STORM AVERAGE LOSS RATES*

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SUMMARY

The disposition of storm precipitation is outlined and definitions of various storm losses explained. Reasons for non-homogeneity of published data on infiltration indices are discussed; they fall into two main categories, misinterpretation of definition and variation in method of calculation of the indices. The need for standardization is stressed. Relations between the average loss rate and the duration of excess precipitation are given for some Australian and New Zealand catchments, and uses of the average loss rate are discussed.

INTRODUCTION

The estimation of flood discharges using unitgraph techniques requires a knowledge of the magnitude of storm loss rates, or infiltration indices, for various conditions of soil type and antecedent moisture, and cover. A relation exists between the average storm loss rate and the duration of excess precipitation. The average loss rate is the most useful of the various infiltration indices for large heterogenous catchments and an extension of the type of relations described to all hydrologic regions in New Zealand would facilitate more precise estimation of flood discharges.

DISPOSITION OF STORM PRECIPITATION

The volume of surface run-off from a catchment is always less than the volume of precipitation which generates it, and the difference is dependent on both the storage capacities of the vegetation, upper soil layers, and deeper aquifer, and on storage in surface depressions.

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*Presented at N.Z. Hydrol. Soc. Technical Session, Wellington, Dec., 1964.
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Most of the initial precipitation is intercepted by vegetation and is subsequently evaporated. When this interception loss is satisfied, precipitation falls on the surface, filling depressions and infiltrating into the soil. The volume of water retained in depressions is termed depression storage and some of this may be lost to evaporation.

When the above initial losses are satisfied the precipitation will continue to infiltrate. It is important to remember that in large heterogeneous catchments, these storm losses may not occur simultaneously over the whole area because of variations in soil type, cover, topography and rainfall. The maximum rate at which water can enter the soil at any instant is termed infiltration capacity, and surface run-off will not occur unless the rate of precipitation exceeds the infiltration capacity of the soil.

Infiltration capacity depends mainly on the type of soil, the degree of compaction of the soil surface layer, and the type of vegetal cover. The initial infiltration capacity for given soils and cover conditions is dependent also on antecedent wetness of the soil and to a certain extent on the season of the year.

Excess precipitation which subsequently flows overland to reach the stream is known as surface run-off. A portion of the water which infiltrates into the soil may travel downhill at relatively shallow depths towards the stream and re-emerge to flow overland. This is referred to as interflow. The combination of surface run-off and interflow is known as direct run-off as distinct from surface run-off referred to above.

The remainder of the water which has infiltrated into the soil may either percolate to the water table and re-emerge in the stream bed as ground water or base flow, or may be held in the upper layers of the soil by capillary forces to be subsequently available for plant growth and transpiration.

Thus the relation between storm precipitation and run-off is complicated. Techniques have been developed to arrive at values for each section of storm rainfall, as defined above, but these are mostly applicable to small single-complex catchments. Owing to the heterogenous nature of larger natural catchments ($>$ 1 sq. mile), these techniques become unwieldy and more approximate and, for this reason, methods have been developed for calculating the average rates of capacity loss during the storm period.

CALCULATION OF STORM AVERAGE LOSS RATE

Non-homogeneity of Published Data

A degree of non-homogeneity exists in published data on loss rates owing mainly to (a) a difference in interpretation of definitions, and (b) a difference in method of analysis. This non-homogeneity necessitates a certain amount of care and close scrutiny when using the data elsewhere.

Differences due to Definition

Firstly, the terms phi index and storm average loss rate are synonymous. Linsley et al. (1949) define the phi index as "the average rainfall intensity above which the volume of rainfall exceeds the volume of surface runoff." The term has been defined also (Anon. 1949) as "the average rainfall intensity over and above which the mass of rainfall (supra rain) equals the mass of run-off." Laurenson and Pilgrim (1963) define the average loss rate as "the average rate of capacity loss to surface run-off during the supply period of the storm."

The first definition, which applies to surface run-off, implies that base flow and interflow must be deducted from the total flow hydrograph before calculating the loss rate. However, Toebes (1961) recommends that only base flow should be separated from the hydrograph.

