An Analysis of Medium and Long Duration Extreme Rainfalls in the Southern Cape Coastal Lakes Region for the Purposes of Flood Hydrograph Generation

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Abstract

The influence of area on the depth-duration-frequency relationships in the southern Cape coastal lakes region has been investigated. Graphs have been drawn which allow the user to find correction factors for any sub-area, such as a particular river catchment, within the study region. These can then be applied to a table of extreme rainfalls for the whole area to determine design rainfalls, taking into account the mean annual precipitation of the sub-area or catchment.

The Research Framework

During recent years a pressing need for basic research into the causes of and cures for the deterioration of the scenic Wilderness Lakes in the south eastern Cape (see Fig. 1) became evident. The interest taken since 1978 in the ecology, limnology, hydraulics and hydrology of the lakes by the Working Group for Coastal Lakes of the Council for Scientific and Industrial Research (CSIR), has been a timely response to meet these research needs. Based on preliminary investigations by members of the Working Group one of the conclusions made was that the hydraulic and ecological response of the system of inter-connected lakes to the backing up of floodwater from the Touw River, the major freshwater source, is extremely complex.

This dictated that an efficient and careful system of management of the movement of water within the system would have to be developed, and as an aid to this, the Working Group launched a collaborative programme which has as one of its aims the development of a mathematical model of the dynamics of the Lake system. This model is being developed by the National Research Institute for Oceanology of the CSIR which is represented on the Working Group.

