THE APPLICATION OF ISOLATED EVENT CONCEPTUAL MODELS TO SIMULATING FLOODS IN AREAS WITH DIFFERENT CLIMATE AND PHYSIOGRAPHIC CHARACTERISTICS.

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Final report to the Water Research Commission for part of the project "Hydrological Research in catchments of the eastern and southern Cape."

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FOREWORD

The Hydrological Research Unit of the Department of Geography at Rhodes University has been involved in research in the field of mathematical modelling of the processes of rainfall-runoff since its inception in 1974. In 1982 the Unit expanded it's interests to begin research into processes of mineralisation. A total of three 5-year duration projects have been successfully completed and the associated reports to the Water Research Commission have been accepted and published. This report presents the results of part of a fourth 5-year project which was carried out between 1983 and 1988. The project was entitled 'Hydrological Research in catchments of the eastern and southern Cape' and had two major themes; one associated with isolated event deterministic modelling and the second with statistical modelling of rainfall and runoff in semi-arid areas. This report addresses the former topic and follows on from an earlier interim report by Dr Hughes and Ms Beater. The report on statistical modelling by Mr Herald is presented seperately.

Since 1974 the Unit has established two areas where hydrological data are collected for research purposes. The first is in the semi-arid Ecca catchments of the eastern Cape, while the second is in the sub-humid coastal area of the southern Cape. Data collection in the Ecca catchments is being brought to a close due to the development of a water supply scheme within the research area. These catchments will no longer be representative of natural conditions and therefore are being replaced by a new set of research catchments in the Bedford district of the eastern Cape. Instrumentation of this area began in 1988 and their establishment as research areas will form part of a new project (1988-1993).

The need to relinquish the Ecca catchments as a prime research area represents the end of an era which lasted 15 years. It is therefore appropriate to pay tribute to those who worked on projects in the area over this period of time. The first research officer was Dr. Peter Roberts, who was followed by Dr. Andre Görgens and Dr. Denis Hughes who worked on the second project. The third contract was conducted by Dr. Hughes, Mr Herald and Ms. Anne Beater. This report is the work of Dr. Hughes who joined the Unit in 1980 and Ms. Beater who is a graduate student who is working towards an MSc degree.

The research that has been completed since 1974, as well as the current activities of the Unit, have been made possible because of the funding from the Water Research Commission and due to the facilities provided by Rhodes University to the Geography Department. As in the past, at the conclusion of other projects, I wish to express my gratitude and appreciation to both organisations.

I shall be retiring as Professor of Geography during 1989 and therefore will not see another project through to it's conclusion. I wish my successor and the research, secretarial and technical personnel of the Unit every success for the future. I am sure that the high research and administrative standards of the past will continue to be maintained.

Professor J B McI Daniel
(Project leader and Head of the Department of Geography, Rhodes University)

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We are indebted to the officials of the Forestry Division of the Department of Environment Affairs in the Knysna region for their help and co-operation in the collection of rainfall data in the southern Cape catchments. The flow data for these catchments were obtained from the Department of Water Affairs.

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The following people comprised the Steering Committee for this project and the authors are grateful to them for their contributions to this report or to the project in general. A special thanks is due to Mr Dave Cousens for guidance throughout the project in his role as the responsible WRC advisor.

Mr J.M. Bosch : Department of Environment Affairs (alternate)
Mr H.C. Chapman : Water Research Commission
Mr D.W.H. Cousens : Water Research Commission (Chairman)
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ABSTRACT

This report represents part of the final report to the Water Research Commission on the project 'Hydrological research in catchments of the eastern and southern Cape'. The report concentrates on presenting the results of applying four isolated event deterministic models to a number of catchments drawn from various climatic and physiographic regions of South Africa and the U.S.A. The models can be operated in either lumped or semi-distributed modes. Some of the background to the study, complete descriptions of the models as well as some of the initial results are presented in an earlier report (Hughes and Beater, 1987). The complete investigation has progressed through four stages which are summarised below.

Stage 1 involved calibrating the models on two sets of catchments so that an initial evaluation could be carried out and any obvious deficiencies in the model structures identified, and where practical, corrected. These results are reported in Hughes and Beater (1987), which includes discussions of the curve fitting capabilities of the models, the stability of the parameters and the ease with which the models can be calibrated. Although some interesting comparisons between the models emerged, proper comparative evaluations were left until more catchments had been used and some model validations carried out.

Stage 2 consisted of applying the models to a further 8 groups of catchments (chapter 4) and a set of eight questions was posed (section 5.1) to assist in evaluating the models performances after calibration and validation on individual catchments (chapter 6). One of the most important results indicated that the parameters of model OSE2 (variable runoff proportion model) could remain stable for all storms on the same catchment and still produce reasonably acceptable simulations. This was not true for the other models. The value of at least one parameter of the other models had to vary between storms on the same catchment to account for variations in storm or antecedent moisture characteristics. It was impossible to carry out complete validations for these models as one parameter requires calibration for each individual event. The semi-distributed versions of the models were demonstrated to perform better than the lumped in some circumstances, but this did not appear to be a generally applicable conclusion. Some of the uncertainties about the comparative performance of the models and their different versions are at least partly a result of uncertainties in the accuracy of the input rainfall data.

Stage 3 consisted of compiling quantitative descriptions of the physical characteristics of the catchments and the rainfall events (section 5.2) and an attempt to relate the calibrated parameter values with the relevant physical characteristics (chapter 7) for the purposes of estimating parameter values when calibration is not possible. Despite the fact that the catchments used can be classified as research catchments, it was very difficult to obtain quantitative measures of some hydrologically important characteristics. This was especially true of soil characteristics and it was necessary to resort to indices based upon an ordinal measurement scale and some subjective interpretation of qualitative descriptions. The general trends exibited by many of the relationships are encouraging and the format of the combinations of physical variables used, do make sense with respect to the original parameter conceptualisations. The relationships between storm characteristics and some of the parameters of OSE1 and OSE3 are less satisfactory. There is a high degree of scatter and the between-catchment variation in the form of the relationships, indicates that the derived relationships are likely to be of little use for parameter estimation purposes.

Stage 4 represents a validation exercise of the relationships derived in stage 3. New parameters were estimated, from the physical variable-parameter relationships, for all the catchments previously used, as well as a further 4. The new parameter values were then used to re-simulate all the storms and a comparison made between these results and the original calibration results chapter 8). Model OSE2 performed better than the others and appears to be the model which is likely to give the more reliable results in situations where calibration is not possible. The relationships developed for some of the OSE1 and OSE3 parameters are so catchment specific that transfer to other areas will produce unpredictable results. Using the relationships to estimate the OSE2 parameters for the additional four catchments produced acceptable results. This was not the case for the estimated parameters of OSE1 and OSE3.

Apart from summarising the conclusions of the investigation, the final chapter of the report also places the results into the context of the future developments of hydrological modelling techniques. The authors of this report agree with other hydrologists that the ability of a model user to provide the input information required by many models has not kept pace with recent model developments. An example, taken from the field of design flood determination, is given to illustrate one aspect of the problem.

Chapter 1

INTRODUCTION

This report is one of a set of final reports which deals with the results of the Water Research Commission project undertaken by the Hydrological Research Unit (HRU) of the Department of Geography at Rhodes University and titled 'Hydrological research in catchments of the eastern and southern Cape'. There were two groups of objectives referred to in the project proposal. One (objectives 3.1a-d) was to investigate the application of statistical (regression type) and stochastic modelling techniques to semi-arid areas. This study was concentrated in the Ecca catchments of the eastern Cape and is reported in a separate volume (Herald, 1989). The collection of hydrological data in the Ecca catchments (3.1a), which began in 1976, has now ceased owing to the construction of an off-channel storage reservoir within the catchment. This reservoir is intended to store water transferred from the Orange River and used to supply the Lower Fish River irrigation scheme. The HRU is compiling a summary report of the hydrological characteristics of the Ecca catchments as represented by the 12 years of data collected. The second group of objectives (3.2a-g) was initially to be based upon the southern Cape catchments and intended to investigate the use of single event deterministic models for simulating the complete hydrograph of flood events. The project clearance committee meeting, held in February 1983, recommended that the single event modelling study be extended to as many catchments as practically possible (Special Consideration 4.d). This report deals with the flood modelling part of the project and follows on from the interim report that was published in 1987 (Hughes and Beater, 1987) and it will be seen from the contents that the models have been applied to a number of different catchments as recommended.

Two of the objectives referred to in the project proposal are not addressed in this report. The first (3.2c) is the proposal to compare the results of the single event models with an existing continuous water balance model. The progress report on this project (Hughes and Herald, 1985) indicated that a great deal of data would be required to satisfactorily calibrate a continuous model, even if operated with a coarse time step during non-flood event periods. For many of the catchments used in this study such long periods of record are not available and it was considered that the results of comparing the single event models with a continuous model would be inconclusive. The other objective not addressed (3.2f) refers to the generation of historical flood hydrographs from long records of daily rainfall and characteristic storm rainfall distributions. Some recent publications (notably Hershenhorn and Woolhiser, 1987) indicate that such a simplistic approach is unlikely to be of much value. The conclusion reached in this report about the importance of properly defining rainfall input to deterministic models further suggests that a simple approach to characterising historical storm rainfall distribution is not likely to be successful. There has been insufficient time during the project to investigate more complex approaches.

This report therefore concentrates on a discussion of the procedures used and the results obtained from applying four deterministic rainfall-runoff models to the simulation of isolated flood events to a wide range of different catchments. The four models can be operated in lumped or semi-distributed format and while having some similarities in their structures, are different in at least one major respect. Some of the background to this study, complete descriptions of the models and their parameters, the perceived physical associations of the parameters, as well as some of the initial results were presented in an earlier report (Hughes and Beater, 1987). The purpose of this report is to explain the methods used to evaluate and compare the models (and their different versions) using the complete data set, to present the results and to draw conclusions on the basis of the results about the applicability of the models to different situations.

The study has progressed through several stages, each one designed to reveal information about the relative usefulness of the models. The first stage of the model assessment involved carrying out model calibrations on two sets of catchments which have very different physical characteristics. The main purpose of this exercise was to try and identify any obvious deficiencies in the models' structures which could easily be corrected before continuing with the larger data set incorporating far more catchments. The semi-arid, South African, Ecca catchments (Roberts, 1978; Görgens,1983) and the temperate, forested, USA, North Danville catchments (USDA, 1955-1973) were chosen for initial calibration. The results were presented and discussed in the earlier report (Hughes and Beater, 1987). Relatively detailed discussions are contained within that report on the capabilities of the different models in terms of curve fitting, parameter stability, the physical interpretation of parameters and the ease of model calibration. There was no discussion of model parameter validation or the extension of use of the models to other areas.

The second stage consisted of applying the models to a further 8 groups of catchments drawn from different parts of South Africa and North America (chapters 4 and 6 of this report). The exact nature of the model testing procedure is discussed in chapter 5 of this report and involves calibration of the models (or some of the parameters) on a subset of the available storm data followed by validation of the parameter values on the remaining data. The proportion of calibration to validation events depends to a certain extent upon the type of model, how many catchments there are within a particular group and how similar they are to each other. A further factor is the range of runoff response characteristics represented by the available events for a particular catchment. If all the events are of a similar type then splitting the data set into two groups is straightforward. If several types of events (in terms of magnitude, duration, intensity or spatial variation characteristics) are represented it was considered important that both the calibration and validation groups contained some of the different storm types. The results of this second stage of the investigation are interpreted with respect to the different model types, different catchment types as well as the amount and quality of the available data with which to define the rainfall input.

The third stage consisted of compiling quantitative descriptions of the physical characteristics of the catchments (chapter 5) and an attempt to find relationships between the parameter values and relevant characteristics (chapter 7). Owing to a lack of available detailed information on the soil characteristics of the catchments, the quantification of some physical variables had to be based upon ordinal scale indices. It was not expected that perfect or even good relationships would be found initially. The intention was to determine whether single or (more commonly) a combination of catchment characteristics could be found that explains the general trend of differences in parameter values between different catchments. This stage therefore begins to address objective 3.2(d) of the original proposal which referred to examining parameter stability and relationships between parameter values and catchment characteristics. The way in which the catchment characteristics were quantified and the methods used to identify those combinations which could be used to explain the variation in parameter values are explained in section 5.2 and chapter 7 of this report.

Inevitably a great deal of scatter exists in the parameter value-catchment variable relationships. The next stage therefore consisted of assessing the effects on the model simulations of reducing this scatter to zero (chapter 8). This was carried out by re-running the models with parameter values predicted by the general trend lines of the relationships. These new simulation results were then compared to those given by stage two. This fourth stage therefore represents a validation exercise which evaluates the predictive value of the relationships derived to estimate parameter values. Several catchments not used previously were included at this stage to investigate whether the relationships can be considered applicable to areas outside those used to develop them.

Stages one to four may be summarised as follows :

Stage 1 : Model calibrations on two sets of catchments to verify the conceptual structure of the models and to identify any obvious deficiencies in the structures that could be readily corrected before continuing with the larger data set.

Stage 2 : Calibration of the models on individual catchments with some validation of the results on a sub-set of the storms.

Stage 3 : Identification of relationships between parameter values and catchment characteristics for the complete range of catchments used in stage 2.

Stage 4 : Validation of the relationships identified in stage 3 by predicting the expected parameter values from physical catchment variables and generating new simulated storms. The new simulation results are compared with the stage 2 results.

It should be noted that due to strong interrelationships between the effects of different parameters on the model results (particularly in the semi-distributed model version) stage 2 does not necessarily yield a single optimum set of parameter values. Consequently, the results to be expected from stage 4 are quite unpredictable and could suggest a set of parameter values which simulate observed flows better than, similar to, or worse than, the calibrations of stage 2. While none of the models chosen is physically-based in the sense that the parameters can be directly measured from field data, stages 3 and 4 should indicate to what extent they can be successfully associated with physical variables. It is important that the physical variables associated with a specific parameter are relevant and related to the conceptualisation of that paramter. There are inevitably limitations to a study of this kind and they are discussed in the appropriate chapters. Part of the discussion of the stage 4 results centres around the likely usefulness of the models in situations where calibration is not possible. These situations include totally ungauged catchments or catchments where observed flow data are limited and insufficient for complete calibration.

The format of this report closely follows the stages through which the investigation has progressed. At the end of most chapters a summary of the procedures used, or the results obtained, is presented to enable the reader to obtain a broad overview without necessarily reading the full details. The final chapter not only summarises the conclusions of the investigation but also discusses the use of these types of model in the broader contexts of the future of hydrological modelling and applied hydrological problem solving. The specific application of this type of model is in the field of design flood determination for medium sized catchments. Computer listings of various physical indices, parameters and results are given in the appendices. Also contained within the appendices is a copy of a paper recently published in Water S.A. and a report on attendance at a NATO, Advanced Study Institute held recently (July 1988) on the subject of 'Recent Advances in Hydrological Modelling'.

Chapter 2

THE APPLICATION OF DETERMINISTIC SINGLE EVENT MODELS

The earlier report (Hughes and Beater, 1987) discussed various aspects of modelling approaches to simulating flood events. Specifically, that report discussed the distinctions between models based upon their complexity in terms of the degree of spatial distribution as well as the complexity of the approach to modelling individual components of the rainfall-runoff system. This chapter expands on the earlier discussion and looks at the associations between model complexity and model application. The purpose of the chapter is to provide the contextual framework within which the investigation of the applicability of several isolated models was carried out.

2.1 MODEL COMPLEXITY

The complexity of any approach to modelling rainfall-runoff processes encompasses three main aspects (figure 2.1). Two are related to the levels of spatial and temporal distribution that are allowed for in the model structure. While the third is related to the modelling approach to the various components of the hydrological cycle. The three aspects are not necessarily independent and the methods used to model processes can influence the time interval of modelling or the nature of the spatial distribution system that must be used.

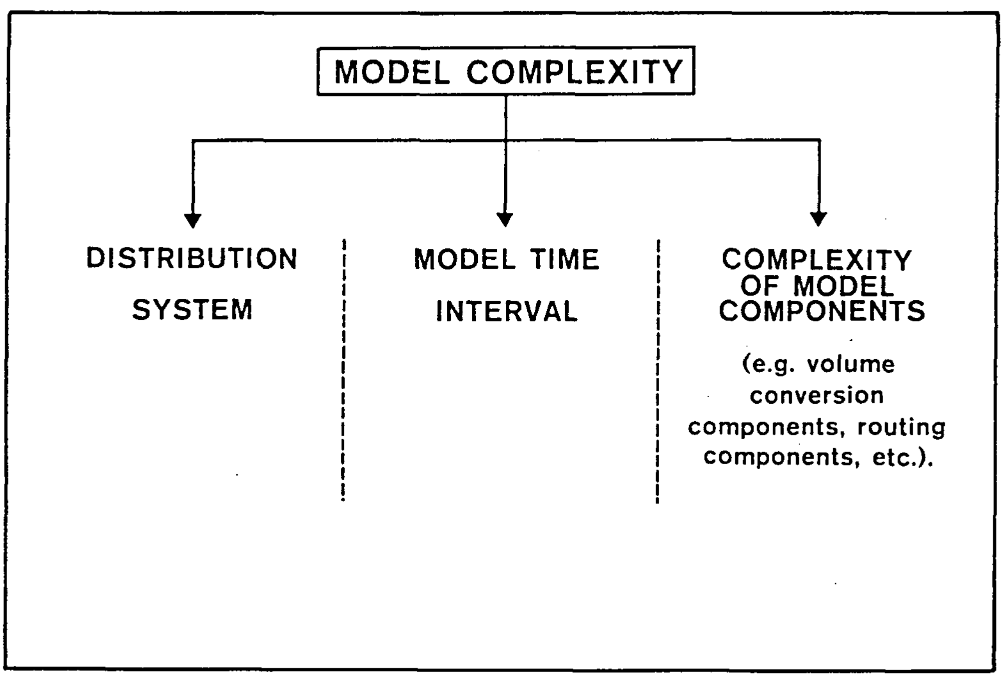


Figure 2.1 Aspects of model complexity.

An important rule that should govern all model building is that the different aspects of complexity should be compatible with each other in a single model structure. For example, there is little point in incorporating complex physical equations of moisture movement in a model where the spatial variations of that moisture movement are unaccounted for. Recent contributions to the literature on deterministic modelling have raised a number of important (if at times contradictory) issues about the desired level of complexity that is required in a hydrological model.

i) It is considered by some that many conceptual models have little relevance to the processes operating in a catchment (Roberts, 1984) and by others that this is because of lack of a thorough understanding of these processes (Naef, 1981; Morton, 1982).

ii) Complex models have not always shown demonstrable improvements over simpler approaches (Görgens, 1983; Loague and Freeze, 1985).

iii) Models have been refined to a point where the accuracy of the input data is the limiting factor in successful simulation (Roberts, 1984; Loague and Freeze, 1985).

iv) Quantification of the uncertainty of simulation results is only possible if the physical significance of model parameters is understood (Abbot, Bathurst, Cunge, O'Connell and Rasmussen, 1986). Only then is it possible to quantify the range over which model parameters can realistically vary in a specific area or catchment.

As it was not the purpose of this research project to check or refine the current theories of runoff generation (succinctly summarised by Ward, 1984), point i) above will not be addressed in any detail. It is sufficient to note that many single event type models are based upon infiltration excess runoff generation followed by surface flow routing. There is adequate evidence to suggest that this is not the only process by which rainfall contributes to stormflow generation (Ward, 1984). Most active workers in this field of hydrological modelling will accept that some explicit or implicit method of allowing for sub-surface redistribution of moisture is necessary for many catchment situations. The second point raised above (ii) may be a consequence of the first (i) but must also be related to the lack of accuracy or detail in the available input data or information used to evaluate the model parameters (point iii). The final point (iv), while being important, may assume secondary significance to point iii). It is a simple truth that while complex physically-based models should be more successful than simpler approaches there are few comprehensive tests of such models reported in the literature. One reason is that the satisfactory testing of their abilities requires the collection of large amounts of data. This is often beyond the resources of many hydrological research organisations, particularly in the present day context of financial constraints. Such models may be tested in a few small catchments, where the necessary information is relatively straightforward to collect or has already been collected for another purpose. There are no reports of such tests over a wide range of catchment types. Consequently, the degree of confidence in the successful application of complex models has not yet reached a level where a user is likely to invest the large amounts of time and money necessary to apply them. Model users will commonly adopt a pragmatic approach to model choice, selecting a model that is relatively simple to operate (where operation is assumed to include the definition of input data and parameter values) and 'works' for the intended application. The word 'works' refers to the successful application in a specific field of operation and must clearly be a relative term. To differentiate between applications of hydrological models involves a consideration of a number of interrelated factors. These are illustrated in figure 2.2 and discussed in the next section.

2.2 MODEL APPLICATIONS

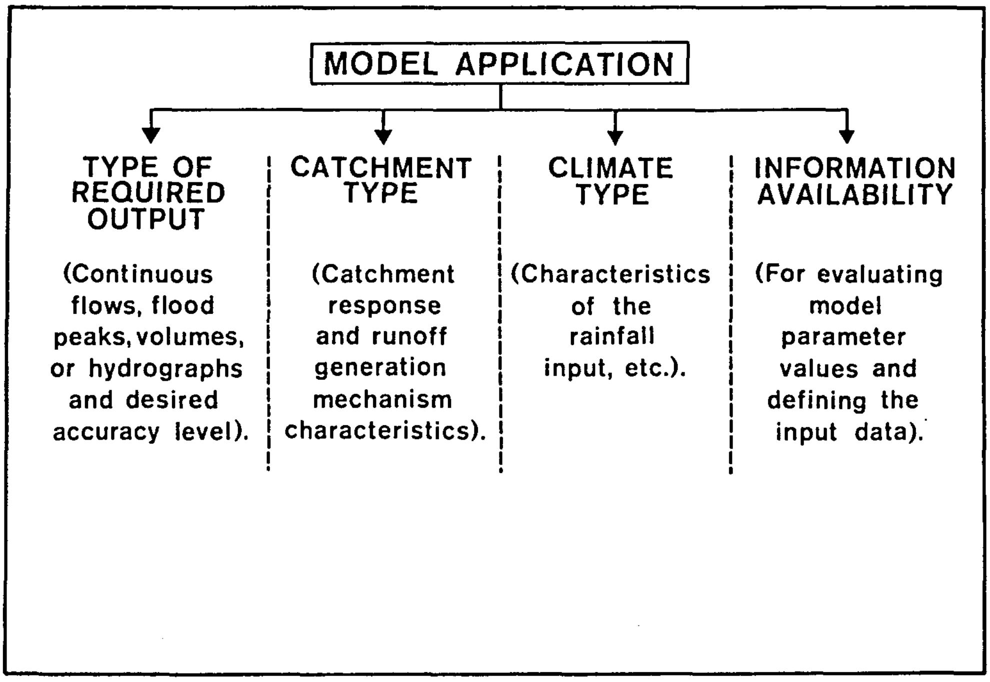


Figure 2.2 Interrelated factors associated with the differentiation of deterministic model applications.

It is conventional to consider model applications in terms of the output required to solve a particular problem. That is, models may be used to generate long sequences of streamflows for surface water resource evaluations or information about flood peaks and volumes for extreme event analysis or real time forecasting. They may also be used to assess the effects of land use change or to estimate sediment and solute loads (Fleming, 1984). It is also necessary to consider the level of accuracy with which the output information is required. A further distinction that is often made in the literature is on the basis of climate type. A particular model may have limitations (or special features) that prevent (or favour) its valid use in specific climate regimes. Such climate considerations may be based upon temperature or potential evapotranspiration regimes or the range of storm types and rainfall intensities experienced within an area.

It is also necessary to define model applications in terms of the type of catchment to be modelled, its size, land use cover, geology and soil characteristics as well as the slope steepness and surface drainage pattern. A further distinction could be based upon the degree of spatial variation of physical characteristics that exists within a catchment. A very important factor which distinguishes between model applications is the amount and type of information which is available for evaluating the model parameter values and defining the input variables such as rainfall or evapotranspiration. As stated earlier, it is often the availability of this information which is the limiting factor in the choice of model type to use for a particular application.

Given the diversity of potential applications of hydrological models, it is hardly surprising that a large number of models have been developed. The broad spectrum of models from simple empirical, through conceptual to physically-based or from lumped to fully distributed, for example, is partly a response by model developers to satisfy the wide range of applications. Some models concentrate on solving specific problems in specific regions and have not been tested outside the catchment type or climate region in which they were developed. Others have been used more widely, often after adaptation to extend their range of applicability. Few models appear to have been originally designed to be of wide ranging applicability, incorporating a sufficient number of components within their structure to be likely to satisfactorily achieve this. Models have usually been demonstrated to work within the area of application for which they were developed but often little is known about many models performance elsewhere.

2.3 INTERACTION BETWEEN COMPLEXITY AND APPLICATION

The preceeding paragraphs have highlighted the fact that it is not always easy to state how simple or complex a modelling approach must be in order to 'work' for a particular application. Figure 2.3 illustrates that there can exist a large number of poorly understood interactions between the type of model application and the level of sophistication that is required to produce acceptable results. This problem has not been adequately addressed in the hydrological literature. Only when these interactions are better understood will it be practical to offer guidelines about the best approach to adopt for a given application.

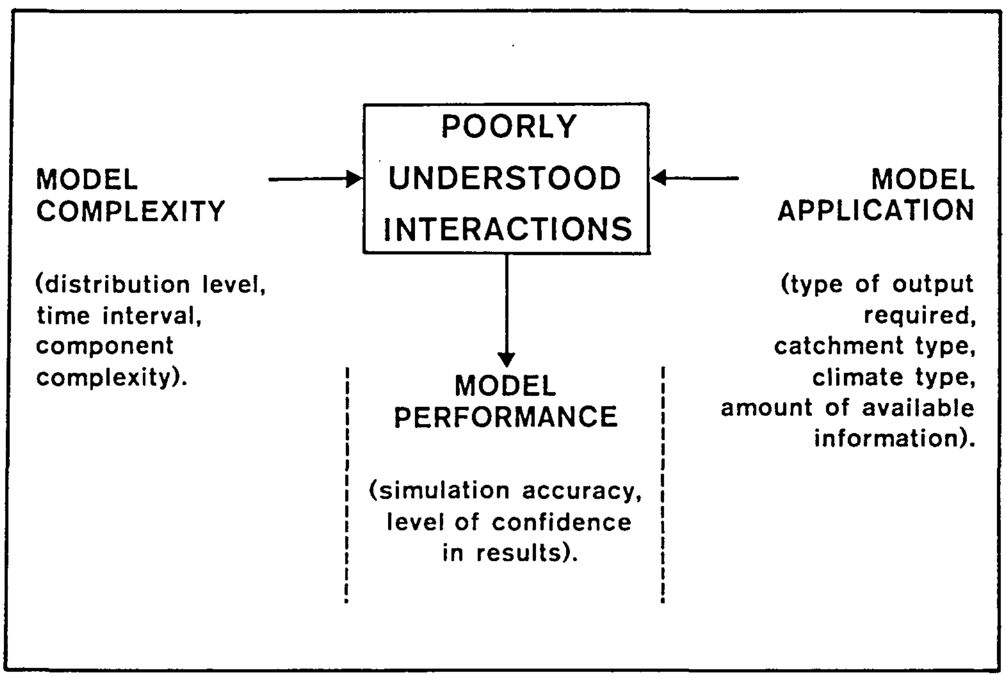


Figure 2.3 Interrelationships between model complexity, model applications and model performance.

The use of a spatial distribution system is required to account for spatial variations in rainfall-runoff response characteristics as well as input rainfall or other climate variables. However, the extent to which distributed models perform more successfully than lumped models might be expected to vary between different modelling situations. It seems reasonable to suggest that a distributed approach will be required when modelling storm events with spatially variable intensities. Similarly, distinct heterogeneity in runoff response may be difficult to account for in a lumped model. However, which is the best approach to use (if any) if the spatial variation is poorly defined in either case? Similar uncertainties may be associated with identifying the most appropriate time interval over which to carry out model iterations. There are therefore many modelling situations for which the expected relative performance of different modelling approaches is less than clear. It is the author's suggestion that all model testing and evaluation should address this point in order to contribute to a better understanding of the interactions illustrated in figure 2.3.

2.4 MODEL TESTING AND EVALUATION

With respect to their eventual practical application, testing of hydrological models involves an attempt to evaluate how useful they will be to predict something that is not already known. This includes prediction of future events or reconstruction of past events under static or changed climate or physical catchment characteristics. It also includes simulation of hydrological variables in areas where no measurements exist. Inevitably, the application of models in this way cannot be directly tested. They can only be directly tested in situations where observed data exist with which to compare the simulation results. Conclusions about a model's applicability therefore represents an extrapolation of the test results and will be more reliable the more comprehensive the test with respect to the intended field of application.

In the preliminary report on this project (Hughes and Beater, 1987), various aspects of model calibration and validation were discussed. The report concluded that thorough model testing should incorporate six levels of evaluation or assessment.

i) An evaluation of the efficiency with which a model may be calibrated.

ii) An evaluation of the stability of any calibration results.

iii) An analysis of the sensitivity of the model results to changes in the model parameter values as well as input data errors.

iv) An assessment of the range of hydrological response types that can be satisfactorily simulated by the model.

v) An assessment of the transferability of model parameters to other situations (storms or catchments) not represented in the calibration or development data sets.

vi) The testing of any hypothesised or perceived associations between model parameters and physical catchment or storm characteristics.

The relative importance of these six points will vary with model type. For example, physically-based models should not require calibration. Their parameter values should be quantifiable from physical catchment variables. Consequently, points i) and ii) are largely irrelevant to physically-based models, but point iii) assumes great importance in that the results may be heavily dependent upon the accuracy with which certain catchment variables are quantified. For less physically-based models, the alternative approach is to build up information about the associations between parameter values and catchment or storm characteristics through calibrating a model for a wide variety of different catchments. It may then be possible to develop such qualitative associations into more formal quantitative relationships which can be tested on other catchments and, if successful, used for estimation in ungauged catchments. This is not always a straightforward exercise, particularly when there is a high degree of interaction between parameters giving rise to non-unique calibration solutions. Several solutions may produce similar calibration results but only one might be achieved using parameter values corresponding to the 'correct' physical interpretation of the parameters role in the model. 'Correctness' in this sense must be viewed in the context of the applicability of the model conceptualisation to the real hydrological system.

Point iv) above refers to associations between parameters and catchment or storm characteristics. Some models may be developed in such a way that parameter values are expected to remain stable on a single catchment no matter what type of storm is being modelled. This would be expected of models with a sufficient number of components and a satisfactory conceptualisation. Variations in the amount of rainfall that contributes to stormflow due to variations in antecedent moisture status and rainfall total, intensity and duration might then be accounted for. However, it is unlikely that the same can be expected of simpler models that utilise more or less constant loss coefficients. For such models, the parameter values should be expected to vary, not only between catchments, but also between storms on the same catchment. This is clearly an added complication which may turn a simple model into a much more complicated one in the context of application to ungauged situations.

When comparing models with different conceptual structures or with different degrees of complexity (either component or spatial and temporal resolution), it is essential that the circumstances under which one model performs more satisfactorily than another is also identified. These circumstances may be related to the type of rainfall-runoff response or to the nature of the causative rainfall event in terms of the spatial and temporal characteristics. They may also be related to the amount or detail of the available information with which to define the input rainfall. Identifying these circumstances should allow a better understanding of the relative abilities of the models to perform satisfactorily and should highlight their strengths and weaknesses.

The points raised in this section as well as those in chapter 3 of the earlier report (Hughes and Beater, 1987) have formed the basis for the way in which the models discussed in the next chapter have been evaluated. The specific elements of this evaluation procedure are discussed later (chapter 5 of this report) after the models themselves, and the data set upon which the evaluations are based, are described.

Chapter 3

THE MODELS

The choice of which models to include in a research project of this nature is not easy. A great number of conceptual models designed to simulate flood hydrographs have been reported in the literature and it would have been impossible to test even a representative proportion of them. The four models that have been tested were selected on the basis of the criteria discussed in the section below. The authors admit that such criteria were not necessarily likely to favour those models in common use. An earlier report to the Water Research Commission by Campbell, Ward and Middleton (1987) presents the results of a study designed to assess flood models commonly used in South Africa. Several of the catchments referred to in this report were also used in their study. The combination of the models chosen, the data set available for testing and the testing procedures used have revealed some important general information about different approaches to single event modelling. The authors believe that this point justifies the selection of models regardless of the unknown results that might have been achieved had a different set of models been selected.

3.1 MODEL SELECTION CRITERIA

The first group of criteria is based upon certain aspects of the structure of deterministic models that it was considered important to investigate.

i) The models should be operable at different levels of spatial distribution. In particular, the possibility of running the model in a lumped as well as a semi-distributed format was considered necessary, even if this required some modification to the original computer code. This was judged necessary to assess the effects of allowing for the spatial variation in either input rainfall or runoff response characteristics.

ii) The models should be operable at different levels of temporal resolution. This requirement implies that the time interval used for iterations is, or can be made, flexible. Hughes and Herald (1987) illustrated the need for flexibility in the time interval used for integration if a model is to be applicable to a range of catchments having different runoff process time resolutions.

iii) At least one of the models should have a component that estimates the initial catchment moisture conditions at the start of an event. Similarly, at least one should not have such a component. While it would also have been desirable to assess different methods of estimating initial catchment moisture levels, this was considered to be beyond the scope of the project.

iv) There should be a fundamental difference in the conceptual approach to runoff generation between some of the models. Without such a criterion it would be difficult to ascribe reasons for differences in model performance. In effect this criterion suggested that some of the models should be simple, while at least one should have a more complex structure given other constraints on model choice.

v) The models should be capable of simulating the full flood hydrograph but can be assumed to simulate either the total catchment outflows (no separation of baseflow) or separated stormflows.

The second group of criteria is based upon constraints levied by the data which are available to test the models.

vi) None of the models could be truly physically-based in the sense that their parameters would have to be field evaluated. Much of the available data comes from catchments outside South Africa and even for those within the country, the time and cost of attempting to establish parameter values by field measurement would have been prohibitive. It is also unlikely that many applied users of models have such resources available.

vii) The methods of estimating initial catchment moisture status had to be based upon data at no finer resolution than daily total values.

viii) The models should have no reported restrictions that prevent their application to the range of climate types that are experienced within South Africa. Snowmelt floods or runoff events occurring on frozen ground are specifically excluded as they are not relevant to the South African situation in general.

ix) The models should not be specially developed for use on small catchments but should be initially considered applicable to medium sized catchments (in the range of a few to a few hundred km^2).

The third and final group of criteria are based upon personnel and computing constraints.

x) The models should be capable of running on the Rhodes University Cyber computer, with or without modifications, and preferably have a future capability of being modified to operate on a PC.

xi) The model structure should be documented sufficiently clearly to be understandable to the project personnel. This is based upon the obvious fact that there is little point in discovering differences in simulation performance between models if those differences cannot be investigated in terms of differences in the models structures.

xii) The time gap between selecting a model and its successful implementation on the Rhodes Cyber should not be so long that there would be little time for model testing during the projects duration. This is not a serious constraint in a 5 year project but does imply that development of a complex model from the beginning was precluded.

This set of 12 criterion led to the selection of the four models that were described in detail in Hughes and Beater (1987). The earlier report discussed the origins of the models and any modifications that were made to them prior to testing. It also discusses the physical relevance of the model parameters and initially perceived associations with catchment characteristics. As will be seen later (in chapter 5 of this report), these perceived associations played a role in the calibration of some of the models. The following sections, which summarise the basic structure of the four models, are included in the present report for the sake of completeness and to avoid the necessity of referring back to Hughes and Beater (1987) for an appreciation of the main differences between the models.

3.2 MODEL OSE1 - Simple antecedent moisture model

The basic structure of this model originates from the IEM4 model described in the UK Flood Studies Report (I.O.H., 1975). OES1 is a relatively simple model (figure 3.1) which uses a constant runoff proportion to reduce the total rainfall amount in any model interval to a net (or excess) rainfall amount. The initial losses depth (a parameter) is first of all decreased by an amount equal to the two day antecedent rainfall total. The remaining losses are satisfied from the early part of the storm rainfall hyetograph. An index of initial soil moisture, based upon a decay function of the previous 30 days of rainfall, yields the abscissa value in an S-curve relationship between relative moisture status and the runoff proportion. The resulting runoff proportion is multiplied by the rainfall inputs in each time period to yield the net rainfall hyetograph. This is then routed through a non-linear storage routing equation of the type discussed in Hughes and Murrell (1986). In the lumped version of the model only one rainfall input profile is used (averaged for the total catchment) and one set of parameters (table 3.1) is considered applicable to the whole catchment. In the semi-distributed version each sub-area has its own set of parameters and rainfall profile and the part of the model described so far is applied to each sub-area independently. For the lumped version, the initial 'land phase' (Hughes and Beater, 1987) routing is followed by a simple delay or timeshift, after which the flows generated for each time interval are attenuated through a triangular time-area diagram and accumulated to produce the outflow hydrograph. The base of the time-area triangle is an inverse power function of discharge with two parameters. The final routing phase (or channel routing) in the semi-distributed version is achieved by subjecting each sub-area output to a time delay and then routing the flows sequentially, through downstream sub-areas, using a non-linear storage routing equation. The parameters of the sub-area routing equations are intended to represent the effects of storage attenuation in the channel between the centroid of the sub-area and the centroid of the next downstream sub-area. The output from the lowest sub-area then represents the total catchment outflow hydrograph. As all the models utilize much the same sub-division system a more complete explanation of this is included in section 3.6.

This model was chosen as its structure represents a much simpler approach to determining the proportion of rainfall that becomes runoff than the next model (OSE2), yet has identical routing components. It should therefore be possible to associate differences in model performance to this easily identifiable difference in the two structures. It is worth noting that the use of a fixed runoff-proportion for any one event is unlikely to allow all parameter values to remain constant for different storms on the same catchment. Although differences in the degree of runoff response due to antecedent moisture status are allowed for in the model, differences due to intensity, total rainfall amount or storm duration are not. It is expected therefore that parameter values will vary between events on the same catchment.

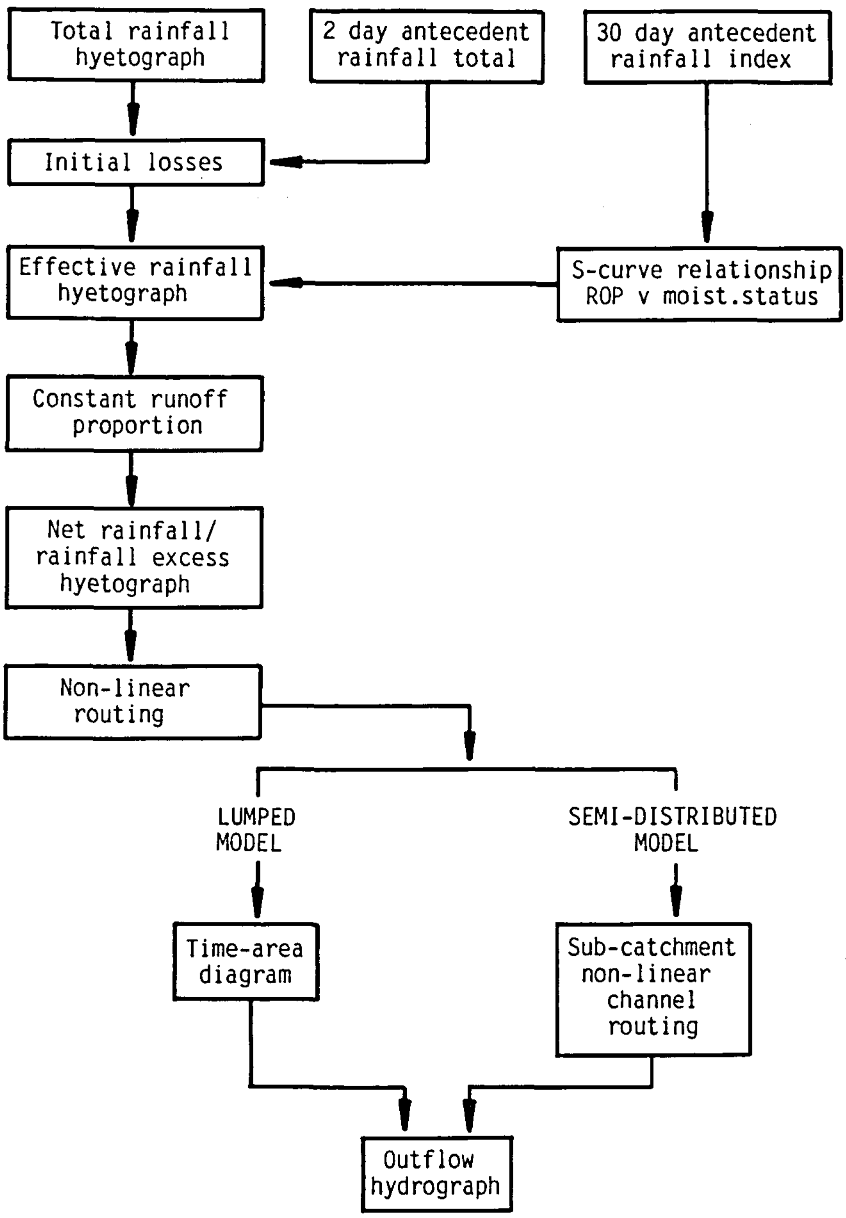


Figure 3.1 Structure of model OSE1 - Simple antecedent moisture model.

Table 3.1 Summary of OSE1 model parameters.

Symbol	Model type	Description	Range of values used in this study
K	Both	Catchment routing scale parameter	0,1 - 8,0
N	Both	Catchment routing power parameter	0,7
CDEL	SD	Channel delay time (hr)	0,0 - 5,25
KC	SD	Channel routing scale parameter	0,1 - 1,2
DEL	LM	Catchment delay time (hr)	0,8 - 0,85
A	LM	Time area base constant (hr)	1,0 - 5,5
B	LM	Time area relation power	0,1
SMAX	Both	Maximum soil moisture (mm)	70 - 270
DA	Both	Ordinate of S-curve parameter	0,12 - 0,75
C	Both	Abscisa of S-curve parameter	0,03 - 0,672
APF	Both	Antecedent precipitation factor	0,80 - 0,95
IL	Both	Initial losses (mm)	0 - 35

SD = Semi-distributed

LM = Lumped

3.3 MODEL OSE2 - Variable runoff proportion model

This model is an extended version of the implicit source area model presented in Hughes (1983a; 1984) but also has the Flood Studies Report (I.O.H., 1975) IEM4 model to thank for the original inspiration. As with OSE1, the starting point is an estimate of the initial moisture status of the catchment using a 30 day antecedent rainfall index. This moisture status is used to calculate the runoff proportion to be multiplied by the first interval of rainfall input. The runoff proportion-moisture status relationship is an asymmetric S-curve function. Runoff is also generated from a different S-curve function controlled by the intensity of the rainfall input. Thus two different functions, one controlled by the moisture status of the catchment and the other by the rainfall intensity, are responsible for generating runoff in any one time interval. That rainfall which does not contribute directly to runoff is added to a slope storage from which moisture is taken to increment the moisture status in the S-curve function. This moisture status can also be decreased by a baseflow seepage function. Thus the moisture status and therefore the relative runoff response to rainfall is variable throughout the duration of the storm. The three runoff components are referred to as HR, VSAR and baseflow in figure 3.2 which illustrates that all three are subjected to non-linear storage routing, HR and VSAR first being combined and baseflow being routed more slowly than the others.

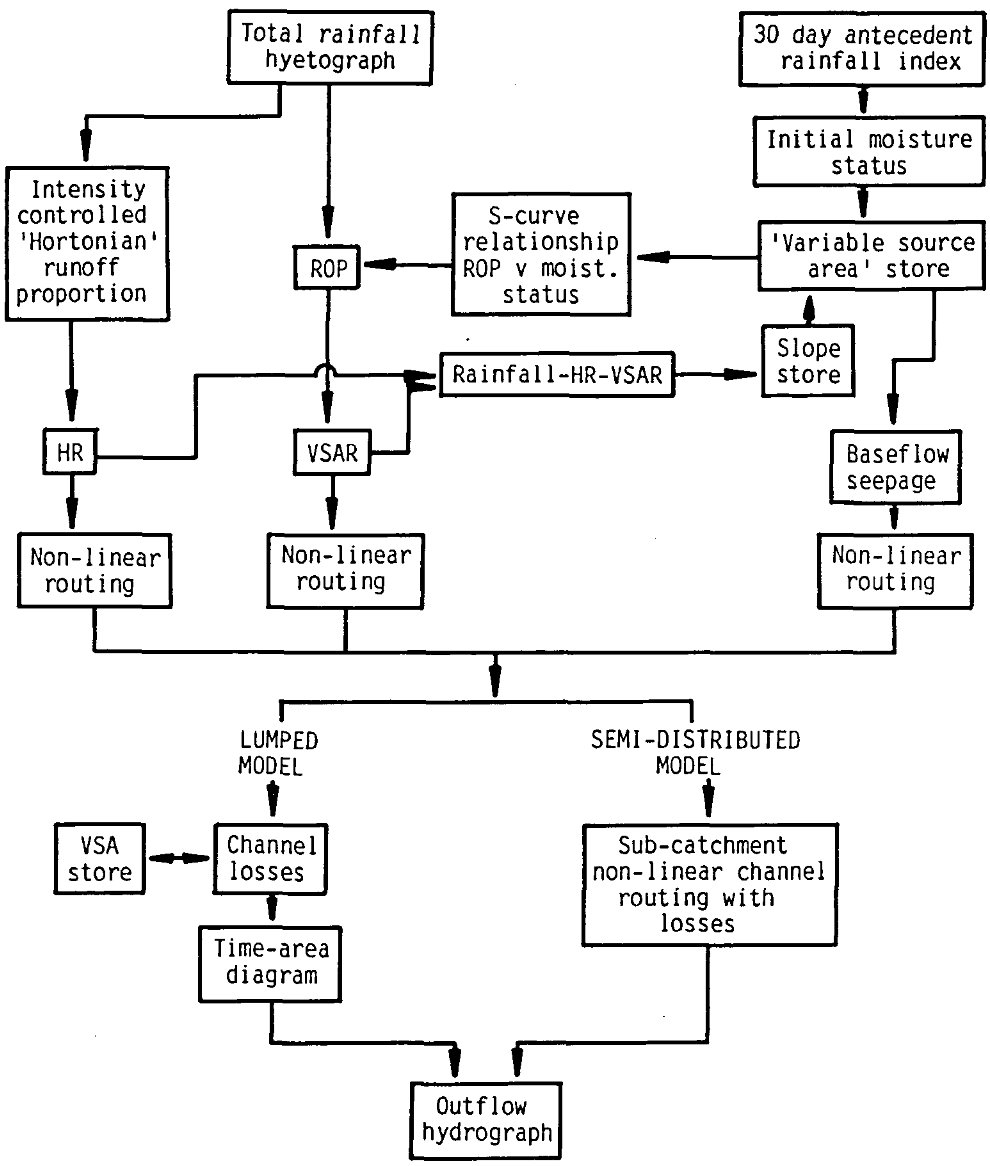


Figure 3.2 Structure of model OSE2 - Variable runoff proportion model.

The remainder of the model structure is similar to that of OSE1 in the way that the outflow from the non-linear routed flows are treated. The only difference is that additional components for both the lumped and semi-distributed versions are added to allow for channel losses in a simplistic way. As the amount of channel losses is conceptualised to decrease with increasing catchment moisture status, the channel loss component is a function of the level of the so called 'variable source area' store. A summary of the 15 parameters is given in table 3.2 which also identifies those that are required for the two different versions of the model.

The model has been developed such that each parameter should have relevance to some aspect of the hydrological response characteristics of catchments. It is not intended to be physically-based in the sense that the parameters could be directly evaluated from field measurements. In contrast to OSE1, the time-variant nature of the rainfall-runoff response ratio is intended to permit a greater degree of stability in parameter values for different storm types on the same catchment. In this respect, OSE2 represents the most complex of the four modelling methods adopted.

Table 3.2 Summary of OSE2 model parameters.

Symbol	Model type	Description	Range of values used in this study
K	Both	Catchment routing scale parameter	1,2 - 10,0
N	Both	Catchment routing power parameter	0,55 - 0,90
CDEL	SD	Channel delay time (hr)	0,0 - 5,25
KC	SD	Channel routing scale parameter	0,16 - 1,15
DEL	LM	Catchment delay time	0,0 - 0,5
A	LM	Time area base constant (hr)	0,8 - 5,5
B	LM	Time area relation power	0,05 - 0,12
SMAX	Both	Maximum soil moisture (MM)	70 - 270
DA	Both	Ordinate of S-curve parameter	0,13 - 0,66
C	Both	Abscisa of S-curve parameter	0,02 - 0,95
PCSLP	Both	% flow from slope to VSA store ($\%.hr^{-1}$)	111 - 480
PSVSA	Both	% flow from VSA store ($\%.hr^{-1}$)	0,5 - 4,3
IAF	Both	Impervious area factor	0,13 - 0,98
APF	Both	Antecedent precipitation factor	0,78 - 0,95
CLP	Both	Channel losses power	0,0 - 2,7

SD = Semi-distributed

LM = Lumped

3.4 MODEL OSE3 - Augmented hydrograph model

OSE3 is based upon the Augmented Hydrograph model of Mandeville (1983), modifications being made to the routing components to allow its use in both lumped and semi-distributed formats. The usual procedure in conceptual models is to estimate the volume reduction from rainfall to storm runoff to produce an excess rainfall hyetograph and apply this to the shape transformation or routing components to generate the final flow hydrograph (figure 3.3). This traditional order of model components is used in the other three models. Mandeville (1983) suggested that the volume reduction components are not independent of the shape transformation components in this type of model and proposed a reversal of their order (figure 3.4).

The routing components of OSE3 are the same as used in OSE2 except that they are applied to the gross rainfall (minus initial losses) before volume reduction. The volume reduction component is then simply a constant (for a specific storm) runoff proportion which can be defined as the ratio of the gross runoff to the gross rainfall (minus initial losses). If the model is being calibrated using observed flow data it is trivial to calculate this ratio when operating the lumped version of the model. In the semi-distributed version it is not so easy, as each sub-area can have different rainfall inputs and runoff proportion values. The list of parameters is given in table 3.3.

It should be noted that there is no function in this model that allows for the estimation of antecedent catchment moisture conditions. It is assumed therefore that the runoff proportion parameter will vary not only with storm characteristics (total rainfall, duration and intensities) but also with antecedent conditions. The routing parameter values might, however, be expected to remain constant for a single catchment. Mandeville (1983) suggested that this is unlikely to be the case for models adopting the conventional order of components. The relative stability of the routing parameter values of OSE1 and OSE3 for a single catchment is clearly one aspect that requires investigation during the model testing programme.

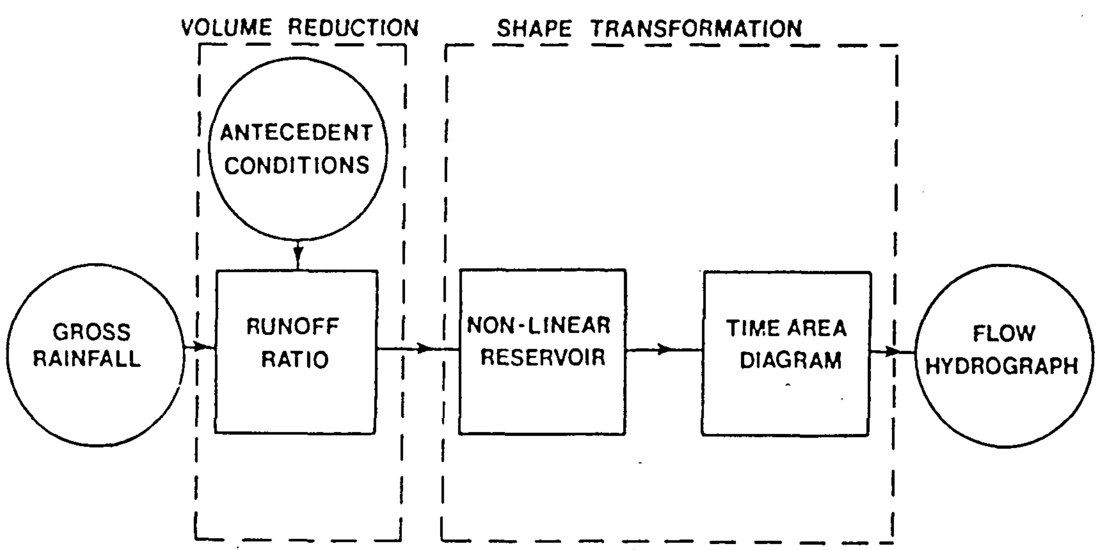


Figure 3.3 Traditional order of model components (from Mandeville, 1983).

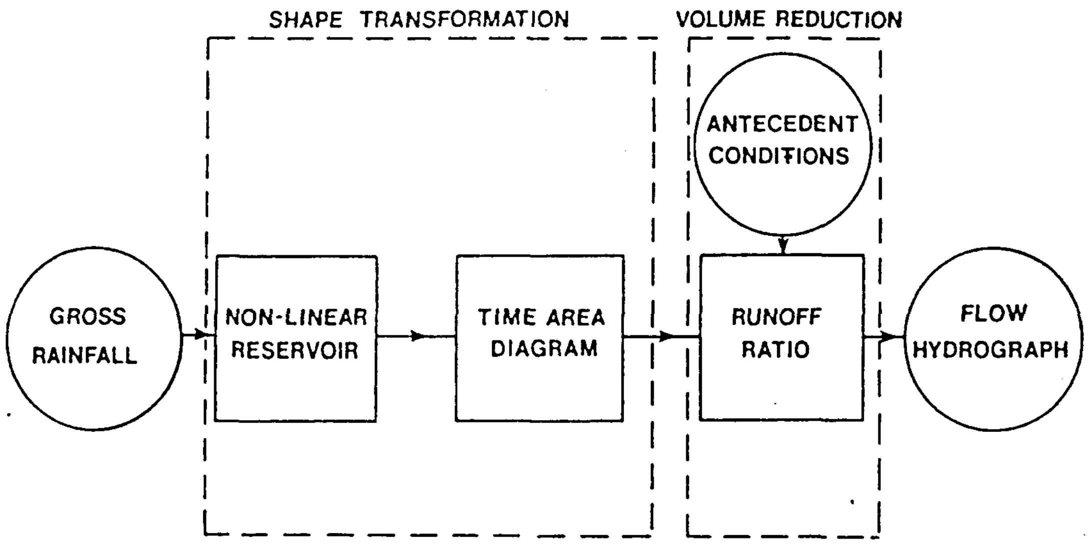


Figure 3.4 Augmented hydrograph model : component order (from Mandeville, 1983).

Table 3.3 Summary of OSE3 model parameters.

Symbol	Model type	Description	Range of values used in this study
K	Both	Catchment routing scale parameter	0,1 - 16,0
N	Both	Catchment routing power	0,5
CDEL	SD	Channel delay time (hr)	0,0 - 5,25
KC	SD	Channel routing scale parameter	0,1 - 1,2
DEL	LM	Catchment delay time (hr)	0,8 - 1,0
A	LM	Time area base constant (hr)	1,0 - 5,5
B	LM	Time area relation power	0,1
ROP	Both	Runoff coefficient (proportion or ratio)	0,02 - 0,878
IL	Both	Initial losses	0,35

SD = Semi-distributed

LM = Lumped

3.5 MODEL OSE4 - Runoff-routing model (RORB)

The basic conceptual structure of this model is described by Mein, Laurenson and McMahon (1974) while the brief description given here is drawn from the very comprehensive User Manual supplied by Monash University (Laurenson and Mein, 1985) with the computer program. It is a general rainfall-runoff and streamflow routing model which can also take into account the effects of storage reservoirs, floodplains or retarding basins. The model uses a sub-catchment distribution system similar to the models already discussed. In fact OSE4 provided much of the inspiration for the distribution and sub-area routing approach adopted in OSE1 to 3. OSE4 allows for several types of inflow to, and outflow from the channel network. Unlike the previous models, only one routing component is used which combines the attenuation effects of flow across the land surface and in the channel of a particular sub-area. The storage parameter is the product of a parameter applicable to the whole catchment and sub-area values, calculated within the program, from input data of channel reach length and channel type. The program allows the user to specify where observed streamflow data are to be used to compare with simulated flows. This feature is very useful where streamflow gauging networks are nested and when assessment of simulation results is required at several points in a catchment.

The calculation of rainfall excess can be effected using a constant runoff coefficient or a continuing loss rate. Both methods incorporate an initial loss component that must be satisfied before runoff can occur. The variability of losses between sub-areas is accommodated through specifying the impervious fraction of each sub-area. Variations in runoff response over time during one event can be allowed for by defining the input rainfall as a series of separate bursts. Different loss parameters are calculated for different bursts but the method assumes that the user has some knowledge of the relative runoff responses of the different bursts.

The model was selected as it was readily available as a FORTRAN coded simulation model and has been reputedly used quite extensively in applied situations in Australia. It can be used as a lumped (one sub-area) or semi-distributed model and its operation with the continuing loss rate option can be compared with its operation (and that of OSE1) with the constant runoff coefficient option.

The model has many features which are not tested in this investigation. It has only been applied to the available test data in its very simplest form, ignoring some of the options which may have produced improved simulations. The use of most of these options would, however, have required more information about the test catchments than was readily available. The way in which it has been applied is considered by the authors to be compatible with the way in which the other models have been applied.

3.6 SUB-AREA DEFINITION

Sub-areas are defined by distinct drainage elements within the total catchment area, each one considered to have a single outflow point which is usually a point on the channel network. The areas are defined by the user and would normally be selected to have a relatively high degree of internal homogeneity in terms of physical characteristics. However, the definition of sub-areas can also be usefully related to the network of available input rainfall data. The sequence in which the flow is routed through the channel network is also user defined in all the models and scope exists for storing output from sets of sub-areas to be added to output from other sets later in the sequence. There is nothing to prevent a user from defining just channel segments (without significant catchment area) as sub-areas. In this case only the parameters of the channel routing components would be relevent. The authors believe that this sub-area approach to spatial distribution is more flexible as well as being more physically relevant (Hughes and Herald, 1987) than a grid square approach.

Inevitably, the greater the number of sub-areas that a user defines, the more complex the model becomes, the number of parameters to be quantified increases and the computer run-time increases. In the program code for models OSE1 to 3 the number of sub-areas is limited to 20 but could be easily increased if necessary. While the size, number and organisation of the sub-areas will clearly have some effect on the modelling results, the effects are likely to be highly dependent upon the nature of the storm input on any specific catchment. It is therefore difficult to make any general recommendations beyond those related to homogeneity and raingauge network referred to above.

Chapter 4

TEST CATCHMENTS AND AVAILABLE DATA

The compilation of a data set suitable for testing the usefulness or applicability of deterministic models is not always an easy task. One of the problems involves obtaining reasonably quick access to data from a wide range of different catchment types such that the collection of data does not dominate a project which is really designed to assess models. The data must also be of sufficiently high quality for any results to be meaningful. However, it must also be recognised that within any comprehensive data set there will be variations in the level of detail and quality of the data. These effects must be considered in the interpretation of the results obtained. Specifically, the number and spatial distribution pattern of raingauges will affect the accuracy with which the input storm rainfall can be defined (Roberts, 1984).

Within South Africa there are a number of catchments which were established for research purposes. These include catchments operated by various universities and government departments or research institutions. As this project was specifically designed to investigate the applicability of models to medium-sized catchments, data from small (less than about 2 km^2) research catchments in the country have not been used. Reference to table 4.1 indicates that six regions of South Africa are covered by the data that have been used. These are two areas of Natal (De Hoek and Cedara catchments, obtained from the Department of Agricultural Engineering, University of Natal, Pietermaritzburg), Zululand (Ntuze catchment, also from Pietermaritzburg), Orange Free State (Bethlehem catchment, obtained from the Hydrological Research Institute of the Department of Water Affairs), and the eastern and southern Cape (Ecca and southern Cape catchments, available from Rhodes HRU, Department of Geography).

A useful source of single event data from catchments in various parts of the United States is the various miscellaneous publications of the United States Department of Agriculture, (USDA), Agricultural Research Service (USDA 1955 to 1973). Copies of these volumes are held by the Department of Agricultural Engineering, University of Natal, Pietermaritzburg. Many of the catchments referred to in these volumes are also small but it has been possible to extract four sets of medium sized catchments from climatically and physiographically different parts of the United States. The four areas are Arizona in the arid south west, Mississippi in the south eastern central region, Vermont in the north east and Oklahoma in the south western praries (table 4.1).

Table 4.1 summarises the 33 catchments that this study has used. Listed in the table are the catchment areas (3 - 150 km^2), the total number of events extracted from the available data (355), the range of catchment slopes, the location and a brief description of the climate and physical characteristics of the catchments. The distribution of the catchments within South Africa and the United States is shown in figures 4.1 and 4.2. The remainder of this chapter deals with each group of catchments in turn, supplies more information on their characteristics and discusses the nature of the available data for the purposes of defining input rainfall as well as quantifying their physical characteristics. Simplified maps illustrating the drainage pattern, the position of individual gauged catchments in each area and the location of raingauges are also given.

Table 4.1 Summary of test catchments and their general characteristics

Catchment Name	Area (km²)	No. of storm events	Location	Slopes (%)	Climate	Generally Represents
TOMBSTONE :						
TM1	150	2	Arizona		Arid to	Desert grass & scrubland
TM2	114	5	South-	8-12	semi-arid	region. Soils are moderately
TM3	9	11	west		MAP=300mm	permeable gravelly loams
TM6	95	2	USA		Predominantly	mainly underlain by deep
TM8	15	11			summer rains.	alluvial deposits.
TM11	8	12				
ECCA :						
Q9M20	73	15	E. Cape		Semi-arid	Steeply sloping valley sides
Q9M21	9	14	South	13-20	MAP=490mm	with thin soils & fine grained
Q9M24	23	5	Africa		All year round rainfall.	alluvial soils in valley bottom. Scrub brush with brush with sparse ground cover.
BETHLEHEM :						
C8M25	83	11	O.F.S. South Africa	3-4	Temperate summer rainfall area. MAP=700mm	Cultivated & natural grassland. Light sandy soils with clayey soils in valley bottoms. Large number of farm dams.
DE HOEK :						
V1M19	15	16	Natal S. Africa	10-35	Sub-humid summer rainfall area. MAP=720 -1115mm.	Two distinct physiographic zones of valley & plateau Soils developed on mudstones & sandstones. Steep slopes - shallow & stoney, elsewhere - deeper silty clays to clay loams. Grassland vegetation (some overgrazed). Many soil conservation structures.
CEDARA :						
U2M16	5	10	Natal S. Africa	12-20	Humid summer rainfall area MAP=875mm	Forest, pastures & cropland. Mainly deep, dolerite derived soils with low surface runoff potential.
ZULULAND :						
W1M15	14	15	Kwa-Zulu	16-34	Humid summer	Mixed Eucalyptus plantation,
W1M16	3	15	S. Africa		rainfall area. MAP=1000mm.	indigenous forest & grassland. Soils variable from bare rock to deep soils.
OXFORD :						
OXW4	8	5	Mississippi		Temperate	Cultivated, eroded uplands
OXW5	5	9	S.E.		MAP=1350mm	with seasonal variation in
OXW10	22	12	Central	7-13	All year	vegetation cover. Silty loam
OXW12	92	12	USA		round	soils with moderate to rapid
OXW17	130	13			rainfall.	permeabilities. Relatively
OXW24	2	8				wide and flat alluvial valleys.
OXW28	4	7				Large number of desilting and
OXW32	81	14				retention dams.
OXW35	30	12				
SOUTHERN CAPE :						
K3M01	48	17	S. Cape		Sub-humid	Steeply sloping mountain
K3M04	34	18	coast	22-48	MAP=900mm	catchments with bushland
K4M02	22	7	S. Africa		All year	(fynbos), pine plantations &
K4M03	35	12			round rainfall.	indigenous forest mixed. Variable soils, deep in lower areas but shallow & stoney on hill tops.
NORTH DANVILLE :						
ND1	43	15	Vermont		Temperate	Sloping forest and farmland
ND3	8	13	N.E.	11-16	MAP=950mm	having loamy soils of
ND4	43	9	USA		snowcover	moderate depth with moderate
ND5	112	15			in winter.	to high permeability developed on glacial till deposits.
CHICKASHA :						
CH111	68	5	Oklahoma		Temperate	Range & cultivated land with
CH512	92	8	South-Western Prairies USA	5-6	MAP=700mm predominantly summer rainfall.	some woods. Relatively deep alluvial soils with moderate permeability derived from sandstones.

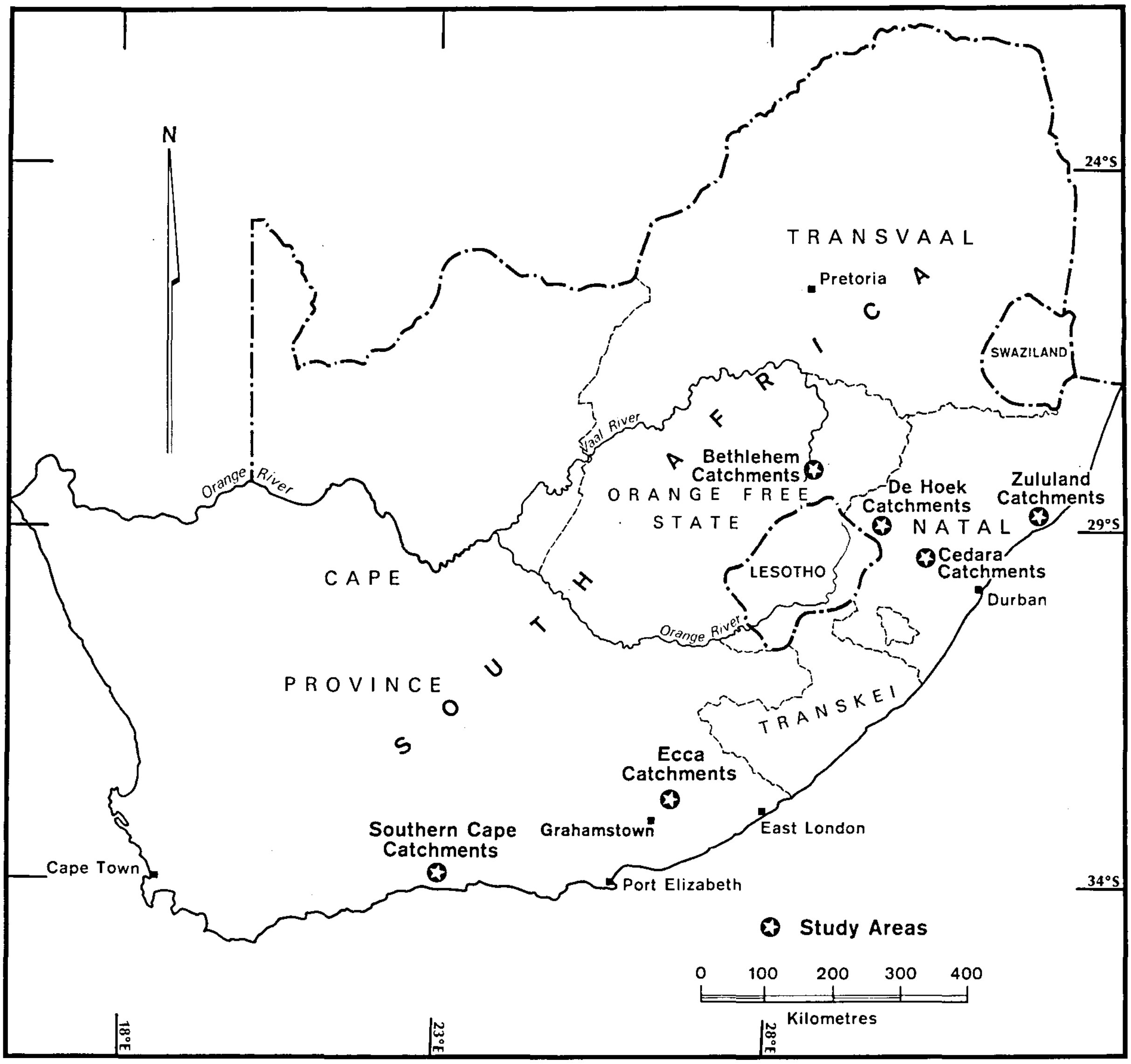


Figure 4.1 Distribution of test catchments within South Africa.

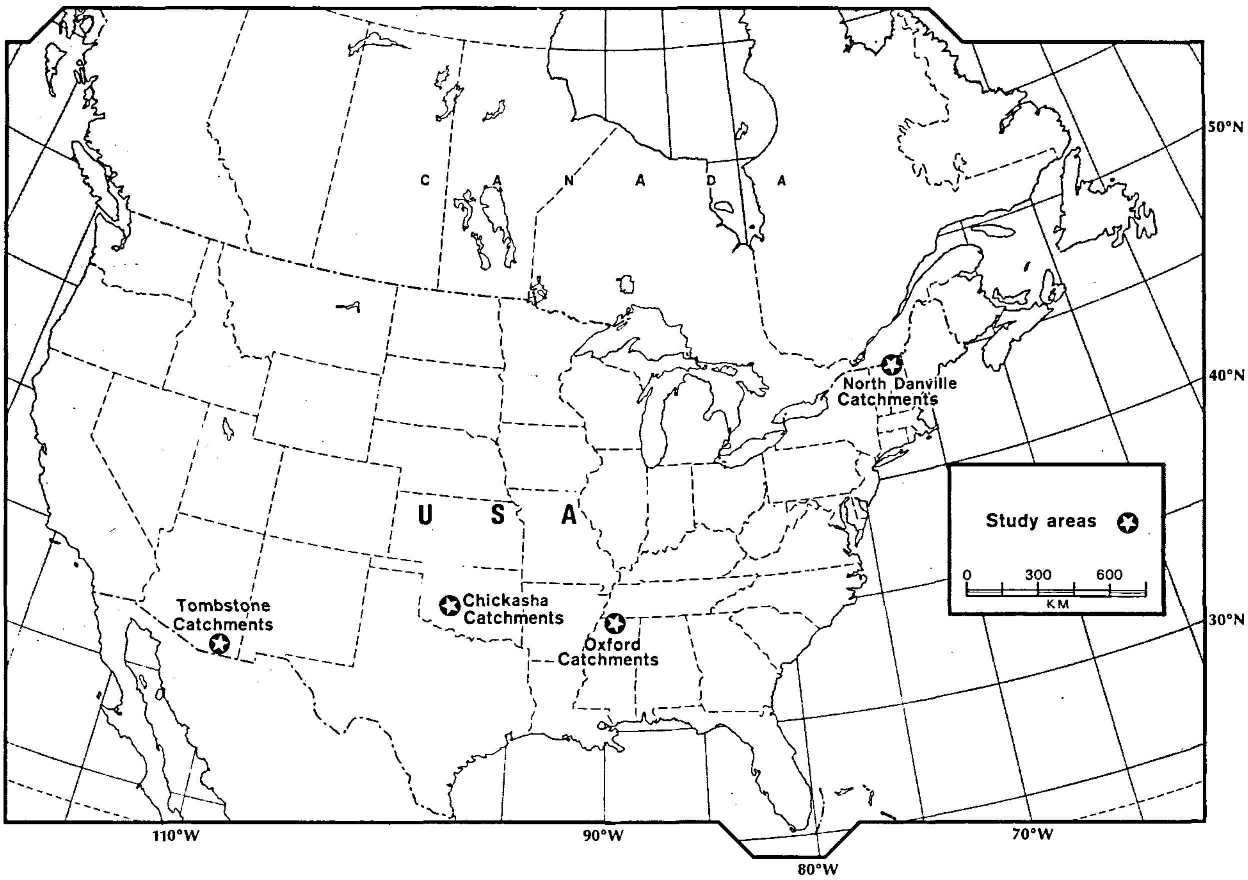


Figure 4.2 Distribution of test catchments within the U.S.A.

4.1 TOMBSTONE CATCHMENTS

The Tombstone catchments are within the USDA Walnut Gulch experimental watershed, a tributary area of the San Pedro River in Cochise County, Arizona. Within the main catchment there are a further five gauged sub-catchments (table 4.1 and figure 4.3). The catchments represent the arid to semi-arid desert grassland area of the south eastern Arizona basin. The slopes are moderate except in a few areas close to the catchment boundary where they are quite steep. The majority of the information on the Tombstone catchments is derived from USDA (1955-1973).

The majority of the area is underlain by interbedded sand and gravel alluvium which is very deep in the east but is shallowly underlain by granodiorite in the west. The granodiorites outcrop in the south west and are capped in places by limestones. Soils are gravelly or stony clay loams which are moderately permeable. Given that the alluvium is also permeable it can be assumed that the effective depth of the soil from a hydrological point of view is high. Vegetation cover is sparse and consists mainly of desert shrubs and grasses. Mean annual rainfall is about 300mm with a clear peak in July and August. There are no available data on evaporation rates but mean daily temperatures during these months exceed 26°C.

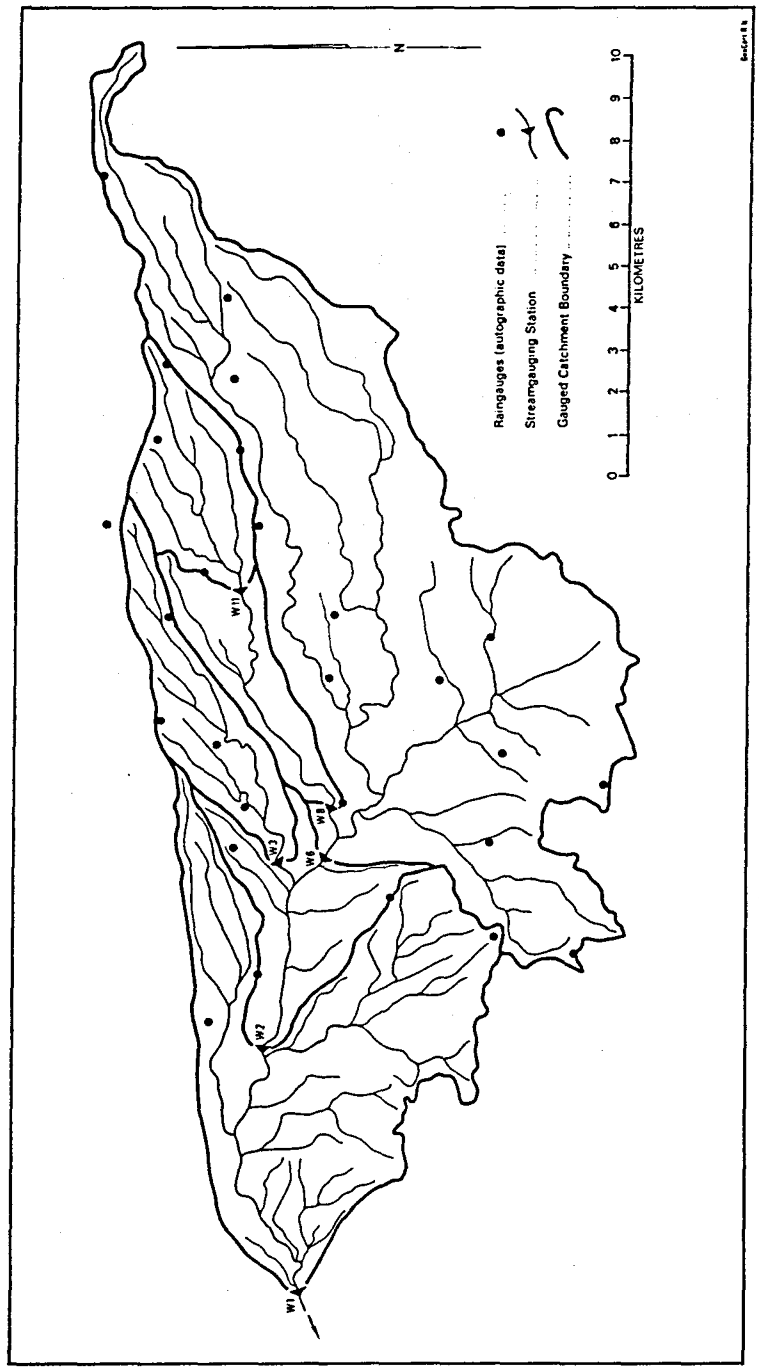


Figure 4.3 Gauged catchments and raingauge network in the Tombstone area (total area of 150km^2; raingauge density for catchments range from 1 gauge per 1,6 and 5,5km^2).

All of the storms used in the model tests are summer events of short duration and high intensity, typically of small areal extent. Consequently, there is a high degree of spatial variation in rainfall with some parts of the whole catchment receiving up to 68mm while other parts receive less than 10mm. Figure 4.3 illustrates the distribution of raingauges for which storm profile data are available for some of the events. However, not all gauges are represented for all events. These data are supplemented by isoyetal maps (USDA, 1955-1973) of storm total rainfall which assist in defining the spatial variation of rainfall input. One advantage is that the gauges for which the detailed data exist are those closest to the storm centre for each event.

The runoff response is extremely 'flashy', particularly from the smaller catchments (TM3, 8 and 11). Events on TM8, for example, rarely last more than 3h and the peak of the largest event reached $121m^3s^{-1}$, 35 min. after the onset of flow. One event in August 1971 progressed from zero flow at TM6 at 19h31 to over $70m^3s^{-1}$ at 19h35 reaching a peak of $107m^3s^{-1}$ at 19h47. Flows of over $50m^3s^{-1}$ were sustained for 1h, while 2h later the flow had reduced to below $1m^3s^{-1}$. While most of the other catchments were modelled using a 15 min. time interval, it was considered necessary to reduce the interval to 5 min. for the Tombstone events. Renard and Keppel (1966) as well as Burkham (1970) have documented the importance of channel loss processes in this region. The volumes and peaks at TM8 (catchment area of $15km^2$) are usually substantially less than those at the upstream gauging point at the outlet of TM11 ($8km^2$). It is unlikely that any of the models will be able to adequately account for this process.

4.2 ECCA CATCHMENTS

Figure 4.4 illustrates the Ecca catchments and the location of the flow and rainfall gauging stations. The Ecca is a tributary of the Great Fish River and situated in the semi-arid eastern Cape Province. Roberts (1978) and Görgens (1983) provide detailed descriptions of the climate and physical characteristics of the catchments. The catchment is underlain by interbedded shales and sandstones with harder formations of quartzite and tillite on the southern boundary. Headwater areas and valley bottoms are characterised by shallow slopes and separated by very steep slopes forming the valley sides. Soil depth is strongly related to slope, being thin and stoney on most valley sides but deeper in parts of the valley bottoms where they are associated with an uneven spread of alluvial and colluvial deposits. The deeper soils are fine grained with low permeabilities.

Vegetation consists of succulent to sub-succulent bush with variable density. Ground cover is temporally variable, disappearing from large parts of the catchment during droughts but reappearing after wetter periods. These variations appear to be more important than any seasonally related changes.

The climate is semi-arid with relatively low (MAP = 490mm with little seasonality) and erratically occurring rainfall and high potential evapotranspiration losses (annual mean of 1360mm, with peaks of 173mm $month^{-1}$ in December and January). The main storm type in summer is caused by convectional or convergence uplift resulting in short duration and often high intensity storms. Rainfall amounts and intensities can be very spatially variable with the valley bottoms receiving the highest falls. The runoff response from the steep and thin-soil valley sides can be high during such events but losses in the channels and alluvial valley bottoms result in only minor flow events at the gauging weirs. The most important runoff generating events are long duration, relatively lower intensity frontal or advection storms. While these can occur all year round they appear to be more common in winter.

If they occur after a dry period no flow occurs until at least 30mm of rain has fallen after which runoff proportions progressively increase. Spatial variations in rainfall amount and intensity during these events are usually low but there is a minor orographic effect giving rise to higher rainfalls on the south and east catchment boundaries.

Figure 4.5 illustrates the sub-area division that has been used for catchment Q9M20. The diagram shows the sub-area nodes and conceptual storages that are used to route modelled flows through the channel network.

4.3 BETHLEHEM CATCHMENT

The Bethlehem research catchments are situated in the upper reaches of the Wilge River, a tributary of the Vaal River, in the dryland farming area of the eastern Orange Free State. The information about physical characteristics is drawn from Mason-Williams (1984) and Maaren (1979), while the rainfall and flow data were provided by the Hydrological Research Institute of the Department of Water Affairs. The majority of the area is underlain by mudstones with some thin interbedded sandstone bands and several dolerite dyke and sill intrusions. The catchment is characterised by gently sloping relief with slopes mainly in the 0 - 6% category. There are a significant number of surface depressions or pans covering areas up to several hectares.

Away from the major streams, the soils are dominantly light sandy topsoils overlying fine sandy loams. The soils adjacent to the major streams are heavy, structured clays. Intermediate duplex type soils, with light sandy surface horizons overlying clays also occur. Soil depth is very variable but is on average about 600mm in the upper slope areas. The vegetation pattern is a mixture of dryland cropping, dominated by maize and wheat, planted pastureland and natural grassland veld. Some of the cultivated land is contoured while much of the natural veld is overgrazed and subject to erosion. There are a large number of farm dams within the catchment and 59% of the catchment area lies above these dams. These can be expected to have some impact on the runoff response.

Mean annual rainfall is about 700mm with 79% on average falling in the months October to March. Mean daily maximum temperatures during this period are above 24^{o}C while mean daily S-pan evaporation is 4,7mm or greater. All of the events used in the model tests are summer storms which are frequently characterised by spatially variable amounts and intensity. Figure 4.6 illustrates the distribution of raingauges for which intensity data are available for some of the storms. There are an additional four gauges outside the limits of the diagram which have assisted in determining spatial patterns. All of the storms used are of relatively short duration (rainfall lasting less than 3h) with relatively high intensities in the central area of the storm.

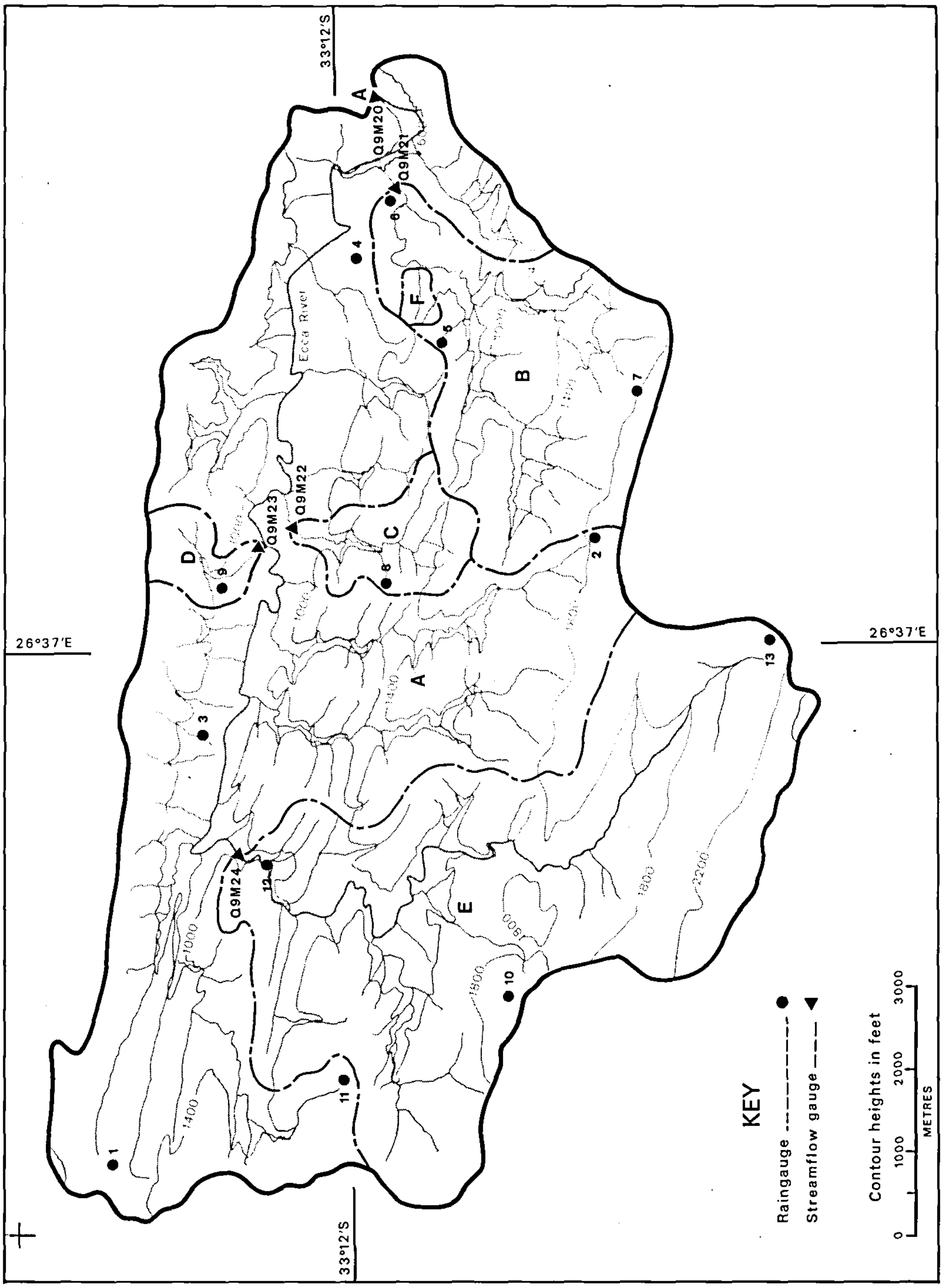


Figure 4.4 Ecca catchments and hydrological gauging network (from Görgens, 1983). The raingauge density for Q9M20 (73km^2) is 1 gauge per 7,3 km^2.

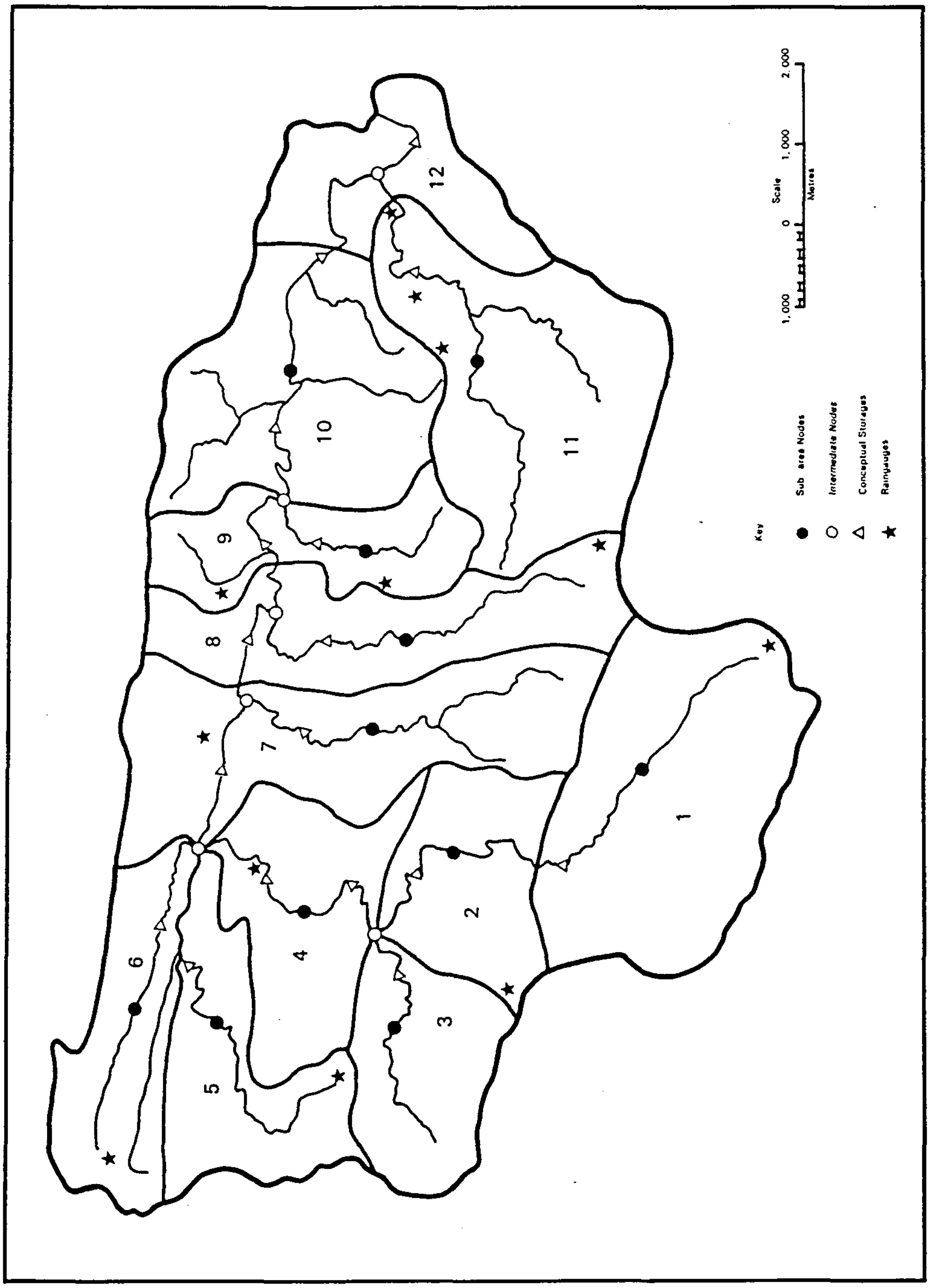


Figure 4.5 Sub-area definition for the gauged Ecca catchments.

