1. INTRODUCTION

There are at least two good reasons why it is important to develop methods of assessing the risk of deficiencies in streamflow. Firstly streamflow constitutes the inflow to reservoirs whose storage levels during times of drought are a matter of national concern. The annual inflow to most reservoirs in South Africa varies so much from year to year that it is obviously inadequate to base water resources planning on only the average inflow, the risk of deficiencies simply has to be taken into account.

Secondly as the integral of spatial catchment processes, with rainfall as the driving force, streamflow constitutes a direct measure of spatial drought. The spatial correlation structure of rainfall particularly on a seasonal basis is extremely difficult to adequately reproduce in a model. Although theory for this type of model is available its practical application, for example the simulation of spatial daily rainfall, is unrealistic at the present time. The problem involves the estimation of more parameters than is feasible with present methodology and with the available data base.

The study of droughts in terms of duration, magnitude (mean deficit) and severity (maximum deficit) is one of the most neglected aspects of engineering hydrology. Particularly little attention has been directed towards the quantitative assessment of drought risk compared to, say, the massive body of literature accorded to the study of extreme-values such as floods and storm rainfall. No valid methodology for the frequency analysis of drought is generally available and stochastic models used to generate event series fail to accurately reproduce historical critical periods (Askew *et al*, 1971) unless the appropriate generating model is very carefully identified. Yevjevich of the effort which went into the research described in this report was devoted to developing a statistical theory for model selection, a subject which is not adequately covered in existing statistical literature. The details of this theory are discussed in Appendix 2. The purpose of concentrating on this particular aspect of the overall project is that as with other applications which involve the use of statistical models, so here one's estimate of the risk associated with a given event will vary considerably if different models are fitted to the historical record. In the final analysis the accuracy of one's estimates is directly dependent on the accuracy of the model and therefore on the quality of one's model selection technique.

The available historical data records are typically quite short (for the purpose of assessing drought risk) and consequently one would expect estimates to be accordingly inaccurate. Any realistic assessment of risk must take account of potential unreliability of the estimates. The analytical derivation of confidence limits or even standard errors for the estimates which we need here is, except for a few special models, hopelessly complex. We propose that this problem can be solved by using something of a statistical innovation - the Bootstrap technique.

The proposed approach is adventurous and somewhat contrary to much of the direction of current statistical hydrological research and method. This has to an increasing degree moved forward in terms of theoretical developments based on classical statistical theory, but the practical application of these achievements has been minimal because of their mathematical complexity and the specialist skills needed to implement them. Our intention is to illustrate a scheme for the probabalistic analysis of annual and monthly streamflow which although computer intensive,

(1967) applied the statistical theory of runs to drought analysis but little if any of this approach has found its way into standard hydrological analysis, This is largely confined to the examination of flow-duration curves (NERC, 1980) or the identification of a frequency model for regional analysis. In the latter case Eratakulan (1970) used moment-ratio diagrams to select between competing univariate models but such a procedure fails to associate sufficient weight to the appropriate portion of the distribution function, that is the lower tail.

The statistical problems associated with drought analysis are fairly complex since a drought, unlike a flood or a storm, is not an "instantaneous" event. It has a duration and a critical deficit associated with each level of risk. One needs, therefore, to consider not only modelling a simple sequence of random variables, such as the annual sequence of inflows to a reservoir, but further to consider the distribution of sums of these variables, for example the 2, 3, 4,... year total inflow volume, and the distribution of these sums over, say, an operational horizon of interest such as 5 years. Statistical models which accommodate all of these requirements are in fact available, but they can be complex and analytically intractable. In general, one has little choice but to resort to Monte Carlo methods. In this respect this report offers no new alternative.

The two main issues which arise when one attempts to answer questions by statistical means are the choice of model and the accuracy of the estimates. A substantial proportion requires no specialist mathematical skills to comprehend. The methods have been applied to extreme storm rainfall (Zucchini and Adamson, 1983) and have considerable potential in the field of hydrology in general.

The traditional hydrological measure of risk is the return period, i.e. the reciprocal of the probability that a given event will take place in any given year. For some of the questions which we consider the return period is an inappropriate measure of risk, and we will simply use probability instead. In fact one of the points which we wish to emphasise in this report is that there is a broad diversity of design and operational questions which can be proposed, and that the risk of deficiencies in streamflow can be elaborated beyond the simple assessment of the return period associated with a particular event. Our purpose here is to demonstrate how the proposed methodology can be applied to answer a variety of questions which may be of interest, the four discussed in Chapter 2 should be regarded as examples and not a complete list.