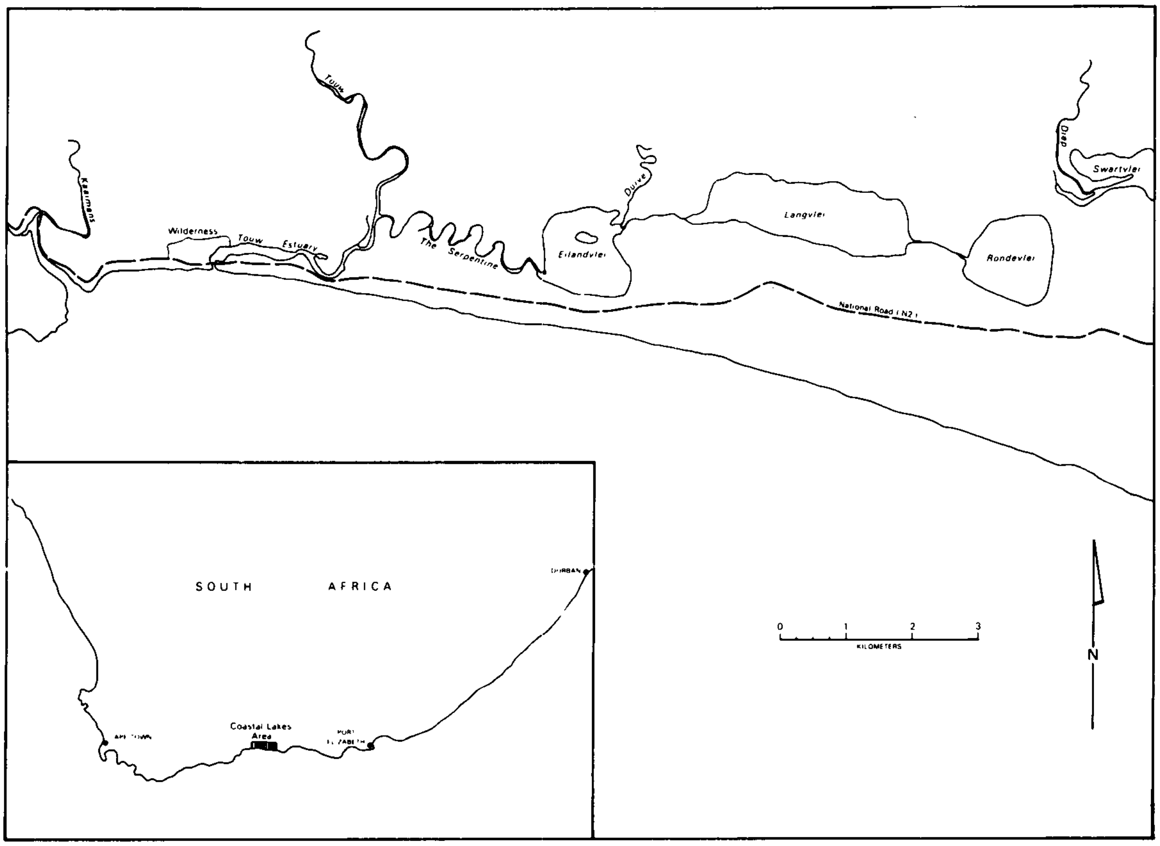

Figure 1
The Wilderness Lakes system with inset showing location

Given the importance of flood events to the well-being of the lakes and their surrounds, it follows that a major application of the lake system model is the simulation of lake level responses to the inter-lake exchanges during various combinations of flood events in the major influent streams and sand bar obstructions across the Touw River mouth. Different ameliorative measures (both structural and operational) can then be superimposed on the system model and their effects on the system simulated and evaluated. Preliminary applications of the model are at present in progress (Botes, 1980).

The Hydrological Contribution

The Hydrological Research Unit of the Geography Department at Rhodes University is making its contribution to the above programme by an analysis of the hydrological characteristics of an area some 2 200 km^2 in extent, bounded to the north by the Outeniqua Mountains and to the east and west by the catchments of the Knysna and Maalgate Rivers respectively (see Fig. 2), as an essential background to the provision of the hydrological and meteorological data that constitute the input information to the lake system model (Görgens and Hughes, 1980).

Specifically the Rhodes Unit is at present engaged in generating simulated flood hydrographs for the influent streams by the use of various deterministic modelling techniques. Two sets of flood hydrographs for various return periods have already been generated; one set by using synthetic regional unit hydrographs (Görgens, 1979), and the other set by applying the run hydrograph technique of Hiemstra and Francis (1979) to generate a "family" of 50- and 100-year flood hydrographs for the influent streams (Görgens, 1980). A comparison of some of these hydrographs is depicted in Figure 3. Furthermore, attention is also being given to the use of conceptual catchment models for the generation of the required flood hydrographs.

Problems with Design Storm Data

Attempts to develop design storms for the generation of flood hydrographs revealed a paucity of information on potential flood-producing rains, as well as of suitable depth-duration-frequency (DDF) rainfall information for the whole Mossel Bay — Knysna coastal belt. The standard DDF analyses that are available for this region can be divided into two categories: point-rainfall analyses and analyses of large-area storm rainfalls.

Point rainfall

Although the DDF-relationships in the reports by the HRU (1972) and Midgley and Pitman (1978) make provision for regionality through mean annual precipitation (MAP) and broad geographical location distinctions, they are based on a data set that includes only one autographic rain station in the study region, i.e. at George. A problem with applying these relationships to the study area is that meteorological conditions in the area have been found to be very complex (Hughes and Görgens, 1981), with strong local orographic, rain shadow and other physiographic influences on rainfalls. Consequently, MAP might be a poor predictor of storm rainfall in this case.

Alexander (1980) suggests a promising DDF-relationship that uses the mean of the annual series of maximum daily precipitation amounts, as well as the average number of thunderstorm days as independent variables. However, he gives data for only one gauge, i.e. George in the study area, for which he happens to report the worst verification error in his whole data set.

Van Heerden (1978) reports useful standard DDF curves for a number of point locations grouped into sets, but unfortunately attempts no realistic regionalization.

Henderson-Sellers (1980) suggests an empirical function by which, for a specific return period, rainfall for any duration