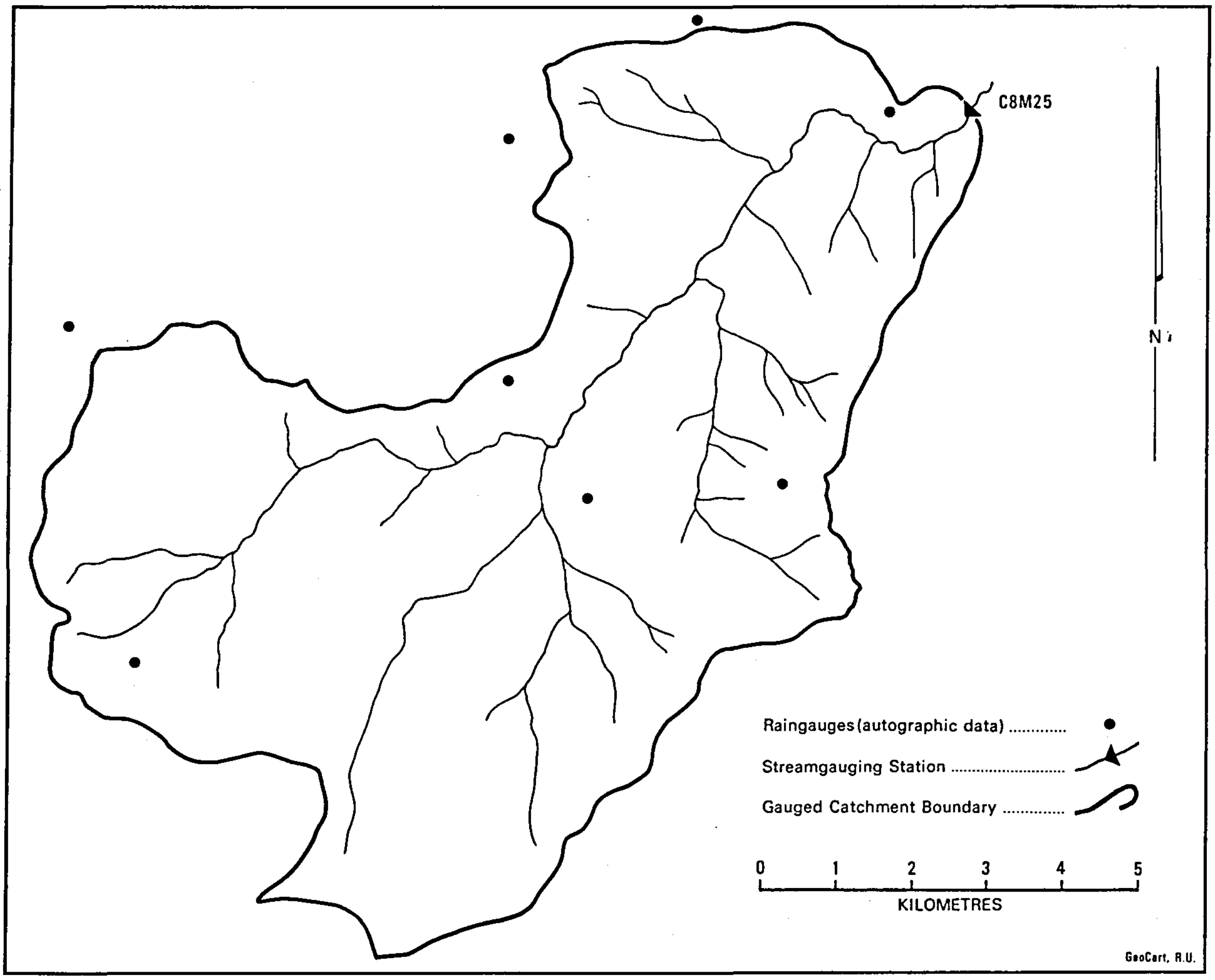


Figure 4.6 Bethlehem catchment and raingauge locations (total area 83km^2, overall raingauge density is 1 gauge per 10,4km^2).

4.4 DE HOEK CATCHMENT

The De Hoek catchment is located at the base of the Drakensberg escarpment in the Natal Midlands, to the west of Estcourt. Information about the catchment used (V1M19) is available from Hope and Mulder (1979) and Schulze (1985). Figure 4.7 illustrates that there are three physiographic divisions; the plateau area; the steep escarpment and the valley of the so called De Hoek "amphitheatre". The valley and plateau are underlain by mudstones, while the escarpment is made up of sandstones. Dolerite sills and dykes occur in the valley and on the plateau. Soil variations are related to the physiographic divisions.

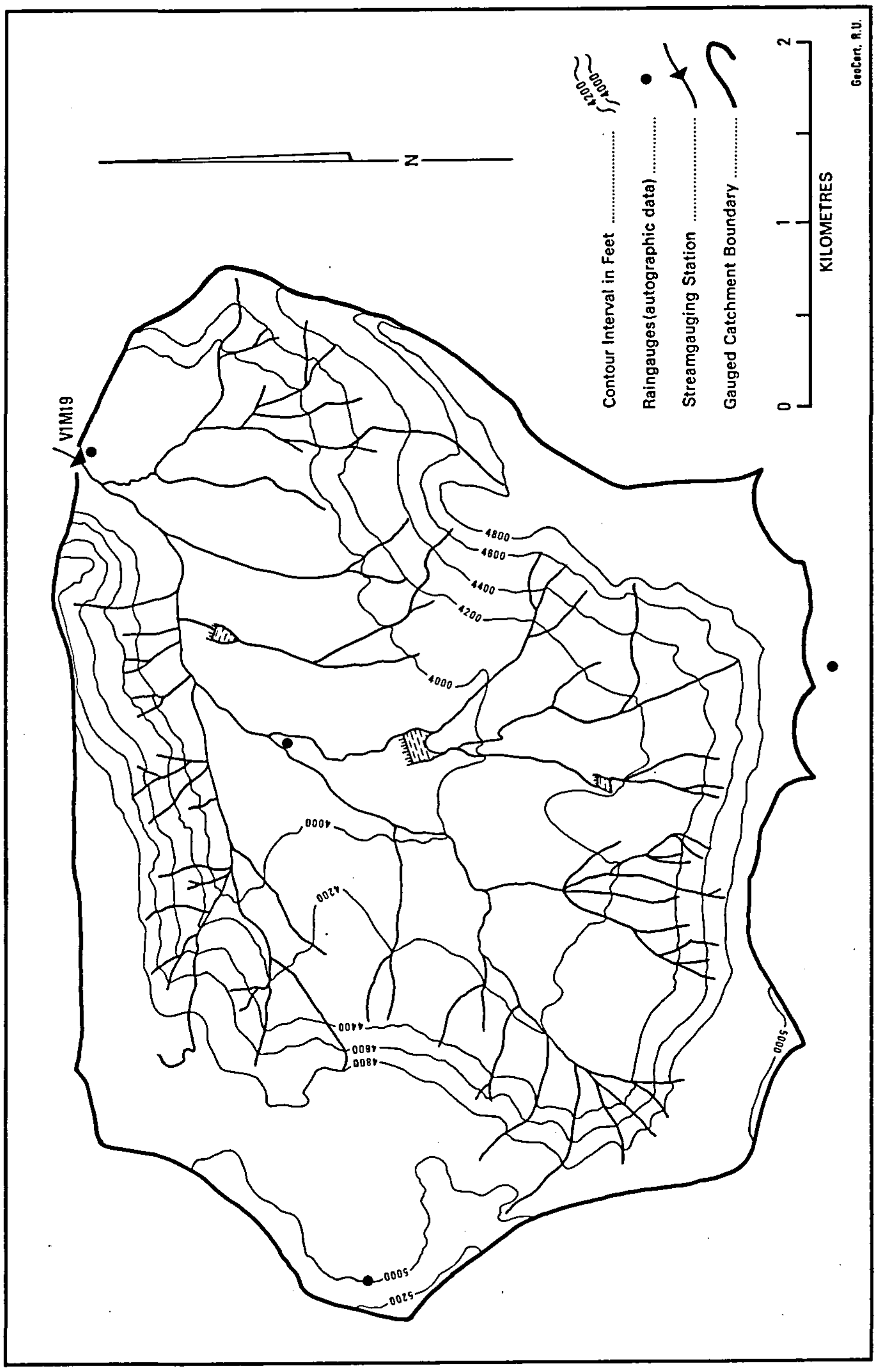


Figure 4.7 De Hoek catchment and raingauge locations with the escarpment of the amphitheatre indicated by the contours (total area of 15km^2; raingauge density is 1 gauge per 3,75km^2).

The upland soils are silt clay and clay loams with relatively rapid permeabilities. Escarpment soils are very thin and stoney. The valley bottom soils are more variable with clay loams and loamy duplex soils having permeabilities ranging from moderate to very slow. There is only limited information on soil depth for the plateau and valley areas. The plateau soils are generally deeper than 750mm, while the valley soils appear to be very variable but can have much deeper subsoils. Vegetation is dominantly grazed grassland and bush with some cultivation and wattle plantations.

The catchments lie in a summer rainfall region and consequently all the events used in the model tests occurred in the months October to March. Long term rainfall figures from representative stations (Schulze, 1985) suggest that differences will exist between rainfall on the plateau (MAP = 1115mm) and in the valley (MAP = 723mm). Mean annual A-pan evaporation is over 1500mm with the months of October to January experiencing greater than 150mm on average. Rainfall data are available from four gauges (two in the valley and two on the plateau; figure 4.7). There are a large number of small farm dams and soil conservation structures as well as a relatively large dam structure in the centre of the catchment.

4.5 CEDARA CATCHMENT

The Cedara catchment is located close to Pietermaritzburg in the Natal Midlands (Figure 4.1 and 4.8). U2M16 is drained by the Rietspruit which is tributary to the Mgeni River. A large amount of information about U2M16 is available in Schulze (1979) and the data have been obtained from the Department of Agricultural Engineering, University of Natal, Pietermaritzburg. The catchment is underlain by shales which have been intruded by dolerite sills and dykes. Slopes are moderate and average less than 20%. The upstream southern parts of the catchment have the steepest slopes but are rarely over 30%. Soils are predominantly deep (over 1m), dolerite derived with relatively high clay percentages (>50%). These soils are considered by Schulze (1979) to have a low runoff potential. Pine, eucalyptus or wattle plantations occupy 57% of the catchment. Some 12% of the catchment is occupied by smallholdings and farms growing a variety of crops and 8% by scrub. The remaining area is occupied by veld under controlled grazing.

Mean annual rainfall is approximately 875mm with 79% falling in the summer months when mean daily potential evaporation exceeds 4mm (Schulze, 1979). As with the other summer rainfall areas of South Africa all the storms used occurred in summer and are relatively short duration events with a variable degree of spatial variability in rainfall amount. Except for events at the beginning of the wet season, antecedent rainfall totals are usually quite high due to the frequency of occurrence of storm events.

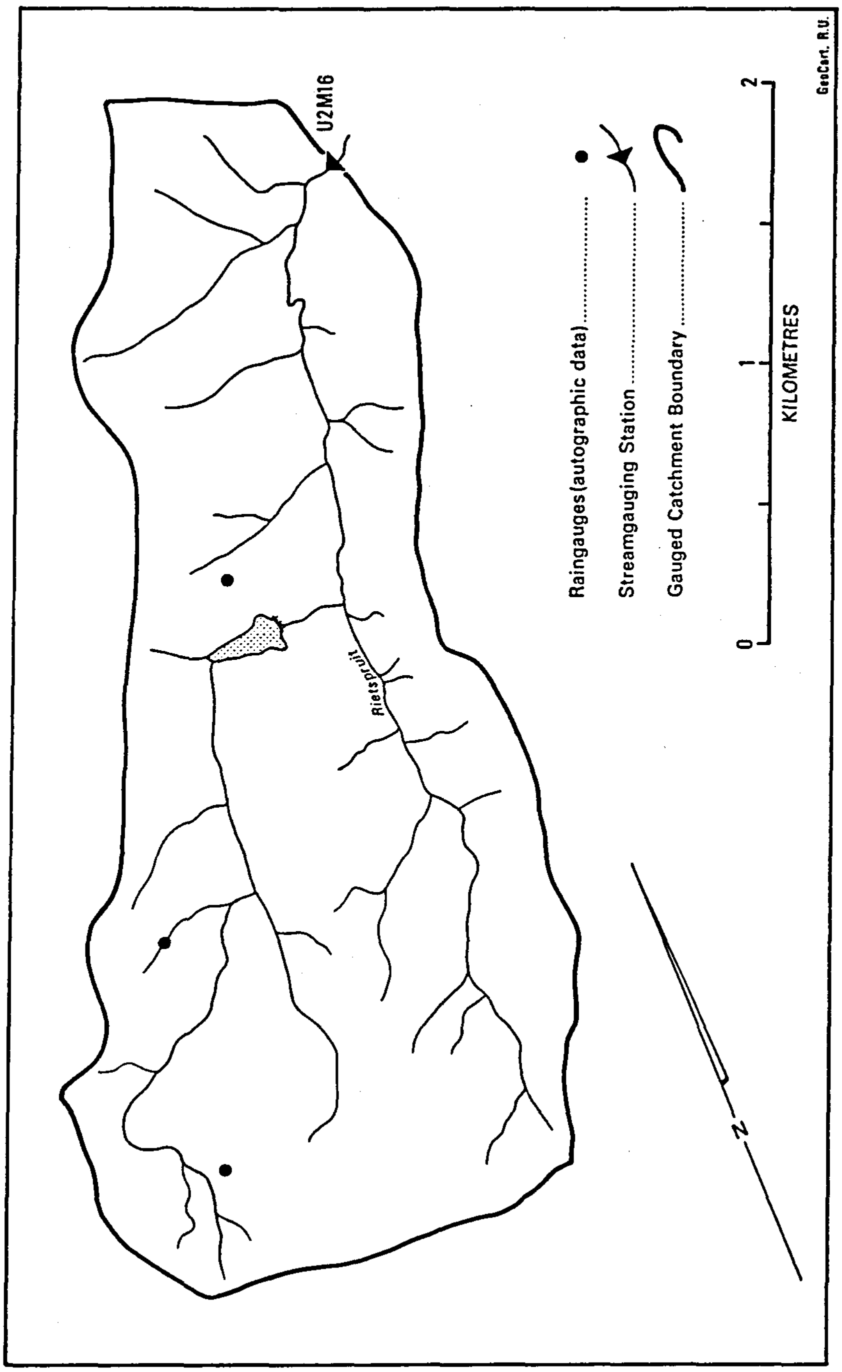


Figure 4.8 Cedara catchment and location of raingauges used (total area of 5km^2; raingauge density is 1 gauge per 1,7km^2.

4.6 ZULULAND CATCHMENTS

The Zululand catchments are situated south east of Empangeni close to the Natal/KwaZulu coast. Catchment information is derived from Hope and Mulder (1979) while the data were obtained from the Department of Agricultural Engineering, University of Natal, Pietermaritzburg. The northern parts of the catchment are underlain by biotite granite gneiss while to the south the rocks are less resistant biotite quartzo-feldspathic schists. There is an abrupt rise of about 100m coinciding with the north-south orientated drainage pattern (figure 4.9) in the centre of W1M15. Hope and Mulder (1979, p78) present a useful 'hydrological response unit' map which incorporates soil type and depth, slope and land use. Soils are dominated by coarse textured soils but of variable depth. The deeper soils occur along the river channels and within catchment W1M16 while there is a high proportion of bare rock areas in the western part of W1M15 south of the W1M16 catchment boundary. Land use is predominantly grassland with some agricultural crops, eucalyptus plantations and indigenous forest. Marshland grasses and vegetation are found adjacent to most of the main river channels.

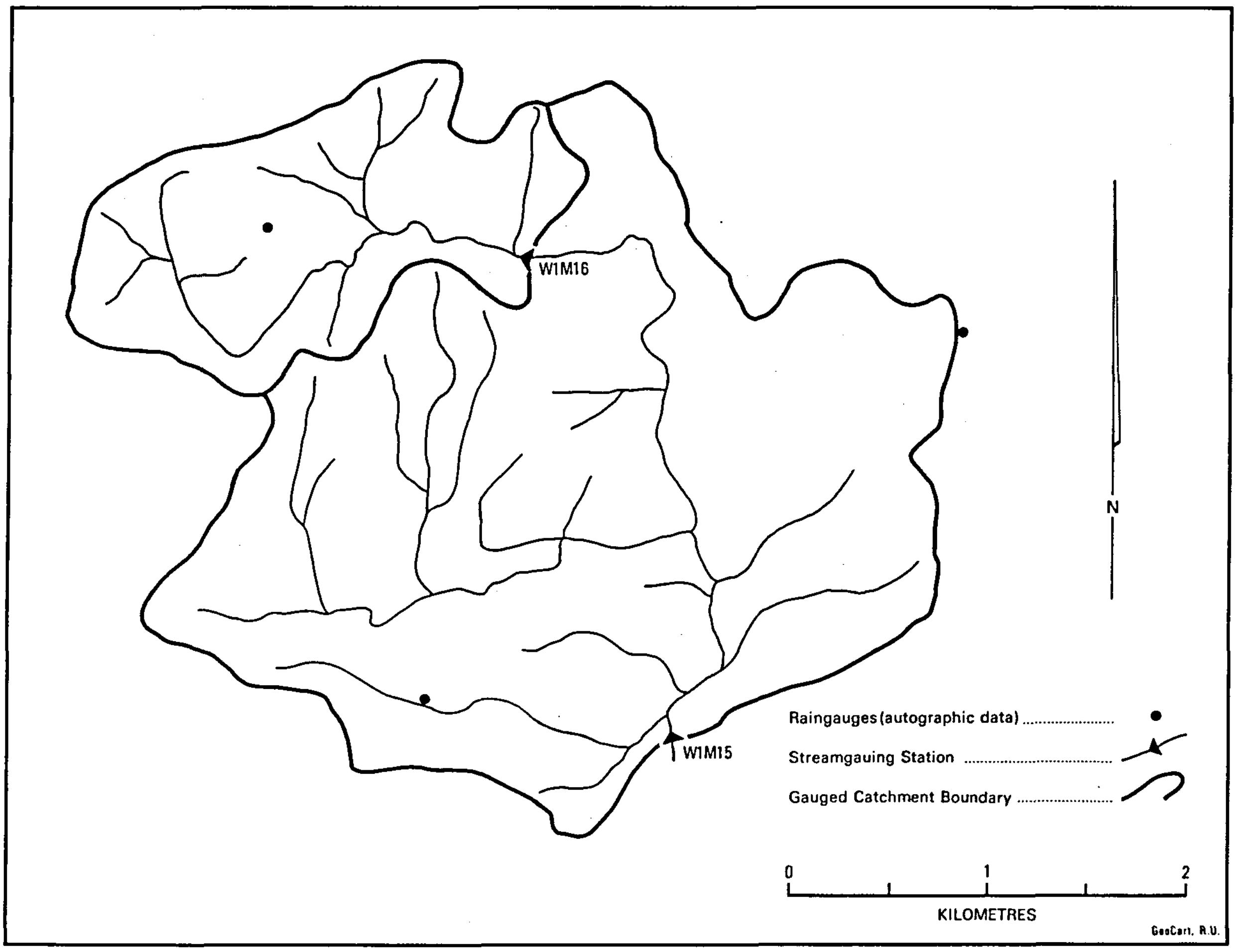


Figure 4.9 Zululand catchments and raingauge locations (total area of 14km^2; raingauge density is 1 gauge per 4,7km^2).

Mean annual rainfall is approximately 1000mm, while annual A-pan evaporation is generally above 1700mm. As with the other Natal catchments all the storms are drawn from the summer months (October to March). However, the majority of the events used are of much longer duration than those used for De Hoek and Cedara but relatively high intensities are also experienced. The longer duration events experienced in this area compared with the Natal Midlands is a reflection of the coastal location of the Zululand catchments. The rainfall generating mechanisms are more a consequence of orographic uplift of maritime air circulating inland then the more common convective mechanisms of the Natal Midlands. Spatial variation in rainfall is also comparatively reduced. While data from only three raingauges are available, the gauges are positioned to represent the main physiographic zones.

4.7 OXFORD CATCHMENTS

The Oxford catchments cover a total area of over 300km^2 in Marshall County, Mississippi State. There are numerous sub-catchments within this area of which 9 have been used in this study (table 4.1 and figure 4.10). Information on the catchment characteristics and the single event data have been extracted from the USDA (1955 to 1973) volumes. The area represents the eroded uplands in the transitional zone between the southern coastal plain and the southern Mississippi Valley uplands. The area is gently to moderately sloping and underlain by sandstones which have many clay lenses. The main river valleys are underlain by mixed alluvial material and are broad and flat with well developed floodplains. Soils are silty clay loams to fine sandy loams with moderate to rapid subsurface permeabilities. Soil depths are generally less than 1m but can be much deeper. Some of the soil types have impeding layers at 400 - 500mm. Although there is no specific information on the spatial distribution of soil types, comparison of the soil descriptions given for the various catchments indicates only small variations between catchments.

Land use includes approximately 20% under cotton and corn cultivation, over 30% with poor to good cover of broomsedge and grasses, 10 - 15% pasture and up to 25% under woods having fair to good cover. An interesting feature of the vegetation cover is the great seasonal variation, particular in the cultivated areas. During winter the cover characteristics are poor to fair depending upon the stage of ground preparation for the next crop and the state of the residue from the previous crop. In spring and early summer the cover improves as the crop growth increases and in August and September the mature crops provide fair cover. Such variations can be expected to be hydrologically significant. To investigate the importance of these seasonal changes, rainfall-runoff depth relationships were plotted for events in January, March, May/June and September. These are illustrated in figure 4.11 which demonstrates that the seasonal differences are marked. Despite the inevitable scatter in the relationships the decrease in runoff proportion from high values in the January to March period, through intermediate values in spring, to the low values in late summer is clear. These differences cannot be attributed to any changes in intensity between the seasons as summer intensities are generally similar or higher than winter intensities. This evidence for seasonal differences prompted the separation of all Oxford events into those occurring in the winter months (November through to April), those in the spring and early summer (May and June), and those in the later summer months (mainly July to September). The three groups have been modelled separately under the assumption that different sets of model parameter values will be applicable to each.

A further consideration with respect to runoff response is the number of small desilting and retention dams. Up to 25% of the catchment areas lie above such structures. Finally, large runoff events on the bigger catchments are likely to be affected by attenuation on the floodplains along the major rivers. There are no components in models OSE1 to 3 to account for such attenuation.

Mean annual rainfall is about 1350mm and there is little seasonality in the monthly distribution. There is no detailed information available on the temperature or evaporation regimes. Although the raingauge network density appears to be reasonably adequate from figure 4.10, there are some storms for which only total rainfall amount (no intensity distribution) at some of these stations exists. For some of the events on the large catchments, only one Thiessen weighted average intensity distribution is given in USDA (1955 - 1973). Therefore, while the data allow an adequate definition of the spatial variation in total storm depth, they do not always allow spatial variations in intensity distribution to be defined. From what little evidence there is, the degree of spatial variability in intensity distribution is very different for the range of events used.

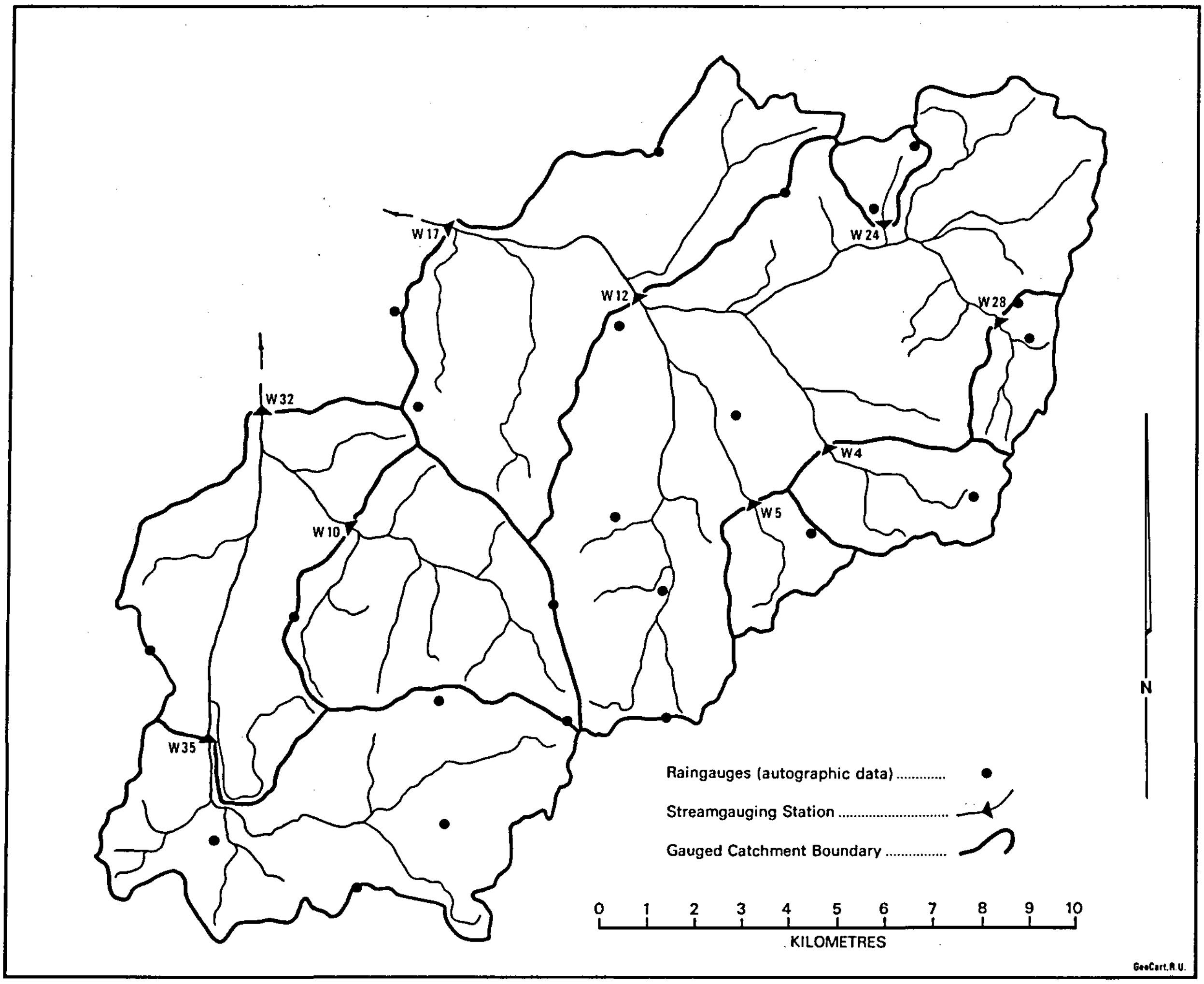


Figure 4.10 Oxford catchments and raingauge locations. The two main catchments of W17 ($130km^2$) and W32 ($81km^2$) have raingauge densities of 1 gauge per 8,1 and $9{,}0km^2$ respectively.

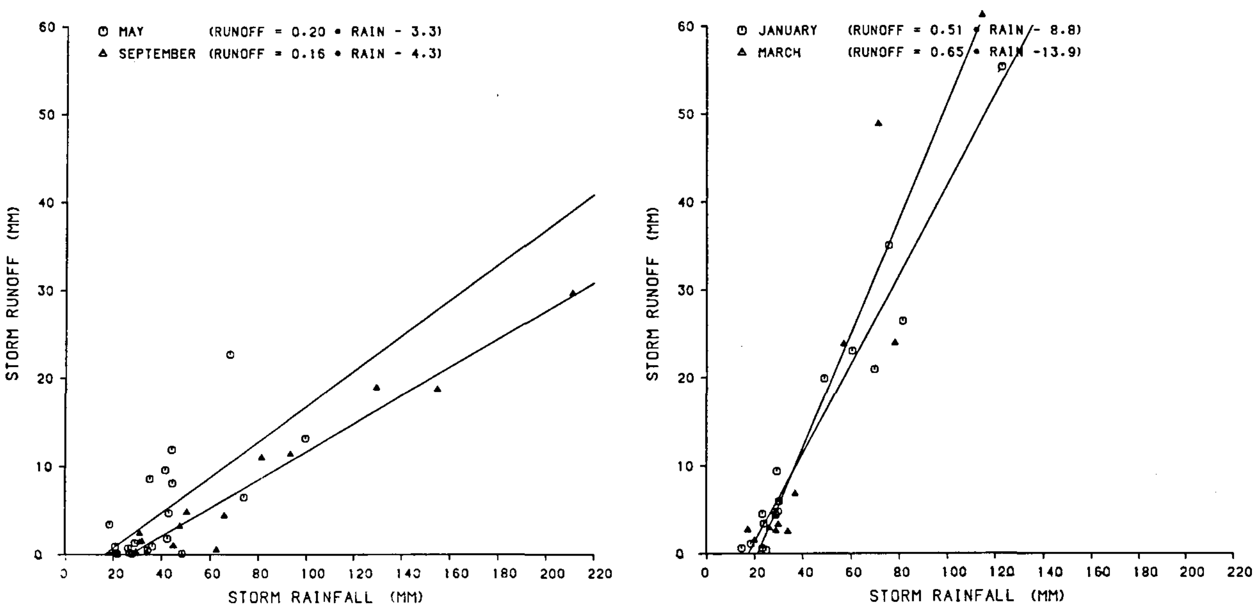


Figure 4.11 Relationships between total storm rainfall and runoff for a number of events taken from four seasons. The lines are least squares best fit lines and their equations are given in the annotation.

4.8 SOUTHERN CAPE CATCHMENTS

These four catchments are situated in the coastal area of the southern Cape Province between George and Knysna and have their headwaters in the Outeniqua Mountains (figure 4.12). The gauging weirs are part of the national Water Affairs network, who made the water level recorder charts available to Rhodes for digitising. The available rainfall data are available from several sources. The Weather Bureau operates a number of daily raingauges in the area plus a single autographic gauge at George. Water Affairs operated several autographic gauges in a small area to the east of George during the 1970's. Finally, Rhodes University HRU have operated a continuously recording raingauge network in the area since the early 1980's. Mean annual rainfall varies from as low as 500mm near the coast in the western part of the region to over 1200mm in the Outeniqua mountains. Annual potential evapotranspiration is approximately 1050mm with a maximum of about 140mm.month^{-1} in December and January and minimums of 54mm during May to July. Further details of the raingauge network as well as the regions characteristics can be obtained from Hughes and Görgens (1981), Hughes (1982), and Hughes and Wright (1988).

The headwater areas are underlain by quartz sandstones with shale bands, while south of the mountains the geology consists of contorted bands of schist phyllites, feldspathic quartzites and schists within which there are outcrops of intrusive granites (Tyson, 1971). There are three main physiographic zones, consisting of the Outeniqua mountains, the steeply sloping foothills zones and the incised coastal platform. There are also three main vegetation types in the region. The exposed mountains and parts of the foothills are covered with the natural bush vegetation (Fynbos). The other form of natural vegetation is the dense temperate forest dominated by yellowwoods, wild elder and ironwood. These forests have been cleared in many places to be replaced by managed pine plantations. There is inevitably a great deal of variety in the cover characteristics of these plantations depending upon their stage of growth.

Azonal soils are found on the steeper slopes and are generally shallow and sandy in texture. In other areas humus-rich soils have develolped and can be relatively deep (about 2m). Exposures of some soil profiles alongside forestry service roads indicates that subsurface piping may play a significant role in the hydrological response of these catchments.

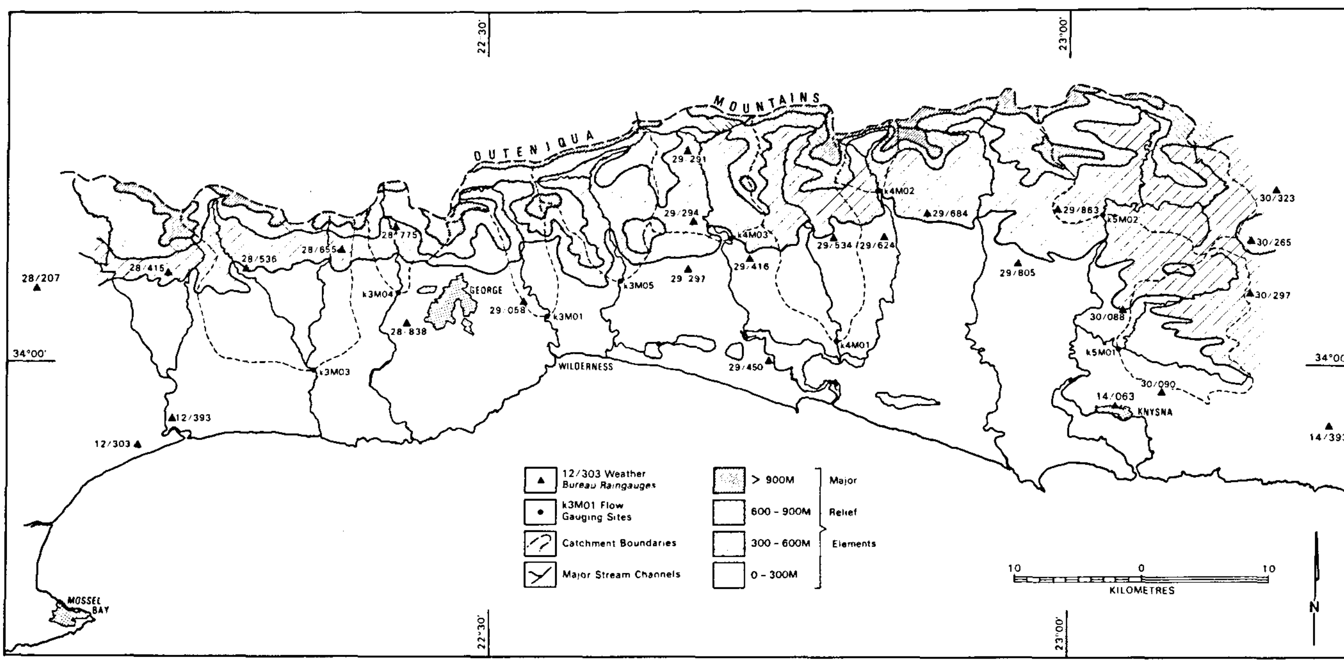


Figure 4.12 Southern Cape coastal area illustrating topgraphy, gauged catchments and raingauge network.

The four catchments included in this study are the Malgas (K3M04, northwest of George), Kaaimans (K3M01, northeast and east of George), Diep (K4M03, northeast of Wilderness) and Karatara (K4M02, a small headwater catchment midway between Knysna and Wilderness). Being part of a national network, the gauging weirs were not originally designed for measuring high flows. However, the rating curves were checked and extended by Ninham Shand Inc. (Hughes and Herald, 1985, Appendix A) using a backwater estimation technique. Figures 4.13 to 4.16 illustrate the drainage patterns and positions of the relevant raingauges for each catchment. Figure 4.14 shows no raingauges on the diagram and this illustrates one of the major problems with attempting to simulate flood events for these catchments. The steep slopes and forest vegetation prevent raingauges from being sited at locations most suitable for assessing catchment rainfall input. In many cases storm rainfall definition relies upon the use of a gauge (or gauges) close to the catchment for the intensity distribution, plus additional autographic and daily gauges further away to assist in determining the spatial variation of storm total. A detailed study of the short term spatial variability of rainfall by Hughes and Wright (1988) indicates that the patterns are complex and not easy to define given the amount of data available. They found a fairly high degree of similarity in the timing and shape of individual station storm profiles, but there is less consistency in the pattern of storm totals. A copy of the paper appears in appendix A.

The majority of the storm events occurring within this region are caused by the passage of cold fronts or the advection of moist maritime air. Oragraphic influences are strong and it is thought that the inconsistent patterns of spatial variation in storm rainfall are a consequence of variations in these orographic influences during different weather patterns. In general, storm events are characterised by low intensity, long duration rainfall. The occurrence of shorter duration cells of higher intensity rainfall during these events can result in complex multi-peaked hydrographs.

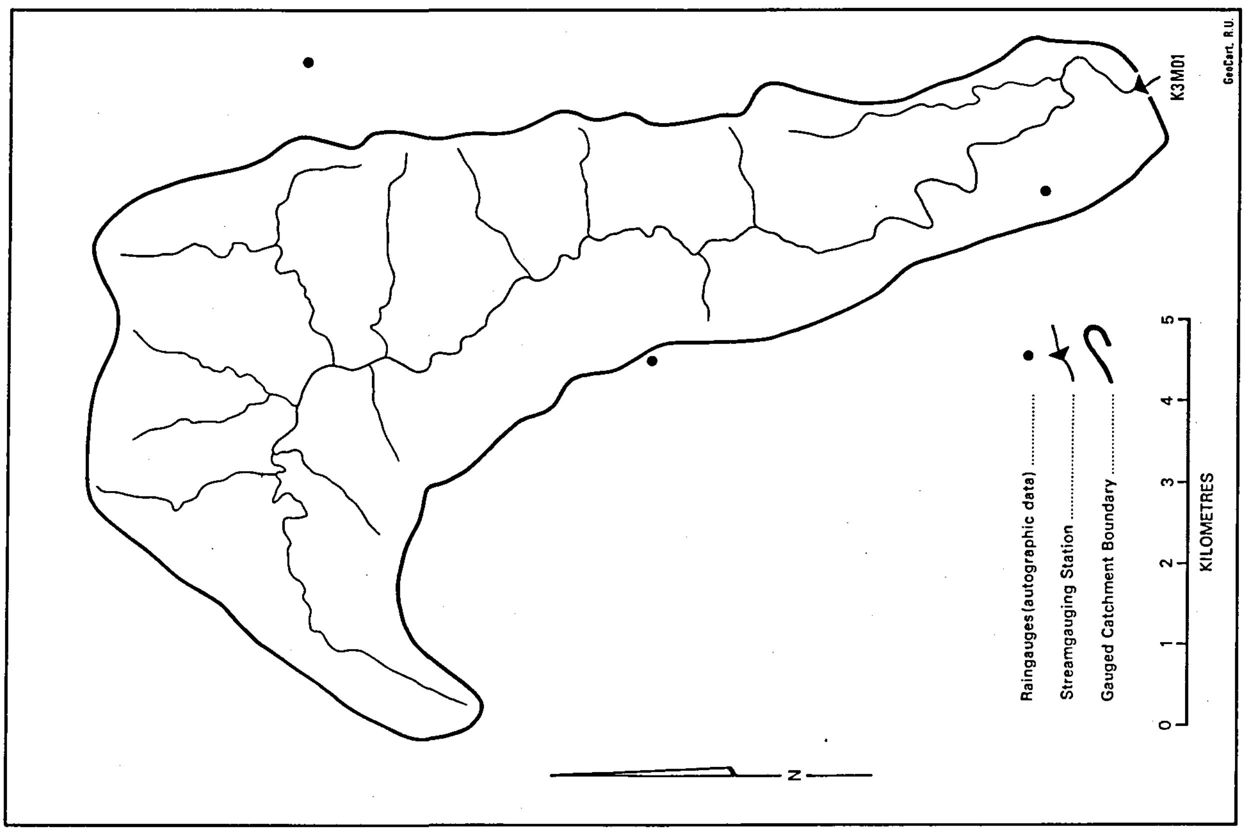


Figure 4.13 Kaaimans (K3M01) catchment and raingauge locations (total area of 48km^2; raingauge density is 1 gauge per 16km^2).

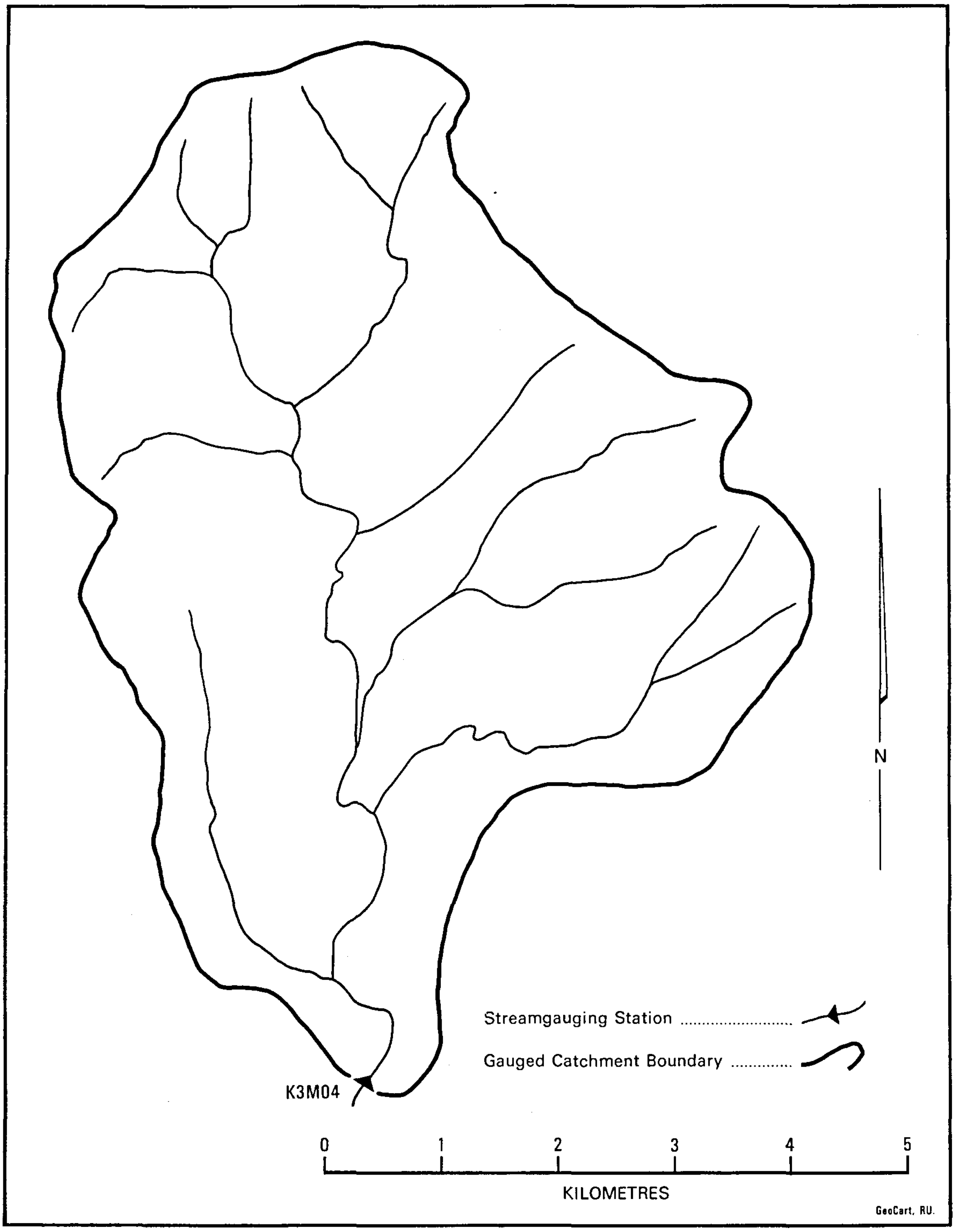


Figure 4.14 Malgas (K3M04) catchment (total area of $34km^2$; no raingauges lie within the catchment boundary).

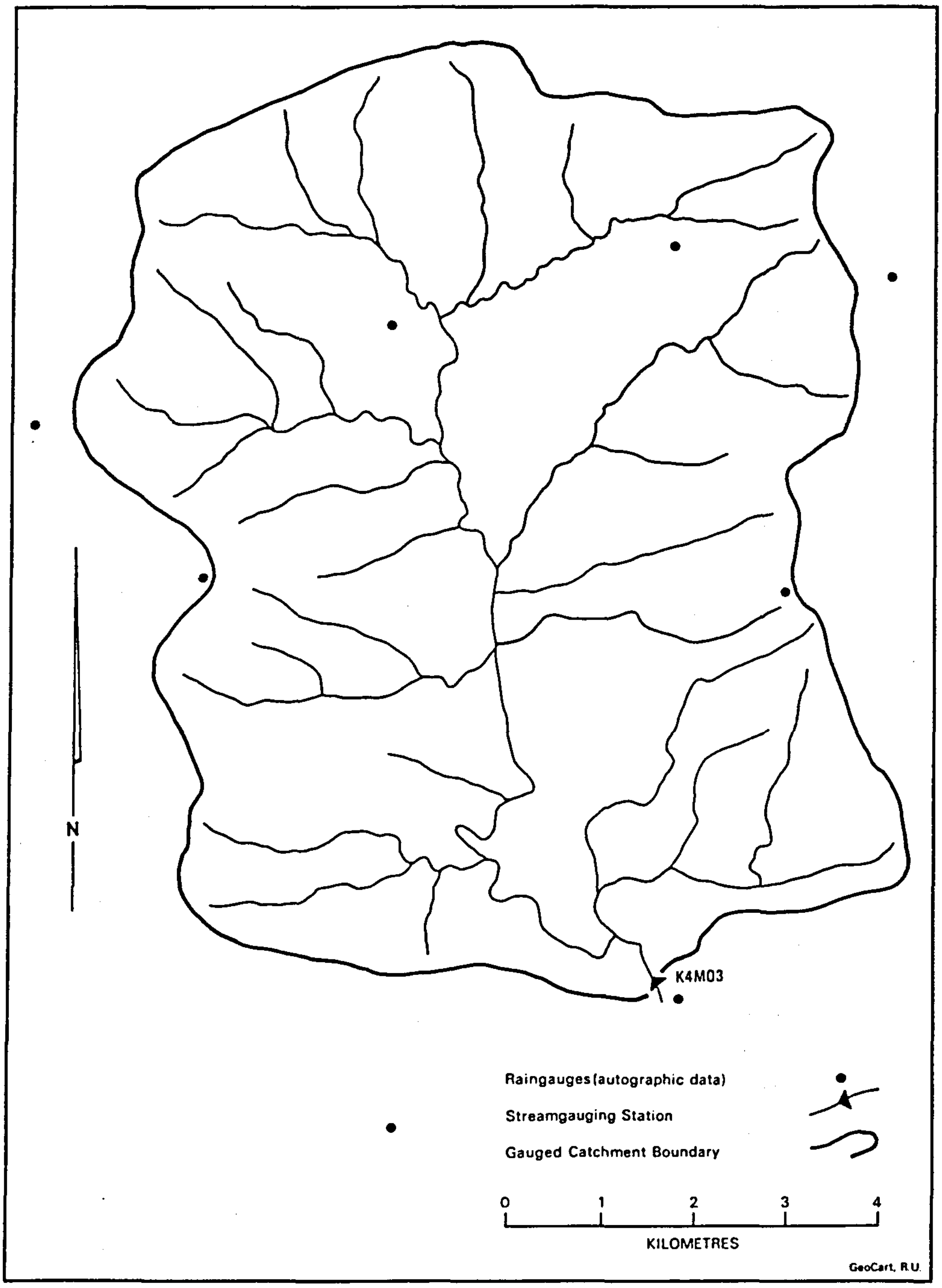


Figure 4.15 Diep (K4M03) catchment and raingauge locations (total area of 35km^2; raingauge density, including only those in or close to the boundary, is 1 gauge per 5,8km^2.

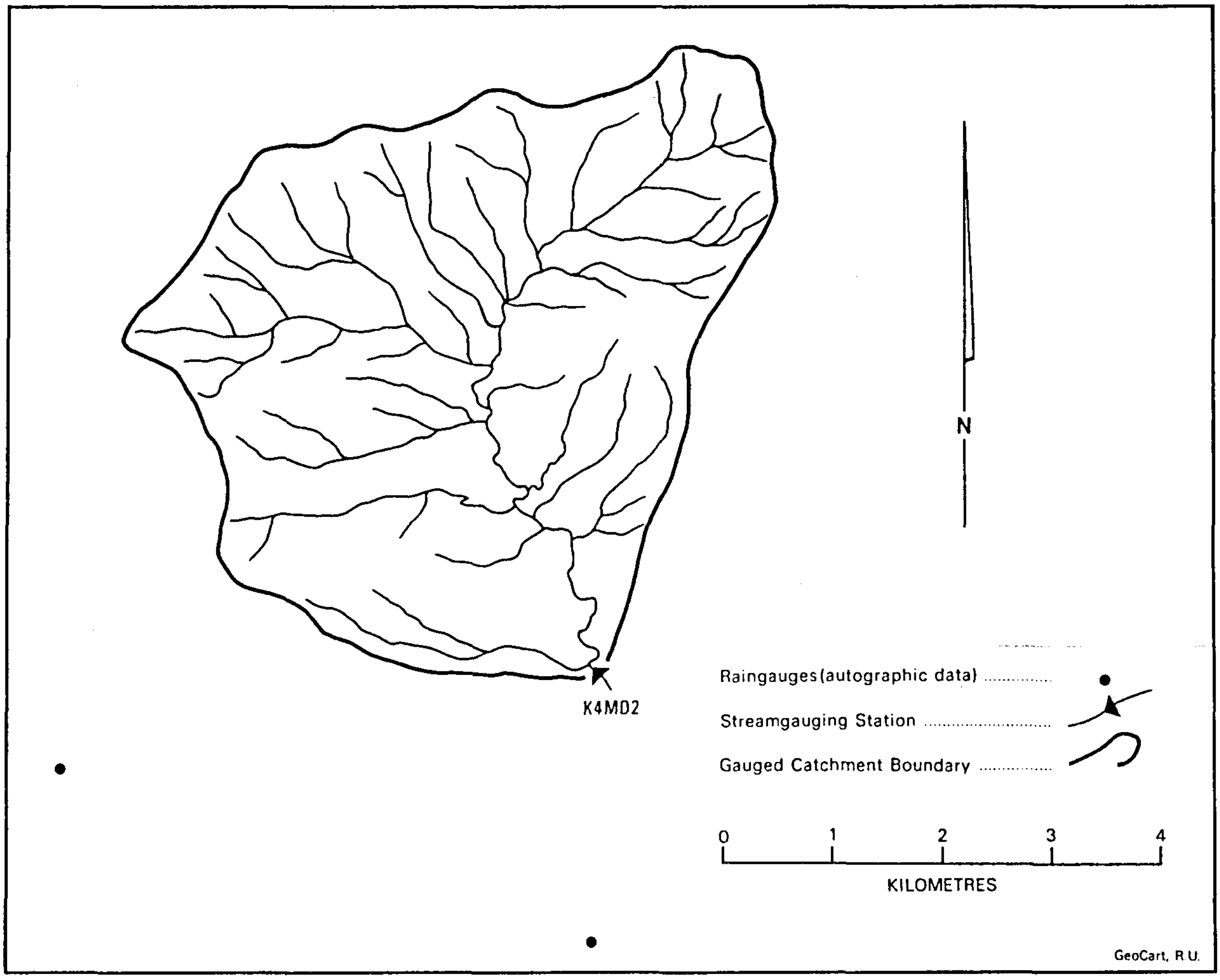


Figure 4.16 Karatara (K4M02) catchment and raingauge locations (total area of $22km^2$; no raingauges within the catchment boundary).

4.9 NORTH DANVILLE CATCHMENTS

The North Danville catchments are located in Caledonia County, Vermont State in the northeastern USA and are part of the Connecticut River basin. The information on their characteristics and the single event data have been taken from USDA (1955-1973), while figure 4.17 illustrates the gauging network and the sub-area division used for the semi-distributed models in this study.

The catchments are underlain by calcerious schists and calsilicate rocks interbedded with quartz-mica schists and micaceous quartzite. Hydrologically more important is the impervious boulder clay which overlies the solid geological formations. Soil types vary from rocky, fine sandy loams with rapid permeabilities to silty loams with moderate to slow permeabilities. Soil depth varies from 0,3 to 0,8m and the information given for the four catchments (ND1, 3, 4 and 5) suggests little variation in the soil characteristics at the catchment scale. Vegetation type is predominantly deciduous hardwood with some softwoods and approximately 30% of the area is under pasture or cultivation.

Mean annual precipitation is about 950mm and while relatively evenly distributed throughout the year, much of the winter precipitation occurs as snowfall. Mean daily temperatures during the summer months are in excess of 15°C while five months of the year experience sub-zero mean daily temperatures and there appears to be a spring snowmelt runoff period in April and May. All of the storms used in model testing have therefore been drawn from the summer months when rainfall storm characteristics can vary between relatively high intensity and short duration events to longer duration (up to and over 12h) events with generally lower intensities. There are similarly large differences in the degree of spatial variability between events. The distribution of raingauges for which storm total data are available is fairly satisfactory, but intensity data are available for only a few of these (figure 4.17). The adequate definition of spatial variability in input rainfall is not always possible.

4.10 CHICKASHA CATCHMENTS

The Chickasha catchments are tributary to the Washita River and located in various counties of Oklahoma state in the Southwestern U.S. prairies. Two of the catchments (CH111 and CH512) have been used in this study and their position within the whole area as well as their drainage pattern and the position of available raingauges is shown in figure 4.18. The single event data and descriptions of the catchments have been drawn from USDA (1955-1973).

Catchment CH111 is underlain by fine grained, even-bedded sandstone formations while CH512 is underlain by a mixture of cross-bedded shales, sillstones, sandstones and conglomerates. Both have relatively small amounts of alluvium in the valley bottoms of the major streams. The soils developed on the sandstones are deep sandy to fine sandy loams with moderate permeabilities. CH512 soils appear to be of a finer texture (silt loams to loams), marginally shallower but still with moderate permeabilities. The USDA (1955-1973) reports present a relatively confusing impression of the land use differences between the two catchments. There is a mixture of cultivation (rotation of grain, alfalfa and cotton) pasture and rangeland. The exact proportions of the different land uses appear to be fairly dynamic and it is difficult to obtain representative values. Catchment CH512 has a greater number of soil conservation measures than CH111 although both have terraced land in the sloping areas.

Mean annual precipitation is about 700mm with a peak in spring and late summer. Mean daily temperatures are about 13°C in early spring but reach up to 26°C in mid-summer. The majority of the storms used for model testing are taken from the spring to summer months of the year and are characterised by high intensities and short durations. There is only one suitable raingauge in CH111 (figure 4.18), the nearest additional gauge for which intensity data are available being several kilometres outside the catchment. Comparisons between these gauges indicate that large differences in storm totals do occur but that the shape of the intensity profiles are usually similar. However, the additional gauge is of little use in defining patterns of spatial variability of rainfall. The situation is marginally better for CH512 but although more gauges are indicated in figure 4.18 to be within or close to the catchment, data are not always given for all gauges for individual events.

4.11 CONCLUDING REMARKS ABOUT THE TEST DATA SET

This chapter is designed to give an overview of the test data set rather than to describe fully each catchment. Reference can be made to the original sources for more complete descriptions where they are available. It is important to point out, however, that in many cases the original descriptions are far from complete. This is particularly true of the descriptions of soil characteristics and very little quantitative information is available for comparitive purposes. Consequently, a great deal of reliance has had to be placed upon the qualitative references to such as 'rapid' or 'moderate' permeability and 'deep' or 'shallow' soils. This lack of detailed quantitative information would be extremely limiting if strongly physically-based models were to be applied to the catchments without collecting more data than is available in the publications. The amount of field work involved in collecting additional data would be beyond the resources of most single research organisations and could only be achieved by many such organisations co-operating together. These factors serve to further illustrate the difficulties of assessing physically-based models on a wide range of catchment types.

The summary information in each section of this chapter is also designed to illustrate the type of rainfall regime prevalent over the catchments during the seasons for which storms have been extracted. Of particular importance is the type of storm event in terms of intensity and duration as well as the degree of spatial variation in storm rainfall characteristics over the catchments. Coupled with this is the extent to which the available data are considered to adequately represent the spatial variation. Owing to the great differences in amount of available rainfall data, not only between catchments, but also between storms on some catchments, the ability of these data to satisfactorily represent the actual storm rainfall characteristics is highly variable. This will inevitably have some influence on the simulation results and must be taken into account when assessing these results. It has not been possible to standardise the way in which rainfall input to sub-areas (in semi-distributed models) or whole catchments (in lumped models) have been defined, largely because of the differences in the type of rainfall data available. However, the maximum amount of information has been used in all cases. Where data for a number of gauges are present then the most appropriate gauge profile, or weighted combination of gauge profiles has been used. The choice of the most appropriate gauges has been based upon the relative positions of the gauges and the sub-areas as well as a consideration of the spatial pattern of storm rainfall total. For some catchments there are few storm profiles but additional data in the form of storm totals at other gauge sites, or isohyetal maps of storm total, have been used to weight the available profiles. Weighting is carried out on the basis of storm total such that intensity variations within the storms will not always be adequately represented.

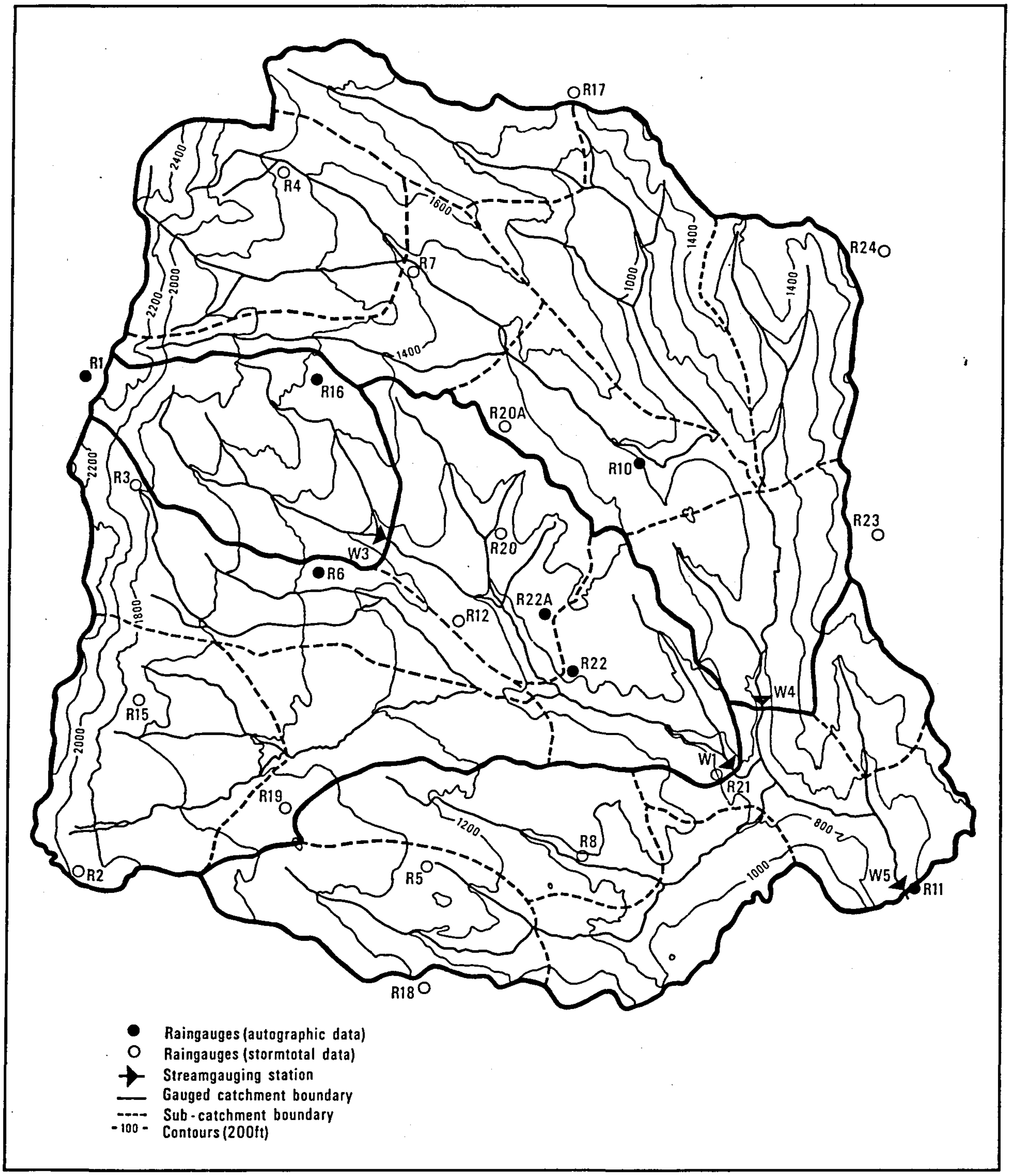


Figure 4.17 North Danville catchments, raingauge locations and sub-area boundaries (total area is 112km^2; overall raingauge density is 1 gauge per 4,9km^2; autographic gauge density is 1 gauge per 16km^2 and very uneven).

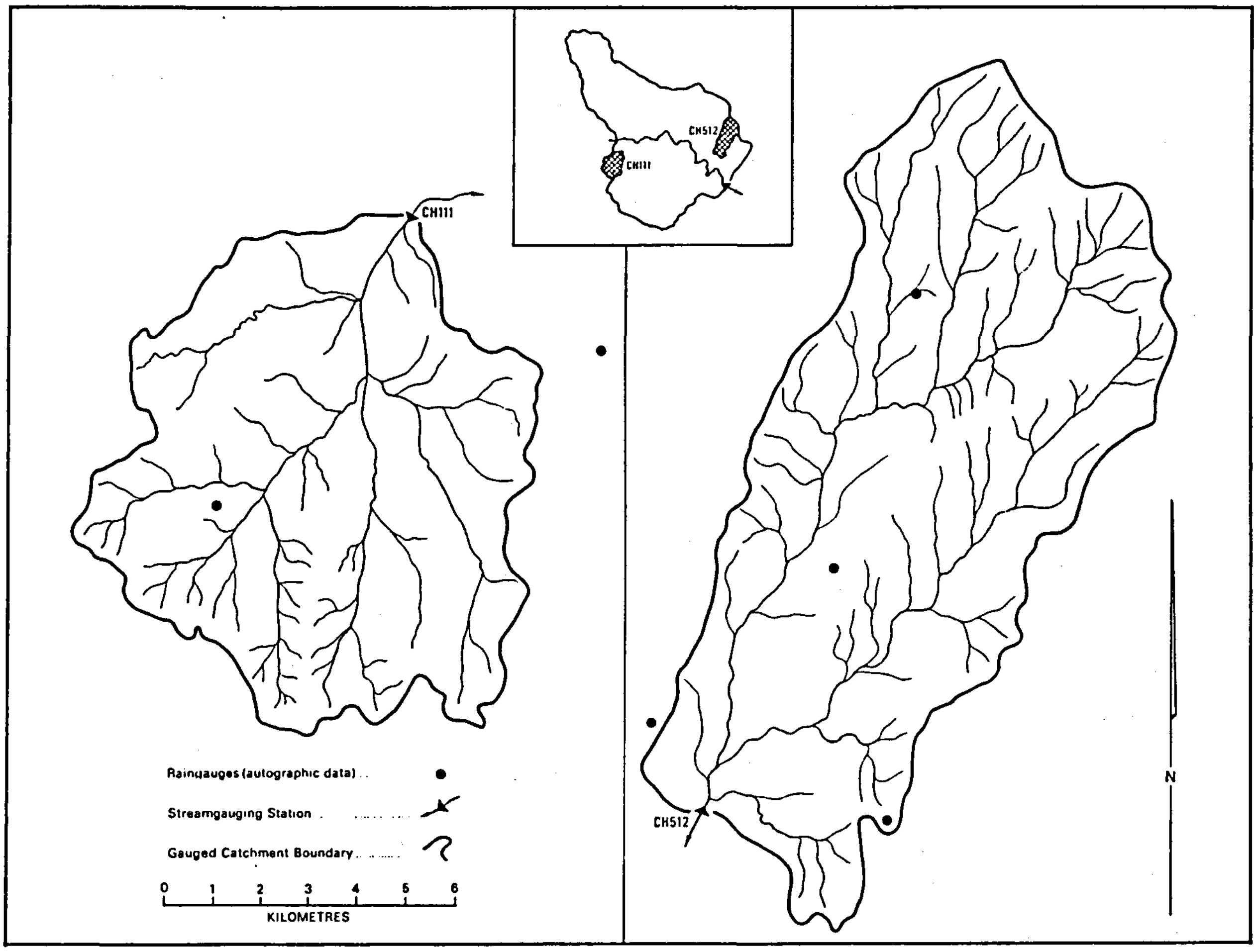


Figure 4.18 Chickasha catchments and raingauge locations (areas are 68km^2 for CH111 and 92km^2 for CH512; raingauge densities are 1 gauge per 34 and 23km^2 respectively).

Chapter 5

THE BASIS FOR MODEL EVALUATIONS AND COMPARISONS

This chapter is included in the report to explain the approaches used in the different stages of model testing. It therefore serves to place the later chapters into context. As indicated in the introduction to the report, the model testing has progressed through four stages. The first stage involved only two catchment areas (Ecca and North Danville) and consisted of an initial evaluation of the four models' capabilities. No validation of parameter values was carried out during this stage as all storms were used for calibration. The main purpose of this exercise was to try and identify major weaknesses in the models and correct these where desirable and possible. In effect this stage allowed the authors to obtain initial experience of the models operation and the sensitivity of the simulations to changes in parameter values as well as to different input storm characteristics. The results of this preliminary study are reported in Hughes and Beater (1987).

The second stage involved the application of the models to the remaining catchments, calibrating on a sub-set of the available storms and validating the applicability of some of the parameter values on other storms. Not all the parameters of some models (notably OSE3 and OSE4) could be validated at this stage as they have to be calculated or estimated on an individual storm basis. During this stage other aspects of model evaluation were also investigated, such as the sensitivity of the results to changing the modelling time interval and variations in parameter sensitivity with varying storm type or other factors.

The third stage represents an attempt to derive relationships between the model parameter values given by stage 2 and a variety of physical catchment characteristics. There will inevitably be a high degree of scatter in the relationships derived from stage 3 such that stage 4 consists of re-running the models using parameter values estimated from the general trends of these relationships and comparisons of the model results with those obtained from stage 2. The details of stages 2 to 4 are discussed in the following sections.

5.1 MODEL CALIBRATION AND VALIDATION FOR INDIVIDUAL CATCHMENTS

5.1.1 Input data details.

The first step for this stage of model testing involves the compilation of the input data files from the original data sources referred to in chapter 4. All models share the main input data file consisting of regular time interval rainfall (for one or more or a combination of raingauges) and observed flow values for the complete set of storms on any one catchment. The selection of the time period of modelling has been based mainly upon the observed response characteristics of the catchments as well as the rainstorm durations. The need for a short time period for the Tombstone catchments has already been referred to (section 4.1). Some of the storms on the Oxford catchments are of relatively short duration and the response from the smaller catchments in this area are quite rapid. A 10 min. time interval was used for this area. A 15 min. time period was used for the remaining catchments. A suite of FORTRAN programs have been established to extract regular time interval data from the original sources and to output the values in the required format. Three of the models also share the need for a data file of antecedent daily rainfall values.

The third data file consists of the catchment average parameter values, the catchment definition variables and the run control details. As well as the nominal parameter values, the control data files also hold the range of these values within which the automatic optimiser (included as an option in the model program package) is constrained to operate (if used) and the sub-area weighting factors which determine the actual parameter values for each sub-area. This method of parameter input is used so that the optimiser only operates on the nominal catchment average parameter values, and any changes to the sub-area weights must be performed by hand. Attempting to optimise the sub-area parameter values would increase the dimensions of the optimisation problem to an unmanageable level. Any one of the rainfall input profiles can be selected for each sub-area and weighted separately if necessary. The control files for OSE1 to 3 also allow one or more of the storms to be selected for modelling. If more than one storm is selected, overall fit statistics are given as well as the statistics for each event. Storm selection is achieved interactively in model OSE4 and only one may be chosen. The multiple storm selection option is very useful for these models where it is expected that parameters will remain stable across a range of storm types. The computer program need only be run once for each set of storms. The catchment definition variables include catchment area, time interval of modelling, number of sub-areas and the arrangement of the sub-areas for the purpose of channel routing in the semi-distributed model versions. Run control details include the number of optimisations (if any) which parameters are to be optimised and which objective function is to be used as a basis for optimisation (Hughes and Beater, 1987). Only models OSE1 to 3 have an optimisation facility. There is also a control variable which allows the user to choose the level of detail given in the output.

The output files for models OSE1 to 3 initially contain a summary of all the input data. They also always contain summary statistics of the simulation results and a lineprinter plot of the average catchment rainfall, observed flows and simulated flows. The summary statistics given are the percentage errors of the simulated volumes (mm) and peaks ($m.^3s^{-1}$), the coefficients of efficiency using both ordinary and natural logarithm values and the coefficient of determination (Hughes and Beater, 1987). Although not quite the same, similar information is output from OSE4. An additional option in the package used for OSE1 to 3 allows the output of each flow component for each sub-area. While such output can be very useful for calibration purposes, the printouts can get very long if the catchment is divided into a large number of sub-areas and the storms have long durations. The parameters of OSE4 can be changed interactively during program running. This is a feasible proposition when the model has only a few parameters that can be changed, but does not really represent an advantage if more than a few parameters are to be changed. The alternative of finalising the run, viewing the results, editing a well documented control file and re-running the program has been found to be efficient and easy to operate.

The definition of the sub-areas for the semi-distributed models is not always an easy task, particularly when this must be done without knowing the effect of different sub-area pattern choices. For some of the catchments, the drainage and relief patterns suggest fairly obvious sub-area divisions, given the constraint that a greater number of sub-areas not only increases the computer simulation time, but also the number of sub-area parameters that have to be quantified. Where small gauged sub-catchments are nested within larger gauged areas, sub-areas have been defined for the large area at the scale of the small gauged areas. It is then possible to check the runoff simulations at some areas within the total area. Where obvious changes in physical catchment characteristics exist, then at least some of the boundaries between sub-areas are easy to define given the desire for a high degree of internal homogeneity. A further important consideration in defining sub-areas is the position of the rain gauges which are to provide the different input storm profiles. If some gauge locations are relatively close and they experience different rainfalls, it is clearly worth creating small sub-areas that can accommodate these differences. Alternatively, for catchments with only a few widely separated gauges other factors will dominate, as the resolution with which the rainfall spatial variability can be defined will be relatively poor.

5.1.2 Calibration details

The way in which the four models are calibrated is necessarily different. **Model OSE2** is expected to have a stable parameter set for all storms on the same catchment. Therefore those storms to be used for calibration are modelled together to find the parameter values that give the 'best' overall fit. The 'best' overall fit is decided on the basis of minimising the percentage errors and maximising the coefficients of efficiency and determination for all the calibration events. The initial values of the parameters are decided upon using the perceived associations with physical catchment characteristics discussed in the earlier report (Hughes and Beater, 1987). Modifications are made to the parameter values mainly using a manual optimisation procedure. This is based upon experience of the effects of changing the values of different parameters and an assessment of the simulation results to determine what aspect of the simulated runoff response requires modification. In some cases the automatic optimiser is useful to refine the values of some parameters or to attempt to find the best balance between two or more parameters which have similar effects on the runoff response. An example of the use of the automatic optimiser could be to find the balance between the intensity controlled runoff parameter (IAF in table 4.1) and one or more parameters of the S-curve used to generate so-called variable source area runoff. All of these parameters have an effect on the amount of runoff generated by the model but the effects differ according to the simulated moisture content and input rainfall intensity at any one time during a storm. The effects on the simulated hydrograph of changing these parameter values are therefore quite complex and the automatic optimiser is sometimes (but not always) a useful way of determining the parameter values that produce the best overall fit for a group of events. As mentioned earlier, changes to the sub-area weighting factors for the parameter values can only be effected manually. Any changes made are based upon an examination of the simulation results combined with a consideration of the relative amounts and intensity of rainfall over the sub-areas and their position relative to other sub-areas and the catchment outlet. The latter will affect the degree of attenuation and delay that the sub-area runoff undergoes before contributing to the shape of the total catchment hydrograph. It is clear that manually calibrating OSE2 involves taking into account a number of different interacting effects. This is true even if the model is being calibrated for one event. When calibrating for several events together, the problem becomes highly complex and confusing. For this reason it is rarely possible to decide when the 'best' calibration has been achieved, if in fact there is such a thing as a unique 'best' result.

For **Model OSE1** the first calibration step is to establish the values of the S-curve and antecedent rainfall index parameters. Using a micro-computer, interactive graphics program, these parameter values can be varied in order to fit the S-curve (or curves) to plotted points represented by the observed runoff ratio (runoff depth/catchment average rainfall) and the estimated initial moisture status (antecedent rainfall index/maximum moisture storage) of the calibration storms (figure 5.1). The position of the storm points can be moved horizontally by varying the antecedent rainfall index (APF) or the maximum soil moisture (SMAX) parameter values. Alternatively the shape of the S-curve can be changed by varying the coordinates of the inflexion point (3,0: 5,5 in figure 5.1). It was anticipated that more than one S-curve shape would be applicable to each catchment, with the changes in the S-curves related to variations in rainfall intensity, duration or total amount. In calibrating the S-curves an attempt was made to group the calibration events and to keep the number of different curves to a minimum. This procedure was followed to try and make it easier to relate the S-curve parameters to storm characteristics at a later stage. Calibration of the routing parameters and any changes to sub-area weighting factors was carried out for OSE1 in the same way as OSE2.

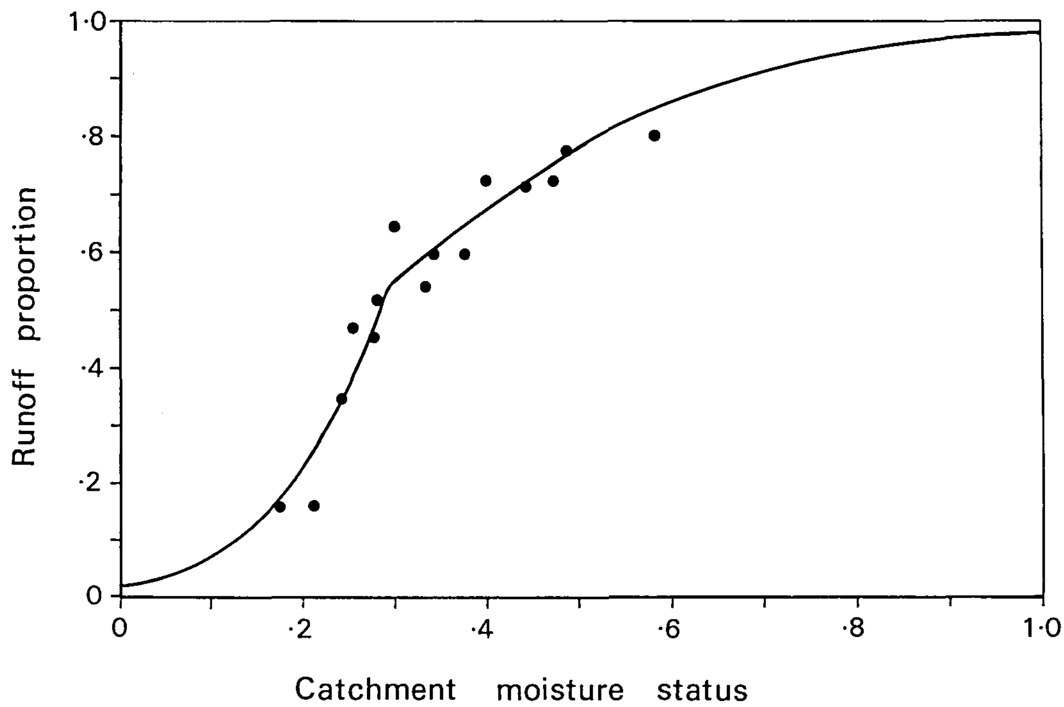


Figure 5.1 Example of an S-curve plot (using PC screen graphics) with observed data points superimposed to assist OSE1 parameter calibration

The starting point for **Model OSE3** is to calculate the runoff proportion from the ratio of observed runoff depth to average rainfall depth. As with the S-curve parameters of OSE1, the runoff proportions of OSE3 are expected to vary between storm events on the same catchment and consequently groups of events cannot be calibrated together. The remaining parameters of OSE3 are the same as in OSE1 and the calibration of these proceeds as before.

The previous three models are programmed as sub-routines of the same modelling package and therefore their calibrations share certain similarities. **Model OSE4** was obtained as an already computer coded model and modified only slightly to accept the same input data files as the other models. The calibration operation is therefore somewhat different and follows an interactive procedure. The model is run interactively as many times as desired, altering the initial losses and routing parameters after each run in an attempt to improve the simulation results. The type of model (constant runoff proportion or continuing losses) is also chosen for each run but the program calculates the actual runoff volume parameter such that volume errors are always close to zero. Any volume error that does occur is a consequence of the simulated flow not being completely routed out at the end of the observed duration. Any changes to the relative contribution of each sub-area to the runoff volume or to the delay or relative attenuation of the runoff from each sub-area can only be made by changing the parameters in the input control file. As with the other models such changes do not normally form part of the calibration procedure but are based upon perceived differences in the sub-area characteristics, the spatial organisation of the sub-areas and the length and slope characteristics of the channel segments joining sub-areas.

5.1.3 Parameter validation details

The major volume conversion parameters of models OSE1, 3 and 4 generally require calibration on an individual storm basis. Without formulating some kind of relationship between these parameters and storm characteristics (for a specific catchment), parameter validation is more or less meaningless except for the routing parameters. The only way in which validation can take place is to group events on the basis of their storm characteristics (intensity, duration and total depth) and divide each group up into calibration and validation sub-sets. This is much the same as calibrating all storms individually and subsequently noting similarities (or differences) in the volume conversion parameters for storms with similar characteristics.

Model OSE2 can be validated in the normal way by selecting a representative set of several storms (up to half of the available number) for calibration and then testing the applicability of the calibrated parameters to the remaining storms. This approach can be extended where a group of catchments from the same area having closely similar characteristics form part of the test data set (Tombstone and Oxford catchments, for example). Parameter values calibrated on one catchment can then be validated on an adjacent catchment which is assumed to have similar physical characteristics.

5.1.4 Model evaluation and comparison details

First of all it should be stated that a complete evaluation of the comparative success of the four models is not possible after the calibration/validation exercise on individual catchments. This is largely because of the different ways in which the models are calibrated. The errors in the volume predictions for models OSE1, 3 and 4 are likely to be low compared with OSE2 due to the fact that reasonably accurate estimation of volume is a consequence of the calibration procedure for the three simpler models. Only at a later stage can the predictability of the parameters that determine the runoff proportion be assessed. This aspect is discussed in the next section. Despite this limitation, the results for individual catchments can be used to reveal a number of points of comparison between the models and their different versions (lumped and semi-distributed). The procedure for evaluating and comparing the models has been designed to provide answers to the following group of questions.

i) What aspect of the storm simulations are most affected by which parameters (of all models) and to what degree? How is this parameter sensitivity affected by differences in storm characteristics or response characteristics?

ii) Do the results indicate that the use of a stable set of parameters in OSE2 for all storms on the same catchment is an acceptable assumption? Are there clearly defined situations where this assumption is, or is not, acceptable? Similarly, are there some parameters for which this assumption could be considered valid and others not?

iii) Do the results indicate that the parameters of OSE1, 3 and 4, other than the main volume conversion parameters, can remain constant for all storms on the same catchment?

iv) Do there appear to be patterns in the variation of the values of the main volume conversion parameters of models OSE1, 3 and 4 that could be attributable to differences in storm characteristics?

v) Are there any situations (storm type or catchment type) where one (or more) model clearly performs better than the others? Can this better performance be related to a specific feature of the model structure?

vi) Do the semi-distributed versions of the models consistently perform better than the lumped versions? If not, is there a particular situation for which either of the versions demonstrates improved performance?

vii) What is the effect of varying the level of spatial distribution and is this effect dependent upon any other factors such as spatial variations in storm or physical catchment characteristics?

viii) What is the effect of varying the time interval of modelling and how does this effect vary for different catchment or storm characteristics?

It should be emphasised that the phrasing of these questions places a great deal of emphasis on the liklehood of the answers being heavily dependent upon not only the characteristics of the storm but also the physical properties of the catchment that control the runoff response. The authors consider this to be a very important point. If the point is shown to be relevant by the results of this study it is clear that any hydrological model simulation results must be viewed in the context of the data set used to obtain those results. Conclusions drawn from hydrological simulation studies could not be considered generally applicable unless an extremely comprehensive set of catchments and storms were used.

Chapter 6 presents the individual catchment simulations and concentrates on using the results to attempt to answer the above questions.

5.2 THE PROCEDURE FOR DERIVING RELATIONSHIPS BETWEEN PARAMETER VALUES AND CATCHMENT OR STORM CHARACTERISTICS

The usefulness of any hydrological model is probably best measured by the success with which it can be applied to situations where calibration is not possible. This aspect is covered to a certain extent by the individual catchment validations that form part of the previous sections test procedure. However, such validations only allow the models to be extended to storms over a catchment for which the model has been calibrated or at best where calibration on an adjacent and very similar catchment is possible. It has already been stated that validation of all the parameters of OSE1, 3 and 4 is not possible as their parameters are likely to be storm specific. Extending the application of any of the models to other catchments, where calibration is not possible, has not been discussed yet. There is, however, a great need to understand the limitations that exist in applying models to ungauged catchments. The part of the model testing procedure outlined in this section is designed to investigate the possibility of deriving relationships between model parameter values and quantifiable catchment characteristics and, in the cases of models OSE1, 3 and 4, storm characteristics.

The starting point for this procedure is to identify those characteristics that can be evaluated from the types of information source available. Chapter 4 has already illustrated that while the data used in the study are drawn from essentially well instrumented research catchments, the information that is available on their physical characteristics is less than complete. This level of detail is more typical of the situation that may be faced under 'applied' conditions rather than under 'research' conditions. In one sense this gives the study a realistic image. However, the lack of detail also means that a degree of subjectivity and imprecision is inherent in the quantification of certain characteristics. As this was recognised at the outset, the evaluation of certain physical variables was confined to the ordinal scale of measurement. This procedure consisted of assigning ranked indices between 1 and 10. The physical characteristics form two basic groups; those that can be measured in a straightforward manner from topographic maps and those that must be ranked from catchment descriptions. Each variable is discussed separately below and the values assigned to the sub-areas of the test catchments are given in appendix B. Where nested catchment situations occur, the sub-areas are only included once. For example (at the top of the listings in appendix B) sub-areas TM11 1 to 3 are also sub-areas 1 to 3 of Tombstone TM8. A third group consisting of storm characteristics are also discussed below and can be evaluated directly from the input rainfall data.

5.2.1 Catchment slope (SLOPE)

Catchment slope is readily measured from contour maps using the equation :

$$\text{SLOPE} = \frac{\text{total contour length * contour interval}}{\text{catchment area}}$$

Variations in the calculated value of this variable are inevitable if maps compiled at different original scales are used. However, such variations are likely to be small if maps of similar scale and detail are used. For the South African catchments 1 : 50 000 scale maps were used in this study, while those given in USDA (1955-1973) were used for the USA catchments. Hughes (1983b) demonstrated the importance of slope as a physical variable affecting runoff response in the southern Cape region and Hughes (1985) found it a useful variable for estimating the parameters of monthly time interval water resource models.

5.2.2 Drainage Density (DDENS)

While being similarly easy to measure from topographic maps, the effect of map scale and detail is likely to be greater than for SLOPE. A great deal depends upon the degree to which small ephemeral channels are included as well as what the map compiler chose to define as a channel. The runoff generation theories of Hewlett and Hibbert (1967) as well as others suggest that the channel network expands during storm events. Drainage density may therefore be considered a dynamic variable that is difficult to quantify. For the purpose of this study it has been based upon the channels identified by the map compilers.

5.2.3 Time of concentration (TC)
There appear to be a number of different equations for this variable that have been reported in the literature, however, the majority are based upon the length and slope of a channel segment. The measure used in this study can be calculated from the equation (Shaw, 1988):

$$TC = 0.00025 * \frac{(L*1000)^{0.8}}{S^{0.5}}$$

Where L = sub catchment area (km^2)/channel length (km) with channel length being the distance from the sub-area centre of gravity to the catchment outlet
and S = average slope over the channel length ($m.m^{-1}$).

As will be seen later TC is used to assist in the evaluation of sub-area channel delays, hence the length and slope components are related to the section of channel over which that delay is deemed to take place.

5.2.4. Channel Order (ORD1)
In the same way as drainage density, the evaluated channel order will also be dependent upon map scale and detail. There is little that can be done about this problem except to attempt to always use map sources compiled using similar principles. There are also several different approaches to stream ordering. In this study, the scheme (Shreve, 1966) has been used which evaluates stream order as the sum of the upstream headwater tributaries.

5.2.5 Channel distance (CDIST)
This variable is evaluated for channel routing purposes and is measured as the distance (km) of the channel segment which the conceptual storages are designed to represent. This normally means the distance from one sub-area centre of gravity to the next one downstream. The actual channel segments over which the distance is measured depends upon the arrangement of the sub-areas and the conceptualisation of the storages in the channel storage-routing component of the models.

5.2.6 Soil depth (DEPTH)
Soil depth represents an obviously important and hydrologically significant variable. However, there is very little direct information available about this as well as the other soil variables for any of the catchments included. Even where some indication of the depth is given, there is usually little information about the spatial variation of depth. This is understandable given the amount of work involved in collecting this information. The values given in appendix B must therefore be viewed in the light of the degree of extrapolation that has been necessary. Integer values between 1 and 10 have been assigned most sub-areas but occasionally a midway point between two integers was considered desirable. The greatest values have been given to the Tombstone, Cedara and some Zululand sub-catchments. The arid Tombstone soils are developed on alluvial sands and gravels and the assumption has been made that the effective hydrological depth is high. The descriptions of the Cedara and relevant Zululand sub-areas imply comparitively deep soils. Conversely, other Zululand sub-areas (5, 6 and 7) are described as having shallow soils with a high proportion of bare rock. These have therefore been assigned the lowest values.

5.2.7 Infiltration characteristics (INFIL)
There is even less information about this physical characteristic than soil depth and a heavy reliance has been placed upon descriptions of the texture of the surface soil layers. Again the coarse texture of the Tombstone soils suggests a high infiltration index value.

5.2.8 Permeability characteristics (PERMC)
The information given in the USDA (1955-1973) reports offer relative descriptions of the sub-surface permeability of the soils. This information proved useful and was combined with details of soil texture to derive the indices of permeability. The low values given for the Ecca seem to be justified by the *in-situ* drainage studies conducted by Moolman (1985) in this area. The relatively high values for the southern Cape soils have been assigned to account for the stoney soils of the hill tops as well as the observed occurrence of macro-pores in the deeper, humus rich, soils found on many of the slopes.

5.2.9 Water holding capacity (WHCAP)
As with the permeability characteristics, WHCAP is largely based upon textural descriptions. It was expected that, combined with soil depth, this variable would be important for estimating those parameters related to the maximum moisture retention capabilities of the sub-areas. However, the authors readily admit that this variable has not been quantified with much precision. An approximate inverse relation between WHCAP and PERMC might be expected (compare the values for the fine grained Ecca soils and the lighter textured Bethlehem soils) but clearly the real situation is not as simple as that.

5.2.10 Slope to valley soil ratio (SL/V)
This variable was added because it was considered important to account for the spatial pattern (with respect to the distance from the main drainage channels) of soil depth within sub-areas. The importance of including such a measure is based upon the scale of sub-area definition used (up to 14,7 km^2). This variable is an estimation of the ratio of soil depth on the valley sides to that in the valley bottom. In the flatter catchments, which have relatively uniform soil depths, the ratio has been set close to unity. However, in the Ecca in particular there is a great difference between the thin soils of the valley sides and the deeper alluvial soils in some of the valley bottoms.

