Institute of Hydrology

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Natural Environment Research Council

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Studies of Hydrology of the Lesotho Highlands Water Project for Royalties Assessment

Progress Report No. 10

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1. Introduction

This tenth monthly progress report covers the period 15 April to 31 May 1994. During this period, work has continued mainly on developing validation tests for the output from the core stochastic model and on follow up work arising from the meeting in Maseru on 30 March 1994. Appendix A describes the current status of the core stochastic model.

2. Key dates

To date

14/6/93	Project begins
15/6/93	Project team arrives in Maseru
12/7/93	First progress report issued
3/8/93	Second progress report presented verbally to JPTC
10/8/93	Project team returns to UK
17/9/93	Third progress report issued
15/10/93	Fourth progress report issued
27/10/93	Working paper 1 despatched from UK
10/11/93	Working paper 2 despatched from UK
15/11/93	Fifth progress report issued
9/12/93	Working paper 3 despatched from UK
14/12/93	Sixth progress report issued
1/2/94	Seventh progress report issued
1/3/94	Eight progress report issued
30/3/94	Meeting with all parties in Maseru
15/4/94	Ninth progress report issued

Planned

There have been several revisions to the work program since the last progress report was issued. We understand that LHDA and DWAF experienced some unavoidable delays in starting work on producing agreed stage records for the Crump and rated sections at Whitehill, Paray and Marakabei. Also, that recent work has raised doubts about the theoretical rating curve for the Crump weir at Whitehill. Consequently, it has not yet been possible to revise the overall water balance as envisaged in the last progress report or to run the revised flows through the stochastic model. As a result, the planned meetings for 18-20 May have been delayed until these issues have been resolved, with no new date set as yet for this meeting.

3. Work completed

The following work has been completed in the current reporting period:

1. LHDA have requested the involvement of Dr Rodney White of Hydraulics Research Ltd., UK, to help resolve doubts about the theoretical rating curve for the Whitehill Crump weir. Dr White is a leading expert on the performance of river gauging structures and is planning to make a site visit in mid-July. Some time was spent briefing Dr White in advance of this visit.

2. A diskette and report were received from DWAF in response to various actions arising out of the minutes of the meeting on 30 March. The information supplied included (a) an evaluation of the chart records for Whitehill (b) daily flows, rating tables and two new discharge measurements for Oranjedraai (from Jan 1994) (c) the results of submergence tests for the Crump weirs (d) an evaluation of the site conditions at Marakabei and (e) DWAF water level and flow records for Marakabei and Whitehill. Work is underway on evaluating the information supplied, although it will not be possible to reach any firm conclusions until the agreed flow records (LHDA/DWAF combined) have been received for all three Crump weir sites.

3. Work has continued on testing and evaluating the results from the stochastic model. The model testing procedures have been reviewed and new ways of presenting the data have been devised to supplement the various graphs and tabulations used to date. For example, the model now generates multi-site box plots for the means and standard deviations, serial correlations and cross correlations, and for various storage-related parameters including minimum run sums, maximum deficit, duration of maximum deficit and duration of longest depletion. Some example results from the most recent version of the model are given in Appendix A.

Appendix A Current status of the core stochastic model

Work is nearing completion on the core stochastic model to be used for generating the annual flows over the Royalty period. This Appendix presents some example results from the current version of the model and discusses some of the issues currently being examined. Over the past few months, three main changes have been made to the model compared to the version used to produce the exploratory results shown in Working Paper 2, namely:

(a) Including the serial correlation within annual flow series

(b) Imposing overall constraints on the total flows generated by combinations of two or more incremental catchment areas; for example, the incremental flows from all individual incremental areas must sum to the flows for Oranjedraai.

(c) Imposing more realistic upper and lower bounds on annual flows and rainfalls in years with long periods of missing data.

In addition, several alternative rainfall-flow transformations and combinations of rainguages are being evaluated and the annual values have been reprocessed assuming an August-July hydrological year. Testing of the 6 unit configuration (i.e. including Nkaus) has now been suspended following the general consensus at the meeting on 30 March about the poor reliability of the flow data for Nkaus. The model has also been configured to work in three modes of operation:

(a) Mode 1 ('using rain and flow data') - flows are generated to take full account of all the known flow and rainfall information. In this mode, known flows are used where available and generated flows obey any known bounds (as do rainfall values).