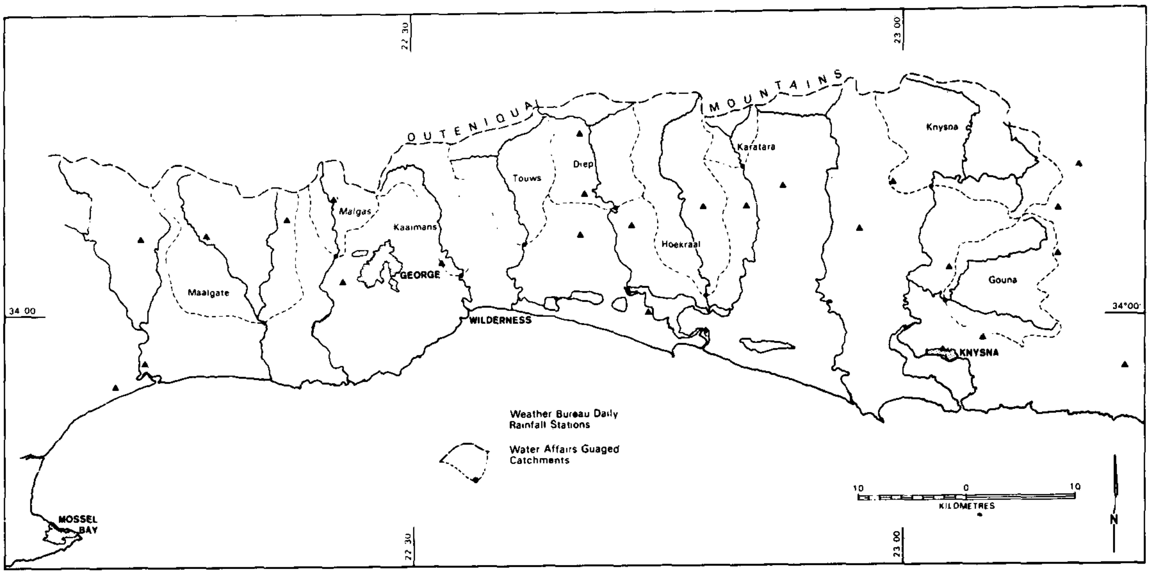

Figure 2
Location of gauged catchments and daily rainfall stations used in the analysis

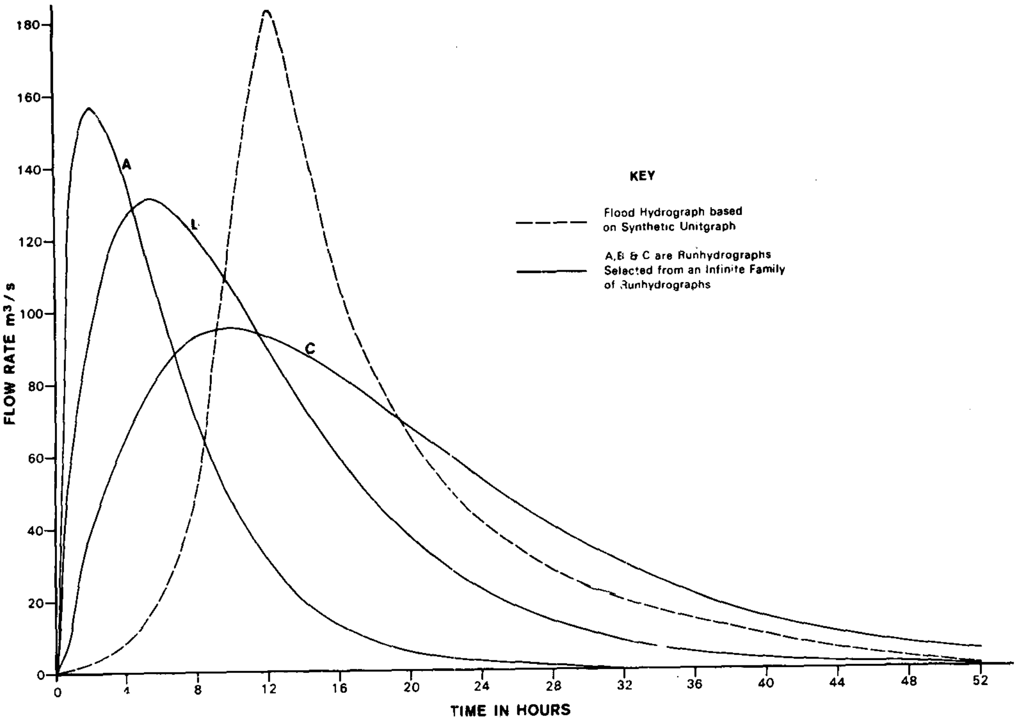

Figure 3
Generated 50 year design hydrographs for the whole Touw River catchment

can be derived from the 1-day rainfall, making use of a regionalized index, n, which is defined by climatic zone location. As his analysis does not include a single station from the study region, it might also be too generalized, given the rainfall pattern complexities referred to in Hughes and Görgens (1981). (In any case, the 1-day rainfall would still have to be estimated with an existing standard method).

Averaged areal rainfalls

The HRU (1972) flood design manual provides two techniques for the calculation of design rainfalls averaged over a particular area.