5.2.11 Vegetation characteristics (VEGC)
The vegetation cover characteristics of a catchment are clearly important from a hydrological point of view. They affect the evapotranspiration (not important in isolated event modelling except with respect to antecedent moisture status) and interception characteristics of a catchment as well as infiltration and surface runoff. The effect of roots may also play a major role in determining secondary permeabilities. Quantifying vegetation cover proved to be an easier task than that for the soil variables. This may be partly a consequence of the great range that exists in the data set from the sparse cover of the Tombstone catchments to the dense indigenous forests of the southern Cape. It should be noted that three sets of data exist for most of the Oxford catchments. These have been included to account for the documented (USDA, 1955-1973 and refer to section 4.7 of this report) seasonal variation in land use and cover characteristics of this area. No such major distinction was evident for the other catchments because, either the cover characteristics are less seasonal, or the storms have all been drawn from a single season.

5.2.12 Energy characteristics (ENERGY)

The final physical variable that has been included is a measure of the radiation energy input experienced by the catchments. Its evaluation has been mainly based upon figures given for mean daily temperatures. The values of the index given in appendix B refer to the season in which either all or most of the storm data for that catchment occurred. For example, the majority of the Ecca storms used occurred in winter while those of the southern Cape occurred in spring and autumn.

5.2.13 Storm characteristic indices

Included in this group are two measures of antecedent precipitation. One is a decay function of the previous 30 days rainfall and is the same index as that used in the models which have an antecedent moisture component (OSE1 and 2). The other is the previous 2 day rainfall total and can be viewed as an antecedent surface storage factor rather than an antecedent soil moisture index. The other indices are based upon the intensity, depth and duration characteristics of the rainstorm event and are itemised below.

i) Total rainfall depth.
ii) Total rainfall duration.
iii) Maximum intensity for the time interval used.
iv) Mean intensity (total depth/duration).
v) Percentage of the total depth falling in the four quartiles of the storm duration.

It would be strictly correct to quantify these indices for the rain profiles relevant to each sub-area and then relate the values to the relevant sub-area parameters. However, for simplicity the values used in this analysis are based upon the average catchment rainfall profile. Where large spatial variations in the various indices occur this method of quantifying them will obviously affect the results and should be considered when the results are evaluated.

5.2.14 Derivation of relationships

The derivation of the relationships between parameter values and physical characteristics is confined to the semi-distributed versions of the models. This avoids the problem of attempting to estimate average catchment characteristics in an area where these may be highly spatially variable as would be necessary if the lumped model results were to be included. The conventional approach to deriving relationships between physical catchment or storm variables and model parameters would almost certainly be some kind of least squares regression analysis. However, most of the statistical packages available for carrying out such analyses are restricted to linear combinations of the independent variables or of transformations of these variables. The type of relationships expected by the authors would not fit this pattern and therefore an alternative approach was adopted. The method is still based upon a least squares fitting procedure but the regression coefficient calculated is used more as confirmation of a visual assessment of the degree of fit. Furthermore, the type of relationships are not restricted to linear combinations.

The approach makes use of a computer BASIC program operated on a PC interactively. All sub-area parameter and characteristic indices values are read into arrays, the form of the relationship to be tested is entered interactively and sets of X and Y values calculated and plotted using screen graphics. For a specific parameter (usually the Y values) any combination of characteristic indices can be put together, a new (X) variable computed and the relationship between them viewed. An optional component of the program allows the R^2 (coefficient of determination) to be calculated. The objective is to find the combination (linear or otherwise) of physical characteristic variables (transformed or not) that produces the best linear relationship with each model parameter (transformed or not).

The starting point was usually a simple combination of those variables deemed to be most relevant to the particular parameter. The perceived associations between parameter values and catchment characteristics discussed in the earlier report (Hughes and Beater, 1987) were used to suggest which variables to start with. An assessment of the initial relationships as well as a knowledge of the differences between the characteristics of each catchment area were used to suggest changes to the form of the equations. Given the imprecision with which some physical variables are quantified as well as model limitations, it was never expected that relationships with a low degree of scatter would be produced. The exercise consists mainly of finding the relationship which produces the least amount of scatter. A further constraint is that the relationships should have some meaning in the context of the individual parameter conceptualisations and not be simply mathematical abstractions. For example, channel routing parameters were expected to be related to the channel characteristics rather than such as soil depth or water holding capacity. The results of this exercise are discussed in chapter 7.

The derivation of relationships between storm characteristics and some of the parameters of the simple models (OSE1, 3 and 4) presents a more complex problem. One of the problems is separating the influences of catchment characteristics and storm characteristics. The procedure adopted in this study has been to calculate the average parameter value over the range of storm events for a specific sub-area. This is then considered to be the representative value to be used in the derivation of relationships with catchment characteristics. The actual values, which vary between storms, can then be used in an attempt to quantify relationships between these values and storm characteristics. How such relationships might be used to estimate the parameter values is discussed in the next section and in chapter 8 when the results of this part of the study are presented.

5.3 THE PROCEDURE FOR ASSESSING THE USEFULNESS OF THE RELATIONSHIPS BETWEEN PARAMETER VALUES AND CATCHMENT OR STORM CHARACTERISTICS

The 'usefulness' of the relationships is defined in the context of this study as the extent to which they be used to estimate parameter values when calibration is not possible. This may be viewed as the final level of model validation, assuming of course that the definition of such relationships are to be considered part of the model. The first approach to investigating the question of usefulness is to calculate new parameter values from the derived relationships for all the sub-areas of the catchments. The models can then be run with the new parameter values and the new simulated flows compared with observed flows. The success of these simulations should be indicative of the accuracy with which storms on ungauged catchments can be simulated. There is of course the usual limitation that the results can only really be considered relevant to catchments within the range of characteristics represented by the test data set. Clearly the greater the degree of scatter of the original parameter values around the relationships, the more the new parameter values will differ from the originals. This could also be taken to mean that a high degree of scatter will result in poor validation results. However, the existence of interaction between parameter values suggests that this will not necessarily be the case. Major changes to several parameter values may have a variety of effects on the simulated flows which tend toward cancelling each other out and produce results closely similar to the original calibration results. The point about the non-uniqueness of calibration solutions in hydrological models was discussed earlier in section 2.4.

The final testing phase is to estimate the values of the relevant characteristics for a group of gauged catchments not previously used and substitute these values into the relationships to obtain model parameter values. An assessment of the level of accuracy achieved by simulations using these parameter values should further indicate the applicability to ungauged catchments of the combined model/parameter quantification approach. Of the catchments that are listed in table 4.1, four were reserved for this final testing phase. Two of these are located in the southern Cape (Karatara - K4M02 and Diep - K4M03) while the others are the Chickasha catchments of the US southwestern Prairies.

For those models where storm characteristics are expected to effect the values of some parameters, it is necessary to carry out an additional procedure before any validation results can be obtained. As previously discussed, the sub-area parameter values can be related to catchment characteristics. However, these values are expected to increase or decrease according to variations in those storm characteristics that appear to be most relevant in affecting the runoff response of a particular catchment. The procedure used to calibrate these models was to fix the sub-area parameter weights and vary the overall catchment parameter value with storm characteristics. Therefore, the relative difference between sub-area parameters remains the same for all storms. This simplifies the parameter estimation procedure in that an overall catchment parameter value can first be estimated from the derived relationship with storm characteristics. The sub-area parameter values are then determined from catchment characteristics and their mean value calculated. These sub-area values are then weighted by the ratios of the storm based, overall catchment value to the mean value. The problem of the effect of spatial variations (between sub-areas) in storm characteristics is recognised by the authors but has not been addressed. If this effect had been allowed for the dimensions of the model testing exercise would have been increased, especially during calibration.

5.4 CONCLUDING REMARKS ABOUT THE BASIS FOR MODEL EVALUATION AND COMPARISON

This chapter has outlined the procedures that have been followed in the study to enable the models to be evaluated and compared. There are essentially two levels of evaluation. The first is based upon the capability of the models to simulate a variety of storm events on individual catchments after some form of calibration. The second level represents an evaluation of the liklihood of success in applying the models to situations where calibration is not possible and the parameter values have to be estimated from derived relationships with catchment and/or storm characteristics.

Section 5.1.4 identified eight groups of questions related to comparisons of the success of simulations between models, between catchments and between storms on the same catchments. The combined calibration and parameter validation results for 28 catchments presented in the next chapter are discussed within the framework of these questions and the conclusions about the relative merits of the modelling approaches are based upon the answers.

Sections 5.2.1 to 5.2.13 discussed the quantification of a number of catchments and storm characteristics that have been included in an attempt to define relationships with model parameter values. The choice of these characteristics has been based upon the perceived physical meaning of the parameters given the constraint that the characteristics should be quantifiable from available information. Section 5.2.14 describes the procedure for establishing the form of the relationships. Conventional multivariate regression techniques (such as stepwise multiple regression) which can be very restrictive in terms of relationship type, were rejected as being inappropriate tools for this study. A graphical fitting procedure is used instead which is based upon trial and error selection of physical characteristic variables in different equation forms to find the most suitable relationships for estimating the different model parameters. The results of this procedure are discussed in chapter 7. The value of the derived relationships are assessed by using them to re-generate parameter values for the 28 catchments already modelled (as well as an additional four validation catchments). The simulation results using these new parameter values are discussed in chapter 8 and should provide an indication of the likely success of applying the models to ungauged catchments.

Chapter 6

RESULTS OF MODEL CALIBRATION/VALIDATION FOR INDIVIDUAL CATCHMENTS

The purpose of this chapter is to discuss the results of applying the models to some or all of the catchments referred to in chapter 4 and listed in table 4.1 As already explained in section 5.1.3, some of the results for model OSE2 represent validations of parameter values calibrated on a subset of the available storm data for some catchments. To report all of the results in detail would occupy a great deal of space. The discussion is therefore limited to highlighting the most important points with respect to the overall aims of the study which has been stated to be an assessment of the general applicability of the models. For those readers who wish to study the results in more detail, listings of the model parameters and statistics of correspondence between simulated and observed values for individual storms are given in appendices C and D respectively. The statistics used are the percentage errors of simulated volume and peak as well as the coefficients of efficiency and determination. Initially certain aspects of the results for each model are discussed, while the latter part of the chapter provides some of the answers to the eight questions raised in section 5.1.4.

6.1 MODEL OSE1

In the earlier report (Hughes and Beater, 1987), reference was made to the difficulties of calibrating the main volume reduction parameters. These difficulties were experienced due to the strong interaction between the five parameters that have an effect on the proportion of rainfall that contributes to runoff. These five are initial losses, antecedent precipitation factor (APF) and the three parameters of the S-curve (SMAX, DA and C). After the initial modelling attempts on the Ecca and North Danville catchments, a general calibration procedure was established, whereby all the parameters except one were kept constant for a particular catchment and variations in C or APF allowed to account for the differing storm effects. This made calibration a great deal less complicated and did not have an adverse effect on the overall results. The initial losses parameter does not appear to be important and its inclusion was only necessary for the Ecca catchments which experience long duration, relatively low frequency storms occurring on very dry catchments. Under such conditions, up to 50mm of the first part of a storm has been observed to generate no runoff at all. The sensitivity of the other volume conversion parameters depends to a large extent upon the antecedent precipitation characteristics. For those catchments that have a highly seasonal regime, with frequent rainfall events in the previous 30 days, antecedent precipitation values are relatively high and the resulting initial moisture values are very sensitive to the APF parameter. The southern Cape and Ecca catchments have a non-seasonal and more irregular regime giving rise frequent to low initial moisture values. Under these conditions, changes to either APF or SMAX have relatively minor effects on the simulations, unless the amount of runoff is very small compared to the rainfall. The latter type of storm is represented in both the Ecca and Tombstone data sets and any small parameter change can affect the simulations dramatically.

The effects of the power parameters in the routing components of both the lumped (N and B) and semi-distributed (just N) versions are difficult to separate from the effects of the relevant scale parameters (K and A in lumped, just K in semi-distributed). The N (catchment routing power) and B (time area relation power) values were therefore fixed at values of 0,7 and 0,1 respectively for all the catchments. In terms of the shapes of the simulated hydrographs, the most important parameters are A and K in the lumped model and K, together with variations in the sub-area channel delays (CDEL), in the semi-distributed model.

The lumped channel delay (DEL) merely represents a time shift of the complete hydrograph. The simulations were found not to be very sensitive to changes in KC, assuming such changes were constrained to lie in the range suggested by the physical interpretation of this parameter (channel storage factor). The relative importance of the two semi-distributed routing parameters K and KC indicates that attenuation over or under the surface of the catchment (K) is more important than attenuation in the channel segments (KC). This would seem to be an acceptable conclusion given the size of sub-areas involved. However, if the catchment is considered as a whole, the relative time of arrival at the outlet of flow derived from different parts of the catchment is also important. This is reflected in the lumped model by parameter A and in the semi-distributed model by the sub-area CDEL's, both important parameters.

The model calibrations were obtained by fixing the values of all the parameters except C or APF for any one catchment. The number of different C or APF values was kept to a minimum, the graphical fitting procedure explained in section 5.1.2 and illustrated in figure 5.1 being used to identify groups of storms requiring the same C value. This procedure produced generally acceptable results (tables 6.1 and 6.2) for many of the catchments, although it was noticeable that changes to the routing parameters would have improved the fits for some storms on certain catchments. The summary of the statistics given in tables 6.1 and 6.2 suggests that the Ecca results are amongst the best. However, this was one situation where the routing parameters were allowed to vary. Two groups of events are represented in the Ecca data set; very small runoff events resulting from high intensity, short duration storms and larger runoff events from long duration but lower intensity rainfall. The timing characteristics of these different types of events is such that a single set of routing parameter values would produce, overall, very poor results.

Relatively long duration, multiple peaked events occurring on catchments with low initial moisture status are not modelled successfully by OSE1. This is assumed to be the result of large temporal variations in the proportion of rainfall that becomes runoff as the catchment moisture status increases during the event. Multi-peaked events on wetter catchments are likely to have lower runoff proportion variations which can be more closely simulated by a model such as OSE1 which uses a runoff proportion that is constant for each storm.

6.2 MODEL OSE2

The importance and sensitivity of the simulation results to changes in the values of those parameters shared by OSE1 and OSE2 have already been discussed. The similarities between the models mainly concern the routing parameters. As with OSE1, K and A are the most important routing parameters in the lumped version and K and CDEL the most important in the semi-distributed version. For OSE2, variations (between catchment) in the routing parameter N appeared to be justified during model calibration and contributed to improved simulations of peak flows. A different value to 0,7 sometimes helped to achieve better correspondence between observed and simulated peaks for the full range of events on a catchment than could be achieved by modifying other parameter values. No physical explanation could be found for this particular feature of the model performance.

Table 6.1 Comparison of mean absolute percentage errors for different models for each area.

	OSE1				OSE2				OSE3			
	LM		SD		LM		SD		LM		SD	
Area	Vol.	Pk.	Vol.	Pk.	Vol.	Pk.	Vol.	Pk.	Vol.	Pk.	Vol.	Pk.
Tombstone	12	16	13	24	56	54	63	32	7	19	4	24
	(14)	(17)	(11)	(21)	(66)	(88)	(61)	(23)	(6)	(19)	(5)	(22)
Ecca	12	10	13	9	8	11	34	31	5	6	6	6
	(12)	(13)	(15)	(11)	(8)	(11)	(31)	(30)	(6)	(6)	(7)	(5)
Bethlehem	16	20	13	18	26	33	20	18	11	18	7	11
	(15)	(23)	(8)	(14)	(19)	(24)	(25)	(29)	(7)	(17)	(5)	(6)
De Hoek	20	40	21	42	16	15	17	16	9	30	9	29
	(14)	(29)	(14)	(30)	(14)	(13)	(15)	(14)	(6)	(25)	(8)	(23)
Cedara	11	23	15	38	13	34	18	23	7	27	10	7
	(6)	(13)	(8)	(34)	(7)	(36)	(13)	(19)	(6)	(24)	(6)	(9)
Zululand	11	14	13	16	20	25	20	22	5	18	8	17
	(7)	(13)	(6)	(21)	(22)	(25)	(18)	(20)	(5)	(12)	(6)	(13)
Oxford	14	34	11	29	24	31	23	26	8	22	6	22
	(21)	(31)	(12)	(30)	(27)	(27)	(22)	(20)	(8)	(19)	(7)	(17)
Kaaimans	11	20	9	12	16	27	14	26	5	14	6	13
	(9)	(28)	(6)	(6)	(10)	(36)	(11)	(34)	(3)	(14)	(4)	(14)
Malgas	8	16	11	11	26	32	27	33	9	13	8	15
	(6)	(18)	(6)	(9)	(23)	(37)	(26)	(41)	(4)	(12)	(3)	(12)
N. Danville	8	10	10	14	15	18	20	21	4	4	3	5
	(7)	(8)	(17)	(18)	(14)	(13)	(20)	(17)	(2)	(2)	(3)	(4)

Figures in parenthesis are standard deviations

Table 6.2 Comparison of mean coefficients of efficiency and determination for different models for each area.

	OSE1				OSE2				OSE3			
	LM		SD		LM		SD		LM		SD	
Area	Eff.	Det.	Eff.	Det.	Eff.	Det.	Eff.	Det.	Eff.	Det.	Eff.	Det.
Tombstone	59	63	30	55	-102	58	8	63	76	82	39	59
	(32)	(33)	(65)	(30)	(458)	(29)	(95)	(25)	(17)	(13)	(57)	(29)
Ecca	76	84	52	72	59	71	71	72	83	87	70	81
	(24)	(12)	(46)	(20)	(41)	(29)	(255)	(31)	(16)	(10)	(42)	(26)
Bethlehem	34	55	59	66	28	58	74	85	55	67	54	68
	(59)	(35)	(36)	(31)	(65)	(34)	(21)	(11)	(46)	(36)	(55)	(31)
De Hoek	22	60	27	63	35	60	43	64	34	58	49	60
	(79)	(35)	(64)	(34)	(78)	(32)	(59)	(25)	(59)	(29)	(45)	(31)
Cedara	48	72	15	67	46	70	65	75	-2	41	53	72
	(54)	(23)	(121)	(24)	(43)	(20)	(9)	(10)	(62)	(18)	(34)	(17)
Zululand	65	78	67	80	57	83	62	83	71	77	74	79
	(26)	(20)	(27)	(14)	(63)	(15)	(50)	(15)	(21)	(19)	(18)	(18)
Oxford	58	77	66	79	52	77	66	84	70	78	76	81
	(60)	(18)	(30)	(18)	(70)	(19)	(49)	(16)	(28)	(21)	(24)	(17)
Kaaimans	11	51	41	63	4	56	36	68	45	58	64	75
	(89)	(28)	(59)	(25)	(95)	(31)	(72)	(27)	(39)	(25)	(30)	(20)
Malgas	37	60	38	63	5	72	2	76	51	67	46	66
	(56)	(34)	(66)	(33)	(158)	(25)	(173)	(22)	(55)	(29)	(58)	(30)
N. Danville	68	83	76	87	71	88	61	91	92	94	90	92
	(49)	(22)	(38)	(12)	(35)	(19)	(67)	(14)	(14)	(9)	(20)	(13)

Figures in parenthesis are standard deviations
Eff. = Coefficient of efficiency * 100
Det. - Coefficient of determination * 100

The comments made in 6.1 above about the sensitivity of parameter APF are equally applicable to OSE2, in that variations in the value are of greater importance when larger quantities of rain occurred in the 30 days prior to the event than if little rain occurred. The sensitivity of the results to SMAX, DA, C and IAF are very dependent upon storm characteristics as well as antecedent moisture status. The location of the inflexion point on the S-curve (C, DA) can be critical for long duration events which begin with a moisture status lower than C and progress beyond C. This is particularly true when a sharp change in the gradient (rate of increase of runoff proportion with moisture status) of the curve occurs at the inflexion point. The inflexion point can be moved to achieve a similar average runoff proportion for the storm as a whole, but not without changing the relative proportions at the start and end of the event. Similarly, when dealing with a group of storms having a variety of antecedent conditions, total rainfalls and durations, changes to the S-curve shape can have a very complex effect upon the overall results. It is apparent that simplistic statements about the sensitivity of these parameters is not possible. Changes to parameter IAF (impervious area factor) inevitably have a greater effect upon storms with high intensities. If such storms also have short durations and low antecedent moisture status, IAF becomes the dominant runoff producing parameter. The experience gained from modelling the Zululand catchments which have some sub-area with a high percentage of bare rock (impervious) outcrops suggested that the name given the IAF parameter is a misnomer. Light rain falling on such surfaces produces a high proportion of runoff regardless of the moisture status but the IAF function generates runoff as a function of intensity. The only way that the model can generate large proportions of runoff under such conditions is by defining an S-curve which rises rapidly from zero runoff proportion at zero moisture status to a high proportion at a relatively low moisture status (inflexion point at low C, high DA coupled with low SMAX).

Of the two percentage flow parameters, PCSLP is the most important, although has a relatively minor effect for short duration events. PCVSA is very limited in the values it can assume (usually less than 5.0) before the effect on the latter part of the recession curve indicates that it has been set too high. Its effect on the main part of the hydrograph is negligible for relatively short duration events but increasing PCVSA for longer events will depress the flows in the earlier part of the hydrograph. The effect on the later flows is not always easy to determine as PCVSA generates baseflow, but also decreases the VSA store, consequently decreasing the runoff proportion from the later rainfall. A great deal depends upon the balance between the VSA store level and the quantity and intensity of rainfall in the latter part of the event. The remaining parameter (CLP) was included to try and account for channel losses. The Tombstone catchments, in which this process is well documented (Renard and Keppel, 1966; Burkham, 1970), demonstrated that the way in which channel losses are accounted for in the model is not adequate. Channel losses were not considered relevant to some of the catchments (Zululand, southern Cape and North Danville) while for others this parameter may be accounting for the storage and attenuation effects of farm dams or soil conservation structures (Bethlehem, De Hoek, Cedara and Oxford) rather than natural channel losses. This parameter is very important for short duration events on dry catchments. Part of the problems associated with modelling the Tombstone catchments are related to the fact that most of the events are of this type. When longer duration events are also present it is easier to establish a value for channel losses during calibration because the effect diminishes with increasing moisture status. Without a range of different event types it is often difficult to know whether the best results can be obtained by very low runoff proportions with some channel losses or higher runoff proportions with greater channel losses. Without the availability of the nested pair of catchments in Tombstone (TM11 and TM8) it is unlikely that even the somewhat poor overall results given in table 6.1 and 6.2 could have been achieved.

If comparisons are made between models using the results presented in tables 6.1 and 6.2, it is apparent that OSE2 produces generally poorer simulations. However, the results must be viewed in the light of the fact that the OSE2 parameter values were fixed for all events on the same catchment. The same is not true of the other models. The lumped results for the Ecca are the only ones which represent non-fixed OSE2 parameters and illustrate the effects of varying just the APF parameter. Fixing the values for APF in model OSE2 produces statistics similar to or worse than the semi-distributed results. Alternatively, varying APF in the semi-distributed model reduces the overall percentage errors to below 15%. The same is true for most of the other catchments with the possible exception of Tombstone, where the major runoff component is intensity controlled rather than moisture controlled. The method used in the model to estimate initial moisture as a decay function of antecedent rainfall is very simplistic and unlikely to be able to fully account for the dynamic catchment moisture balance in the period leading up to the storm. The alternative is a more complex component (or continuous water balance model) which would involve a larger number of parameters.

Apart from the problems of accounting for channel losses in the Tombstone catchments, there do not appear to be any particular storm types that the model is consistently incapable of simulating. Unlike the fixed runoff proportion model (OSE1), complex, multi-peaked events are generally simulated as successfully as single peaked events. For a number of storms where the rainfall input is spatially variable and well defined by the available data, the semi-distributed model definitely produces improved simulations over the lumped. However, this is certainly not always the case even when the spatial variations are extreme. One possible explanation for this lies in the difficulties of establishing the 'correct' relative parameter values between sub-areas.

The results of simulating storms from the Oxford catchments using OSE2 deserve special mention. During the initial calibration phase for these catchments the usual procedure of not varying parameter values was adopted. However, it became very clear that the runoff response characteristics were extremely variable and closer examination of the results revealed a strong seasonal grouping of events. Winter (November to April), spring (May and June) and summer (July to October) groupings were identified from the model results as being distinct from each other in terms of response characteristics. A vast improvement in simulation results was obtained when these groups were modelled using different parameter values. A closer look at the physical characteristics of the catchments revealed major seasonal differences in vegetation cover characteristics that are consistent with the seasonal parameter value differences. Section 4.7 discussed the seasonality in the vegetation cover, while figure 4.10 graphically illustrates the effect on runoff response. It should be noted that the initial model results gave the first indication to the authors that a degree of seasonality was present. The descriptions of vegetation characterisics and the data used for figure 4.10 were sought later in an attempt to confirm the model results. It is extremely gratifying that the confirmation was acceptable.

The previous chapter, as well as the beginning of this chapter, mentioned that the OSE2 results are a mixture of calibrations and validations. No attempt has been made to distinguish between them in tables 6.1 and 6.2. This is partly to save space in an already cluttered table but mainly because there is little overall difference between the two sets of results. It is inevitable that at least some storms within the calibration sub-set would be well simulated, otherwise further calibration would have been carried out. However, it was not always possible to achieve good simulations on all the calibration events. Similarly, good and poor simulations were represented when the calibrated parameter values were used for the validation sub-sets of events. 'Good' and 'poor' are used here in a relative sense with respect to the overall simulation capabilities of the model for a particular catchment. The authors do not therefore consider it necessary to define these terms more precisely.

6.3 MODEL OSE3

Model OSE3 is similar to OSE1 in that the fixed runoff proportion (ROP) has to be calibrated for each individual event. ROP is actually calculated as the ratio of the observed runoff depth to average catchment rainfall depth. In the first instance, no variations in ROP between sub-areas in the semi-distributed model were allowed. A later attempt was made on some catchments to include sub-area variations based upon perceived physical differences that were considered to affect runoff response. However, these changes were not generally found to improve the simulations. The lack of success might be attributable to poor correspondence between perceived and real physical sub-area differences in the context of their effects on runoff response.

The routing components of OSE3 are much the same as OSE1 except for the order in which they occur within the model structure. This does not appear to affect their importance or the sensitivity of the simulation results to changes in their values. Consequently, the comments made about these parameters during the discussion of OSE1 are equally valid for this model. Very few differences in the calibration performance of the two models (OSE1 and 3) could be detected and the routing K values could be kept constant for each catchment for both. Mandeville (1983) suggested that the change in the order of the components should lead to greater stability in the value of the routing parameter. Given that a single value of K is acceptable for each catchment in OSE1, an improvement in stability is not possible. An assessment of the differences is usefulness of the two models can only be made at a later stage, after attempts are made to develop relationships for the estimation of parameter values. This point is considered further in chapters 7 and 8.

6.4 MODEL OSE4

For reasons discussed below model OSE4 was not applied to all the catchments and no performance results are listed in this report. The earlier report (Hughes and Beater, 1987) discusses the application of the model to the Ecca and North Danville catchments and little more was learned about the model during further calibrations.

As indicated in Hughes and Beater (1987) the use of the continuing losses function was not as successful as the use of a constant runoff coefficient. This is especially evident where large variations in intensity occur during an event. The effect of using continuous losses is to exclude the lower intensity periods from making any contribution to runoff. This is contrary to the real nature of the response as indicated by the hydrographs of some storms. Where relatively high intensities are followed by extended periods of lighter rainfall, the hydrographs experienced on some catchments are broad with slow initial recessions. This suggests a contribution from the later light rainfall which helps to sustain the flows after the peak. The continuing losses function is unable to simulate such events. Where the rainfall input is of short duration or of relatively uniform intensity the differences in model performance between using the two loss functions is negligible.

Unlike OSE1 and 3, the performance of OSE4 benefitted by the inclusion of initial losses. However, the variation in the values of intial losses did not appear to be reflected in differences in the patterns of antecedent rainfall. It was also found necessary to vary the value of the routing parameter (KC) between storms on the same catchment. Although for some catchments there does appear to be a pattern in the values of KC that is related to storm characteristics, this is not always the case and attempting to quantify these relationships was considered unlikely to be very successful. The fact that the values of the three major parameters of this model (initial losses, KC and runoff ratio) need to be varied for different events on the same catchment suggests that it would be difficult to use unless calibration data are available.

The structure of this model was not examined as closely as the others and the authors admit that there are additional features in the model package that were not fully tested. However, some preliminary investigations into the use of the facilities for accommodating both temporally and spatially variable runoff ratios were not very encouraging. With respect to the relatively more encouraging results being returned from the simulations using the other models, and given the time constraints of the project, further investigations of OSE4 were not persued.

6.5 MODEL EVALUATION AND COMPARISON

Section 5.1.4 in the previous chapter presented eight questions, the answers to which should provide a sound basis for a comparative evaluation of the models after the calibration phase of the study. These questions are addressed in separate sections below.

6.5.1 The question of parameter sensitivity

Most contributions to the modelling literature place a great deal of emphasis on identifying the relationships between changes in the values of model parameters and the effects of these changes on certain aspects of the simulated flows. Such statements about parameter sensitivity are useful to a model user as they give some indication of how much the values of parameters should be changed to achieve a desired result. They also indicate how far an estimate of a parameter value can be from its 'real' value before the simulation results deteriorate beyond acceptable limits. However, the usefulness of this information becomes somewhat limited without some information about what that 'real' value should be. This point is central to the problem of estimating parameter values for situations where complete calibration is not possible. It is also relevant to the debate about the comparative worth of physically-based and conceptual models. Abbott et al. (1986) suggest that the closer direct association there exists between parameters and physical characteristics then the easier it is to achieve an accurate estimate of the 'real' parameter value.

This study has revealed that some of the parameters of the models are only of minor importance assuming that their values are kept within certain limits. This may be because other parameters can achieve much the same effect on the simulations or because the parameters control a relatively unimportant component of the model (for example, PCVSA in model OSE2). Perhaps more importantly, most of the effects of varying parameter values are highly dependent upon some characteristics of the storm or antecedent rainfall input. This makes it extremely difficult to make general statements about parameter sensitivities. Parameter N, in the storage routing equation used in all the models, can be considered constant at 0,7 for the catchments modelled. Only minor improvements were obtained by varying this value. Varying K between catchments represents a more straightforward method of accounting for land phase routing differences. The PCVSA parameter of model OSE2 was found to vary only over a small range. Values of greater than about 5% produce very sustained low flows at the end of the event. Apart from the effect of this parameter on the relatively unimportant (from a flooding point of view) late recession part of the hydrograph, most event simulations were insensitive to changes in PCVSA within the acceptable range (0-5%). Only for quite long duration events (occurring on the southern Cape catchments for example) do small changes in PCVSA (of the order of 2%) have a significant effect on simulations. However, the importance of this parameter is still secondary to most of the others. The channel routing KC also has secondary importance compared to parameter K and channel delays in the semi-distributed versions of OSE1 to 3.

The sensitivity of the simulations to changes in APF (models OSE1 and 2) depends upon the pattern of rainfalls in the 30 days prior to the event. Frequent occurrences of relatively high rainfalls, and particularly rainfall in the few days before the event, mean that model output is very sensitive to APF values. This type of antecedent rainfall regime is associated with those catchments experiencing frequent heavy convective storms during the summer season. The effects of changes in the S-curve parameters of OSE1 and particularly OSE2 are very difficult to generalise due to strong interaction between the parameters and the influence of a variety of storm characteristics.

6.5.2 Stability of parameters in model OSE2

The answer to question (ii) posed in section 5.1.4 is that the results do tend to indicate that in general a stable parameter set can be used for all storms on the same catchment. Tables 6.1 and 6.2 indicate that the mean absolute percentage errors in peak and volume estimation are frequently close to or below 20% and that mean coefficients of efficiency are often greater than 0,5. Where coefficients of efficiency are very low (Malgas for example), the mean coefficient of determination is usually quite high, indicating a systematic error. It should be noted that these mean values are strongly affected by poor simulations for one or two storms. This is especially true of the coefficient of efficiency. Perfect definition of the spatial pattern of input rainfall is rarely possible and for a lot of storms the input data falls very short of perfect. Consequently, it is usually not possible to ascribe simulation errors to any particular cause. They may be related to input data inadequacies or deficiencies in the structure of the model with respect to the specific rainfall-runoff processes prevailing. They may also be associated with the fact that model calibration may have been stopped short of identifying the optimum parameter set. Given these potential sources of error, the results for most catchments are as good as might be expected.

The second part of the question addresses parameter stability with respect to particular situations or particular parameters. The simplicity of the antecedent moisture function has already been referred to and there is no doubt that allowing the APF parameter values to vary between storms would have improved the results on most catchments and removed most of the systematic errors. Changing the values of most of the other parameters usually affects the simulations in a more non-linear or non-uniform manner than APF. Therefore, the APF parameter seems to be the logical choice to correct systematic errors. Three catchments emerge as having the poorest results using the semi-distributed format; Tombstone, Ecca and Malgas. The problems of accounting for the channel loss processes in the Tombstone catchments have already been referred to. The two types of storm event in the Ecca, and the need for some differences in the model parameter values has also been discussed in this report and in Hughes and Beater (1987). The Malgas catchment has no raingauges within its boundary. Although the work of Hughes and Wright (1988) indicates that the timing of the input rainfall may be reasonably accurately estimated from adjacent gauges, total storm amounts may be difficult to estimate. The results (table 6.2) demonstrate that a strong systematic error exists in the simulations (Coeff. of Eff. = 0,02; Coeff. of Det. = 0,76). Poor definition of total storm amount would account for this. The semi-distributed results for the Kaaimans (adjacent to and physically similar to the Malgas) are somewhat better than for the Malgas. The input rainfall definition is also better, being based upon gauges that are better situated with respect to the catchment boundary. It therefore seems reasonable to suggest that at least part of the cause for poor simulations on the Malgas is due to data errors.

6.5.3 Stability of parameters in OSE1, 3 and 4

It was never expected that the main volume conversion parameters of these models would be able to remain constant for all storms on the same catchment. The question of parameter stability therefore refers mainly to the routing parameters. For OSE1 it was only found necessary to vary one of the volume conversion parameters and the best results were generally obtained when the S-curve parameter C was varied. Varying the APF parameter was also relatively successful. Similar conclusions are applicable to model OSE3 for which storm dependent variations can generally be accounted for by differences in ROP. The Ecca is the only catchment where routing parameter variations were necessary and the reasons are the same as for model OSE2.

Although not applied to all catchments, very little stability is evident in the parameters of OSE4. Not only was it found necessary to change the runoff coefficient but also the initial losses and main routing (KC) parameter. It was these variations that prompted the curtailment of further tests on this model.

6.5.4 Patterns of variability in the parameters of OSE1, 3 and 4.

The natural extension to the third question raised in 5.1.4 and answered above, refers to the possibility of patterns of variation in the volume conversion parameters of OSE1 and 3 being related to storm characteristics. For OSE3 the relevant characteristics could include antecedent precipitation, wheras in OSE1 as antecedent catchment moisture estimation is a component of the model. It has previously been suggested that no associations between storm characteristics and OSE4 parameters were evident during the calibrations. OSE4 is therefore not considered further in this section.

Some relatively vague and imprecise associations were noted during the calibration of OSE1 and as might be expected the important storm characteristics varied between catchments. In some areas, intensity variations appeared to be relevant while in others the C parameter increased with increasing duration or total rainfall amount. These somewhat casual observations suggested that determining quantitative relationships would not be an easy task and that it would be difficult to generalise and fix the form of a relationship applicable to a range of different catchments. The observations suggested that different combinations of storm variables would be most appropriate to different catchments. Despite these not very encouraging remarks, attempts were made to develop useful relationships after all calibrations had been completed. These attempts are discussed in chapter 7.

In model OSE3 there is no component to account for antecedent catchment moisture status and therefore it was expected that variations in ROP would have to account for this factor as well as other storm characteristics. This additional dimension made it difficult to assess the likelihood of success of trying to establish quantitative relationships. Further discussion of these attempts is confined to chapter 7.

6.5.5 Comparitive model performance relative to specific storm or catchment types

The most noticeable difference in model performance was observed for complex, multi-peaked events, particularly when they begin with relatively low catchment moisture states. The variable runoff proportion model (OSE2) performed more successfully in these situations than the others.

The improvement in performance was less noticeable for multi-peaked events starting with wet conditions. This is presumably because the temporal variations in proportional amounts of rainfall that contribute to storm runoff is greater in the former situations than the latter. Some storm events are characterised by short, high intensity bursts of rainfall superimposed upon longer duration, low intensity rain. The runoff response from these events on some of the smaller catchments is a smooth, rounded hydrograph with a sharper peak rising from it. OSE2 demonstrated a tendency to simulate these events better. This is readily explained by the fact that the intensity controlled runoff is routed with less attenuation than other runoff. However, because the decrease in degree of attenuation (compared to the moisture controlled runoff) is fixed and no allowance is made for differences between catchments, the results were not always an improvement over the other models. OSE1 and 3 have only one runoff component and therefore only one level of attenuation is possible for a given flow rate.

Further general conclusions about the comparitive results after the so-called calibration stage are difficult to make. This is because the OSE2 results represent a mixture of calibrations and validations based upon fixed parameters for individual catchments while one of the parameters of the other models was allowed to vary. The mean absolute percentage volume errors in table 6.1 are nearly always lower for OSE1 and 3 as are the peak errors. Where either of these goodness of fit statistics for OSE2 come close to, or are better than those for OSE1 and 3, it is reasonable to suggest that OSE2 is the more useful model for those catchments. Examples are Bethlehem, Oxford and certainly De Hoek.

6.5.6 Comparisons between lumped and semi-distributed model versions

Tables 6.1 and 6.2 indicate that the lumped models do not generally perform less satisfactorily than the semi-distributed versions. There are some exceptions that do not conform to this general observation and these occur on those catchments where the spatial variations in storm rainfall are consistently the greatest. The semi-distributed version of OSE2 generates peaks more accurately for the Tombstone, Bethlehem and Cedara catchments but there is little difference in the volume simulations. This effect is also demonstrated by higher mean coefficients of efficiency for the semi-distributed version of OSE2 listed in table 6.2. Not only are the mean values higher but the standard deviations are lower. The same improvement of the semi-distributed over the lumped versions is not evident for OSE1 and 3, in fact in many cases the lumped results appear to be better.

There are many examples of individual events where the rainfall is spatially variable and the semi-distributed results for all models show improved simulations over the lumped. One of the possible reasons why the differences are not clearer could be related to the variety of storm types represented by the computer data set. Storm type in this context refers to not only the degree of spatial variation but also the extent to which the spatial variation is satisfactorily defined by the available data. The events were therefore divided up into three groups. A-type events are those where the available data demonstrates that the degree of spatial variation in total rainfall and intensity is small. B-type events are defined as having a relatively high degree of spatial variability due to either the small size of the storm area, or spatially variable orographic effects (southern Cape for example). To be classified as a B-type event there must also be a reasonable amount of available data with which to define the variability. Inevitably, the greater the degree of variability, the more data are required to define it. C-type events are those where the available data indicate variability but are not considered sufficient to define it. An example of a C-type situation would be where only one gauge exists within the catchment boundary while another gauge, some distance away, records dissimilar storm characteristics. The tables of goodness of fit statistics for all the model simulations given in appendix D also include a column specifying the storm type. Clearly, the loose definitions used for the different types will result in rather ill-defined boundaries between the groups. However, the authors are confident that most of the storms classified as belonging to one of the groups are different enough from those storms in the other groups. A final point about this classification is that few of the spatially variable events (even group B) are extremely well defined by dense gauge networks. Tables 6.3 and 6.4 list the means of the goodness of fit statistics for the simulation results grouped under storm and model type headings. Figure 6.1, consisting of 6 pages of computer plots, illustrates the same results using histograms of the distributions of the goodness of fit statistics for the storms falling into the three categories. Figure 6.1 indicates that due to the skewed nature of the distributions the mean values, given in tables 6.3 and 6.4, are not always a satisfactory index for comparison.

Table 6.3 Comparison of mean absolute percentage errors for different models for different storm types.

	Storm Type					
	A		B		C	
Model	Volume	Peak	Volume	Peak	Volume	Peak
OSE1 Lumped	14 (19)	25 (24)	13 (11)	20 (18)	10 (11)	20 (29)
OSE1 Semi-dist.	13 (13)	25 (26)	16 (15)	26 (26)	14 (16)	24 (27)
OSE2 Lumped	18 (22)	22 (21)	22 (20)	24 (22)	34 (47)	42 (62)
OSE2 Semi-dist.	20 (18)	21 (18)	27 (27)	25 (24)	38 (46)	31 (29)
OSE3 Lumped	7 (6)	19 (19)	8 (8)	19 (17)	6 (5)	14 (15)
OSE3 Semi-dist.	7 (6)	17 (15)	6 (7)	22 (21)	5 (5)	15 (15)

Figures in parenthesis are standard deviations.

There is very little difference between the lumped and semi-distributed versions of any model for the A events, except for a noticeaby higher coefficient of efficiency for OSE2. Surprisingly, the same is true for the B events. The only notable improvements demonstrated by the semi-distributed versions are the reduction in the standard deviation of the coefficient of efficiency values for OSE1 and an increase in the mean coefficient of determination values for OSE2. The semi-distributed version of OSE2 has fewer storms with poor coefficient of efficiency and determination values than the lumped version. The semi-distributed version of OSE2 also seems to produce the better simulations for the C events, although both sets of results are not very good. The majority of the events with a very high degree of spatial variability fall into this category. Even though the definition of that variability is poor, even some allowance for it in OSE2 seems to produce better results. It is not surprising that the two versions of OSE1 and 3 do not show large differences in results bearing in mind that the main volume conversion parameter is calibrated for each event individually. It may be concluded therefore that the variation in the values of these parameters is influenced by the spatial patterns of rainfall as well as other storm characteristics.

Table 6.4 Comparison of mean coefficients of efficiency and determination for different models for different storm types.

	Storm Type					
	A		B		C	
Model	Eff.	Det.	Eff.	Det.	Eff.	Det.
OSE1 Lumped	59 (59)	80 (18)	45 (65)	65 (30)	54 (41)	66 (29)
OSE1 Semi-dist.	58 (55)	80 (19)	48 (49)	68 (26)	39 (60)	65 (29)
OSE2 Lumped	60 (57)	78 (20)	38 (78)	68 (29)	-20 (305)	68 (28)
OSE2 Semi-dist.	76 (105)	82 (20)	39 (78)	76 (21)	24 (105)	74 (24)
OSE3 Lumped	68 (37)	77 (23)	61 (38)	72 (25)	68 (37)	77 (21)
OSE3 Semi-dist.	73 (29)	81 (19)	64 (32)	72 (24)	68 (53)	77 (28)

Figures in parenthesis are standard deviations.
Eff. = Coefficient of efficiency *100
Det. = Coefficient of determination * 1000

The semi-distributed models were calibrated first and the initial estimates of some of the lumped parameters were obtained from sub-area weighted averages of the semi-distributed parameter values. The lumped routing parameters A and DEL were inferred from the distribution of channel delays used for the semi-distributed versions. In general this practice was satisfactory and little adjustment of the parameter values was necessary to obtain overall results similar to the semi-distributed versions. Further adjustment did not generally improve the overall results for the group of events used on each catchment. As mentioned earlier, there were some events with highly spatially variable rainfall input that the lumped versions were unable to model satisfactorily.

Contrary to expectations, the semi-distributed versions do not produce demonstrably better simulations in general terms than the lumped models even for category B events. The authors have considered four possible reasons for this conclusion.

i) Many of the B category storms are less than adequately defined by the available data. This is the group where the semi-distributed versions would be expected to show the greatest improvements over the lumped. The fact that generally they don't, suggests that input data errors might be dominating any other factors.

ii) The channel routing function of the semi-distributed version is inferior to the time-area function in the lumped versions. This is unlikely to be a major reason as the dominant parameter in the channel routing component is the channel delay and the distribution of these delays over the sub-areas performs very much the same function as the time area diagram in the lumped models.

iii) The larger dimension of the parameter calibration problem inherent in the semi-distributed models makes it more difficult to reach a final result which is close to the optimum. This may be particularly relevant when calibrating on several storms simultaneously, as is the case for OSE2.

iv) Neither versions of the models are satisfactory conceptualisations of the processes of runoff generation and are therefore likely to produce equally bad results. The models have demonstrated their capabilities of simulating a wide range of individual events successfully. The fact that some storms are not modelled well illustrates that there are inadequacies in their structures with respect to their application to certain situations. Such inadequacies are inevitable in these relatively simple models. However, the authors do not consider that this is the main reason for the lack of better results given by the semi-distributed versions.

The above discussion indicates that reasons i) and iii) above are the main causes of the similarity in overall results between the lumped and semi-distributed versions. The fourth reason cannot be totally discounted when dealing with relatively simplified conceptualisations of the real physical system but it is not considered to be the main cause.

6.5.7 Effects of varying the level of spatial distribution

Given the conclusions reached in the previous section it is unlikely that any attempts to investigate the effects of varying the level of spatial distribution would yield conclusive results. The original level of distribution chosen partly reflected the distribution of available raingauge data and was partly based upon variations in known physical catchment characteristics. The intention was to identify relatively homogenous sub-areas for which a distinct rainfall profile could be defined. This was not always possible due to the lack of a dense gauge network. However, one result of the intention is that a more detailed level of distribution would not have been accompanied by an equally detailed definition of input rainfall. The previous section has already identified this factor as having a major influence on simulation results. Despite these reservations, changes to the level of distribution of the Ecca catchment (highest raingauge density) were tested using model OSE2. No conclusive results emerged, some storms were modelled more successfully using more sub-areas (20 against 12 in the original simulations), while others were not. Those modelled better were not necessarily storms with a high degree of spatial variability in input rainfall.

6.5.8 Effects of varying the time interval of modelling

Table 6.5 illustrates the effect of increasing the model time interval used in the semi-distributed version of OSE2. The simulation results for several storms drawn from three catchments are given, as well as the effect of changing the time interval on the observed peak. The storms on the three catchments referred to in the table are reasonably representative of the data set as a whole. The Malgas events tend to be of long duration with low to moderate intensities. Although a steep mountain catchment, the runoff response is not very rapid and a time interval of 15 min. was used in the original simulations. The storms on the Tombstone catchment are exclusively high intensity, short duration events and the runoff response is very rapid indeed. A typical flow duration of less than a few hours prompted the use of a 5 min. time interval. In this test of the effects of varying the time interval it has been increased to 30 min. Bethlehem experiences a range of different event types but the seven storms used are of moderate to high intensity and of relatively short duration but not as short as the Tombstone events. Runoff responses on this low slope catchment are intermediate between the Malgas and Tombstone.

Table 6.5 Summary of the effects of changing the modelling time interval in model OSE2 (semi-distributed).

Catchment & no. of storms	Time interval(h)	Abs. mean volume	% error peak	Mean coefficient Eff.	Det.	Effect on*[1] obs. peak
Malgas,	0,25	15,4	9,5	84	89	0,8
K3M04	0,50	19,1	14,9	80	87	1,6
(5 storms)	0,75	17,1	15,0	81	87	2,2
Bethlehem,	0,25	13,6	9,0	78	84	1,2
C8M25	0,50	22,1	22,4	69	82	3,2
(7 storms)	0,75	28,5	26,3	49	75	4,4
	1,00	30,9	28,2	34	74	7,8
Tombstone,	0,08	20,6	13,7	71	79	2,2
TM11	0,17	57,4	62,0	28	82	10,2
	0,25	36,1	48,0	43	78	
(4 storms)	0,50	93,6	64,7	-81	79	38,3

*[1] Figures given are the absolute mean % differences with respect to the real peak flow based upon digitized breakpoint data.

Eff. = coefficient of efficiency x 100

Det. = coefficient of deterministic x 100

There is little deterioration in the simulations of the Malgas storms even up to a 1h time interval. The Tombstone results indicate that the results deteriorate significantly as the time interval is increased. The last column indicates that part of the problem is caused by a reduction in the observed peak when using coarse time interval data. However, comparison of the 5 min. and 15 min. results indicate that even when the observed data reflect the real peak adequately, there is still a substantial deterioration in the goodness of fit statistics. The effects for the Bethlehem storms are intermediate between the others. While the absolute mean percentage errors in peak estimation do not change a great deal after the interval has been increased to 30 min., the progressive decrease in the mean coefficient of efficiency illustrates that the simulation results continue to deteriorate as the interval is increased.

These results are not unexpected and illustrate the necessity of choosing a model time interval that is consistent with the time scale over which processes operate in a particular environment. The results also indicate that a relatively low level of temporal resolution will be acceptable for some catchments.

6.6 CONCLUDING REMARKS ABOUT THE RESULTS AFTER INDIVIDUAL CATCHMENT CALIBRATION

Although the calibration results have been able to provide some of the answers to the questions posed in section 5.1.4, not all of them can be answered without a degree of uncertainty. This uncertainty is caused by a number of different factors. Uncertainty in defining parameter sensitivity is related to variations between catchments and storm types such that general statements on sensitivity are difficult to make. Uncertainties about the comparative performance of the models are related to the differences in the calibration procedures and can only be resolved after further evaluations of the models capabilities. This conclusion highlights the fairly commonly held belief that even simple models can appear to perform satisfactorily under calibration conditions. The uncertainties about the comparative performance of the lumped and semi-distributed model versions appear to be at least partly a result of uncertainties in the accuracy of the input rainfall data. The authors are forced to admit that the impossibility of satisfactorily defining spatially distributed rainfall input for many of the storm events presents a serious limitation to a comparison of some of the model results. However, this is a common problem (although not always emphasised enough) experienced when attempting to assess modelling approaches using real data.

Figure 6.1 Distributions of goodness of fit statistics for the lumped and semi-distributed versions of models OSE1, 2 and 3, grouped by storm type (A, B and C).

Key to the following 6 pages of computer plots.

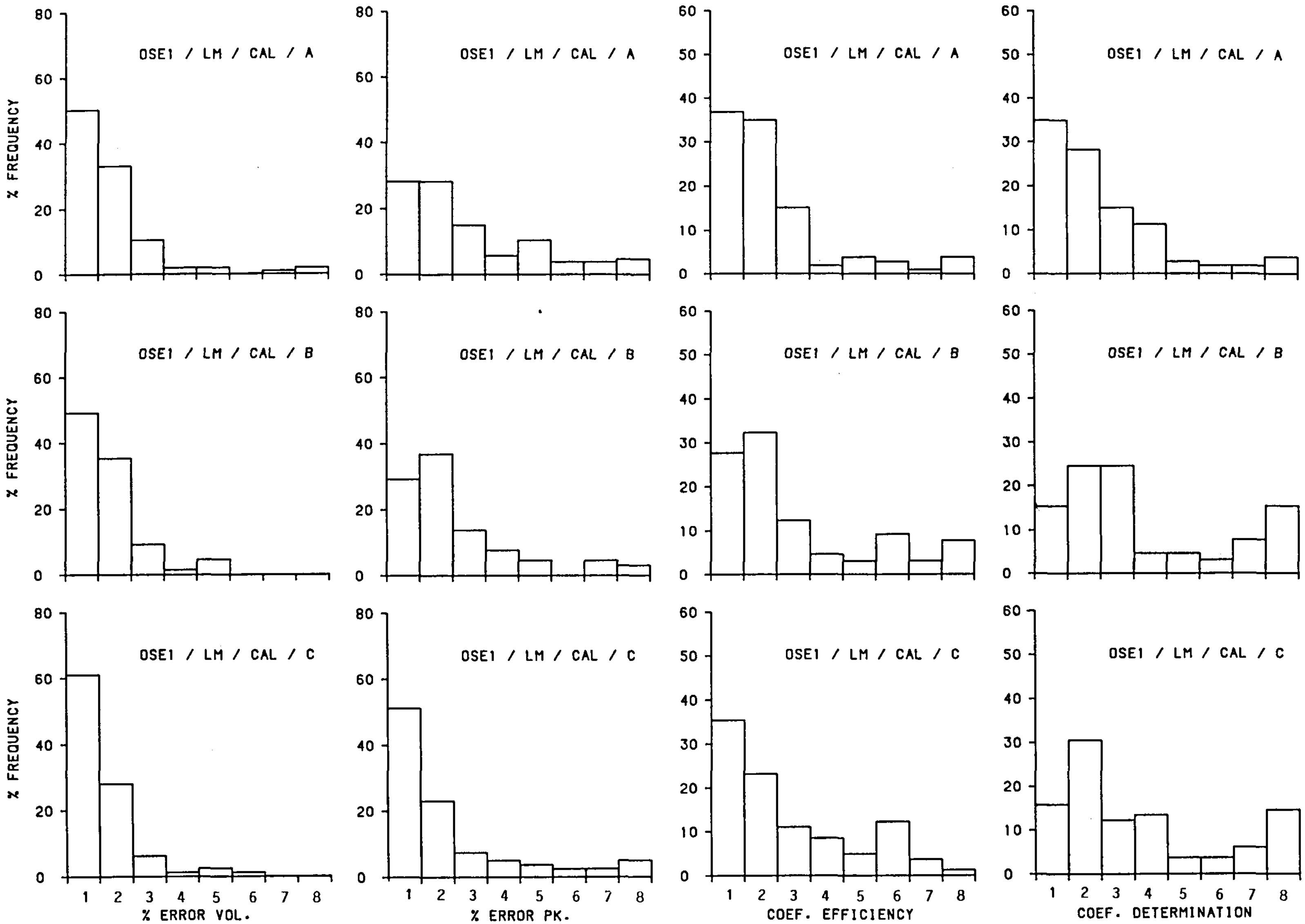
Each histogram is labelled with a four part code

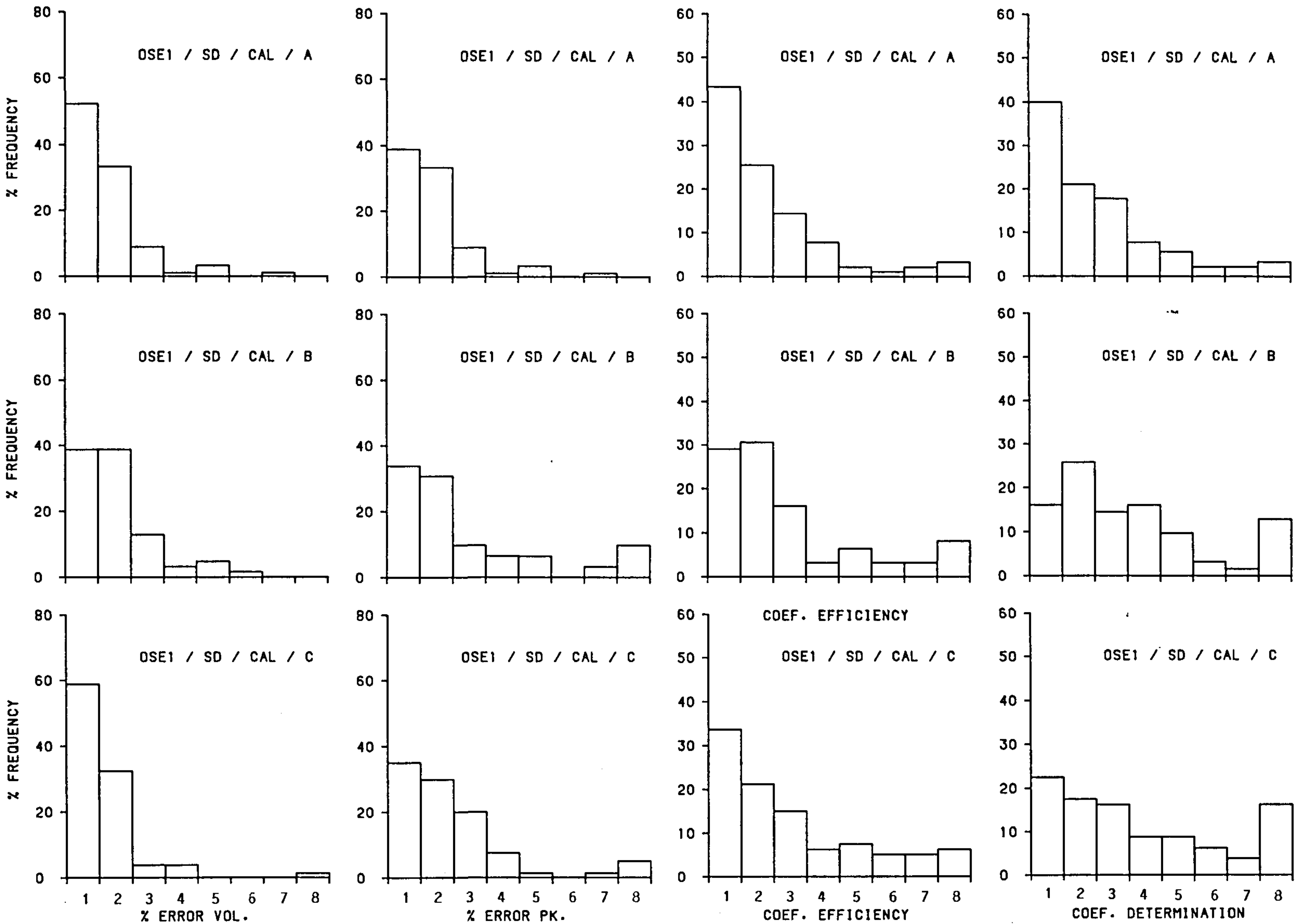
Model name / Lumped or semi-dist. / Calibration or validation / Storm type.

The eight histogram categories are as follows.

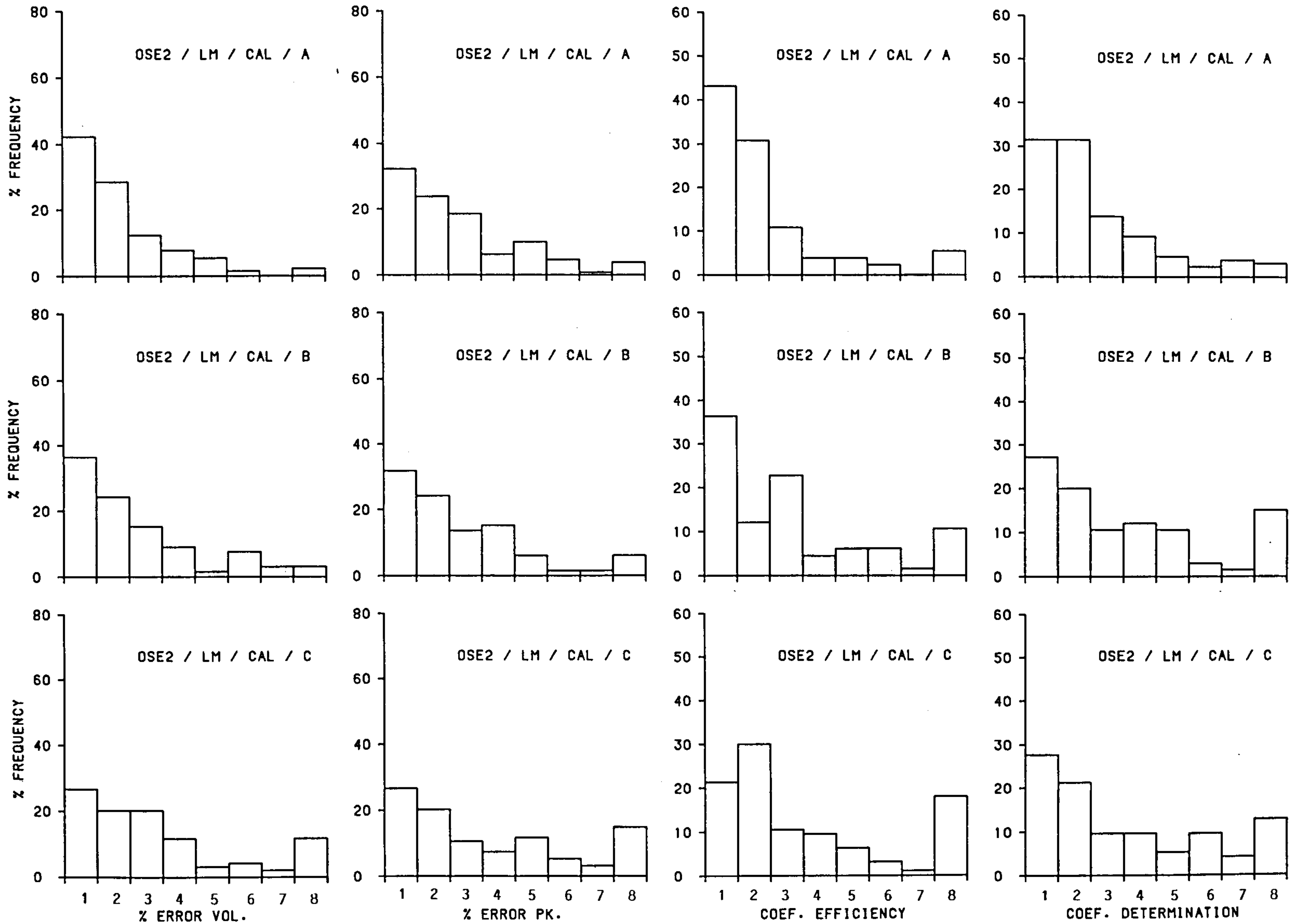
HISTOGRAM CATEGORY	GOODNESS OF FIT STATISTIC		
	ABSOLUTE % ERRORS IN	COEFFICIENTS OF	
	VOLUME AND PEAK	EFFICIENCY	DETERMINATION
1	0 to 10	1,0 to 0,8	1,0 to 0,9
2	10 to 20	0,8 to 0,6	0,9 to 0,8
3	20 to 30	0,6 to 0,4	0,8 to 0,7
4	30 to 40	0,4 to 0,2	0,7 to 0,6
5	40 to 50	0,2 to 0,0	0,6 to 0,5
6	50 to 60	0,0 to -0,2	0,5 to 0,4
7	60 to 70	-0,2 to -0,4	0,4 to 0,3
8	>70	<-0,4	<0,3

OSE1 Lumped calibration results.

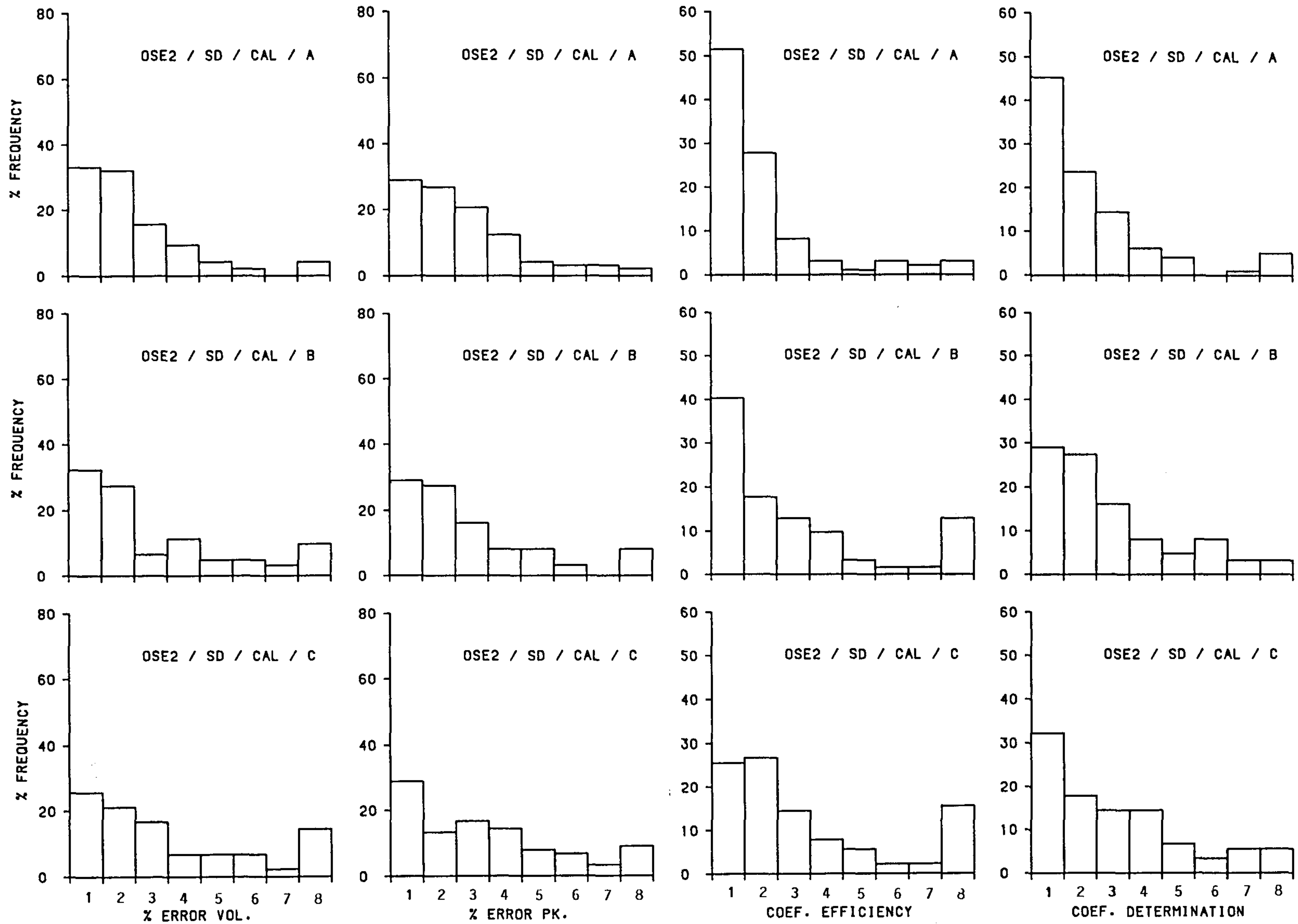




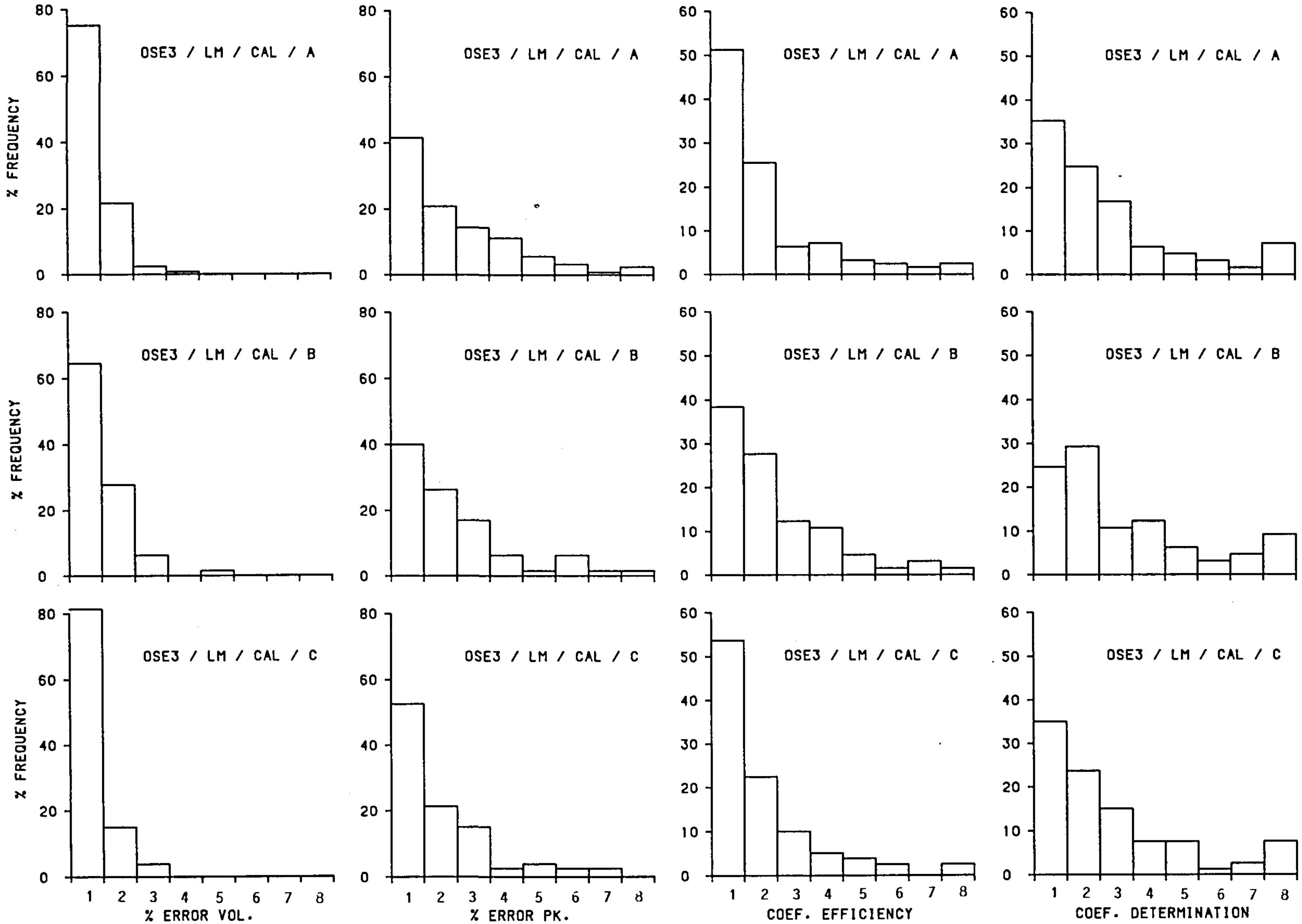
OSE1 Semi-distributed calibration results.



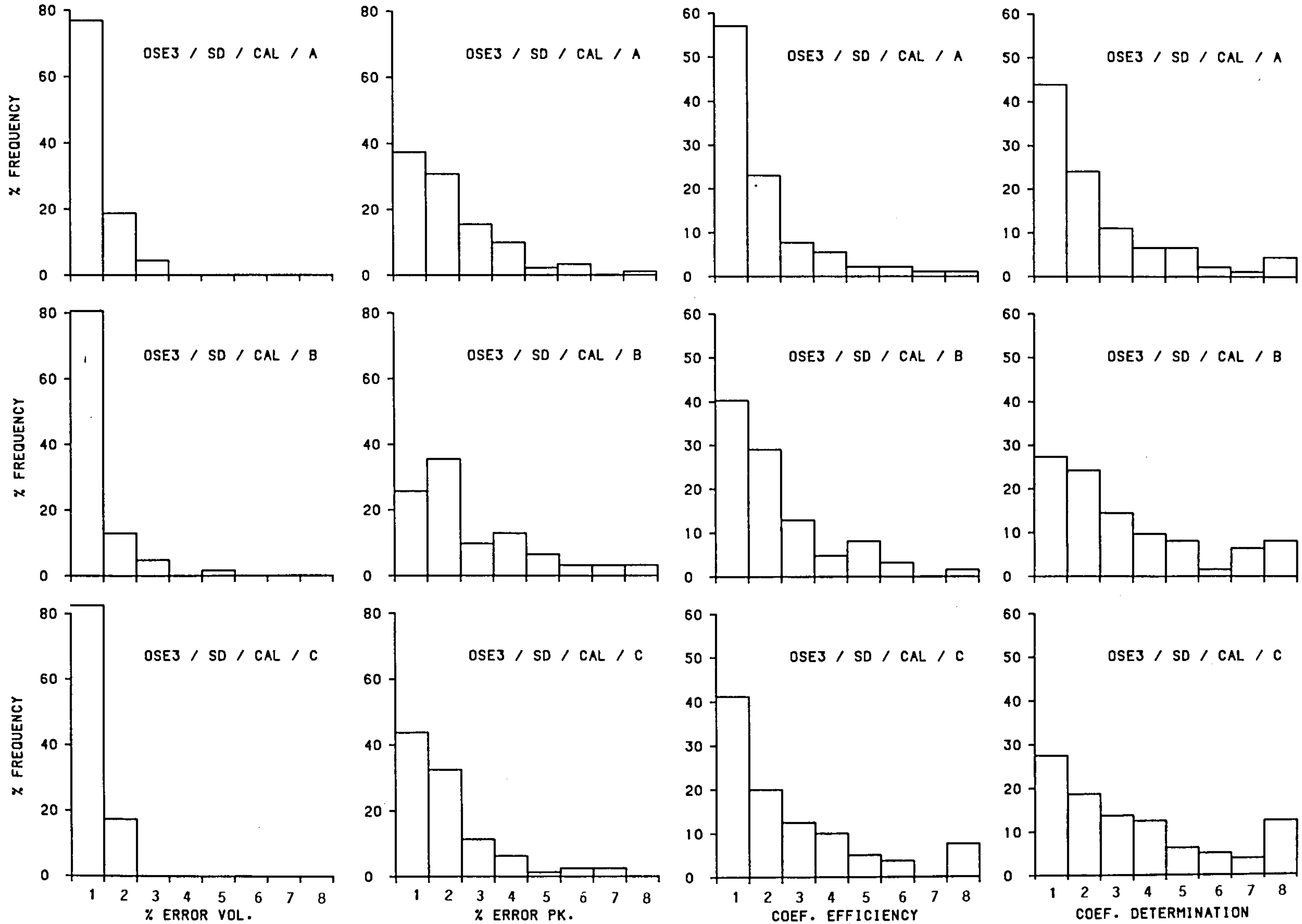
OSE2 Lumped calibration results.



OSE2 Semi-distributed calibration results.



OSE3 Lumped calibration results.



OSE3 Semi-distributed calibration results.

Chapter 7

THE DEVELOPMENT OF RELATIONSHIPS BETWEEN PARAMETER VALUES AND CATCHMENT CHARACTERISTICS

This chapter reports the results of the third stage of the complete investigation in which an attempt was made to derive relationships between the model parameter values obtained by calibration on individual catchments and physical properties of these catchments. The background to this part of the study is discussed in chapter 5, section 5.2 where the way in which the physical characteristics were quantified is also discussed. This part of the study is confined to using the calibration results of the semi-distributed versions of OSE1, 2 and 3. Estimated values of the physical characteristic variables for the sub-areas of each catchment are given in appendix B while the equivalent parameter values for the three models are given in appendix C. It should be noted that the values for parameter C in OSE1 and ROP in OSE3 are average sub-area values for the range of storm events used. The values of these parameters could not be fixed for all storms on the same sub-areas and the derivation of relationships between the storm-dependent parameter weightings (applied to the average values given in appendix C to obtain actual parameter values) and storm characteristics are discussed later in this chapter.

It was recognised during the early phases of this stage of the investigation that developing relationships by a multiple regression approach whereby variables are included or excluded on the basis of some statistical criterion would not produce the best results. This is partly due to the type of equations that would be produced by such a technique, partly by the time taken to explore a wide variety of possible variable transformations (involving both single and combined variables) and partly by the problem of outliers obscuring otherwise strong general trends in the relationships. The latter prompted a technique dominated by visual assessment of graphical plots backed up by the calculation of the square of the least squares regression coefficient (R^2=Coefficient of determination) for different sub-sets of the data. A micro-computer program was developed to enable the authors to interactively set the form of the equation, plot the resulting relationship on the screen and optionally calculate the R^2 value and the parameters of the equation. Once the form of the equation is set, different sub-sets of the data can be viewed seperately. Similarly, the program allows the form of the equation to be changed easily and rapidly and the new results plotted. The format of the equations allowed in the program is :

$$Y = A*X + B$$

where Y = Transformed or untransformed model parameter.
X = Single physical variable or combination of variables with or without transformation.
B = Constant.

Clearly once the form of X and Y are determined, the equation becomes a simple linear regression equation for which the calculation of R^2 and the parameters A and B is trivial. The advantage is that individual variables used to create the X values can be given different transformations or weights and can be combined in many different ways. A further advantage is that if the graphical plot indicates a non-linear trend then additional transformations of either X or Y can be imposed. The authors do not claim that such a technique could not be achieved using any of the standard statistical packages available for micro or mainframe computers. However, the main advantage of this technique is that a large number of possible variable combinations can be assessed rapidly with a minimum of effort in terms of data file editing. This is an important advantage given the very large number of possible combinations of variables and transformations that could produce useful relationships. In practice, the number of combinations tested were limited by including only those variables that were considered to be conceptually associated with the parameters.

The results are discussed for each model in turn and illustrated using the graphical plots given in the figures of this chapter and summarised in the tables. The relationships for the parameters of OSE2 are presented first as there are no complications associated with changes in values due to storm characteristics.

7.1 PARAMETERS OF MODEL OSE2

Figures 7.1 to 7.3 graphically illustrate the relationships for 9 of the semi-distributed parameters of OSE2, while table 7.1 lists the formats of the transformation variables and a few summary comments on the nature of the relationships.

7.1.1 Parameter CDEL

Initially this parameter was plotted against the single variable TC (time of concentration). A set of approximately straight line relationships for different areas resulted, but with no single trend present. An attempt was made to correct TC to account for the different conditions present in the data. Once such attempt (TC * VEG/ENERGY) represented a form of aridity correction and is shown in figure 7.1 (top left). While the number of trends is reduced there is still no general relationship that could be considered applicable to all areas. A consideration of the channel conditions prevailing in the various catchments suggested the later addition of a further physical variable to account for channel roughness. In this context, roughness includes all those factors which prohibit the rapid movement of a body of water through a channel reach. It can therefore include the effects of farm dams, conservation structures, in-channel and riparian vegetation as well as the more conventional channel roughness factors such as the short distance variations in width and depth and the degree of channel meandering. As with many of the other physical variables, the values have well defined channels without restrictive vegetation and have been assigned to each catchment on an ordinal scale of measurement between 1 and 10. The Tombstone catchments have been assigned a value of 2. At the other end of the scale, the Ecca channels are less well defined with great variations in width and depth over short lengths and even at moderate flow levels are restricted by in-channel bushes and trees. Some of the other catchments (Bethlehem and De Hoek especially) have been assigned relatively high values due to the incidence of conservation structures, farm dams and shallow natural ponds or vleis. The values of ROUGH for all the catchments are given in appendix B and it should be noted that no attempt was made to vary the ROUGH variable for sub-areas due to a lack of available detailed information on channel characteristics. The relationship between CDEL and TC * ROUGH is illustrated in figure 7.3 and the coefficient of determination is 0,92.

7.1.2 Parameter KC

This parameter represents the degree of attenuation in the channel reach between sub-area nodes or centres. It is logical that it should be related to the length of that channel reach (CDIST) as well as the dimensions of the channel. A surrogate measure of channel dimension has been used and that is the channel order (Shreve order - variable ORD1). The combination of variables giving the best overall trend for all the data is CDIST + Log (ORD1) and is illustrated in figure 7.1 (top right). Some of the scatter in the relationship may be related to some of the effects referred to in the previous section that will have an influence on the attenuation as well as the speed of movement of a flood wave. The model results are relatively insensitive to changes in KC within the range of values used and therefore the degree of scatter present in the relationship may not be seriously restrictive with respect to its use as a prediction tool.

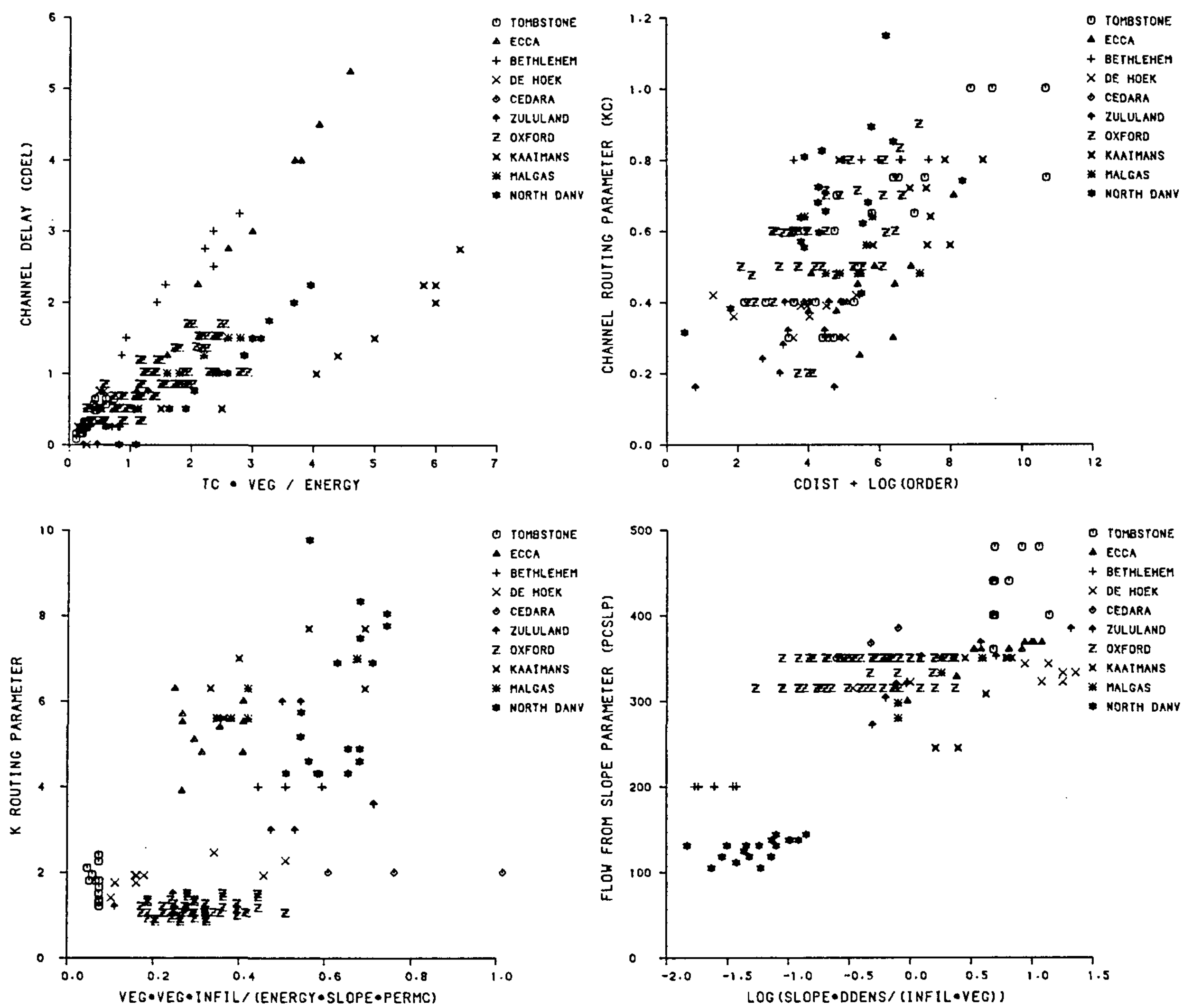


Figure 7.1 Plots of parameter - catchment variable relationships for CDEL, KC, K and PCSLP parameters of OSE2.

7.1.3 Parameter K

This parameter controls the degree of attenuation in the land phase of the flow routing component. The importance of different physical variables largely depends upon the runoff generation processes prevailing in each catchment. This is especially true if some catchments are dominated by surface runoff processes and others by sub-surface processes. To try and account for these in a general equation is difficult. The equation given in table 7.1 and the resulting plot in figure 7.1 (lower left) is the attempt that gave the best overall trend. The inclusion of SLOPE is self explanatory, while vegetation cover is also likely to be important if surface runoff (in any form) prevails. Low infiltration rates, exacerbated by sparse vegetation and the possibility of surface crusting (Berndtsson and Larson, 1987) could be indicative of surface runoff and low attenuation while higher rates may be more indicative of the presence of an important sub-surface flow component and higher degrees of attenuation. The inclusion of the ENERGY variable was found to be useful and possibly reflects the occurrence of high intensity rainfalls promoting greater proportions of surface runoff and decreasing attenuation. The division by PERMC is possibly a reflection of lower attenuation for sub-surface flow environments with high soil permeability characteristics. There is a great deal of scatter in the relationship and in particular the Oxford and Cedara values appear to be anomalous.

7.1.4 Parameter PCSLP

This parameter controls the rate at which the proportion of rain that does not contribute to runoff in the same time period is added to the catchment slope moisture store. For most catchments the value was kept constant for different sub-areas and this is reflected in the horizontal trend of data points shown in figure 7.1 (lower right). There is nevertheless a relatively good general trend with the natural logarithm transformed combination of four variables (table 7.1). The inclusion of SLOPE is once again self explanatory, while the use of DDENS reflects the distance over which water falling on hillsides has to travel to reach the moisture storage which is assumed to be concentrated close to the river channels. The INFIL * VEG divisor is once again an attempt to account for differences in the dominance of either surface or sub-surface processes controlling the movement of moisture on slopes.

7.1.5 Parameter SMAX

The simplest variable combination designed to account for variations in the maximum soil moisture capacity parameter is DEPTH * WHCAP. Figure 7.2 (top left) illustrates that further variables or transformations appear to be unnecessary as there is a strong relationship. Some of the vertical line trends can be ascribed to the fact that the values of these two physical variables were only approximately estimated and therefore there is little variation in sub-area values.

7.1.6 Parameter DA

The derivation of relationships for the two S-curve parameters DA and C proved to be the most difficult. This is partly related to the difficulty of defining the associations of these parameters with physical characteristics. Higher values of DA, for a given value of C represent a more rapid rate of increase in the conceptual variable source area at low relative moisture states. Variables which affect the spatial location of areas of surface saturation might be expected to be important. However, it is not easy to identify which of the variables described in section 5.2 should be involved. The variable SL/V was specifically evaluated for this purpose, while SLOPE, DEPTH and PERMC of the equation reflects the conditions that catchments with higher slopes, shallow soils and poor drainage (LOW PERMC) will have more rapidly expanding source areas. The equation also suggests that this will be the case for catchments where the distribution of soil depth is more evenly spread between the slopes and valley bottoms.

7.1.7 S-curve area approximation (SCA)

No acceptable relationship could be derived for parameter C and therefore a new variable was created which represents a simple approximation of the area under the S-curve. The variable SCA (S-curve area approximation) is defined by the areas of two triangles (co-ordinates 0,0: C,0: C,DA and C,DA: 1,DA: 1,1) and one rectangle (co-ordinates C,0: 1,0: 1,DA: C,DA) lying below the S-curve. The areas of these three components are;

lower triangle; (C x DA)/2
upper triangle; (1-C) x (1-DA)/2
rectangle; (1-C) * DA

Combining these areas gives the equation for SCA as

$$SCA = (1 + DA - C)/2$$

It is clear that if DA and SCA can be estimated then a value for C can also be obtained. The comments about trying to find a suitable relationship for DA are equally valid for the SCA variable. Figure 7.2 (lower left) and table 7.1 respectively illustrate the final result and give the format of the selected equation.

7.1.8 Parameter IAF

The format of the prediction equation derived for IAF is given in table 7.1 and is effectively a combination of a slope factor (SLOPE), an infiltration factor weighted with vegetation cover to account in some way for the likelihood of raindrop impact crusting (INFIL*VEG), a vegetation cover factor (VEG^2) and an energy factor. The energy factor is likely to reflect the fact that the higher energy areas experience higher intensity rainfalls. There is no obvious reason why energy should otherwise directly affect intensity controlled runoff generation. The resulting relationship demonstrates a strong trend (figure 7.2, lower right) but with a relatively high degree of scatter amongst the low values. The existence of this scatter is unlikely to be a serious impediment to the usefulness of the relationship for predictive purposes as the model is relatively insensitive to low IAF values, particularly when prevailing rainfall intensities are low.

7.1.9 Parameter APF

Within the model the nominal APF value is reduced by 0,05 for summer (October to March in the southern hemisphere) events. The values used to derive a relationship for this parameter reflect the dominant flood event season for each area. For example, all the Tombstone and Bethlehem storms are summer events while the majority of the large events in the southern Cape are in the winter period. The two variables referred to in table 7.1 and figure 7.3 were chosen to represent an evapotranspiration component and a drainage component. The general trend of decreasing APF values with increases in the value of the combined variable is marred by the Cedara and Tombstone results. The Tombstone simulations are primarily affected by rainfall intensity and the IAF parameter and therefore changes to the value of APF is likely to have a relatively minor effect.

7.1.10 Other parameters of OSE2

No attempt was made to derive relationships for PCVSA because this parameter has a minor effect on the simulation results and the variations in the calibrated values are very small. The remaining parameter, CLOSS is much more important for some catchments, although the importance is confined to relatively low catchment moisture levels. Unfortunately, no sensible relationships could be derived for the channel loss parameter as all the combinations of physical variables that were tested, showed no general trends. This could be due to the fact that none of the physical variables referred to in section 5.2 is relevant to the processes involved.