The author prefers to carry out the analysis on surface run-off only because it is more convenient when the data is subsequently used in the application of unitgraph techniques, owing to the shorter base length of the surface run-off hydrograph. Provided interflow does not represent a great proportion of the total run-off this does not lead to great differences in estimated peak discharges.

Non-homogeneity also results from the use of the definition of Laurenson and Pilgrim who use only the supply period of the storm, or the overall period during which excess precipitation occurs. From the total storm is deducted an amount equal to the estimated initial losses; and this may, depending on the initial intensity of the precipitation and on the degree of antecedent catchment wetness, lead to a difference in the calculated loss rate.

Fig. 1 illustrates the difference which can arise for two storms having different temporal patterns. The author has not used Laurenson and Pilgrim's method because:

(a) Little is known about the magnitude of initial losses for various types of cover and physiography.

(b) In large catchments, there can be initial losses in some portions of the catchment at the same time as infiltration in other areas.

Differences due to Method of Storm Analysis

There are two main methods for loss rate analysis. The "average storm" method assumes, after calculation of catchment mean precipitation, that the one hyetograph applies equally to all points within the catchment. This assumes that precipitation excess is being generated simultaneously and at the same rate, throughout the catchment; a condition which may not be obtained in many larger (> 1 sq. mile) catchments.

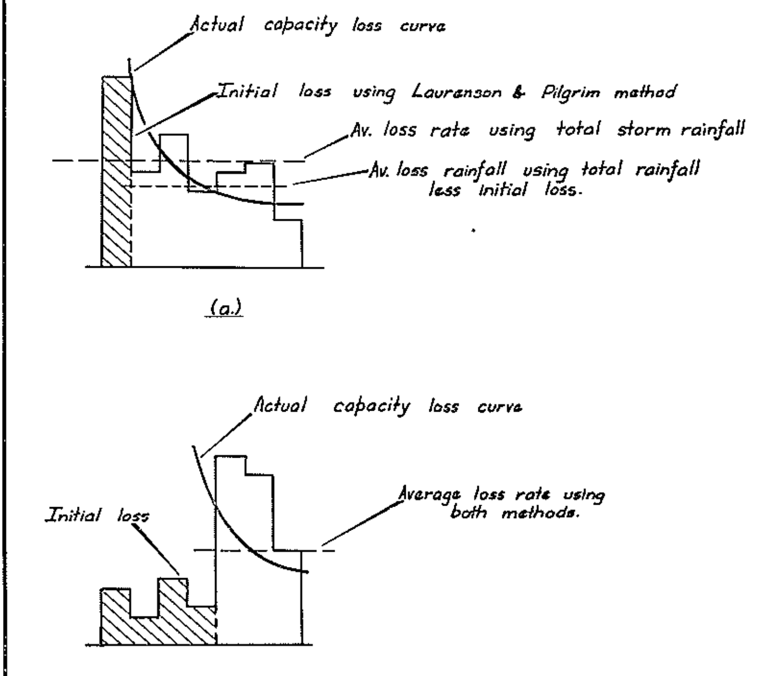


FIG. 1

The Horton (1937) method allows for areal variation of storm precipitation. This method requires the division of the catchment into sub-areas within which precipitation is assumed to be uniform. The sub-areas may be Thiessen polygons, or areas between isohyets. The precipitation temporal pattern for each sub-area is assumed to be the same as that at the nearest recording raingauge and several trial values of loss rate are applied to the precipitation for each sub-area. The resulting precipitation excess for each area is weighted and summed to give the total precipitation excess for the catchment.

