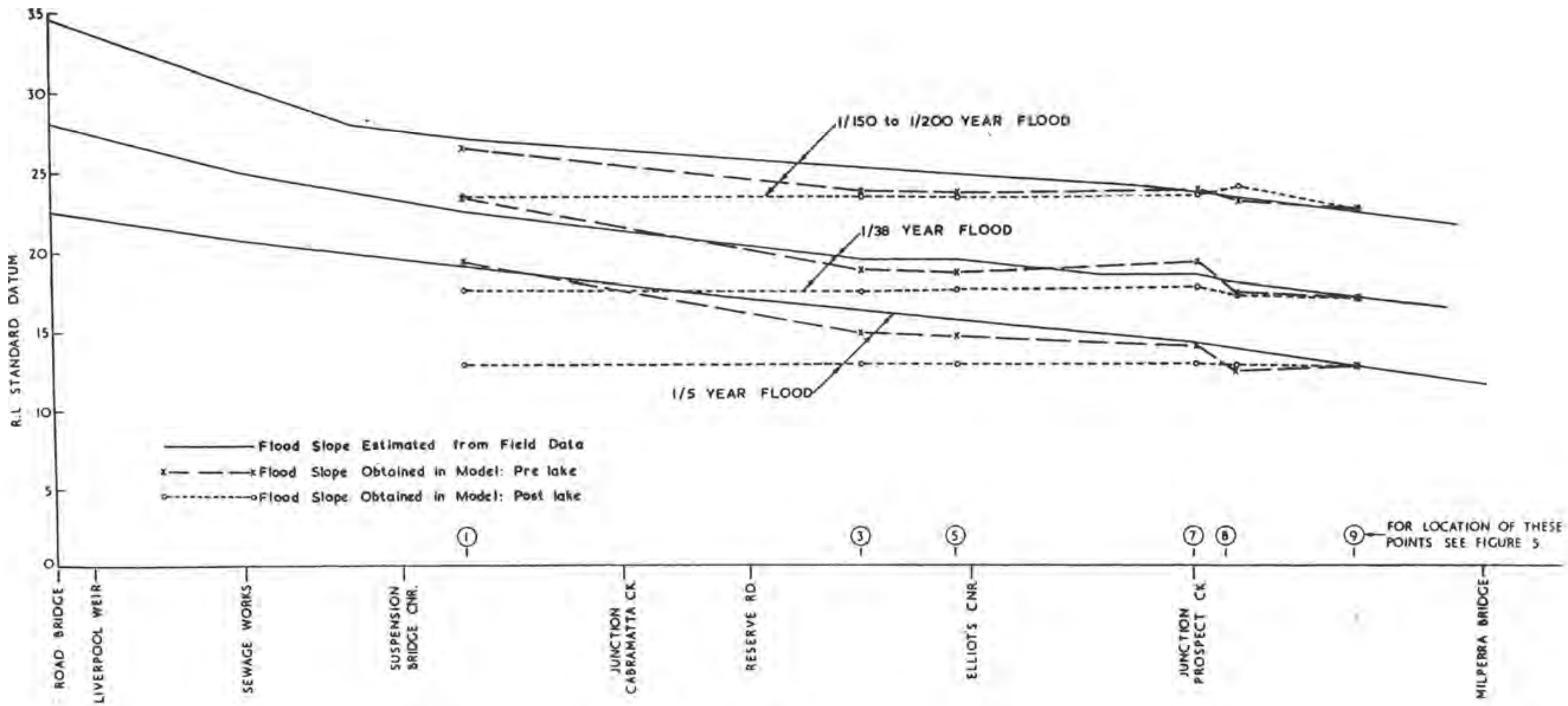
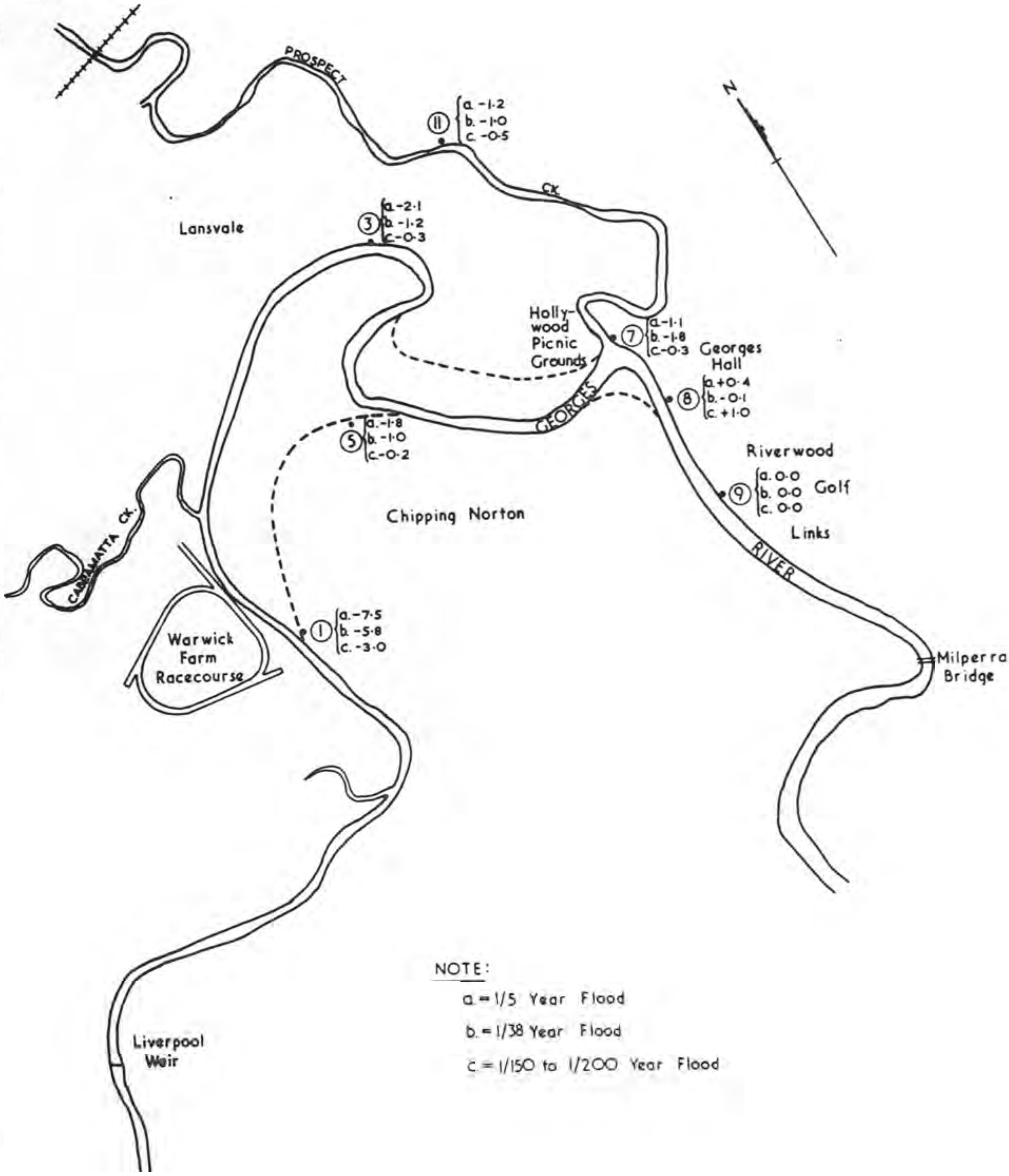



FIGURE 9: FLOOD LEVELS FOR BOTH PRE-LAKE AND POST-LAKE CONDITIONS

(FROM REFERENCE 11.)

CE-C-7235




CE-D-7236

**FIGURE 10: EFFECT OF LAKE ON FLOOD LEVELS**
(FROM REFERENCE 11.)

CE-D-7236