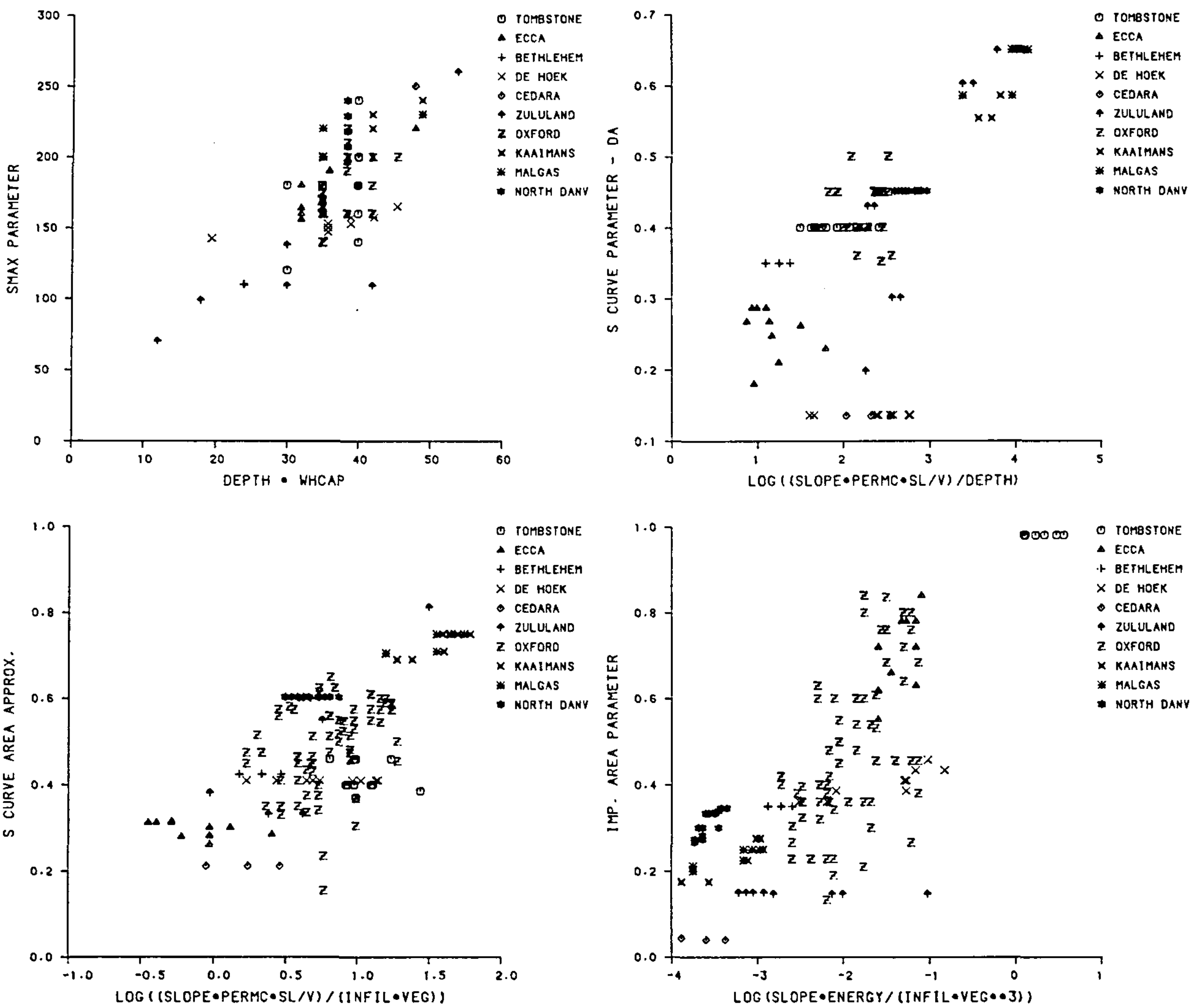
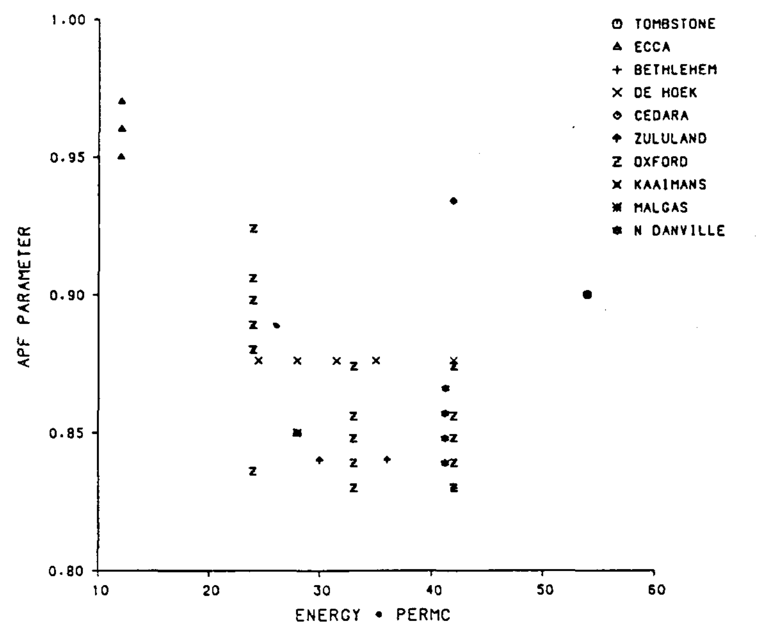


Figure 7.2 Plots of parameter - catchment variable relationships for SMAX, DA, SCA and IAF parameters of OSE2.



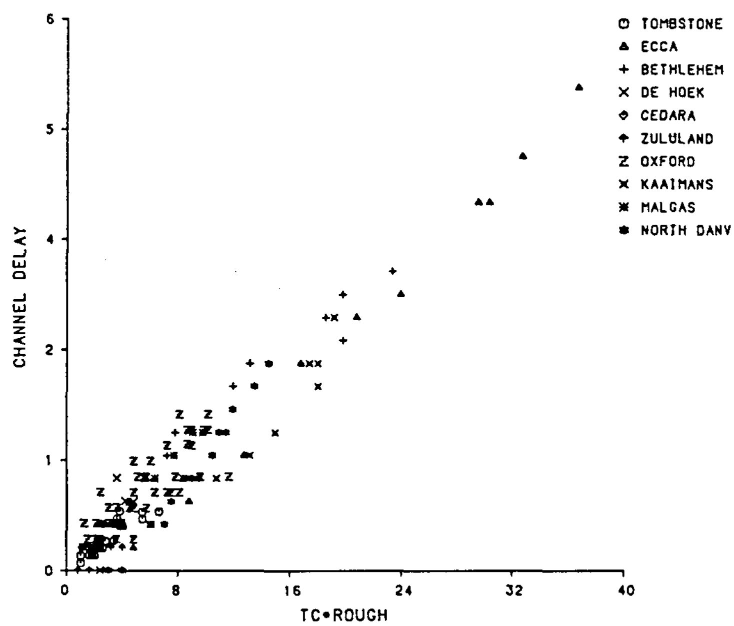


Figure 7.3 Plots of parameter - catchment variable relationships for CDEL and APF parameters of OSE2.

Table 7.1 Derived equations relating model OSE2 parameters with catchment characteristics

Model parameter	Format of the transformation variable and comments on the initial relationships
CDEL	TC - Good relationships for individual areas but no generally applicable relationship.
CDEL	TC * VEG/ENERGY - Reduces the number of trends but still no generally applicable relationship.
CDEL	TC * ROUGH - Excellent relationship with an R^2 value of 0,92.
KC	CDIST + Log (ORD1) - Moderate degree of scatter but all catchments conform to a general trend.
K	VEG^2 * INFIL/(ENERGY * SLOPE * PERMC) - High degree of scatter. Oxford & Cedara catchments have low values lying off the general trend.
PCSLP	log (SLOPE * DDENS/(INFIL * VEG)) - Good general trend with scatter caused largely by the fact that constant values were used for most sub-areas on the same catchment.
SMAX	DEPTH * WHCAP - Relatively small amount of scatter.
DA	Log (SLOPE * PERMC * SL/V/DEPTH)) - Strong general trend except for De Hoek, Cedara and some Zululand sub-areas.
SCA*[1]	Log (SLOPE * PERMC * SL/V/(INFIL * VEG)) - Comments similar to these made for DA.
IAF	Log (SLOPE * ENERGY/(INFIL * VEG^3)) - Good general trend but with a lot of scatter close to the origin.
APF	ENERGY * PERMC - High degree of scatter caused partly by variations in sub-area parameters but little or no variations in sub-area physical variable values.

*[1] SCA = S-curve area approximation = (1 + DA - C)/2

7.2 PARAMETERS OF MODEL OSE1

Figure 7.4 graphically illustrates some of the relationships for 4 of the semi-distributed parameters of OSE1. The routing parameters common to this model and OSE2 have almost identical relationships as those derived for OSE2 and need not be repeated. Table 7.2 lists the formats of the transformations combining the physical and storm characteristic variables.

7.2.1 Routing parameters of OSE1 (CDEL, K and KC)
These have exactly the same conceptual meaning and very much the same values as for model OSE2. The format of the transformation variables is identical and the comments made in sections 7.1.1 to 7.1.3 are equally applicable to this model.

7.2.2 SMAX parameter
The relationship plotted in figure 7.4 (top left) is very similar to the equivalent graph of figure 7.2 and no further comments are necessary for this model.

7.2.3 DA parameter
The combination of variables producing the best relationship (figure 7.4, top right) with this DA parameter is similar to that derived for OSE2 but without the division by DEPTH. The differences with and without DEPTH were, however, marginal. There is a higher degree of scatter in the relationship for OSE1's DA, partly as a result of the little variation allowed in the values of this parameter for different sub-areas on the same catchment during calibration.

7.2.4 S-curve area approximation (SCA)
This combination of two parameters includes C which was allowed to change for different storm characteristics on the same catchment. The values plotted are therefore average values for each sub-area (figure 7.4, lower left). The relationship between the individual event weighting factors and storm characteristics will be presented and discussed in section 7.2.6 below. The format of the combination of variables (table 7.2) is the same as for OSE2.

7.2.5 APF parameter
A similar general trend as for the equivalent OSE2 parameter is evident in figure 7.4 (lower right) but with a higher degree of scatter.

7.2.6 C parameter versus storm characteristics
Some of the relationships between the individual event weighting factors of parameter C and storm characteristics are illustrated in figure 7.5. Table 7.2 lists the equations relevant to the different catchment areas. The first notable characteristic of figure 7.5 is the high degree of scatter present in all the relationships. It is in fact difficult to recognise trends in the plots for all the separate catchments. The solid lines drawn on the plots are the least squares best fit lines and no lines have been drawn for Bethlehem and Cedara because the calculated best fit slopes are positive. This implies increasing C (and therefore decreasing runoff proportion) with increasing total rain and duration which makes little hydrological sense. Some of the other relationships are hardly an improvement on this situation and are unlikely to be of great value from the point of view of predicting C values for other storms. The use of different storm indices did not produce any better results. The Tombstone catchments were the only ones for which the inclusion of the maximum intensity variable reduced the degree of scatter. The figures indicate that the majority of the relationships, as well as being very weak, are also unique to individual catchments. It is therefore

difficult to imagine how such results could be extrapolated to ungauged catchments with any success. This point is further discussed in the next chapter.

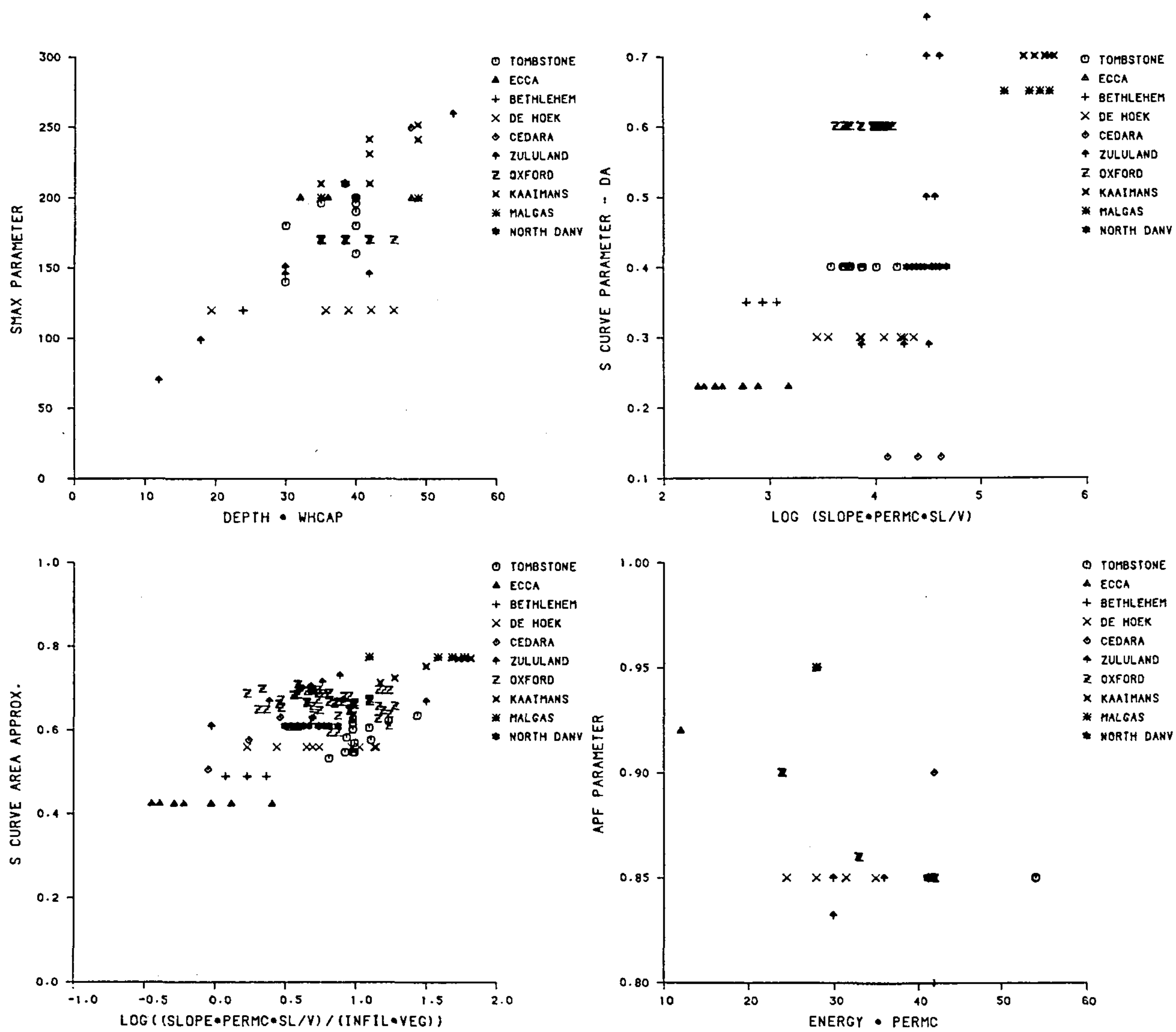


Figure 7.4 Plots of parameter - catchment variable relationships for SMAX, DA, SCA and APF parameters of OSE1.

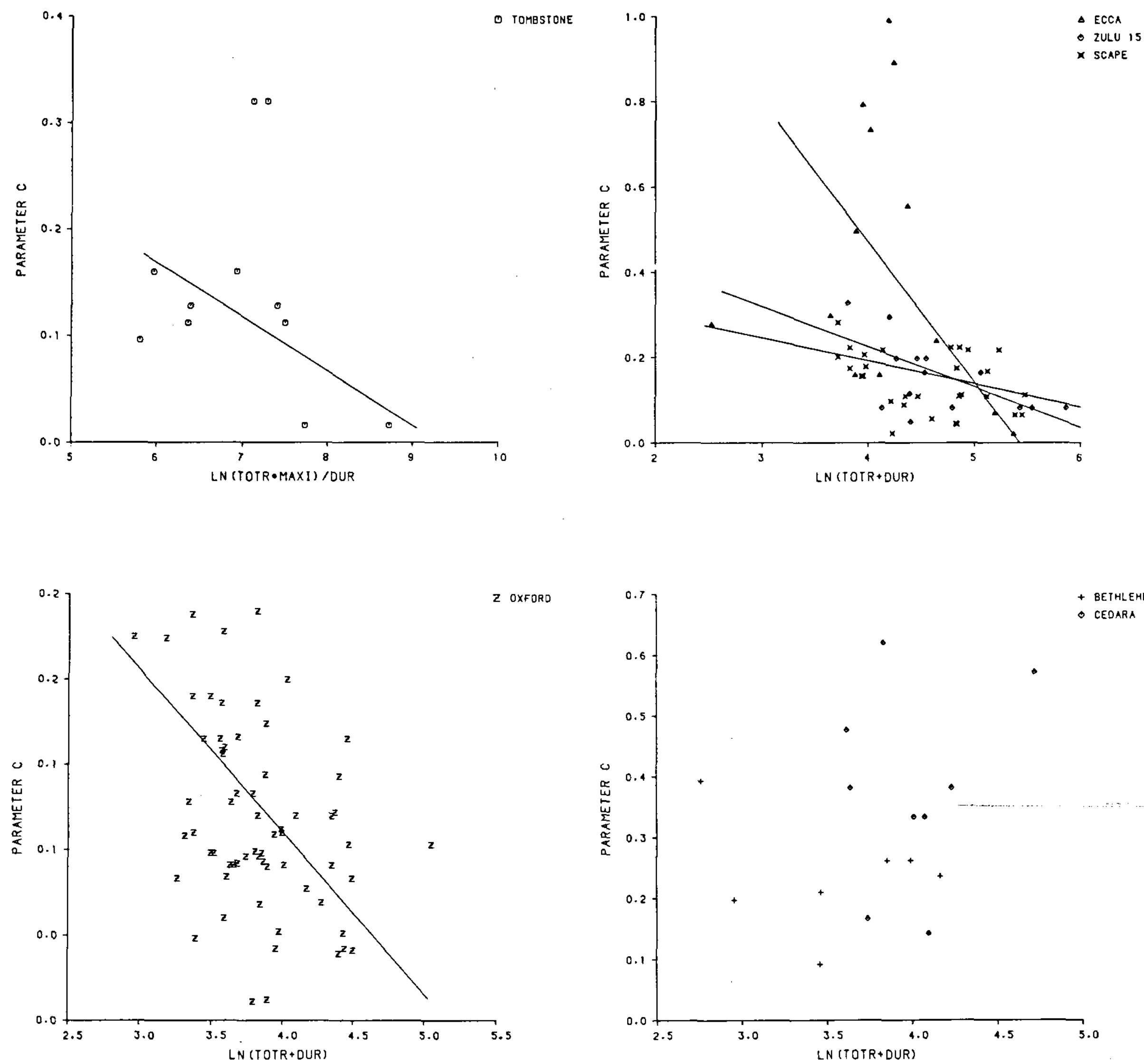


Figure 7.5 Plots of parameter - storm variables for the individual event weighting factors for parameter C of OSE1.

Table 7.2 Derived equations relating model OSE1 parameters with catchment and storm characteristics.

Model Parameter	*Format of the transformation variable and comments on the initial relationships.*
CDEL	TC * ROUGH - Almost identical parameter values as for model OSE2 and therefore similarly good relationship.
KC	CDIST + Log (ORD1) - similar to OSE2.
K	VEG^2 * INFIL/(ENERGY * SLOPE) - Similar to OSE2.
SMAX	DEPTH * WHCAP - Similar to OSE2.
DA	Log (SLOPE * PERMC * SL/V) - A general trend is present but the scatter is very great.
SCA	Log ((SLOPE * PERMC * SL/V)/(INFIL * VEG)) - A general trend is present but with a moderately high degree of scatter. Values plotted are based on average C values for all storms on the catchment.
APF	ENERGY * PERMC - Similar to OSE2 but more scatter.
C (Storm	Log (TOTR * MAXI/DUR) - Applicable to Tombstone and De Hoek catchments.
Weights)	Log (TOTR * MAXI/DUR) - Applicable to Ecca, Zululand, Oxford, southern Cape and North Danville catchments.
	- No relationship possible for Bethlehem & Cedara.

SCA = S-curve area approximation = (1 + DA - C)/2

TOTR = Total storm rainfall (mm)

MAXI = Maximum intensity over model time interval (mm hr^{-1})

DUR = Total rainfall duration (hr)

7.3 PARAMETERS OF MODEL OSE3

Figure 7.6 illustrates two of the relationships between OSE3 parameters and catchment characteristics. The channel delay (CDEL) values used for this model were almost identical to these used for OSE2 and the relationship shown in figure 7.3 is applicable. Table 7.3 lists the formats of the transformations combining the catchment and storm characteristics that have been used in the relationships.

7.3.1 Routing parameters of OSE3 (CDEL, K and KC)

The relationships for these parameters of OSE3 have been derived using the same combinations of variables as in OSE1 and 2. The CDEL values used for all models were identical but figure 7.6 illustrates that the amount of scatter in the relationships for K and KC is somewhat greater than for the other two models. The same variable combinations have been used as in OSE1 and 2 as no general improvement was possible using different combinations.

7.3.2 Runoff proportion (ROP) parameter of OSE3

Unlike OSE1, no combination of physical catchment variables produced a relationship for which even a general trend could be identified. Consequently, the relationships for ROP are totally based upon storm characteristics. As the storm characteristic values were only calculated on a total catchment basis, no sub-area variations in ROP were allowed for in the model. This effectively reduces OSE3 to a lumped volume conversion model with a semi-distributed routing component.

The relationships are illustrated in figures 7.7 and 7.8 where it can be seen that not only are different combinations of storm variables applicable to different catchments but also the slope of the relationships are highly variable. Linear least squares best fit lines have been included in the figures more to highlight the general trends (and the differences between catchments) than for any other reason. The inclusion of the maximum intensity variable for the Tombstone and Bethlehem catchments reflects the importance of intensity variations between events when the prevailing storms are of short duration. Its inclusion for the other catchments did not reduce the degree of scatter in the relationships. The use of the amount of rain falling during the first half of the storm duration (TOTR*2QT/100) for the southern Cape catchments, possibly reflects the fact that these storms are of long duration. For most flood events with high rainfall amounts, the proportion falling at the end of the storm on a wet catchment might be expected to have less influence on the overall runoff proportion than the quantity of rain falling during the earlier part of the storm. The linear trends suggested by the solid lines in figure 7.7 (lower) are probably misleading (note the incercept on the ROP axis at storm variable = 0). A curvilinear relationship horizontally asymptotic at a runoff proportion close to 0,9 is probably more realistic. It should be stressed that for all the relationships, extrapolation of the trend lines beyond the data points is not recommended. For the remainder of the catchments a combination variable defined by TOTR + 30 day API (using a fixed decay constant of 0,9) appears to be the most applicable (figure 7.8). Some of the relationships exhibit a relatively low degree of scatter (De Hoek, Cedara and North Danville) while others, such as the winter Oxford events, are very scattered. Close to the origin, the De Hoek and Zululand relationships appear to be very similar and it is only the three high rainfall events on Zululand that prevent the slopes of the least squares best fit lines being similar. Once again a curvilinear relationship through the De Hoek and Zululand data points and horizontally asymptotic at an ROP of 0,7 to 0,8 is probably more realistic.

The Oxford catchments have been divided up by season into winter (Oxford W in figure 7.8, lower left), spring (SP) and summer (S). The visual trends of the three groups of data points are similar to the seasonal differences found between observed total storm rainfall and runoff (figure 4.11) which are discussed earlier in section 4.7 and attributed to variations in landuse and vegetation cover. However, the least squares best fit line through the winter data has a similar slope to the line for spring. This seems to be mainly a result of the wide scatter in the winter relationship.

Table 7.3 Derived equations relating model OSE3 parameters with catchment and storm characteristics.

Model Parameter	Format of the transformation variable and comments on the initial relationships.
CDEL	TC * ROUGH - Similar to OSE2.
KC	CDIST + Log (ORD1) - Great deal of scatter.
K	VEG^2 * INFIL/(ENERGY * SLOPE * PERMC) - Similar general trend to OSE2 but with somewhat more scatter.
ROP	TOTR * $(MAXI)^{0.5}$ + 30 day API - Applicable to Tombstone and Bethlehem catchments.
ROP	TOTR * 2QT)/100 + 30 day API - Applicable to southern Cape catchments.
ROP	TOTR + 30 day API - Applicable to Ecca, De Hoek, Cedara, Zululand, Oxford and North Danville catchments.
	There is a great variation in the degree of scatter as well as the slope of the relationships for ROP.

TOTR = Total storm rainfall (mm)

MAXI = Maximum intensity over model time interval (mm hr^{-1})

2QT = Percentage of total rain falling in the first half of the storm duration.

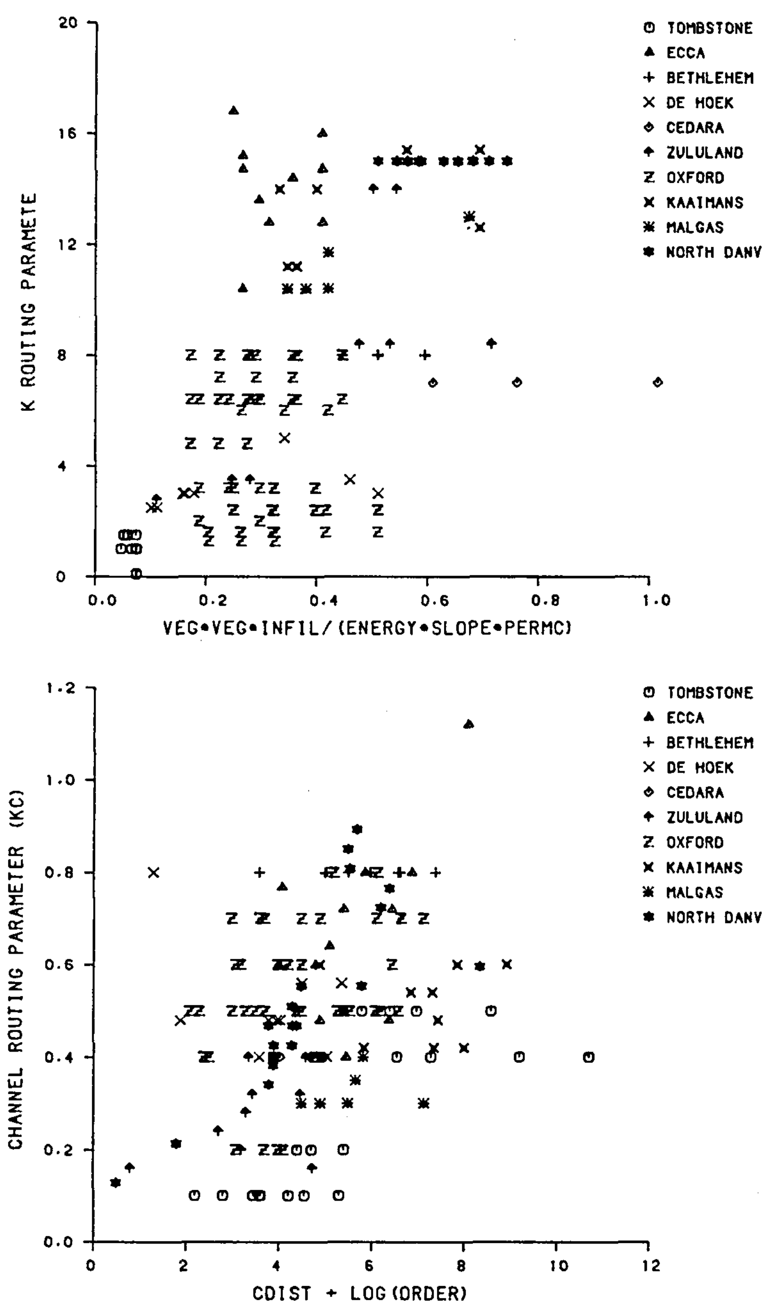


Figure 7.6 Plots of parameter - catchment variable relationships fo K and KC of OSE3.

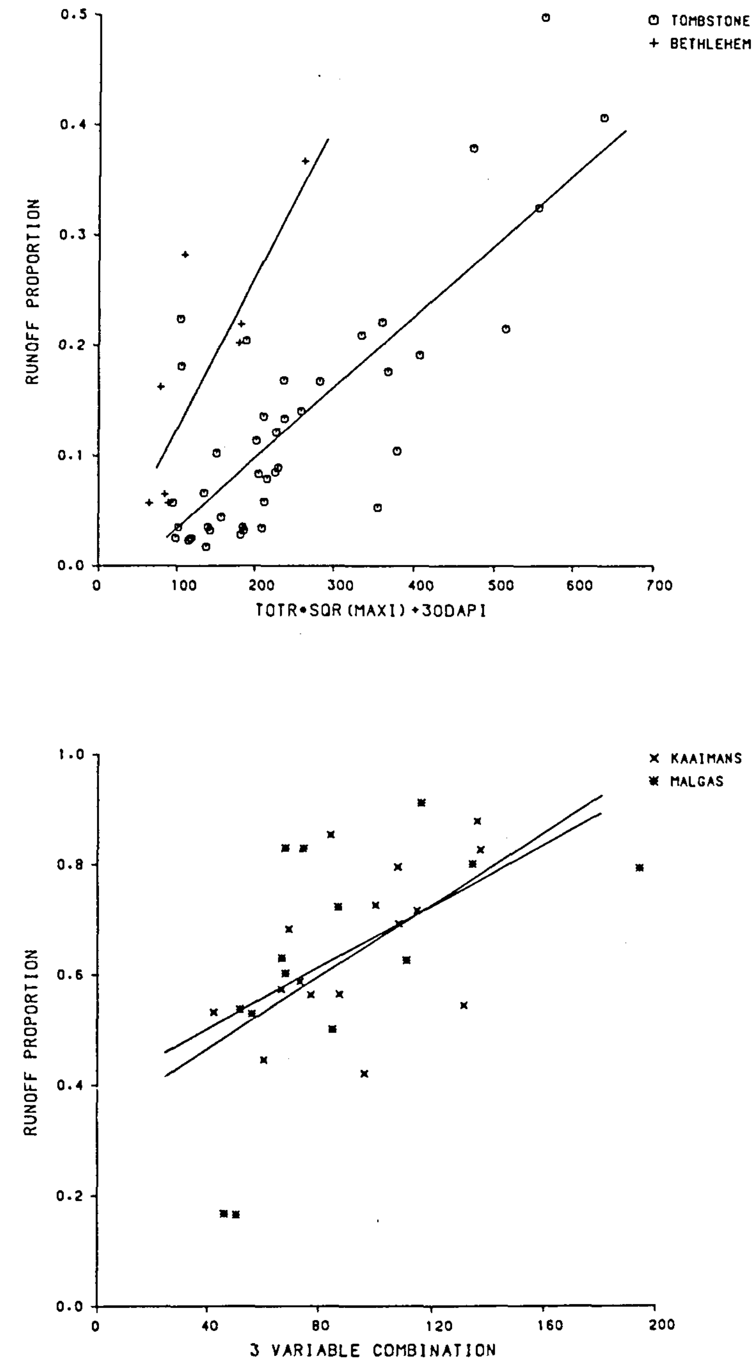
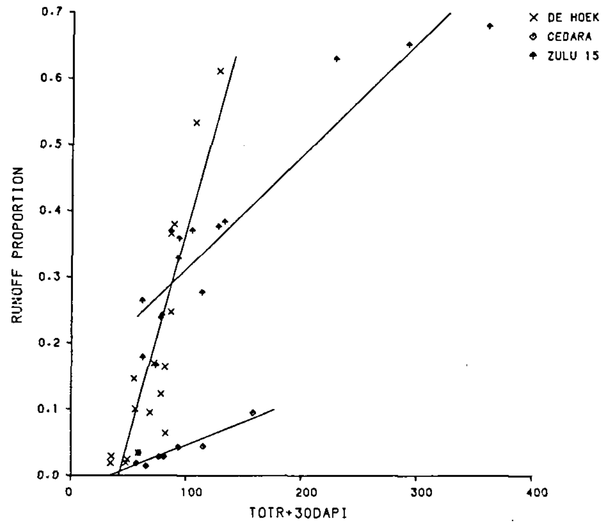
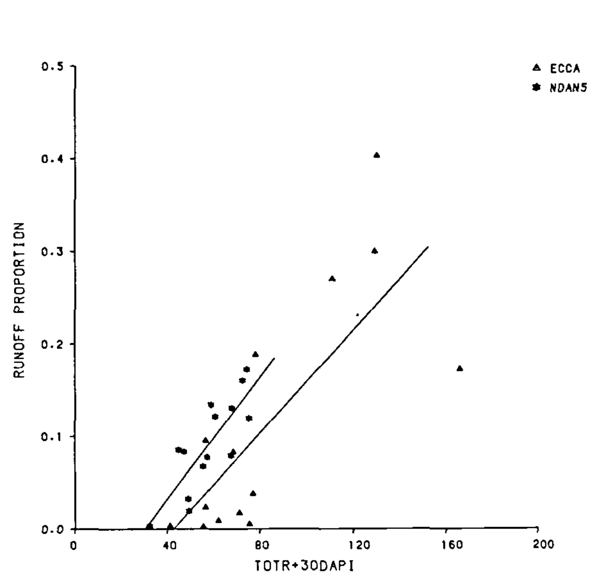


Figure 7.7 Plots of parameter - storm variable relationships for ROP of OSE3 (Tombstone, Bethlehem, Kaaimans and Malgas). Solid lines represent least squares best fit lines for the different data sets.





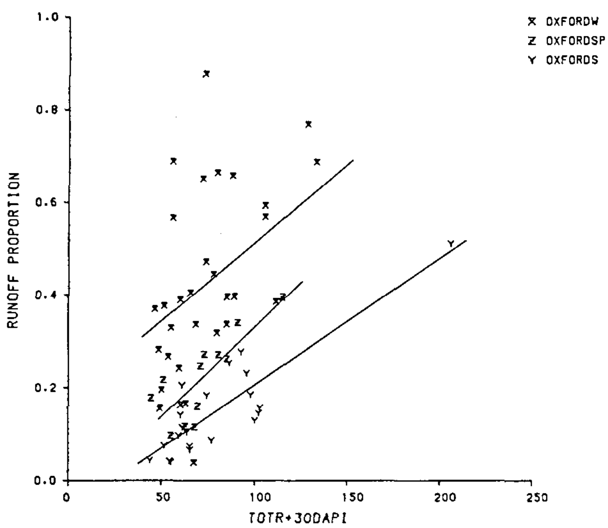


Figure 7.8 Plots of parameter - storm variable relationships for ROP of OSE3 (De Hoek, Cedara, Zululand, Ecca, North Danville and Ecca). Solid lines represent least squares best fit lines for the different data sets.

7.4 CONCLUSIONS ABOUT THE ATTEMPTS TO DEVELOP RELATIONSHIPS BETWEEN MODEL PARAMETER VALUES AND CATCHMENT OR STORM VARIABLES

The overall conclusion of this chapter is that the attempts to relate model parameter values to measureable indices of catchment characteristics has been relatively successful. Except for the CLOSS parameter, combinations of variables could be found which demonstrate approximate linear trends with the calibrated OSE2 parameter values for the sub-areas of the catchments. The degree of scatter in most of the relationships is not unexpected given the imprecision with which some of the physical variables have been quantified. It should also be remembered that the model is not a truly physically-based one and therefore exact relationships between physical variables and model parameters is highly unlikely. Similar comments are applicable to the routing parameters of the other two models as well as to most of the volume conversion parameters of OSE1.

The fact that no relationship could be derived for the event based weights of parameter C (OSE1) for some catchments represents a major drawback to the application of model OSE1 when calibration is not possible. A further limitation is that the nature of the relationships (and particularly the slopes) is different for individual catchments or groups of catchments. Extrapolation to ungauged catchments is therefore likely to meet with limited success. A similar conclusion can be applied to the results of developing relationships for ROP (OSE3). Although some of the relationships are quite good and may be useful for the estimation of ROP values for other events on the same catchments, the results give little guidance for extrapolation to other catchments.

Many readers will have noted that no statistics have been given to quantify the strengths or significance of the derived relationships. This is largely because the next chapter addresses this point in a way that is considered by the authors to be of greater value with respect to the application of the models and the estimation of parameter values. Chapter 8 discusses the results of stage four of the investigation in which linear trend lines (largely fitted by eye and ignoring outliers) are used to re-estimate new parameter values for the sub-areas of the catchments. The new parameter values are then used to simulate the storms again and these validation results compared with the original simulation results. Validation in this context refers to validation of the derived trend lines which relate parameter values to physical catchment and storm characteristics.

Chapter 8

VALIDATION OF THE RELATIONSHIPS DERIVED FOR THE ESTIMATION OF MODEL PARAMETERS AND THE EXTENSION TO FURTHER CATCHMENTS

This chapter discusses the final stage of the model testing investigation which was designed to assess the likely degree of success of applying the models to situations where calibration is not possible. Such situations may arise when it is desired to simulate a storm for which there is no experience but on a catchment where other observed storms offer the opportunity of carrying out some calibration. To a certain extent the likelihood of success of such an exercise has already been covered in this report. The so called calibration results for OSE2 have been obtained with a single set of parameter values for each catchment. Consequently, the same sort of results as illustrated in tables 6.1 and 6.2 and figure 6.1 can be expected, as long as the new storm to be simulated is not totally unlike those used to calibrate the model. If it is very different and the dominant processes of runoff generation and flow routing change, then the reliability of the results would be unpredictable.

The majority of applied modelling problems involve ungauged catchments or situations where some change to the characteristics of the catchment (landuse for example) means that existing observed data are unlikely to produce satisfactory model calibrations that are applicable to the changed conditions. In these situations the parameters have to be estimated by whatever means are available. The following sections discuss the results of using the relationships derived in the previous chapter to estimate the parameter values of the sub-areas of the catchments already used as well as a further four (two in the southern Cape, two in Oklahoma State, USA). The validation results are compared with the original calibration results and conclusions reached about the relative usefulness of the three models. Figure 8.1 uses histogram plots of distributions of the goodness of fit statistics to illustrate and compare the calibration and validation results for the semi-distributed versions of the three models. The data are grouped by storm type (A, B and C) and plotted in the same way as figure 6.1. The semi-distributed calibration histograms are included in figure 8.1 to facilitate comparison with the validation plots.

8.1 Model OSE2

Table 8.1 repeats the formats of the transformed combinations (X) of physical variables that are used in linear equations (Y = AX + B) to estimate the model parameter values (Y). The values for the slopes (A) and intercepts (B) are also given. Table 8.2 compares the mean values of the four goodness of fit statistics for the original calibrations simulations with the validation simulations for all the catchments. The validation statistics which have values close to or better than the originals are highlighted, demonstrating that at least some aspects of the simulations for many catchments have not deteriorated. Similarity of coefficient of determination values without equivalent similarity of the coefficients of efficiency does represent a deterioration but indicates that the increased error is a systematic one (i.e. the hydrograph shape may be satisfactory accompanied by general over or under prediction).

Some specific comments about the validation results for different catchments will serve to illustrate the usefulness of this model. The Tombstone validations are very similar to the calibrations with some storms being modelled comparitively well and others poorly. The relatively high standard deviations of the coefficient of efficiency is indicative of this effect. A similar situation occurs for the Ecca catchment but in this case there is a noticeable trend towards better simulations of the larger events and much poorer results for the smaller events. The overall coefficient of efficiency for all storms taken as a single set of data (i.e. allowing high flows to dominate the statistic) is 0,66 compared to the average of the individual storm values given in table 8.2 of -0,25. This difference indicates that the higher flows are more closely simulated than the lower flows. There is a relatively large deterioration in the Bethlehem results and this is due to general under-prediction of the flows using the parameters estimated from the relationships. This may be due to an error in estimating the index value of one of the physical characteristics or because the derived relationships are not truly applicable to the conditions prevailing in this catchment.

Table 8.1 Format of the equations for estimation of model OSE2 (semi-distributed) parameters.

Model Parameter	Format of the transfored combination	Linear equation parameter A	B
CDEL	TC * ROUGH	0,132	0,055
K	VEG^2 * INFIL/(ENERGY * SLOPE * PERMC)	6,93	0,799
KC	CDIST + Log (ORD1)	0,096	0,105
SMAX	DEPTH * WHCAP	4,6	12.0
DA	Log (SLOPE * PERMC * SL/V/DEPTH))	0,128	0,107
SCA	Log (SLOPE * PERMC * SL/V/(INFIL * VEG))	0,242	0,313
PCSLP	Log (SLOPE * DDENS/(INFIL * VEG))	84,4	305,0
IAF	Log (SLOPE * ENERGY/(INFIL * VEG^3))	0,181	0,840
APF	ENERGY * PERMC	-0,003	0,949

Parameter C = 1 + DA - 2*SCA model parameter values = A * combination variable + B

Table 8.2 Comparison of original and validation goodness of fit statistics for model OSE2

Catchment	No. of Storms	Original fit statistics % Errors Vol.	Original fit statistics % Errors Pk.	Original fit statistics Coefficients Eff.	Original fit statistics Coefficients Det.	Validation fit statistics % Errors Vol.	Validation fit statistics % Errors Pk.	Validation fit statistics Coefficents Eff.	Validation fit statistics Coefficents Det.
Tombstone	11	38	35	38	60	47	**36**	**37**	**66**
TM11		(27)	(28)	(55)	(31)	(49)	(19)	(65)	(27)
Tombstone	9	64	31	-04	48	87	39	**5**	**47**
TM8		(43)	(27)	(82)	(27)	(53)	(23)	(58)	(27)
Tombstone	8	96	33	-28	64	114	**34**	-40	**65**
TM3		(76)	(23)	(104)	(22)	(96)	(17)	(110)	(18)
Tombstone	8	43	26	10	67	**42**	**26**	-3	**66**
TM1,2 & 8		(55)	(12)	(117)	(21)	(56)	(13)	(138)	(22)
Ecca	13	40	45	-49	59	46	**43**	**-25**	**66**
Q9M20		(32)	(35)	(143)	(32)	(39)	(29)	(120)	(32)
Bethlehem	7	12	9	77	82	28	28	63	**80**
C8M25		(7)	(7)	(16)	(13)	(12)	(16)	(15)	(14)
De Hoek	16	34	49	-79	61	49	68	-119	58
V1M19		(39)	(59)	(320)	(25)	(32)	(44)	(359)	(27)
Cedara	10	18	23	65	75	30	30	**62**	**86**
U2M16		(13)	(19)	(09)	(10)	(15)	(24)	(24)	(11)
Zululand	15	21	22	65	83	**24**	32	52	79
W1M15		(19)	(15)	(33)	(14)	(17)	(14)	(30)	(16)
Oxford	5	11	20	87	89	25	**20**	**85**	**91**
W4		(7)	(18)	(06)	(06)	(20)	(15)	(7)	(07)
Oxford	12	12	28	44	81	24	34	**66**	**81**
W10		(32)	(29)	(88)	(16)	(19)	(16)	(22)	(19)
Oxford	11	18	19	82	88	24	24	75	84
W12		(14)	(13)	(19)	(12)	(17)	(17)	(17)	(15)
Oxford	13	19	31	75	85	**20**	**34**	**72**	81
W17		(13)	(23)	(17)	(12)	(11)	(31)	(18)	(13)
Oxford	14	20	27	73	84	43	57	27	65
W32		(19)	(17)	(30)	(21)	(19)	(23)	(70)	(27)
Oxford	12	35	31	45	77	41	45	**46**	**77**
W35		(21)	(18)	(59)	(21)	(17)	(21)	(20)	(20)
Kaaimans	16	16	27	31	68	23	**25**	**27**	**66**
K3M01		(14)	(33)	(73)	(25)	(12)	(29)	(73)	(27)
Malgas	16	28	32	03	75	27	**36**	**15**	71
K3M04		(26)	(40)	(168)	(22)	(19)	(28)	(103)	(24)
Diep	12	catchment not used				31	57	-2	78
K4M03						(33)	(27)	(73)	(15)
Karatara	7	catchment not used				24	26	40	66
K4M02						(13)	(26)	(49)	(23)
N. Danville	11	18	19	79	96	48	51	12	89
NDS		(14)	(15)	(26)	(2)	(13)	(12)	(52)	(15)
Chickasha	5	catchment not used				23	16	65	79
CH111						(16)	(9)	(18)	(13)
Chickasha	8	catchment not used				28	38	58	86
CH512						(20)	(24)	(33)	(14)

The validation statistics where the values are close to or better than the originals are highlighted.
Coefficients of efficiency and determination are expressed as % values.

The very high standard deviations for all four of the goodness of fit statistics for the De Hoek data are indicative of some very poor results for some storms. Although the Cedara and Zululand events are generally less well simulated by the validations, this is not due to any trend in a particular direction (i.e. over or under prediction). The Oxford validation results are generally very satisfactory compared to the calibrations. This is true for all of the three seasonal groups of events which are modelled with different parameters due to landuse differences. However, catchment W32 has much poorer results, suggesting that perhaps there is something different about its response characteristics which has not been reflected in the catchment characteristic data. This effect is also noticeable in the % errors for W35 which forms part of W32. The validation simulations of the bigger storms on the Malgas and Kaaimans catchments are generally better than the smaller events which have a tendency to be underpredicted. The same is true for the Karatara events, while the Diep simulations tend to somewhat over-predict the observed flows. The North Danville results represent the greatest deterioration from calibration to validation and this is due to under-prediction and a relatively high systematic error. Similar comments made above with reference to the Bethlehem catchments are likely to be applicable. The results for CH111 are extremely encouraging indeed and while those for CH512 are not as good, they nevertheless indicate that the derived relationships between parameter values and catchment characteristics can be applicable to other catchments not included in the calibration data set.

Table 8.3 Effects of different CLOSS parameter values on resulting percentage losses for a range of moisture status conditions.

$(RAT * ROP)^{0,5}$	CLOSS Parameter value					
	0,2	0,6	1,0	1,5	2,0	3,0
0,1		3	9	131	99	100
0,2		2	4	10	24	100
0,3	All	1	2	5	10	36
0,4	values		1	3	5	15
0,5	less		1	2	3	7
0,6	than			1	2	4
0,7	1%				1	2
0,8						1

% channel losses = $(1{,}0 / (RAT*ROP)^{0{,}5\ closs}) - 1{,}0$ Up to maximum value of 100%

(RAT*ROP) is the product of the relative moisture status and the runoff proportion values and increases nonlinearly during the storm event depending upon the S-curve shape.

Percentage distribution of actual CLOSS values used for 210 sub-areas

CLOSS	<0,4	0,4-0,8	0,8-1,25	1,25-1,75	1,75-2,5	>2,5
% Sub-areas	31	43	8	5	11	2

It was noted in chapter 7 that no suitable relationship could be found for the channel losses parameter (CLOSS). Table 8.3 illustrates the effect of several values of CLOSS for ten values of the expression $(RAT*ROP)^{0.5}$. The figures given in the table are the resulting percentage losses and indicate that even at low moisture and runoff proportion levels , CLOSS values of less than 1,0 have little effect. At moderate levels the CLOSS parameter must have a value of 2,0 or greater to be of importance. The lower part of the table gives the percentage number of sub-areas in the calibration data set having CLOSS values lying in 6 groups. 74% of the sub-areas are simulated without any effective channel losses (CLOSS < 0,8). It is hoped that the range of CLOSS values for the different catchments used in this study (appendix C),together with the descriptions of the catchments, can be used to give rough estimates for ungauged situations. This component of the model is only relevant to those situations where storms occur on relatively dry catchments or where channels are developed in permeable alluvium that has the capacity to absorb large proportions of channel flow. As mentioned previously, this parameter can also be useful to account for the storage effects of small farm dams during the initial stages of flood events.

8.2 MODEL OSE1

Table 8.4 lists the formats of the combination variables and the linear equation parameters required to estimate the model parameters. To estimate parameter C it is first necessary to estimate SCA and DA from the relationships with catchment characteristics and calculate a catchment C value (1 + DA - 2 * SCA). The storm weights for C are then estimated from the relationships with storm characteristics. Table 8.5 gives the results of simulating the storms on some of the catchments using the parameter values estimated from the relationships given in table 8.4. The validation results are also presented in figure 8.1 as distributions of the four goodness of fit statistics and compared to the semi-distributed calibration results.

It is immediately obvious that the validation results for OSE1 are much worse than for OSE2. Only in the cases of the Zululand and Oxford catchments are the mean coefficients of efficiency greater than zero. Many individual storms are simulated quite satisfactorily but the effect of very poor simulations on others is seen quite clearly in the histograms of figure 8.1 as well as the high standard deviations of table 8.5. For example, extremely bad fits for two storms on a particular catchment may give coefficients of efficiency of less than -10,0 while the values for eight others may be better than 0,6. The resulting mean value would still be highly negative. For some of the catchments (Ecca, Malgas and Kaaimans) the bigger events were generally those with better simulation results. The storm weights for Diep and Karatara are estimated using the relationship for the other southern Cape catchments. The Diep simulations are generally over-predictions while those for the Karatara are under-predictions. The Karatara is a steep headwater catchment (relatively higher runoff proportions) while the Diep has somewhat lower slopes, denser vegetation and a corresponding lower runoff response. The Malgas and Kaaimans have characteristics lying between the extremes of the Karatara and Diep. One possible reason for the over- and under-prediction on the Diep and Karatara is that the storm characteristic based equations for the C weights also include some effects of catchment characteristics. Ideally these effects should have been already accounted for through the catchment characteristic equations for SCA and DA. A further possible reason that may explain the simulation differences between the Karatara and Diep is related to the difficulties of estimating the storm rainfall input to these catchments. The simulations for the Chickasha catchments are based upon using the Tombstone equations for the C storm weights. The Tombstone equations were used as the Chickasha storms are high intensity, relatively short duration events. However, the results suggest that transferring the storm weight relationships to other catchments is unlikely to meet with much success. This conclusion is more or less a direct consequence of the differences found in the form of the equations derived for the calibration catchments (table 8.4).

Table 8.4 Format of the equations for estimation of model OSE1 (semi-distributed) parameters.

MODEL PARAMETER	FORMAT OF TRANSFORMED COMBINATION OF PHYSICAL VARIABLES		LINEAR EQUATION PARAMETERS A	B
CDEL	TC * ROUGH		0,132	0,055
K	VEG^2 * INFIL/(ENERGY * SLOPE * PERMC)		8,04	-0,280
KC	CDIST + Log (ORD1)		0,125	0,018
SMAX	DEPTH * WHC		4,65	10,5
DA	Log (SLOPE * PERMC * SL/V)		0,138	-0,099
SCA	Log (SLOPE * PERMC * SL/V/(INFIL * VEG))		0,153	0,503
APF	ENERGY * PERMC		-0,003	0,949
C(storm weights)	Log (TOTR * MAXI/DUR)	- Tombstone	-0,051	0,475
		- De Hoek	-0,130	0,811
	Log (TOTR + DUR)	- Ecca	-0,330	1,79
		- Zululand	-0,095	0,603
		- Oxford	-0,095	0,491
		- S. Cape	-0,054	0,408
		- N. Danville	-0,266	1,212

For parameter c: (1+DA-2*SCA) * C(storm weight)

model parameter values = A * combination variable + B

Table 8.5 Comparison of original and validation goodness of fit statistics for model OSE1.

Catchment	No. of Storms	Original fit statistics				Validation fit statistics			
		% Errors		Coefficients		% Errors		Coefficents	
		Vol.	Pk.	Eff.	Det.	Vol.	Pk.	Eff.	Det.
Tombstone	11	16	38	30	62	72	68	-36	63
TM11		(19)	(33)	(64)	(27)	(59)	(45)	(205)	(33)
Tombstone	9	11	25	16	48	127	60	-209	33
TM8		(11)	(17)	(85)	(31)	(120)	(75)	(549)	(18)
Tombstone	8	13	18	27	49	79	57	-29	62
TM3		(14)	(11)	(62)	(35)	(69)	(32)	(160)	(19)
Ecca	13	13	9	49	72	125	134	-840	40
Q9M20		(15)	(11)	(48)	(20)	(154)	(162)	(174)	(22)
De Hoek	16	21	42	27	63	71	63	-334	64
V1M19		(14)	(30)	(64)	(34)	(89)	(86)	(957)	(29)
Zululand	15	16	22	61	77	36	46	21	**76**
W1M15		(13)	(17)	(17)	(14)	(31)	(38)	(68)	(15)
Oxford	12	10	21	71	78	52	57	-1	70
W10		(9)	(18)	(23)	(19)	(48)	(49)	(102)	(23)
Oxford	11	6	24	69	75	42	60	22	**76**
W12		(4)	(11)	(24)	(25)	(26)	(47)	(61)	(27)
Oxford	13	15	31	64	73	34	53	44	68
W17		(7)	(38)	(25)	(18)	(24)	(37)	(31)	(28)
Oxford	14	11	28	72	79	36	47	36	52
W32		(8)	(17)	(24)	(20)	(18)	(30)	(50)	(36)
Oxford	12	9	29	61	74	33	48	49	68
W35		(8)	(25)	(24)	(19)	(21)	(24)	(33)	(30)
Kaaimans	16	9	12	41	63	36	51	-41	53
K3M01		(6)	(6)	(59)	(25)	(29)	(42)	(162)	(29)
Malgas	16	11	11	38	63	45	47	-22	55
K3M04		(6)	(9)	(66)	(33)	(31)	(33)	(80)	(30)
Diep	13	catchment not used				47	60	-120	58
K4M03						(29)	(44)	(221)	(27)
Karatara	7	catchment not used				62	50	-25	59
K4M02						(23)	(27)	(40)	(24)
N.Danville	11	6	9	87	90	62	82	-201	85
ND5		(5)	(5)	(08)	(09)	(47)	(75)	(543)	(08)
Chickasha	5	catchment not used				98	75	-242	31
CH111						(66)	(41)	(345)	(35)
Chickasha	8	catchment not used				81	55	-125	47
CH512						(87)	(66)	(324)	(39)

These validation statistics where the values are close to or better than the originals are highlighted. Coefficients of efficiency and determination are expressed as % values.

8.3 MODEL OSE3

The equations for the parameters of model OSE3 are given in table 8.6 and the values for the goodness of fit statistics after validation compared to those after calibration in table 8.7. As with the other models, the distributions of the statistics are illustrated in figure 8.1

Many of the conclusions reached about the validation exercise for OSE1 are also applicable to this model. Some of the OSE3 results are better (Tombstone and Zululand, for example) while others are worse (Malgas and Chickasha, for example). The Chickasha results illustrate the problems of trying to apply relationships for ROP developed in one group of catchments to a very different group of catchments. The Tombstone equation for ROP is used for the Chickasha catchments and thus results in very high over-prediction of most of the events. The Chickasha total storm rainfalls are usually higher than for Tombstone which means that the values for TOTR * $MAXI^{0.5}$ + 30D API are usually outside the range used to develop this relationship. The Tombstone relationship is therefore demonstrated to be inapplicable to the Chickasha catchments. However, none of the alternative equations (using TOTR and 30DAPI) was applicable either.

Table 8.6 Format of the equations for estimation of model OSE3 (semi-distributed) parameters

MODEL PARAMETER	FORMAT OF TRANSFORMED COMBINATION OF PHYSICAL VARIABLES		LINEAR EQUATION PARAMETERS A	B
CDEL	TC * ROUGH		0,132	0,055
K	VEG^2 * INFIL/(ENERGY * SLOPE * PERMC)		16,2	-0,096
KC	CDIST + Log (ORD1)		0,125	0,019
ROP	TOTR * $MAXI^{0.5}$ + 30DAPI	- Tombstone	0,0006	-0,030
		- Bethlehem	0,0014	-0,013
	TOTR + 30DAPI	- Ecca	0,0028	-0,118
		- De Hoek	0,0063	-0,261
		- Cedara	0,0007	-0,024
		- Zululand	0,0017	0,142
		- Oxford W	0,0034	0,175
		- Oxford P	0,0039	-0,056
		- Oxford S	0,0027	-0,067
		- Kaaimans	0,0028	0,391
		- Malgas	0,0032	0,336
		- N. Danville	0,0033	-0,099

Model parameter values = A * combination variable + B

Table 8.7 Comparison of original fit statistics and validation fit statistics for model OSE3

Catchment	No. of Storms	Original fit statistics % Errors Vol.	Pk.	Coefficients Eff.	Det.	Validation fit statistics % Errors Vol.	Pk.	Coefficents Eff.	Det.
Tombstone TM11	11	4 (6)	24 (19)	58 (44)	66 (26)	27 (21)	39 (29)	50 (32)	60 (33)
Tombstone TM8	9	3 (4)	23 (20)	22 (74)	50 (30)	46 (40)	66 (23)	12 (32)	30 (30)
Tombstone TM3	8	5 (7)	25 (36)	16 (62)	51 (32)	60 (65)	32 (24)	11 (97)	56 (23)
Ecca Q9M20	13	6 (7)	6 (5)	75 (38)	87 (11)	178 (243)	136 (159)	-632 (1060)	56 (26)
Bethlehem C8M25	7	6 (4)	11 (7)	52 (59)	66 (33)	27 (26)	34 (32)	27 (59)	58 (39)
De Hoek V1M19	14	9 (8)	29 (23)	49 (45)	60 (32)	46 (51)	64 (89)	-221 (923)	63 (29)
Cedara U2M16	10	10 (6)	17 (9)	53 (34)	72 (17)	32 (23)	51 (28)	34 (45)	58 (29)
Zululand W1M15	15	5 (4)	14 (10)	77 (17)	81 (16)	17 (13)	22 (10)	61 (22)	76 (15)
Oxford W10	12	6 (12)	21 (20)	63 (37)	76 (22)	27 (37)	41 (38)	46 (68)	76 (19)
Oxford W12	11	7 (8)	23 (15)	82 (18)	84 (15)	31 (32)	41 (30)	56 (55)	88 (13)
Oxford W17	13	11 (5)	23 (15)	82 (10)	87 (09)	22 (16)	58 (55)	53 (33)	80 (16)
Oxford W32	13	1 (2)	25 (16)	75 (25)	79 (21)	32 (14)	54 (21)	37 (46)	54 (31)
Oxford W35	12	5 (5)	23 (23)	71 (22)	78 (20)	58 (62)	39 (25)	8 (115)	75 (24)
Kaaimans K3M01	16	6 (4)	13 (14)	64 (30)	75 (20)	16 (14)	39 (56)	-20 (129)	56 (25)
Malgas K3M04	16	8 (3)	15 (12)	46 (56)	66 (30)	36 (50)	71 (85)	-180 (638)	56 (36)
Diep K4M03	13	catchment not used				269 (337)	343 (380)	-2700 (4000)	60 (25)
Karatara K4M02	7	catchment not used				24 (16)	73 (70)	-77 (148)	51 (28)
N.Danville ND5	12	3 (2)	3 (3)	94 (5)	95 (5)	25 (17)	29 (15)	60 (34)	91 (07)
Chickasha CH111	5	catchment not used				275 (166)	176 (167)	-1558 (1618)	39 (40)
Chickasha CH512	8	catchment not used				138 (146)	119 (123)	-777 (1707)	56 (29)

These validation statistics where the values are close to or better than the originals are highlighted. Coefficients of efficiency and determination are expressed as % values.

8.4 COMPARISONS BETWEEN MODELS AND STORM TYPES (A, B and C)

Table 8.8 lists the mean values for the goodness of fit statistics grouped according to storm type (A, B and C) as defined in section 6.5.6. As the histogram plots of figure 8.1 demonstrate the mean values do not always represent a satisfactory measure of central tendency when the distributions are skewed. However, the authors believe that the values given in table 8.8 do give an immediate and easy to read impression of the relative performance of the three models after validation. The OSE2 results for the three storm type groups follow a similar pattern to the calibration results given in tables 6.3 and 6.4. The A and B groups have broadly similar means except for the coefficient of efficiency. The results are generally worse for the C-type events. This might be expected given the poorer definition of the input rainfall that characterises the C events. The same is not true for the other models and it is difficult to explain why those events which have poorly defined storm input should produce the better results particularly with respect to the % volume errors. This is undoubtedly a reflection of the more erratic nature of the validation simulations for OSE1 and 3.

Table 8.8 Validation results - mean goodness of fit statistics grouped by model and storm type

STORM TYPE		MODEL OSE1	OSE2	OSE3
	% error Vol.	49 (70)	32 (22)	50 (102)
A	% error Pk.	62 (86)	39 (25)	55 (68)
	Coeff. Eff.	-120 (840)	43 (64)	-111 (654)
	Coeff. Det.	73 (26)	76 (24)	74 (24)
	% error Vol.	64 (72)	35 (27)	42 (55)
B	% error Pk.	65 (57)	38 (30)	43 (31)
	Coeff. Eff.	-146 (597)	6 (202)	-2 (200)
	Coeff. Det.	54 (30)	73 (22)	63 (28)
	% error Vol.	62 (67)	60 (88)	30 (37)
C	% error Pk.	63 (63)	43 (42)	47 (51)
	Coeff. Eff.	-94 (338)	-24 (329)	-23 (314)
	Coeff. Det.	57 (28)	67 (25)	58 (32)

Figures in parenthesis are standard deviations

% Errors in volume and peak are means of the absolute values

Coefficients of efficiency and determination are mean values * 100

8.5 SUMMARY COMMENTS ABOUT THE SUCCESS OF THE VALIDATION EXERCISE

There is no doubt that, considering the overall results, model OSE2 has performed better than the others and appears to be the model that is likely to produce the more reliable simulations in situations where calibration is not possible. Some of the relationships developed to estimate the parameter values of OSE1 and 3 are so catchment specific that transfer to other areas will produce unpredictable results. If flow data are available for catchments close to and similar to the ungauged catchment then the results may be considered more reliable, but the southern Cape simulations indicate that even this type of transfer may be largely unsuccessful, particularly using model OSE3. For those catchments where channel loss processes are important, this report has only offered approximate guidelines for the estimation of the CLOSS parameter in model OSE2.

The comments made above about the comparative reliability involved in applying these models have to be viewed in the context of the actual errors. The catchment average volume and peak errors, after the validation exercise, were rarely within 20% of the observed values and average coefficients of efficiency were usually below 0,7. Any user expecting to be able to apply the models and achieve simulations within 20% of the true peaks and volumes is likely to be disappointed. However, even some of the worst results using models OSE1 and 3 can be viewed in a favourable light compared with the results reported in Campbell, Ward and Middleton (1987) for several other models currently being used to derive design floods.

Figure 8.1 Distributions of goodness of fit statistics for the calibration and validation results of models OSE1, 2 and 3, grouped by storm type (A, B and C).

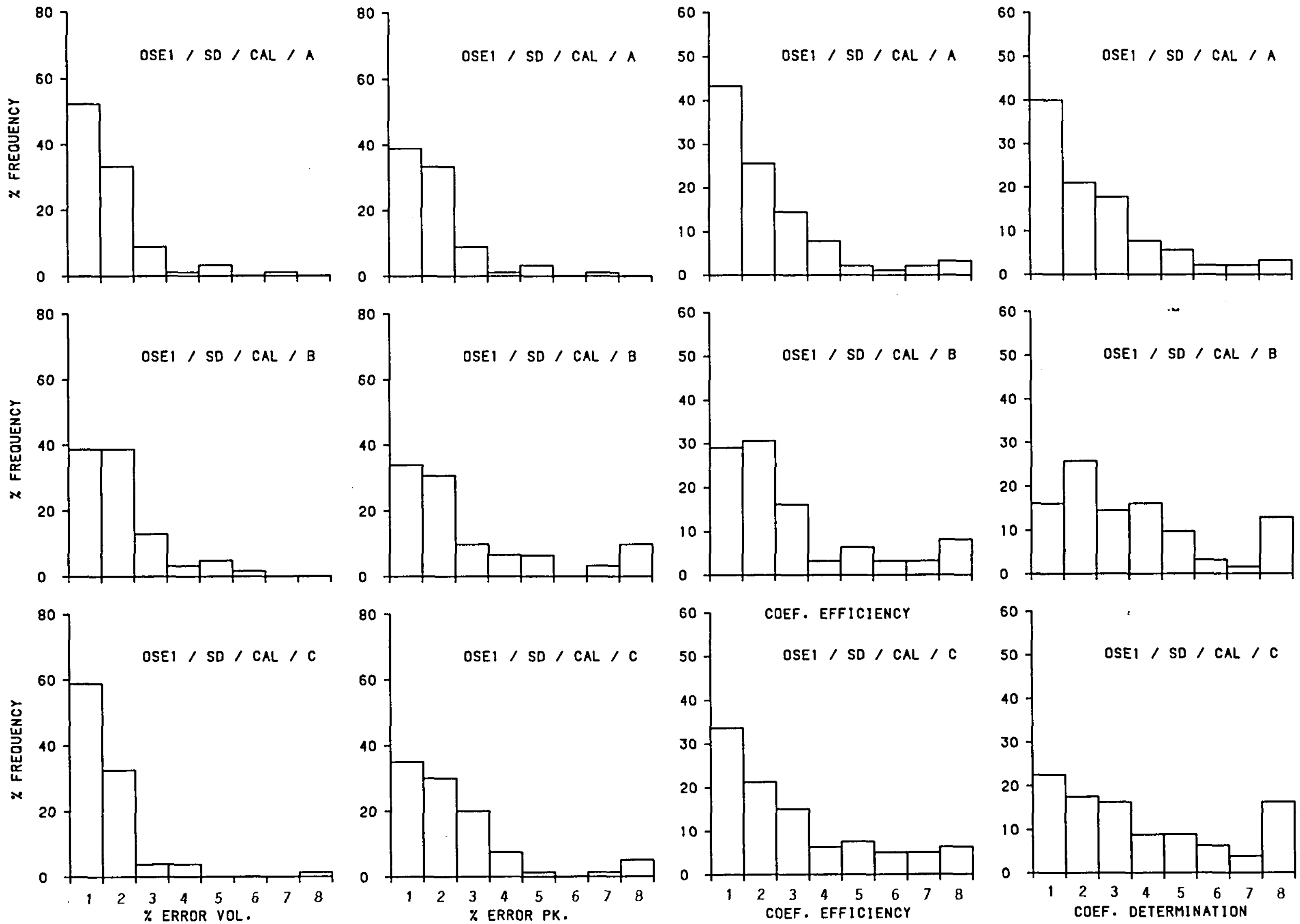
Key to the following 6 pages of computer plots.

Each histogram is labelled with a four part code

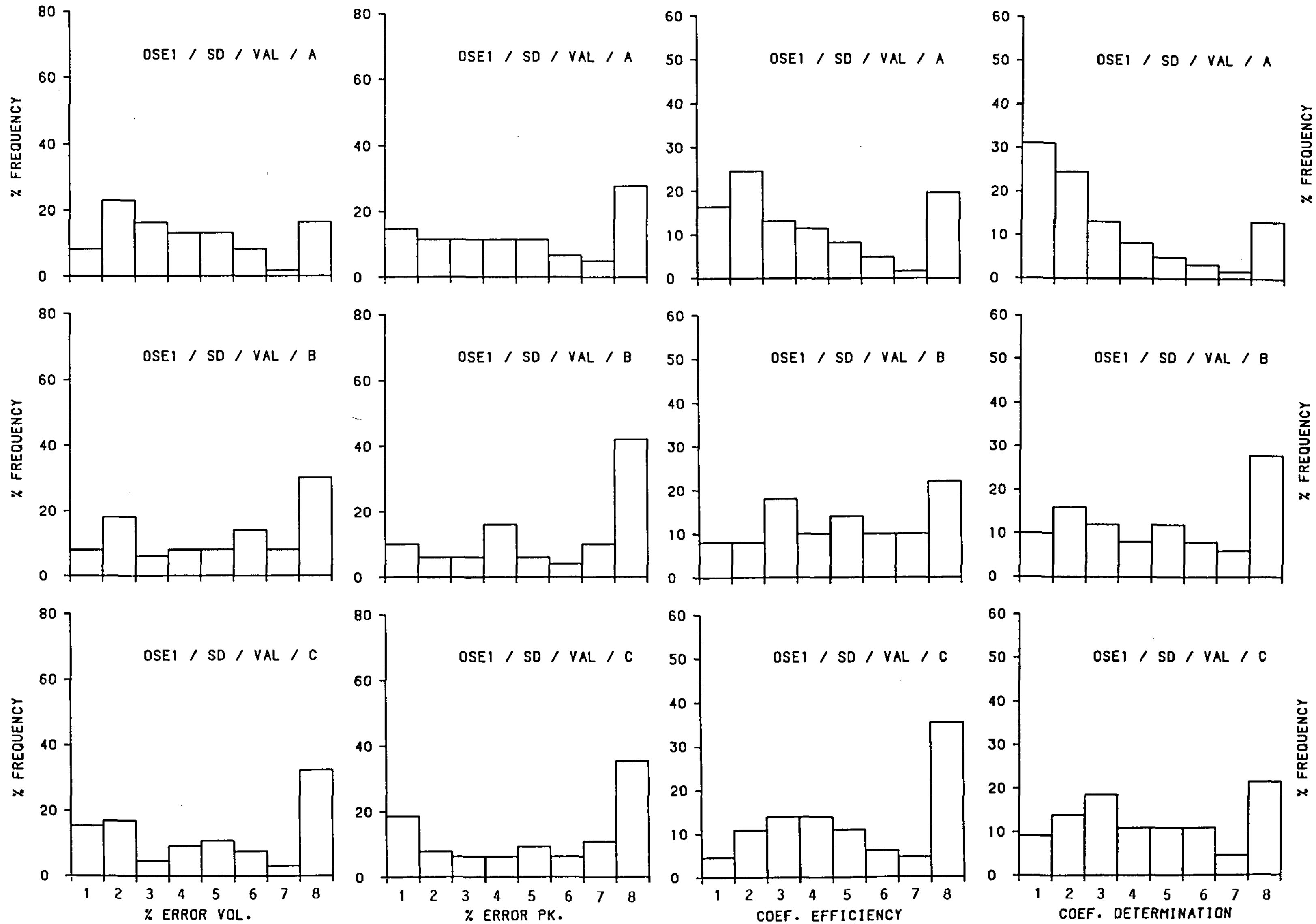
Model name / Lumped or semi-dist. / Calibration or validation / Storm type.

The eight histogram categories are as follows.

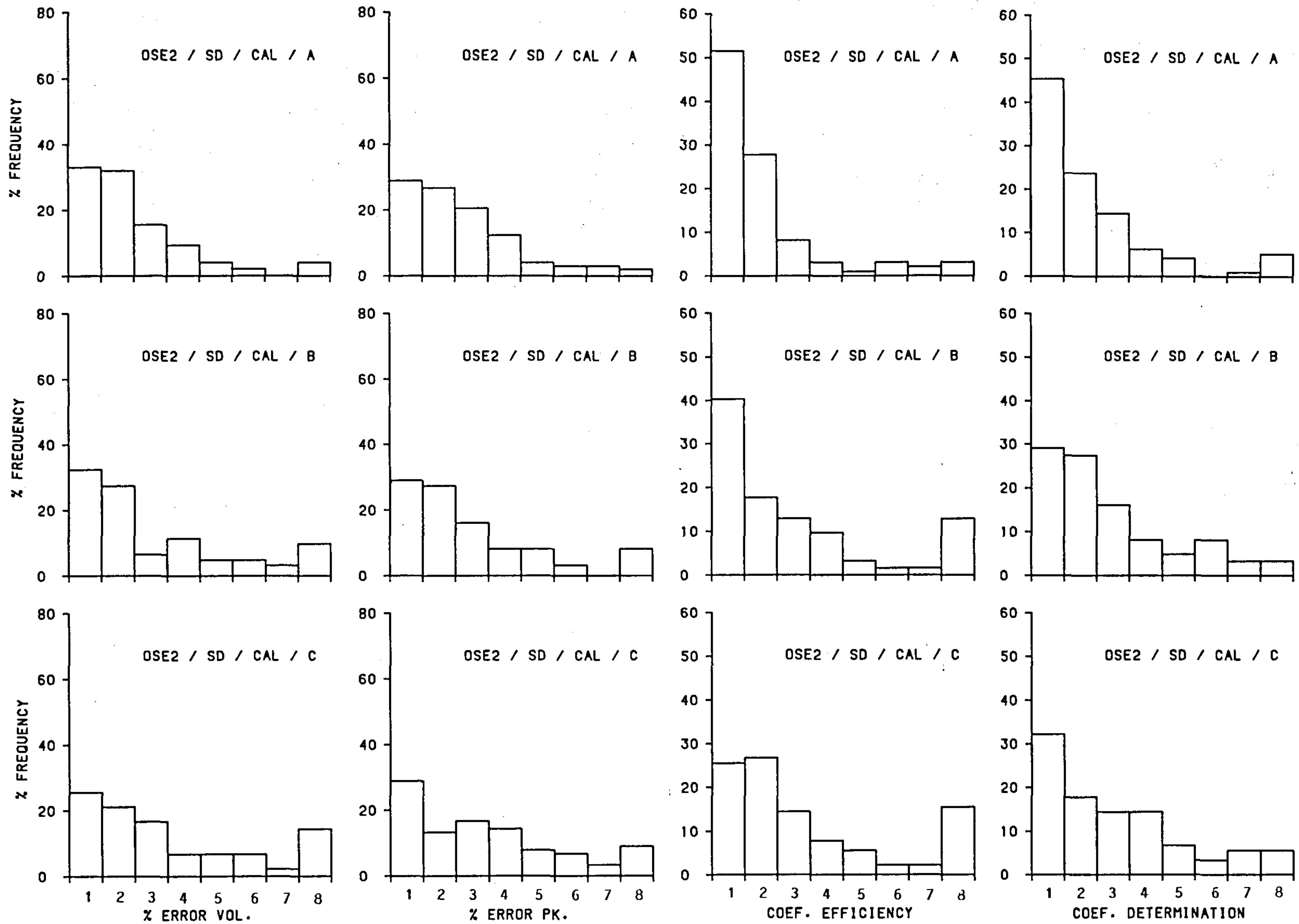
HISTOGRAM CATEGORY	GOODNESS OF FIT STATISTIC		
	ABSOLUTE % ERRORS IN VOLUME AND PEAK	COEFFICIENTS OF EFFICIENCY	COEFFICIENTS OF DETERMINATION
1	0 to 10	1,0 to 0,8	1,0 to 0,9
2	10 to 20	0,8 to 0,6	0,9 to 0,8
3	20 to 30	0,6 to 0,4	0,8 to 0,7
4	30 to 40	0,4 to 0,2	0,7 to 0,6
5	40 to 50	0,2 to 0,0	0,6 to 0,5
6	50 to 60	0,0 to -0,2	0,5 to 0,4
7	60 to 70	-0,2 to -0,4	0,4 to 0,3
8	>70	<-0,4	<0,3



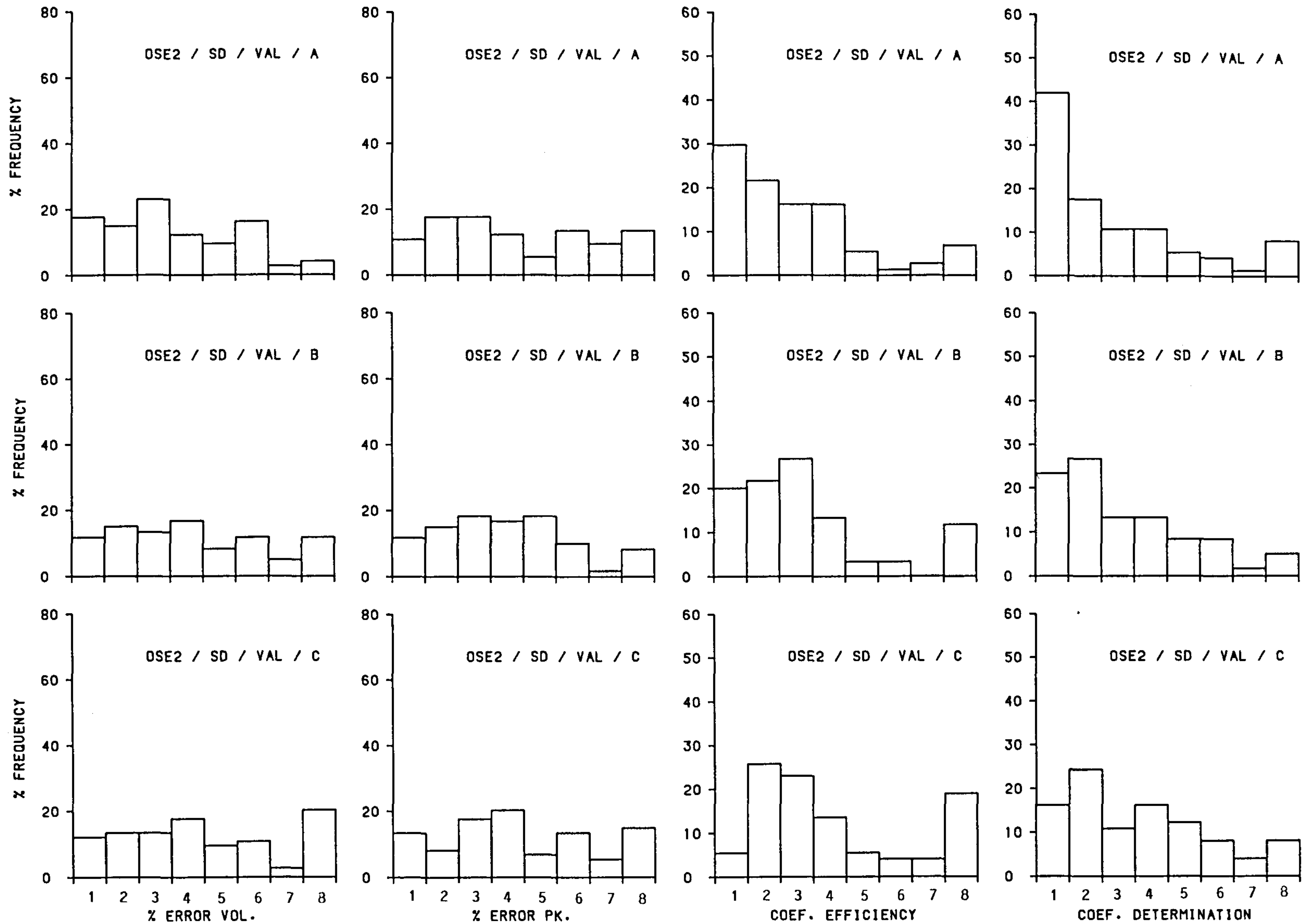
OSE1 Semi-distributed calibration results.



OSE1 Semi-distributed validation results.

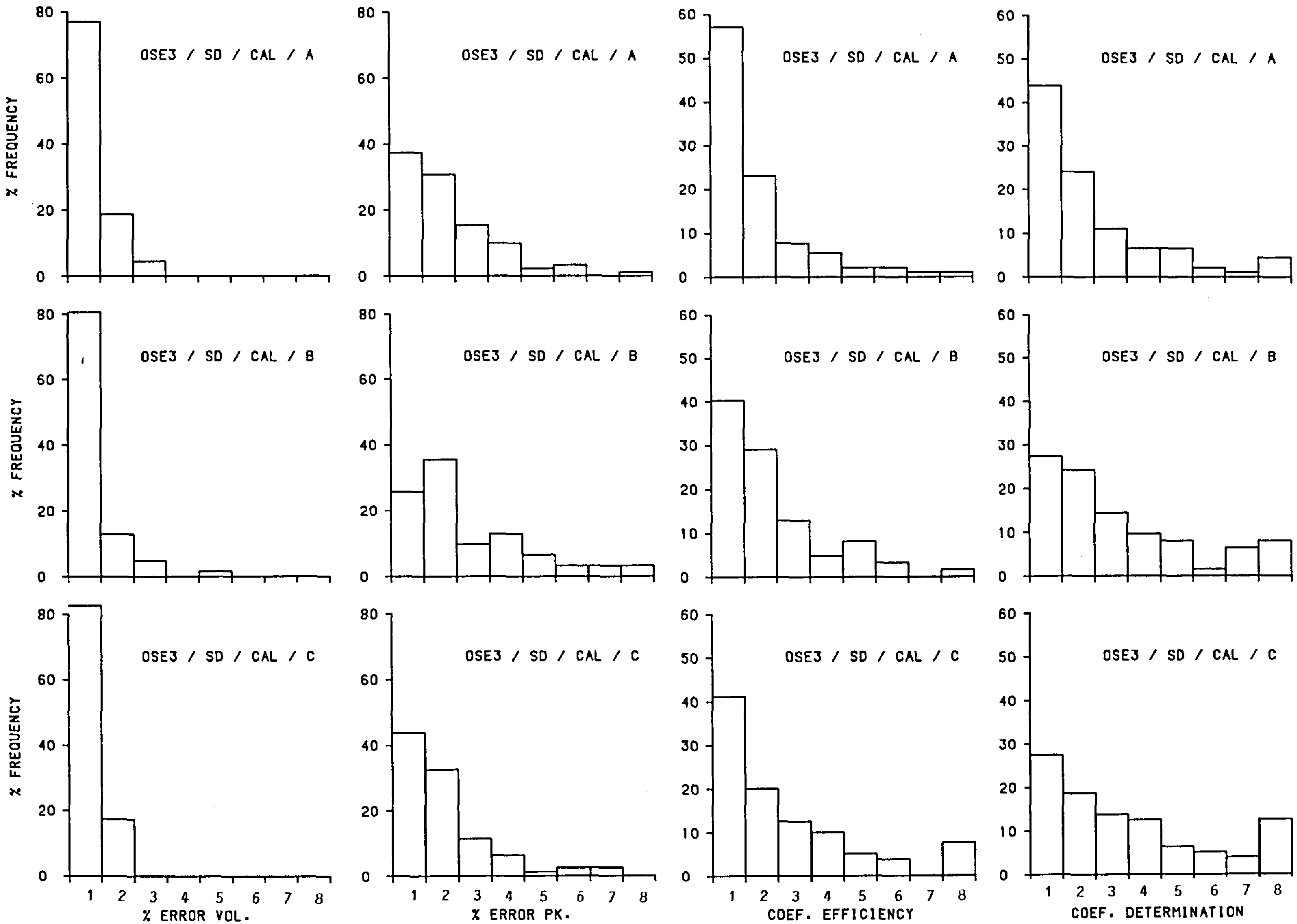


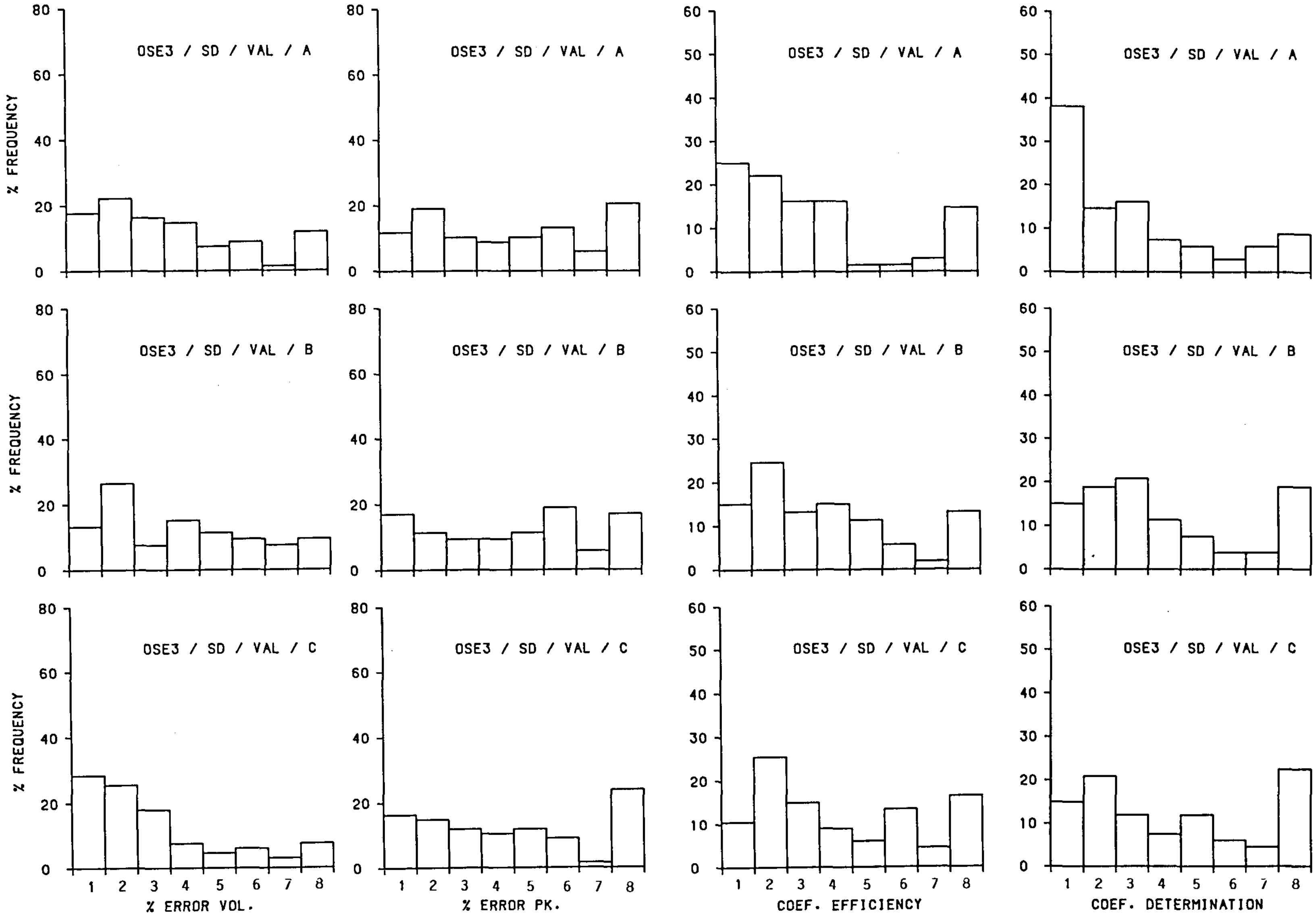
OSE2 Semi-distributed calibration results.



OSE2 Semi-distributed validation results.

OSE3 Semi-distributed calibration results.





OSE3 Semi-distributed validation results.

Chapter 9

CONCLUSIONS AND IMPLICATIONS FOR THE APPLICATION OF DETERMINISTIC MODELS

The purpose of this chapter is firstly to summarise the major findings of the research project discussed within the other chapters of this report. This chapter is also intended to place the conclusions of this investigation into the broader context of the development and use of hydrological models in general and their application for estimating floods in particular.