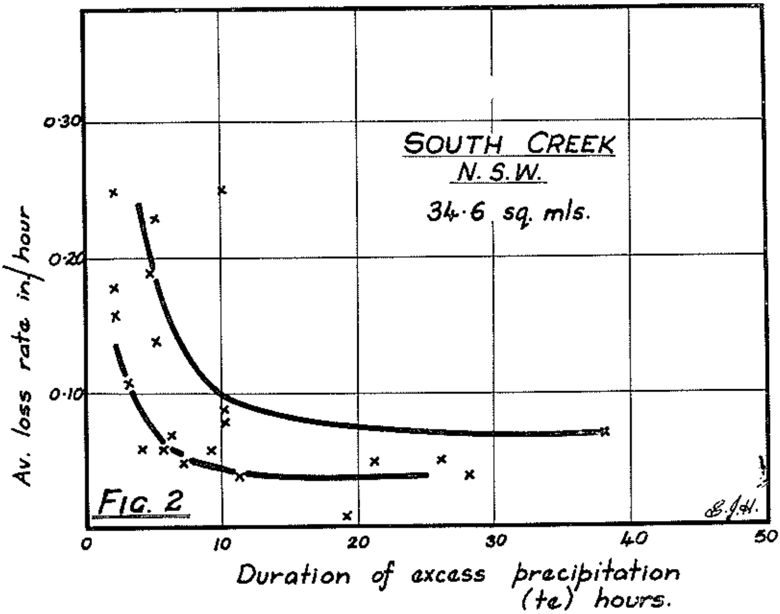
A storm of 20 April, 1963, in the Selwyn River catchment, North Canterbury, was analysed by both methods. Precipitation was recorded at seven stations and the storm totals ranged from 4.9in. to 8.7in. The resulting loss rate was 0.16in. per 2-hr period by the average storm method and 0.175in. per 2-hr by the Horton method. Although further comparisons are required on other storms it is considered that the additional work involved with the Horton method is not warranted unless there is extreme variability of rainfall.

Derivation of the loss rate using various unit periods will also result in different answers and is a further reason for non-homogeneity of published data.

Relation between Loss Rate and Duration of Precipitation Excess

The author has shown (de Leon, 1963) that a reasonably good relation can be established between loss rate and duration of excess precipitation if antecedent moisture conditions are used as a parameter.

Laurenson and Pilgrim (1963) arrived at a correlation coefficient of -0.69 between average loss rate and duration of excess precipitation for the 21 storms analysed in the South Creek Experimental Catchment, New South Wales. They did not allow for differences in antecedent conditions and it is considered that a higher degree of correlation would be obtained if a sufficient number of values were available to enable this factor to be taken into account.



The author has reproduced their results for South Creek in Fig. 2 and from additional information (pers. comm. Laurenson and Pilgrim) Figures 3 and 4 have been compiled.

Results of the analysis of 69 storms in the Taita Native Catchment have been tabulated (Anon., 1962); a considerable number of the storms were of low intensity with very little run-off. Bearing in mind that infiltration capacity is independent of precipitation intensity, provided that the latter exceeds infiltration capacity, selected values were used to obtain the curves shown in Fig. 5. The analysis was based only upon those storms where the total precipitation exceeded 1.0in. and where the maximum rate exceeded 0.20in. per hour.

It should be noted that the unit period is 3 hours and averaging of intensities over this period will produce some inconsistency in the results. Time has not permitted an analysis of variations in antecedent moisture conditions, but a relation similar to that for the Roding River (Fig. 7) exists. Antecedent moisture would probably be more satisfactorily classified according to antecedent rainfall instead of ground water flow.

Four storms in the Selwyn River basin, North Canterbury, have also been analysed (Fig. 6).