(b) Mode 2 ('using rain data') - flows are generated taking account of rainfall information only. In this mode, known rainfall values are used where available and otherwise are generated subject to the known bounds.

(c) Mode 3 ('no data') - flows are generated without using any of the observed rainfall or flow data. In this mode, both rainfall and flow values are generated over the whole period.

The values generated in the three modes are independent, except that the model parameters generated in Mode 1 are also used in the other two modes. The uses of these alternative modes are described in more detail below; briefly, Mode 1 will be used to generate the Royalty sequences, Mode 2 is used for testing and Mode 3 is designed for generating the long term design sequences.

As a result of these changes, we believe that the model is now producing results for the Royalty flow sequences which are more likely to be acceptable to all parties. Figures A.1 and A.2 give some examples of the results from the current version of the model. The figures give box plots showing the distributions of the means and standard deviations of annual flows produced by 400 realisations of the model for the Royalty period for a typical combination of raingauges and flow transformations. The results are shown for each of the five key incremental flow sites and for the cumulative flows at Koma Koma, Seaka and Oranjedraai. Since the number of years having complete observed data are generally rather few, we have used the model to infill the values between the bounds in years with incomplete data. As a result, the 'observed' flows need to be shown as box plots representing the range of likely flows generated by the model. The 'observed' flows have been calculated for the site-data period only, which is defined as the period over which there are at least some flow values for the site or incremental area in question. These box plots can be taken to be the best possible estimate of the observed flows over the site-data period based on the data available.

The comparisons show that, for the particular combination of raingauges chosen, the model generally tended to produce lower means and standard deviations over the full Royalty period than in the site-data period alone. We believe that this is due mainly to differences in rainfall between the site-data period and the Royalty period. Several previous studies have compared the mean rainfall over the observational period with that for the full Royalty period but no firm conclusions have yet been reached about whether there is any significant trend between the two periods. In fact, an analysis of the most recent rainfall data (Figure A.3) shows that there are considerable spatial variations in the ratio of the mean rainfall in the two periods. The likely impact on flows is therefore unclear particularly since - as indicated in Working Papers 2 and 3 - the relationships between flows and rainfall are highly non-linear.

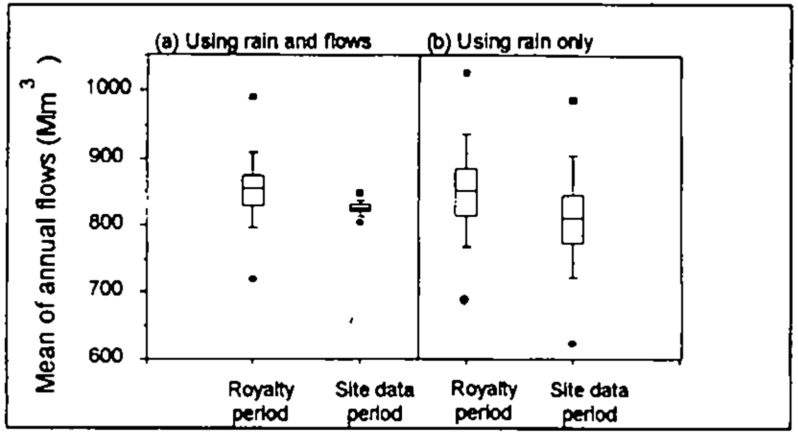
Because of these difficulties, we have shown a further comparison of the model runs for each site on Figures A.1 and A.2. In these runs, the model is generating flows based on the rainfall only; that is, it is assumed that only the relationship between flow and rainfall is known, and that the observed flows themselves are not known. These plots, marked "using rain only" (i.e. Mode 2), highlight the effect of the differences in rainfall between the two periods. Examination of the two sets of plots for each site shows that where the flows for the full model (marked "using rain and flow") in the Royalty period differ from the site-data period, the flows produced "using rain only" generally also differ in a similar way. This is a strong indication that differences between the model results for the Royalty period and the observed flow period are caused primarily by differences in rainfall in the two periods. Some further work is required before deciding on the most appropriate combination of raingauges to use in generating the final Royalty flow sequences.