In the first, which is meant for short to medium durations and storm depths, it is suggested that point rainfall be converted to areal rainfalls through the use of a "reduction factor", which is dependent on storm duration and area, but independent of return period. All the reservations on point rainfalls mentioned above, obviously apply in the case of this method as well. Furthermore, one of the two sets of relationships provided was developed on storms in the Pretoria region only.

In the second HRU technique, which is meant for large catchment, long duration designs, the design rainfall depends on duration and area, as well as on return period and geographical location. Although this technique seemed the most suitable for application in the study region, because it is based on storms analysed for that very region, upon use it also revealed two major shortcomings:

- It produces, for the same area, duration and return period, the same design rainfall, no matter where in the study region one's interest lies. Clearly, this is not possible, in the light of the established rainfall pattern complexities (Hughes and Görgens, 1981).
- It produces design rainfalls that by simple comparison with available long-term daily rainfall records for the region, are manifestly too high.

Schulze (1980) compiled isoline maps of expected extreme rainfall for selected return periods for the whole of southern Africa. However, the scale of his maps is so small that the geographical distribution of extreme values within the study area cannot be defined realistically. It is unlikely that his method of interpolation could adequately make provision for the very localised influences of a strong physiographic barrier such as the Outeniqua Mountain range.

In the light of the above reservations associated with the development of reliable design storms for the study area based on available standard analyses, it was decided to process all available rainfall records for the region and execute a DDF analysis, using an extreme value approach. Such an analysis would be region-specific and would make provision for the influence of both area and return period on design rainfalls.

The Data

As there is only one autographic rainfall station that has a suitable record in terms of quality and record length in the study region, i.e. the one at George, the extreme value analysis is of necessity restricted to the records of the daily-read rain gauges

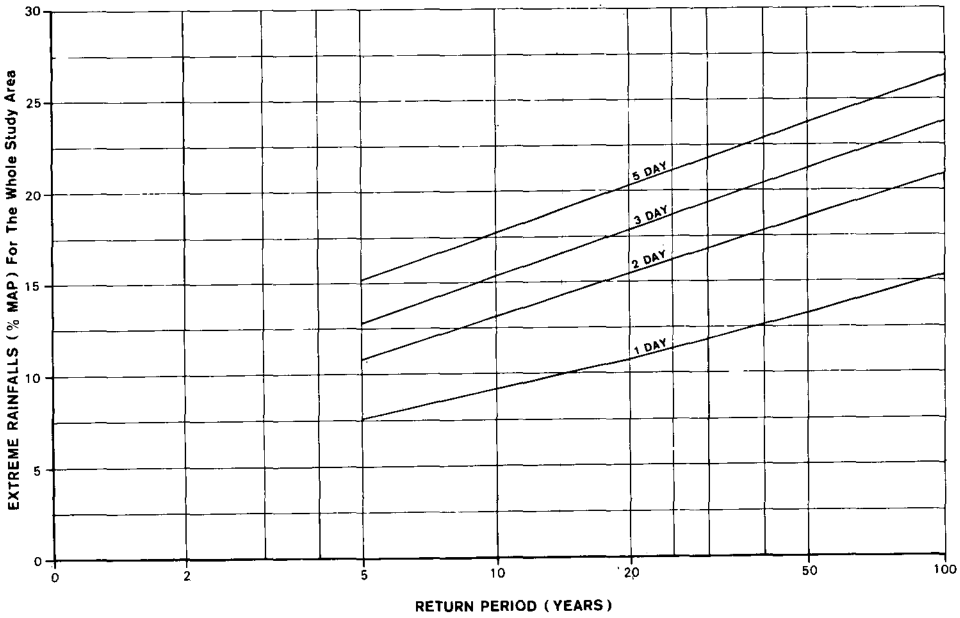

Figure 4
Depth-Duration-Frequency curves for the whole study area

of the S.A. Weather Bureau that are maintained throughout the region. In total, 26 daily stations were found to be suitable for inclusion in the analysis. Their locations are shown in Figure 2. While the earliest records date from about 1880, there are a number of large gaps in the records for some stations. A period of 39 years between 1940 and 1978 was selected for analysis as the records for all stations during this time had relatively fewer gaps than any other period of a similar length.