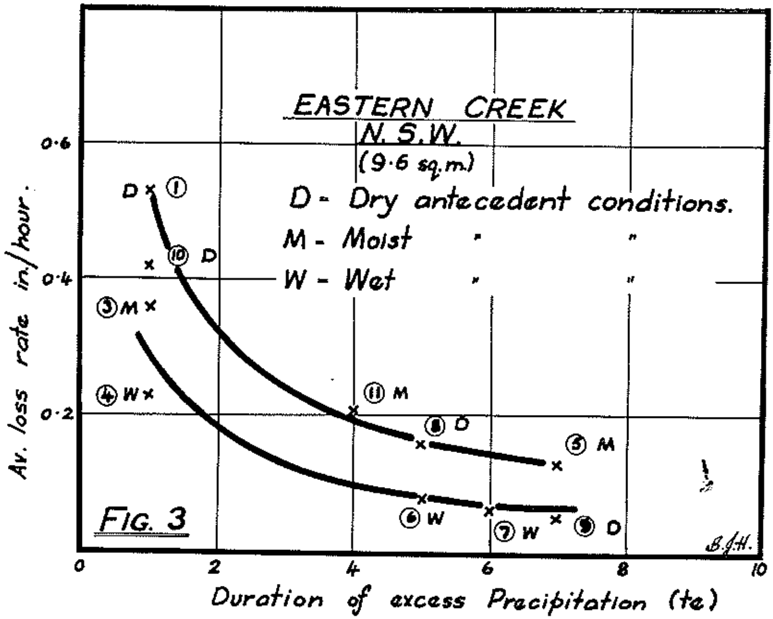

EASTERN CREEK
N.S.W.
(9·6 sq.m.)
D - Dry antecedent conditions.
M - Moist " "
W - Wet " "
Av. loss rate in./hour.
0·6
0·4
0·2
0
2
4
6
8
10
Duration of excess Precipitation (te)
B.J.H.

FIG. 3

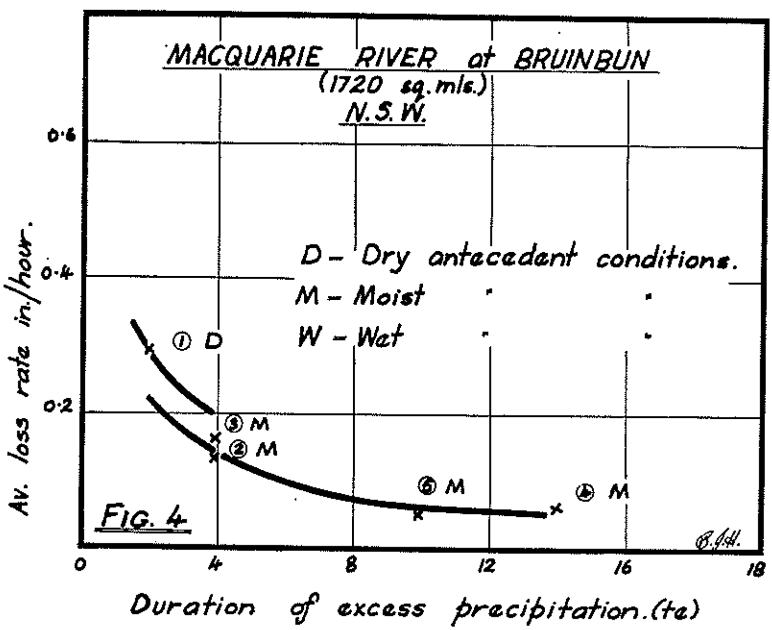

MACQUARIE RIVER at BRUINBUN
(1720 sq.mls.)
N.S.W.
D - Dry antecedent conditions.
M - Moist " "
W - Wet " "
Av. loss rate in./hour.
0·6
0·4
0·2
0
4
8
12
16
18
Duration of excess precipitation. (te)
B.J.H.