9.1 SUMMARY OF THE CONCLUSIONS OF THE INVESTIGATION

i) With respect to their ability to reproduce observed hydrographs, regardless of the values of the parameters (curve-fitting capability), there is little difference between the four models. However, the use of the continuing losses function in OSE4 is less generally applicable than the constant runoff proportion function. Model OSE2, with its variable runoff proportion capabilities, is able to simulate complex multi-peaked events better than the other models, particularly when the antecedent catchment moisture status is low. Given that the relative contribution to runoff of separate bursts in a complex rainfall event could be defined, model OSE4 is also quite capable of simulating this type of event. The similarity in the 'curve-fitting' capabilities of the models is hardly surprising when it is remembered that they all have very much the same flow routing functions. This conclusion merely serves to confirm the criticism that is often levelled at conceptual models; that is that they can be made to reproduce just about any rainfall-runoff response after calibration but that the resulting parameters may be meaningless. Reports of modelling results that do not address the issue of validation or meaningfulness of the calibrated parameters are therefore of little applied value.

ii) After the calibration stage of the study, Model OSE2 was demonstrated to perform almost as well (sometimes worse, sometimes better) as the other models, despite the constraint of fixed parameter values for all events on the same catchment. A certain element of validation is therefore built into the calibration procedure for OSE2 while this was not possible for the other models. In general terms, the routing parameters of OSE1 and 3 were found to be stable for most individual catchments. However, these models and OSE4 have at least one parameter which must be calibrated for each individual event to achieve anything close to acceptable results. It was therefore difficult to make valid comparisons between the models at the end of the calibration stage of the investigation. The real comparisons could only be made after an assessment of the success of attempts to develop relationships between parameter values and measurable physical characteristics of either the catchment, the storms or both.

iii) There are definitely events for which the semi-distributed versions of the models perform more satisfactorily than the lumped versions. The fact that this conclusion is not applicable to all the events where a high degree of spatial variation exists in the storm rainfall characteristics is at least partly related to the lack of available data with which to define that variability. Although obvious, the conclusion that the quality of the input rainfall will have an effect on the reliability of the modelling results regardless of the sophistication of the model used, is extremely important. This point will be referred to later during a discussion of the applied aspects of model usage. The study has shown that the lumped versions perform as well as the semi-distributed models when there is little spatial variation in the input rainfall. This is an important conclusion from the applied point of view as the lumped models are certainly simpler to use and require a great deal less computer time. Care must be taken in considering this to be a general conclusion. Many of the catchments used in this study for which the input rainfall was not spatially variable had few major differences in the characteristics of the sub-areas. Where large differences do occur in the runoff response of different parts of the catchment the lumped models will not necessarily continue to perform as well as the semi-distributed versions. However, it must also be recognised that for the semi-distributed models to be better in such situations two conditions must be satisfied. First of all the user must have the ability to recognise the differences, and secondly the values assigned to the sub-area parameter values must necessarily have an effect on the runoff simulations that truly reflect the real differences.

iv) The effects of varying the time interval of modelling are different depending upon the characteristics of the rainfall input and the runoff response. For those catchments where relatively low intensity and long duration storms prevail the results indicate that modelling time intervals up to about one hour are acceptable if the runoff response is not very rapid. The rapidity of the response will depend upon catchment size, slope steepness and the prevailing runoff generation mechanisms. The steeply sloping southern Cape catchments (22 to 48 km^2 in area) do not appear to have a runoff response that is too rapid to prevent the use of a coarse modelling time interval. The effect of changing the time interval for the Bethlehem events is more important and mainly related to the higher intensity of the rainfall events. The Tombstone catchments experience very high intensity and short duration storms producing a very rapid (flash flood) runoff response despite the relatively low relief of the region. The results indicate that a short time interval (less than 10 min.) is necessary, not only to adequately reflect the temporal variation in rainfall intensity, but also the speed of response of the catchment. Overall, it may be concluded that a model with a structure that allows for variations in the time interval during an event could be a better approach than the fixed interval method used in this study. The modifications to OSE2, for example, that would be necessary to achieve this would be relatively minor. Such a change to the model's structure would only be of benefit when the time resolution of the available data is high enough to take advantage of higher resolution allowed for in the model. Many organisations responsible for the collection of hydrometeorological data store breakpoint rainfall intensity values if their field instruments are capable of collecting information continuously on charts, magnetic tape or solid state memory. With the increasing use of electronic data loggers, it is becoming easier to collect this type of data and the authors believe that developments in hydrological estimation techniques should reflect this fact.

v) The results of a limited study to assess the effects of changing the degree of spatial disaggregation were inconclusive. This was thought to be at least partly related to point (iii) above which refers to the relatively small number of raingauges in some catchments with which to define the spatial variation in storm rainfall characteristics. If the conclusions reached by the present authors, as well as others (Roberts, 1984; Loague and Freeze, 1985), about the importance of defining this variation are valid, then it is not surprising that the results were inconclusive. What is perhaps of some concern is the fact that the South African catchments used in this study represent some of the best instrumented, medium sized catchments in the country. If the spatial variation of rainfall cannot be defined for these catchments then there is little hope of defining rainfall input adequately in applied situations.

vi) The results of simulating the storms on the Oxford catchments indicated that differences in the parameter values of OSE2 could be associated with differences in catchment characteristics. The effect of seasonal variations in landuse resulting in decreased vegetation cover during the winter months and consequently higher runoff proportions are reflected in the model through an increase in the value of the intensity controlled runoff parameter. The USDA (1955-1973) publications indicate that soil erosion is greater during these months corroborating the effects indicated by the model. The indications given by the other models were not as clear and this result was taken as the first real evidence that some of the OSE2 parameters may be better related to physical catchment characteristics than the parameters of the other models.

vii) It proved to be a difficult task to obtain adequate information with which to quantify physical catchment characteristics. This observation is particularly true of soil characteristics. The available information is often sketchy, very generalised and not always of relevance to hydrological processes. The authors were therefore forced into the use of indices based upon an ordinal measurement scale and a certain degree of subjective interpretation of qualitative descriptions contained within the various sources. It is quite clear that the availability of information with which to describe the hydrologically important aspects of catchments is very limited. The development of methods to collect this information are certainly lagging behind the development of models which increasingly claim to be based upon these physical characteristics (Abbott, *et al.*,1986).

viii) The results of the attempts to derive relationships between physical variables and the sub-area model parameters must clearly be seen in the light of the above conclusion (vii). Nevertheless, the authors have concluded that the general trends exhibited by many of the relationships are encouraging, particularly in view of the fact that the format of the combinations of physical variables do make sense with respect to the original parameter conceptualisations. This conclusion cannot be extended to the relationships for the main volume conversion parameters of OSE1 and 3 which are based upon storm characteristics. The degree of scatter, as well as the between-catchment variation in the form of the relationships, indicate that they are likely to be of little value for parameter estimation purposes.

ix) Given conclusion (viii) it is not surprising that the validation results, and particularly those for the catchments not included in deriving the relationships (Diep, Karatara and Chickasha), are far better for OSE2 than the other models. 'Better' is of course a relative term and it is for a potential user to decide whether any of the results can be considered adequate for a specific application. The histograms of validation results indicate that the relationships used to predict OSE3 parameter ROP are useful but only if some calibration data are available to determine the form of the relationship for a specific catchment. Transferring the relationships derived for Kaaimans and Malgas to similar catchments in the same area produced very poor results, particularly for the Diep. Transferring relationships to the Chickasha catchments was a total failure (% errors well in excess of 100%).

x) While guidelines have been given in this report about how to estimate most of the parameters of OSE2, no relationship was found between the channel loss parameter and measurable physical variables. Where channel losses are considered to be important, a potential user only has table 8.3 (indicating the effects of various CLOSS values) and the range of values used on the catchments included in this study to suggest a suitable value. Given more, or different types of information about physical characteristics, there may be better alternative methods of estimating some of the parameter values. An example could be the approaches adopted by Heerdegan and Beran (1982) or O'Loughlin (1981 and 1986) to determine areas of surface saturation. It may be possible to extend or modify this type of approach to estimating the shape of the S-curve in model OSE2.

The overall conclusion of this study is that the models tested do not appear to give results that are any worse than techniques already in common use for the simulation of flood hydrographs (Campbell, Ward and Middleton, 1987). In fact, model OSE2 is likely to offer a better alternative to many existing flood simulation techniques for catchment sizes within the range used in this study (approximately 5 to $150km^2$). As the model can be used in a semi-distributed format there seems to be no reason why this size range cannot be extended upwards, assuming that the data are available to evaluate the indices of physical characteristics at a similar scale to the one used in the study.

9.2 THE CONTEXT OF FUTURE DEVELOPMENTS OF HYDROLOGICAL MODELS

There has been an ever increasing trend in the development and popularity of distributed physically-based models. However, there is evidence in the hydrological literature to indicate that there are distinct problems associated with this trend. The following points summarise some of these problems.

i) Hydrologists do not understand enough about the processes of runoff generation at the catchment scale to be able to build truly physically-based models (Morton, 1982; Kundzewicz, Fouda and Szolgay, 1987).

ii) There is insufficient information available about the physical characteristics of the environment (Naef, 1981) to be able to evaluate the parameters of physically-based models at the required scale (Loague and Freeze, 1985). The collection of this information is very expensive and time consuming and therefore one of the major barriers to model development or testing is the acquisition of the necessary data (Beven and O'Connell, 1982; Beven, 1983; Kundzewicz, *et al.*, 1987).

iii) A further barrier to successful simulation is the lack of information with which to define the rainfall (or other meteorological) inputs at an adequate level of spatial detail. It is certainly true that the high level of spatial disaggregation allowed for in many distributed models is not consistent with the amount of rainfall data (or number of raingauges) available in most situations.

iv) Some studies have demonstrated that simple modelling techniques are often as successful as more complex approaches, implying that the selection of the model is less than critical (Naef, 1981; Pilgrim and McDermott, 1982; Görgens, 1983; Loague and Freeze, 1985). This point is clearly associated with all three previous points and it is extremely difficult to identify which of the above plays the dominant rôle in any comparison of modelling approaches.

This study has clearly demonstrated that points ii) and iii) above are relevant to the application of single event models in South Africa. As suggested by Szollosi-Nagy, Kundzewicz and Cordova-Rodrigiuez (1987) more attention needs to be paid to precipitation processes in order that they are better understood at different scales and to improve techniques for disaggregation in time and space (Hershenhorn and Woolhiser, 1987). With respect to physical catchment characteristics, future advances in remote sensing techniques may play an important role in allowing the necessary physical information to be collected (Rango, 1985). The development of improved methods to model the sub-surface redistribution of moisture is likely to play an important part in moving towards models that are closer to physical reality. The success of such methods will certainly be heavily reliant upon an ability to quantitatively describe the relevant sub-surface soil characteristics. It is difficult to understand how satellite or airborne remote sensing techniques can provide (even in the future) this information at the desired level of detail.

This investigation has indicated that some increase in the level of sophistication of the model structure (point iv) can lead to an improvement in simulation results. This improvement may be attributed to the inclusion of a time-variant runoff proportion function in the more complex model OSE2. It is not suggested that a further increase in the complexity or level of sophistication will lead to further improvements in the simulation results (given the amount and quality of input data used in the study). The authors accept that there is an increasing need for models which are closer to reality such that more complex water resource problems can be addressed with a greater degree of confidence. Amongst others, Fleming (1984) has indicated that approaches involving estimations of water quality, as well as quantity, are necessry for the solution of many water resource problems. These approaches should also be able to take into account anticipated or likely changes to the physical characteristics of catchments (land use, for example). Simple models have generally been shown to be incapable of satisfying this requirement. However, it appears that more research on sophisticated models and their use is required before they can be demonstrated to produce better results than simple models.

It would appear that future developments in hydrological modelling techniques face a dilemma. An increase in the understanding of hydrological processes at various scales provides the necessary theoretical background with which to build better models which are closer to reality. Modelling studies can contribute to this understanding but only if uncertainties related to the quality of the model input information can be overcome. . The enormous increases in the power of computers (PC's, minis and mainframes) have effectively removed any computational barriers to developing complex distributed models. However, the ability of the user to provide such models with the information that they need has not kept pace even with recent model developments (for example the SHE model discussed in Abbott, *et al.*, 1986) and there are few signs that it is likely to catch up. Any individual model user is therefore faced with a choice of the following options.

i) The use of a sophisticated model with less than perfect input data, knowing that the results will be consequently less than reliable.

ii) The use of a less complex model which is based upon a simpler conceptualisation of reality but for which the data requirements are less stringent. The user is still often unable to express any degree of confidence in the results.

The reliability of the results of adopting either of these options will remain largely unknown unless studies are carried out to indicate how reliable they can be in a wide variety of different situations (defined by the same factors as identified in chapter 2, figure 2.2). The authors believe that the results of this investigation have contributed to an understanding of the reliability that can be expected from the type of models used.

9.3 DESIGN FLOOD DETERMINATION APPLICATIONS.

The comments made in the previous section are non-specific with respect to the type of deterministic model. However, if an isolated event model is to be used for design flood purposes then there are further implications to consider. These are not so much related to the modelling approach that is adopted, but more to do with the design flood concept itself. Several recent South African publications have discussed the limitations of the conventional deterministic design flood approach (Hughes, 1986; Schmidt and Schulze, 1987; Lambourne, 1988), and in turn referred to earlier discussions in the international literature of these limitations. Most of these studies have concentrated on incorporating variations in antecedent catchment moisture status in the design storm definition. Some have demonstrated that by doing this the return periods (or probabilities of recurrence) of the causative event and resulting flood are more closely matched. These are clearly important contributions to improving design flood estimations but in medium to large catchments there is an additional problem for which there does not appear to be an available method of solution.

One of the problems can be best illustrated by an example. Flood producing rainfalls occurred in parts of the southern and eastern Cape Province during March 1981. Post flood surveys were carried out by the Department of Water Affairs at various points within the Swartkops catchment (area of approximately 1200km^2 and draining a mountainous region inland of Port Elizabeth) and peak discharges estimated using the slope-area method (Du Plessis, 1984). Regionalised flood frequency information indicated that the return periods of the peak flows from different parts of the catchment varied between 50 and 200 years. Accepting that the return period estimations are little more than guesses, the implication is that spatial variations in rainfall amounts and probabilities of recurrence suggest that it is very difficult to define the input necessary to generate a flood of a given return period for the complete catchment. If antecedent moisture effects are included in a design statement it is necessary to know how likely is the combination of a particular catchment wetness and particular storm rainfall. In the same way it is necessary to know how likely are different patterns of spatial rainfall variation over relatively large catchments. In a lumped approach to simulating a design flood in this type of situation, the input rainfall may consist of a suitably chosen point rainfall depth to which is applied an areal reduction factor (ARF). The ARF therefore represents an attempt to account for the fact that not all of the catchment will experience as much storm rainfall as the point rainfall value. There do not appear to be any studies to indicate whether the ARF is an adequate representation of the effects of typical spatial variations that do occur in different regions. If there is also a temporal dimension to the spatial variation (as in a moving storm situation) then the use of a single point value and an ARF will certainly be inadequate.

Some design situations warrant a more than simplistic approach. This may be the case where storage and attenuation of flow play an important rôle and a realistic estimate of the shape of the hydrograph is required. A distributed (or semi-distributed) single event model might then offer the best method of simulating the design event. The effects on different hydrograph parameters, (peak, volume, time to peak, etc.) and therefore on the design dituation, of various combinations (timing and rainfall amount) of distributed input can be assessed. However, without a technique which allows the combination of distributed rainfall inputs to be defined in terms of a joint probability of recurrence, no statement can be made about the return period of the simulated flood. This is another situation where the modelling approach used is less critical than the definition (in the broadest sense) of the input to the model. It is apparent from this conclusion, as well as from some of the others reached above, that for deterministic models to become useful hydrological tools, developments are required in other fields as well as improvements to the models themselves.

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APPENDIX A

Reprint of :

Hughes, D.A. and Wright, A. (1988) Spatial variability of short-term rainfall amounts in a coastal mountain region of southern Africa. **Water S.A.**, 14(3), 131-138.

Spatial variability of short-term rainfall amounts in a coastal mountain region of southern Africa

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Abstract

This paper discusses spatial variations in short-term rainfall in the southern Cape coastal mountain region of southern Africa. The analyses of storm rainfall totals and storm profiles reveal patterns of variability that are similar to those suggested by an earlier analysis of mean annual data in the same region. The patterns of spatial variation appear to be more consistent in winter when a lower diversity of weather patterns is responsible for generating rainfall. Superimposed upon a general increase in storm rainfall with altitude, is a pattern of local rain shadows in the lee of higher relief areas relative to rain bearing winds. For 9 continuously recording rainfall stations, storm profiles exhibit a high degree of similarity in timing and shape but not total rainfall depth. This feature suggests that the spatial variation of temporal intensity occurs on a relatively large scale. The data analysed did not suggest any consistent differences between station profiles that could be attributed to differences in weather patterns.

Introduction

The importance of adequately defining the spatial variation in rainfall for modelling streamflow runoff response has been identified by many authors (Dawdy and Bergmann, 1969; Wilson *et al.*, 1979; Beven and Hornberger, 1982; Bras *et al.*, 1985). If the spatial variability of rainfall input to a model is important (relative to other modelling uncertainties) it follows that the use of a distributed modelling structure is clearly justified (Beven and Hornberger, 1982). This would still be true even when catchment response characteristics are spatially homogeneous. For the purpose of this paper the spatial variability of rainfall is considered at three time-scales.

- Long-term scales, including such measures as mean annual rainfall and mean annual number of rain days.
- Medium-term scales, concentrating on monthly or seasonal totals of rainfall.
- Short-term scales, including daily or individual storm totals as well as the intensity variations within storm events.

With respect to the first two time-scales, spatial variability within a single climate region is most likely to be associated with those physiographic factors that influence the meteorological mechanisms that generate precipitation. Over the long term, relationships between individual gauge totals should be stable as long as the prevailing rainfall generating mechanisms remain the same. This should also be true for the medium term, although seasonal differences in meteorological patterns could produce seasonally variable spatial relationships. The definition of spatial variability at these time-scales should therefore be relatively straightforward. The methods that have been developed (Singh and Chowdhury, 1986) to estimate areal rainfall or to extrapolate point rainfall measurements to ungauged areas should be applicable. Such methods include simple averages, Thiessen polygons and polynomial surfaces.

While the effects of spatial variability in rainfall producing mechanisms may be stable over medium to long time-scales, this may not be generally true over short time-scales. Convective rainstorms usually cover small areas less than about 30km^2 (Waymire and Gupta, 1981) and do not necessarily occur over the same part of some catchment during a number of separate events. Similarly, in areas where orographic effects are important, the differential role of relief during different meteorological situations will influence the spatial variability of rainfall. This is especially true when the relief patterns are complex and where a specific region experiences more than one dominant rainfall producing weather pattern. For example, areas that are in localised rain shadows during some storm types may not be during storms with different characteristics.

The areal extrapolation methods reviewed in Singh and Chowdhury (1986) are difficult to apply at the shorter time-scales because the patterns of variability may not remain the same for different events. Thus a different set of Thiessen polygons or a different polynomial surface would be applicable to each event or group of events. These methods also more or less ignore the meteorological or physiographic causes of spatial variation. Other methods have concentrated on modelling the meteorological causes of spatial and temporal variation. This has been done implicitly using stochastic or mathematical representations of dynamic cells of rainfall during storms (Colton, 1976; Waymire and Gupta, 1981; Amorocho, 1982; Valdes *et al.*, 1985) or explicitly by modelling the physics of storm development and progression (Browning *et al.*, 1973; Harrold, 1973; Hill and Browning, 1979; Hoskins, 1983). The latter are probably too complex for general application to most hydrological problems. The former should have great potential for design storm definition assuming that physiographic effects can be incorporated where necessary. They also have the advantage that the effects of a moving storm and dynamic space-time rainfall relationships are included.

Before any technique can be used to model and estimate the spatial variation of rainfall amounts over a specific area it is necessary to obtain a better understanding of the local complexity of rainfall processes. This paper discusses the spatial variation in short time-scale rainfall in a coastal mountain region of southern Africa where relief has already been shown to have an influence on medium and long time-scale rainfall variables (Hughes, 1982). The analysis is based upon daily rainfall totals for a large number of events as well as intensity data for a smaller number of events. The study reported in this paper was prompted by the need to gain an improved understanding of the spatial variation of rainfall on a shorter time-scale than that used in Hughes (1982). This understanding is needed to better define spatially distributed rainfall input to single event hydrological models.

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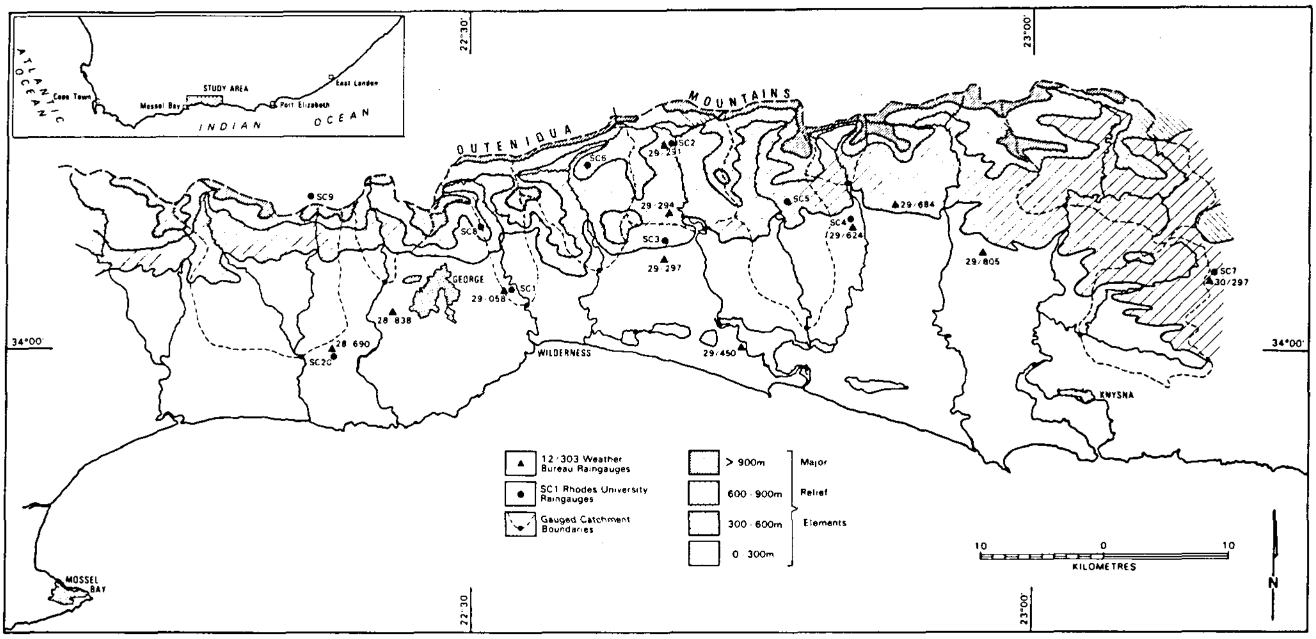

Figure 1
The southern Cape coastal region and the location of the rain gauges used in this study.

Study area

General; weather patterns and instrumentation

The study area is situated on the southern coast of the Republic of South Africa (Fig. 1) and is bounded to the north by the intensively folded Outeniqua Mountains. The physiography and general physical characteristics of the region have been described by Tyson (1971) and Hughes and Görgens (1981). The Outeniqua Mountains reach elevations of 1 600m and are separated from the narrow coastal embayment by a foothills zone and a much wider and deeply incised coastal platform. The region experiences an all-year-round rainfall regime with mean annual precipitation varying between 500mm on parts of the coastline to over 1 200mm in the mountains. Hughes and Görgens (1981) and Hughes (1982) investigated some of the rainfall characteristics of the area based on medium and long time-period rainfall totals. Specifically, a least squares multiple regression approach was used to derive relationships between mean annual and seasonal rainfall totals and physiographic variables. Altitude, longitude and an index of exposure were found to have significant effects on the dependent rainfall variables and the existence of localised but poorly quantified rain-shadow effects was identified. There was found to be a difference between the form of the equations for winter and summer average seasonal totals (Hughes, 1982).

A number of different weather patterns are responsible for generating rainfall over this region. While some have well-defined characteristics in terms of direction of storm movement, storm size, rainfall intensities and wind direction, others are less clear. Tyson (1971), Heydorn and Tinley (1980), and Hurry and Van Heerden (1981) refer to the following rain producing weather systems:

(i) Shallow coastal lows in advance of cold fronts often resulting in low intensity, intermittent rainfall. Rain bearing winds are generally from the south-west.

(ii) Cold fronts resulting in variable intensity and duration (few hours to several days) rainfall. Rain bearing winds from the west to south-west. This system is the dominant rain generating system during the winter months.

(iii) Advection of cool moist air from the south Indian or Atlantic high pressure system. Rain bearing winds can be from the east to south-east.

(iv) Summer convectional storms often enhanced by (iii) with highly variable intensities but usually short durations. Wind directions are locally variable and these storm types are less common than others in this region.

(v) Particularly heavy and often long duration rains are associated with stagnated or slowed down depressions referred to as cut-off lows. Wind directions can be from the south-east or south-west depending upon the positioning of the low pressure system.

Within the study area, there are 26 daily rainfall stations with reasonably long and consistent records, some dating back to the 1880's. Of these, 19 are operated today by the South African Weather Bureau. The average distance separating these gauges is 5,6km and the overall gauge density is approximately 1 gauge per 83km^2. Unfortunately few of the gauges are situated in the relatively inaccessible mountain areas. The Weather Bureau operates an autographic rain gauge at George in the western part of the region and a further 9 continuously recording rain gauges have been established by Rhodes University since 1981. The positions of all gauges are shown in Fig. 1. The only readily available information on the weather systems prevailing during previous storm events is published by the South African Weather Bureau (SAWB, 1980 to 1986) in the form of daily maps of the situation at 14h00 SAST (12h00 GMT).

Available data and methods of analysis

The analysis of short time-scale spatial variations in rainfall amount is initially based upon a data set of 'event totals'. 'Event totals' are defined as the amount of rain over a period of days where rain was recorded on all days. Thus, the 'events' represent continuous rainfall on a daily basis but do not imply truly continuous rainfall. This method of extracting rainfall totals was used, as many of the gauging stations only record daily rainfall. Had individual daily rainfall totals been used, problems would have arisen when short time differences in rain falling at different stations occurred close to the time boundary between days. The distribution of durations of the 218 events used in the analysis is positively skewed with a modal value of 2 d and a mean of 2,9 d. The event totals cover a wide range of rainfall depths from about 1mm to over 200mm. The main area of interest is the western two thirds of the region and consequently 9 daily and 9 continuously recording rain gauges are used in the analysis. Not all stations have records coincident in time and interstation comparisons are based upon different sub-sets of the complete data set. Conventional correlation and least squares regression analyses are used to investigate the patterns of spatial variability for storms occurring during different seasons of the year. The regression relationships between gauge pairs are used to rank the gauges on the basis of the relative amounts of rainfall they receive. This ranking is then assessed in terms of the physiographic position of the gauge locations (mountain top, plateau, ridge, valley, etc.).

Only those nine stations where continuous rainfall data are available (Fig. 1) can be used to examine spatial variations in intensity during events. Their positions vary from the mountain tops (SC9), through different locations in the foothills zone, to the coastal platform area (SC20). The objective of examining a series of individual storm profiles is to identify differences in storm profile shape or timing between differently located gauges and to note whether the weather pattern and particularly the wind direction during rainfall has a consistent effect upon such differences. If there is little consistency, then extrapolation from the available observed rainfall data will be difficult. As timing and gross rainfall depths are important in comparing stations, the storm profiles are plotted using absolute and not relative axes scales. A total of 20 storms are examined but not every gauge is represented for all events. Emphasis is placed on the larger rainfall events that occurred during the period over which continuous rainfall data have been collected (1981 to 1986).

Results and discussion

Of the 153 pairwise correlations (the maximum possible using 18 rain gauge stations), 102 are based upon more than 10 values in both winter and summer seasons and have correlation coefficients significant at the 1% level or better. Table 1 lists the number of pairs having coefficients of determination (R^2) values within 10 groups of range 0,1. The greater number of higher correlations and fewer low correlations suggest that the pattern of spatial variation in rainfall during winter is generally more consistent than during summer. The average distance separating gauge pairs having R^2 values of 0,9 or greater is 2,7km for the summer data and 5,5km for winter.

The results in Table 1 might be expected if the relief plays a differential role during different rainfall producing weather types. The differential role may be due to differences in wind direction affecting local rain-shadow effects. It may also be due to differences in the larger scale orographic effect on uplift during different meteorological conditions. During winter the predominant rainfall generating weather system is an east-moving cold front trough with associated west to south-westerly winds during the rain period. In summer a greater diversity of weather system types are responsible for rainfall. These can be small or large area storms and also have a wider variety of associated rain bearing wind directions than winter storms. There are, unfortunately, insufficient readily available meteorological data to allow a more thorough analysis based upon individual weather types.

TABLE 1
COMPARISON OF COEFFICIENT OF DETERMINATION VALUES FOR THE SUMMER AND WINTER SEASON ANALYSES.

Coefficient of determination (range of R^2)	Number of pairs (total 102) Summer	Winter
1,0 to 0,9	11	46
0,9 to 0,8	32	19
0,8 to 0,7	25	21
0,7 to 0,6	14	6
0,6 to 0,5	10	6
0,5 to 0,4	5	2
0,4 to 0,3	4	1
0,3 to 0,2	1	0
0,2 to 0,1	0	0
0,1 to 0,0	0	1

Summer: months 10 to 3; Winter: months 4 to 9

To estimate which gauges receive more rainfall during storm events, each individual gauge is selected to be the dependent variable and regression equations calculated using all other gauges in turn as independent variables. Scattergram plots (Fig. 2) of all relationships indicate that the linear regression model is applicable and no noticeable curvilinear relationships between gauge pairs are evident. The analyses are based on all the data as well as separated summer and winter season data. Figures for the average equivalent rainfall expected at other stations given 50mm at the dependent variable station are calculated (Table 2) from the following equation.

$$\text{Average equivalent rain} = \frac{1}{n}\sum_{i=1}^{n} (50-\text{Int}_i)/\text{Sl}_i$$

where n = number of other stations

Int_i and Sl_i = intercept and slope in the regression equation with station i as the independent variable.

The stations are ranked in Table 2 using the figures for the average equivalent rainfall (AER) based on all the data. The figures for AER based on summer and winter data are also given where a sufficient number of data points allow their calculation. A different pattern would only be produced if a much lower constant rainfall value had been chosen as most of the intercepts are small (less than 5mm). Those stations that emerge as having

TABLE 2
RANKING OF STATIONS BASED ON REGRESSION ANALYSIS.

Station name of dependent variable rain = 50mm		Average equivalent rain at other stations All data (mm)	Summer data (mm)	Winter data (mm)	MAP (mm)
SC9	Mtn.top	28,0	25,5	??	
SC8	F.hill ridge	35,2	34,4	??	
28/838	Plateau	45,8	45,1	47,2	885
29/297	Plateau	46,7	53,9	43,3	800
SC5	F.hill ridge	47,1	49,5	45,4	
SC1	Plateau	50,7	44,7	47,8	
29/058	Plateau	51,8	51,1	50,7	848
29/294	F.hill val.	55,7	57,1	49,5	837
29/291	Mtn.val.	56,4	67,6	53,9	613
SC3	F.hill ridge	58,7	58,9	59,0	
29/805	Plateau	59,0	62,6	54,4	810
SC6	Mtn. ridge	62,7	64,7	62,9	
29/624	Plateau	62,9	68,1	54,5	827
29/690	Plateau	63,1	62,9	56,5	
SC20	Plateau	64,6	63,1	73,0	
29/450	Coast	66,3	73,9	54,4	652
SC2	Mtn.val	76,0	79,6	76,9	
SC4	Plateau	84,4	90,4	95,1	

Mtn.top - Mountain top; Mtn./F.hill ridge - mountain/foothill ridge; Mtn./F.hill val - valley area in mountains/foothills; Plateau - coastal plateau; Coast - coastal plain; ?? Insufficient data

relatively high rainfall amounts are the mountain top station (SC9), foothill ridge stations (SC8 and SC5) and some of the plateau stations which are close to the edge of the foothills (SC1, 29/058, 29/297). Those emerging as lower rainfall stations are the coastal site (29/450), some enclosed valley areas in the mountains (SC2 and 29/291) and two of the plateau sites that are remote from the foothills (SC20, 29/690). Stations SC6 and SC3 are ranked relatively low and reference to Fig. 1 illustrates that they may be in a westerly rain shadow from the NW-SE trending ridge to the west. A comparison between the summer and winter AER values reveals a rather confusing pattern. In many cases the two values are similar (29/058, SC3 and SC2 for example) while others have higher summer values (29/297 and 29/450 for example) or winter values (SC20). The mean annual rainfall values for those stations common to this study and that of Hughes (1982) are included in Table 2 for comparative purposes.

The pattern of differences between the rainfall at the various stations corresponds to a certain extent with the pattern suggested by analysis of the long time period data in Hughes (1982). However, there appear to be several differences, notably stations 29/297 and 29/291. The pattern remains one of increasing rainfall with elevation but confused by local rain-shadow influences during at least some of the prevailing rainfall producing weather types. The additional data provided by the more recently established gauges have extended the information about the patterns of spatial rainfall variation. This is particularly true of gauges SC6, SC8 and SC9. The position of SC6 in an elevated location, but in the lee of hills to both the west and east, is not represented by any of the earlier established gauges. Similarly, SC9 provides more information about likely mountain top maximums and SC8 about exposed mid-elevation locations. However, the additional data are still not adequate to define the complexity of the spatial variations satisfactorily.

There are insufficient data to thoroughly analyse the influence of various weather patterns on storm totals which may otherwise provide greater insight into the suggested rain-shadow effects. If the data were grouped according to weather system type, the number of storms represented in some groups would be insufficient to satisfactorily define the inter-station relationships. In addition, definition of weather system type is based upon the weather maps produced for 14h00 SAST (12h00 GMT) each day by the South African Weather Bureau (SAWB, 1980 to 1986). Although these provide a good impression of the general synoptic situation they do not contain enough detail for satisfactory definition of the meteorological conditions prevailing over the study area during storm events. This factor places some limitations on any analysis of intensity variations within storms. It is often difficult to determine the predominant wind direction, as the synoptic charts illustrate that it can move through 180° during some storms. Despite these problems, 20 storm profiles are investigated. The storm durations vary between 5 and 70 h while total rainfall amount varies between 10 and 180mm. Data from 9 continuously recording rain gauges are used (SC1 to SC3, SC5 to SC9 and SC20) but not all gauges are represented for each storm. Although outside the main area of interest, SC7 was included to discover if any time differences between rain falling at the western and eastern edges of the region could be noted. Four of the storm profiles are illustrated in Figs. 3 to 6.

There is generally a high degree of similarity in the shapes of the profiles. High and low intensity periods during the storms occur at very similar times at all the stations for most of the events analysed. It is interesting to note that for the higher rainfall

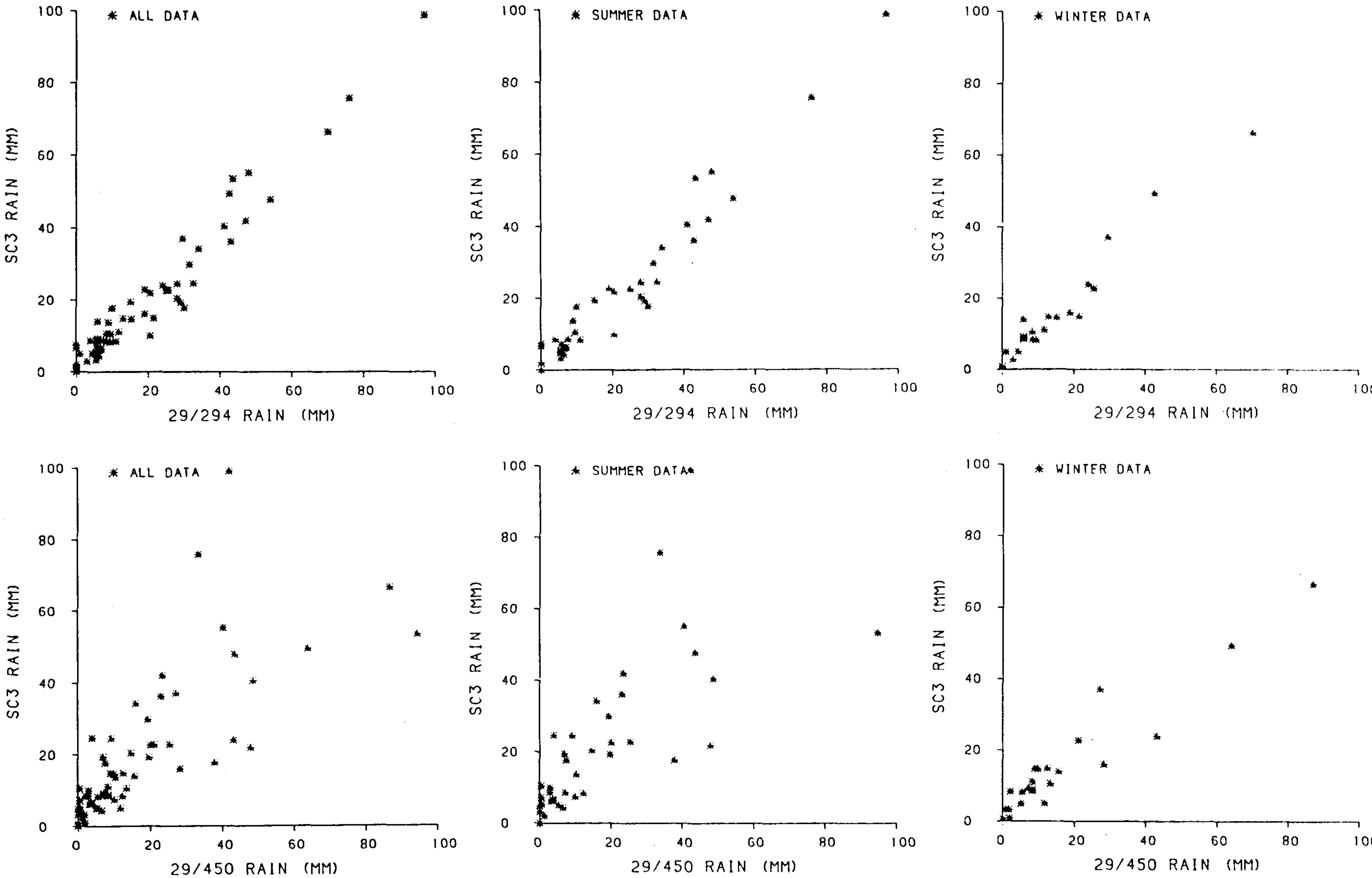

Figure 2
Scattergrams for two station pairs. In both cases all the data, summer data and winter data are plotted separately.

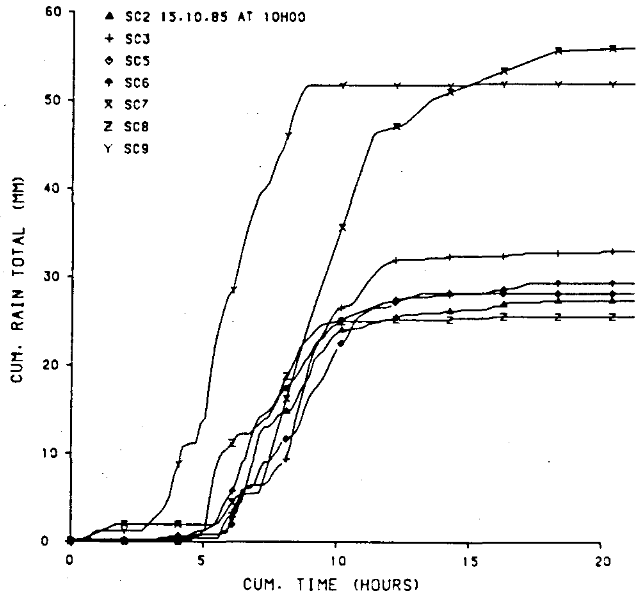

Figure 3
Storm profiles for the event of 15 October 1985: A cold front passed the southern Cape during the morning of 15 October.

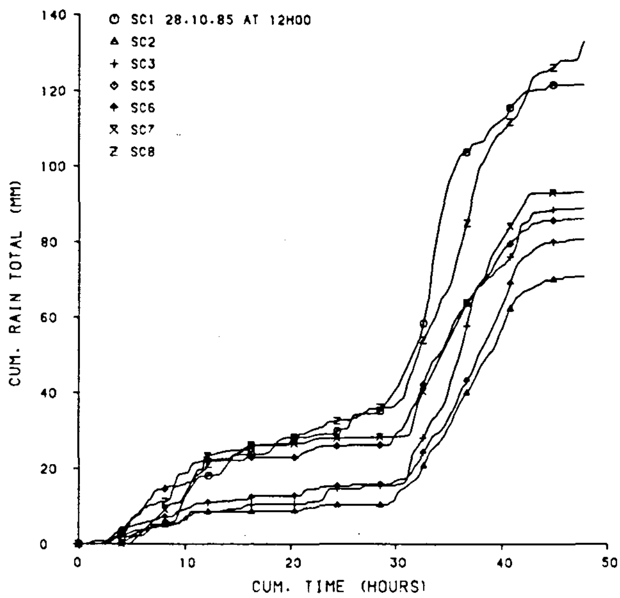

Figure 4
Storm profiles for the event of 28 October 1985: A cold front passed the southern Cape during the morning of 28 October. By 14h00 on 29 October the south Atlantic high had ridged in below the coast and a cut-off had developed over the western parts of southern Africa.

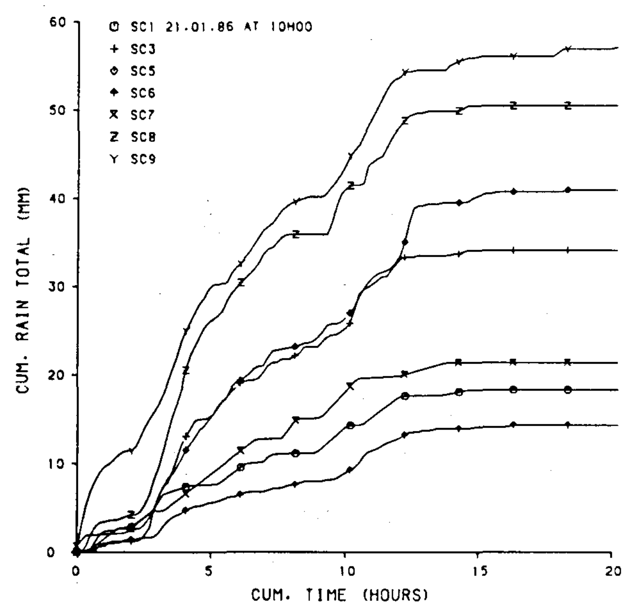

Figure 5
Storm profiles for the event of 21 January 1986: A weak front passed over the southern Cape during the morning of 21 January to be followed by advection of moist air from the south east.

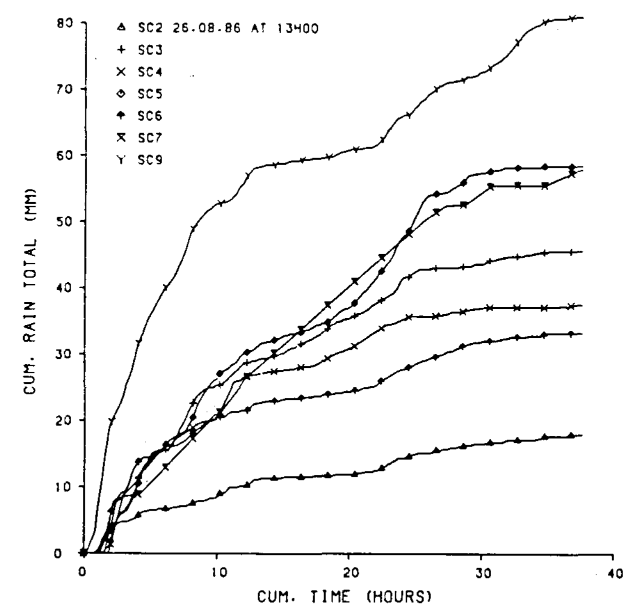

Figure 6
Storm profiles for the event of 26 August 1986: A cold front passed over the southern Cape at midday on 26 August giving rise to SW winds. On 27 August, an interior low developed and light SE winds prevailed towards the end of the event.

advection storms, very similar start times and durations occur for the gauges discussed here and a gauge situated in Grahamstown some 350 to 400km to the east. An exception to the timing similarity is that during most cold front situations (Figs. 3 and 6) rainfall begins sooner at SC9 (up to 3 h) than at the other stations. Comparison with SC20 indicates that this is related to its elevated location rather than its westerly position in the region. Similarly, during the passage of some cold fronts, SC7 can experience substantially more rainfall than most other stations. However, during advection situations with predominantly SE winds, SC7 receives relatively lower rainfalls. This feature is illustrated by the storm of 28.10.85 (Fig. 4) where a cold front (SW winds) is followed immediately by advection (SE winds) caused by the Atlantic high ridging in to the south of the Cape coast. This type of weather pattern appears to be common in the region. The 7 profiles exhibit similar shapes but have different relative intensities throughout the storm. In the early part (cold front), the more exposed stations (SC1, 5, 7 and 8) rise to between 30 and 40mm while SC2, 3 and 6 only experience between 10 and 15mm. During the advection storm SC1 and 8 receive an additional 90 to 100mm, SC3 and 6 about 70mm while the remainder receive less than 60mm. Fig. 5 illustrates a similar situation where the passage of a front is represented by only the first few hours of the profiles and resulted in less than 5mm of rain at most stations.

In general, the pattern of relative amounts of rainfall occurring at the stations is not consistent. In addition, the rainfall differences are not easily attributable to differences in weather type using the information available from the weather maps. However, some general observations can be made. Despite being in relatively elevated positions, SC2 and SC6 commonly experience some of the lowest rainfalls. The exposed mountain top and ridge stations (SC5, 8 and 9) more consistently experience the higher rainfalls. The remaining stations exhibit little consistency, sometimes having relatively high amounts and at other times low rainfalls.

Both the storm total and the profile analyses demonstrate that there is a great deal of variability in the spatial patterns of rainfall. Although some general observations can be made, quantification of the patterns at a level that might be useful for satisfactorily defining the input to distributed catchment models does not appear to be possible.

Conclusions

- The analysis of short time-scale spatial variations confirms some of the conclusions reached by Hughes (1982) based upon mean annual totals. While there appears to be a general increase in storm total rainfall with altitude, this pattern is confused by localised lower rainfall areas within the foothills or mountains. The pattern is not very consistent for the range of storms included in the analysis.
- Hughes (1982) observed some differences between the relationships of dry and wet season rainfall totals with physiographic factors. In a similar way, there is a lower degree of scatter in pairwise relationships between gauges based on winter storm data (wet season in Hughes (1982) refers to April to July) than for summer storms. The difference may be attributable to a lower diversity of rainfall generating weather types in winter than summer.
- Given the second conclusion it is unfortunate that the available information does not allow a more thorough analysis of the effects of different meteorological conditions, prevailing during storms, on relative station rainfalls. The storm profile analysis revealed some station differences that are apparently related to storm type. However, few or no reasons could be found for the differences. Perhaps the most useful observation is the degree of similarity in the timing and shape of the station profiles for individual storms. This suggests that temporal intensity variations during storm events over this region occur at a relatively large spatial scale. Cells of higher intensity rainfall due to purely atmospheric processes (as within convective storms) do not appear to occur over this area at spatial scales that are relevant to modelling hydrological processes.
- To provide adequate rainfall input to hydrological models it is necessary to extrapolate from the data observed at existing rain gauges. It was initially hoped that a detailed analysis of the few years of rainfall intensity data would reveal more consistent inter-station relationships. Such relationships might then have been used to extrapolate from the data provided by the many daily and few autographic gauges that existed before the network was expanded after 1981. The inconsistent patterns that have been demonstrated by this study preclude the likelihood of successful extrapolation. The conclusions illustrate that the application of deterministic hydrological models in this and similar mountain areas of South Africa is severely handicapped by our ability to adequately define the catchment rainfall input.

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APPENDIX B

Computer listing of catchment characteristic indices.

PHYSIOGRAPHIC INDICES :

AREA	Sub-catchment area (km^2)
SLOPE	Average sub-catchment slope (%)
DDENS	Drainage density (km/km^2)
TC	Time of concentration (units of length)
ORD1	Shreve channel order
CDIST	Channel distance between sub-area nodes (km)
ROUGH	Channel roughness characteristic index

SOIL AND VEGETATION INDICES :

DEPTH	Soil depth index
INFIL	Soil infiltration characteristics index
PERMC	Soil permeability characteristics index
VEGC	Catchment vegetation cover index
ENERG	Incoming radiation index
WHCAP	Soil water holding capacity index
SL/V	Valley slope to valley bottom soil depth ratio

PHYSIOGRAPHIC INDICES

Area	ID	1 AREA	2 SLOPE	3 DDENS	4 TC	5 ORD1	6 CDIST	7 ROUGH
TM11	1	3.000	7.900	4.000	1.000	1.000	4.400	2.000
TM11	2	3.200	7.900	4.000	0.900	3.000	4.300	2.000
TM11	3	2.000	7.900	4.000	1.000	5.000	3.100	2.000
TM8	4	2.100	7.900	4.000	1.300	2.000	2.100	2.000
TM8	5	1.800	7.900	4.000	1.200	5.000	2.000	2.000
TM8	6	1.600	7.900	4.000	0.900	7.000	1.500	2.000
TM8	7	1.800	7.900	4.000	0.500	7.000	2.600	2.000
TM3	1	2.200	7.900	4.000	1.700	5.000	2.600	2.000
TM3	2	2.400	7.900	4.000	1.300	6.000	3.500	2.000
TM3	3	2.300	7.900	4.000	0.800	2.000	1.500	2.000
TM3	4	2.100	7.900	4.000	0.500	8.000	1.500	2.000
TM6	1	9.500	9.000	4.000	3.300	5.000	9.100	2.000
TM6	2	7.600	7.900	4.000	1.900	6.000	5.500	2.000
TM6	3	13.300	7.900	4.000	2.700	1.000	9.200	2.000
TM6	4	10.400	7.900	4.000	2.700	3.000	9.600	2.000
TM6	5	13.300	8.000	4.000	2.000	4.000	2.500	2.000
TM6	6	8.600	8.000	4.000	1.400	7.000	2.800	2.000
TM6	7	10.500	12.500	4.000	1.200	5.000	3.200	2.000
TM6	8	7.100	8.000	4.000	0.800	21.000	3.500	2.000
TM2	10	10.200	8.000	4.000	1.100	40.000	4.900	2.000
TM1	11	10.200	10.000	4.000	1.900	11.000	3.400	2.000
TM1	12	11.200	8.000	4.000	1.800	3.000	5.300	2.000
TM1	13	10.500	11.500	4.000	1.100	66.000	2.800	2.000
ECCA	1	9.900	13.000	1.200	4.600	6.000	3.300	8.000
ECCA	2	4.400	13.000	1.800	4.100	14.000	3.800	8.000
ECCA	3	4.100	13.000	1.800	4.100	9.000	3.200	8.000
ECCA	4	5.100	20.000	1.800	3.700	32.000	2.400	8.000
ECCA	5	4.600	15.000	1.800	3.700	6.000	3.000	8.000
ECCA	6	5.200	15.000	1.800	3.800	5.000	2.400	8.000
ECCA	7	8.300	18.000	2.400	3.000	19.000	2.500	8.000
ECCA	8	5.800	17.000	2.400	2.600	18.000	2.000	8.000
ECCA	9	4.400	20.000	2.200	2.100	12.000	1.600	8.000
ECCA	10	7.100	20.000	2.000	1.600	110.000	3.400	8.000
ECCA	11	9.500	21.400	2.200	1.100	22.000	3.800	8.000
ECCA	12	5.500	13.000	2.200	0.600	146.000	1.400	8.000
BETH	1	10.300	3.500	1.000	3.900	5.000	3.900	6.000
BETH	2	11.200	3.500	0.750	3.100	8.000	3.900	6.000
BETH	3	10.100	3.000	0.850	3.300	2.000	5.300	6.000
BETH	4	14.700	3.000	1.000	3.300	6.000	4.800	6.000
BETH	5	6.900	4.000	0.750	2.000	17.000	3.800	6.000
BETH	6	11.200	3.500	1.000	2.200	11.000	5.000	6.000
BETH	7	3.600	3.500	0.750	1.300	1.000	3.600	6.000
BETH	8	8.000	4.000	0.900	1.200	5.000	3.400	6.000
BETH	9	7.000	3.000	1.000	0.400	38.000	1.400	6.000
HOEK	1	2.100	15.000	1.500	0.600	1.000	1.300	6.000
HOEK	2	0.800	32.000	2.000	0.600	8.000	1.500	6.000
HOEK	3	3.000	25.000	3.500	0.800	23.000	1.900	6.000
HOEK	4	2.100	25.000	3.500	0.800	14.000	1.400	6.000
HOEK	5	1.000	22.000	3.000	0.700	2.000	1.200	6.000
HOEK	6	1.300	10.000	2.000	0.600	41.000	0.800	6.000
HOEK	7	1.000	35.000	2.000	0.400	58.000	1.300	6.000
HOEK	8	1.300	10.000	2.500	0.400	6.000	2.000	6.000

HOEK	9	2.000	25.000	3.500	0.200	13.000	1.400	6.000
CED	1	1.900	20.000	2.900	0.450	8.000	1.950	6.000
CED	2	1.600	16.000	2.900	0.420	8.000	1.800	6.000
CED	3	1.700	12.000	2.900	0.180	24.000	1.800	6.000
ZULU	1	1.700	19.000	2.500	1.100	7.000	1.400	4.000
ZULU	2	1.400	17.500	2.500	0.900	12.000	2.100	4.000
ZULU	3	1.800	21.500	2.500	0.600	17.000	0.600	4.000
ZULU	4	1.800	24.000	1.500	0.600	1.000	0.800	4.000
ZULU	5	1.200	30.000	2.500	1.000	3.000	2.100	4.000
ZULU	6	1.500	30.000	2.500	0.800	3.000	1.600	4.000
ZULU	7	1.200	34.000	2.500	0.600	9.000	1.100	4.000
ZULU	8	1.000	16.000	2.500	0.400	31.000	1.300	4.000
ZULU	9	0.600	16.000	2.500	0.200	32.000	1.000	4.000
ZULU	10	1.400	16.000	2.500	0.300	34.000	1.400	4.000
OX4W	1	4.100	12.000	2.000	0.800	2.000	1.400	3.000
OX4W	2	4.000	12.000	2.000	0.400	5.000	1.400	3.000
OX4S	1	4.100	12.000	2.000	0.800	2.000	1.400	3.000
OX4S	2	4.000	12.000	2.000	0.400	5.000	1.400	3.000
OX12W	1	8.400	13.000	2.000	3.300	5.000	4.500	3.000
OX12W	2	8.200	13.000	2.000	3.000	7.000	4.700	3.000
OX12W	3	4.000	12.000	2.000	3.400	5.000	2.100	3.000
OX12W	4	7.200	12.000	2.000	2.900	7.000	4.500	3.000
OX12W	5	9.300	8.000	1.500	1.600	23.000	3.500	3.000
OX12W	7	11.800	8.000	1.500	1.600	7.000	4.200	3.000
OX12W	8	10.000	12.000	2.000	2.700	6.000	2.200	3.000
OX12W	9	7.100	13.000	2.000	2.000	9.000	2.300	3.000
OX12W	10	7.800	8.000	1.500	1.200	9.000	2.700	3.000
OX12W	11	4.500	8.500	1.800	2.400	1.000	2.300	3.000
OX12W	12	6.100	8.000	1.800	1.700	2.000	4.500	3.000
OX12P	1	8.400	13.000	2.000	3.300	5.000	4.500	3.000
OX12P	2	8.200	13.000	2.000	3.000	7.000	4.700	3.000
OX12P	3	4.000	12.000	2.000	3.400	5.000	2.100	3.000
OX12P	4	7.200	12.000	2.000	2.900	7.000	4.500	3.000
OX12P	5	9.300	8.000	1.500	1.600	23.000	3.500	3.000
OX12P	7	11.800	8.000	1.500	1.600	7.000	4.200	3.000
OX12P	8	10.000	12.000	2.000	2.700	6.000	2.200	3.000
OX12P	9	7.100	13.000	2.000	2.000	9.000	2.300	3.000
OX12P	10	7.800	8.000	1.500	1.200	9.000	2.300	3.000
OX12P	11	4.500	8.500	1.800	2.400	1.000	2.300	3.000
OX12P	12	6.100	8.000	1.800	1.700	2.000	4.500	3.000
OX12S	1	8.400	13.000	2.000	3.300	5.000	4.500	3.000
OX12S	2	8.200	13.000	2.000	3.000	7.000	4.700	3.000
OX12S	3	4.000	12.000	2.000	3.400	5.000	2.100	3.000
OX12S	4	7.200	12.000	2.000	2.900	7.000	4.500	3.000
OX12S	5	9.300	8.000	1.500	1.600	23.000	3.500	3.000
OX12S	7	11.800	8.000	1.500	1.600	7.000	4.200	3.000
OX12S	8	10.000	12.000	2.000	2.700	6.000	2.200	3.000
OX12S	9	7.100	13.000	2.000	2.000	9.000	2.300	3.000
OX12S	10	7.800	8.000	1.500	1.200	9.000	2.700	3.000
OX12S	11	4.500	8.500	1.800	2.400	1.000	2.300	3.000
OX12S	12	6.100	8.000	1.800	1.700	2.000	4.500	3.000
OX10W	1	6.100	11.000	2.000	1.600	4.000	1.700	3.000
OX10W	2	4.800	11.000	2.000	1.000	5.000	2.500	3.000
OX10W	3	3.900	11.000	2.000	1.300	2.000	3.300	3.000
OX10W	4	4.500	11.000	2.000	0.700	2.000	1.800	3.000
OX10W	5	3.100	11.000	2.000	0.500	9.000	1.500	3.000
OX10P	1	6.100	11.000	2.000	1.600	4.000	1.700	3.000

OX10P	2	4.800	11.000	2.000	1.000	5.000	2.500	3.000
OX10P	3	3.900	11.000	2.000	1.300	2.000	3.300	3.000
OX10P	4	4.500	11.000	2.000	0.700	2.000	1.800	3.000
OX10P	5	3.100	11.000	2.000	0.500	9.000	1.500	3.000
OX10S	1	6.100	11.000	2.000	1.600	4.000	1.700	3.000
OX10S	2	4.800	11.000	2.000	1.000	5.000	2.500	3.000
OX10S	3	3.900	11.000	2.000	1.300	2.000	3.300	3.000
OX10S	4	4.500	11.000	2.000	0.700	2.000	1.800	3.000
OX10S	5	3.100	11.000	2.000	0.500	9.000	1.500	3.000
OX35W	1	4.200	9.000	1.500	3.200	2.000	2.600	3.000
OX35W	2	5.000	9.000	1.500	2.400	6.000	2.700	3.000
OX35W	3	2.100	9.000	1.500	2.600	2.000	1.700	3.000
OX35W	4	3.100	9.000	1.500	2.100	3.000	2.400	3.000
OX35W	5	2.700	9.000	1.500	2.100	12.000	2.300	3.000
OX35W	6	4.600	9.000	1.500	1.500	12.000	4.100	3.000
OX35W	7	4.000	9.000	2.000	1.000	6.000	3.600	3.000
OX35W	8	4.700	9.000	2.000	0.800	22.000	3.100	3.000
OX35P	1	4.200	9.000	1.500	3.200	2.000	2.600	3.000
OX35P	2	5.000	9.000	1.500	2.400	6.000	2.700	3.000
OX35P	3	2.100	9.000	1.500	2.600	2.000	1.700	3.000
OX35P	4	3.100	9.000	1.500	2.100	3.000	2.400	3.000
OX35P	5	2.700	9.000	1.500	2.100	12.000	2.300	3.000
OX35P	6	4.600	9.000	1.500	1.500	12.000	4.100	3.000
OX35P	7	4.000	9.000	2.000	1.000	6.000	3.600	3.000
OX35P	8	4.700	9.000	2.000	0.800	22.000	3.100	3.000
OX35S	1	4.200	9.000	1.500	3.200	2.000	2.600	3.000
OX35S	2	5.000	9.000	1.500	2.400	6.000	2.700	3.000
OX35S	3	2.100	9.000	1.500	2.600	2.000	1.700	3.000
OX35S	4	3.100	9.000	1.500	2.100	3.000	2.400	3.000
OX35S	5	2.700	9.000	1.500	2.100	12.000	2.300	3.000
OX35S	6	4.600	9.000	1.500	1.500	12.000	4.100	3.000
OX35S	7	4.000	9.000	2.000	1.000	6.000	3.600	3.000
OX35S	8	4.700	9.000	2.000	0.800	22.000	3.100	3.000
OX17W	11	6.400	12.000	1.800	3.000	4.000	1.800	3.000
OX17W	12	5.200	10.000	1.500	2.500	5.000	2.600	3.000
OX17W	13	6.400	10.000	1.500	1.600	46.000	3.300	3.000
OX17W	14	9.200	13.000	2.000	1.900	3.000	2.500	3.000
OX17W	15	6.500	8.000	1.500	1.100	3.000	2.600	3.000
OX17W	16	4.700	10.000	1.500	0.700	2.000	2.300	3.000
OX17P	11	6.400	12.000	1.800	3.000	4.000	1.800	3.000
OX17P	12	5.200	10.000	1.500	2.500	5.000	2.600	3.000
OX17P	13	6.400	10.000	1.500	1.600	46.000	3.300	3.000
OX17P	14	9.200	13.000	2.000	1.900	3.000	2.500	3.000
OX17P	15	6.500	8.000	1.500	1.100	3.000	2.600	3.000
OX17P	16	4.700	10.000	1.500	0.700	2.000	2.300	3.000
OX17S	11	6.400	12.000	1.800	3.000	4.000	1.800	3.000
OX17S	12	5.200	10.000	1.500	2.500	5.000	2.600	3.000
OX17S	13	6.400	10.000	1.500	1.600	46.000	3.300	3.000
OX17S	14	9.200	13.000	2.000	1.900	3.000	2.500	3.000
OX17S	15	6.500	8.000	1.500	1.100	3.000	2.600	3.000
OX17S	16	4.700	10.000	1.500	0.700	2.000	2.300	3.000
OX32W	9	4.400	7.000	1.500	3.900	2.000	3.700	3.000
OX32W	10	5.200	7.000	1.200	2.700	24.000	2.100	3.000
OX32W	11	5.900	7.000	1.200	1.900	25.000	0.500	3.000
OX32W	12	6.000	7.000	1.200	1.200	28.000	2.200	3.000
OX32W	18	6.900	7.000	1.800	0.800	40.000	2.400	3.000
OX32P	9	4.400	7.000	1.500	3.900	2.000	3.700	3.000

OX32P	10	5.200	7.000	1.200	2.700	24.000	2.100	3.000
OX32P	11	5.900	7.000	1.200	1.900	25.000	0.500	3.000
OX32P	12	6.000	7.000	1.200	1.200	28.000	2.200	3.000
OX32P	18	6.900	7.000	1.800	0.800	40.000	2.400	3.000
OX32S	9	4.400	7.000	1.500	3.900	2.000	3.700	3.000
OX32S	10	5.200	7.000	1.500	2.700	24.000	2.100	3.000
OX32S	11	5.900	7.000	1.200	1.900	25.000	0.500	3.000
OX32S	12	6.000	7.000	1.200	1.200	28.000	2.200	3.000
OX32S	18	6.900	7.000	1.800	0.800	40.000	2.400	3.000
KAAI	1	7.500	44.000	2.800	3.200	17.000	3.000	6.000
KAAI	2	4.100	44.000	2.000	3.000	52.000	3.400	6.000
KAAI	3	4.200	46.000	2.800	2.900	33.000	4.500	6.000
KAAI	4	8.300	44.000	2.800	3.000	19.000	4.500	6.000
KAAI	5	5.300	48.000	2.600	2.500	87.000	2.400	6.000
KAAI	6	6.200	40.000	2.600	2.200	102.000	2.700	6.000
KAAI	7	5.300	36.000	2.600	1.800	113.000	4.200	6.000
KAAI	8	4.400	36.000	2.400	1.000	129.000	3.000	6.000
KAAI	9	2.700	36.000	2.400	0.600	4.000	3.500	6.000
MALG	1	5.200	46.000	2.200	1.400	12.000	3.000	7.000
MALG	2	4.400	46.000	2.200	1.300	11.000	2.500	7.000
MALG	3	2.700	42.000	1.900	1.100	2.000	3.800	7.000
MALG	4	4.100	42.000	1.900	1.200	38.000	3.500	7.000
MALG	5	5.400	38.000	1.900	0.900	5.000	3.800	7.000
MALG	6	4.900	38.000	1.900	0.800	7.000	3.700	7.000
MALG	7	2.900	30.000	1.900	0.500	50.000	1.900	7.000
MALG	8	4.400	30.000	1.900	0.500	3.000	2.800	7.000
NDAN5	1	8.400	12.500	1.200	2.200	4.000	2.900	5.000
NDAN5	2	5.800	11.000	1.200	1.900	7.000	6.400	5.000
NDAN5	3	7.700	12.000	1.200	2.100	3.000	5.100	5.000
NDAN5	4	8.400	13.900	1.200	2.200	3.000	3.200	5.000
NDAN5	5	7.200	12.000	0.800	1.900	6.000	2.700	5.000
NDAN5	6	5.400	12.500	0.800	1.400	14.000	2.900	5.000
NDAN5	7	5.800	11.500	1.000	1.800	2.000	3.700	5.000
NDAN5	8	6.200	11.000	0.800	1.500	1.000	1.800	5.000
NDAN5	9	4.800	12.000	0.600	1.200	3.000	2.700	5.000
NDAN5	10	8.600	14.000	1.200	2.900	4.000	2.500	5.000
NDAN5	11	5.500	12.000	1.000	2.700	5.000	2.700	5.000
NDAN5	12	5.500	12.000	0.900	2.300	9.000	4.200	5.000
NDAN5	13	4.900	13.000	0.900	2.900	1.000	3.900	5.000
NDAN5	14	8.400	15.000	1.200	2.400	4.000	4.400	5.000
NDAN5	15	5.100	16.000	1.200	2.100	2.000	3.100	5.000
NDAN5	16	6.000	15.000	1.000	1.500	12.000	3.200	5.000
NDAN5	17	2.200	14.500	1.000	0.600	1.000	0.500	5.000
NDAN5	18	5.700	14.500	0.900	0.800	2.000	2.100	5.000

SOIL AND VEGETATION INDICES

Area	ID	1 DEPTH	2 INFIL	3 PERMC	4 VEGC	5 ENERG	6 WHCAP	7 Sl/V
TM11	1	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM11	2	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM11	3	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM8	4	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM8	5	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM8	6	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM8	7	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM3	1	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM3	2	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM3	3	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM3	4	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	1	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	2	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	3	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	4	7.000	8.000	6.000	2.000	9.000	5.000	0.850
TM6	5	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	6	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	7	6.000	8.000	6.000	2.000	9.000	5.000	0.900
TM6	8	8.000	8.000	6.000	2.000	9.000	5.000	0.750
TM2	10	8.000	8.000	6.000	2.000	9.000	5.000	0.900
TM1	11	6.000	8.000	6.000	2.000	9.000	5.000	0.800
TM1	12	8.000	8.000	6.000	2.000	9.000	5.000	0.850
TM1	13	8.000	8.000	6.000	2.000	9.000	5.000	0.800
ECCA	1	6.000	4.000	3.000	4.000	4.000	8.000	0.400
ECCA	2	4.500	4.000	3.000	4.000	4.000	8.000	0.400
ECCA	3	4.500	4.000	3.000	4.000	4.000	8.000	0.400
ECCA	4	4.000	4.000	3.000	4.000	4.000	8.000	0.400
ECCA	5	4.000	4.000	3.000	4.000	4.000	8.000	0.400
ECCA	6	4.000	4.000	3.000	4.000	4.000	8.000	0.400
ECCA	7	4.000	4.000	3.000	4.000	4.000	8.000	0.200
ECCA	8	4.000	4.000	3.000	4.000	4.000	8.000	0.200
ECCA	9	4.000	4.000	3.000	4.000	4.000	8.000	0.200
ECCA	10	5.000	4.000	3.000	4.000	4.000	8.000	0.200
ECCA	11	4.000	4.000	3.000	4.000	4.000	8.000	0.200
ECCA	12	5.000	4.000	3.000	4.000	4.000	8.000	0.400
BETH	1	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	2	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	3	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	4	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	5	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	6	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	7	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	8	6.000	3.000	6.000	5.000	7.000	4.000	1.000
BETH	9	6.000	3.000	6.000	5.000	7.000	4.000	1.000
HOEK	1	6.500	6.000	6.000	6.000	7.000	6.500	0.800
HOEK	2	3.000	5.000	5.000	5.000	7.000	6.500	0.300
HOEK	3	5.500	4.500	4.000	5.000	7.000	6.500	0.700
HOEK	4	6.000	5.000	4.500	5.000	7.000	6.500	0.700
HOEK	5	5.500	4.500	4.500	5.000	7.000	6.500	0.600
HOEK	6	7.000	4.500	3.500	5.000	7.000	6.500	1.000
HOEK	7	3.000	4.500	4.500	5.000	7.000	6.500	0.300
HOEK	8	6.000	5.000	3.500	5.000	7.000	6.500	0.900

HOEK 9	5.500	5.000	4.000	5.000	7.000	6.500	0.700
CED 1	8.000	8.000	6.000	8.000	7.000	6.000	0.850
CED 2	8.000	8.000	6.000	8.000	7.000	6.000	0.850
CED 3	8.000	8.000	6.000	8.000	7.000	6.000	0.850
ZULU 1	9.000	7.000	6.000	7.000	6.000	6.000	0.850
ZULU 2	9.000	7.000	6.000	7.000	6.000	6.000	0.850
ZULU 3	7.000	7.000	5.000	7.000	6.000	6.000	0.850
ZULU 4	5.000	7.000	5.000	7.000	6.000	6.000	0.600
ZULU 5	2.000	4.000	5.000	5.000	6.000	6.000	0.600
ZULU 6	3.000	7.000	5.000	6.000	6.000	6.000	0.600
ZULU 7	3.000	7.000	5.000	6.000	6.000	6.000	0.600
ZULU 8	5.000	7.000	5.000	7.000	6.000	6.000	0.600
ZULU 9	5.000	7.000	5.000	7.000	6.000	6.000	0.600
ZULU 10	5.000	7.000	5.000	7.000	6.000	6.000	0.600
OX4W 1	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX4W 2	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX4S 1	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX4S 2	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX12W 1	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX12W 2	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX12W 3	5.000	6.000	6.000	3.000	4.000	7.000	0.900
OX12W 4	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX12W 5	5.500	6.000	6.000	3.000	4.000	7.000	1.000
OX12W 7	5.500	6.000	6.000	3.000	4.000	7.000	1.000
OX12W 8	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX12W 9	5.500	6.000	6.000	3.000	4.000	7.000	0.800
OX12W 10	5.500	6.000	6.000	3.000	4.000	7.000	1.000
OX12W 11	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX12W 12	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX12P 1	5.000	6.000	6.000	4.000	5.500	7.000	0.800
OX12P 2	5.000	6.000	6.000	4.000	5.500	7.000	0.800
OX12P 3	5.000	6.000	6.000	4.000	5.500	7.000	0.900
OX12P 4	5.500	6.000	6.000	4.000	5.500	7.000	0.900
OX12P 5	5.500	6.000	6.000	4.000	5.500	7.000	1.000
OX12P 7	5.500	6.000	6.000	4.000	5.500	7.000	1.000
OX12P 8	5.000	6.000	6.000	4.000	5.500	7.000	0.800
OX12P 9	5.500	6.000	6.000	4.000	5.500	7.000	0.800
OX12P 10	5.500	6.000	6.000	4.000	5.500	7.000	1.000
OX12P 11	5.000	6.000	6.000	4.000	5.500	7.000	0.800
OX12P 12	5.500	6.000	6.000	4.000	5.500	7.000	0.900
OX12S 1	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX12S 2	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX12S 3	5.000	6.000	6.000	5.000	7.000	7.000	0.900
OX12S 4	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX12S 5	5.500	6.000	6.000	5.000	7.000	7.000	1.000
OX12S 7	5.500	6.000	6.000	5.000	7.000	7.000	1.000
OX12S 8	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX12S 9	5.500	6.000	6.000	5.000	7.000	7.000	0.800
OX12S 10	5.500	6.000	6.000	5.000	7.000	7.000	1.000
OX12S 11	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX12S 12	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX10W 1	5.000	6.000	6.000	3.000	4.000	7.000	0.900
OX10W 2	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX10W 3	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX10W 4	5.000	6.000	6.000	3.000	4.000	7.000	0.900
OX10W 5	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX10P 1	5.000	6.000	6.000	4.000	5.500	7.000	0.900

OX10P 2	5.500	6.000	6.000	4.000	5.500	7.000	0.900
OX10P 3	5.500	6.000	6.000	4.000	5.500	7.000	0.900
OX10P 4	5.000	6.000	6.000	4.000	5.500	7.000	0.900
OX10P 5	5.500	6.000	6.000	4.000	5.500	7.000	0.900
OX10S 1	5.000	6.000	6.000	5.000	7.000	7.000	0.900
OX10S 2	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX10S 3	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX10S 4	5.000	6.000	6.000	5.000	7.000	7.000	0.900
OX10S 5	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX35W 1	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 2	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 3	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 4	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 5	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 6	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 7	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35W 8	5.000	6.000	6.000	3.000	4.000	7.000	1.000
OX35P 1	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 2	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 3	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 4	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 5	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 6	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 7	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35P 8	5.000	6.000	6.000	4.000	5.500	7.000	1.000
OX35S 1	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 2	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 3	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 4	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 5	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 6	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 7	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX35S 8	5.000	6.000	6.000	5.000	7.000	7.000	1.000
OX17W 11	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX17W 12	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX17W 13	6.000	6.000	6.000	3.000	4.000	7.000	1.000
OX17W 14	5.000	6.000	6.000	3.000	4.000	7.000	0.800
OX17W 15	6.500	6.000	6.000	3.000	4.000	7.000	1.000
OX17W 16	6.000	6.000	6.000	3.000	4.000	7.000	0.900
OX17P 11	5.000	6.000	6.000	4.000	5.500	7.000	0.800
OX17P 12	5.500	6.000	6.000	4.000	5.500	7.000	0.900
OX17P 13	6.000	6.000	6.000	4.000	5.500	7.000	1.000
OX17P 14	5.000	6.000	6.000	4.000	5.500	7.000	0.800
OX17P 15	6.500	6.000	6.000	4.000	5.500	7.000	1.000
OX17P 16	6.000	6.000	6.000	4.000	5.500	7.000	0.900
OX17S 11	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX17S 12	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX17S 13	6.000	6.000	6.000	5.000	7.000	7.000	1.000
OX17S 14	5.000	6.000	6.000	5.000	7.000	7.000	0.800
OX17S 15	6.500	6.000	6.000	5.000	7.000	7.000	1.000
OX17S 16	6.000	6.000	6.000	5.000	7.000	7.000	0.900
OX32W 9	5.500	6.000	6.000	3.000	4.000	7.000	0.900
OX32W 10	6.000	6.000	6.000	3.000	4.000	7.000	1.000
OX32W 11	6.000	6.000	6.000	3.000	4.000	7.000	1.000
OX32W 12	6.000	6.000	6.000	3.000	4.000	7.000	1.000
OX32W 18	6.000	6.000	6.000	3.000	4.000	7.000	0.900
OX32P 9	5.500	6.000	6.000	4.000	5.500	7.000	0.900

OX32P 10	6.000	6.000	6.000	4.000	5.500	7.000	1.000
OX32P 11	6.000	6.000	6.000	4.000	5.500	7.000	1.000
OX32P 12	6.000	6.000	6.000	4.000	5.500	7.000	1.000
OX32P 18	6.000	6.000	6.000	4.000	5.500	7.000	0.900
OX32S 9	5.500	6.000	6.000	5.000	7.000	7.000	0.900
OX32S 10	6.000	6.000	6.000	5.000	7.000	7.000	1.000
OX32S 11	6.000	6.000	6.000	5.000	7.000	7.000	1.000
OX32S 12	6.000	6.000	6.000	5.000	7.000	7.000	1.000
OX32S 18	6.000	6.000	6.000	5.000	7.000	7.000	0.900
KAAI 1	5.000	7.000	7.000	8.000	4.000	7.000	0.900
KAAI 2	5.000	7.000	7.000	8.000	4.000	7.000	0.900
KAAI 3	5.000	7.000	7.000	8.000	4.000	7.000	0.900
KAAI 4	5.000	7.000	7.000	8.000	4.000	7.000	1.000
KAAI 5	6.000	7.000	7.000	8.000	4.000	7.000	1.000
KAAI 6	6.000	7.000	7.000	8.000	4.000	7.000	1.000
KAAI 7	6.000	7.000	7.000	9.000	4.000	7.000	1.000
KAAI 8	7.000	7.000	7.000	10.000	4.000	7.000	1.000
KAAI 9	7.000	7.000	7.000	10.000	4.000	7.000	1.000
MALG 1	5.000	7.000	7.000	8.000	4.000	7.000	1.000
MALG 2	5.000	7.000	7.000	8.000	4.000	7.000	1.000
MALG 3	5.000	7.000	7.000	8.000	4.000	7.000	1.000
MALG 4	5.000	7.000	7.000	8.000	4.000	7.000	1.000
MALG 5	5.000	7.000	7.000	8.000	4.000	7.000	1.000
MALG 6	5.000	7.000	7.000	8.000	4.000	7.000	1.000
MALG 7	7.000	7.000	7.000	9.000	4.000	7.000	1.000
MALG 8	7.000	7.000	7.000	9.000	4.000	7.000	1.000
NDAN5 1	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 2	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 3	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 4	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 5	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 6	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 7	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 8	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 9	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 10	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 11	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 12	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 13	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 14	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 15	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 16	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 17	5.500	6.000	7.500	7.500	5.500	7.000	0.900
NDAN5 18	5.500	6.000	7.500	7.500	5.500	7.000	0.900

APPENDIX C

Computer listing of the semi-distributed model parameters used in calibration and validation (derived from relationships with physical characteristics) runs.