Analyses of Maximum Rainfalls

In the first instance, the daily rainfalls averaged over the whole region were analysed for the 39 year period. The 26 records were standardised by expressing each daily rainfall as a percentage of the MAP at that station and an average record created by taking the arithmetic means of all available data. The maximum 1, 2, 3 and 5 day rainfalls for each year were then extracted and the means, standard deviations and skewness coefficients of the resultant 39 point annual series calculated. Using the tables published by Adamson (1978) to derive the function parameters, goodness-of-fit tests revealed that the annual series for all durations fitted the family of general extreme value distributions at the 5% level of significance. The resulting extreme values for return periods of 5 to 100 years are given in Table 1 (and graphically in Fig. 4) where the tabulated numbers are expressed as percentages of the MAP for the whole area (calculated by Thiessen polygon weighting of all gauges).

To assess the influence of area on extreme rainfalls, a number of sub-areas within the study region were defined, based upon Thiessen polygons drawn around individual gauges. The areas used in the analysis ranged in size from 50 km^2 to 2 170 km^2. As for the total area, an average daily record was created for each sub-area using standardised (% MAP) daily values at individual gauges. Extreme value analyses for all the sub-areas using the family of general extreme value distributions, yielded matrices of extreme rainfalls similar to Table 1. All of these were then compared to Table 1 and new matrices of correction factors calculated by dividing each sub-area extreme value by each equivalent total area extreme value. The smoothed relationships between area, correction factor and return period are given in Figure 5 for durations of 1, 2, 3 and 5 days.

TABLE 1
EXTREME RAINFALLS (1 TO 5 DAY DURATIONS) FOR THE STUDY AREA (VALUES GIVEN ARE PERCENT MAP)

Duration (days)	Return period (years) 5	10	20	50	100
1	7,53	9,24	10,99	13,41	15,35
2	10,97	13,27	15,55	18,61	20,99
3	12,90	15,48	17,98	21,25	23,71
5	15,10	17,83	20,43	23,78	26,29

Figures 4 and 5 can now be used to derive design rainfalls for any catchment within the study area. The user first calculates the area of the catchment, decides upon the duration of the design storm and consults the relevant graph (Fig. 5). A correction factor can then be read off for a return period between 5 and 100 years which is then multiplied by the relevant ordinate from Figure 4. This yields an extreme rainfall for the catchment in question, expressed as a percentage of its MAP