FIG. 4

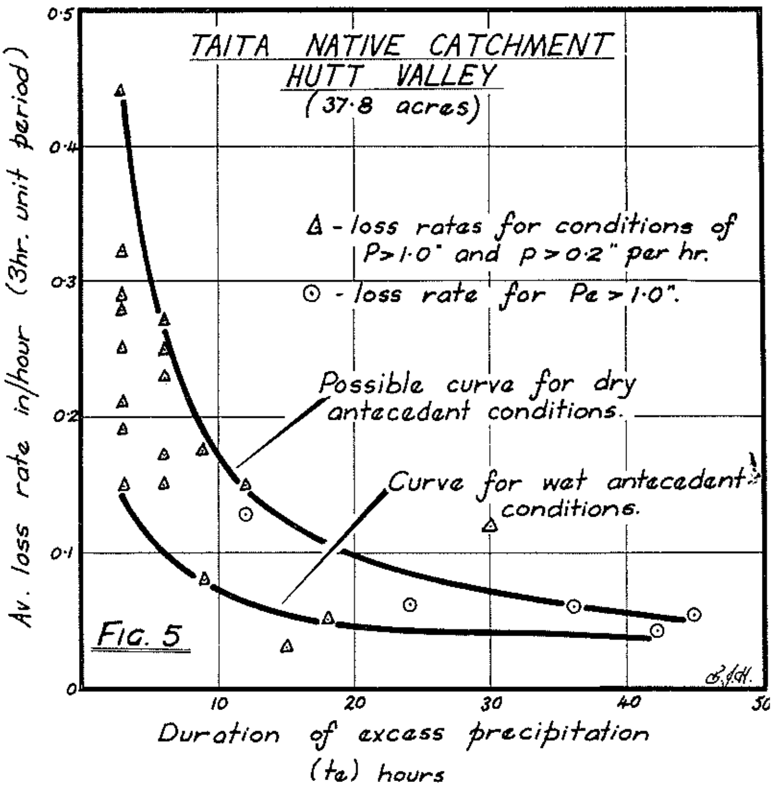


FIG. 5

DISCUSSION AND APPLICATION

For New Zealand conditions the ideal catchment for loss rate analysis is less than 100 sq. miles in area, provided that good rainfall sampling is possible. The larger storms give the best results.

It must be emphasised that Figs 2 - 7 are not curves of progressive instantaneous values of loss rate; instead they show the average loss rate, or phi index, for the respective duration of excess precipitation of a number of separate storms. A storm loss rate curve could be drawn for each particular duration and it is reasonable to assume that the curves would be proportionately the same as those shown in Figs 2 - 7. Further work is required on this aspect.

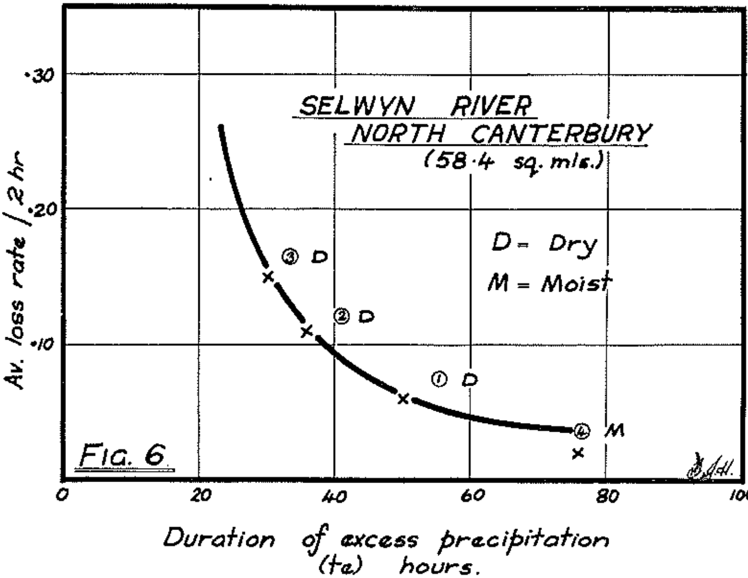

SELWYN RIVER
NORTH CANTERBURY
(58·4 sq. mls.)
D = Dry
M = Moist
Av. loss rate / 2 hr
·30
·20
·10
0
20
40
60
80
100
Duration of excess precipitation (te) hours.