Model OSE1	Calibration parameters Validation parameters
Model OSE2	Calibration parameters Validation parameters
Model OSE3	Calibration parameters Validation parameters

OSE1-CALIBRATION PARAMETERS

Area	ID	1 K	2 N	3 CDEL	4 KC	5 SMAX	6 DA	7 C	8 APF	9 IL
TM11	1	0.100	0.700	0.240	0.100	200.000	0.400	0.191	0.850	0.000
TM11	2	0.100	0.700	0.240	0.100	200.000	0.400	0.191	0.850	0.000
TM11	3	0.100	0.700	0.160	0.100	200.000	0.400	0.191	0.850	0.000
TM8	4	0.100	0.700	0.240	0.100	200.000	0.400	0.350	0.850	0.000
TM8	5	0.100	0.700	0.240	0.100	200.000	0.400	0.350	0.850	0.000
TM8	6	0.100	0.700	0.160	0.100	200.000	0.400	0.350	0.850	0.000
TM8	7	0.100	0.700	0.080	0.100	200.000	0.400	0.350	0.850	0.000
TM3	1	0.100	0.700	0.320	0.100	200.000	0.400	0.413	0.850	0.000
TM3	2	0.100	0.700	0.240	0.100	200.000	0.400	0.413	0.850	0.000
TM3	3	0.100	0.700	0.160	0.100	200.000	0.400	0.413	0.850	0.000
TM3	4	0.100	0.700	0.160	0.100	200.000	0.400	0.413	0.850	0.000
TM6	1	0.100	0.700	0.640	0.400	190.000	0.400	0.319	0.850	0.000
TM6	2	0.100	0.700	0.480	0.400	200.000	0.400	0.319	0.850	0.000
TM6	3	0.100	0.700	0.560	0.400	180.000	0.400	0.319	0.850	0.000
TM6	4	0.100	0.700	0.640	0.400	196.000	0.400	0.319	0.850	0.000
TM6	5	0.100	0.700	0.480	0.400	190.000	0.400	0.319	0.850	0.000
TM6	6	0.100	0.700	0.320	0.400	196.000	0.400	0.319	0.850	0.000
TM6	7	0.100	0.700	0.320	0.400	180.000	0.400	0.319	0.850	0.000
TM6	8	0.100	0.700	0.240	0.400	196.000	0.400	0.319	0.850	0.000
TM2	10	0.200	0.700	0.320	0.500	180.000	0.400	0.319	0.850	0.000
TM1	11	0.200	0.700	0.640	0.500	140.000	0.400	0.319	0.850	0.000
TM1	12	0.200	0.700	0.560	0.500	190.000	0.400	0.319	0.850	0.000
TM1	13	0.200	0.700	0.320	0.500	160.000	0.400	0.319	0.850	0.000
ECCA	1	6.000	0.700	5.250	0.640	200.000	0.230	0.400	0.920	1.000
ECCA	2	6.000	0.700	4.500	0.720	200.000	0.230	0.400	0.920	1.000
ECCA	3	6.000	0.700	4.500	0.720	200.000	0.230	0.400	0.920	1.000
ECCA	4	6.000	0.700	4.000	0.800	200.000	0.230	0.400	0.920	1.000
ECCA	5	6.000	0.700	4.000	0.600	200.000	0.230	0.400	0.920	1.000
ECCA	6	6.000	0.700	4.000	0.600	200.000	0.230	0.400	0.920	1.000
ECCA	7	6.000	0.700	3.000	0.400	200.000	0.230	0.400	0.920	1.000
ECCA	8	6.000	0.700	2.750	0.480	200.000	0.230	0.400	0.920	1.000
ECCA	9	6.000	0.700	2.250	0.768	200.000	0.230	0.400	0.920	1.000
ECCA	10	6.000	0.700	1.250	0.800	200.000	0.230	0.400	0.920	1.000
ECCA	11	6.000	0.700	0.750	0.480	200.000	0.230	0.400	0.920	1.000
ECCA	12	6.000	0.700	0.750	0.480	200.000	0.230	0.400	0.920	1.000
BETH	1	4.000	0.700	3.250	0.800	120.000	0.350	0.400	0.800	0.000
BETH	2	4.000	0.700	2.750	0.800	120.000	0.350	0.400	0.800	0.000
BETH	3	4.000	0.700	3.000	0.800	120.000	0.350	0.400	0.800	0.000
BETH	4	4.000	0.700	2.500	0.800	120.000	0.350	0.400	0.800	0.000
BETH	5	4.000	0.700	2.000	0.800	120.000	0.350	0.400	0.800	0.000
BETH	6	4.000	0.700	2.250	0.800	120.000	0.350	0.400	0.800	0.000
BETH	7	4.000	0.700	1.500	0.800	120.000	0.350	0.400	0.800	0.000
BETH	8	4.000	0.700	1.250	0.800	120.000	0.350	0.400	0.800	0.000
BETH	9	4.000	0.700	0.500	0.800	120.000	0.350	0.400	0.800	0.000
HOEK	1	1.800	0.700	0.750	0.720	120.000	0.300	0.400	0.850	0.000
HOEK	2	1.000	0.700	0.500	0.400	120.000	0.300	0.400	0.850	0.000
HOEK	3	1.200	0.700	0.750	0.400	120.000	0.300	0.400	0.850	0.000
HOEK	4	1.200	0.700	0.750	0.480	120.000	0.300	0.400	0.850	0.000
HOEK	5	1.200	0.700	0.750	0.480	120.000	0.300	0.400	0.850	0.000
HOEK	6	1.400	0.700	0.500	0.560	120.000	0.300	0.400	0.850	0.000
HOEK	7	1.000	0.700	0.000	0.560	120.000	0.300	0.400	0.850	0.000
HOEK	8	1.200	0.700	0.250	0.480	120.000	0.300	0.400	0.850	0.000

HOEK	9	1.200	0.700	0.250	0.480	120.000	0.300	0.400	0.850	0.000
CED	1	1.500	0.700	0.500	0.400	250.000	0.130	0.300	0.900	0.000
CED	2	1.500	0.700	0.500	0.400	250.000	0.130	0.300	0.900	0.000
CED	3	1.500	0.700	0.250	0.400	250.000	0.130	0.300	0.900	0.000
ZULU	1	6.000	0.700	0.750	0.400	260.000	0.500	0.125	0.850	0.000
ZULU	2	6.000	0.700	0.500	0.400	260.000	0.500	0.125	0.850	0.000
ZULU	3	3.600	0.700	0.250	0.320	145.600	0.290	0.200	0.850	0.000
ZULU	4	3.600	0.700	0.250	0.160	145.600	0.290	0.200	0.832	0.000
ZULU	5	1.200	0.700	0.250	0.200	70.200	0.755	0.001	0.832	0.000
ZULU	6	1.500	0.700	0.250	0.240	98.800	0.700	0.250	0.832	0.000
ZULU	7	1.500	0.700	0.250	0.280	98.800	0.700	0.250	0.832	0.000
ZULU	8	3.600	0.700	0.000	0.160	150.800	0.290	0.200	0.850	0.000
ZULU	9	3.600	0.700	0.000	0.320	150.800	0.290	0.200	0.850	0.000
ZULU	10	3.600	0.700	0.250	0.400	150.800	0.290	0.200	0.850	0.000
OX4W	1	0.900	0.700	0.850	0.500	170.000	0.600	0.225	0.900	0.000
OX4W	2	1.000	0.700	0.510	0.500	170.000	0.600	0.225	0.900	0.000
OX4S	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX4S	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12W	1	1.200	0.700	1.530	0.700	170.000	0.600	0.300	0.900	0.000
OX12W	2	1.200	0.700	1.530	0.700	170.000	0.600	0.300	0.900	0.000
OX12W	3	1.050	0.790	1.700	0.500	170.000	0.600	0.400	0.900	0.000
OX12W	4	1.350	0.700	1.530	0.600	170.000	0.600	0.250	0.900	0.000
OX12W	5	1.500	0.700	0.850	0.700	170.000	0.600	0.250	0.900	0.000
OX12W	7	1.500	0.700	1.190	0.800	170.000	0.600	0.230	0.900	0.000
OX12W	8	1.350	0.700	1.700	0.600	170.000	0.600	0.300	0.900	0.000
OX12W	9	1.050	0.700	1.190	0.600	170.000	0.600	0.250	0.900	0.000
OX12W	10	1.425	0.700	0.680	0.700	170.000	0.600	0.230	0.900	0.000
OX12W	11	1.050	0.700	1.360	0.500	170.000	0.600	0.200	0.900	0.000
OX12W	12	1.500	0.700	1.020	0.800	170.000	0.600	0.230	0.900	0.000
OX12P	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12P	12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX12S	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX12S	12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX10W	1	1.125	0.700	0.680	0.600	170.000	0.600	2.200	0.900	0.000
OX10W	2	1.125	0.700	0.680	0.200	170.000	0.600	2.200	0.900	0.000
OX10W	3	1.050	0.700	0.510	0.200	170.000	0.600	2.200	0.900	0.000
OX10W	4	1.050	0.700	0.340	0.400	170.000	0.600	2.200	0.900	0.000
OX10W	5	1.005	0.700	0.340	0.200	170.000	0.600	2.200	0.900	0.000
OX10P	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000

OX10P 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX10P 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX10P 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX10P 5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX10S 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX10S 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX10S 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX10S 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX10S 5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35W 1	1.050	0.700	1.190	0.500	170.000	0.600	0.180	0.900	0.000
OX35W 2	1.125	0.700	1.020	0.500	170.000	0.600	0.180	0.900	0.000
OX35W 3	1.005	0.700	1.020	0.400	170.000	0.600	0.180	0.900	0.000
OX35W 4	1.050	0.700	0.850	0.500	170.000	0.600	0.180	0.900	0.000
OX35W 5	1.050	0.700	0.850	0.400	170.000	0.600	0.180	0.900	0.000
OX35W 6	1.125	0.700	0.680	0.500	170.000	0.600	0.180	0.900	0.000
OX35W 7	1.050	0.700	0.510	0.500	170.000	0.600	0.180	0.900	0.000
OX35W 8	1.050	0.700	0.340	0.500	170.000	0.600	0.180	0.900	0.000
OX35P 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35P 8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX35S 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX35S 8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX17W 11	1.200	0.700	1.360	0.600	170.000	0.600	0.200	0.900	0.000
OX17W 12	1.200	0.700	0.850	0.600	170.000	0.600	0.180	0.900	0.000
OX17W 13	1.200	0.700	0.340	0.700	170.000	0.600	0.180	0.900	0.000
OX17W 14	1.200	0.700	1.020	0.700	170.000	0.600	0.200	0.900	0.000
OX17W 15	1.350	0.700	0.510	0.700	170.000	0.600	0.180	0.900	0.000
OX17W 16	1.200	0.700	0.510	0.600	170.000	0.600	0.180	0.900	0.000
OX17P 11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX17P 12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX17P 13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX17P 14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX17P 15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX17P 16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX17S 11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX17S 12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX17S 13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX17S 14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX17S 15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX17S 16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX32W 9	1.050	0.700	1.360	0.500	170.000	0.600	0.160	0.900	0.000
OX32W 10	1.050	0.700	1.020	0.500	170.000	0.600	0.160	0.900	0.000
OX32W 11	1.050	0.700	0.680	0.500	170.000	0.600	0.160	0.900	0.000
OX32W 12	1.050	0.700	0.340	0.500	170.000	0.600	0.160	0.900	0.000
OX32W 18	1.050	0.700	0.340	0.500	170.000	0.600	0.160	0.900	0.000
OX32P 9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000

OX32P 10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX32P 11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX32P 12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX32P 18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.860	0.000
OX32S 9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX32S 10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX32S 11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX32S 12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
OX32S 18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.850	0.000
KAAI 1	5.600	0.700	2.750	0.420	210.000	0.700	0.200	0.950	0.000
KAAI 2	5.600	0.700	2.000	0.420	210.000	0.700	0.200	0.950	0.000
KAAI 3	5.600	0.700	2.250	0.420	210.000	0.700	0.200	0.950	0.000
KAAI 4	5.600	0.700	2.250	0.480	210.000	0.700	0.200	0.950	0.000
KAAI 5	6.300	0.700	1.500	0.540	210.000	0.700	0.200	0.950	0.000
KAAI 6	7.000	0.700	1.250	0.540	231.000	0.700	0.220	0.950	0.000
KAAI 7	7.700	0.700	1.000	0.600	241.500	0.700	0.230	0.950	0.000
KAAI 8	7.700	0.700	0.500	0.600	241.500	0.700	0.230	0.950	0.000
KAAI 9	6.300	0.700	0.500	0.600	252.000	0.700	0.230	0.950	0.000
MALG 1	4.800	0.700	1.500	0.480	200.000	0.650	0.150	0.950	0.000
MALG 2	4.800	0.700	1.500	0.480	200.000	0.650	0.150	0.950	0.000
MALG 3	4.800	0.700	1.250	0.480	200.000	0.650	0.150	0.950	0.000
MALG 4	4.800	0.700	1.000	0.480	200.000	0.650	0.150	0.950	0.000
MALG 5	4.800	0.700	1.000	0.480	200.000	0.650	0.150	0.950	0.000
MALG 6	5.400	0.700	1.000	0.560	200.000	0.650	0.150	0.950	0.000
MALG 7	6.000	0.700	0.500	0.640	200.000	0.650	0.150	0.950	0.000
MALG 8	6.000	0.700	0.500	0.640	200.000	0.650	0.150	0.950	0.000
NDAN5 1	6.000	0.700	1.500	0.680	210.000	0.400	0.200	0.850	0.000
NDAN5 2	6.000	0.700	1.000	0.740	210.000	0.400	0.200	0.850	0.000
NDAN5 3	6.000	0.700	1.250	1.148	210.000	0.400	0.200	0.850	0.000
NDAN5 4	6.000	0.700	1.550	0.723	210.000	0.400	0.200	0.850	0.000
NDAN5 5	6.000	0.700	1.000	0.655	210.000	0.400	0.200	0.850	0.000
NDAN5 6	6.000	0.700	0.500	0.620	210.000	0.400	0.200	0.850	0.000
NDAN5 7	6.000	0.700	1.000	0.825	210.000	0.400	0.200	0.850	0.000
NDAN5 8	6.000	0.700	0.750	0.382	210.000	0.400	0.200	0.850	0.000
NDAN5 9	6.000	0.700	0.500	0.570	210.000	0.400	0.200	0.850	0.000
NDAN5 9	6.000	0.700	0.500	0.570	210.000	0.400	0.200	0.850	0.000
NDAN5 10	6.000	0.700	2.250	0.553	210.000	0.400	0.200	0.850	0.000
NDAN5 11	6.000	0.700	2.000	0.595	210.000	0.400	0.200	0.850	0.000
NDAN5 13	6.000	0.700	2.250	0.808	210.000	0.400	0.200	0.850	0.000
NDAN5 14	6.000	0.700	1.750	0.892	210.000	0.400	0.200	0.850	0.000
NDAN5 15	6.000	0.700	1.250	0.638	210.000	0.400	0.200	0.900	0.000
NDAN5 16	6.000	0.700	0.750	0.680	210.000	0.400	0.200	0.900	0.000
NDAN5 17	6.000	0.700	0.000	0.315	210.000	0.400	0.200	0.900	0.000
NDAN5 18	6.000	0.700	0.000	0.425	210.000	0.400	0.200	0.900	0.000

OSE1-VALIDATION PARAMETERS

AREA	ID	1 K	2 N	3 CDEL	4 KC	5 SMAX	6 DA	7 C	8 APF	9 IL
TM11	1	0.100	0.700	0.240	0.530	193.000	0.400	0.146	0.820	0.000
TM11	2	0.100	0.700	0.240	0.650	193.000	0.400	0.146	0.820	0.000
TM11	3	0.100	0.700	0.160	0.590	193.000	0.400	0.146	0.820	0.000
TM8	4	0.100	0.700	0.240	0.360	193.000	0.400	0.197	0.820	0.000
TM8	5	0.100	0.700	0.240	0.430	193.000	0.400	0.197	0.820	0.000
TM8	6	0.100	0.700	0.160	0.430	193.000	0.400	0.197	0.820	0.000
TM8	7	0.100	0.700	0.080	0.570	193.000	0.400	0.197	0.820	0.000
TM3	1	0.100	0.700	0.320	0.520	193.000	0.400	0.166	0.820	0.000
TM3	2	0.100	0.700	0.240	0.630	193.000	0.400	0.166	0.820	0.000
TM3	3	0.100	0.700	0.160	0.270	193.000	0.400	0.166	0.820	0.000
TM3	4	0.100	0.700	0.160	0.430	193.000	0.400	0.166	0.820	0.000
TM6	1	0.100	0.700	0.640	1.290	193.000	0.430	0.276	0.820	0.000
TM6	2	0.100	0.700	0.480	0.910	193.000	0.400	0.304	0.820	0.000
TM6	3	0.100	0.700	0.560	1.100	193.000	0.400	0.304	0.820	0.000
TM6	4	0.100	0.700	0.640	1.290	165.100	0.400	0.304	0.820	0.000
TM6	5	0.100	0.700	0.480	0.480	193.000	0.400	0.304	0.820	0.000
TM6	6	0.100	0.700	0.320	0.590	193.000	0.400	0.304	0.820	0.000
TM6	7	0.100	0.700	0.320	0.600	146.100	0.490	0.219	0.820	0.000
TM6	8	0.100	0.700	0.240	0.760	193.000	0.400	0.333	0.820	0.000
TM2	10	0.200	0.700	0.320	1.060	193.000	0.430	0.269	0.820	0.000
TM1	11	0.200	0.700	0.640	0.710	146.100	0.440	0.228	0.820	0.000
TM1	12	0.200	0.700	0.560	0.820	193.000	0.430	0.265	0.820	0.000
TM1	13	0.200	0.700	0.320	0.880	193.000	0.470	0.243	0.820	0.000
ECCA	1	3.200	0.700	5.250	0.620	235.000	0.280	0.432	0.940	1.000
ECCA	2	3.200	0.700	4.500	0.820	178.400	0.280	0.432	0.940	1.000
ECCA	3	3.200	0.700	4.500	0.690	178.400	0.280	0.432	0.940	1.000
ECCA	4	2.300	0.700	4.000	0.770	159.400	0.340	0.240	0.940	1.000
ECCA	5	2.600	0.700	4.000	0.650	159.400	0.300	0.336	0.940	1.000
ECCA	6	2.600	0.700	4.000	0.540	159.400	0.300	0.336	0.940	1.000
ECCA	7	2.300	0.700	3.000	0.690	159.400	0.240	0.624	0.940	1.000
ECCA	8	2.300	0.700	2.750	0.620	159.400	0.240	0.672	0.940	1.000
ECCA	9	2.000	0.700	2.250	0.540	159.400	0.260	0.576	0.940	1.000
ECCA	10	2.300	0.700	1.250	1.000	200.000	0.260	0.576	0.940	1.000
ECCA	11	2.000	0.700	0.750	0.870	159.400	0.270	0.600	0.940	1.000
ECCA	12	3.200	0.700	0.750	0.820	200.000	0.280	0.432	0.940	1.000
BETH	1	4.000	0.700	3.250	0.740	125.200	0.300	0.300	0.830	0.000
BETH	2	3.780	0.700	2.750	0.800	125.200	0.300	0.300	0.830	0.000
BETH	3	4.630	0.700	3.000	0.800	125.200	0.280	0.300	0.830	0.000
BETH	4	4.630	0.700	2.500	0.860	125.200	0.280	0.300	0.830	0.000
BETH	5	3.400	0.700	2.000	0.860	125.200	0.321	0.214	0.830	0.000
BETH	6	3.780	0.700	2.250	0.990	125.200	0.300	0.300	0.830	0.000
BETH	7	3.780	0.700	1.500	0.448	125.200	0.300	0.300	0.830	0.000
BETH	8	3.400	0.700	1.250	0.680	125.200	0.321	0.214	0.830	0.000
BETH	9	4.630	0.700	0.500	0.680	125.200	0.280	0.300	0.830	0.000
HOEK	1	2.700	0.700	0.750	0.170	206.900	0.490	0.350	0.807	0.000
HOEK	2	0.520	0.700	0.500	0.440	105.000	0.440	0.297	0.850	0.000
HOEK	3	1.200	0.700	0.750	0.680	175.000	0.490	0.181	0.859	0.000
HOEK	4	1.200	0.700	0.750	0.530	195.000	0.500	0.181	0.859	0.000
HOEK	5	1.200	0.700	0.750	0.250	175.000	0.450	0.194	0.859	0.000
HOEK	6	3.500	0.700	0.500	0.560	222.000	0.400	0.334	0.867	0.000
HOEK	7	0.520	0.700	0.000	0.648	105.000	0.440	0.271	0.859	0.000
HOEK	8	3.840	0.700	0.250	0.480	195.000	0.370	0.388	0.867	0.000

HOEK 9	1.230	0.700	0.250	0.480	175.000	0.490	0.220	0.859	0.000
CED 1	4.630	0.700	0.500	0.510	235.000	0.540	0.279	0.820	0.000
CED 2	5.760	0.700	0.500	0.510	235.000	0.500	0.347	0.820	0.000
CED 3	7.000	0.700	0.250	0.510	235.000	0.465	0.453	0.820	0.000
ZULU 1	2.930	0.700	0.750	0.440	260.000	0.560	0.150	0.840	0.000
ZULU 2	3.220	0.700	0.500	0.580	260.000	0.500	0.100	0.840	0.000
ZULU 3	3.500	0.700	0.250	0.440	208.000	0.530	0.130	0.840	0.000
ZULU 4	3.210	0.700	0.250	0.072	150.000	0.490	0.150	0.840	0.000
ZULU 5	0.380	0.700	0.250	0.440	70.200	0.530	0.190	0.840	0.000
ZULU 6	1.520	0.700	0.250	0.340	98.800	0.560	0.130	0.840	0.000
ZULU 7	1.500	0.700	0.250	0.440	98.800	0.560	0.100	0.840	0.000
ZULU 8	4.630	0.700	0.000	0.580	150.800	0.450	0.230	0.840	0.000
ZULU 9	4.630	0.700	0.000	0.620	150.800	0.450	0.230	0.840	0.000
ZULU 10	4.630	0.700	0.250	0.640	150.800	0.450	0.230	0.840	0.000
OX4W 1	1.000	0.700	0.850	0.250	170.000	0.450	0.195	0.880	0.000
OX4W 2	1.000	0.700	0.510	0.380	170.000	0.450	0.195	0.880	0.000
OX4S 1	1.950	0.700	0.850	0.250	170.000	0.450	0.115	0.830	0.000
OX4S 2	1.950	0.700	0.510	0.380	170.000	0.450	0.115	0.830	0.000
OX12W 1	1.200	0.700	1.530	0.780	170.000	0.490	0.211	0.880	0.000
OX12W 2	1.200	0.700	1.530	0.860	170.000	0.490	0.211	0.880	0.000
OX12W 3	1.050	0.790	1.700	0.500	170.000	0.490	0.173	0.880	0.000
OX12W 4	1.350	0.700	1.530	0.830	187.000	0.490	0.173	0.880	0.000
OX12W 5	1.920	0.700	0.850	0.860	187.000	0.440	0.173	0.880	0.000
OX12W 7	1.920	0.700	1.190	0.800	187.000	0.440	0.134	0.880	0.000
OX12W 8	1.350	0.700	1.700	0.500	170.000	0.450	0.134	0.880	0.000
OX12W 9	1.050	0.700	1.190	0.600	187.000	0.490	0.269	0.880	0.000
OX12W 10	1.920	0.700	0.680	0.620	187.000	0.440	0.115	0.880	0.000
OX12W 11	1.900	0.700	1.360	0.300	170.000	0.420	0.230	0.880	0.000
OX12W 12	1.920	0.700	1.020	0.680	187.000	0.420	0.230	0.880	0.000
OX12P 1	1.550	0.700	1.530	0.780	170.000	0.490	0.196	0.840	0.000
OX12P 2	1.550	0.700	1.530	0.860	170.000	0.490	0.196	0.840	0.000
OX12P 3	1.550	0.700	1.700	0.500	170.000	0.490	0.156	0.840	0.000
OX12P 4	1.550	0.700	1.530	0.830	187.000	0.490	0.168	0.840	0.000
OX12P 5	2.510	0.700	0.850	0.860	187.000	0.440	0.168	0.840	0.000
OX12P 7	2.510	0.700	1.190	0.800	187.000	0.440	0.192	0.840	0.000
OX12P 8	1.550	0.700	1.700	0.500	170.000	0.450	0.180	0.840	0.000
OX12P 9	1.550	0.700	1.190	0.600	187.000	0.490	0.168	0.840	0.000
OX12P 10	2.510	0.700	0.680	0.620	187.000	0.440	0.192	0.840	0.000
OX12P 11	2.510	0.700	1.360	0.300	170.000	0.420	0.204	0.840	0.000
OX12P 12	2.510	0.700	1.020	0.680	187.000	0.420	0.204	0.840	0.000
OX12S 1	1.950	0.700	1.530	0.780	170.000	0.490	0.114	0.830	0.000
OX12S 2	1.950	0.700	1.530	0.860	170.000	0.490	0.114	0.830	0.000
OX12S 3	1.950	0.700	1.700	0.500	170.000	0.490	0.114	0.830	0.000
OX12S 4	1.950	0.700	1.530	0.830	187.000	0.490	0.114	0.830	0.000
OX12S 5	3.100	0.700	0.850	0.860	187.000	0.440	0.132	0.830	0.000
OX12S 7	3.100	0.700	1.190	0.800	187.000	0.440	0.132	0.830	0.000
OX12S 8	1.950	0.700	1.700	0.500	170.000	0.450	0.120	0.830	0.000
OX12S 9	1.950	0.700	1.190	0.600	187.000	0.490	0.144	0.830	0.000
OX12S 10	3.100	0.700	0.680	0.620	187.000	0.440	0.132	0.830	0.000
OX12S 11	3.100	0.700	1.360	0.300	170.000	0.420	0.120	0.830	0.000
OX12S 12	3.100	0.700	1.020	0.680	187.000	0.420	0.120	0.830	0.000
OX10W 1	1.380	0.700	0.680	0.410	170.000	0.455	0.160	0.880	0.000
OX10W 2	1.380	0.700	0.680	0.550	187.000	0.455	0.160	0.880	0.000
OX10W 3	1.380	0.700	0.510	0.550	187.000	0.455	0.160	0.880	0.000
OX10W 4	1.380	0.700	0.340	0.300	170.000	0.455	0.160	0.880	0.000
OX10W 5	1.380	0.700	0.340	0.480	187.000	0.455	0.160	0.880	0.000
OX10P 1	2.000	0.700	0.680	0.410	170.000	0.455	0.120	0.840	0.000

OX10P 2	2.000	0.700	0.680	0.550	187.000	0.455	0.120	0.840	0.000
OX10P 3	2.000	0.700	0.510	0.550	187.000	0.455	0.120	0.840	0.000
OX10P 4	2.000	0.700	0.340	0.300	170.000	0.455	0.120	0.840	0.000
OX10P 5	2.000	0.700	0.340	0.480	187.000	0.455	0.120	0.840	0.000
OX10S 1	2.400	0.700	0.680	0.410	170.000	0.455	0.060	0.830	0.000
OX10S 2	2.400	0.700	0.680	0.550	187.000	0.455	0.060	0.830	0.000
OX10S 3	2.400	0.700	0.510	0.550	187.000	0.455	0.060	0.830	0.000
OX10S 4	2.400	0.700	0.340	0.300	170.000	0.455	0.060	0.830	0.000
OX10S 5	2.400	0.700	0.340	0.480	187.000	0.455	0.060	0.830	0.000
OX35W 1	1.950	0.700	1.190	0.410	170.000	0.448	0.110	0.880	0.000
OX35W 2	1.950	0.700	1.020	0.620	170.000	0.448	0.110	0.880	0.000
OX35W 3	1.950	0.700	1.020	0.300	170.000	0.448	0.110	0.880	0.000
OX35W 4	1.950	0.700	0.850	0.480	170.000	0.448	0.110	0.880	0.000
OX35W 5	1.950	0.700	0.850	0.630	170.000	0.448	0.110	0.880	0.000
OX35W 6	1.950	0.700	0.680	0.890	170.000	0.448	0.110	0.880	0.000
OX35W 7	1.950	0.700	0.510	0.720	170.000	0.448	0.110	0.880	0.000
OX35W 8	1.950	0.700	0.340	0.820	170.000	0.448	0.110	0.880	0.000
OX35P 1	2.380	0.700	1.190	0.410	170.000	0.448	0.070	0.840	0.000
OX35P 2	2.380	0.700	1.020	0.620	170.000	0.448	0.070	0.840	0.000
OX35P 3	2.380	0.700	1.020	0.300	170.000	0.448	0.070	0.840	0.000
OX35P 4	2.380	0.700	0.850	0.480	170.000	0.448	0.070	0.840	0.000
OX35P 5	2.380	0.700	0.850	0.630	170.000	0.448	0.070	0.840	0.000
OX35P 6	2.380	0.700	0.680	0.890	170.000	0.448	0.070	0.840	0.000
OX35P 7	2.380	0.700	0.510	0.720	170.000	0.448	0.070	0.840	0.000
OX35P 8	2.380	0.700	0.340	0.820	170.000	0.448	0.070	0.840	0.000
OX35S 1	3.150	0.700	1.190	0.410	170.000	0.448	0.030	0.830	0.000
OX35S 2	3.150	0.700	1.020	0.620	170.000	0.448	0.030	0.830	0.000
OX35S 3	3.150	0.700	1.020	0.300	170.000	0.448	0.030	0.830	0.000
OX35S 4	3.150	0.700	0.850	0.480	170.000	0.448	0.030	0.830	0.000
OX35S 5	3.150	0.700	0.850	0.630	170.000	0.448	0.030	0.830	0.000
OX35S 6	3.150	0.700	0.680	0.890	170.000	0.448	0.030	0.830	0.000
OX35S 7	3.150	0.700	0.510	0.720	170.000	0.448	0.030	0.830	0.000
OX35S 8	3.150	0.700	0.340	0.820	170.000	0.448	0.030	0.830	0.000
OX17W 11	1.200	0.700	1.360	0.410	170.000	0.470	0.077	0.880	0.000
OX17W 12	1.620	0.700	0.850	0.600	187.000	0.460	0.110	0.880	0.000
OX17W 13	1.620	0.700	0.340	0.960	212.500	0.470	0.077	0.880	0.000
OX17W 14	1.200	0.700	1.020	0.480	170.000	0.480	0.088	0.880	0.000
OX17W 15	2.000	0.700	0.510	0.480	222.000	0.440	0.121	0.880	0.000
OX17W 16	1.620	0.700	0.510	0.410	212.500	0.460	0.110	0.880	0.000
OX17P 11	1.620	0.700	1.360	0.410	170.000	0.470	0.132	0.840	0.000
OX17P 12	2.000	0.700	0.850	0.600	187.000	0.460	0.124	0.840	0.000
OX17P 13	2.000	0.700	0.340	0.960	212.500	0.470	0.109	0.840	0.000
OX17P 14	1.620	0.700	1.020	0.480	170.000	0.480	0.116	0.840	0.000
OX17P 15	2.380	0.700	0.510	0.480	222.000	0.440	0.124	0.840	0.000
OX17P 16	2.000	0.700	0.510	0.410	212.500	0.460	0.124	0.840	0.000
OX17S 11	2.000	0.700	1.360	0.410	170.000	0.470	0.085	0.830	0.000
OX17S 12	2.380	0.700	0.850	0.600	187.000	0.460	0.090	0.830	0.000
OX17S 13	2.000	0.700	0.340	0.960	212.500	0.470	0.081	0.830	0.000
OX17S 14	2.380	0.700	1.020	0.480	170.000	0.480	0.085	0.830	0.000
OX17S 15	3.140	0.700	0.510	0.480	222.000	0.440	0.094	0.830	0.000
OX17S 16	2.380	0.700	0.510	0.410	212.500	0.460	0.089	0.830	0.000
OX32W 9	2.380	0.700	1.360	0.560	187.000	0.406	0.110	0.880	0.000
OX32W 10	2.380	0.700	1.020	0.760	212.500	0.427	0.100	0.880	0.000
OX32W 11	2.380	0.700	0.680	0.500	212.500	0.427	0.100	0.880	0.000
OX32W 12	2.380	0.700	0.340	0.760	212.500	0.427	0.100	0.880	0.000
OX32W 18	2.380	0.700	0.340	0.820	212.500	0.406	0.110	0.880	0.000
OX32P 9	3.140	0.700	1.360	0.560	187.000	0.406	0.080	0.840	0.000

OX32P 10	3.140	0.700	1.020	0.760	212.500	0.427	0.060	0.840	0.000
OX32P 11	3.140	0.700	0.680	0.500	212.500	0.427	0.060	0.840	0.000
OX32P 12	3.140	0.700	0.340	0.760	212.500	0.427	0.060	0.840	0.000
OX32P 18	3.140	0.700	0.340	0.820	212.500	0.406	0.080	0.840	0.000
OX32S 9	3.900	0.700	1.360	0.560	187.000	0.406	0.030	0.830	0.000
OX32S 10	3.900	0.700	1.020	0.760	212.500	0.427	0.030	0.830	0.000
OX32S 11	3.900	0.700	0.680	0.500	212.500	0.427	0.030	0.830	0.000
OX32S 12	3.900	0.700	0.340	0.760	212.500	0.427	0.030	0.830	0.000
OX32S 18	3.900	0.700	0.340	0.820	212.500	0.406	0.030	0.830	0.000
KAAI 1	1.970	0.700	2.750	0.670	184.000	0.680	0.139	0.860	0.000
KAAI 2	1.970	0.700	2.000	0.920	184.000	0.680	0.139	0.860	0.000
KAAI 3	1.800	0.700	2.250	1.000	184.000	0.680	0.139	0.860	0.000
KAAI 4	1.970	0.700	2.250	0.920	184.000	0.680	0.139	0.860	0.000
KAAI 5	1.750	0.700	1.500	0.860	212.000	0.690	0.147	0.860	0.000
KAAI 6	2.900	0.700	1.250	0.920	212.000	0.660	0.154	0.860	0.000
KAAI 7	3.900	0.700	1.000	1.100	212.000	0.650	0.201	0.860	0.000
KAAI 8	5.040	0.700	0.500	1.000	240.000	0.650	0.224	0.860	0.000
KAAI 9	5.040	0.700	0.500	0.620	240.000	0.650	0.224	0.860	0.000
MALG 1	1.800	0.700	1.500	0.680	184.000	0.690	0.124	0.860	0.000
MALG 2	1.800	0.700	1.500	0.620	184.000	0.690	0.124	0.860	0.000
MALG 3	2.080	0.700	1.250	0.560	184.000	0.680	0.131	0.860	0.000
MALG 4	2.080	0.700	1.000	0.890	184.000	0.680	0.131	0.860	0.000
MALG 5	2.360	0.700	1.000	0.680	184.000	0.650	0.137	0.860	0.000
MALG 6	2.360	0.700	1.000	0.710	184.000	0.650	0.137	0.860	0.000
MALG 7	5.190	0.700	0.500	0.740	240.000	0.620	0.189	0.860	0.000
MALG 8	5.190	0.700	0.500	0.500	240.000	0.620	0.189	0.860	0.000
NDAN5 1	4.900	0.700	1.500	0.560	194.000	0.510	0.204	0.835	0.000
NDAN5 2	5.700	0.700	1.000	1.050	194.000	0.500	0.224	0.835	0.000
NDAN5 3	5.200	0.700	1.250	0.820	194.000	0.485	0.198	0.835	0.000
NDAN5 4	4.500	0.700	1.500	0.560	194.000	0.520	0.191	0.835	0.000
NDAN5 5	4.900	0.700	1.000	0.550	194.000	0.500	0.204	0.835	0.000
NDAN5 6	4.900	0.700	0.500	0.700	194.000	0.510	0.204	0.835	0.000
NDAN5 7	5.480	0.700	1.000	0.560	194.000	0.500	0.218	0.835	0.000
NDAN5 8	5.760	0.700	0.750	0.240	194.000	0.500	0.224	0.835	0.000
NDAN5 9	5.250	0.700	0.500	0.500	194.000	0.485	0.198	0.835	0.000
NDAN5 10	4.500	0.700	2.250	0.500	194.000	0.520	0.191	0.835	0.000
NDAN5 11	5.200	0.700	2.000	0.550	194.000	0.530	0.224	0.835	0.000
NDAN5 12	5.250	0.700	1.500	0.830	194.000	0.530	0.224	0.835	0.000
NDAN5 13	4.700	0.700	2.250	0.500	194.000	0.530	0.211	0.835	0.000
NDAN5 14	4.060	0.700	1.750	0.740	194.000	0.550	0.198	0.835	0.000
NDAN5 15	4.000	0.700	1.250	0.500	194.000	0.540	0.178	0.835	0.000
NDAN5 16	4.100	0.700	0.750	0.700	194.000	0.540	0.191	0.835	0.000
NDAN5 17	4.300	0.700	0.000	0.072	194.000	0.540	0.198	0.835	0.000
NDAN5 18	4.300	0.700	0.000	0.730	194.000	0.540	0.198	0.835	0.000

OSE2-CALIBRATION PARAMETERS

Area	ID	1 K	2 N	3 CDEL	4 KC	5 SMAX	6 DA	7 C	8 PCSLP	9 PCVSA	10 IAF	11 APF	12 CLP
TM11	1	1.200	0.700	0.240	0.300	200.000	0.400	0.600	440.000	1.000	0.980	0.950	1.298
TM11	2	1.650	0.700	0.240	0.500	200.000	0.400	0.600	360.000	1.000	0.980	0.950	1.416
TM11	3	1.350	0.700	0.160	0.300	200.000	0.400	0.600	440.000	1.000	0.980	0.950	1.062
TM8	4	1.350	0.700	0.240	0.400	200.000	0.400	0.480	360.000	1.000	0.980	0.950	1.121
TM8	5	1.350	0.700	0.240	0.400	200.000	0.400	0.600	360.000	1.000	0.980	0.950	1.180
TM8	6	1.350	0.700	0.160	0.300	200.000	0.400	0.480	440.000	1.000	0.980	0.950	1.121
TM8	7	1.350	0.700	0.080	0.300	200.000	0.400	0.480	440.000	1.000	0.980	0.950	1.121
TM3	1	1.300	0.700	0.320	0.400	200.000	0.400	0.600	400.000	1.000	0.980	0.950	1.430
TM3	2	1.300	0.700	0.240	0.400	200.000	0.400	0.600	400.000	1.000	0.980	0.950	1.430
TM3	3	1.300	0.700	0.160	0.400	200.000	0.400	0.600	400.000	1.000	0.980	0.950	1.430
TM3	4	1.300	0.700	0.160	0.400	200.000	0.400	0.600	400.000	1.000	0.980	0.950	1.430
TM6	1	1.800	0.700	0.640	0.750	180.000	0.400	0.600	440.000	1.000	0.980	0.950	1.600
TM6	2	1.800	0.700	0.480	0.750	200.000	0.400	0.600	400.000	1.000	0.980	0.950	1.600
TM6	3	1.800	0.700	0.560	1.000	160.000	0.400	0.600	440.000	1.000	0.980	0.950	1.920
TM6	4	1.800	0.700	0.640	1.000	180.000	0.400	0.600	400.000	1.000	0.980	0.950	1.920
TM6	5	2.400	0.700	0.480	0.600	180.000	0.400	0.660	400.000	1.000	0.980	0.950	1.600
TM6	6	2.400	0.700	0.320	0.600	200.000	0.400	0.660	400.000	1.000	0.980	0.950	1.680
TM6	7	2.100	0.700	0.320	0.700	180.000	0.400	0.630	400.000	1.000	0.980	0.950	2.240
TM6	8	2.250	0.700	0.240	0.750	240.000	0.400	0.480	440.000	1.000	0.980	0.950	0.960
TM2	10	2.250	0.700	0.320	1.000	180.000	0.400	0.480	480.000	1.000	0.980	0.950	0.480
TM1	11	1.950	0.700	0.640	0.650	120.000	0.400	0.600	480.000	1.000	0.980	0.950	1.920
TM1	12	1.500	0.700	0.560	0.750	180.000	0.400	0.600	400.000	1.000	0.980	0.950	1.600
TM1	13	1.800	0.700	0.320	0.650	140.000	0.400	0.480	480.000	1.000	0.980	0.950	0.320
ECCA	1	6.000	0.600	5.250	0.400	220.000	0.180	0.577	300.000	0.600	0.552	0.960	2.700
ECCA	2	5.520	0.600	4.500	0.450	190.000	0.210	0.646	328.000	0.498	0.618	0.960	2.403
ECCA	3	5.520	0.600	4.500	0.450	190.000	0.210	0.646	328.000	0.498	0.618	0.960	2.403
ECCA	4	5.520	0.600	4.000	0.500	180.000	0.230	0.660	360.000	0.498	0.630	0.950	2.538
ECCA	5	5.400	0.600	4.000	0.375	164.000	0.262	0.660	360.000	0.498	0.660	0.960	2.295
ECCA	6	5.400	0.600	4.000	0.375	164.000	0.262	0.660	360.000	0.498	0.660	0.960	2.295
ECCA	7	5.100	0.600	3.000	0.250	156.000	0.287	0.660	368.000	0.498	0.780	0.960	2.025
ECCA	8	4.800	0.600	2.750	0.300	156.000	0.287	0.660	368.000	0.540	0.780	0.960	2.025
ECCA	9	3.900	0.600	2.250	0.480	156.000	0.287	0.660	368.000	0.540	0.780	0.960	2.025
ECCA	10	5.700	0.600	1.250	0.700	180.000	0.268	0.639	360.000	0.600	0.720	0.970	2.376
ECCA	11	6.300	0.600	0.750	0.500	160.000	0.248	0.688	368.000	0.498	0.840	0.950	2.295
ECCA	12	4.800	0.600	0.250	0.300	180.000	0.268	0.744	360.000	0.600	0.720	0.970	2.160
BETH	1	4.000	0.700	3.250	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	2	4.000	0.700	2.750	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	3	4.000	0.700	3.000	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	4	4.000	0.700	2.500	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	5	4.000	0.700	2.000	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	6	4.000	0.700	2.250	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	7	4.000	0.700	1.500	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	8	4.000	0.700	1.250	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
BETH	9	4.000	0.700	0.500	0.800	110.000	0.350	0.500	200.000	1.000	0.350	0.880	1.000
HOEK	1	2.450	0.550	0.750	0.420	157.500	0.136	0.315	315.000	1.000	0.361	0.926	1.800
HOEK	2	1.750	0.550	0.500	0.300	142.500	0.136	0.315	343.000	1.000	0.458	0.926	1.800
HOEK	3	1.750	0.550	0.750	0.300	147.000	0.136	0.315	332.500	1.000	0.434	0.926	2.100
HOEK	4	1.925	0.550	0.750	0.360	153.000	0.136	0.315	332.500	1.000	0.410	0.926	2.400
HOEK	5	1.925	0.550	0.750	0.360	153.000	0.136	0.315	322.000	1.000	0.410	0.926	2.400
HOEK	6	1.925	0.550	0.500	0.390	165.000	0.136	0.315	315.000	1.000	0.386	0.926	2.250
HOEK	7	1.400	0.550	0.000	0.420	142.500	0.136	0.315	343.000	1.000	0.434	0.926	2.100
HOEK	8	2.275	0.550	0.250	0.390	157.500	0.136	0.315	322.000	1.000	0.361	0.926	2.250

HOEK 9	1.925	0.550	0.250	0.390	150.000	0.136	0.315	322.000	1.000	0.386	0.926	2.250
CED 1	2.000	0.700	0.500	0.400	250.000	0.135	0.711	385.000	0.500	0.040	0.984	0.300
CED 2	2.000	0.700	0.500	0.400	250.000	0.135	0.711	367.500	0.500	0.040	0.984	0.100
CED 3	2.000	0.700	0.250	0.400	250.000	0.135	0.711	350.000	0.500	0.044	0.984	0.100
ZULU 1	6.000	0.900	0.750	0.400	260.000	0.430	0.230	320.000	1.500	0.150	0.890	0.050
ZULU 2	6.000	0.900	0.500	0.400	260.000	0.430	0.230	320.000	1.500	0.150	0.890	0.050
ZULU 3	3.000	0.900	0.250	0.320	109.200	0.301	0.637	352.000	1.500	0.150	0.890	0.050
ZULU 4	3.000	0.900	0.250	0.160	109.200	0.301	0.637	272.000	1.500	0.147	0.890	0.050
ZULU 5	1.200	0.900	0.250	0.200	70.200	0.649	0.023	384.000	1.500	0.147	0.890	0.050
ZULU 6	1.500	0.900	0.250	0.240	98.800	0.602	0.499	368.000	1.500	0.147	0.890	0.050
ZULU 7	1.500	0.900	0.250	0.280	98.800	0.602	0.499	352.000	1.500	0.147	0.890	0.050
ZULU 8	3.600	0.900	0.000	0.160	137.800	0.198	0.435	304.000	1.500	0.150	0.890	0.050
ZULU 9	3.600	0.900	0.000	0.320	137.800	0.198	0.435	304.000	1.500	0.150	0.890	0.050
ZULU 10	3.600	0.900	0.250	0.400	137.800	0.198	0.435	304.000	1.500	0.150	0.890	0.050
OX4W 1	1.300	0.900	0.850	0.500	170.000	0.352	0.260	350.000	1.000	0.800	0.836	0.660
OX4W 2	1.300	0.900	0.510	0.400	170.000	0.352	0.260	350.000	1.000	0.800	0.924	0.540
OX4S 1	1.300	0.900	0.850	0.500	170.000	0.352	0.681	350.000	1.000	0.400	0.836	0.660
OX4S 2	1.300	0.900	0.510	0.400	170.000	0.352	0.681	350.000	1.000	0.400	0.924	0.540
OX12W 1	1.200	0.900	1.530	0.700	170.000	0.500	0.351	350.000	1.000	0.456	0.880	0.500
OX12W 2	1.200	0.900	1.530	0.700	170.000	0.500	0.321	350.000	1.000	0.380	0.880	0.500
OX12W 3	1.050	0.900	1.700	0.500	180.000	0.360	0.450	350.000	1.500	0.266	0.880	0.500
OX12W 4	1.350	0.900	1.530	0.600	190.000	0.400	0.399	350.000	1.500	0.456	0.889	0.500
OX12W 5	*1.500*	*0.900*	*0.850*	*0.700*	*220.000*	*0.400*	*0.300*	*315.000*	*2.000*	*0.456*	*0.906*	*0.500*
OX12W 7	1.500	0.900	1.190	0.800	220.000	0.360	0.300	315.000	1.700	0.456	0.898	0.500
OX12W 8	1.350	0.900	1.700	0.600	170.000	0.450	0.249	350.000	1.000	0.760	0.880	0.500
OX12W 9	1.050	0.900	1.190	0.600	190.000	0.450	0.300	315.000	1.000	0.684	0.889	0.500
OX12W 10	1.425	0.900	0.680	0.700	210.000	0.400	0.300	315.000	2.000	0.608	0.906	0.500
OX12W 11	1.050	0.900	1.360	0.400	140.000	0.500	0.201	350.000	1.000	0.760	0.880	0.500
OX12W 12	1.500	0.900	1.020	0.800	200.000	0.400	0.300	315.000	1.500	0.608	0.898	0.500
OX12P 1	1.200	0.900	1.530	0.700	170.000	0.500	0.585	350.000	1.000	0.360	0.880	0.500
OX12P 2	1.200	0.900	1.530	0.700	170.000	0.500	0.535	350.000	1.000	0.300	0.880	0.500
OX12P 3	1.050	0.900	1.700	0.500	180.000	0.360	0.750	350.000	1.000	0.210	0.880	0.500
OX12P 4	1.350	0.900	1.530	0.600	190.000	0.400	0.665	350.000	1.500	0.360	0.889	0.500
OX12P 5	1.500	0.900	0.850	0.700	220.000	0.400	0.500	315.000	2.000	0.360	0.906	0.500
OX12P 7	1.500	0.900	1.190	0.800	220.000	0.360	0.500	315.000	1.700	0.360	0.898	0.500
OX12P 8	1.350	0.900	1.700	0.600	170.000	0.450	0.415	350.000	1.000	0.600	0.880	0.500
OX12P 9	1.050	0.900	1.190	0.600	190.000	0.450	0.500	315.000	1.000	0.540	0.889	0.500
OX12P 10	1.425	0.900	0.680	0.700	210.000	0.400	0.500	315.000	2.000	0.480	0.906	0.500
OX12P 11	1.050	0.900	1.360	0.400	140.000	0.500	0.335	350.000	1.000	0.600	0.880	0.500
OX12P 12	1.500	0.900	1.020	0.800	200.000	0.400	0.500	315.000	1.500	0.480	0.898	0.500
OX12S 1	1.200	0.900	1.530	0.700	170.000	0.500	0.819	350.000	1.000	0.228	0.880	0.500
OX12S 2	1.200	0.900	1.530	0.700	170.000	0.500	0.749	350.000	1.000	0.190	0.880	0.500
OX12S 3	1.050	0.900	1.530	0.500	180.000	0.360	1.050	350.000	1.000	0.133	0.880	0.500
OX12S 4	1.350	0.900	1.377	0.600	190.000	0.400	0.931	350.000	1.500	0.228	0.889	0.500
OX12S 5	1.500	0.900	0.850	0.700	220.000	0.400	0.700	315.000	2.000	0.228	0.906	0.500
OX12S 7	1.500	0.900	1.190	0.800	220.000	0.360	0.700	315.000	1.700	0.228	0.898	0.500
OX12S 8	1.350	0.900	1.700	0.600	170.000	0.450	0.581	350.000	1.000	0.380	0.880	0.500
OX12S 9	1.050	0.900	1.190	0.600	190.000	0.450	0.700	315.000	1.000	0.342	0.889	0.500
OX12S 10	1.425	0.900	0.680	0.700	210.000	0.400	0.700	315.000	2.000	0.304	0.906	0.500
OX12S 11	1.050	0.900	1.360	0.400	140.000	0.500	0.469	350.000	1.000	0.380	0.880	0.500
OX12S 12	1.500	0.900	1.020	0.800	200.000	0.400	0.700	315.000	1.500	0.304	0.898	0.500
OX10W 1	0.900	0.900	0.680	0.600	160.000	0.450	0.270	350.000	1.000	0.800	0.880	0.500
OX10W 2	0.900	0.900	0.680	0.200	160.000	0.450	0.270	350.000	1.000	0.800	0.889	0.500
OX10W 3	0.900	0.900	0.510	0.200	160.000	0.450	0.270	350.000	1.100	0.800	0.889	0.500
OX10W 4	0.900	0.900	0.340	0.400	160.000	0.450	0.270	350.000	1.100	0.720	0.898	0.500
OX10W 5	0.840	0.900	0.340	0.200	160.000	0.450	0.270	315.000	1.200	0.640	0.906	0.500
OX10P 1	0.900	0.900	0.680	0.600	160.000	0.450	0.400	350.000	1.000	0.600	0.880	0.500

OX10P 2	0.900	0.900	0.680	0.200	160.000	0.450	0.400	350.000	1.000	0.600	0.889	0.500
OX10P 3	0.900	0.900	0.510	0.200	160.000	0.450	0.400	350.000	1.100	0.600	0.889	0.500
OX10P 4	0.900	0.900	0.340	0.400	160.000	0.450	0.400	350.000	1.100	0.540	0.898	0.500
OX10P 5	0.840	0.900	0.340	0.200	160.000	0.450	0.400	315.000	1.200	0.480	0.906	0.500
OX10S 1	0.900	0.900	0.680	0.600	160.000	0.450	0.550	350.000	1.000	0.400	0.880	0.500
OX10S 2	0.900	0.900	0.680	0.200	160.000	0.450	0.550	350.000	1.000	0.400	0.889	0.500
OX10S 3	0.900	0.900	0.510	0.200	160.000	0.450	0.550	350.000	1.100	0.400	0.889	0.500
OX10S 4	0.900	0.900	0.340	0.400	160.000	0.450	0.550	350.000	1.100	0.360	0.898	0.500
OX10S 5	0.840	0.900	0.340	0.200	160.000	0.450	0.550	315.000	1.200	0.320	0.906	0.500
OX35W 1	1.120	0.900	1.020	0.595	160.000	0.450	0.230	350.000	0.950	0.684	0.880	0.500
OX35W 2	1.260	0.900	0.850	0.714	164.000	0.450	0.230	350.000	1.000	0.760	0.880	0.500
OX35W 3	0.980	0.900	1.020	0.476	160.000	0.450	0.230	350.000	0.900	0.760	0.880	0.500
OX35W 4	1.120	0.900	0.850	0.595	164.000	0.450	0.230	350.000	1.000	0.760	0.889	0.500
OX35W 5	0.980	0.900	0.850	0.476	164.000	0.450	0.230	350.000	1.000	0.760	0.889	0.500
OX35W 6	1.260	0.900	0.680	0.833	174.000	0.450	0.230	350.000	1.100	0.684	0.898	0.500
OX35W 7	1.120	0.900	0.510	0.714	160.000	0.450	0.230	350.000	0.950	0.836	0.880	0.500
OX35W 8	1.120	0.900	0.340	0.595	160.000	0.450	0.230	350.000	1.100	0.760	0.889	0.500
OX35P 1	1.120	0.900	1.020	0.595	160.000	0.450	0.330	350.000	0.950	0.450	0.880	0.500
OX35P 2	1.260	0.900	0.850	0.714	164.000	0.450	0.330	350.000	1.000	0.500	0.880	0.500
OX35P 3	0.980	0.900	1.020	0.476	160.000	0.450	0.330	350.000	0.900	0.500	0.880	0.500
OX35P 4	1.120	0.900	0.850	0.595	164.000	0.450	0.330	350.000	1.000	0.500	0.889	0.500
OX35P 5	0.980	0.900	0.850	0.476	164.000	0.450	0.330	350.000	1.000	0.500	0.889	0.500
OX35P 6	1.260	0.900	0.680	0.833	174.000	0.450	0.330	350.000	1.100	0.450	0.898	0.500
OX35P 7	1.120	0.900	0.510	0.714	160.000	0.450	0.330	350.000	0.950	0.550	0.880	0.500
OX35P 8	1.120	0.900	0.340	0.595	160.000	0.450	0.330	350.000	1.100	0.500	0.889	0.500
OX35S 1	1.120	0.900	1.020	0.595	160.000	0.450	0.520	350.000	0.950	0.324	0.880	0.500
OX35S 2	1.260	0.900	0.850	0.714	164.000	0.450	0.520	350.000	1.000	0.360	0.880	0.500
OX35S 3	0.980	0.900	1.020	0.476	160.000	0.450	0.520	350.000	0.900	0.360	0.880	0.500
OX35S 4	1.120	0.900	0.850	0.595	164.000	0.450	0.520	350.000	1.000	0.360	0.889	0.500
OX35S 5	0.980	0.900	0.850	0.476	164.000	0.450	0.520	350.000	1.000	0.360	0.889	0.500
OX35S 6	1.260	0.900	0.680	0.833	174.000	0.450	0.520	350.000	1.100	0.324	0.898	0.500
OX35S 7	1.120	0.900	0.510	0.714	160.000	0.450	0.520	350.000	0.950	0.396	0.880	0.500
OX35S 8	1.120	0.900	0.340	0.595	160.000	0.450	0.520	350.000	1.100	0.360	0.889	0.500
OX17W 11	0.910	0.900	1.360	0.500	160.000	0.450	0.300	332.500	1.200	0.456	0.880	0.500
OX17W 12	1.040	0.900	0.850	0.500	200.000	0.400	0.249	350.000	1.800	0.456	0.889	0.400
OX17W 13	1.040	0.900	0.340	0.900	200.000	0.400	0.201	350.000	2.160	0.456	0.898	0.250
OX17W 14	1.040	0.900	1.020	0.600	180.000	0.450	0.279	315.000	1.200	0.684	0.880	0.500
OX17W 15	1.170	0.900	0.510	0.600	200.000	0.400	0.249	350.000	2.160	0.532	0.898	0.400
OX17W 16	1.040	0.900	0.510	0.600	180.000	0.400	0.300	350.000	1.800	0.456	0.880	0.500
OX17P 11	0.910	0.900	1.360	0.500	160.000	0.450	0.450	332.500	1.200	0.360	0.880	0.500
OX17P 12	1.040	0.900	0.850	0.500	200.000	0.400	0.373	350.000	1.800	0.360	0.889	0.400
OX17P 13	1.040	0.900	0.340	0.900	200.000	0.400	0.301	350.000	2.160	0.360	0.898	0.250
OX17P 14	1.040	0.900	1.020	0.600	180.000	0.450	0.419	315.000	1.200	0.540	0.880	0.500
OX17P 15	1.170	0.900	0.510	0.600	200.000	0.400	0.373	350.000	2.160	0.420	0.898	0.400
OX17P 16	1.040	0.900	0.510	0.600	180.000	0.400	0.450	350.000	1.800	0.360	0.880	0.500
OX17S 11	0.910	0.900	1.360	0.500	160.000	0.450	0.700	332.500	1.200	0.228	0.880	0.500
OX17S 12	1.040	0.900	0.850	0.500	200.000	0.400	0.581	350.000	1.800	0.228	0.889	0.400
OX17S 13	1.040	0.900	0.340	0.900	200.000	0.400	0.469	350.000	2.160	0.228	0.898	0.250
OX17S 14	1.040	0.900	1.020	0.600	180.000	0.450	0.651	315.000	1.200	0.342	0.880	0.500
OX17S 15	1.170	0.900	0.510	0.600	200.000	0.400	0.581	350.000	2.160	0.266	0.898	0.400
OX17S 16	1.040	0.900	0.510	0.600	180.000	0.400	0.700	350.000	1.800	0.228	0.880	0.500
OX32W 9	1.050	0.900	1.020	0.500	160.000	0.450	0.220	350.000	1.100	0.800	0.898	0.500
OX32W 10	1.050	0.900	0.850	0.500	160.000	0.450	0.200	315.000	1.100	0.840	0.924	0.500
OX32W 11	1.050	0.900	0.680	0.500	160.000	0.450	0.200	315.000	1.100	0.840	0.924	0.500
OX32W 12	1.050	0.900	0.340	0.500	160.000	0.450	0.200	315.000	1.200	0.840	0.924	0.500
OX32W 18	1.050	0.900	0.340	0.500	160.000	0.450	0.200	315.000	1.200	0.840	0.924	0.500
OX32P 9	1.050	0.900	1.020	0.500	160.000	0.450	0.330	350.000	1.100	0.600	0.898	0.500

OX32P 10	1.050	0.900	0.850	0.500	160.000	0.450	0.300	315.000	1.100	0.630	0.924	0.500
OX32P 11	1.050	0.900	0.680	0.500	160.000	0.450	0.300	315.000	1.100	0.630	0.924	0.500
OX32P 12	1.050	0.900	0.340	0.500	160.000	0.450	0.300	315.000	1.200	0.630	0.924	0.500
OX32P 18	1.050	0.900	0.340	0.500	160.000	0.450	0.300	315.000	1.200	0.630	0.924	0.500
OX32S 9	1.050	0.900	1.020	0.500	160.000	0.450	0.550	350.000	1.100	0.400	0.898	0.500
OX32S 10	1.050	0.900	0.850	0.500	160.000	0.450	0.500	315.000	1.100	0.420	0.924	0.500
OX32S 11	1.050	0.900	0.680	0.500	160.000	0.450	0.500	315.000	1.100	0.420	0.924	0.500
OX32S 12	1.050	0.900	0.340	0.500	160.000	0.450	0.500	315.000	1.200	0.420	0.924	0.500
OX32S 18	1.050	0.900	0.340	0.500	160.000	0.450	0.500	315.000	1.200	0.420	0.924	0.500
KAAI 1	5.600	0.700	2.750	0.560	200.000	0.650	0.150	350.000	1.000	0.275	0.850	0.000
KAAI 2	5.600	0.700	2.000	0.560	200.000	0.650	0.150	350.000	1.000	0.275	0.850	0.000
KAAI 3	5.600	0.700	2.250	0.560	200.000	0.650	0.150	350.000	1.000	0.275	0.850	0.000
KAAI 4	5.600	0.700	2.250	0.640	200.000	0.650	0.150	350.000	1.000	0.275	0.850	0.000
KAAI 5	6.300	0.700	1.500	0.720	200.000	0.650	0.150	350.000	1.000	0.250	0.850	0.000
KAAI 6	7.000	0.700	1.250	0.720	220.000	0.585	0.165	308.000	1.000	0.225	0.850	0.000
KAAI 7	7.700	0.700	1.000	0.800	230.000	0.553	0.172	245.000	1.000	0.175	0.850	0.000
KAAI 8	7.700	0.700	0.500	0.800	230.000	0.553	0.172	245.000	1.000	0.175	0.850	0.000
KAAI 9	6.300	0.700	0.500	0.800	240.000	0.553	0.172	245.000	1.000	0.175	0.850	0.000
MALG 1	5.600	0.700	1.500	0.480	200.000	0.650	0.150	350.000	1.000	0.250	0.850	0.000
MALG 2	5.600	0.700	1.500	0.480	200.000	0.650	0.150	350.000	1.000	0.250	0.850	0.000
MALG 3	5.600	0.700	1.250	0.480	200.000	0.650	0.150	350.000	1.000	0.250	0.850	0.000
MALG 4	5.600	0.700	1.000	0.480	200.000	0.650	0.150	350.000	1.000	0.250	0.850	0.000
MALG 5	5.600	0.700	1.000	0.480	200.000	0.650	0.150	350.000	1.000	0.250	0.850	0.000
MALG 6	6.300	0.700	1.000	0.560	220.000	0.585	0.165	332.500	1.000	0.225	0.850	0.000
MALG 7	7.000	0.700	0.500	0.640	230.000	0.585	0.172	280.000	1.000	0.200	0.850	0.000
MALG 8	7.000	0.700	0.500	0.640	230.000	0.585	0.172	297.500	1.000	0.212	0.850	0.000
NDAN5 1	4.888	0.700	1.500	0.680	218.000	0.451	0.245	131.000	3.870	0.333	0.889	0.000
NDAN5 2	8.050	0.700	1.000	0.740	239.800	0.451	0.245	104.800	3.096	0.267	0.898	0.000
NDAN5 3	4.600	0.700	1.250	1.148	228.900	0.451	0.245	117.900	3.483	0.300	0.898	0.000
NDAN5 4	4.313	0.700	1.500	0.723	207.100	0.451	0.245	137.550	4.063	0.333	0.889	0.000
NDAN5 5	4.600	0.700	1.000	0.655	228.900	0.451	0.245	117.900	3.483	0.282	0.898	0.000
NDAN5 6	4.313	0.700	0.500	0.621	218.000	0.451	0.245	131.000	3.870	0.333	0.907	0.000
NDAN5 7	6.900	0.700	1.000	0.825	228.900	0.451	0.245	124.450	3.676	0.300	0.889	0.000
NDAN5 8	7.763	0.700	0.750	0.382	239.800	0.451	0.245	104.800	3.096	0.273	0.817	0.000
NDAN5 9	7.475	0.700	0.500	0.570	228.900	0.451	0.245	131.000	3.870	0.300	0.898	0.000
NDAN5 10	4.313	0.700	2.250	0.553	207.100	0.451	0.245	137.550	4.063	0.336	0.889	0.000
NDAN5 11	4.888	0.700	2.000	0.595	239.800	0.451	0.245	117.900	3.483	0.282	0.889	0.000
NDAN5 12	8.338	0.700	1.500	0.850	239.800	0.451	0.245	111.350	3.290	0.273	0.898	0.000
NDAN5 13	6.900	0.700	2.250	0.808	218.000	0.451	0.245	131.000	3.870	0.333	0.889	0.000
NDAN5 14	5.175	0.700	1.750	0.892	196.200	0.451	0.245	137.550	4.063	0.345	0.898	0.000
NDAN5 15	4.313	0.700	1.250	0.638	196.200	0.451	0.245	144.100	4.257	0.345	0.889	0.000
NDAN5 16	5.750	0.700	0.750	0.680	196.200	0.451	0.245	144.100	4.257	0.345	0.907	0.000
NDAN5 17	4.600	0.700	0.000	0.315	207.100	0.451	0.245	137.550	4.063	0.339	0.889	0.000
NDAN5 18	9.775	0.700	0.000	0.425	228.900	0.451	0.245	131.000	3.870	0.300	0.916	0.000

OSE2-VALIDATION PARAMETERS

Area ID	1 K	2 N	3 CDEL	4 KC	5 SMAX	6 DA	7 C	8 PCSLP	9 PCVSA	10 IAF	11 APF	12 CLP
TM11 1	1.340	0.700	0.240	0.530	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.298
TM11 2	1.340	0.700	0.240	0.620	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.416
TM11 3	1.340	0.700	0.160	0.560	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.060
TM8 4	1.340	0.700	0.240	0.370	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.200
TM8 5	1.340	0.700	0.240	0.450	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.000
TM8 6	1.340	0.700	0.160	0.430	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.000
TM8 7	1.340	0.700	0.080	0.540	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.000
TM3 1	1.340	0.700	0.320	0.510	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.400
TM3 2	1.340	0.700	0.240	0.610	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.300
TM3 3	1.340	0.700	0.160	0.310	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.200
TM3 4	1.340	0.700	0.160	0.450	196.000	0.320	0.220	361.000	1.000	0.848	0.806	1.000
TM6 1	1.280	0.700	0.640	1.130	196.000	0.340	0.180	372.000	1.000	0.870	0.806	3.000
TM6 2	1.340	0.700	0.480	0.800	196.000	0.320	0.220	361.000	1.000	0.850	0.806	2.800
TM6 3	1.340	0.700	0.560	0.990	196.000	0.320	0.250	361.000	1.000	0.850	0.806	3.000
TM6 4	1.340	0.700	0.640	1.130	174.000	0.330	0.220	361.000	1.000	0.850	0.806	3.000
TM6 5	1.340	0.700	0.480	0.480	196.000	0.320	0.220	362.000	1.000	0.850	0.806	2.600
TM6 6	1.340	0.700	0.320	0.560	196.000	0.320	0.220	362.000	1.000	0.850	0.806	2.400
TM6 7	1.150	0.700	0.320	0.560	152.000	0.400	0.160	399.000	1.000	0.930	0.806	2.400
TM6 8	1.340	0.700	0.240	0.730	196.000	0.320	0.220	362.000	1.000	0.850	0.806	1.600
TM2 10	1.340	0.700	0.320	0.930	196.000	0.320	0.220	362.000	1.000	0.850	0.806	1.000
TM1 11	1.240	0.700	0.640	0.640	152.000	0.380	0.220	380.000	1.000	0.890	0.806	1.800
TM1 12	1.340	0.700	0.560	0.700	196.000	0.320	0.240	362.000	1.000	0.850	0.806	2.400
TM1 13	1.180	0.700	0.320	0.770	196.000	0.360	0.140	392.000	1.000	0.920	0.806	1.000
ECCA 1	3.600	0.700	5.250	0.550	233.000	0.230	0.620	302.000	0.600	0.600	0.950	2.300
ECCA 2	3.600	0.700	4.500	0.700	178.000	0.268	0.658	336.000	0.498	0.618	0.950	2.070
ECCA 3	3.600	0.700	4.500	0.600	178.000	0.268	0.658	336.000	0.498	0.618	0.950	2.070
ECCA 4	2.700	0.700	4.000	0.650	160.000	0.340	0.520	372.000	0.498	0.648	0.950	2.185
ECCA 5	3.360	0.700	4.000	0.550	160.000	0.302	0.620	347.000	0.498	0.618	0.950	2.070
ECCA 6	3.360	0.700	4.000	0.450	160.000	0.302	0.620	347.000	0.498	0.618	0.950	2.070
ECCA 7	2.820	0.700	3.000	0.600	160.000	0.212	0.778	387.000	0.498	0.648	0.950	1.725
ECCA 8	2.820	0.700	2.750	0.550	160.000	0.219	0.813	382.000	0.540	0.648	0.950	1.725
ECCA 9	2.700	0.700	2.250	0.450	160.000	0.249	0.765	389.000	0.540	0.648	0.950	1.725
ECCA 10	2.700	0.700	1.250	0.900	196.000	0.220	0.736	381.000	0.600	0.648	0.950	1.955
ECCA 11	2.640	0.700	0.750	0.750	160.000	0.258	0.742	394.000	0.498	0.702	0.950	2.070
ECCA 12	3.600	0.700	0.250	0.700	196.000	0.254	0.646	353.000	0.600	0.600	0.950	1.840
BETH 1	4.400	0.700	3.250	0.600	118.000	0.287	0.499	160.000	1.000	0.399	0.830	0.800
BETH 2	4.400	0.700	2.750	0.680	118.000	0.287	0.499	160.000	1.000	0.399	0.830	0.640
BETH 3	5.000	0.700	3.000	0.680	118.000	0.273	0.561	160.000	1.000	0.367	0.830	0.800
BETH 4	5.000	0.700	2.500	0.720	118.000	0.273	0.561	160.000	1.000	0.367	0.830	0.800
BETH 5	4.000	0.700	2.000	0.720	118.000	0.315	0.443	160.000	1.000	0.420	0.830	0.560
BETH 6	4.400	0.700	2.250	0.780	118.000	0.287	0.499	160.000	1.000	0.399	0.830	0.800
BETH 7	4.400	0.700	1.500	0.450	118.000	0.287	0.499	160.000	1.000	0.399	0.830	0.800
BETH 8	4.000	0.700	1.250	0.550	118.000	0.315	0.471	160.000	1.000	0.420	0.830	0.800
BETH 9	5.000	0.700	0.500	0.550	118.000	0.273	0.589	160.000	1.000	0.367	0.830	0.400
HOEK 1	2.720	0.700	1.000	0.210	205.000	0.420	0.450	254.000	1.500	0.420	0.832	1.300
HOEK 2	1.720	0.700	0.500	0.438	105.000	0.468	0.440	385.000	1.500	0.680	0.850	1.500
HOEK 3	1.920	0.700	0.750	0.552	177.000	0.420	0.240	385.000	1.500	0.620	0.859	2.300
HOEK 4	1.920	0.700	0.750	0.480	192.000	0.440	0.250	385.000	1.500	0.610	0.859	2.300
HOEK 5	1.920	0.700	0.750	0.270	177.000	0.388	0.290	385.000	1.500	0.610	0.859	2.300
HOEK 6	4.000	0.700	0.500	0.528	220.000	0.340	0.562	292.000	1.500	0.460	0.868	2.300
HOEK 7	1.720	0.700	0.000	0.612	105.000	0.464	0.360	400.000	1.500	0.700	0.859	2.000
HOEK 8	4.000	0.700	0.250	0.462	192.000	0.320	0.640	322.000	1.500	0.460	0.868	2.300

HOEK 9	2.200	0.700	0.250	0.468	177.000	0.420	0.300	385.500	1.500	0.610	0.859	2.300
CED 1	5.490	0.700	0.500	0.500	232.500	0.408	0.570	291.000	0.500	0.180	0.817	2.000
CED 2	6.020	0.700	0.500	0.500	232.500	0.392	0.714	261.000	0.500	0.160	0.817	0.800
CED 3	7.750	0.700	0.250	0.500	232.500	0.352	0.774	252.000	0.500	0.134	0.817	0.800
ZULU 1	4.380	0.700	0.750	0.380	260.000	0.400	0.448	309.000	1.500	0.250	0.840	0.050
ZULU 2	4.830	0.700	0.500	0.528	260.000	0.400	0.484	291.000	1.500	0.240	0.840	0.050
ZULU 3	4.380	0.700	0.250	0.380	202.800	0.424	0.572	312.000	1.500	0.270	0.850	0.050
ZULU 4	4.020	0.700	0.250	0.160	148.200	0.424	0.652	273.000	1.500	0.320	0.850	0.050
ZULU 5	1.620	0.700	0.250	0.368	70.200	0.600	0.144	399.000	1.500	0.620	0.850	0.050
ZULU 6	2.580	0.700	0.250	0.352	98.800	0.552	0.584	348.000	1.500	0.420	0.850	0.050
ZULU 7	2.220	0.700	0.250	0.380	98.800	0.572	0.576	366.000	1.500	0.440	0.850	0.050
ZULU 8	5.700	0.700	0.000	0.540	148.200	0.392	0.716	291.000	1.500	0.230	0.850	0.050
ZULU 9	5.700	0.700	0.000	0.500	148.200	0.392	0.716	291.000	1.500	0.230	0.850	0.050
ZULU 10	5.700	0.700	0.250	0.548	148.200	0.392	0.716	291.000	1.500	0.230	0.850	0.050
OX4W 1	1.980	0.700	0.850	0.310	174.000	0.410	0.200	339.000	1.000	0.630	0.876	0.660
OX4W 2	1.980	0.700	0.510	0.400	174.000	0.410	0.200	339.000	1.000	0.630	0.876	0.540
OX4S 1	2.860	0.700	0.850	0.310	174.000	0.410	0.490	290.000	1.000	0.440	0.831	0.660
OX4S 2	2.860	0.700	0.510	0.400	174.000	0.410	0.490	290.000	1.000	0.440	0.821	0.540
OX12W 1	1.870	0.700	1.530	0.700	174.000	0.430	0.190	346.500	2.000	0.640	0.876	0.600
OX12W 2	1.870	0.700	1.530	0.750	174.000	0.430	0.190	346.500	2.000	0.640	0.876	0.600
OX12W 3	1.980	0.700	1.700	0.470	174.000	0.430	0.160	339.500	2.000	0.630	0.876	0.600
OX12W 4	1.980	0.700	1.530	0.730	190.000	0.420	0.160	339.500	3.000	0.630	0.876	0.600
OX12W 5	2.730	0.700	0.850	0.750	190.000	0.380	0.280	273.000	4.000	0.550	0.876	0.600
OX12W 7	2.730	0.700	1.190	0.710	190.000	0.380	0.280	273.000	3.400	0.550	0.876	0.600
OX12W 8	1.980	0.700	1.700	0.500	174.000	0.420	0.210	339.500	2.000	0.630	0.876	0.600
OX12W 9	1.870	0.700	1.190	0.550	190.000	0.420	0.170	346.500	2.000	0.640	0.876	0.600
OX12W10	2.730	0.700	0.680	0.590	190.000	0.380	0.280	273.000	4.000	0.550	0.876	0.600
OX12W11	2.600	0.700	1.360	0.330	174.000	0.360	0.350	297.500	2.000	0.560	0.876	0.600
OX12W12	2.730	0.700	1.020	0.610	190.000	0.360	0.320	297.500	3.000	0.550	0.876	0.600
OX12P 1	2.270	0.700	1.530	0.700	174.000	0.430	0.340	318.500	1.800	0.540	0.848	0.600
OX12P 2	2.270	0.700	1.530	0.750	174.000	0.430	0.340	318.500	1.800	0.540	0.848	0.600
OX12P 3	2.420	0.700	1.700	0.470	174.000	0.430	0.320	311.500	1.800	0.530	0.848	0.600
OX12P 4	2.420	0.700	1.530	0.730	190.000	0.420	0.310	311.500	2.700	0.530	0.848	0.600
OX12P 5	3.380	0.700	0.850	0.750	190.000	0.380	0.430	245.000	3.600	0.460	0.848	0.600
OX12P 7	3.380	0.700	1.190	0.710	190.000	0.380	0.430	245.000	3.060	0.460	0.848	0.600
OX12P 8	2.420	0.700	1.700	0.500	174.000	0.420	0.370	311.500	1.800	0.530	0.848	0.600
OX12P 9	2.270	0.700	1.190	0.550	190.000	0.420	0.330	318.500	1.800	0.540	0.848	0.600
OX12P10	3.385	0.700	0.680	0.590	190.000	0.380	0.430	245.000	3.600	0.460	0.848	0.600
OX12P11	3.210	0.700	1.360	0.330	174.000	0.360	0.510	266.000	1.800	0.460	0.848	0.600
OX12P12	3.380	0.700	1.020	0.610	190.000	0.360	0.480	262.500	2.700	0.460	0.848	0.600
OX12S 1	2.680	0.700	1.530	0.700	174.000	0.430	0.470	297.500	1.500	0.460	0.831	0.600
OX12S 2	2.680	0.700	1.530	0.750	174.000	0.430	0.470	297.500	1.500	0.460	0.831	0.600
OX12S 3	2.860	0.700	1.530	0.470	174.000	0.430	0.440	290.500	1.500	0.440	0.831	0.600
OX12S 4	2.860	0.700	1.377	0.730	190.000	0.420	0.440	290.500	2.250	0.440	0.831	0.600
OX12S 5	4.040	0.700	0.850	0.750	190.000	0.380	0.560	220.500	3.000	0.370	0.831	0.600
OX12S 7	4.040	0.700	1.190	0.710	190.000	0.380	0.560	220.500	2.550	0.370	0.831	0.600
OX12S 8	2.860	0.700	1.700	0.500	174.000	0.420	0.500	290.500	1.500	0.440	0.831	0.600
OX12S 9	2.680	0.700	1.190	0.550	190.000	0.420	0.450	297.500	1.500	0.460	0.831	0.600
OX12S10	4.040	0.700	0.680	0.590	190.000	0.380	0.560	220.500	3.000	0.370	0.831	0.600
OX12S11	3.830	0.700	1.360	0.330	174.000	0.360	0.640	245.000	1.500	0.380	0.831	0.600
OX12S12	4.040	0.700	1.020	0.610	190.000	0.360	0.600	241.500	2.250	0.370	0.831	0.600
OX10W 1	2.120	0.900	0.680	0.410	174.000	0.430	0.220	330.000	2.000	0.590	0.876	0.500
OX10W 2	2.120	0.900	0.680	0.510	190.000	0.420	0.210	330.000	2.000	0.590	0.876	0.450
OX10W 3	2.120	0.900	0.510	0.500	190.000	0.420	0.210	330.000	2.200	0.590	0.876	0.450
OX10W 4	2.120	0.900	0.340	0.350	174.000	0.430	0.220	330.000	2.200	0.590	0.876	0.500
OX10W 5	2.120	0.900	0.340	0.470	190.000	0.420	0.210	330.000	2.400	0.590	0.876	0.500
OX10P 1	2.600	0.900	0.680	0.410	174.000	0.430	0.370	303.000	1.500	0.500	0.848	0.500

OX10P 2	2.600	0.900	0.680	0.510	190.000	0.420	0.360	303.000	1.500	0.500	0.848	0.450
OX10P 3	2.600	0.900	0.510	0.500	190.000	0.420	0.360	303.000	1.650	0.500	0.848	0.450
OX10P 4	2.600	0.900	0.340	0.350	174.000	0.430	0.370	303.000	1.650	0.500	0.848	0.500
OX10P 5	2.600	0.900	0.340	0.470	190.000	0.420	0.360	303.000	1.800	0.500	0.848	0.500
OX10S 1	3.080	0.900	0.680	0.410	174.000	0.430	0.470	281.000	1.000	0.420	0.831	0.500
OX10S 2	3.080	0.900	0.680	0.510	190.000	0.420	0.460	281.000	1.000	0.420	0.831	0.450
OX10S 3	3.080	0.900	0.510	0.500	190.000	0.420	0.460	281.000	1.100	0.420	0.831	0.450
OX10S 4	3.080	0.900	0.340	0.350	174.000	0.430	0.470	281.000	1.100	0.420	0.831	0.500
OX10S 5	3.080	0.900	0.340	0.470	190.000	0.420	0.460	281.000	1.200	0.420	0.831	0.500
OX35W 1	2.490	0.900	1.020	0.430	174.000	0.400	0.240	283.500	1.710	0.560	0.876	0.400
OX35W 2	2.490	0.900	0.850	0.550	174.000	0.400	0.240	283.500	1.800	0.560	0.876	0.360
OX35W 3	2.490	0.900	1.020	0.340	174.000	0.400	0.240	283.500	1.620	0.560	0.876	0.400
OX35W 4	2.490	0.900	0.850	0.450	174.000	0.400	0.240	283.500	1.800	0.560	0.876	0.400
OX35W 5	2.490	0.900	0.850	0.570	174.000	0.400	0.240	283.500	1.800	0.560	0.876	0.400
OX35W 6	2.490	0.900	0.680	0.750	174.000	0.400	0.240	283.500	1.980	0.560	0.876	0.320
OX35W 7	2.490	0.900	0.510	0.630	174.000	0.400	0.240	311.500	1.710	0.560	0.876	0.400
OX35W 8	2.490	0.900	0.340	0.710	174.000	0.400	0.240	311.500	1.980	0.560	0.876	0.400
OX35P 1	3.070	0.900	1.020	0.430	174.000	0.400	0.380	255.500	1.710	0.460	0.848	0.400
OX35P 2	3.070	0.900	0.850	0.550	174.000	0.400	0.380	255.500	1.800	0.460	0.848	0.360
OX35P 3	3.070	0.900	1.020	0.340	174.000	0.400	0.380	255.500	1.620	0.460	0.848	0.400
OX35P 4	3.070	0.900	0.850	0.450	174.000	0.400	0.380	255.500	1.800	0.460	0.848	0.400
OX35P 5	3.070	0.900	0.850	0.570	174.000	0.400	0.380	255.500	1.800	0.460	0.848	0.400
OX35P 6	3.070	0.900	0.680	0.750	174.000	0.400	0.380	255.500	1.980	0.460	0.848	0.320
OX35P 7	3.070	0.900	0.510	0.630	174.000	0.400	0.380	283.500	1.710	0.460	0.848	0.400
OX35P 8	3.070	0.900	0.340	0.710	174.000	0.400	0.380	283.500	1.980	0.460	0.848	0.400
OX35S 1	3.670	0.900	1.020	0.430	174.000	0.400	0.490	234.500	1.140	0.390	0.831	0.400
OX35S 2	3.670	0.900	0.850	0.550	174.000	0.400	0.490	234.500	1.200	0.390	0.831	0.360
OX35S 3	3.670	0.900	1.020	0.340	174.000	0.400	0.490	234.500	1.080	0.390	0.831	0.400
OX35S 4	3.670	0.900	0.850	0.450	174.000	0.400	0.490	234.500	1.200	0.390	0.831	0.400
OX35S 5	3.670	0.900	0.850	0.570	174.000	0.400	0.490	234.500	1.200	0.390	0.831	0.400
OX35S 6	3.670	0.900	0.680	0.750	174.000	0.400	0.490	234.500	1.320	0.390	0.831	0.320
OX35S 7	3.670	0.900	0.510	0.630	174.000	0.400	0.490	262.500	1.140	0.390	0.831	0.400
OX35S 8	3.670	0.900	0.340	0.710	174.000	0.400	0.490	262.500	1.320	0.390	0.831	0.400
OX17W11	1.980	0.700	1.360	0.420	174.000	0.420	0.210	329.000	2.000	0.630	0.876	0.500
OX17W12	2.351	0.700	0.850	0.520	190.000	0.400	0.230	293.000	3.000	0.590	0.876	0.500
OX17W13	2.351	0.700	0.340	0.800	206.000	0.400	0.170	293.000	3.600	0.590	0.876	0.500
OX17W14	1.87.	0.700	1.020	0.460	174.000	0.430	0.180	347.000	2.000	0.640	0.876	0.500
OX17W15	2.731	0.700	0.510	0.470	222.000	0.360	0.260	272.000	3.600	0.550	0.876	0.500
OX17W16	2.351	0.700	0.510	0.400	206.000	0.390	0.240	293.000	3.000	0.590	0.876	0.500
OX17P11	2.420	0.700	1.360	0.420	174.000	0.420	0.370	301.000	1.500	0.530	0.848	0.500
OX17P12	2.901	0.700	0.850	0.520	190.000	0.400	0.390	270.000	2.250	0.490	0.848	0.500
OX17P13	2.901	0.700	0.340	0.800	206.000	0.400	0.330	270.000	2.700	0.490	0.848	0.500
OX17P14	2.271	0.700	1.020	0.460	174.000	0.430	0.340	319.000	1.500	0.540	0.848	0.500
OX17P15	3.381	0.700	0.510	0.470	222.000	0.360	0.420	244.000	2.700	0.460	0.848	0.500
OX17P16	2.901	0.700	0.510	0.400	206.000	0.390	0.380	270.000	2.250	0.490	0.848	0.500
OX17S11	2.860	0.700	1.360	0.420	174.000	0.420	0.500	280.000	1.500	0.440	0.831	0.500
OX17S12	3.451	0.700	0.850	0.520	190.000	0.400	0.520	243.000	2.250	0.400	0.831	0.500
OX17S13	3.452	0.700	0.340	0.800	206.000	0.400	0.460	243.000	2.700	0.400	0.831	0.500
OX17S14	2.688	0.700	1.020	0.460	174.000	0.430	0.470	297.000	1.500	0.460	0.831	0.500
OX17S15	4.041	0.700	0.510	0.470	222.000	0.360	0.540	222.000	2.700	0.370	0.831	0.500
OX17S16	3.451	0.700	0.510	0.400	206.000	0.390	0.510	243.000	2.250	0.400	0.831	0.500
OX32W 9	3.020	0.700	1.020	0.530	190.000	0.360	0.320	259.000	2.200	0.520	0.876	0.300
OX32W10	3.020	0.700	0.850	0.710	206.000	0.360	0.320	241.500	2.200	0.520	0.876	0.150
OX32W11	3.020	0.700	0.680	0.460	206.000	0.360	0.320	241.500	2.200	0.520	0.876	0.090
OX32W12	3.020	0.700	0.340	0.630	206.000	0.360	0.320	241.500	2.400	0.520	0.876	0.030
OX32W18	3.020	0.700	0.340	0.690	206.000	0.360	0.320	276.500	2.400	0.520	0.876	0.030
OX32P 9	3.660	0.700	1.020	0.530	190.000	0.360	0.460	234.500	1.650	0.420	0.848	0.300

OX32P10	3.660	0.700	0.850	0.710	206.000	0.360	0.460	217.000	1.650	0.420	0.848	0.150
OX32P11	3.660	0.700	0.680	0.460	206.000	0.360	0.460	217.000	1.650	0.420	0.848	0.090
OX32P12	3.660	0.700	0.340	0.630	206.000	0.360	0.460	217.000	1.800	0.420	0.848	0.030
OX32P18	3.660	0.700	0.340	0.690	206.000	0.360	0.460	252.000	1.800	0.420	0.848	0.030
OX32S 9	4.310	0.700	1.020	0.530	190.000	0.360	0.560	217.000	1.320	0.340	0.831	0.300
OX32S10	4.310	0.700	0.850	0.710	206.000	0.360	0.560	199.500	1.320	0.340	0.831	0.150
OX32S11	4.310	0.700	0.680	0.460	206.000	0.360	0.560	199.500	1.320	0.340	0.831	0.090
OX32S12	4.310	0.700	0.340	0.630	206.000	0.360	0.560	199.500	1.440	0.340	0.831	0.030
OX32S18	4.310	0.700	0.340	0.690	206.000	0.360	0.560	231.000	1.440	0.340	0.831	0.030
KAAI 1	3.310	0.700	2.750	0.660	174.000	0.630	0.230	370.000	2.000	0.290	0.859	0.000
KAAI 2	3.310	0.700	2.000	0.810	174.000	0.630	0.230	342.000	2.000	0.290	0.859	0.000
KAAI 3	3.200	0.700	2.250	0.870	174.000	0.640	0.220	374.000	2.000	0.300	0.859	0.000
KAAI 4	3.310	0.700	2.250	0.820	174.000	0.640	0.200	370.000	2.000	0.290	0.859	0.000
KAAI 5	3.100	0.700	1.500	0.760	206.000	0.630	0.150	371.000	2.000	0.300	0.859	0.000
KAAI 6	3.560	0.700	1.250	0.810	206.000	0.610	0.210	356.000	2.000	0.270	0.859	0.000
KAAI 7	4.660	0.700	1.000	0.960	206.000	0.590	0.290	337.000	2.000	0.190	0.859	0.000
KAAI 8	5.560	0.700	0.500	0.860	236.000	0.570	0.330	322.000	2.000	0.130	0.859	0.000
KAAI 9	5.560	0.700	0.500	0.570	236.000	0.570	0.330	322.000	2.000	0.130	0.859	0.000
MALG 1	3.200	0.700	1.500	0.630	174.000	0.650	0.190	354.000	3.000	0.300	0.859	0.000
MALG 2	3.200	0.700	1.500	0.570	174.000	0.650	0.190	354.000	3.000	0.300	0.859	0.000
MALG 3	3.430	0.700	1.250	0.530	174.000	0.640	0.220	334.000	3.000	0.280	0.859	0.000
MALG 4	3.430	0.700	1.000	0.790	174.000	0.640	0.220	334.000	3.000	0.280	0.859	0.000
MALG 5	3.700	0.700	1.000	0.620	174.000	0.620	0.240	325.000	3.000	0.260	0.859	0.000
MALG 6	3.700	0.700	1.000	0.640	174.000	0.630	0.250	325.000	3.000	0.260	0.859	0.000
MALG 7	5.430	0.700	0.500	0.660	236.000	0.550	0.350	296.000	3.000	0.160	0.859	0.000
MALG 8	5.430	0.700	0.500	0.480	236.000	0.550	0.350	296.000	3.000	0.160	0.859	0.000
NDAN5 1	5.290	0.700	1.500	0.510	189.000	0.460	0.490	213.000	1.500	0.180	0.834	0.000
NDAN5 2	5.900	0.700	1.000	0.900	189.000	0.440	0.500	202.000	1.500	0.160	0.834	0.000
NDAN5 3	5.480	0.700	1.250	0.700	189.000	0.450	0.490	209.000	1.500	0.180	0.834	0.000
NDAN5 4	4.840	0.700	1.500	0.520	189.000	0.470	0.480	222.000	1.500	0.200	0.834	0.000
NDAN5 5	5.480	0.700	1.000	0.530	189.000	0.450	0.490	176.000	1.500	0.180	0.834	0.000
NDAN5 6	5.290	0.700	0.500	0.630	189.000	0.470	0.490	179.000	1.500	0.180	0.834	0.000
NDAN5 7	5.680	0.700	1.000	0.520	189.000	0.450	0.500	191.000	1.500	0.170	0.834	0.000
NDAN5 8	5.900	0.700	0.750	0.280	189.000	0.440	0.500	168.000	1.500	0.160	0.834	0.000
NDAN5 9	5.480	0.700	0.500	0.470	189.000	0.450	0.490	152.000	1.500	0.180	0.834	0.000
NDAN5 10	4.810	0.700	2.250	0.480	189.000	0.470	0.480	222.000	1.500	0.200	0.834	0.000
NDAN5 11	5.480	0.700	2.000	0.520	189.000	0.450	0.490	194.000	1.500	0.180	0.834	0.000
NDAN5 12	5.480	0.700	1.500	0.720	189.000	0.450	0.490	186.000	1.500	0.180	0.834	0.000
NDAN5 13	5.120	0.700	2.250	0.480	189.000	0.470	0.500	192.000	1.500	0.190	0.834	0.000
NDAN5 14	4.550	0.700	1.750	0.660	189.000	0.480	0.480	228.000	1.500	0.220	0.834	0.000
NDAN5 15	4.320	0.700	1.250	0.470	189.000	0.490	0.480	233.000	1.500	0.230	0.834	0.000
NDAN5 16	4.550	0.700	0.750	0.650	189.000	0.480	0.480	213.000	1.500	0.220	0.834	0.000
NDAN5 17	4.670	0.700	0.000	0.150	189.000	0.480	0.490	209.000	1.500	0.210	0.834	0.000
NDAN5 18	4.670	0.700	0.000	0.630	189.000	0.480	0.490	201.000	1.500	0.210	0.834	0.000

OSE3-CALIBRATION PARAMETERS

Area	ID	1 CDEL	2 KC	3 ROP	4 N	5 K	6 IL
TM11	1	0.240	0.200	0.200	0.500	0.100	0.000
TM11	2	0.240	0.200	0.200	0.500	0.100	0.000
TM11	3	0.160	0.200	0.200	0.500	0.100	0.000
TM8	4	0.240	0.100	0.120	0.500	0.100	0.000
TM8	5	0.240	0.100	0.120	0.500	0.100	0.000
TM8	6	0.160	0.100	0.120	0.500	0.100	0.000
TM8	7	0.080	0.100	0.120	0.500	0.100	0.000
TM3	1	0.320	0.100	0.190	0.500	0.100	0.000
TM3	2	0.240	0.100	0.190	0.500	0.100	0.000
TM3	3	0.160	0.100	0.190	0.500	0.100	0.000
TM3	4	0.160	0.100	0.190	0.500	0.100	0.000
TM6	1	0.640	0.400	0.060	0.500	1.000	0.000
TM6	2	0.480	0.400	0.060	0.500	1.000	0.000
TM6	3	0.560	0.400	0.060	0.500	1.000	0.000
TM6	4	0.640	0.400	0.060	0.500	1.000	0.000
TM6	5	0.480	0.400	0.060	0.500	1.000	0.000
TM6	6	0.320	0.400	0.060	0.500	1.000	0.000
TM6	7	0.320	0.400	0.060	0.500	1.000	0.000
TM6	8	0.240	0.400	0.060	0.500	1.000	0.000
TM2	10	0.320	0.500	0.110	0.500	1.000	0.000
TM1	11	0.640	0.500	0.110	0.500	1.500	0.000
TM1	12	0.560	0.500	0.110	0.500	1.500	0.000
TM1	13	0.320	0.500	0.110	0.500	1.500	0.000
ECCA	1	5.250	0.640	0.330	0.500	16.000	15.000
ECCA	2	4.500	0.720	0.330	0.500	14.720	15.000
ECCA	3	4.500	0.720	0.330	0.500	14.720	15.000
ECCA	4	4.000	0.800	0.330	0.500	14.720	15.000
ECCA	5	4.000	0.600	0.330	0.500	14.400	15.000
ECCA	6	4.000	0.600	0.330	0.500	14.400	15.000
ECCA	7	3.000	0.400	0.330	0.500	13.600	13.000
ECCA	8	2.750	0.480	0.330	0.500	12.800	12.000
ECCA	9	2.250	0.768	0.330	0.500	10.400	11.000
ECCA	10	1.250	1.120	0.330	0.500	15.200	9.500
ECCA	11	0.750	0.800	0.330	0.500	16.800	9.000
ECCA	12	0.750	0.480	0.330	0.500	12.800	8.500
BETH	1	3.250	0.800	0.250	0.500	8.000	0.000
BETH	2	2.750	0.800	0.250	0.500	8.000	0.000
BETH	3	3.000	0.800	0.250	0.500	8.000	0.000
BETH	4	2.500	0.800	0.250	0.500	8.000	0.000
BETH	5	2.000	0.800	0.250	0.500	8.000	0.000
BETH	6	2.250	0.800	0.250	0.500	8.000	0.000
BETH	7	1.500	0.800	0.250	0.500	8.000	0.000
BETH	8	1.250	0.800	0.250	0.500	8.000	0.000
BETH	9	0.500	0.800	0.250	0.500	8.000	0.000
HOEK	1	0.750	0.800	0.230	0.500	5.000	0.000
HOEK	2	0.500	0.400	0.230	0.500	2.500	0.000
HOEK	3	0.750	0.400	0.230	0.500	3.000	0.000
HOEK	4	0.750	0.480	0.230	0.500	3.000	0.000
HOEK	5	0.750	0.480	0.230	0.500	3.000	0.000
HOEK	6	0.500	0.560	0.230	0.500	3.500	0.000
HOEK	7	0.000	0.560	0.230	0.500	2.500	0.000

HOEK 8	0.250	0.480	0.230	0.500	3.000	0.000
HOEK 9	0.250	0.480	0.230	0.500	3.000	0.000
CED 1	0.500	0.400	0.040	0.500	7.000	0.000
CED 2	0.500	0.400	0.040	0.500	7.000	0.000
CED 3	0.250	0.400	0.040	0.500	7.000	0.000
ZULU 1	0.750	0.400	0.380	0.500	14.000	0.000
ZULU 2	0.500	0.400	0.380	0.500	14.000	0.000
ZULU 3	0.250	0.320	0.380	0.500	8.400	0.000
ZULU 4	0.250	0.160	0.380	0.500	8.400	0.000
ZULU 5	0.250	0.200	0.380	0.500	2.800	0.000
ZULU 6	0.250	0.240	0.380	0.500	3.500	0.000
ZULU 7	0.250	0.280	0.380	0.500	3.500	0.000
ZULU 8	0.000	0.160	0.380	0.500	8.400	0.000
ZULU 9	0.000	0.320	0.380	0.500	8.400	0.000
ZULU 10	0.250	0.400	0.380	0.500	8.400	0.000
OX4W 1	0.850	0.500	0.170	0.500	2.000	0.000
OX4W 2	0.510	0.500	0.170	0.500	2.000	0.000
OX4S 1	0.000	0.000	0.000	0.000	0.000	0.000
OX4S 2	0.000	0.000	0.000	0.000	0.000	0.000
OX12W 1	1.530	0.700	0.270	0.500	4.800	0.000
OX12W 2	1.530	0.700	0.270	0.500	4.800	0.000
OX12W 3	1.700	0.500	0.270	0.500	3.200	0.000
OX12W 4	1.530	0.600	0.270	0.500	6.400	0.000
OX12W 5	0.850	0.700	0.270	0.500	8.000	0.000
OX12W 7	1.190	0.800	0.270	0.500	8.000	0.000
OX12W 8	1.700	0.600	0.270	0.500	6.400	0.000
OX12W 9	1.190	0.600	0.270	0.500	8.000	0.000
OX12W 10	0.680	0.700	0.270	0.500	8.000	0.000
OX12W 11	1.360	0.500	0.270	0.500	6.000	0.000
OX12W 12	1.020	0.800	0.270	0.500	8.000	0.000
OX12P 1	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 2	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 3	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 4	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 5	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 7	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 8	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 9	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 10	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 11	0.000	0.000	0.000	0.000	0.000	0.000
OX12P 12	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 1	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 2	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 3	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 4	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 5	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 7	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 8	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 9	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 10	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 11	0.000	0.000	0.000	0.000	0.000	0.000
OX12S 12	0.000	0.000	0.000	0.000	0.000	0.000
OX10W 1	0.680	0.600	0.250	0.500	1.600	0.000
OX10W 2	0.680	0.200	0.250	0.500	1.600	0.000
OX10W 3	0.510	0.200	0.250	0.500	1.600	0.000
OX10W 4	0.340	0.400	0.250	0.500	1.280	0.000
OX10W 5	0.340	0.200	0.250	0.500	1.280	0.000

OX10P 1	0.000	0.000	0.000	0.000	0.000	0.000
OX10P 2	0.000	0.000	0.000	0.000	0.000	0.000
OX10P 3	0.000	0.000	0.000	0.000	0.000	0.000
OX10P 4	0.000	0.000	0.000	0.000	0.000	0.000
OX10P 5	0.000	0.000	0.000	0.000	0.000	0.000
OX10S 1	0.000	0.000	0.000	0.000	0.000	0.000
OX10S 2	0.000	0.000	0.000	0.000	0.000	0.000
OX10S 3	0.000	0.000	0.000	0.000	0.000	0.000
OX10S 4	0.000	0.000	0.000	0.000	0.000	0.000
OX10S 5	0.000	0.000	0.000	0.000	0.000	0.000
OX35W 1	1.190	0.500	0.360	0.500	2.400	0.000
OX35W 2	1.020	0.500	0.360	0.500	3.200	0.000
OX35W 3	1.020	0.400	0.360	0.500	2.400	0.000
OX35W 4	0.850	0.500	0.360	0.500	2.400	0.000
OX35W 5	0.850	0.400	0.360	0.500	3.200	0.000
OX35W 6	0.680	0.500	0.360	0.500	3.200	0.000
OX35W 7	0.510	0.500	0.360	0.500	2.400	0.000
OX35W 8	0.340	0.500	0.360	0.500	2.400	0.000
OX35P 1	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 2	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 3	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 4	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 5	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 6	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 7	0.000	0.000	0.000	0.000	0.000	0.000
OX35P 8	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 1	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 2	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 3	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 4	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 5	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 6	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 7	0.000	0.000	0.000	0.000	0.000	0.000
OX35S 8	0.000	0.000	0.000	0.000	0.000	0.000
OX17W 11	1.360	0.600	0.290	0.500	6.400	0.000
OX17W 12	0.850	0.600	0.290	0.500	6.400	0.000
OX17W 13	0.340	0.700	0.290	0.500	8.000	0.000
OX17W 14	1.020	0.700	0.290	0.500	6.400	0.000
OX17W 15	0.510	0.700	0.290	0.500	6.400	0.000
OX17W 16	0.510	0.700	0.290	0.500	7.200	0.000
OX17P 11	0.000	0.000	0.000	0.000	0.000	0.000
OX17P 12	0.000	0.000	0.000	0.000	0.000	0.000
OX17P 13	0.000	0.000	0.000	0.000	0.000	0.000
OX17P 14	0.000	0.000	0.000	0.000	0.000	0.000
OX17P 15	0.000	0.000	0.000	0.000	0.000	0.000
OX17P 16	0.000	0.000	0.000	0.000	0.000	0.000
OX17S 11	0.000	0.000	0.000	0.000	0.000	0.000
OX17S 12	0.000	0.000	0.000	0.000	0.000	0.000
OX17S 13	0.000	0.000	0.000	0.000	0.000	0.000
OX17S 14	0.000	0.000	0.000	0.000	0.000	0.000
OX17S 15	0.000	0.000	0.000	0.000	0.000	0.000
OX17S 16	0.000	0.000	0.000	0.000	0.000	0.000
OX32W 9	1.360	0.500	0.350	0.500	2.400	0.000
OX32W 10	1.020	0.500	0.350	0.500	2.400	0.000
OX32W 11	0.680	0.500	0.350	0.500	2.400	0.000
OX32W 12	0.340	0.500	0.350	0.500	2.400	0.000
OX32W 18	0.340	0.500	0.350	0.500	1.600	0.000