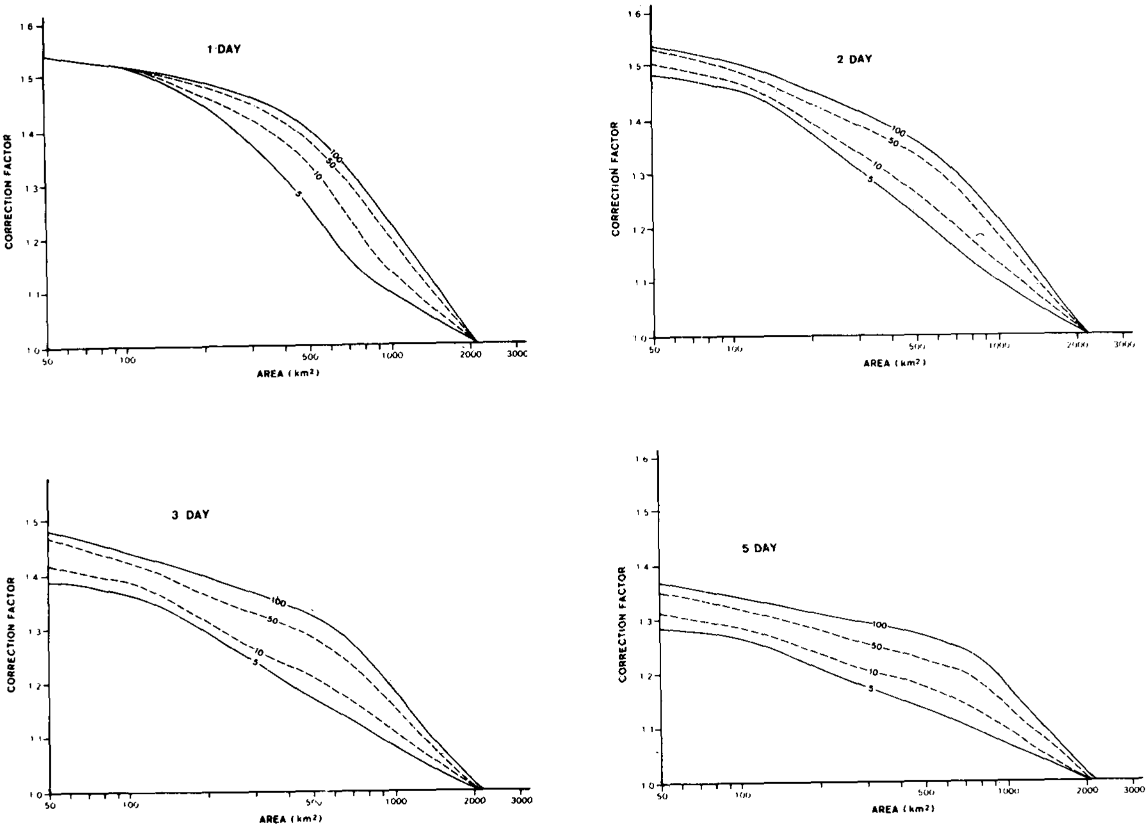

Figure 5
Areal correction factor curves showing influence of return period and duration

For example, consider the total Touw River catchment covering an area of 103 km² and with a MAP of approximately 900 mm. The correction factor for a 1-day, 100 year return period rainfall would be 1,53 (Fig. 5) which, multiplied by 15,35 (Fig. 4), gives a % MAP value of 23,48. This then yields a design rainfall of 211 mm.

Figure 6 illustrates the variation of MAP throughout the area and while there is a general trend of increasing rainfall with elevation, from the individual station values given, it is clear that some stations diverge markedly from this pattern. These apparent anomalies seem to be due to localised rainshadow effects which are important and must be taken into consideration

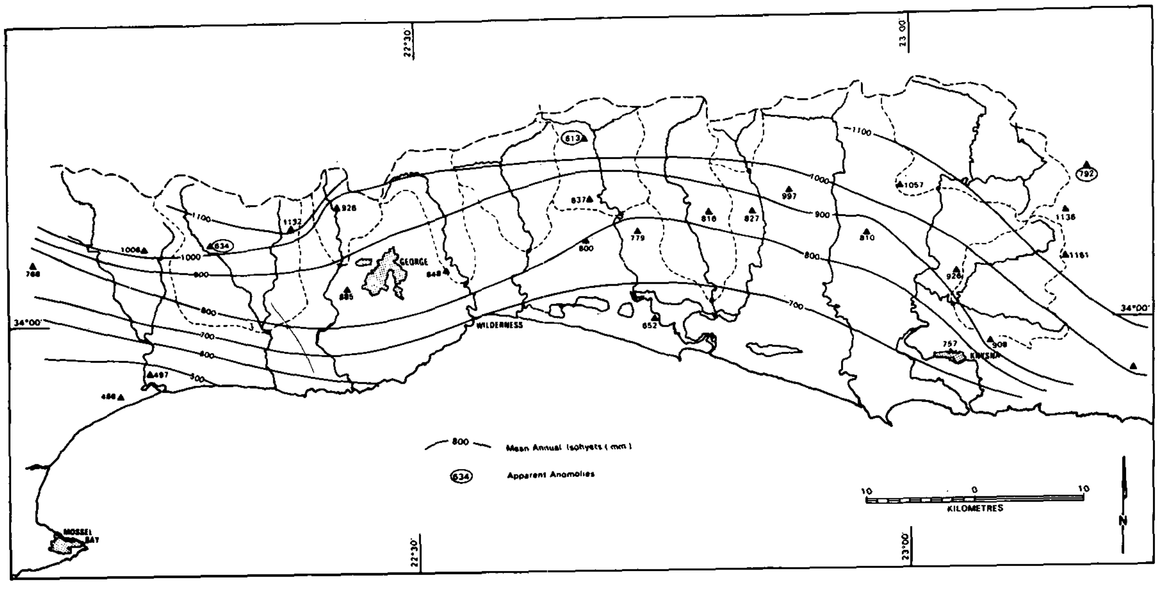

Figure 6
Variation of mean annual precipitation over the study area

TABLE 2
DESIGN RAINFALLS CALCULATED BY THREE DIFFERENT METHODS FOR AN AREA OF 500 km² WITH A MAP OF 850 mm

	10 year return period			100 year return period		
	1 day	3 day	5 day	1 day	3 day	5 day
HRU (1972)	140 mm	280 mm	330 mm	230 mm	470 mm	560 mm
*Midgley and Pitman (1978)	87 mm	123 mm	156 mm**	182 mm	264 mm	294 mm**
This report	106 mm	160 mm	179 mm	185 mm	266 mm	282 mm