Overall, these results illustrate the value of using a stochastic model which also takes account of the rainfall over the whole period, thereby producing a better estimate of the Royalty flows than a more standard stochastic model in which the generated flows would be solely dependent on the much shorter period of observed flows. It is also important to remember that, although a stochastic model is being used, the main aim is to develop a range of plausible scenarios for the flows which really occurred in the Lesotho Highlands during the Royalty period. With the exception of some dubious early data for Whitehill, we understand that no reliable flow measurements were made in the Lesotho Highlands before the 1960s. However, flows were measured at the Aliwal North site in RSA from 1914. Although previous studies (e.g. LMC 1983) have raised doubts about the absolute magnitude of the Aliwal flows, the recorded values should nevertheless provide a valuable indicator of the variability in flows in the Orange river over the Royalty period, as should previous results obtained using other modelling approaches.

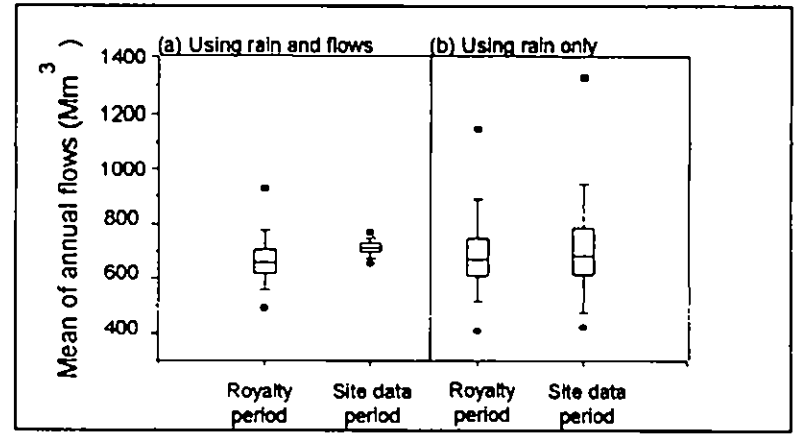
As an example, Figure A.4 compares the observed flows at Aliwal North with the 50 percentile flows generated by the model. The values for Aliwal North are approximate and were taken from a graph in an earlier report (LMC 1983); more recent estimates may be available and should be used if this validation test is acceptable to the parties. The figure also shows the results produced by BKS/DWAF (1986) during the Interim Hydrology. In interpreting the model results, it is important to remember that the 50% line does not represent any one realisation of the model; in fact, every sequence is different, although the estimated flows are guided by the observed rainfall (see Figure A.5 for example, which shows 5 sequences picked at random from a set of 400 realisations). Nevertheless the 50% line does provide a guide to the median flow generated in any one year. Given this proviso, these results are reasonably encouraging, and show that both the BKS/DWAF model and stochastic model generate flows similar magnitude, although with minor differences due to the different modelling approaches, hydrological years, raingauge combinations and flow datasets used. The main advantage of the stochastic approach is that it also provides quantitative estimates of the uncertainty in the results arising from the short length of the observed records and from the many gaps in the observed data.

Comparison of observed and simulated mean flows for several representative basins