FIG. 6

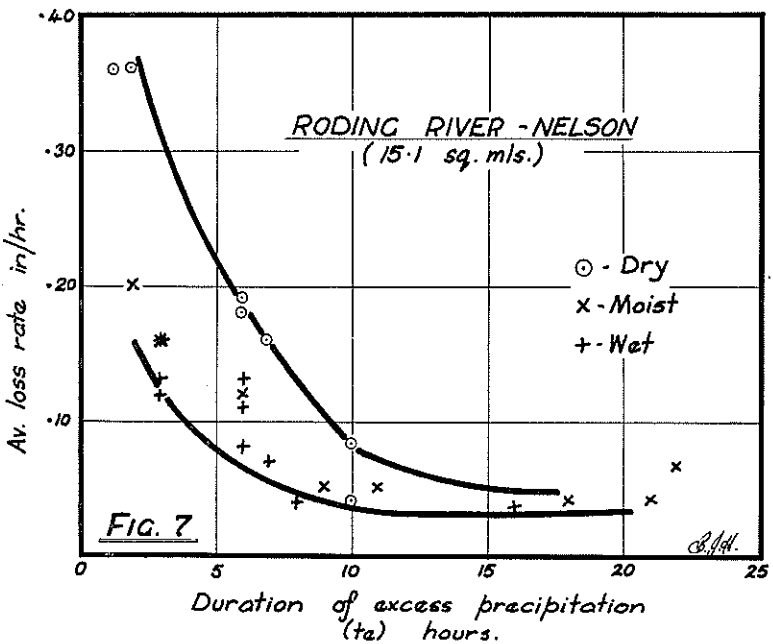

RODING RIVER - NELSON
(15·1 sq. mls.)
⊙ - Dry
x - Moist
+ - Wet
Av. loss rate in/hr.
·40
·30
·20
·10
0
5
10
15
20
25
Duration of excess precipitation (te) hours.

FIG. 7

The main use for the loss rate is in the application of unitgraph techniques to arrive at a design flood hydrograph. It can also be used in the same way in conjunction with past rainfall records to fill in missing flow data. The main disadvantage with the average loss rate method in unitgraph application is that it over-estimates the volume of precipitation excess at the beginning of the storm and under-estimates it at the end. The result is generally a hydrograph which has an under-estimated peak value.

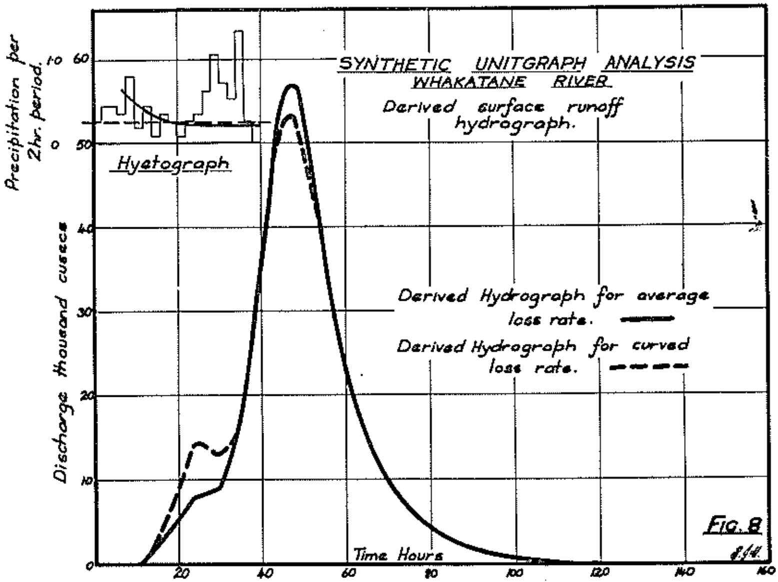


Fig. 8 shows the resulting hydrographs when average and variable loss rates were applied to a synthetic unitgraph for the storm of 11 March, 1964 in the Whakatane River catchment. The variable loss rate produced a 7% increase in the peak discharge of the derived hydrograph.

A potential use for the loss rate is its application in flood estimation formulae such as that now widely in use (Anon., 1964). The coefficients in this formula were originally based on unitgraph —peak discharge — catchment characteristics correlations, but the formula uses total precipitation for its application. Loss rates should be derived for all Representative Basins and the results used to amend the method so that excess precipitation can be used to estimate peak discharges.

Owing to the lack of basic data, standardization of method is not always possible but there is no great disadvantage in the non-homogeneity of published data which exists, provided that the user is aware of it. Therefore, when publishing, all information on method of analysis should be given.

ACKNOWLEDGMENT

The author is indebted to the Chief Engineer, Bay of Plenty Catchment Commission, for permission to publish this paper.

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