* Using Figure 4 in Midgley and Pitman (1978) for point rainfalls, then Figure C.7 in HRU (1972) to reduce these to areal averages

** Figure 4 (Midgley and Pitman, 1978) was slightly extrapolated to arrive at a 5 day rainfall and an areal reduction factor of 0,92 was used

when attempting to estimate MAP for any sub-area, such as a catchment. A more detailed discussion of the variation of MAP within this region is outside the scope of this paper but can be found in Hughes and Görgens (1981).

Discussion

Comparison of our analysis with the previously mentioned South African studies, as well as similar studies in the United Kingdom by the Flood Studies Team (N.E.R.C., 1975), revealed notable differences in DDF-relationships. Firstly, contrary to the conclusions of the Flood Studies Report (N.E.R.C., 1975), return period was found to have a marked influence on area correction factors, as shown in Figure 5. Secondly, extreme rainfalls calculated from the HRU flood design manual (HRU, 1972) and Midgley and Pitman (1978) in some cases differ markedly from those produced by our analysis. For example, if we consider an area within the study region some 500 km² in extent which has an MAP of 850 mm, Table 2 illustrates the variation in design rainfalls that are predicted by the three methods. It appears that those suggested in the earlier report by the HRU (1972, Fig. D.7) are over estimates, in some cases to a large degree. For the 100 year return period rainfalls (all durations) it would appear that the technique presented here gives broadly similar estimates to those using the point rainfalls of Midgley and Pitman (1978, Fig. 4) and the correction factors of the HRU (1972, Fig. C.7). This does not hold for lower return periods for which the values calculated by us are consistently higher. A possible reason for this is that the autographic gauge at George was the only one used by Midgley and Pitman (1978) that falls in the study area. As longer return period events are usually more regional in character, it is expected that they would produce relatively little variation between individual gauging stations. Consequently, the extreme rainfall for a 100 year return period based upon data from coastal stations only (such as George) is likely to be (and is) similar to one based upon data from all 26 stations in the region. However, for shorter return periods this regional agreement will not hold to the same degree and the 10 year extreme rainfalls based upon more stations in the higher rainfall areas should be greater than an estimate based solely on coastal gauges. While Table 2 supports these assumptions for durations of 1 day or greater, it is accepted that they may not be realistic for short durations (less than 6 hours perhaps).

We believe that more reliable estimates of design rainfalls for durations of between 1 and 5 days than those yielded by the earlier more general studies, should be obtained using the methods presented here. Unfortunately, we are unable to offer firm recommendations for the derivation of short duration extreme rainfalls due to the lack of suitable autographic records. However, a combination of the techniques presented here to estimate 1 day rainfalls over a small area (i.e. close to point rainfall), with the equation suggested by Henderson-Sellers (1980) to derive point rainfalls of any shorter duration from daily rainfalls in South Africa, should be a useful alternative to the estimation techniques of Midgley and Pitman (1978). In both cases only point rainfalls would be produced and reference to Figure C.7 in the HRU (1972) report would be necessary to determine area correction factors.

Conclusions

An extreme value analysis of 39 years of daily rainfall records in the southern Cape coastal lakes region revealed clear relationships between extreme rainfalls, return periods, durations equal to or greater than one day and area.

Graphs are presented which allow the user to determine an areal correction factor for a specific duration, return period and area. When multiplied by the relevant extreme rainfall for the whole area, the correction factor produces an extreme rainfall for the sub-area in question. The values given are expressed as a percentage of the MAP for that sub-area, which can be derived or estimated independently.

Comparison with other methods available in South Africa for estimating areally averaged design rainfalls suggests that, while the techniques used by Midgley and Pitman (1978) gave similar estimates for 100 year return period events, lower return period rainfalls were usually below ours. The estimates given the HRU (1972) design flood manual, however, were consistently much higher.

The results of the above DDF-area analysis are regarded as promising enough to warrant their use as input in the generation of improved flood hydrographs for the Wilderness lakes study.

Acknowledgements

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