OX32P 9	0.000	0.000	0.000	0.000	0.000	0.000
OX32P 10	0.000	0.000	0.000	0.000	0.000	0.000
OX32P 11	0.000	0.000	0.000	0.000	0.000	0.000
OX32P 12	0.000	0.000	0.000	0.000	0.000	0.000
OX32P 18	0.000	0.000	0.000	0.000	0.000	0.000
OX32S 9	0.000	0.000	0.000	0.000	0.000	0.000
OX32S 10	0.000	0.000	0.000	0.000	0.000	0.000
OX32S 11	0.000	0.000	0.000	0.000	0.000	0.000
OX32S 12	0.000	0.000	0.000	0.000	0.000	0.000
OX32S 18	0.000	0.000	0.000	0.000	0.000	0.000
KAAI 1	2.750	0.420	0.600	0.500	11.200	0.000
KAAI 2	2.000	0.420	0.600	0.500	11.200	0.000
KAAI 3	2.250	0.420	0.600	0.500	11.200	0.000
KAAI 4	2.250	0.480	0.600	0.500	11.200	0.000
KAAI 5	1.500	0.540	0.600	0.500	14.000	0.000
KAAI 6	1.250	0.540	0.600	0.500	14.000	0.000
KAAI 7	1.000	0.600	0.600	0.500	15.400	0.000
KAAI 8	0.500	0.600	0.600	0.500	15.400	0.000
KAAI 9	0.500	0.600	0.600	0.500	12.600	0.000
MALG 1	1.500	0.300	0.600	0.500	10.400	0.000
MALG 2	1.500	0.300	0.600	0.500	10.400	0.000
MALG 3	1.250	0.300	0.600	0.500	10.400	0.000
MALG 4	1.000	0.300	0.600	0.500	10.400	0.000
MALG 5	0.600	0.500	0.600	0.400	10.400	0.000
MALG 6	1.000	0.350	0.600	0.500	11.700	0.000
MALG 7	0.500	0.400	0.600	0.500	13.000	0.000
MALG 8	0.500	0.400	0.600	0.500	13.000	0.000
NDAN5 1	1.500	0.425	0.200	0.500	15.000	2.500
NDAN5 2	1.000	0.595	0.200	0.500	15.000	2.500
NDAN5 3	1.250	0.723	0.200	0.500	15.000	2.500
NDAN5 4	1.550	0.510	0.200	0.500	15.000	2.500
NDAN5 5	1.000	0.553	0.200	0.500	15.000	2.500
NDAN5 6	0.500	0.808	0.200	0.500	15.000	2.500
NDAN5 7	1.000	0.468	0.200	0.500	15.000	2.500
NDAN5 8	0.750	0.213	0.200	0.500	15.000	2.500
NDAN5 9	0.500	0.468	0.200	0.500	15.000	2.500
NDAN5 10	2.250	0.382	0.200	0.500	15.000	2.500
NDAN5 11	2.000	0.468	0.200	0.500	15.000	2.500
NDAN5 12	1.500	0.765	0.200	0.500	15.000	2.500
NDAN5 13	2.250	0.425	0.200	0.500	15.000	2.500
NDAN5 14	1.750	0.553	0.200	0.500	15.000	2.500
NDAN5 15	1.250	0.340	0.200	0.500	15.000	2.500
NDAN5 16	0.750	0.892	0.200	0.500	15.000	2.500
NDAN5 17	0.000	0.128	0.200	0.500	15.000	2.500
NDAN5 18	0.000	0.850	0.200	0.500	15.000	2.500

OSE3-VALIDATION PARAMETERS

Area	ID	1 CDEL	2 KC	3 ROP	4 N	5 K	6 IL
TM11	1	0.240	0.530	0.200	0.500	0.100	0.000
TM11	2	0.240	0.650	0.200	0.500	0.100	0.000
TM11	3	0.160	0.590	0.200	0.500	0.100	0.000
TM8	4	0.240	0.360	0.120	0.500	0.100	0.000
TM8	5	0.240	0.430	0.120	0.500	0.100	0.000
TM8	6	0.160	0.430	0.120	0.500	0.100	0.000
TM8	7	0.080	0.570	0.120	0.500	0.100	0.000
TM3	1	0.320	0.520	0.190	0.500	0.100	0.000
TM3	2	0.240	0.630	0.190	0.500	0.100	0.000
TM3	3	0.160	0.270	0.190	0.500	0.100	0.000
TM3	4	0.160	0.430	0.190	0.500	0.100	0.000
TM6	1	0.640	1.290	0.060	0.500	1.000	0.000
TM6	2	0.480	0.910	0.060	0.500	1.000	0.000
TM6	3	0.560	1.100	0.060	0.500	1.000	0.000
TM6	4	0.640	1.290	0.060	0.500	1.000	0.000
TM6	5	0.480	0.480	0.060	0.500	1.000	0.000
TM6	6	0.320	0.590	0.060	0.500	1.000	0.000
TM6	7	0.320	0.600	0.060	0.500	1.000	0.000
TM6	8	0.240	0.760	0.060	0.500	1.000	0.000
TM2	10	0.320	1.060	0.110	0.500	1.000	0.000
TM1	11	0.640	0.710	0.110	0.500	1.500	0.000
TM1	12	0.560	0.820	0.110	0.500	1.500	0.000
TM1	13	0.320	0.880	0.110	0.500	1.500	0.000
ECCA	1	5.250	0.620	0.330	0.500	6.540	15.000
ECCA	2	4.500	0.820	0.330	0.500	6.540	15.000
ECCA	3	4.500	0.690	0.330	0.500	6.540	15.000
ECCA	4	4.000	0.770	0.330	0.500	4.290	15.000
ECCA	5	4.000	0.650	0.330	0.500	5.700	15.000
ECCA	6	4.000	0.540	0.330	0.500	5.700	15.000
ECCA	7	3.000	0.690	0.330	0.500	4.750	13.000
ECCA	8	2.750	0.620	0.330	0.500	5.030	12.000
ECCA	9	2.250	0.540	0.330	0.500	4.290	11.000
ECCA	10	1.250	1.000	0.330	0.500	4.290	9.500
ECCA	11	0.750	0.870	0.330	0.500	4.010	9.000
ECCA	12	0.750	0.820	0.330	0.500	6.540	8.500
BETH	1	3.250	0.740	0.250	0.500	8.100	0.000
BETH	2	2.750	0.800	0.250	0.500	8.100	0.000
BETH	3	3.000	0.800	0.250	0.500	9.450	0.000
BETH	4	2.500	0.860	0.250	0.500	9.450	0.000
BETH	5	2.000	0.860	0.250	0.500	7.110	0.000
BETH	6	2.250	0.990	0.250	0.500	8.100	0.000
BETH	7	1.500	0.448	0.250	0.500	8.100	0.000
BETH	8	1.250	0.680	0.250	0.500	7.110	0.000
BETH	9	0.500	0.680	0.250	0.500	9.450	0.000
HOEK	1	0.750	0.170	0.230	0.500	5.500	0.000
HOEK	2	0.500	0.440	0.230	0.500	1.850	0.000
HOEK	3	0.750	0.680	0.230	0.500	2.600	0.000
HOEK	4	0.750	0.530	0.230	0.500	2.330	0.000
HOEK	5	0.750	0.250	0.230	0.500	2.640	0.000
HOEK	6	0.500	0.560	0.230	0.500	7.310	0.000
HOEK	7	0.000	0.648	0.230	0.500	1.700	0.000

HOEK 8	0.250	0.480	0.230	0.500	8.120	0.000
HOEK 9	0.250	0.480	0.230	0.500	2.900	0.000
CED 1	0.500	0.510	0.040	0.500	9.690	0.000
CED 2	0.500	0.510	0.040	0.500	12.080	0.000
CED 3	0.250	0.510	0.040	0.500	16.000	0.000
ZULU 1	0.750	0.440	0.380	0.500	6.860	0.000
ZULU 2	0.500	0.580	0.380	0.500	7.440	0.000
ZULU 3	0.250	0.440	0.380	0.500	7.270	0.000
ZULU 4	0.250	0.072	0.380	0.500	6.510	0.000
ZULU 5	0.250	0.440	0.380	0.500	1.590	0.000
ZULU 6	0.250	0.340	0.380	0.500	3.870	0.000
ZULU 7	0.250	0.440	0.380	0.500	3.330	0.000
ZULU 8	0.000	0.580	0.380	0.500	9.740	0.000
ZULU 9	0.000	0.620	0.380	0.500	9.740	0.000
ZULU 10	0.250	0.640	0.380	0.500	9.740	0.000
OX4W 1	0.850	0.250	0.170	0.500	3.050	0.000
OX4W 2	0.510	0.380	0.170	0.500	3.050	0.000
OX4S 1	0.000	0.250	0.000	0.000	4.780	0.000
OX4S 2	0.000	0.380	0.000	0.000	4.780	0.000
OX12W 1	1.530	0.780	0.270	0.500	2.820	0.000
OX12W 2	1.530	0.860	0.270	0.500	2.820	0.000
OX12W 3	1.700	0.500	0.270	0.500	3.050	0.000
OX12W 4	1.530	0.830	0.270	0.500	3.050	0.000
OX12W 5	0.850	0.860	0.270	0.500	4.510	0.000
OX12W 7	1.190	0.800	0.270	0.500	4.510	0.000
OX12W 8	1.700	0.500	0.270	0.500	3.050	0.000
OX12W 9	1.190	0.600	0.270	0.500	2.820	0.000
OX12W 10	0.680	0.620	0.270	0.500	4.510	0.000
OX12W 11	1.360	0.300	0.270	0.500	4.260	0.000
OX12W 12	1.020	0.680	0.270	0.500	4.510	0.000
OX12P 1	5.250	0.780	0.044	0.500	3.620	0.000
OX12P 2	4.500	0.860	0.044	0.500	3.620	0.000
OX12P 3	4.500	0.500	0.044	0.500	3.900	0.000
OX12P 4	4.000	0.830	0.044	0.500	3.900	0.000
OX12P 5	4.000	0.860	0.044	0.500	5.820	0.000
OX12P 7	4.000	0.800	0.044	0.500	5.820	0.000
OX12P 8	3.000	0.500	0.044	0.500	3.900	0.000
OX12P 9	2.750	0.600	0.044	0.500	3.620	0.000
OX12P 10	2.250	0.620	0.044	0.500	5.820	0.000
OX12P 11	1.250	0.300	0.044	0.500	5.470	0.000
OX12P 12	0.750	0.680	0.044	0.500	5.820	0.000
OX12P 1	0.750	0.780	0.044	0.500	4.420	0.000
OX12S 2	0.000	0.860	0.000	0.000	4.420	0.000
OX12S 3	0.000	0.500	0.000	0.000	4.780	0.000
OX12S 4	0.000	0.830	0.000	0.000	4.780	0.000
OX12S 5	0.000	0.860	0.000	0.000	7.110	0.000
OX12S 7	0.000	0.800	0.000	0.000	7.110	0.000
OX12S 8	0.000	0.500	0.000	0.000	4.780	0.000
OX12S 9	0.000	0.600	0.000	0.000	4.420	0.000
OX12S 10	0.000	0.620	0.000	0.000	7.110	0.000
OX12S 11	0.000	0.300	0.000	0.000	6.700	0.000
OX12S 12	0.000	0.680	0.000	0.000	7.110	0.000
OX10W 1	0.680	0.410	0.250	0.500	3.320	0.000
OX10W 2	0.680	0.550	0.250	0.500	3.320	0.000
OX10W 3	0.510	0.550	0.250	0.500	3.320	0.000
OX10W 4	0.340	0.300	0.250	0.500	3.320	0.000
OX10W 5	0.340	0.480	0.250	0.500	3.320	0.000

OX10P 1	0.000	0.410	0.000	0.000	5.170	0.000
OX10P 2	0.000	0.550	0.000	0.000	5.170	0.000
OX10P 3	0.000	0.550	0.000	0.000	5.170	0.000
OX10P 4	0.000	0.300	0.000	0.000	5.170	0.000
OX10P 5	0.000	0.480	0.000	0.000	5.170	0.000
OX10S 1	0.000	0.410	0.000	0.000	6.340	0.000
OX10S 2	0.000	0.550	0.000	0.000	6.340	0.000
OX10S 3	0.000	0.550	0.000	0.000	6.340	0.000
OX10S 4	0.000	0.300	0.000	0.000	6.340	0.000
OX10S 5	0.000	0.480	0.000	0.000	6.340	0.000
OX35W 1	1.190	0.410	0.360	0.500	4.030	0.000
OX35W 2	1.020	0.620	0.360	0.500	4.030	0.000
OX35W 3	1.020	0.300	0.360	0.500	4.030	0.000
OX35W 4	0.850	0.480	0.360	0.500	4.030	0.000
OX35W 5	0.850	0.630	0.360	0.500	4.030	0.000
OX35W 6	0.680	0.890	0.360	0.500	4.030	0.000
OX35W 7	0.510	0.720	0.360	0.500	4.030	0.000
OX35W 8	0.340	0.820	0.360	0.500	4.030	0.000
OX35P 1	0.000	0.410	0.000	0.000	5.170	0.000
OX35P 2	0.000	0.620	0.000	0.000	5.170	0.000
OX35P 3	0.000	0.300	0.000	0.000	5.170	0.000
OX35P 4	0.000	0.480	0.000	0.000	5.170	0.000
OX35P 5	0.000	0.630	0.000	0.000	5.170	0.000
OX35P 6	0.000	0.890	0.000	0.000	5.170	0.000
OX35P 7	0.000	0.720	0.000	0.000	5.170	0.000
OX35P 8	0.000	0.820	0.000	0.000	5.170	0.000
OX35S 1	0.000	0.410	0.000	0.000	6.340	0.000
OX35S 2	0.000	0.620	0.000	0.000	6.340	0.000
OX35S 3	0.000	0.300	0.000	0.000	6.340	0.000
OX35S 4	0.000	0.480	0.000	0.000	6.340	0.000
OX35S 5	0.000	0.630	0.000	0.000	6.340	0.000
OX35S 6	0.000	0.890	0.000	0.000	6.340	0.000
OX35S 7	0.000	0.720	0.000	0.000	6.340	0.000
OX35S 8	0.000	0.820	0.000	0.000	6.340	0.000
OX17W 11	1.360	0.410	0.290	0.500	3.050	0.000
OX17W 12	0.850	0.600	0.290	0.500	3.630	0.000
OX17W 13	0.340	0.960	0.290	0.500	3.630	0.000
OX17W 14	1.020	0.480	0.290	0.500	2.820	0.000
OX17W 15	0.510	0.480	0.290	0.500	4.510	0.000
OX17W 16	0.510	0.410	0.290	0.500	3.630	0.000
OX17P 11	0.000	0.410	0.000	0.000	3.900	0.000
OX17P 12	0.000	0.600	0.000	0.000	4.670	0.000
OX17P 13	0.000	0.960	0.000	0.000	4.670	0.000
OX17P 14	0.000	0.480	0.000	0.000	3.620	0.000
OX17P 15	0.000	0.480	0.000	0.000	5.820	0.000
OX17P 16	0.000	0.410	0.000	0.000	4.670	0.000
OX17S 11	0.000	0.410	0.000	0.000	4.780	0.000
OX17S 12	0.000	0.600	0.000	0.000	5.710	0.000
OX17S 13	0.000	0.960	0.000	0.000	5.710	0.000
OX17S 14	0.000	0.480	0.000	0.000	4.420	0.000
OX17S 15	0.000	0.480	0.000	0.000	7.110	0.000
OX17S 16	0.000	0.410	0.000	0.000	5.710	0.000
OX32W 9	1.360	0.560	0.350	0.500	5.140	0.000
OX32W 10	1.020	0.760	0.350	0.500	5.140	0.000
OX32W 11	0.680	0.500	0.350	0.500	5.140	0.000
OX32W 12	0.340	0.760	0.350	0.500	5.140	0.000
OX32W 18	0.340	0.820	0.350	0.500	5.140	0.000

OX32P	9	0.000	0.560	0.000	0.000	6.640	0.000
OX32P	10	0.000	0.760	0.000	0.000	6.640	0.000
OX32P	11	0.000	0.500	0.000	0.000	6.640	0.000
OX32P	12	0.000	0.760	0.000	0.000	6.640	0.000
OX32P	18	0.000	0.820	0.000	0.000	6.640	0.000
OX32S	9	0.000	0.560	0.000	0.000	8.120	0.000
OX32S	10	0.000	0.760	0.000	0.000	8.120	0.000
OX32S	11	0.000	0.500	0.000	0.000	8.120	0.000
OX32S	12	0.000	0.760	0.000	0.000	8.120	0.000
OX32S	18	0.000	0.820	0.000	0.000	8.120	0.000
KAAI	1	2.750	0.670	0.600	0.500	4.470	0.000
KAAI	2	2.000	0.920	0.600	0.500	4.470	0.000
KAAI	3	2.250	1.000	0.600	0.500	4.280	0.000
KAAI	4	2.250	0.920	0.600	0.500	4.470	0.000
KAAI	5	1.500	0.860	0.600	0.500	4.110	0.000
KAAI	6	1.250	0.920	0.600	0.500	6.390	0.000
KAAI	7	1.000	1.100	0.600	0.500	8.950	0.000
KAAI	8	0.500	1.000	0.600	0.500	11.010	0.000
KAAI	9	0.500	0.620	0.600	0.500	11.010	0.000
MALG	1	1.500	0.680	0.600	0.500	4.280	0.000
MALG	2	1.500	0.620	0.600	0.500	4.280	0.000
MALG	3	1.250	0.560	0.600	0.500	4.690	0.000
MALG	4	1.000	0.890	0.600	0.500	4.690	0.000
MALG	5	0.600	0.680	0.600	0.400	5.160	0.000
MALG	6	1.000	0.710	0.600	0.500	5.160	0.000
MALG	7	0.500	0.740	0.600	0.500	10.710	0.000
MALG	8	0.500	0.500	0.600	0.500	10.710	0.000
NDAN5	1	1.500	0.560	0.200	0.500	10.400	0.000
NDAN5	2	1.000	1.050	0.200	0.500	11.800	0.000
NDAN5	3	1.250	0.820	0.200	0.500	10.820	0.000
NDAN5	4	1.550	0.560	0.200	0.500	9.360	0.000
NDAN5	5	1.000	0.550	0.200	0.500	11.800	0.000
NDAN5	6	0.500	0.700	0.200	0.500	10.400	0.000
NDAN5	7	1.000	0.560	0.200	0.500	11.280	0.000
NDAN5	8	0.750	0.240	0.200	0.500	11.780	0.000
NDAN5	9	0.500	0.500	0.200	0.500	10.820	0.000
NDAN5	10	2.250	0.500	0.200	0.500	9.280	0.000
NDAN5	11	2.000	0.550	0.200	0.500	10.820	0.000
NDAN5	12	1.500	0.830	0.200	0.500	10.820	0.000
NDAN5	13	2.250	0.500	0.200	0.500	9.990	0.000
NDAN5	14	1.750	0.740	0.200	0.500	8.670	0.000
NDAN5	15	1.250	0.500	0.200	0.500	8.130	0.000
NDAN5	16	0.750	0.700	0.200	0.500	8.670	0.000
NDAN5	17	0.000	0.072	0.200	0.500	8.970	0.000
NDAN5	18	0.000	0.730	0.200	0.500	8.970	0.000

APPENDIX D

Individual storm simulation statistics.

Model OSE1	Lumped calibration Semi-distributed calibration Semi-distributed validation
Model OSE2	Lumped calibration Semi-distributed calibration Semi-distributed validation
Model OSE3	Lumped calibration Semi-distributed calibration Semi-distributed validation

MODEL OSE1 Lumped calibration results

Catch name		Storm No.	Storm date	Storm type	Calibration % Error Vol.	Calibration % Error Peak	Coefficient Eff.	Coefficient Det.
TM	1	1	26.07.59	B	-10.5	-15.3	0.666	0.724
TM	1	2	4.09.65	C	24.6	-18.2	0.365	0.624
TM	2	1	26.07.59	B	-12.4	-19.8	0.791	0.799
TM	2	2	17.08.61	C	SUSPECT DATA			
TM	2	3	4.09.65	B	-5.9	-8.3	0.772	0.822
TM	2	4	25.08.68	C	SUSPECT DATA			
TM	2	5	31.08.68	C	-11.8	-20.9	0.804	0.815
TM	3	1	19.07.55	C	SUSPECT DATA			
TM	3	2	14.08.58	B	-8.3	-23.9	0.903	0.906
TM	3	3	16.08.58	C	-1.0	-32.2	0.679	0.703
TM	3	4	17.08.61	B	SUSPECT DATA			
TM	3	5	25.07.62	C	7.2	-30.2	0.841	0.843
TM	3	7	25.08.68	C	38.0	-29.1	0.653	0.688
TM	3	8	31.08.68	C	20.8	-25.7	0.782	0.800
TM	3	11	27.07.73	C	19.9	-14.1	0.649	0.686
TM	6	1	4.09.65	B	-3.4	-3.0	0.700	0.756
TM	6	2	31.08.68	B	9.8	-10.7	0.421	0.576
TM	8	1	19.08.63	C	-11.4	3.7	0.870	0.900
TM	8	2	22.07.64	C	-49.2	-75.6	0.465	0.708
TM	8	3	9.09.64	C	-5.6	-7.9	0.872	0.873
TM	8	5	11.09.64	C	59.0	-45.3	0.577	0.619
TM	8	6	17.07.65	C	-10.3	-1.1	0.828	0.842
TM	8	7	4.09.65	B	-8.5	0.2	0.763	0.847
TM	8	8	30.07.66	C	-11.6	-15.1	0.791	0.804
TM	8	10	31.08.68	C	16.7	-2.6	0.853	0.940
TM	8	11	24.07.72	C	42.0	-39.9	0.256	0.362
TM	11	1	19.08.63	C	14.4	-8.3	0.899	0.834
TM	11	2	22.07.64	B	SUSPECT DATA			
TM	11	3	9.09.64	C	-8.1	8.3	0.840	0.843
TM	11	4	11.09.64	B	-12.0	-5.4	0.883	0.887
TM	11	5	17.07.65	C	4.1	-48.2	0.692	0.694
TM	11	6	4.09.65	B	7.9	-18.0	0.930	0.931
TM	11	7	30.07.66	C	0.7	-17.5	0.943	0.949
TM	11	9	31.08.68	C	SUSPECT DATA			
TM	11	10	13.08.69	B	8.2	8.3	0.612	0.719
TM	11	11	15.09.69	C	-13.1	-24.5	0.783	0.799
TM	11	12	21.08.73	B	SUSPECT DATA			
EC	1	1	28.02.77	A	3.0	3.5	0.936	0.942
EC	1	2	6.03.77	B	-3.7	-6.2	0.671	0.771
EC	1	3	7.05.77	B	-3.6	7.0	0.792	0.803
EC	1	4	19.04.78	A	-5.0	-8.2	0.927	0.928
EC	1	5	21.04.78	A	-17.6	9.2	0.360	0.770
EC	1	6	20.07.79	A	-61.5	-60.8	-0.053	0.676
EC	1	7	23.07.79	A	-7.3	2.1	0.923	0.973
EC	1	8	19.08.79	A	-8.8	1.0	0.834	0.872
EC	1	9	26.03.81	A	11.7	-12.7	0.932	0.956
EC	1	10	22.10.81	B	-19.6	-10.0	0.530	0.745
EC	1	11	23.12.81	A	14.2	-12.0	0.906	0.917
EC	1	12	2.11.85	A	-12.3	2.2	0.887	0.958
EC	1	13	25.11.85	B	-16.2	2.2	0.608	0.685

EC	1	14	1.12.85	B	-7.4	1.1	0.885	0.940
EC	2	1	28.02.77	A	9.0	-19.9	0.806	0.815
EC	2	2	6.03.77	B	26.3	-17.2	0.794	0.794
EC	2	3	7.05.77	B	-18.4	-21.5	0.836	0.836
EC	2	5	21.04.78	A	-0.9	-0.4	0.660	0.779
EC	2	6	20.07.79	A	-15.4	-4.9	0.773	0.794
EC	2	7	23.07.79	A	-4.3	-3.8	0.952	0.975
EC	2	8	19.08.79	A	1.7	-0.7	0.897	0.912
EC	2	9	26.03.81	A	13.6	-14.4	0.409	0.524
EC	2	11	23.12.81	A	2.1	-21.5	0.710	0.729
EC	2	12	2.11.85	A	-6.9	-9.3	0.927	0.957
EC	2	14	1.12.85	B	-0.1	1.3	0.977	0.984
BETH		1	1.11.80	C	SUSPECT DATA			
BETH		2	15.12.80	B	6.2	12.2	0.787	0.890
BETH		5	05.02.81	B	-49.7	-73.6	-0.817	0.296
BETH		6	10.02.81	B	-7.3	-15.0	0.945	0.952
BETH		7	14.02.81	B	18.6	-15.1	0.704	0.800
BETH		8	17.02.81	B	-18.6	-21.5	0.759	0.780
BETH		9	27.02.81	C	11.0	-23.3	0.263	0.380
BETH		10	22.03.81	C	-16.9	-1.0	0.072	0.310
HOEK		1	2.03.79	A	13.4	101.3	0.618	0.835
HOEK		2	4.05.79	B	-44.0	-70.5	-0.372	0.026
HOEK		3	16.02.80	A	-41.8	-44.9	0.645	0.945
HOEK		4	17.02.80	B	16.1	-30.1	0.848	0.875
HOEK		5	17.12.80	B	-8.1	-6.5	0.716	0.748
HOEK		6	8.01.81	B	-43.2	-62.1	-0.924	0.124
HOEK		7	1.02.81	A	14.6	-1.6	0.704	0.918
HOEK		8	19.02.81	B	3.7	33.7	0.549	0.794
HOEK		9	21.02.81	B	-5.8	-11.9	0.796	0.810
HOEK		10	24.02.81	B	27.4	30.0	0.129	0.629
HOEK		11	21.03.82	A	23.1	70.4	-1.732	0.061
HOEK		12	8.04.82	B	-11.1	-62.1	-0.924	0.124
HOEK		13	26.11.83	B	2.5	-19.4	0.566	0.566
HOEK		14	28.11.83	B	36.2	-10.5	0.767	0.870
HOEK		15	17.12.83	B	-15.7	-69.5	0.273	0.304
HOEK		16	24.12.83	B	18.6	20.2	0.841	0.928
CED		1	11.11.78	A	-4.2	-26.5	0.858	0.892
CED		2	9.12.78	A	9.0	29.3	0.654	0.837
CED		3	28.12.78	A	-11.4	-22.2	0.788	0.804
CED		4	2.01.79	A	-1.8	41.9	-0.856	0.238
CED		5	25.02.79	A	15.4	2.9	0.735	0.864
CED		6	2.12.84	A	-11.2	36.6	0.760	0.852
CED		7	9.02.85	A	7.7	8.5	0.566	0.674
CED		8	24.02.85	C	23.1	6.7	0.805	0.895
CED		9	11.03.85	A	-12.2	30.8	-0.057	0.375
CED		10	14.03.86	C	-11.7	22.6	0.559	0.777
ZL	15	1	29.01.77	B	-14.6	8.9	0.779	0.870
ZL	15	2	6.02.77	B	4.2	-16.4	0.418	0.495
ZL	15	3	14.02.77	B	18.1	11.1	0.485	0.733
ZL	15	4	14.03.77	B	SUSPECT DATA			
ZL	15	5	9.10.77	A	-0.5	9.4	0.870	0.921
ZL	15	6	9.11.77	B	10.2	-14.1	0.950	0.958
ZL	15	7	19.12.77	B	20.0	-7.5	0.836	0.890
ZL	15	8	19.01.78	C	5.3	-3.5	0.844	0.940
ZL	15	9	21.01.78	A	-6.3	-22.1	0.950	0.957
ZL	15	10	21.02.78	B	0.8	-15.0	0.827	0.832
ZL	15	11	1.03.78	A	6.5	17.9	0.525	0.894

ZL	15	12	9.03.78	B	14.6	50.0	-0.136	0.717
ZL	15	13	27.03.78	B	-10.2	13.2	0.512	0.750
ZL	15	14	8.09.78	A	1.7	-12.4	0.684	0.690
ZL	15	15	18.10.78	A	27.5	18.2	0.665	0.889
ZL	16	1	29.01.77	A	-5.6	17.6	0.779	0.870
ZL	16	3	14.02.77	A	18.1	11.1	0.485	0.733
ZL	16	5	9.10.77	A	-12.2	3.7	0.848	0.880
ZL	16	6	9.11.77	A	7.2	4.5	0.778	0.802
ZL	16	7	19.12.77	A	-15.8	-7.0	0.680	0.722
ZL	16	8	19.01.78	A	-6.5	-3.8	0.790	0.840
ZL	16	9	21.01.78	A	-6.4	-3.4	0.936	0.943
ZL	16	10	21.02.78	A	-24.4	-10.8	0.810	0.906
ZL	16	11	1.03.78	A	-21.0	9.7	0.701	0.839
ZL	16	12	9.03.78	A	-10.3	28.8	0.455	0.723
ZL	16	13	27.03.78	A	-16.6	-53.7	0.461	0.485
ZL	16	14	8.09.78	A	10.3	0.3	0.690	0.710
ZL	16	15	18.10.78	A	16.2	15.8	0.561	0.789
OX	4	1	3.04.58	A	1.8	45.1	0.720	0.964
OX	4	2	17.01.60	A	23.9	24.5	0.475	0.691
OX	4	3	31.08.61	A	-27.2	-56.3	0.619	0.852
OX	4	4	4.09.62	A	-8.3	-45.4	0.785	0.815
OX	4	5	29.08.63	A	-3.7	-17.1	0.955	0.972
OX	10	1	22.05.59	B	-7.3	48.6	0.681	0.757
OX	10	2	17.01.60	A	-0.4	6.5	0.511	0.646
OX	10	3	31.08.61	B	-28.0	-22.9	0.798	0.877
OX	10	4	4.09.62	A	-15.0	-41.0	0.819	0.946
OX	10	5	29.08.63	A	-2.7	-10.3	0.956	0.968
OX	10	6	4.03.64	A	-21.0	-9.7	0.947	0.977
OX	10	7	1.03.65	A	-18.5	14.0	0.438	0.633
OX	10	8	27.12.66	C	9.7	-3.6	0.523	0.571
OX	10	9	31.05.67	A	-7.5	-14.0	0.831	0.837
OX	10	10	1.02.68	A	-6.7	16.4	0.400	0.525
OX	10	11	17.04.69	A	-2.6	16.8	0.913	0.914
OX	10	12	26.08.71	C	-1.1	-17.5	0.859	0.875
OX	12	1	2.03.60	A	1.3	-13.2	0.840	0.920
OX	12	2	31.08.61	B	16.1	-11.1	0.542	0.600
OX	12	3	4.09.62	B	11.0	-34.9	0.840	0.877
OX	12	4	29.08.63	A	-0.7	-11.0	0.965	0.982
OX	12	5	4.03.64	A	5.5	44.5	0.865	0.929
OX	12	6	1.03.65	A	17.9	31.4	0.746	0.920
OX	12	7	24.05.66	A	9.7	24.5	0.933	0.989
OX	12	8	31.05.67	A	5.7	-18.1	0.890	0.897
OX	12	9	1.02.68	A	26.3	3.6	0.783	0.831
OX	12	10	17.04.69	A	14.4	41.7	0.850	0.980
OX	12	11	21.02.71	C	5.2	51.8	0.542	0.655
OX	17	1	2.03.60	A	-23.7	-14.3	0.709	0.823
OX	17	2	31.08.61	B	-4.4	-20.1	0.363	0.385
OX	17	3	4.09.62	B	8.9	-28.9	0.710	0.645
OX	17	4	29.08.63	A	1.6	9.2	0.788	0.791
OX	17	5	4.03.64	A	-0.3	45.6	0.697	0.785
OX	17	6	1.03.65	A	-5.5	-16.1	0.923	0.927
OX	17	7	24.05.66	A	-31.8	-19.4	0.596	0.667
OX	17	8	31.05.67	A	-11.8	-30.3	0.708	0.729
OX	17	9	1.02.68	A	-3.5	2.7	0.976	0.977
OX	17	10	17.04.69	A	-12.5	21.4	0.912	0.938
OX	17	11	21.02.71	C	2.0	59.3	0.552	0.658
OX	17	12	2.07.72	C	-4.4	107.5	0.269	0.513

OX	17	13	19.04.73	C	-4.1	183.2	-0.277	0.598
OX	28	1	17.01.60	A	4.5	-49.3	0.750	0.796
OX	28	2	4.09.62	A	-28.5	-58.3	0.511	0.687
OX	28	3	29.08.63	A	-17.5	-41.8	0.776	0.919
OX	28	4	4.03.64	A	-36.7	-49.3	0.716	0.948
OX	28	5	1.03.65	A	116.3	50.3	-1.207	0.774
OX	28	6	24.05.66	A	132.2	89.6	-3.631	0.671
OX	28	7	31.05.67	A	-48.9	-69.9	0.095	0.169
OX	32	1	22.05.59	B	20.1	-14.6	0.876	0.891
OX	32	2	2.03.60	A	-7.8	27.9	0.305	0.698
OX	32	3	31.08.61	B	4.5	-9.2	0.202	0.342
OX	32	4	4.09.62	A	-19.2	-20.2	0.690	0.727
OX	32	5	29.08.63	A	-14.7	-36.1	0.457	0.466
OX	32	6	4.03.64	A	1.9	10.3	0.965	0.983
OX	32	7	1.03.65	A	-0.4	-21.5	0.868	0.870
OX	32	8	24.05.66	A	-13.8	3.7	0.799	0.807
OX	32	9	31.05.67	A	-14.9	-25.7	0.783	0.834
OX	32	10	1.02.68	A	17.1	19.7	0.754	0.803
OX	32	11	17.04.69	A	0.1	67.6	0.749	0.889
OX	32	12	18.06.71	C	-1.9	-12.6	0.724	0.737
OX	32	13	25.06.72	C	0.6	20.0	0.880	0.931
OX	32	14	19.04.73	C	-11.4	62.1	0.740	0.846
OX	35	1	22.05.59	B	6.6	16.8	0.935	0.940
OX	35	2	2.03.60	A	0.5	90.1	-0.059	0.821
OX	35	3	31.08.61	B	-12.6	-38.1	0.643	0.706
OX	35	4	4.09.62	A	7.3	-25.4	0.187	0.329
OX	35	5	29.08.63	A	11.5	-20.8	0.194	0.281
OX	35	6	4.03.64	A	-22.2	0.7	0.707	0.738
OX	35	7	1.03.65	A	-1.0	27.9	0.402	0.669
OX	35	8	24.05.66	A	4.2	31.0	0.924	0.931
OX	35	9	31.05.67	A	7.8	64.0	0.729	0.871
OX	35	10	1.02.68	A	3.5	13.1	0.482	0.556
OX	35	11	17.04.69	A	0.4	140.6	0.092	0.656
OX	35	12	26.08.71	C	9.6	2.5	0.729	0.771
KAAI		1	25.03.81	C	-16.2	0.7	0.863	0.880
KAAI		2	26.04.81	C	-14.0	-19.2	0.845	0.860
KAAI		3	5.05.81	C	18.2	6.9	-0.359	0.210
KAAI		4	28.05.81	C	-7.7	-19.9	0.881	0.890
KAAI		6	24.08.81	C	-29.0	-33.2	0.581	0.690
KAAI		7	27.08.81	C	-2.5	13.3	0.143	0.459
KAAI		8	30.08.81	C	-6.7	-8.0	-0.025	0.417
KAAI		9	18.02.82	C	-4.3	-12.2	0.156	0.360
KAAI		10	3.03.82	C	18.2	-2.7	0.278	0.440
KAAI		11	12.09.82	C	-20.2	118.5	-0.207	0.130
KAAI		12	12.06.83	C	0.8	-3.9	0.658	0.780
KAAI		13	2.10.83	C	-0.9	-18.4	0.543	0.630
KAAI		14	28.10.85	C	-2.1	-7.7	0.648	0.660
KAAI		15	2.11.85	B	16.5	26.3	-2.823	0.001
KAAI		16	8.11.85	B	-22.2	14.5	-0.237	0.320
KAAI		17	2.12.85	B	-0.5	-18.2	-0.198	0.370
MALGAS		1	25.03.81	C	-7.1	-3.1	0.824	0.829
MALGAS		2	26.04.81	C	-3.8	4.7	0.876	0.881
MALGAS		3	5.05.81	C	1.4	49.0	0.202	0.813
MALGAS		4	28.05.81	C	-9.6	14.3	0.916	0.934
MALGAS		6	24.08.81	C	-4.8	19.9	-1.131	0.030
MALGAS		7	27.08.81	C	19.4	61.3	-0.159	0.623
MALGAS		8	30.08.81	C	3.7	7.2	0.592	0.808

MALGAS	9	15.10.81	C	-4.1	-2.7	0.703	0.816
MALGAS	10	15.01.82	C	12.8	-13.6	0.163	0.288
MALGAS	11	18.02.82	C	1.1	-9.9	0.787	0.809
MALGAS	12	3.03.82	C	-12.8	16.0	0.925	0.964
MALGAS	13	1.09.82	C	SUSPECT DATA			
MALGAS	14	11.06.83	C	-11.2	-8.9	-0.038	0.215
MALGAS	15	22.09.83	C	-18.0	1.7	0.202	0.396
MALGAS	16	15.10.85	B	-12.0	-10.1	0.917	0.928
MALGAS	17	21.01.86	B	-0.8	-41.1	0.173	0.239
ND 1	1	24.10.59	A	-18.0	-14.5	0.837	0.909
ND 1	2	30.07.60	A	19.4	-15.2	-0.245	0.846
ND 1	4	31.07.62	B	5.9	-11.5	0.802	0.865
ND 1	6	22.07.64	B	27.6	38.3	-1.110	0.420
ND 1	7	7.06.65	C	SUSPECT DATA			
ND 1	8	19.10.66	C	-13.4	0.9	0.725	0.830
ND 1	9	16.07.67	C	-8.9	8.9	0.700	0.820
ND 1	10	11.09.68	C	-6.3	-16.6	0.962	0.980
ND 1	12	23.08.71	C	4.3	6.7	0.916	0.960
ND 1	13	3.07.72	C	-9.7	7.2	0.649	0.739
ND 1	14	10.07.72	C	-11.2	-6.1	0.909	0.930
ND 1	15	17.09.73	A	3.2	-3.1	0.904	0.910
ND 5	1	30.07.60	A	15.6	-14.1	0.808	0.840
ND 5	3	31.07.62	B	-10.0	-17.2	0.941	0.960
ND 5	6	7.06.65	C	-2.8	-11.6	0.879	0.880
ND 5	7	19.10.66	C	-2.0	7.9	0.938	0.980
ND 5	8	16.07.67	C	1.1	-1.2	0.739	0.780
ND 5	9	11.09.68	C	0.0	-3.2	0.944	0.950
ND 5	11	23.08.71	C	3.3	11.8	0.886	0.941
ND 5	12	10.07.72	C	-7.2	-3.0	0.922	0.940
ND 5	13	20.07.72	C	3.2	-1.4	0.864	0.890
ND 5	14	14.07.73	C	-4.3	9.9	0.779	0.850
ND 5	15	17.09.73	A	0.1	-10.9	0.934	0.940

MODEL OSE1 Semi-distributed calibration and validation results

Catch name	Storm No.	Storm date	Storm type	Calibration % Error Vol.	Calibration % Error Peak	Calibration Coefficient Eff.	Calibration Coefficient Det.	Validation % Error Vol.	Validation % Error Peak	Validation Coefficient Eff.	Validation Coefficient Det.
TM 1	1	26.07.59	B	-11.7	-13.0	0.568	0.602	NOT MODELLED			
TM 1	2	4.09.65	C	22.1	-20.9	0.606	0.705	NOT MODELLED			
TM 2	1	26.07.59	B	-19.6	19.2	0.840	0.870	NOT MODELLED			
TM 2	2	17.08.61	C	9.2	-15.1	0.487	0.597	NOT MODELLED			
TM 2	3	4.09.65	B	-14.6	-1.3	0.840	0.870	NOT MODELLED			
TM 2	4	25.08.68	C	37.0	-41.0	0.670	0.710	NOT MODELLED			
TM 2	5	31.08.68	C	-19.1	-11.1	-0.390	0.062	NOT MODELLED			
TM 3	1	19.07.55	C	-3.0	-33.4	0.843	0.851	14.5	-36.2	0.776	0.784
TM 3	2	14.08.58	B	-2.1	0.2	0.721	0.792	-51.7	-68.1	0.392	0.718
TM 3	3	16.08.58	C	2.4	-5.8	0.739	0.829	222.3	97.4	-4.184	0.711
TM 3	4	17.08.61	B	-43.6	15.1	0.599	0.679	-88.6	-91.1	-0.094	0.835
TM 3	5	25.07.62	C	-2.4	-21.6	-0.949	0.002	7.6	-63.2	0.283	0.285
TM 3	7	25.08.68	C	16.1	-24.5	0.076	0.195	104.6	-9.7	0.209	0.537
TM 3	8	31.08.68	C	19.3	-19.6	-0.240	0.116	97.6	-21.8	0.090	0.452
TM 3	11	27.07.73	C	-18.2	-22.3	0.376	0.416	-44.8	-69.6	0.234	0.616
TM 6	1	4.09.65	B	0.4	13.8	0.814	0.837	NOT MODELLED			
TM 6	2	31.08.68	B	17.1	6.8	-0.559	0.129	NOT MODELLED			
TM 8	1	19.08.63	C	-38.0	-24.5	0.106	0.247	-84.9	-93.9	-0.375	0.101
TM 8	2	22.07.64	C	9.3	-26.3	0.876	0.884	109.0	-23.3	-0.080	0.400
TM 8	3	9.09.64	C	-4.6	7.0	0.750	0.751	1.2	-58.5	0.214	0.215
TM 8	5	11.09.64	C	3.7	-60.8	0.453	0.467	248.8	-13.0	-1.162	0.319
TM 8	6	17.07.65	C	10.8	15.8	0.505	0.628	118.6	2.8	-0.255	0.485
TM 8	7	4.09.65	B	-3.4	-9.2	0.657	0.728	19.2	-40.9	0.497	0.530
TM 8	8	30.07.66	C	-2.0	32.2	-1.920	0.008	355.7	243.2	-16.661	0.185
TM 8	10	31.08.68	C	12.3	10.5	0.237	0.478	11.7	-63.8	0.131	0.154
TM 8	11	24.07.72	C	13.9	-39.6	-0.187	0.080	197.0	4.6	-1.100	0.581
TM 11	1	19.08.63	C	18.1	39.0	-0.372	0.223	-90.2	-93.4	-0.070	0.753
TM 11	2	22.07.64	B	10.1	-17.9	0.648	0.662	-12.1	-37.1	0.864	0.931
TM 11	3	9.09.64	C	3.2	77.4	0.599	0.714	-55.3	-59.5	0.416	0.707
TM 11	4	11.09.64	B	2.8	40.1	0.773	0.853	67.3	81.7	0.195	0.894
TM 11	5	17.07.65	C	7.6	25.5	0.507	0.574	126.3	1.3	-0.106	0.680
TM 11	6	4.09.65	B	-6.8	3.0	0.807	0.818	85.9	28.1	0.374	0.916
TM 11	7	30.07.66	C	0.8	17.5	-1.194	0.000	206.2	170.9	-6.435	0.084
TM 11	9	31.08.68	C	31.3	4.2	0.802	0.849	0.2	-71.5	0.102	0.104
TM 11	10	13.08.69	B	13.1	108.4	-0.184	0.591	-15.5	-37.7	0.823	0.927
TM 11	11	15.09.69	C	-9.6	19.8	0.736	0.763	-50.6	-73.8	0.037	0.234
TM 11	12	21.08.73	B	-32.9	-31.5	0.569	0.650	-86.3	-92.6	-0.167	0.718
EC 1	1	28.02.77	A	12.5	-2.0	0.743	0.831	127.5	183.0	-11.194	0.278
EC 1	2	6.03.77	B	8.5	-16.5	0.790	0.815	-86.9	-94.2	-1.032	0.018
EC 1	3	7.05.77	B	7.1	-12.0	0.640	0.678	393.0	190.3	-16.118	0.272
EC 1	4	19.04.78	A	9.5	-5.3	0.907	0.913	327.9	222.4	-5.776	0.757
EC 1	6	20.07.79	A	-61.9	-46.0	-0.123	0.431	-17.0	-8.5	0.323	0.389
EC 1	7	23.07.79	A	-7.9	6.1	0.839	0.948	58.0	143.5	-5.687	0.546
EC 1	8	19.08.79	A	-7.0	-3.1	0.713	0.787	23.9	4.9	-0.859	0.166
EC 1	9	26.03.81	A	10.3	-2.3	0.704	0.771	438.9	609.6	-63.869	0.476
EC 1	10	22.10.81	B	-9.2	1.5	0.603	0.737	-60.0	-61.4	-2.003	0.344
EC 1	11	23.12.81	A	12.9	-9.8	0.804	0.812	-18.4	-41.7	0.600	0.703
EC 1	12	2.11.85	A	-0.1	7.8	0.909	0.972	42.8	133.4	-3.512	0.555
EC 1	13	25.11.85	B	-12.5	-6.5	0.451	0.588	-23.2	-37.1	0.200	0.520
EC 1	14	1.12.85	B	-17.4	5.4	-0.450	0.272	-11.3	6.7	-0.629	0.173

BETH		2	15.12.80	B	6.1	-2.3	0.836	0.880	NOT MODELLED			
BETH		5	05.02.81	B	-23.9	-46.6	-0.045	0.123	NOT MODELLED			
BETH		6	10.02.81	B	-13.1	-16.8	0.956	0.980	NOT MODELLED			
BETH		7	14.02.81	B	16.6	-17.3	0.717	0.784	NOT MODELLED			
BETH		8	17.02.81	B	-19.3	-13.2	0.815	0.854	NOT MODELLED			
BETH		9	27.02.81	C	-1.0	-20.6	0.602	0.630	NOT MODELLED			
BETH		10	22.03.81	C	-12.5	-7.9	0.232	0.371	NOT MODELLED			
HOEK		1	2.03.79	A	14.9	93.1	-0.214	0.873	-32.2	-2.9	0.816	0.919
HOEK		2	4.05.79	B	-43.1	-77.8	-0.229	0.109	50.7	-39.7	0.017	0.496
HOEK		3	16.02.80	A	-40.3	-57.1	0.596	0.906	86.4	89.3	-1.026	0.897
HOEK		4	17.02.80	B	-15.7	-32.0	0.910	0.940	2.5	-16.6	0.934	0.935
HOEK		5	17.12.80	B	-7.4	-13.9	0.692	0.814	245.0	366.5	-23.477	0.685
HOEK		6	8.01.81	B	-44.7	-71.1	0.192	0.635	66.5	34.5	-0.038	0.783
HOEK		7	1.02.81	A	14.7	27.7	0.688	0.979	-11.0	-7.6	0.958	0.978
HOEK		8	19.02.81	B	4.6	3.3	0.756	0.864	12.2	2.7	0.554	0.742
HOEK		9	21.02.81	B	-5.0	-21.4	0.449	0.509	-12.9	34.8	0.466	0.484
HOEK		10	24.02.81	B	26.7	24.1	0.103	0.691	-45.9	-62.5	0.294	0.548
HOEK		11	21.03.82	A	20.6	70.7	-1.541	0.123	30.0	81.4	-2.044	0.106
HOEK		12	8.04.82	B	-12.2	-64.1	-0.442	0.001	311.2	102.5	-31.511	0.075
HOEK		13	26.11.83	B	5.0	-28.4	0.590	0.594	79.2	31.5	-0.204	0.555
HOEK		14	28.11.83	B	36.8	-6.6	0.799	0.904	-20.1	-50.4	0.750	0.864
HOEK		15	17.12.83	B	-16.2	-72.8	0.137	0.157	113.8	-29.6	-0.837	0.292
HOEK		16	24.12.83	B	20.9	2.2	0.858	0.937	-24.3	-48.4	0.778	0.884
CED		1	11.11.78	A	-3.1	-41.6	0.835	0.885	NOT MODELLED			
CED		2	9.12.78	A	25.2	128.2	-2.896	0.389	NOT MODELLED			
CED		3	28.12.78	A	-9.4	-33.7	0.848	0.865	NOT MODELLED			
CED		4	2.01.79	A	-5.9	20.1	0.145	0.513	NOT MODELLED			
CED		5	25.02.79	A	17.1	-18.4	0.680	0.764	NOT MODELLED			
CED		6	2.12.84	A	-15.6	-16.6	0.893	0.961	NOT MODELLED			
CED		7	9.02.85	A	10.4	57.2	-0.954	0.218	NOT MODELLED			
CED		8	24.02.85	C	21.1	-23.8	0.721	0.754	NOT MODELLED			
CED		9	11.03.85	A	-14.0	-16.1	0.501	0.569	NOT MODELLED			
CED		10	14.03.86	C	25.9	-27.5	0.723	0.798	NOT MODELLED			
ZL	15	1	29.01.77	B	14.5	106.4	-0.481	0.451	63.1	115.7	-1.758	0.672
ZL	15	2	6.02.77	B	-1.0	-23.7	0.387	0.438	8.9	-17.4	0.337	0.476
ZL	15	3	14.02.77	B	16.7	3.7	0.521	0.738	13.2	-33.5	0.595	0.637
ZL	15	4	14.03.77	B	-2.0	-16.5	0.632	0.655	0.5	4.5	0.411	0.553
ZL	15	5	9.10.77	A	-16.8	-8.7	0.888	0.950	14.3	27.7	0.701	0.919
ZL	15	6	9.11.77	B	5.3	-9.1	0.704	0.719	78.8	-89.4	-0.152	0.546
ZL	15	7	19.12.77	B	-16.7	-19.1	0.729	0.750	-46.8	-63.0	0.433	0.810
ZL	15	8	19.01.78	C	-8.3	-8.3	0.873	0.942	-64.4	-78.7	0.250	0.887
ZL	15	9	21.01.78	A	-11.9	-26.6	0.916	0.944	16.3	-4.2	0.913	0.944
ZL	15	10	21.02.78	B	-20.4	-6.6	0.881	0.942	19.3	-30.0	0.807	0.851
ZL	15	11	1.03.78	A	18.3	22.8	0.411	0.784	21.4	47.9	-0.143	0.869
ZL	15	12	9.03.78	B	-12.9	22.8	0.636	0.826	-14.5	7.4	0.555	0.760
ZL	15	13	27.03.78	B	7.6	-4.6	0.707	0.806	-86.8	-92.9	-0.336	0.798
ZL	15	14	8.09.78	A	7.6	-4.6	0.707	0.806	-73.1	-76.6	-0.304	0.859
ZL	15	15	18.10.78	A	12.2	-3.8	0.600	0.761	-4.6	-1.4	0.807	0.834
ZL	16	1	29.01.77	A	-9.5	16.0	0.826	0.914	NOT MODELLED			
ZL	16	3	14.02.77	A	16.7	3.7	0.521	0.738	NOT MODELLED			
ZL	16	5	9.10.77	A	-16.8	-8.7	0.888	0.951	NOT MODELLED			
ZL	16	6	9.11.77	A	5.3	-9.1	0.704	0.719	NOT MODELLED			
ZL	16	7	19.12.77	A	-16.7	-19.1	0.729	0.748	NOT MODELLED			
ZL	16	8	19.01.78	A	-8.3	-8.3	0.870	0.892	NOT MODELLED			
ZL	16	9	21.01.78	A	-8.2	-5.5	0.915	0.923	NOT MODELLED			
ZL	16	10	21.02.78	A	-20.4	-6.6	0.881	0.942	NOT MODELLED			
ZL	16	11	1.03.78	A	-28.1	-4.3	0.691	0.932	NOT MODELLED			

ZL	16	12	9.03.78	A	-12.9	22.8	0.636	0.826	NOT MODELLED			
ZL	16	13	27.03.78	A	-18.2	-58.3	0.574	0.629	NOT MODELLED			
ZL	16	14	8.09.78	A	7.6	-4.6	0.707	0.806	NOT MODELLED			
ZL	16	15	18.10.78	A	12.2	-3.8	0.600	0.761	NOT MODELLED			
OX	4	1	3.04.58	A	-0.1	2.8	0.838	0.934	NOT MODELLED			
OX	4	2	17.01.60	A	20.5	12.3	0.661	0.791	NOT MODELLED			
OX	4	3	31.08.61	A	-30.4	-64.7	0.422	0.589	NOT MODELLED			
OX	4	4	4.09.62	A	-7.7	-46.3	0.823	0.870	NOT MODELLED			
OX	4	5	29.08.63	A	-3.6	-24.9	0.897	0.918	NOT MODELLED			
OX	10	1	22.05.59	B	-12.0	-60.6	0.573	0.688	-38.5	-83.1	0.109	0.266
OX	10	2	17.01.60	A	-0.4	-3.7	0.562	0.703	-29.0	12.0	0.925	0.982
OX	10	3	31.08.61	B	-28.0	-37.7	0.811	0.952	-59.1	-78.1	0.073	0.392
OX	10	4	4.09.62	A	-12.8	-40.5	0.832	0.949	-5.5	-57.6	0.520	0.604
OX	10	5	29.08.63	A	-3.8	-18.6	0.950	0.977	101.8	35.2	0.098	0.878
OX	10	6	4.03.64	A	-21.2	-17.5	0.931	0.962	10.7	12.0	0.925	0.982
OX	10	7	1.03.65	A	-18.4	-6.6	0.408	0.605	26.6	58.3	-0.185	0.725
OX	10	8	27.12.66	C	-9.8	-6.6	0.460	0.517	77.4	80.3	-1.050	0.582
OX	10	9	31.05.67	A	-7.6	-24.8	0.887	0.902	46.0	-6.2	0.291	0.590
OX	10	10	1.02.68	A	-6.6	8.6	0.317	0.463	-12.0	-8.8	0.617	0.642
OX	10	11	17.04.69	A	-2.4	1.1	0.967	0.968	173.1	180.5	-2.781	0.967
OX	10	12	26.08.71	C	-0.8	-23.1	0.760	0.771	-43.1	-70.8	0.345	0.790
OX	12	1	2.03.60	A	-46.0	-47.7	0.349	0.855	7.6	17.1	0.701	0.871
OX	12	2	31.08.61	B	-59.0	-75.7	0.032	0.366	-67.9	-84.6	-0.293	0.015
OX	12	3	4.09.62	B	4.5	-30.9	0.894	0.911	46.6	-17.5	0.548	0.680
OX	12	4	29.08.63	A	-10.7	-14.6	0.967	0.952	42.9	26.0	0.644	0.834
OX	12	5	4.03.64	A	-7.6	30.2	0.896	0.928	30.2	84.8	0.441	0.926
OX	12	6	1.03.65	A	-6.2	3.3	0.872	0.911	15.5	26.4	0.726	0.939
OX	12	7	24.05.66	A	-11.6	5.1	0.982	0.992	74.3	115.9	-0.448	0.975
OX	12	8	31.05.67	A	-3.0	-20.5	0.852	0.854	57.7	35.2	0.146	0.655
OX	12	9	1.02.68	A	6.7	-9.3	0.819	0.823	46.4	27.4	0.557	0.844
OX	12	10	17.04.69	A	-7.7	17.8	0.758	0.882	73.7	160.6	-1.169	0.956
OX	12	11	21.02.71	C	-15.5	19.3	0.622	0.658	3.9	58.9	0.573	0.698
OX	17	1	2.03.60	A	-14.0	-4.9	0.809	0.990	-44.2	-37.9	0.413	0.924
OX	17	2	31.08.61	B	8.7	-17.0	0.858	0.864	-80.0	-90.8	-0.270	0.056
OX	17	3	4.09.62	B	20.4	-6.2	0.832	0.850	-39.7	-66.7	0.160	0.248
OX	17	4	29.08.63	A	7.3	12.8	0.975	0.982	72.5	71.7	0.279	0.885
OX	17	5	4.03.64	A	1.7	56.6	0.335	0.635	-24.2	-18.5	0.690	0.731
OX	17	6	1.03.65	A	9.1	-1.1	0.699	0.771	-20.9	-29.3	0.828	0.864
OX	17	7	24.05.66	A	-29.8	-15.2	0.872	0.959	-23.6	-12.2	0.769	0.812
OX	17	8	31.05.67	A	3.2	-14.5	0.818	0.893	-2.8	-24.6	0.626	0.627
OX	17	9	1.02.68	A	-1.0	6.0	0.779	0.810	-54.1	-50.2	0.560	0.964
OX	17	10	17.04.69	A	45.7	113.6	-0.327	0.931	15.5	67.6	0.648	0.982
OX	17	11	21.02.71	C	-5.2	34.8	0.375	0.508	-33.8	2.5	0.516	0.599
OX	17	12	2.07.72	C	2.3	97.6	0.048	0.435	6.6	90.7	0.312	0.574
OX	17	13	19.04.73	C	-3.4	182.8	-0.391	0.581	-18.3	131.4	0.144	0.611
OX	32	1	22.05.59	B	-17.8	-49.9	0.554	0.600	-56.1	-83.8	-0.068	0.045
OX	32	2	2.03.60	A	-5.5	34.3	0.323	0.737	-52.2	-44.4	-0.865	0.180
OX	32	3	31.08.61	B	14.4	-17.9	0.758	0.785	-82.0	-94.6	-0.247	0.000
OX	32	4	4.09.62	A	-1.9	-51.5	0.689	0.698	-38.0	-81.7	0.166	0.286
OX	32	5	29.08.63	A	-9.5	-46.1	0.780	0.858	-30.3	-71.7	0.175	0.240
OX	32	6	4.03.64	A	2.2	12.8	0.949	0.969	-31.3	-38.1	0.745	0.859
OX	32	7	1.03.65	A	0.5	-49.7	0.182	0.236	-35.3	-71.6	0.193	0.277
OX	32	8	24.05.66	A	4.0	-3.3	0.973	0.976	-17.8	-46.4	0.661	0.703
OX	32	9	31.05.67	A	-12.4	-40.9	0.789	0.852	33.5	-21.6	0.348	0.427
OX	32	10	1.02.68	A	18.2	3.3	0.532	0.627	37.9	-56.2	0.599	0.910
OX	32	11	17.04.69	A	0.7	22.5	0.786	0.874	-26.8	-31.7	0.885	0.951
OX	32	12	18.06.71	C	0.4	-22.5	0.935	0.942	31.7	-14.6	0.419	0.498

OX	32	13	25.06.72	C	1.1	15.9	0.898	0.936	10.3	5.3	0.923	0.943
OX	32	14	19.04.73	C	-11.1	22.0	0.936	0.967	-15.4	-1.7	0.925	0.936
OX	35	1	22.05.59	B	22.6	20.4	0.904	0.956	-57.6	-80.6	0.070	0.347
OX	35	2	2.03.60	A	0.5	37.0	0.607	0.911	-13.1	1.3	0.702	0.800
OX	35	3	31.08.61	B	-12.6	-49.4	0.672	0.808	-45.3	-77.3	0.018	0.137
OX	35	4	4.09.62	A	9.3	-32.3	0.544	0.590	-10.3	-68.8	0.000	0.060
OX	35	5	29.08.63	A	12.8	-23.1	0.355	0.391	29.8	-38.8	0.583	0.672
OX	35	6	4.03.64	A	-22.2	6.0	0.721	0.750	-44.2	-42.8	0.702	0.980
OX	35	7	1.03.65	A	-1.1	22.1	0.358	0.649	-40.9	-41.7	0.697	0.897
OX	35	8	24.05.66	A	3.4	11.0	0.953	0.954	16.8	-13.3	0.833	0.846
OX	35	9	31.05.67	A	2.7	31.9	0.915	0.953	57.1	49.7	0.378	0.780
OX	35	10	1.02.68	A	3.9	8.0	0.405	0.503	-61.1	-70.3	0.282	0.952
OX	35	11	17.04.69	A	0.8	95.8	0.247	0.686	-7.8	38.1	0.879	0.916
OX	35	12	26.08.71	C	10.1	4.6	0.675	0.718	-7.4	-47.0	0.729	0.861
KAAI		1	25.03.81	C	-11.6	4.1	0.841	0.850	-37.0	-10.5	0.722	0.835
KAAI		2	26.04.81	C	-9.0	-14.0	0.875	0.884	-12.6	-4.1	0.791	0.807
KAAI		3	5.05.81	C	-14.6	19.5	-0.089	0.390	35.1	142.7	-2.660	0.162
KAAI		4	28.05.81	C	-6.3	-20.9	0.869	0.868	-29.4	-36.6	0.745	0.856
KAAI		6	24.08.81	C	-8.4	-5.0	0.677	0.720	-17.3	-0.3	0.532	0.620
KAAI		7	27.08.81	C	-1.2	8.6	0.266	0.553	28.1	45.4	-0.404	0.453
KAAI		8	30.08.81	C	-5.7	-10.8	0.075	0.493	42.4	37.7	-1.018	0.346
KAAI		9	18.02.82	C	-11.4	-16.2	0.590	0.652	-17.3	-13.7	0.502	0.574
KAAI		10	3.03.82	C	15.6	8.4	0.540	0.660	-2.7	-95.5	-0.432	0.380
KAAI		11	11.06.83	C	SUSPECT DATA				122.8	330.8	-9.334	0.137
KAAI		12	12.06.83	C	-6.3	-11.2	0.772	0.850	-5.4	-7.1	0.661	0.791
KAAI		13	2.10.83	C	-4.3	-21.6	0.610	0.682	-79.7	-79.3	-0.684	0.013
KAAI		14	28.10.85	C	-4.6	-6.2	0.845	0.850	-74.0	-76.2	-0.286	0.606
KAAI		15	2.11.85	B	-1.1	5.2	-1.389	0.034	-52.0	-50.3	0.427	0.830
KAAI		16	8.11.85	B	-17.5	17.3	0.377	0.684	102.4	96.7	-5.440	0.001
KAAI		17	2.12.85	B	1.3	-3.1	0.776	0.799	7.6	90.2	-0.587	0.486
MALGAS		1	25.03.81	C	6.4	1.3	0.833	0.839	-19.6	6.6	0.849	0.884
MALGAS		2	26.04.81	C	-3.1	9.3	0.845	0.859	18.3	69.1	0.181	0.656
MALGAS		3	5.05.81	C	19.8	21.4	0.435	0.803	-14.3	56.9	-0.119	0.781
MALGAS		4	28.05.81	C	-9.2	-14.4	0.910	0.923	22.4	-20.1	0.790	0.864
MALGAS		6	24.08.81	C	-4.5	31.2	-1.497	0.015	-58.2	-30.5	-0.913	0.001
MALGAS		7	27.08.81	C	-13.3	12.3	0.436	0.621	2.8	83.7	-0.582	0.450
MALGAS		8	30.08.81	C	-4.7	4.9	0.580	0.779	-7.7	11.1	0.135	0.598
MALGAS		9	15.10.81	C	-9.7	0.1	0.888	0.929	-77.7	-74.3	-0.633	0.914
MALGAS		10	15.01.82	C	-10.3	-4.3	0.087	0.286	-30.9	-2.3	-0.580	0.108
MALGAS		11	18.02.82	C	1.1	-2.5	0.746	0.807	-51.5	-42.3	0.470	0.703
MALGAS		12	3.03.82	C	-19.2	18.1	0.900	0.958	-47.9	21.7	0.517	0.789
MALGAS		14	11.06.83	C	-10.5	2.1	-0.192	0.193	-88.1	-86.7	-1.084	0.233
MALGAS		15	22.09.83	C	-17.4	15.3	0.095	0.362	-88.2	-80.6	-1.508	0.408
MALGAS		16	15.10.85	B	-15.2	-5.3	0.927	0.946	-30.1	-7.1	0.740	0.830
MALGAS		17	21.01.86	B	20.9	-19.5	-0.266	0.160	-82.5	-87.3	-0.620	0.221
ND	1	1	24.10.59	A	-12.5	-12.8	0.880	0.921	NOT MODELLED			
ND	1	2	30.07.60	A	17.6	-20.2	0.740	0.783	NOT MODELLED			
ND	1	4	31.07.62	B	2.9	-18.3	0.847	0.863	NOT MODELLED			
ND	1	6	22.07.64	B	-1.8	-11.3	0.514	0.571	NOT MODELLED			
ND	1	7	7.06.65	C	-84.6	-90.1	-0.872	0.929	NOT MODELLED			
ND	1	8	19.10.66	C	-3.4	6.5	0.707	0.771	NOT MODELLED			
ND	1	9	16.07.67	C	-11.8	-4.4	0.883	0.931	NOT MODELLED			
ND	1	10	11.09.68	C	1.6	-18.8	0.956	0.971	NOT MODELLED			
ND	1	12	23.08.71	C	15.0	6.8	0.892	0.993	NOT MODELLED			
ND	1	13	3.07.72	C	-13.5	-12.0	0.500	0.566	NOT MODELLED			
ND	1	14	10.07.72	C	2.0	-1.1	0.936	0.951	NOT MODELLED			
ND	1	15	17.09.73	A	-2.8	-15.0	0.896	0.901	NOT MODELLED			

ND	5	1	30.07.60	A	9.5	-19.9	0.722	0.732	-43.6	-60.2	0.325	0.800
ND	5	3	31.07.62	B	0.8	-6.4	0.942	0.950	-38.0	-43.9	0.618	0.951
ND	5	6	7.06.65	C	-3.2	14.0	0.720	0.730	-61.2	-68.1	-0.448	0.881
ND	5	7	19.10.66	C	0.7	5.4	0.926	0.940	46.5	68.1	-0.797	0.745
ND	5	8	16.07.67	C	-5.5	-10.3	0.914	0.920	-43.9	-46.1	0.312	0.923
ND	5	9	11.09.68	C	-0.1	-7.7	0.937	0.941	32.1	44.3	0.378	0.856
ND	5	11	23.08.71	C	10.1	12.3	0.901	0.977	172.1	274.2	-17.385	0.751
ND	5	12	10.07.72	C	-8.2	-6.2	0.908	0.920	-44.2	-45.7	0.404	0.946
ND	5	13	20.07.72	C	-0.6	-6.5	0.893	0.900	131.5	169.3	-5.884	0.741
ND	5	14	14.07.73	C	9.6	10.1	0.937	0.990	-56.4	-65.0	-0.424	0.910
ND	5	15	17.09.73	A	11.9	0.4	0.803	0.925	-10.6	-16.4	0.798	0.815

MODEL OSE2 Lumped calibration results

Catch name		Storm No.	Storm date	Storm type	Calibration % Error Vol.	Calibration % Error Peak	Coefficient Eff.	Coefficient Det.
TM	1	1	26.07.59	B	-52.0	-49.9	0.533	0.787
TM	1	2	31.08.61	C	93.7	111.2	-3.441	0.437
TM	2	1	26.07.59	B	-39.2	-38.7	0.304	0.370
TM	2	2	17.08.61	C	-92.6	-91.2	-0.412	0.146
TM	2	3	4.09.65	B	-26.6	4.4	0.877	0.927
TM	2	4	25.08.68	C	103.0	5.6	-0.466	0.365
TM	2	5	31.08.68	C	-11.2	-15.1	0.608	0.636
TM	3	1	19.07.55	C	-49.1	-54.4	0.665	0.873
TM	3	2	14.08.58	B	-43.7	-32.0	0.686	0.805
TM	3	3	16.08.58	C	51.4	52.3	-0.931	0.503
TM	3	4	17.08.61	B	-54.6	-1.5	0.597	0.697
TM	3	5	25.07.62	C	71.6	46.4	-2.846	0.004
TM	3	7	25.08.68	C	76.8	11.2	0.546	0.762
TM	3	8	31.08.68	C	242.4	213.7	-8.829	0.102
TM	3	11	27.07.73	C	-28.2	-72.5	-0.344	0.301
TM	6	1	4.09.65	B	-39.8	-15.3	0.740	0.869
TM	6	2	31.08.68	B	6.9	-7.0	0.731	0.765
TM	8	1	19.08.63	C	-28.0	1.3	-0.184	0.162
TM	8	2	22.07.64	C	27.1	-15.8	0.870	0.905
TM	8	3	9.09.64	C	-70.3	-74.8	0.206	0.718
TM	8	5	11.09.64	C	-13.7	-72.2	0.406	0.497
TM	8	6	17.07.65	C	235.3	472.7	-24.584	0.015
TM	8	7	4.09.65	B	-16.6	8.1	0.756	0.834
TM	8	8	30.07.66	C	30.9	12.1	-1.273	0.036
TM	8	10	31.08.68	C	83.7	46.5	-0.406	0.879
TM	8	11	24.07.72	C	292.5	240.9	-8.802	0.683
TM	11	1	19.08.63	C	2.8	3.3	0.538	0.580
TM	11	2	22.07.64	B	-16.6	-34.2	0.829	0.866
TM	11	3	9.09.64	C	-50.4	1.9	0.493	0.561
TM	11	4	11.09.64	B	-27.6	-15.4	0.554	0.574
TM	11	5	17.07.65	C	-6.0	-56.7	0.629	0.652
TM	11	6	4.09.65	B	-6.3	-18.3	0.962	0.974
TM	11	7	30.07.66	C	13.6	-2.3	0.267	0.410
TM	11	9	31.08.68	C	38.9	-30.5	0.004	0.186
TM	11	10	13.08.69	B	27.2	47.2	0.429	0.805
TM	11	11	15.09.69	C	5.0	0.5	0.702	0.736
TM	11	12	21.08.73	B	-11.7	-31.0	0.874	0.914
EC	1	1	28.02.77	A	8.8	-1.9	0.772	0.824
EC	1	2	6.03.77	B	SUSPECT DATA			
EC	1	3	7.05.77	B	-21.3	9.8	0.725	0.761
EC	1	4	19.04.78	A	-12.8	-13.6	0.827	0.845
EC	1	5	21.04.78	A	6.7	11.9	0.303	0.637
EC	1	6	20.07.79	A	3.2	-2.0	0.972	0.974
EC	1	7	23.07.79	A	-1.6	-3.8	0.902	0.911
EC	1	8	19.08.79	A	3.2	4.9	0.856	0.869
EC	1	9	26.03.81	A	5.9	-2.7	0.941	0.956
EC	1	10	22.10.81	B	1.1	44.3	-0.142	0.519
EC	1	11	23.12.81	A	SUSPECT DATA			
EC	1	12	2.11.85	A	-8.4	-18.3	0.923	0.946
EC	1	13	25.11.85	B	-15.4	3.1	0.534	0.597

EC	1	14	1.12.85	B	7.7	-19.3	0.583	0.612
EC	2	1	28.02.77	A	23.0	-40.2	0.313	0.438
EC	2	2	6.03.77	B	16.6	-24.2	0.778	0.794
EC	2	3	7.05.77	B	5.8	-1.3	0.557	0.673
EC	2	5	21.04.78	A	-1.6	3.9	0.300	0.506
EC	2	6	20.07.79	A	-0.6	-9.6	0.981	0.981
EC	2	7	23.07.79	A	-1.1	13.7	0.955	0.980
EC	2	8	19.08.79	A	5.2	13.9	0.858	0.864
EC	2	9	26.03.81	A	2.3	-19.1	0.157	0.395
EC	2	11	23.12.81	A	-26.9	18.5	-0.656	0.039
EC	2	12	2.11.85	A	-1.7	-4.7	0.948	0.949
EC	2	14	1.12.85	B	-13.9	9.7	0.354	0.790
EC	3	1	20.07.79	A	25.9	3.9	0.847	0.934
EC	3	2	23.07.79	A	-2.8	-11.4	0.945	0.947
EC	3	3	19.08.79	A	-7.2	10.5	0.859	0.919
EC	3	4	2.11.85	A	4.2	4.4	0.793	0.833
BETH		1	01.11.80	C	-56.8	-63.5	-0.673	0.028
BETH		2	15.12.80	B	20.4	26.7	0.533	0.860
BETH		5	05.02.81	B	-55.9	-77.1	-0.740	0.239
BETH		6	10.02.81	B	-14.9	-30.3	0.885	0.946
BETH		7	14.02.81	B	7.3	-24.5	0.844	0.852
BETH		8	17.02.81	B	-11.2	-25.3	0.828	0.855
BETH		9	27.02.81	C	20.5	-21.0	0.272	0.400
BETH		10	22.03.81	C	-22.0	-0.6	0.267	0.445
HOEK		1	2.03.79	A	-8.1	6.3	0.798	0.871
HOEK		2	4.05.79	B	15.9	-17.4	-0.306	0.078
HOEK		3	16.02.80	A	-30.1	47.0	-0.017	0.305
HOEK		4	17.02.80	B	-9.5	-16.8	0.908	0.922
HOEK		5	17.12.80	B	-6.9	3.6	0.600	0.683
HOEK		6	8.01.81	B	8.2	-28.6	0.040	0.159
HOEK		7	1.02.81	A	-2.4	-28.5	0.941	0.941
HOEK		8	19.02.81	B	-5.9	19.2	0.693	0.769
HOEK		9	21.02.81	B	-9.1	-0.1	0.837	0.852
HOEK		10	24.02.81	B	5.7	13.2	0.255	0.506
HOEK		11	21.03.82	A	-9.7	0.7	0.689	0.737
HOEK		12	8.04.82	B	35.8	-5.0	-2.215	0.027
HOEK		13	26.11.83	B	-25.7	-6.3	0.456	0.533
HOEK		14	28.11.83	B	18.8	16.2	0.876	0.892
HOEK		15	17.12.83	B	53.9	-31.4	0.198	0.503
HOEK		16	24.12.83	B	5.2	1.5	0.888	0.908
CED		1	11.11.78	A	19.2	6.0	0.857	0.886
CED		2	9.12.78	A	6.2	45.8	0.196	0.628
CED		3	28.12.78	A	-6.6	-36.3	0.855	0.897
CED		4	2.01.79	A	0.7	1.8	0.407	0.529
CED		5	25.02.79	A	9.2	-21.2	0.892	0.900
CED		6	2.12.84	A	17.1	126.1	-0.499	0.564
CED		7	9.02.85	A	13.2	0.8	0.596	0.618
CED		8	24.02.85	C	-26.3	47.6	0.714	0.886
CED		9	11.03.85	A	-18.6	14.9	0.101	0.339
CED		10	14.03.86	C	11.6	38.6	0.481	0.787
ZL	15	1	29.01.77	B	75.8	86.5	-0.968	0.770
ZL	15	2	6.02.77	B	13.9	-29.1	0.402	0.463
ZL	15	3	14.02.77	B	11.9	-38.7	0.662	0.679
ZL	15	4	14.03.77	B	6.7	-1.0	0.909	0.918
ZL	15	5	9.10.77	A	32.6	24.7	0.584	0.944
ZL	15	6	9.11.77	B	-1.2	-20.0	0.952	0.965
ZL	15	7	19.12.77	B	86.1	35.9	-0.174	0.880

ZL	15	8	19.01.78	C	39.6	-5.8	0.641	0.916
ZL	15	9	21.01.78	A	17.4	-16.3	0.900	0.912
ZL	15	10	21.02.78	B	-1.7	-10.1	0.946	0.946
ZL	15	11	1.03.78	A	-3.7	5.5	0.839	0.923
ZL	15	12	9.03.78	B	-3.5	-9.6	0.898	0.922
ZL	15	13	27.03.78	B	11.0	10.9	0.816	0.880
ZL	15	14	8.09.78	A	15.9	28.8	0.885	0.968
ZL	15	15	18.10.78	A	-25.5	-52.9	0.630	0.638
ZL	16	1	29.01.77	A	76.8	97.5	-2.077	0.869
ZL	16	2	6.02.77	A	-17.9	-61.9	0.342	0.379
ZL	16	3	14.02.77	A	24.1	1.4	0.562	0.781
ZL	16	4	14.03.77	A	-2.4	4.5	0.930	0.936
ZL	16	5	9.10.77	A	-5.7	10.1	0.890	0.901
ZL	16	6	9.11.77	A	1.8	58.7	0.559	0.758
ZL	16	7	19.12.77	A	15.0	16.0	0.700	0.800
ZL	16	8	19.01.78	A	7.7	-2.5	0.920	0.950
ZL	16	9	21.01.78	A	18.3	-5.2	0.776	0.819
ZL	16	10	21.02.78	A	-27.0	-15.4	0.833	0.966
ZL	16	11	1.03.78	A	-12.2	22.7	0.828	0.891
ZL	16	12	9.03.78	A	-10.2	-6.1	0.826	0.876
ZL	16	13	27.03.78	A	5.0	-40.0	0.650	0.670
ZL	16	14	8.09.78	A	-17.9	-15.6	0.881	0.985
ZL	16	15	18.10.78	A	-20.0	-25.4	0.615	0.720
OX	4	1	3.04.58	A	-18.8	-9.6	0.858	0.884
OX	4	2	17.01.60	A	8.8	-11.5	0.932	0.936
OX	4	3	31.08.61	A	10.7	0.3	0.913	0.918
OX	4	4	4.09.62	A	1.2	-37.2	0.779	0.793
OX	4	5	29.08.63	A	18.0	42.0	0.851	0.909
OX	5	1	3.04.58	A	-17.1	2.6	0.847	0.881
OX	5	2	17.01.60	A	-7.1	0.2	0.950	0.957
OX	5	3	31.08.61	A	-43.5	-53.3	0.469	0.702
OX	5	4	4.09.62	A	6.6	-28.7	0.648	0.653
OX	5	5	29.08.63	A	-3.2	6.0	0.697	0.700
OX	5	6	4.03.64	A	2.0	7.9	0.744	0.754
OX	5	7	1.03.65	A	20.5	3.5	0.805	0.856
OX	5	8	24.05.66	A	28.4	9.9	0.679	0.799
OX	5	9	31.05.67	A	-13.9	3.8	0.698	0.729
OX	10	1	22.05.59	B	68.3	106.6	-3.010	0.076
OX	10	2	17.01.60	A	1.2	-2.8	0.791	0.877
OX	10	3	31.08.61	B	-21.6	4.8	0.885	0.914
OX	10	4	4.09.62	A	-12.0	-32.0	0.864	0.976
OX	10	5	29.08.63	A	-13.9	-39.0	0.744	0.864
OX	10	6	4.03.64	A	2.6	11.2	0.962	0.975
OX	10	7	1.03.65	A	40.7	72.0	-0.725	0.601
OX	10	8	27.12.66	C	68.7	62.1	-0.525	0.632
OX	10	9	31.05.67	A	7.7	15.0	0.820	0.863
OX	10	10	1.02.68	A	-2.2	21.8	0.667	0.740
OX	10	11	17.04.69	A	28.1	51.1	0.777	0.914
OX	10	12	26.08.71	C	11.3	7.1	0.842	0.848
OX	12	1	2.03.60	A	-48.9	-52.3	0.250	0.836
OX	12	2	31.08.61	B	-26.2	-21.8	0.833	0.903
OX	12	3	4.09.62	B	4.4	-22.4	0.938	0.953
OX	12	4	29.08.63	A	18.2	12.7	0.792	0.821
OX	12	5	4.03.64	A	-24.1	10.9	0.890	0.923
OX	12	6	1.03.65	A	-31.6	-22.2	0.785	0.919
OX	12	7	24.05.66	A	-42.6	-44.8	0.668	0.965
OX	12	8	31.05.67	A	-5.2	15.0	0.933	0.945

OX	12	9	1.02.68	A	-12.2	-13.7	0.803	0.816
OX	12	10	17.04.69	A	-10.6	26.1	0.859	0.894
OX	12	11	21.02.71	C	-25.0	36.4	0.638	0.692
OX	17	1	2.03.60	A	-56.7	-49.4	0.149	0.896
OX	17	2	31.08.61	B	-55.8	-49.4	0.492	0.887
OX	17	3	4.09.62	B	-25.8	-35.6	0.804	0.967
OX	17	4	29.08.63	A	7.4	20.7	0.837	0.843
OX	17	5	4.03.64	A	-23.6	24.2	0.593	0.642
OX	17	6	1.03.65	A	-19.7	-23.4	0.790	0.844
OX	17	7	24.05.66	A	-52.9	-45.6	0.451	0.822
OX	17	8	31.05.67	A	-20.3	3.7	0.874	0.893
OX	17	9	1.02.68	A	-40.5	-21.9	0.715	0.867
OX	17	10	17.04.69	A	-13.2	49.8	0.760	0.837
OX	17	11	21.02.71	C	-32.6	42.4	0.436	0.532
OX	17	12	2.07.72	C	-12.5	110.2	0.321	0.473
OX	17	13	19.04.73	C	-21.3	108.1	0.292	0.579
OX	24	1	17.01.60	A	-48.3	-41.7	0.413	0.561
OX	24	2	31.08.61	A	208.3	41.9	-3.000	0.348
OX	24	4	29.08.63	A	13.8	-29.9	0.629	0.660
OX	24	5	4.03.64	A	-0.3	1.7	0.908	0.909
OX	24	6	1.03.65	A	-10.9	-25.2	0.673	0.685
OX	24	7	24.05.66	A	16.8	3.1	0.665	0.805
OX	24	8	31.05.67	A	-33.4	-45.2	0.756	0.915
OX	28	1	17.01.60	A	-15.7	-59.7	0.640	0.764
OX	28	2	4.09.62	A	-12.8	-39.4	0.545	0.579
OX	28	3	29.08.63	A	37.6	4.5	0.611	0.815
OX	28	4	4.03.64	A	-1.0	-1.6	0.850	0.850
OX	28	5	1.03.65	A	32.1	0.4	0.874	0.958
OX	28	6	24.05.66	A	37.8	25.6	0.527	0.828
OX	28	7	31.05.67	A	-5.6	7.3	-0.416	0.492
OX	32	1	22.05.59	B	30.1	52.5	0.191	0.630
OX	32	2	2.03.60	A	-33.9	-16.5	-0.012	0.483
OX	32	3	31.08.61	B	-34.1	-32.5	0.414	0.456
OX	32	4	4.09.62	A	-1.1	-20.7	0.712	0.721
OX	32	5	29.08.63	A	-23.2	-45.8	0.473	0.514
OX	32	6	4.03.64	A	-6.5	-3.2	0.990	0.992
OX	32	7	1.03.65	A	3.5	-20.2	0.845	0.848
OX	32	8	24.05.66	A	-16.5	-4.5	0.715	0.726
OX	32	9	31.05.67	A	-16.3	16.8	0.804	0.844
OX	32	10	1.02.68	A	18.1	27.5	0.767	0.841
OX	32	11	17.04.69	A	-22.2	30.6	0.865	0.889
OX	32	12	18.06.71	C	58.2	132.9	0.775	0.828
OX	32	13	25.06.72	C	9.8	33.0	0.850	0.936
OX	32	14	19.04.73	C	-7.0	51.8	0.772	0.852
OX	35	1	22.05.59	B	5.4	85.0	0.159	0.577
OX	35	2	2.03.60	A	-8.2	46.6	0.411	0.768
OX	35	3	31.08.61	B	67.1	64.6	-0.886	0.299
OX	35	4	4.09.62	A	0.5	-13.5	0.089	0.290
OX	35	5	29.08.63	A	88.2	70.5	-2.102	0.057
OX	35	6	4.03.64	A	-40.8	-29.6	0.713	0.897
OX	35	7	1.03.65	A	-26.9	-21.5	0.674	0.734
OX	35	8	24.05.66	A	-2.4	13.0	0.902	0.905
OX	35	9	31.05.67	A	-18.6	13.4	0.826	0.843
OX	35	10	1.02.68	A	-18.5	-13.2	0.746	0.772
OX	35	11	17.04.69	A	-12.9	78.8	0.641	0.757
OX	35	12	26.08.71	C	-33.3	-43.7	0.686	0.854
KAAI		1	25.03.81	C	-25.8	1.5	0.832	0.885

KAAI	2	26.04.81	C	12.9	26.4	0.720	0.881
KAAI	3	5.05.81	C	-1.6	43.1	-1.219	0.114
KAAI	4	28.05.81	C	-20.0	-25.8	0.858	0.904
KAAI	6	24.08.81	C	-20.5	-8.4	0.753	0.813
KAAI	7	27.08.81	C	-14.2	15.3	0.165	0.472
KAAI	8	30.08.81	C	-17.2	-15.9	-0.031	0.375
KAAI	9	18.02.82	C	-4.4	0.6	0.077	0.375
KAAI	10	3.03.82	C	-7.5	23.2	0.070	0.430
KAAI	11	12.09.82	C	34.9	153.5	-1.491	0.262
KAAI	12	12.06.83	C	-26.0	-21.3	0.764	0.886
KAAI	13	2.10.83	C	-29.2	-41.4	0.759	0.905
KAAI	14	28.10.85	C	1.7	19.6	0.556	0.703
KAAI	15	2.11.85	B	-1.9	7.8	-2.277	0.008
KAAI	16	8.11.85	B	-25.6	25.3	-0.497	0.260
KAAI	17	2.12.85	B	-16.7	-11.9	0.551	0.638
MALGAS	1	25.03.81	C	-9.2	0.1	0.809	0.818
MALGAS	2	26.04.81	C	34.8	68.1	0.371	0.875
MALGAS	3	5.05.81	C	-17.0	17.1	0.567	0.819
MALGAS	4	28.05.81	C	-12.0	-13.4	0.922	0.946
MALGAS	6	24.08.81	C	30.6	91.4	-3.167	0.045
MALGAS	7	27.08.81	C	6.7	46.9	0.189	0.645
MALGAS	8	30.08.81	C	-10.4	-7.9	0.729	0.810
MALGAS	9	15.10.81	C	-11.9	3.2	0.792	0.867
MALGAS	10	15.01.82	C	96.1	134.3	-4.596	0.277
MALGAS	11	18.02.82	C	-9.9	-18.2	0.825	0.833
MALGAS	12	3.03.82	C	-26.5	-8.7	0.881	0.969
MALGAS	13	1.09.82	C	-48.2	-40.1	-0.071	0.629
MALGAS	14	11.06.83	C	-8.3	-21.1	0.622	0.661
MALGAS	15	22.09.83	C	-33.2	-14.8	0.497	0.753
MALGAS	16	15.10.85	B	-19.7	-17.2	0.881	0.915
MALGAS	17	21.01.86	B	33.5	9.4	0.500	0.699
ND 1	1	24.10.59	A	-1.0	9.5	0.990	0.991
ND 1	2	30.07.60	A	35.9	17.3	0.790	0.970
ND 1	4	31.07.62	B	-11.8	-17.4	0.903	0.953
ND 1	6	22.07.64	B	SUSPECT DATA			
ND 1	7	7.06.65	C	-25.3	-33.2	0.773	0.978
ND 1	8	19.10.66	C	-26.4	-26.3	0.667	0.980
ND 1	9	16.07.67	C	8.7	8.6	0.661	0.772
ND 1	10	11.09.68	C	10.2	-4.4	0.959	0.972
ND 1	12	23.08.71	C	62.2	59.5	-0.786	0.981
ND 1	13	3.07.72	C	10.0	16.4	0.510	0.637
ND 1	14	10.07.72	C	4.0	-3.0	0.941	0.945
ND 1	15	17.09.73	A	4.4	-10.9	0.961	0.967
ND 3	1	30.07.65	A	23.9	11.2	0.495	0.619
ND 3	3	31.07.62	B	9.0	-4.9	0.934	0.953
ND 3	7	19.10.66	C	6.3	2.6	0.678	0.723
ND 3	9	11.09.68	C	3.7	-28.1	0.903	0.933
ND 3	11	23.08.71	C	28.7	16.6	0.726	0.973
ND 3	12	10.07.72	C	-5.4	-42.9	0.696	0.729
ND 3	13	17.09.73	A	6.0	-31.7	0.864	0.886
ND 4	1	7.06.65	C	7.0	16.7	0.749	0.820
ND 4	2	19.10.66	C	-13.7	-9.3	0.894	0.987
ND 4	3	16.07.67	C	14.1	-19.9	0.384	0.486
ND 4	4	11.09.68	C	-8.3	-16.1	0.937	0.968
ND 4	6	23.08.71	C	45.3	36.6	0.007	0.959
ND 4	7	10.07.72	C	6.5	2.8	0.843	0.854
ND 4	8	14.07.73	C	-2.1	-5.2	0.961	0.968

ND	4	9	17.09.73	C	-12.6	-29.2	0.841	0.936
ND	5	1	30.07.60	A	34.0	22.3	0.757	0.919
ND	5	3	31.07.62	B	1.0	19.1	0.957	0.957
ND	5	6	7.06.65	C	-1.5	-2.9	0.918	0.920
ND	5	7	19.10.66	C	-21.5	-19.9	0.789	0.989
ND	5	8	16.07.67	C	2.8	-4.9	0.874	0.877
ND	5	9	11.09.68	C	12.6	10.3	0.934	0.974
ND	5	11	23.08.71	C	34.9	41.8	0.280	0.954
ND	5	12	10.07.72	C	-21.2	-19.0	0.795	0.909
ND	5	13	20.07.72	C	-32.6	-33.7	0.700	0.974
ND	5	14	14.07.73	C	-24.8	-28.2	0.732	0.985
ND	5	15	17.09.73	A	-8.3	-21.3	0.921	0.961

MODEL OSE2 Semi-distributed calibration and validation results

Catch name		Storm No.	Storm date	Storm type	Calibration % Error Vol.	Calibration % Error Peak	Calibration Coefficient Eff.	Calibration Coefficient Det.	Validation % Error Vol.	Validation % Error Peak	Validation Coefficient Eff.	Validation Coefficient Det.
TM	1	1	26.07.59	B	5.0	2.0	0.427	0.557	-16.3	-28.8	0.588	0.604
TM	1	2	4.09.65	C	159.9	37.2	-2.546	0.578	173.7	32.5	-3.203	0.440
TM	2	1	26.07.59	B	17.5	19.9	0.826	0.899	-5.8	-11.5	0.818	0.820
TM	2	2	17.08.61	C	-42.6	-25.8	0.737	0.869	-40.3	-25.5	0.780	0.900
TM	2	3	4.09.65	B	-20.9	-36.3	0.832	0.895	-24.0	-43.1	0.772	0.878
TM	2	4	25.08.68	C	236.9	54.7	-2.092	0.602	662.6	331.0	-27.340	0.690
TM	2	5	31.08.68	C	-6.8	-40.7	0.332	0.413	-5.0	-41.6	0.405	0.410
TM	3	1	19.07.55	C	-26.3	-52.4	0.727	0.842	-4.3	-50.3	0.690	0.735
TM	3	2	14.08.58	B	12.9	-15.5	0.793	0.817	16.2	-20.4	0.817	0.832
TM	3	3	16.08.58	C	86.2	17.1	-0.290	0.607	134.6	10.2	-0.621	0.515
TM	3	4	17.08.61	B	-37.7	-0.6	0.854	0.915	8.2	51.3	0.826	0.948
TM	3	5	25.07.62	C	69.4	-27.2	-0.171	0.210	169.8	-16.6	-0.625	0.378
TM	3	7	25.08.68	C	185.8	39.6	-0.865	0.538	215.8	34.0	-1.064	0.589
TM	3	8	31.08.68	C	220.3	38.6	-1.732	0.584	246.3	37.9	-2.264	0.555
TM	3	11	27.07.73	C	129.2	71.6	-1.555	0.604	119.6	51.6	-0.943	0.666
TM	6	1	4.09.65	B	0.9	-23.8	0.786	0.786	14.7	-16.5	0.832	0.846
TM	6	2	31.08.68	B	88.7	25.1	-0.579	0.387	59.9	-6.0	-0.047	0.387
TM	8	1	19.08.63	C	-7.1	-30.1	0.651	0.663	-30.8	-60.3	0.544	0.834
TM	8	2	22.07.64	C	104.6	3.1	0.322	0.782	81.4	-29.6	0.572	0.713
TM	8	3	9.09.64	C	-54.4	-81.8	0.100	0.372	-50.5	-84.1	-0.059	0.020
TM	8	5	11.09.64	C	61.4	-66.5	0.295	0.342	169.3	-51.5	-0.586	0.076
TM	8	6	17.07.65	C	57.7	-27.8	0.376	0.528	85.6	-30.6	0.265	0.532
TM	8	7	4.09.65	B	34.7	-16.5	0.718	0.810	61.6	-27.6	0.483	0.670
TM	8	8	30.07.66	C	17.8	-11.7	-0.511	0.077	58.3	-24.1	0.211	0.435
TM	8	10	31.08.68	C	109.4	-5.2	-0.461	0.651	61.8	-36.6	0.222	0.537
TM	8	11	24.07.72	C	131.4	38.2	-1.897	0.141	181.0	7.7	-1.168	0.430
TM	11	1	19.08.63	C	-21.2	-34.7	0.602	0.653	-15.7	-47.2	0.662	0.805
TM	11	2	22.07.64	B	-8.8	-11.8	0.958	0.976	-5.0	-33.8	0.889	0.947
TM	11	3	9.09.64	C	-52.5	-15.3	0.493	0.638	-21.5	-30.3	0.535	0.563
TM	11	4	11.09.64	B	-17.7	-26.9	0.632	0.664	52.3	6.0	0.340	0.565
TM	11	5	17.07.65	C	55.3	-8.1	0.049	0.351	72.4	-45.1	0.399	0.523
TM	11	6	4.09.65	B	1.5	-10.7	0.892	0.896	23.8	-34.3	0.723	0.752
TM	11	7	30.07.66	C	77.9	40.8	-0.840	0.815	179.8	60.8	-0.343	0.459
TM	11	9	31.08.68	C	34.0	-57.6	0.060	0.122	5.4	-73.6	-0.144	0.003
TM	11	10	13.08.69	B	78.8	101.5	-0.149	0.941	70.6	30.3	0.492	0.900
TM	11	11	15.09.69	C	50.0	51.0	0.583	0.914	31.3	-23.9	0.797	0.869
TM	11	12	21.08.73	B	16.8	24.3	0.927	0.941	37.8	14.8	0.766	0.831
EC	1	1	28.02.77	A	1.3	-12.7	0.950	0.951	0.1	12.8	0.806	0.832
EC	1	2	6.03.77	B	-53.1	-59.8	0.243	0.772	-59.9	-46.5	0.213	0.790
EC	1	3	7.05.77	B	32.7	8.1	0.556	0.701	1.6	25.3	0.431	0.498
EC	1	4	19.04.78	A	SUSPECT DATA				NOT MODELLED			
EC	1	5	21.04.78	A	14.7	7.2	-0.103	0.575	17.9	21.8	-0.421	0.666
EC	1	6	20.07.79	A	-21.4	-27.8	0.864	0.943	-15.5	-18.9	0.904	0.937
EC	1	7	23.07.79	A	0.8	12.7	0.839	0.921	5.9	25.2	0.476	0.781
EC	1	8	19.08.79	A	-54.2	-64.51	0.175	0.951	-50.2	-56.9	0.268	0.923
EC	1	9	26.03.81	A	78.7	57.7	-0.870	0.786	114.2	79.1	-1.964	0.934
EC	1	10	22.10.81	B	-78.3	-71.4	-2.682	0.602	-79.3	-68.3	-2.756	0.572
EC	1	11	23.12.81	A	-89.6	-82.8	-0.367	0.003	-89.8	-79.1	-0.396	0.002
EC	1	12	2.11.85	A	-29.8	-31.2	0.612	0.960	-26.0	-14.3	0.664	0.859
EC	1	13	25.11.85	B	-42.9	-6.1	0.529	0.823	-45.6	18.1	0.474	0.803

EC	1	14	1.12.85	B	-82.2	-86.0	-1.349	0.360	-94.2	-94.9	-1.962	0.015
EC	3	1	20.07.79	A	14.8	-3.8	0.936	0.965	NOT MODELLED			
EC	3	2	23.07.79	A	-6.8	-6.5	0.953	0.971	NOT MODELLED			
EC	3	3	19.08.79	A	-9.7	10.1	0.857	0.887	NOT MODELLED			
EC	3	4	2.11.85	A	-9.8	-4.1	0.713	0.775	NOT MODELLED			
BETH		1	01.11.80	C	-16.9	5.1	0.701	0.759	-30.3	13.4	0.460	0.645
BETH		2	15.12.80	B	20.0	2.8	0.603	0.794	-7.1	-16.0	0.660	0.679
BETH		5	05.02.81	B	-20.7	-19.6	0.602	0.651	-43.5	-35.6	0.399	0.643
BETH		6	10.02.81	B	-6.2	-14.8	0.971	0.977	-36.3	-49.5	0.641	0.965
BETH		7	14.02.81	B	9.5	-9.8	0.881	0.915	-20.8	-29.7	0.820	0.865
BETH		8	17.02.81	B	-5.6	-5.3	0.843	0.850	-34.1	-45.4	0.635	0.853
BETH		9	27.02.81	C	-80.0	-88.6	0.381	0.850	NOT MODELLED			
BETH		10	22.03.81	C	-3.6	1.3	0.967	0.970	-26.1	-9.8	0.767	0.946
HOEK		1	2.03.79	A	-15.8	-2.7	0.837	0.909	-53.7	-37.9	0.570	0.905
HOEK		2	4.05.79	B	-19.6	-7.3	0.368	0.635	142.4	158.1	-13.986	0.416
HOEK		3	16.02.80	A	-51.6	9.4	-0.219	0.203	6.5	116.7	-1.844	0.239
HOEK		4	17.02.80	B	-12.2	13.6	0.942	0.951	-36.5	-35.1	0.839	0.946
HOEK		5	17.12.80	B	-13.8	-1.3	0.704	0.776	64.3	149.8	-2.706	0.727
HOEK		6	8.01.81	B	2.9	-24.5	0.468	0.477	-54.2	-74.1	0.005	0.545
HOEK		7	1.02.81	A	-7.5	-22.2	0.958	0.960	-36.5	-46.4	0.807	0.934
HOEK		8	19.02.81	B	-4.2	-15.6	0.824	0.833	-47.2	-56.0	0.459	0.707
HOEK		9	21.02.81	B	-12.6	-24.1	0.508	0.532	-36.5	-48.6	0.474	0.532
HOEK		10	24.02.81	B	3.7	-0.9	0.507	0.642	-35.1	-47.6	0.376	0.491
HOEK		11	21.03.82	A	-12.7	-5.1	0.565	0.664	30.0	80.0	-1.813	0.125
HOEK		12	8.04.82	B	-3.0	-49.7	-1.464	0.139	-12.1	-53.8	-1.312	0.143
HOEK		13	26.11.83	B	-2.3	39.6	0.134	0.506	63.3	106.4	-1.527	0.508
HOEK		14	28.11.83	B	33.3	5.6	0.768	0.851	73.1	51.7	0.374	0.954
HOEK		15	17.12.83	B	29.0	-30.6	0.614	0.706	73.5	1.8	-0.068	0.683
HOEK		16	24.12.83	B	-44.2	-7.8	0.367	0.462	-26.4	25.4	0.340	0.492
CED		1	11.11.78	A	47.8	8.2	0.613	0.841	52.3	5.0	0.687	0.925
CED		2	9.12.78	A	-5.9	23.3	0.664	0.837	-38.5	-23.4	0.126	0.857
CED		3	28.12.78	A	24.7	3.4	0.779	0.904	20.0	-1.8	0.875	0.959
CED		4	2.01.79	A	1.8	4.0	0.633	0.693	-21.5	-30.0	0.774	0.903
CED		5	25.02.79	A	15.9	-35.3	0.729	0.749	2.0	-56.7	0.558	0.600
CED		6	2.12.84	A	13.2	24.7	0.646	0.773	23.7	23.9	0.768	0.923
CED		7	9.02.85	A	10.6	-11.2	0.610	0.624	29.6	19.4	0.804	0.950
CED		8	24.02.85	C	-28.9	-65.7	0.528	0.754	-43.2	-72.7	0.424	0.795
CED		9	11.03.85	A	-20.9	-32.1	0.532	0.586	-42.8	-57.2	0.392	0.767
CED		10	14.03.86	C	-12.9	-25.2	0.763	0.782	28.3	-7.3	0.795	0.899
ZL	15	1	29.01.77	B	66.5	52.0	-0.237	0.716	18.6	36.9	0.427	0.607
ZL	15	2	6.02.77	B	11.5	-26.5	0.445	0.478	-1.4	-26.8	0.404	0.416
ZL	15	3	14.02.77	B	13.7	-34.2	0.838	0.869	-3.5	-43.0	0.785	0.856
ZL	15	4	14.03.77	B	-5.8	-16.6	0.878	0.912	-35.7	-45.0	0.527	0.874
ZL	15	5	9.10.77	A	8.2	10.7	0.679	0.734	-17.7	-8.4	0.692	0.732
ZL	15	6	9.11.77	B	-3.3	0.7	0.962	0.967	3.5	42.0	0.742	0.940
ZL	15	7	19.12.77	B	58.8	48.2	0.146	0.952	45.3	57.2	0.087	0.954
ZL	15	8	19.01.78	C	33.6	5.1	0.796	0.933	3.8	26.4	0.737	0.837
ZL	15	9	21.01.78	A	14.3	-16.0	0.941	0.954	-8.6	-38.3	0.842	0.940
ZL	15	10	21.02.78	B	-20.0	-28.1	0.840	0.960	-44.5	-47.1	0.593	0.940
ZL	15	11	1.03.78	A	-18.6	17.1	0.425	0.693	-39.5	-3.7	-0.338	0.586
ZL	15	12	9.03.78	B	-14.7	-19.2	0.845	0.900	-39.5	-34.1	0.511	0.919
ZL	15	13	27.03.78	B	-18.0	-19.9	0.802	0.843	-38.3	-31.6	0.637	0.782
ZL	15	14	8.09.78	A	7.9	4.4	0.817	0.827	-20.4	-26.0	0.719	0.835
ZL	15	15	18.10.78	A	-29.1	-24.5	0.577	0.638	-44.6	-22.2	0.481	0.611
ZL	16	1	29.01.77	A	73.0	88.2	-1.644	0.907	NOT MODELLED			
ZL	16	2	6.02.77	A	-18.3	-62.6	0.345	0.384	NOT MODELLED			
ZL	16	3	14.02.77	A	22.9	0.7	0.543	0.755	NOT MODELLED			

ZL	16	4	14.03.77	A	-6.8	1.3	0.929	0.950	NOT MODELLED			
ZL	16	5	9.10.77	A	-9.5	0.7	0.951	0.970	NOT MODELLED			
ZL	16	6	9.11.77	A	0.4	27.6	0.692	0.780	NOT MODELLED			
ZL	16	7	19.12.77	A	13.7	10.8	0.731	0.803	NOT MODELLED			
ZL	16	8	19.01.78	A	6.1	-5.9	0.946	0.963	NOT MODELLED			
ZL	16	9	21.01.78	A	16.8	-6.5	0.734	0.778	NOT MODELLED			
ZL	16	10	21.02.78	A	-29.2	-18.7	0.786	0.936	NOT MODELLED			
ZL	16	11	1.03.78	A	-17.8	9.0	0.845	0.946	NOT MODELLED			
ZL	16	12	9.03.78	A	-12.2	-10.1	0.870	0.921	NOT MODELLED			
ZL	16	13	27.03.78	A	1.8	-38.4	0.704	0.706	NOT MODELLED			
ZL	16	14	8.09.78	A	-20.2	-21.1	0.875	0.991	NOT MODELLED			
ZL	16	15	18.10.78	A	-22.0	-24.4	0.618	0.707	NOT MODELLED			
OX	4	1	3.04.58	A	-17.6	-10.2	0.875	0.897	3.8	-15.0	0.938	0.943
OX	4	2	17.01.60	A	10.0	-7.6	0.896	0.901	32.7	10.2	0.897	0.967
OX	4	3	31.08.61	A	17.1	-27.1	0.788	0.811	7.1	-36.7	0.771	0.825
OX	4	4	4.09.62	A	11.1	-36.1	0.813	0.822	31.7	-35.4	0.812	0.855
OX	4	5	29.08.63	A	18.9	0.1	0.958	0.974	51.8	4.2	0.844	0.964
OX	10	1	22.05.59	B	112.8	103.4	-2.068	0.452	70.2	29.1	0.440	0.833
OX	10	2	17.01.60	A	-13.0	-14.4	0.897	0.906	-23.2	-35.5	0.819	0.931
OX	10	3	31.08.61	B	-17.1	-3.4	0.826	0.844	-20.4	-21.6	0.839	0.914
OX	10	4	4.09.62	A	2.0	-29.6	0.903	0.957	-14.6	-55.2	0.648	0.854
OX	10	5	29.08.63	A	-19.6	-49.8	0.701	0.894	-30.2	-65.8	0.371	0.613
OX	10	6	4.03.64	A	-4.3	-4.8	0.970	0.972	-11.5	-19.7	0.854	0.870
OX	10	7	1.03.65	A	23.5	45.2	-0.066	0.644	3.1	14.0	0.844	0.903
OX	10	8	27.12.66	C	57.7	47.3	-0.202	0.646	41.6	21.8	0.539	0.843
OX	10	9	31.05.67	A	2.1	-12.7	0.839	0.841	-27.7	-52.2	0.216	0.292
OX	10	10	1.02.68	A	-16.1	-1.8	0.725	0.754	-28.8	-27.1	0.837	0.975
OX	10	11	17.04.69	A	14.9	17.9	0.934	0.960	-6.1	-30.8	0.749	0.766
OX	10	12	26.08.71	C	7.2	-12.3	0.856	0.869	-5.8	-34.9	0.810	0.934
OX	12	1	2.03.60	A	-31.3	-33.4	0.344	0.529	-20.5	-20.4	0.336	0.466
OX	12	2	31.08.61	B	-1.1	-21.3	0.919	0.927	0.3	-23.7	0.876	0.899
OX	12	3	4.09.62	B	37.8	11.7	0.684	0.837	55.8	9.8	0.638	0.862
OX	12	4	29.08.63	A	24.1	-3.1	0.931	0.962	53.9	12.5	0.799	0.956
OX	12	5	4.03.64	A	-5.0	27.0	0.882	0.900	6.1	50.1	0.771	0.860
OX	12	6	1.03.65	A	-21.5	-18.6	0.902	0.966	-12.8	-8.2	0.941	0.960
OX	12	7	24.05.66	A	-38.1	-45.5	0.655	0.885	-23.7	-44.4	0.610	0.688
OX	12	8	31.05.67	A	7.5	-3.2	0.918	0.924	20.8	-5.7	0.761	0.785
OX	12	9	1.02.68	A	4.9	-9.4	0.954	0.957	29.0	16.7	0.897	0.966
OX	12	10	17.04.69	A	1.2	17.9	0.940	0.965	19.7	48.9	0.745	0.911
OX	12	11	21.02.71	C	-22.5	18.0	0.843	0.877	-18.2	27.9	0.837	0.858
OX	17	1	2.03.60	A	-29.3	-28.7	0.566	0.779	-26.4	-19.3	0.499	0.645
OX	17	2	31.08.61	B	-30.9	-48.6	0.703	0.942	-23.2	-36.7	0.727	0.909
OX	17	3	4.09.62	B	6.0	-15.2	0.849	0.863	20.7	-11.2	0.759	0.780
OX	17	4	29.08.63	A	15.0	-7.9	0.939	0.969	33.7	5.0	0.897	0.951
OX	17	5	4.03.64	A	-10.2	17.0	0.863	0.873	-7.2	28.5	0.841	0.862
OX	17	6	1.03.65	A	-12.1	-24.9	0.906	0.940	-11.7	-22.5	0.933	0.964
OX	17	7	24.05.66	A	-47.1	-50.7	0.479	0.802	-41.8	-52.0	0.412	0.618
OX	17	8	31.05.67	A	5.0	-12.6	0.894	0.895	13.1	-15.4	0.733	0.742
OX	17	9	1.02.68	A	-30.3	-30.2	0.842	0.973	-20.8	-15.2	0.888	0.943
OX	17	10	17.04.69	A	-1.1	19.7	0.967	0.988	4.1	38.6	0.901	0.948
OX	17	11	21.02.71	C	-27.7	9.4	0.706	0.766	-28.8	9.0	0.722	0.801
OX	17	12	2.07.72	C	-16.5	47.9	0.587	0.610	-17.3	79.4	0.581	0.656
OX	17	13	19.04.73	C	-15.9	87.5	0.514	0.696	-11.5	109.8	0.436	0.664
OX	32	1	22.05.59	B	65.4	41.8	0.278	0.838	23.5	2.4	0.729	0.781
OX	32	2	2.03.60	A	-34.9	-33.1	0.092	0.544	-70.3	-72.8	-2.011	0.010
OX	32	3	31.08.61	B	-0.8	3.5	0.982	0.986	-17.6	-30.8	0.827	0.879
OX	32	4	4.09.62	A	15.0	-23.1	0.840	0.849	-19.0	-59.8	0.505	0.592

OX	32	5	29.08.63	A	-13.4	-48.5	0.748	0.887	-45.8	-77.4	0.241	0.643
OX	32	6	4.03.64	A	-12.7	-16.5	0.959	0.985	-46.1	-55.1	0.488	0.725
OX	32	7	1.03.65	A	-9.4	-59.9	0.257	0.263	-62.8	-85.6	-0.039	0.301
OX	32	8	24.05.66	A	-21.2	-26.4	0.896	0.981	-56.7	-70.8	0.325	0.787
OX	32	9	31.05.67	A	7.2	-29.7	0.866	0.885	-48.0	-72.1	0.117	0.246
OX	32	10	1.02.68	A	-3.1	-19.7	0.724	0.726	-60.0	-73.9	0.275	0.862
OX	32	11	17.04.69	A	-30.9	-19.9	0.883	0.947	-64.4	-68.7	0.395	0.881
OX	32	12	18.06.71	C	48.6	39.9	0.733	0.976	-16.6	-45.6	0.731	0.873
OX	32	13	25.06.72	C	1.9	1.7	0.979	0.983	-40.3	-51.9	0.488	0.688
OX	32	14	19.04.73	C	-10.7	8.3	0.972	0.979	-32.9	-32.6	0.739	0.856
OX	35	1	22.05.59	B	37.6	71.1	0.384	0.809	13.6	40.2	0.802	0.878
OX	35	2	2.03.60	A	-14.2	-3.0	0.741	0.823	-35.5	-38.2	0.135	0.473
OX	35	3	31.08.61	B	107.1	37.5	-0.706	0.481	53.1	-8.2	0.554	0.712
OX	35	4	4.09.62	A	36.3	20.4	0.425	0.742	8.8	-23.7	0.525	0.553
OX	35	5	29.08.63	A	86.6	21.7	-0.827	0.233	25.2	-32.9	0.427	0.471
OX	35	6	4.03.64	A	-42.8	-38.8	0.718	0.955	-56.2	-56.8	0.467	0.972
OX	35	7	1.03.65	A	-36.2	-35.8	0.686	0.809	-58.1	-63.9	0.340	0.908
OX	35	8	24.05.66	A	-9.2	-18.8	0.894	0.944	-47.7	-61.1	0.440	0.872
OX	35	9	31.05.67	A	-20.5	-11.1	0.820	0.861	-58.2	-63.9	0.231	0.619
OX	35	10	1.02.68	A	-30.2	30.6	0.727	0.845	-56.9	-66.7	0.354	0.968
OX	35	11	17.04.69	A	-18.2	33.6	0.824	0.853	-39.3	-21.6	0.804	0.949
OX	35	12	26.08.71	C	-33.5	-50.9	0.673	0.890	-46.2	-68.6	0.452	0.907
KAAI		1	25.03.81	C	-22.7	-4.7	0.765	0.803	-33.5	-3.5	0.717	0.799
KAAI		2	26.04.81	C	16.0	24.9	0.759	0.903	3.0	26.0	0.798	0.899
KAAI		3	5.05.81	C	-0.7	40.6	-0.187	0.432	6.5	72.6	-0.981	0.267
KAAI		4	28.05.81	C	-18.0	-29.2	0.819	0.853	-22.5	-30.0	0.811	0.870
KAAI		6	24.08.81	C	-12.2	-0.4	0.714	0.775	-32.1	-6.4	0.606	0.749
KAAI		7	27.08.81	C	-10.0	1.8	0.450	0.628	-27.1	-0.9	0.399	0.624
KAAI		8	30.08.81	C	-15.9	-21.1	0.285	0.534	-22.9	-19.2	0.103	0.456
KAAI		9	18.02.82	C	8.1	7.2	0.517	0.731	-21.8	-3.2	0.503	0.695
KAAI		10	3.03.82	C	0.1	26.0	0.515	0.730	20.0	20.2	0.413	0.632
KAAI		11	12.09.82	C	41.9	143.8	-1.467	0.316	105.3	105.3	-0.330	0.312
KAAI		12	12.06.83	C	-19.8	-21.1	0.811	0.891	-33.3	-33.3	0.580	0.886
KAAI		13	2.10.83	C	-25.5	-47.0	0.735	0.837	-28.3	-28.3	-0.196	0.093
KAAI		14	28.10.85	C	5.5	17.6	0.878	0.923	-50.2	-50.2	0.590	0.824
KAAI		15	2.11.85	B	0.4	5.9	-1.231	-0.066	16.2	16.2	0.906	0.931
KAAI		16	8.11.85	B	-21.4	12.4	0.541	0.770	-0.5	-0.5	-1.816	0.015
KAAI		17	2.12.85	B	-7.2	8.8	0.838	0.906	16.4	16.4	0.244	0.682
MALGAS		1	25.03.81	C	-9.5	-2.0	0.713	0.729	-24.4	-3.8	0.679	0.734
MALGAS		2	26.04.81	C	36.3	68.3	0.428	0.923	17.9	64.9	0.607	0.891
MALGAS		3	5.05.81	C	-17.5	15.2	0.472	0.765	-0.1	36.2	0.546	0.817
MALGAS		4	28.05.81	C	-11.7	-15.7	0.909	0.930	-19.0	-20.5	0.864	0.928
MALGAS		6	24.08.81	C	32.6	98.2	-3.110	0.076	1.2	81.7	-2.395	0.024
MALGAS		7	27.08.81	C	5.6	36.5	0.309	0.681	-13.8	33.9	0.383	0.640
MALGAS		8	30.08.81	C	-9.7	-5.3	0.771	0.856	-15.5	-9.3	0.672	0.775
MALGAS		9	15.10.81	C	-10.9	1.6	0.774	0.855	-36.0	-18.3	0.625	0.862
MALGAS		10	15.01.82	C	111.3	156.0	-5.375	0.456	44.5	109.4	-0.383	0.349
MALGAS		11	18.02.82	C	-9.4	-18.0	0.893	0.900	-31.6	-25.0	0.440	0.912
MALGAS		12	3.03.82	C	-26.6	-8.5	0.889	0.979	-43.4	-10.2	0.326	0.939
MALGAS		13	1.09.82	C	-43.8	-31.3	0.153	0.733	-67.2	-51.4	-1.572	0.623
MALGAS		14	11.06.83	C	-6.8	-22.3	0.644	0.682	-35.5	-37.8	0.254	0.587
MALGAS		15	22.09.83	C	-30.5	-21.4	0.600	0.822	-52.2	-34.3	0.030	0.729
MALGAS		16	15.10.85	B	-19.3	-16.2	0.921	0.955	-37.1	-24.8	0.495	0.958
MALGAS		17	21.01.86	B	45.8	17.9	0.356	0.747	1.5	-14.4	0.480	0.632
ND	1	1	24.10.59	A	-2.2	3.7	0.983	0.985	NOT MODELLED			
ND	1	2	30.07.60	A	46.9	20.8	0.651	0.975	NOT MODELLED			
ND	1	4	31.07.62	B	-10.2	-20.9	0.913	0.963	NOT MODELLED			

ND	1	6	22.07.64	B	52.2	43.6	-1.218	0.787	NOT MODELLED			
ND	1	7	7.06.65	C	-25.6	-38.4	0.731	0.943	NOT MODELLED			
ND	1	8	19.10.66	C	-25.2	-25.7	0.682	0.987	NOT MODELLED			
ND	1	9	16.07.67	C	2.5	0.7	0.933	0.942	NOT MODELLED			
ND	1	10	11.09.68	C	13.6	-4.0	0.955	0.978	NOT MODELLED			
ND	1	12	23.08.71	C	83.8	72.9	-2.002	0.992	NOT MODELLED			
ND	1	13	3.07.72	C	12.3	9.9	0.444	0.579	NOT MODELLED			
ND	1	14	10.07.72	C	-1.2	-10.0	0.959	0.961	NOT MODELLED			
ND	1	15	17.09.73	A	2.9	-12.0	0.906	0.973	NOT MODELLED			
ND	4	1	7.06.65	C	11.4	24.9	0.582	0.713	NOT MODELLED			
ND	4	2	19.10.66	C	-6.8	-4.4	0.952	0.965	NOT MODELLED			
ND	4	3	16.07.67	C	29.1	-5.5	0.686	0.740	NOT MODELLED			
ND	4	4	11.09.68	C	1.9	-5.9	0.981	0.983	NOT MODELLED			
ND	4	6	23.08.71	C	57.7	44.6	-0.429	0.335	NOT MODELLED			
ND	4	7	10.07.72	C	-25.9	-31.6	0.735	0.850	NOT MODELLED			
ND	4	8	14.07.73	C	-5.9	-12.3	0.934	0.958	NOT MODELLED			
ND	4	9	17.09.73	C	19.8	-32.9	0.786	0.909	NOT MODELLED			
ND	5	1	30.07.60	A	34.2	13.7	0.816	0.971	-28.8	-41.1	0.704	0.954
ND	5	3	31.07.62	B	-4.9	-1.2	0.937	0.946	-50.3	-53.5	0.291	0.953
ND	5	6	7.06.65	C	-1.9	-7.8	0.957	0.959	-34.2	-37.4	0.218	0.517
ND	5	7	19.10.66	C	20.0	-18.9	0.810	0.986	-56.2	-56.5	-0.537	0.941
ND	5	8	16.07.67	C	0.4	-11.0	0.944	0.947	-51.6	-54.1	0.057	0.962
ND	5	9	11.09.68	C	1.6	1.6	0.964	0.979	-37.7	-42.2	0.607	0.977
ND	5	11	23.08.71	C	44.6	51.1	0.040	0.990	-32.5	-31.5	0.619	0.963
ND	5	12	10.07.72	C	-23.0	-28.6	0.813	0.976	-58.0	-54.8	0.040	0.967
ND	5	13	20.07.72	C	-21.0	-23.6	0.838	0.937	-55.2	-53.0	0.255	0.920
ND	5	14	14.07.73	C	-22.9	-30.1	0.691	0.920	-70.2	-73.9	-1.061	0.679
ND	5	15	17.09.73	A	-13.2	-26.9	0.885	0.958	-56.5	-64.1	0.161	0.935

MODEL OSE3 Lumped calibration results

Catch name		Storm No.	Storm date	Storm type	Calibration % Error Vol.	Peak	Coefficient Eff.	Det.
TM	1	1	26.07.59	B	-1.2	-3.3	0.550	0.675
TM	1	2	4.09.65	C	6.5	-14.1	0.740	0.830
TM	2	1	26.07.59	B	0.8	1.7	0.850	0.886
TM	2	2	17.08.61	C	-0.3	4.7	0.550	0.710
TM	2	3	4.09.65	B	-0.8	14.0	0.749	0.880
TM	2	4	25.08.68	C	-2.7	-53.2	0.670	0.710
TM	2	5	31.08.68	C	-1.9	7.0	0.627	0.740
TM	3	1	19.07.55	C	4.1	-26.9	0.883	0.885
TM	3	2	14.08.58	B	0.1	-5.7	0.855	0.886
TM	3	3	16.08.58	C	3.2	-19.2	0.786	0.830
TM	3	4	17.08.61	B	-4.4	85.2	0.390	0.840
TM	3	5	25.07.62	C	3.7	-17.0	0.920	0.940
TM	3	7	25.08.68	C	23.2	-23.1	0.778	0.793
TM	3	8	31.08.68	C	10.8	-9.5	0.841	0.847
TM	3	11	27.07.73	C	2.2	-8.6	0.925	0.928
TM	6	1	4.09.65	B	-2.1	1.3	0.936	0.952
TM	6	2	31.08.68	B	-1.5	-7.1	0.737	0.780
TM	8	1	19.08.63	C	-7.2	25.6	0.704	0.862
TM	8	2	22.07.64	C	0.1	-46.2	0.803	0.812
TM	8	3	9.09.64	C	1.4	9.6	0.845	0.866
TM	8	5	11.09.64	C	6.0	60.1	0.575	0.627
TM	8	6	17.07.65	C	-18.4	17.2	0.811	0.855
TM	8	7	4.09.65	B	-7.5	16.4	0.659	0.833
TM	8	8	30.07.66	C	0.5	15.6	0.660	0.806
TM	8	10	31.08.68	C	-0.3	4.2	0.804	0.906
TM	8	11	24.07.72	C	5.0	-43.9	0.138	0.205
TM	11	1	19.08.63	C	-4.1	-14.3	0.924	0.930
TM	11	2	22.07.64	B	-1.0	-28.6	0.906	0.916
TM	11	3	9.09.64	C	-4.0	18.5	0.840	0.850
TM	11	4	11.09.64	B	-9.3	2.1	0.870	0.874
TM	11	5	17.07.65	C	-1.7	-44.3	0.718	0.721
TM	11	6	4.09.65	B	21.1	1.5	0.930	0.975
TM	11	7	30.07.66	C	8.2	-0.3	0.953	0.957
TM	11	9	31.08.68	C	22.8	-21.6	0.750	0.770
TM	11	10	13.08.69	B	-6.0	14.5	0.799	0.832
TM	11	11	15.09.69	C	-5.1	6.4	0.865	0.905
TM	11	12	21.08.73	B	10.8	-14.3	0.941	0.946
EC	1	1	28.02.77	A	-1.9	2.6	0.938	0.942
EC	1	2	6.03.77	B	-0.2	3.0	0.737	0.830
EC	1	3	7.05.77	B	-21.3	5.4	0.735	0.775
EC	1	4	19.04.78	A	-0.3	-2.9	0.960	0.961
EC	1	5	21.04.78	A	-4.2	-0.4	0.828	0.888
EC	1	6	20.07.79	A	-1.0	2.1	0.876	0.879
EC	1	7	23.07.79	A	-0.6	-0.7	0.950	0.900
EC	1	8	19.08.79	A	-6.5	1.8	0.917	0.936
EC	1	9	26.03.81	A	2.2	-1.2	0.938	0.939
EC	1	10	22.10.81	B	-16.7	14.4	0.356	0.694
EC	1	11	23.12.81	A	0.3	-3.5	0.979	0.980
EC	1	12	2.11.85	A	-6.8	2.5	0.928	0.962
EC	1	13	25.11.85	B	-19.1	4.6	0.524	0.628

EC	1	14	1.12.85	B	-3.9	-23.8	0.821	0.825
EC	2	1	28.02.77	A	9.5	-10.6	0.848	0.872
EC	2	2	6.03.77	B	5.3	-6.8	0.866	0.868
EC	2	3	7.05.77	B	-12.9	-18.9	0.870	0.892
EC	2	5	21.04.78	A	-1.6	3.9	0.664	0.771
EC	2	6	20.07.79	A	1.2	2.9	0.832	0.841
EC	2	7	23.07.79	A	-1.8	2.6	0.960	0.978
EC	2	8	19.08.79	A	-5.6	9.4	0.938	0.967
EC	2	9	26.03.81	A	-5.1	4.6	0.598	0.656
EC	2	11	23.12.81	A	-2.7	-16.4	0.760	0.783
EC	2	12	2.11.85	A	-4.1	1.9	0.896	0.956
EC	2	14	1.12.85	B	-0.0	-0.2	0.967	0.968
BETH		1	01.11.80	C	-10.8	-3.8	-0.058	0.231
BETH		2	15.12.80	B	-11.6	3.5	0.783	0.859
BETH		5	05.02.81	B	10.9	-51.1	-0.282	0.006
BETH		6	10.02.81	B	-3.3	6.1	0.933	0.956
BETH		7	14.02.81	B	6.2	-7.9	0.876	0.914
BETH		8	17.02.81	B	-5.3	16.2	0.884	0.926
BETH		9	27.02.81	C	23.2	-24.8	0.605	0.662
BETH		10	22.03.81	C	-17.3	30.6	0.664	0.774
HOEK		1	2.03.79	A	-5.0	95.6	0.215	0.780
HOEK		2	4.05.79	B	-16.5	-7.7	0.060	0.345
HOEK		3	16.02.80	A	-4.1	-56.1	0.178	0.569
HOEK		4	17.02.80	B	-6.7	-11.0	0.803	0.804
HOEK		5	17.12.80	B	-7.1	9.4	0.662	0.744
HOEK		6	8.01.81	B	-8.2	-27.1	0.028	0.141
HOEK		7	1.02.81	A	0.0	-23.5	0.925	0.939
HOEK		8	19.02.81	B	-9.2	-19.5	0.737	0.746
HOEK		9	21.02.81	B	-2.6	-13.3	0.783	0.789
HOEK		10	24.02.81	B	-11.3	-29.6	0.390	0.416
HOEK		11	21.03.82	A	-4.9	36.1	-0.706	0.066
HOEK		12	8.04.82	B	-22.6	-59.9	-1.210	0.168
HOEK		13	26.11.83	B	-13.8	-0.7	0.339	0.403
HOEK		14	28.11.83	B	-9.6	-35.9	0.852	0.883
HOEK		15	17.12.83	B	-17.0	-50.1	0.604	0.698
HOEK		16	24.12.83	B	-4.4	12.6	0.828	0.849
CED		1	11.11.78	A	-14.9	-8.0	0.384	0.429
CED		2	9.12.78	A	-6.7	18.7	0.499	0.625
CED		3	28.12.78	A	0.9	-1.0	0.274	0.472
CED		4	2.01.79	A	-0.3	39.7	-0.987	0.136
CED		5	25.02.79	A	-1.3	-5.8	0.433	0.524
CED		6	2.12.84	A	-16.9	60.9	-0.153	0.350
CED		7	9.02.85	A	-5.5	7.2	0.361	0.510
CED		8	24.02.85	C	8.5	-20.6	0.576	0.589
CED		9	11.03.85	A	-11.1	50.8	-0.917	0.097
CED		10	14.03.86	C	-5.8	61.4	-0.667	0.332
ZL	15	1	29.01.77	B	2.2	33.7	0.465	0.691
ZL	15	2	6.02.77	B	-1.0	-19.5	0.458	0.504
ZL	15	3	14.02.77	B	-0.7	-34.5	0.666	0.667
ZL	15	4	14.03.77	B	-0.9	-22.1	0.634	0.664
ZL	15	5	9.10.77	A	-3.4	10.8	0.919	0.942
ZL	15	6	9.11.77	B	-7.5	-17.3	0.948	0.960
ZL	15	7	19.12.77	B	-1.2	-1.9	0.977	0.985
ZL	15	8	19.01.78	C	-6.0	3.3	0.839	0.903
ZL	15	9	21.01.78	A	1.4	-10.1	0.978	0.978
ZL	15	10	21.02.78	B	-1.4	-8.8	0.804	0.894
ZL	15	11	1.03.78	A	-11.9	-4.5	0.776	0.900

ZL	15	12	9.03.78	B	-2.3	24.5	0.616	0.823
ZL	15	13	27.03.78	B	-2.0	1.3	0.552	0.609
ZL	15	14	8.09.78	A	-4.7	-9.8	0.690	0.694
ZL	15	15	18.10.78	A	-7.3	-24.8	0.857	0.870
ZL	16	1	29.01.77	A	-3.3	27.2	0.761	0.867
ZL	16	2	6.02.77	A	-1.3	-38.1	0.205	0.242
ZL	16	3	14.02.77	A	-3.1	-5.2	0.783	0.801
ZL	16	4	14.03.77	A	1.0	11.2	0.638	0.703
ZL	16	5	9.10.77	A	-15.4	2.0	0.867	0.925
ZL	16	6	9.11.77	A	-13.6	-5.1	0.776	0.793
ZL	16	7	19.12.77	A	-15.8	25.5	0.516	0.610
ZL	16	8	19.01.78	A	-7.8	14.2	0.592	0.735
ZL	16	9	21.01.78	A	-0.3	9.7	0.939	0.959
ZL	16	10	21.02.78	A	-6.2	22.1	0.915	0.935
ZL	16	11	1.03.78	A	-4.7	33.4	0.843	0.878
ZL	16	12	9.03.78	A	-3.1	34.8	0.619	0.798
ZL	16	13	27.03.78	A	-5.0	-20.8	0.175	0.314
ZL	16	14	8.09.78	A	-13.7	-13.7	0.693	0.726
ZL	16	15	18.10.78	A	-13.0	-44.5	0.645	0.605
OX	4	1	3.04.58	A	-0.7	51.6	0.363	0.739
OX	4	2	17.01.60	A	-2.1	11.2	0.774	0.800
OX	4	3	31.08.61	A	-12.2	-8.4	0.950	0.975
OX	4	4	4.09.62	A	-3.0	-17.7	0.800	0.808
OX	4	5	29.08.63	A	-1.0	19.3	0.845	0.868
OX	5	1	3.04.58	A	-4.7	12.0	0.960	0.970
OX	5	2	17.01.60	A	-1.8	0.2	0.902	0.914
OX	5	3	31.08.61	A	-5.2	-9.3	0.939	0.961
OX	5	4	4.09.62	A	-7.1	-21.4	0.917	0.954
OX	5	5	29.08.63	A	-0.6	34.3	0.864	0.907
OX	5	6	4.03.64	A	7.2	19.7	0.922	0.941
OX	5	7	1.03.65	A	18.0	7.8	0.853	0.898
OX	5	8	24.05.66	A	-5.0	15.0	0.902	0.909
OX	5	9	31.05.67	A	1.5	13.8	0.892	0.919
OX	10	1	22.05.59	B	-45.9	-61.8	0.468	0.794
OX	10	2	17.01.60	A	-2.7	0.8	0.794	0.820
OX	10	3	31.08.61	B	-12.3	12.1	0.784	0.802
OX	10	4	4.09.62	A	-6.0	-18.8	0.943	0.973
OX	10	5	29.08.63	A	-2.7	-1.8	0.933	0.934
OX	10	6	4.03.64	A	1.1	11.0	0.948	0.960
OX	10	7	1.03.65	A	-4.1	23.0	0.772	0.875
OX	10	8	27.12.66	C	-3.9	4.1	0.693	0.721
OX	10	9	31.05.67	A	-12.1	0.3	0.685	0.722
OX	10	10	1.02.68	A	-5.0	24.3	0.627	0.701
OX	10	11	17.04.69	A	-4.1	30.6	0.823	0.840
OX	10	12	26.08.71	C	-3.5	-7.0	0.899	0.903
OX	12	1	2.03.60	A	-32.4	-42.7	0.368	0.585
OX	12	2	31.08.61	B	-10.9	-23.7	0.562	0.571
OX	12	3	4.09.62	B	4.1	-27.7	0.908	0.941
OX	12	4	29.08.63	A	-3.9	-6.4	0.953	0.968
OX	12	5	4.03.64	A	-10.4	7.4	0.870	0.881
OX	12	6	1.03.65	A	-10.0	-16.5	0.845	0.882
OX	12	7	24.05.66	A	2.9	-10.0	0.885	0.885
OX	12	8	31.05.67	A	-12.7	-33.7	0.767	0.829
OX	12	9	1.02.68	A	-11.6	-34.0	0.845	0.967
OX	12	10	17.04.69	A	-8.8	-24.3	0.858	0.911
OX	12	11	21.02.71	C	-1.0	18.8	0.890	0.891
OX	17	1	2.03.60	A	-14.5	-21.7	0.747	0.796

OX	17	2	31.08.61	B	-17.2	-20.5	0.737	0.787
OX	17	3	4.09.62	B	-20.3	-36.5	0.785	0.953
OX	17	4	29.08.63	A	-8.1	15.1	0.850	0.853
OX	17	5	4.03.64	A	-21.7	2.8	0.717	0.748
OX	17	6	1.03.65	A	-14.7	-27.8	0.889	0.973
OX	17	7	24.05.66	A	-10.2	-4.1	0.754	0.761
OX	17	8	31.05.67	A	-26.1	-34.3	0.796	0.950
OX	17	9	1.02.68	A	-15.3	-15.7	0.889	0.952
OX	17	10	17.04.69	A	-11.8	1.2	0.916	0.930
OX	17	11	21.02.71	C	-4.8	38.5	0.678	0.697
OX	24	1	17.01.60	A	-0.2	22.8	0.093	0.500
OX	24	2	31.08.61	A	-3.8	-49.6	0.535	0.549
OX	24	3	4.09.62	A	SUSPECT DATA			
OX	24	4	29.08.63	A	4.0	-19.4	0.897	0.912
OX	24	5	4.03.64	A	1.6	-7.7	0.941	0.943
OX	24	6	1.03.65	A	1.3	-26.5	0.620	0.628
OX	24	7	24.05.66	A	-13.1	16.6	0.779	0.867
OX	24	8	31.05.67	A	-0.1	-2.8	0.902	0.910
OX	28	1	17.01.60	A	-2.2	-40.5	0.785	0.805
OX	28	2	4.09.62	A	-2.5	-10.0	0.882	0.888
OX	28	3	29.08.63	A	-1.3	15.8	0.887	0.892
OX	28	4	4.03.64	A	-1.3	1.8	0.817	0.838
OX	28	5	1.03.65	A	3.9	-22.4	0.746	0.758
OX	28	6	24.05.66	A	-0.6	41.5	0.209	0.569
OX	28	7	31.05.67	A	-2.8	16.3	-0.345	0.150
OX	32	1	22.05.59	B	-19.1	-55.7	0.627	0.841
OX	32	2	2.03.60	A	-20.7	-20.9	-0.027	0.272
OX	32	3	31.08.61	B	-14.0	-29.5	0.251	0.284
OX	32	4	4.09.62	A	-13.5	-41.1	0.711	0.752
OX	32	5	29.08.63	A	-11.6	-37.7	0.432	0.438
OX	32	6	4.03.64	A	-10.0	-23.2	0.808	0.850
OX	32	7	1.03.65	A	-18.1	-50.0	0.691	0.811
OX	32	8	24.05.66	A	-7.1	-6.3	0.670	0.672
OX	32	9	31.05.67	A	-18.0	-36.9	0.626	0.713
OX	32	10	1.02.68	A	-15.6	-31.3	0.823	0.971
OX	32	11	17.04.69	A	-8.2	10.5	0.887	0.890
OX	32	12	18.06.71	C	-14.3	-15.4	0.610	0.631
OX	32	13	25.06.72	C	-5.3	8.5	0.921	0.922
OX	32	14	19.04.73	C	-3.5	24.5	0.744	0.778
OX	35	1	22.05.59	B	-5.2	16.2	0.935	0.937
OX	35	2	2.03.60	A	-17.7	55.0	0.258	0.692
OX	35	3	31.08.61	B	-10.2	-2.8	0.277	0.360
OX	35	4	4.09.62	A	-5.9	-10.9	0.051	0.291
OX	35	5	29.08.63	A	-7.9	-5.6	-0.315	0.066
OX	35	6	4.03.64	A	-4.0	24.8	0.864	0.883
OX	35	7	1.03.65	A	-4.3	-4.1	0.868	0.901
OX	35	8	24.05.66	A	-4.1	37.5	0.881	0.887
OX	35	9	31.05.67	A	0.5	73.7	0.603	0.762
OX	35	10	1.02.68	A	-6.4	3.4	0.751	0.754
OX	35	11	17.04.69	A	-1.8	120.2	0.419	0.735
OX	35	12	26.08.71	C	-1.5	11.1	0.802	0.815
KAAI		1	25.03.81	C	-5.0	22.2	0.894	0.901
KAAI		2	26.04.81	C	-3.1	1.4	0.833	0.848
KAAI		3	5.05.81	C	-11.1	-8.2	0.470	0.558
KAAI		4	28.05.81	C	-1.9	-10.9	0.921	0.922
KAAI		6	24.08.81	C	-3.5	-1.9	0.678	0.714
KAAI		7	27.08.81	C	-3.6	13.9	0.270	0.516

KAAI	8	30.08.81	C	-0.2	-0.4	0.206	0.515
KAAI	9	18.02.82	C	-5.2	-17.2	0.292	0.378
KAAI	10	3.03.82	C	-10.2	4.1	0.481	0.551
KAAI	11	12.09.82	C	-1.8	57.0	-0.158	0.181
KAAI	12	12.06.83	C	-8.3	-14.3	0.870	0.893
KAAI	13	2.10.83	C	-4.5	-27.6	0.711	0.734
KAAI	14	28.10.85	C	-5.1	-3.6	0.587	0.613
KAAI	15	2.11.85	B	-5.1	-7.1	-0.355	0.070
KAAI	16	8.11.85	B	-2.3	20.2	-0.077	0.389
KAAI	17	2.12.85	B	-8.0	-19.9	0.496	0.539
MALGAS	1	25.03.81	C	-7.3	2.9	0.830	0.840
MALGAS	2	26.04.81	C	-4.1	15.6	0.826	0.845
MALGAS	3	5.05.81	C	-14.7	-0.3	0.533	0.669
MALGAS	4	28.05.81	C	-5.1	-6.1	0.946	0.950
MALGAS	6	24.08.81	C	5.1	23.1	-1.160	0.265
MALGAS	7	27.08.81	C	-6.2	24.5	0.602	0.758
MALGAS	8	30.08.81	C	4.0	2.2	0.825	0.900
MALGAS	9	15.10.81	C	-8.4	-0.3	0.921	0.945
MALGAS	10	15.01.82	C	-15.0	-10.1	0.038	0.220
MALGAS	11	18.02.82	C	-8.4	-24.8	0.856	0.887
MALGAS	12	3.03.82	C	-10.4	-4.5	0.953	0.969
MALGAS	13	1.09.82	C	-13.3	6.2	0.204	0.464
MALGAS	14	11.06.83	C	-6.6	-14.6	0.162	0.300
MALGAS	15	22.09.83	C	-10.7	-7.8	0.484	0.551
MALGAS	16	15.10.85	B	-13.1	-19.8	0.908	0.945
MALGAS	17	21.01.86	B	-14.0	-46.7	0.149	0.215
ND 1	1	24.10.59	A	-0.9	7.1	0.991	0.991
ND 1	2	30.07.60	A	7.3	-8.8	0.900	0.908
ND 1	4	31.07.62	B	6.6	-3.8	0.958	0.967
ND 1	6	22.07.64	B	-2.0	5.9	0.284	0.511
ND 1	7	7.06.65	C	5.3	0.3	0.945	0.958
ND 1	8	19.10.66	C	-4.1	2.5	0.930	0.961
ND 1	9	16.07.67	C	-2.4	-2.2	0.856	0.888
ND 1	10	11.09.68	C	-3.2	-1.9	0.981	0.982
ND 1	12	23.08.71	C	2.3	-1.5	0.963	0.970
ND 1	13	3.07.72	C	3.0	0.1	0.967	0.969
ND 1	14	10.07.72	C	-1.8	0.7	0.969	0.971
ND 1	15	17.09.73	A	4.4	-6.8	0.977	0.980
ND 5	1	30.07.60	A	4.8	-2.4	0.925	0.929
ND 5	3	31.07.62	B	-0.9	8.2	0.986	0.988
ND 5	6	7.06.65	C	-0.6	-0.2	0.945	0.950
ND 5	7	19.10.66	C	-1.2	4.9	0.945	0.957
ND 5	8	16.07.67	C	5.7	-3.7	0.900	0.916
ND 5	9	11.09.68	C	-9.0	8.4	0.968	0.983
ND 5	11	23.08.71	C	-2.5	4.6	0.985	0.993
ND 5	12	10.07.72	C	-3.9	5.1	0.963	0.969
ND 5	13	20.07.72	C	-0.7	0.8	0.966	0.967
ND 5	14	14.07.73	C	4.4	-2.1	0.931	0.937
ND 5	15	17.09.73	A	6.3	-2.6	0.950	0.958

MODEL OSE3 Semi-distributed calibration and validation results

Catch. name		Storm No.	Storm date	Storm type	Calibration % Error Vol.	Peak	Calibration Coefficient Eff.	Det.	Validation % Error Vol.	Peak	Validation Coefficient Eff.	Det.
TM	1	1	26.07.59	B	-6.0	19.8	0.484	0.628	NOT MODELLED			
TM	1	2	4.09.65	C	15.3	-17.3	0.840	0.860	NOT MODELLED			
TM	2	1	26.07.59	B	2.9	45.2	0.680	0.820	NOT MODELLED			
TM	2	2	17.08.61	C	-0.9	-12.7	0.625	0.681	NOT MODELLED			
TM	2	3	4.09.65	B	1.4	16.4	0.850	0.923	NOT MODELLED			
TM	2	4	25.08.68	C	-8.6	-65.0	0.560	0.699	NOT MODELLED			
TM	2	5	31.08.68	C	-2.3	8.8	-0.557	0.080	NOT MODELLED			
TM	3	1	19.07.55	C	0.4	-30.3	0.757	0.757	-6.1	-48.2	0.612	0.630
TM	3	2	14.08.58	B	-0.9	10.8	0.745	0.837	-61.2	-74.3	0.207	0.520
TM	3	3	16.08.58	C	1.5	-4.2	0.391	0.599	8.6	-44.4	0.313	0.365
TM	3	4	17.08.61	B	0.0	110.4	0.021	0.783	-17.8	5.7	0.920	0.931
TM	3	5	25.07.62	C	2.7	-13.3	-1.160	0.003	173.0	21.3	-2.054	0.172
TM	3	7	25.08.68	C	17.3	-17.4	0.228	0.310	48.6	-34.7	0.595	0.662
TM	3	8	31.08.68	C	14.3	-15.1	-0.122	0.133	145.7	4.1	-0.444	0.482
TM	3	11	27.07.73	C	-3.4	0.1	0.404	0.635	18.5	-22.3	0.693	0.727
TM	6	1	4.09.65	B	4.8	-14.1	0.951	0.953	NOT MODELLED			
TM	6	2	31.08.68	B	3.6	-18.2	0.178	0.325	NOT MODELLED			
TM	8	1	19.08.63	C	-8.4	18.6	-0.114	0.275	-17.7	-53.0	0.610	0.749
TM	8	2	22.07.64	C	1.3	-34.8	0.858	0.859	29.1	-58.3	0.030	0.137
TM	8	3	9.09.64	C	1.4	10.5	0.708	0.717	-90.1	-97.2	-0.263	0.039
TM	8	5	11.09.64	C	0.5	-62.0	0.546	0.593	-23.1	-85.3	-0.060	0.001
TM	8	6	17.07.65	C	1.3	11.5	0.640	0.695	-50.6	-83.0	-0.025	0.069
TM	8	7	4.09.65	B	1.0	-1.6	0.620	0.734	-12.6	-59.1	0.391	0.398
TM	8	8	30.07.66	C	-10.5	18.2	-1.517	0.006	-22.5	-65.6	0.573	0.704
TM	8	10	31.08.68	C	-0.6	6.5	0.353	0.510	-37.3	-74.1	-0.014	0.101
TM	8	11	24.07.72	C	5.1	-40.9	-0.081	0.106	133.1	-19.9	-0.146	0.554
TM	11	1	19.08.63	C	0.6	10.6	0.521	0.580	-10.5	-43.6	0.782	0.878
TM	11	2	22.07.64	B	0.9	-12.5	0.915	0.918	-33.5	-53.2	0.687	0.874
TM	11	3	9.09.64	C	-0.2	59.9	0.554	0.647	-8.2	-0.3	0.619	0.621
TM	11	4	11.09.64	B	-5.1	23.2	0.833	0.862	-19.4	-18.4	0.764	0.783
TM	11	5	17.07.65	C	0.7	-38.3	0.779	0.779	-26.4	-71.2	0.366	0.439
TM	11	6	4.09.65	B	0.3	5.4	0.927	0.933	-9.9	-44.1	0.693	0.720
TM	11	7	30.07.66	C	0.2	12.4	-0.645	0.042	19.1	-5.2	0.174	0.322
TM	11	9	31.08.68	C	18.9	-20.1	0.360	0.412	-18.7	-75.5	0.021	0.042
TM	11	10	13.08.69	B	-3.8	51.5	0.656	0.588	18.1	2.5	0.781	0.809
TM	11	11	15.09.69	C	-3.6	16.3	0.588	0.638	-58.7	-76.5	-0.065	0.185
TM	11	12	21.08.73	B	-8.2	-5.9	0.862	0.871	71.3	38.8	0.670	0.961
EC	1	1	28.02.77	A	-3.8	3.5	0.889	0.909	195.8	167.8	-16.025	0.819
EC	1	2	6.03.77	B	-6.5	-3.4	0.744	0.846	65.4	-79.1	-0.385	0.253
EC	1	3	7.05.77	B	-3.4	0.3	0.807	0.819	361.7	123.3	-12.739	0.212
EC	1	4	19.04.78	A	12.1	-7.5	0.944	0.949	801.7	420.1	-35.137	0.819
EC	1	5	21.04.78	A	-25.1	9.4	-0.438	0.587	121.1	124.9	-14.210	0.549
EC	1	6	20.07.79	A	-0.7	-13.8	0.910	0.915	100.2	122.4	-2.554	0.319
EC	1	7	23.07.79	A	0.2	1.9	0.966	0.933	-30.8	-8.3	0.340	0.722
EC	1	8	19.08.79	A	-6.8	-1.2	0.953	0.966	-40.2	-50.7	-0.012	0.223
EC	1	9	26.03.81	A	9.8	-12.3	0.950	0.962	NOT MODELLED			
EC	1	10	22.10.81	B	-2.8	11.1	0.493	0.736	57.3	70.6	-2.304	0.741
EC	1	11	23.12.81	A	4.0	-11.2	0.747	0.783	-54.6	-72.5	0.280	0.785
EC	1	12	2.11.85	A	-3.4	0.8	0.949	0.972	-33.9	-14.9	0.215	0.655
EC	1	13	25.11.85	B	DATA SUSPECT				-11.2	56.7	0.451	0.771

EC 1	14	1.12.85	B	-0.5	-3.7	0.898	0.925	-24.2	-31.4	-0.105	0.200
BETH	1	01.11.80	C	4.6	-14.2	-0.759	0.004	1.3	-20.4	-0.606	0.009
BETH	2	15.12.80	B	-0.6	-10.6	0.831	0.855	-44.3	-50.7	0.186	0.797
BETH	5	05.02.81	B	-1.3	-17.0	0.688	0.689	-69.7	-83.8	-0.402	0.106
BETH	6	10.02.81	B	-7.6	1.7	0.972	0.987	-0.3	6.8	0.964	0.987
BETH	7	14.02.81	B	11.1	-19.6	0.720	0.753	-44.2	-63.3	0.435	0.739
BETH	8	17.02.81	B	-9.9	11.1	0.822	0.873	-12.4	3.0	0.867	0.894
BETH	9	27.02.81	C	14.7	-13.7	0.671	0.822	69.2	-80.5	-0.083	0.868
BETH	10	22.03.81	C	-9.0	3.1	0.371	0.491	-14.4	-8.4	0.430	0.520
HOEK	1	2.03.79		DATA SUSPECT				10.0	79.4	0.140	0.862
HOEK	2	4.05.79	B	-20.8	-59.1	0.432	0.519	NOT MODELLED			
HOEK	3	16.02.80	A	0.4	-0.6	0.965	0.986	-8.4	-12.5	0.960	0.965
HOEK	4	17.02.80	B	-5.6	-17.6	0.933	0.935	-9.9	-27.7	0.893	0.907
HOEK	5	17.12.80	B	-4.5	-3.2	0.504	0.641	77.5	90.5	-2.049	0.627
HOEK	6	8.01.81	B	-8.1	-41.6	0.723	0.792	60.1	16.4	0.330	0.847
HOEK	7	1.02.81	A	0.0	-1.1	0.780	0.861	-19.4	-27.7	0.833	0.847
HOEK	8	19.02.81	B	-5.2	-24.9	0.805	0.808	-33.5	-52.9	0.498	0.660
HOEK	9	21.02.81	B	-1.1	-21.0	0.252	0.366	-11.8	-31.2	0.254	0.319
HOEK	10	24.02.81	B	-7.3	-20.9	0.222	0.367	-26.7	-47.6	0.149	0.244
HOEK	11	21.03.82	A	-9.3	24.7	-0.276	0.206	207.7	360.5	-34.816	0.135
HOEK	12	8.04.82	B	-25.5	-68.2	-0.504	0.002	NOT MODELLED			
HOEK	13	26.11.83	B	-14.6	-31.8	0.520	0.542	58.6	37.4	-0.141	0.497
HOEK	14	28.11.83	B	-8.2	-35.6	0.823	0.846	40.0	-5.2	0.720	0.841
HOEK	15	17.12.83	B	-21.7	-73.3	0.191	0.227	32.5	-51.9	0.078	0.218
HOEK	16	24.12.83	B	-0.6	12.3	0.940	0.941	-42.1	-58.7	0.604	0.854
CED	1	11.11.78	A	DATA SUSPECT				-4.6	-45.3	0.733	0.747
CED	2	9.12.78	A	-14.9	16.4	0.587	0.779	-26.0	-5.2	0.549	0.872
CED	3	28.12.78	A	9.3	11.6	0.691	0.850	-18.6	-57.6	0.459	0.523
CED	4	2.01.79	A	-3.0	36.4	-0.109	0.481	-24.8	-31.1	0.769	0.930
CED	5	25.02.79	A	2.7	-11.0	0.811	0.859	-15.8	-64.8	0.243	0.263
CED	6	2.12.84	A	-13.3	15.6	0.819	0.890	-57.4	-69.1	-0.367	0.289
CED	7	9.02.85	A	-6.7	17.0	0.379	0.566	-19.6	-17.5	0.770	0.817
CED	8	24.02.85	C	13.7	-23.2	0.877	0.876	-70.0	-91.3	-0.168	0.063
CED	9	11.03.85	A	-6.7	19.8	0.109	0.476	-67.2	-81.1	-0.255	0.569
CED	10	14.03.86	C	-18.6	3.0	0.586	0.743	-20.3	-43.7	0.649	0.717
ZL 15	1	29.01.77	B	-0.8	11.2	0.660	0.766	-5.7	19.3	0.733	0.837
ZL 15	2	6.02.77	B	-1.0	-23.7	0.387	0.438	10.9	-13.8	0.264	0.418
ZL 15	3	14.02.77	B	-1.6	-42.3	0.654	0.655	-3.0	-42.1	0.577	0.580
ZL 15	4	14.03.77	B	-2.0	-16.5	0.632	0.655	-5.3	-22.4	0.572	0.621
ZL 15	5	9.10.77	A	-7.5	1.4	0.949	0.957	8.9	15.8	0.843	0.956
ZL 15	6	9.11.77	B	-8.6	-18.4	0.913	0.932	-12.9	-29.8	0.694	0.703
ZL 15	7	19.12.77	B	-7.0	-10.5	0.959	0.962	51.4	33.2	0.110	0.806
ZL 15	8	19.01.78	C	-8.1	-3.2	0.956	0.973	12.1	11.9	0.739	0.938
ZL 15	9	21.01.78	A	0.0	-18.8	0.940	0.942	-17.1	-28.1	0.890	0.924
ZL 15	10	21.02.78	B	-4.6	-12.4	0.902	0.905	-18.7	-23.6	0.841	0.877
ZL 15	11	1.03.78	A	-16.5	-5.1	0.618	0.807	-22.9	-17.4	0.362	0.717
ZL 15	12	9.03.78	B	-3.4	17.3	0.721	0.858	-15.5	7.3	0.717	0.861
ZL 15	13	27.03.78	B	-3.2	-1.7	0.730	0.745	12.3	6.8	0.646	0.759
ZL 15	14	8.09.78	A	-6.9	-16.5	0.754	0.764	32.4	22.6	0.514	0.759
ZL 15	15	18.10.78	A	-7.5	-11.7	0.735	0.739	-28.4	-33.7	0.572	0.623
ZL 16	1	29.01.77	A	-9.5	16.0	0.826	0.914	NOT MODELLED			
ZL 16	2	6.02.77	A	-2.2	-40.7	0.222	0.253	NOT MODELLED			
ZL 16	3	14.02.77	A	-6.0	-14.0	0.720	0.748	NOT MODELLED			
ZL 16	4	14.03.77	A	-9.0	-12.7	0.697	0.752	NOT MODELLED			
ZL 16	5	9.10.77	A	-21.4	-11.6	0.818	0.931	NOT MODELLED			
ZL 16	6	9.11.77	A	-15.6	-22.3	0.580	0.601	NOT MODELLED			
ZL 16	7	19.12.77	A	-17.6	1.4	0.614	0.673	NOT MODELLED			

ZL	16	8	19.01.78	A	-9.9	5.5	0.772	0.853	NOT MODELLED			
ZL	16	9	21.01.78	A	-4.2	6.5	0.869	0.894	NOT MODELLED			
ZL	16	10	21.02.78	A	-11.0	14.3	0.944	0.968	NOT MODELLED			
ZL	16	11	1.03.78	A	-16.4	14.6	0.837	0.927	NOT MODELLED			
ZL	16	12	9.03.78	A	-7.7	28.5	0.799	0.919	NOT MODELLED			
ZL	16	13	27.03.78	A	-7.0	-38.6	0.588	0.600	NOT MODELLED			
ZL	16	14	8.09.78	A	-16.7	-18.5	0.811	0.876	NOT MODELLED			
ZL	16	15	18.10.78	A	-20.0	-51.4	0.463	0.531	NOT MODELLED			
OX	4	1	3.04.58	A	-3.4	19.5	0.888	0.957	NOT MODELLED			
OX	4	2	17.01.60	A	-4.5	-7.9	0.851	0.856	NOT MODELLED			
OX	4	3	31.08.61	A	19.6	-22.4	0.855	0.876	NOT MODELLED			
OX	4	4	4.09.62	A	13.7	-22.9	0.850	0.865	NOT MODELLED			
OX	4	5	29.08.63	A	-0.9	-13.8	0.937	0.938	NOT MODELLED			
OX	10	1	22.05.59	B	-40.1	-60.4	0.465	0.643	35.4	-46.3	0.525	0.583
OX	10	2	17.01.60	A	0.3	-2.8	0.708	0.775	16.8	7.1	0.887	0.953
OX	10	3	31.08.61	B	-9.2	-2.2	0.973	0.977	-40.3	-55.6	0.385	0.535
OX	10	4	4.09.62	A	0.9	-11.0	0.918	0.919	-10.3	-43.6	0.630	0.676
OX	10	5	29.08.63	A	-0.6	1.5	0.939	0.939	-24.5	-46.1	0.614	0.734
OX	10	6	4.03.64	A	4.3	27.8	0.871	0.951	-15.4	-14.8	0.909	0.928
OX	10	7	1.03.65	A	-0.1	55.2	-0.055	0.553	-0.3	19.1	0.827	0.922
OX	10	8	27.12.66	C	-0.6	13.3	0.215	0.424	34.2	35.8	0.446	0.783
OX	10	9	31.05.67	A	-4.6	-1.8	0.945	0.962	5.4	-19.9	0.287	0.383
OX	10	10	1.02.68	A	-1.0	30.3	0.047	0.397	4.6	19.9	0.694	0.775
OX	10	11	17.04.69	A	-0.1	28.2	0.875	0.908	135.3	149.9	-1.599	0.912
OX	10	12	26.08.71	C	-0.4	-11.9	0.676	0.682	-3.0	-28.9	0.883	0.959
OX	12	1	2.03.60	A	-27.4	-35.9	0.464	0.611	7.7	19.5	0.755	0.909
OX	12	2	31.08.61	B	-16.3	-44.3	0.490	0.520	-14.4	-42.9	0.622	0.665
OX	12	3	4.09.62	B	5.1	-36.9	0.971	0.918	54.7	6.3	0.704	0.928
OX	12	4	29.08.63	A	0.7	-3.6	0.981	0.989	51.2	50.4	0.670	0.989
OX	12	5	4.03.64	A	-0.4	27.9	0.898	0.910	10.4	61.5	0.697	0.893
OX	12	6	1.03.65	A	-5.6	-5.8	0.927	0.933	-7.7	2.4	0.960	0.970
OX	12	7	24.05.66	A	3.6	0.4	0.905	0.908	-0.3	14.3	0.977	0.986
OX	12	8	31.05.67	A	-5.1	-28.1	0.728	0.739	48.8	34.7	0.643	0.926
OX	12	9	1.02.68	A	-7.5	-28.5	0.898	0.971	106.7	98.9	-1.048	0.752
OX	12	10	17.04.69	A	-4.9	-9.8	0.902	0.913	29.8	76.5	0.548	0.962
OX	12	11	21.02.71	C	0.8	27.9	0.840	0.844	-7.7	39.4	0.591	0.650
OX	17	1	2.03.60	A	-5.3	-7.1	0.803	0.813	-0.8	11.8	0.945	0.983
OX	17	2	31.08.61	B	-10.9	-39.0	0.658	0.714	-37.1	-59.3	0.507	0.768
OX	17	3	4.09.62	B	-16.1	-34.4	0.724	0.802	27.6	3.9	0.872	0.907
OX	17	4	29.08.63	A	-5.3	3.6	0.935	0.943	30.2	46.3	0.843	0.962
OX	17	5	4.03.64	A	-20.2	5.7	0.790	0.814	-4.1	52.9	0.397	0.605
OX	17	6	1.03.65	A	-11.7	-24.8	0.939	0.981	11.5	0.8	0.786	0.851
OX	17	7	24.05.66	A	-8.8	-2.5	0.786	0.791	-19.0	-0.5	0.885	0.915
OX	17	8	31.05.67	A	-15.2	-31.2	0.777	0.830	57.2	53.4	0.446	0.943
OX	17	9	1.02.68	A	-12.4	-13.4	0.947	0.989	23.9	46.1	0.548	0.820
OX	17	10	17.04.69	A	-9.2	6.7	0.944	0.950	35.3	118.2	0.119	0.923
OX	17	11	21.02.71	C	-3.4	33.6	0.713	0.732	-11.0	42.2	0.413	0.513
OX	32	1	22.05.59	B	0.4	-36.2	0.593	0.593	-43.2	-74.1	0.061	0.132
OX	32	2	2.03.60	A	-5.5	33.5	0.276	0.641	-46.1	-35.6	-0.782	0.138
OX	32	3	31.08.61	B	-2.2	-26.6	0.842	0.842	-58.2	-80.3	0.023	0.177
OX	32	4	4.09.62	A	-0.5	-48.5	0.652	0.652	-25.6	-73.3	0.390	0.493
OX	32	5	29.08.63	A	-1.4	-32.8	0.876	0.908	-35.9	-68.1	0.291	0.444
OX	32	6	4.03.64	A	-0.5	4.6	0.984	0.987	-37.8	-44.9	0.647	0.807
OX	32	7	1.03.65	A	-2.3	-52.8	0.269	0.283	-40.2	-72.7	0.223	0.386
OX	32	8	24.05.66	A	-0.2	-1.6	0.975	0.975	-32.1	-51.1	0.609	0.746
OX	32	9	31.05.67	A	-1.7	-33.2	0.860	0.881	-21.7	-58.2	0.325	0.358
OX	32	10	1.02.68	A	-1.9	-15.2	0.711	0.711	-12.9	-36.0	0.860	0.957

OX	32	11	17.04.69	A	-0.1	23.6	0.859	0.918	-34.4	-38.3	0.831	0.948
OX	32	12	18.06.71	C	0.5	-9.7	0.948	0.952	-23.6	-56.7	0.436	0.509
OX	32	13	25.06.72	C	-1.0	12.2	0.932	0.951	-4.2	-6.6	0.939	0.940
OX	32	14	19.04.73	C	0.2	27.2	0.903	0.975	NOT MODELLED			
OX	35	1	22.05.59	B	12.9	15.5	0.951	0.966	-40.8	-61.6	0.391	0.610
OX	35	2	2.03.60	A	-16.7	11.7	0.743	0.879	-24.9	-7.7	0.485	0.683
OX	35	3	31.08.61	B	-8.5	-39.9	0.710	0.775	183.3	66.5	-1.784	0.772
OX	35	4	4.09.62	A	-0.1	-25.1	0.461	0.534	52.8	-26.4	-0.446	0.159
OX	35	5	29.08.63	A	-7.4	-28.2	0.220	0.266	187.5	85.1	-2.657	0.730
OX	35	6	4.03.64	A	-2.3	18.1	0.846	0.878	-54.1	-50.9	0.555	0.980
OX	35	7	1.03.65	A	-2.2	8.6	0.751	0.847	-49.8	-51.0	0.560	0.917
OX	35	8	24.05.66	A	-3.5	10.3	0.972	0.974	-10.8	-24.7	0.765	0.805
OX	35	9	31.05.67	A	-2.4	30.8	0.853	0.886	-37.4	-41.3	0.418	0.523
OX	35	10	1.02.68	A	-3.4	1.2	0.676	0.689	-17.0	-22.3	0.859	0.931
OX	35	11	17.04.69	A	-0.1	86.0	0.528	0.804	-29.2	7.0	0.889	0.925
OX	35	12	26.08.71	C	-1.5	-1.5	0.807	0.811	5.1	-21.7	0.919	0.955
KAAI		1	25.03.81	C	-5.2	18.4	0.787	0.809	-28.3	6.7	0.795	0.851
KAAI		2	26.04.81	C	-3.4	1.8	0.892	0.901	-6.1	6.4	0.791	0.824
KAAI		3	5.05.81	C	-12.2	1.1	0.716	0.807	11.6	55.2	-0.500	0.371
KAAI		4	28.05.81	C	-1.7	-13.6	0.876	0.879	-13.1	-18.7	0.857	0.872
KAAI		6	24.08.81	C	-3.7	2.2	0.746	0.789	-8.8	16.9	0.451	0.657
KAAI		7	27.08.81	C	-5.1	7.6	0.515	0.692	-6.6	25.3	-0.019	0.502
KAAI		8	30.08.81	C	-2.6	-5.6	0.385	0.645	-13.6	3.2	-0.209	0.412
KAAI		9	18.02.82	C	-7.9	-17.1	0.769	0.785	11.6	44.0	-0.556	0.499
KAAI		10	3.03.82	C	-10.2	-1.4	0.810	0.840	-2.9	73.3	-0.143	0.502
KAAI		11	12.09.82	C	-2.8	56.3	0.024	0.276	52.8	232.6	-4.112	0.121
KAAI		12	12.06.83	C	-14.9	-20.6	0.845	0.892	23.6	-17.4	0.727	0.862
KAAI		13	2.10.83	C	-4.8	-26.0	0.735	0.763	NOT MODELLED			
KAAI		14	28.10.85	C	-5.2	-5.3	0.856	0.858	-10.0	-5.7	0.375	0.574
KAAI		15	2.11.85	B	-3.9	2.8	-0.104	0.275	34.2	44.6	0.323	0.707
KAAI		16	8.11.85	B	-5.1	19.4	0.711	0.871	-2.0	18.7	-2.227	0.022
KAAI		17	2.12.85	B	-7.6	-3.0	0.748	0.881	-19.7	58.5	-0.146	0.601
MALGAS		1	25.03.81	C	-6.5	8.6	0.707	0.735	-17.7	12.2	0.820	0.852
MALGAS		2	26.04.81	C	-3.1	20.1	0.868	0.893	20.3	75.3	0.276	0.730
MALGAS		3	5.05.81	C	-12.9	10.4	0.307	0.600	-26.2	28.5	0.184	0.715
MALGAS		4	28.05.81	C	-4.4	-6.6	0.929	0.932	18.6	23.7	0.752	0.883
MALGAS		6	24.08.81	C	-4.4	39.3	-1.315	0.038	24.8	133.3	-4.871	0.003
MALGAS		7	27.08.81	C	-6.7	27.9	0.417	0.745	5.6	84.9	-0.321	0.575
MALGAS		8	30.08.81	C	2.8	13.1	0.756	0.912	-8.6	11.8	0.423	0.730
MALGAS		9	15.10.81	C	-6.8	5.4	0.922	0.955	-8.7	15.6	0.761	0.883
MALGAS		10	15.01.82	C	-12.3	1.6	0.185	0.362	176.9	327.9	-24.244	0.048
MALGAS		11	18.02.82	C	-7.7	-16.3	0.931	0.940	-15.6	-2.2	0.730	0.801
MALGAS		12	3.03.82	C	-8.7	3.6	0.941	0.956	-32.0	41.2	0.723	0.864
MALGAS		13	1.09.82	C	-11.2	23.9	0.097	0.493	NOT MODELLED			
MALGAS		14	11.06.83	C	-5.1	2.2	0.061	0.301	-4.0	57.9	-1.026	0.135
MALGAS		15	22.09.83	C	-8.8	16.9	0.499	0.601	-11.0	71.4	-0.624	0.217
MALGAS		16	15.10.85	B	-11.0	-5.9	0.912	0.921	-32.4	-14.1	0.872	0.953
MALGAS		17	21.01.86	B	-10.6	-39.1	0.143	0.237	136.1	158.3	-1.430	0.031
ND	1	1	24.10.59	A	-3.8	2.5	0.987	0.991	NOT MODELLED			
ND	1	2	30.07.60	A	11.6	-10.8	0.869	0.886	NOT MODELLED			
ND	1	4	31.07.62	B	2.4	-10.5	0.972	0.973	NOT MODELLED			
ND	1	6	22.07.64	B	-1.4	-0.9	0.043	0.378	NOT MODELLED			
ND	1	7	7.06.65	C	7.5	-6.6	0.906	0.915	NOT MODELLED			
ND	1	8	19.10.66	C	-2.1	-0.3	0.967	0.986	NOT MODELLED			
ND	1	9	16.07.67	C	-5.3	-12.3	0.871	0.883	NOT MODELLED			
ND	1	10	11.09.68	C	1.7	-2.7	0.996	0.997	NOT MODELLED			
ND	1	12	23.08.71	C	-1.3	-1.3	0.972	0.984	NOT MODELLED			

ND	1	13	3.07.72	C	-1.3	-12.6	0.797	0.779	NOT MODELLED			
ND	1	14	10.07.72	C	2.7	-0.6	0.957	0.966	NOT MODELLED			
ND	1	15	17.09.73	A	1.9	-7.0	0.972	0.972	NOT MODELLED			
ND	5	1	30.07.60	A	6.8	-6.8	0.838	0.859	3.7	-16.7	0.748	0.750
ND	5	3	31.07.62	B	-0.1	0.9	0.994	0.995	-21.5	-27.0	0.866	0.969
ND	5	6	7.06.65	C	-0.9	-9.6	0.911	0.912	-43.5	-49.1	0.202	0.815
ND	5	7	19.10.66	C	-1.6	3.9	0.965	0.968	-54.5	-56.9	-0.463	0.984
ND	5	8	16.07.67	C	0.3	3.2	0.947	0.958	-41.1	-39.1	0.384	0.934
ND	5	9	11.09.68	C	-6.8	0.0	0.981	0.988	-1.7	6.8	0.922	0.941
ND	5	10	7.09.69	C	DATA SUSPECT				-10.8	-14.0	0.778	0.868
ND	5	11	23.08.71	C	-1.2	1.0	0.976	0.983	6.4	10.6	0.938	0.984
ND	5	12	10.07.72	C	2.6	2.8	0.978	0.985	-33.9	-32.1	0.646	0.955
ND	5	13	20.07.72	C	1.4	3.6	0.937	0.949	-30.9	-33.3	0.726	0.917
ND	5	14	14.07.73	C	2.8	1.7	0.871	0.881	-28.8	-36.2	0.555	0.900
ND	5	15	17.09.73	A	1.7	-2.9	0.978	0.980	-19.2	-25.0	0.847	0.933

APPENDIX E

Report on attendance at the NATO Advanced Study Institute held in Portugal, 10-23 July, 1988.

REPORT TO THE WATER RESEARCH COMMISSION ON THE NATO ADVANCED STUDY INSTITUTE HELD IN SINTRA, PORTUGAL, JULY 10-23, 1988.

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The structure of this ASI on Recent Advances in the Modelling of Hydrologic systems was divided into two parts. The main part of the programme was occupied by 1-1½ hour lectures from invited speakers on different aspects of the state of the art in hydrological modelling. In addition, some of the participants gave oral and/or poster presentations on work either completed or in progress. There was also time for formal and informal discussions between all those present. The appendix to this report lists the invited speakers, their affiliations and a brief title of the subject matter of their lectures. After review and editing, these lectures are expected to appear in a book published by Reidol. No decision has been made about publishing the papers contributed by other participants. Most of these did not, however, cover any particularly new ground in terms of hydrological modelling and are likely to appear in one form or another in formal publications at some stage in the future. This report will be confined to some of the more general important issues raised and discussed about the current state of hydrological modelling and its expected future direction.

One of the important issues discussed was the fact that hydrological modelling is driven by 'supply' and 'demand' forces. The supply forces are equivalent to the scientific developments in the subject, the improvement of our understanding of hydrological processes as well as the incorporation of this understanding into models. Keith Beven referred to 'perceptual' models (the hydrological system as perceived by the model builder) which are translated into conceptual models (the simplified version of the perception of the real world) and then into a computer model. The problem of building successful models is not only related to the simplification necessary to enable the computer model to be coded but also to the correctness of the modellers perception of the real system. Of additional relevance is the modellers perception of what processes are important to include in a model designed to solve a particular problem. The 'demand' forces are those exerted by model users who require tools to solve a wide range of specific problems. There was a great deal of discussion on this topic and several important points emerged.

i) Many Institutions in both the USA and Europe have adopted modelling approaches in the past and are very reluctant to change and adopt improved modelling techniques. thus the new developments in hydrological modelling are not being used despite the fact that many have been demonstrated to be more scientifically sound.

ii) Part of the problem lies in the fact that those actually operating models in the user agencies are often inexperienced and have a poor knowledge of hydrology and hydrological modelling. Models (old and new approaches) are used incorrectly due to false assumptions or over simplifications being made about the system being modelled. 'Cookbook' type approaches can be dangerous and lead to model misuse as well as false expectations of the reliability of the results. Those involved in the development of the SHE model related experiences of spending several months setting up and explaining the model to other potential users only to find that afterwards the model was being misused through a lack of understanding. Perhaps complex models such as the SHE should only be operated by experienced modellers.

iii) The use of 'expert systems' in modelling was discussed and **NOT** generally considered to be the right approach as they could also suffer from similar criticisms to 'cookbook' approaches. However, an appeal was made to make models more accessible to others through improved presentation and software design. By this I understood the group to mean that they should also be well documented such that others can understand what a particular model is actually doing and what results might be expected under different conditions.

iv) Some of the 'demands' on hydrological modelling have inhibited the develolpment of understanding. For example, Enda O'Connell referred to design floods and suggested that a lot of effort has been expended on how to generate a design flood of a particular return period and not on trying to understand the processes involved and incorporate them into design flood techniques.

David Bowles referred to research versus technological uses of models and the necessity to accept the differences between them. Some models are developed for one of these purposes and may be totally unsuitable for the other.

Soroosh Sorooshian gave a very good lecture on the fitting of conceptual models and parameter identifiability. He stressed the need to understand that it is not necessarily the length of calibration data that is important but the amount of 'information' (on the variety of runoff generating processes experienced in the catchment) contained within the calibration data. If a model is used to simulate events that include different runoff mechanisms than those represented within the calibration data then the results cannot be expected to be reliable. This is one of the reasons for the trend toward models that are more soundly based upon the physical processes and away from those relying solely on parometer fitting. He also suggested that too great an emphasis has been placed upon computational details and not enough on understanding processes. Enda O'Connell suggested that stochastic hydrology should move away from the 'search for the ultimate fit' and more toward developing techniques for understanding such as the impact of spatial variability of hydrological processes. The combination of deterministic and stochastic approaches appears to be a popular trend. It not only recognises the fact that the hydrological system incorporates stochastic elements but also that solving some of the problems of handling spatial variability in deterministic models may be best achieved through stochastic techniques. Effi Foufuola-Georgiou referred to the fact that many hydrologists do not get sufficient training in stochastic techniques. This prompted a call for a more multidisciplinary and integrated approach to hydrology education.

The problem of obtaining the input data necessary to successfully operate hydrological models was discussed by various lecturers and participants. This problem is common to parametric type models, where records of rainfall and runoff are needed for calibration, as well as more physically-based models where soils, vegetation, physiographic data etc. are required to evaluate the model parameters. When dealing with distributed approaches, which are necessary to account for spatial variability, the data requirements are very high and rarely satisfied in applied situations. The development of techniques for collecting these data or estimating parameter values of physically-based models must continue in parallel with the development of models. Although there is a great deal of attention given to satellite remote sensing techniques, they do not seem to offer a practical solution to the problem at the present time. The resolution of most satellite images is too coarse for a lot of applications and the cost is very high if a number of sequential images are required. The use of satellite data on cloud top temperature to estimate rainfall has been used and may be worth evaluating for South African conditions. Aircraft based microwave sensors may also be of value in detecting spatial variations in surface moisture conditions. One of the main limitations of remotely sensed data is that it can only reflect surface conditions whereas information is also needed on subsurface soil moisture characteristics.

At the close of the ASI some participants expressed dissappointment that there were not more discussions on water quality (including sediment) modelling. The lectures on this topic indicated that water quality modelling is not very well advanced. It was suggested by some that the focus should be on modelling quantity processes to provide a satisfactory framework for water quality modelling. Keith Beven indicated that modelling solute fluxes was far more difficult than modelling soil moisture movement (which had been previously discussed at great length and is accepted to be a difficult task).

Some more points about the future of hydrological modelling emerged during the final discussions.

i) Each new generation of hydrological modellers face a different set of constraints. The old constraint was computational but now there is a need to learn how to use the increased power of computers properly.

ii) There is a need to ensure that data collection is compatible with the modelling approach to be used. Collecting data and then choosing a model is the wrong approach.

iii) There is a need to check the assumptions and validity of some of the equations used in models (eg. Darcy's Law and the Richards Euqation).

iv) There is a need for new experimentation at a range of different scales instead of just reworking old data.

v) Some speakers indicated that the days of individuals building their own models should be replaced by concentration of effort on a few large models (SHE?). Others, however, suggested that building a model is a good learning process and helps to improve understanding.

Overall, the ASI was worthwhile attending. It was clear that there exists a certain diversity of opinion on some aspects of modelling. In particular some participants were very pessimistic about future developments in modelling and our ability to use them to solve practical problems while others were more optimistic. While listening to the lectures and partaking in some of the discussions certainly helped to clarify many of my own ideas about modelling, few of the concepts were entirely new to me. I believe that the research carried out in South Africa is comparable with that being undertaken elsewhere given our constraints of limited resources (particularly with respect to manpower). I also believe that we face similar problems related to model development and model application that are faced by others. From the number of conferences and symposia that have occurred recently or are planned within the next two years that have hydrological modelling as one of their focii, it would appear that there is an upsurge of interest in this field of research. It is important that South African hydrological researchers keep pace with new developments so that their own contributions can continue to be relevant.

In conclusion I would like to thank the Water Research Commission for financing my visit to Portugal to attend the ASI. I made a number of new contacts and there are prospects for some future cooperative work with some of them.

ASI Lecturers, their affiliations and lecture topics.

Prof. P.E. O'Connell, University of Newcastle-upon-Tyne, U.K.
Historical perspective of hydrological modelling.

Prof. L.D. James, Utah State Univ., Logan USA.
Science and the user demands of modelling.
Hydrologic modelling for water resources planning.
Hydrologic modelling for the prediction of landslides and debris flow hazards.

Prof. E.F. Georgiou, Iowa State Univ., Ames, USA.
Space-time precipitation modelling.
Real time coupling of hydro and meteorologic models.

Prof. W. Brutsaert, Cornell Univ., Ithaca, NY, USA.
Developments in evaporation estimation.
Recent mesoscale experiments in watershed evaporation estimation.

Dr. E. Morris, British Antarctic Survey, UK.
Snowpack modelling.
Hydrologic modelling for evaluating the effects of acid rain.

Dr. K. Beven, Univ. of Lancaster, UK.
Infiltration, soil moisture, unsaturated flow, interception and detention storage.
Scale considerations in hydrological modelling.
Spatially distributed modelling.

Prof. E. Todini, Univ. of Bologna, Italy.
Overland and channel flow.
Spatially distributed modelling; numerical solutions.

Dr. B. Storm, Danish Hydraulic Institute, Denmark.
Saturated flow.

Dr. D. Decoursey, U.S. Dept. of Agriculture, USA.
Framework for modelling nonpoint source pollution.
Mathematical models as research tools for experimental watersheds.
Integrated quantity/quality modelling.

Dr. J. Bathurst, Univ. of Newcastle-upon-Tyne, UK.
Framework for erosion and sediment transport modelling.

Dr. E. Ledoux, Ecole Nationale Superieure, Paris, France.
Coupling surface and groundwater modelling.

Prof. S. Sorooshian, Univ. of Arizona, USA.
Parameter estimation and identifiability and model verification.
Obstacles to introducing advances in modelling in practice.

Dr. R. Gurney, National Aeronautics and space Admin. (NASA), USA.
Measuring hydrologic variables with emphasis on remote sensing.
Large scale models of hydrologic processes.

Prof. M. Abbott, Int. Inst. for Hydraulics and Environmental Engineering, The Netherlands.
Computer technology developments.

Dr. D. Dawdy, DMA Civil Engineers & Geologists, USA.
Problems related to particular areas or climates.
Comparison of USGS and HEC-1 kinematic wave runoff models.

Prof. F.N. Correia, Director General for Natural Resources, Portugal.
Spatial variability in infiltration.