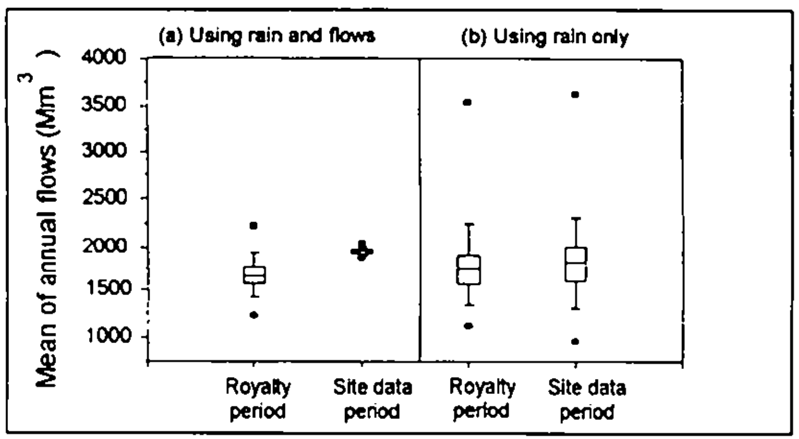
Sub-basin A



Sub-basin B



Sub-basin C



Sub-basin D

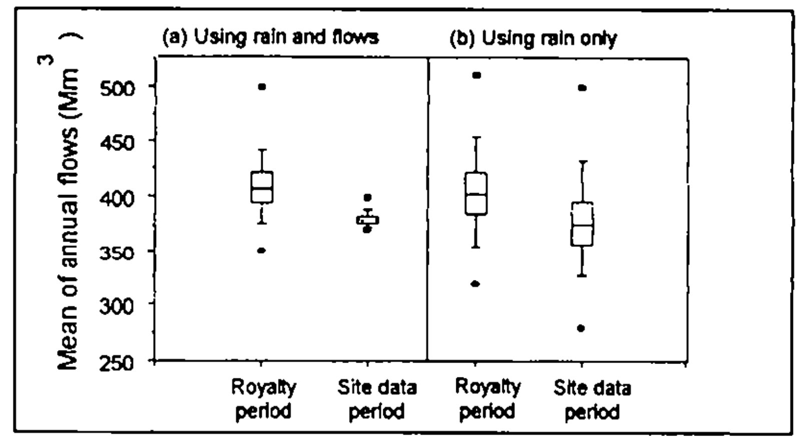
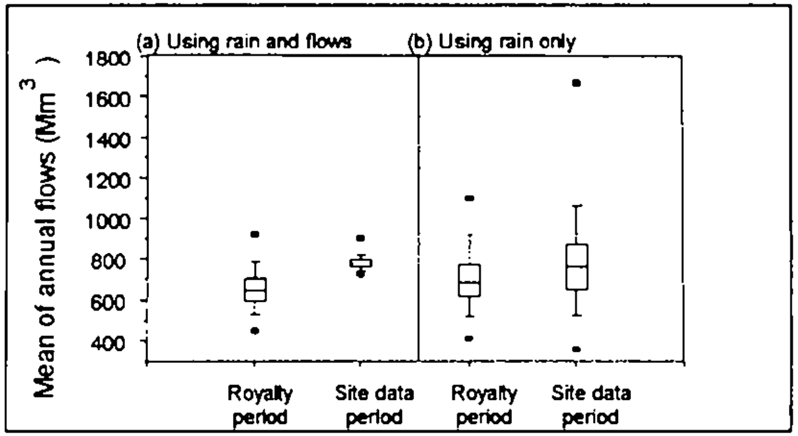


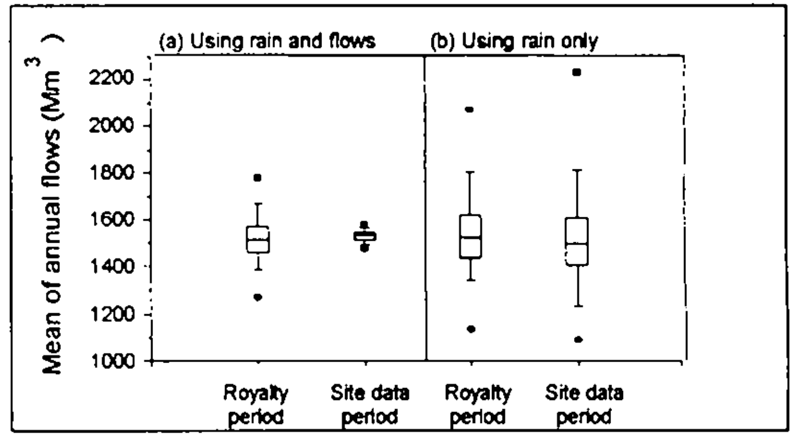
Figure A.1

Comparison of observed and simulated mean flows for several representative basins

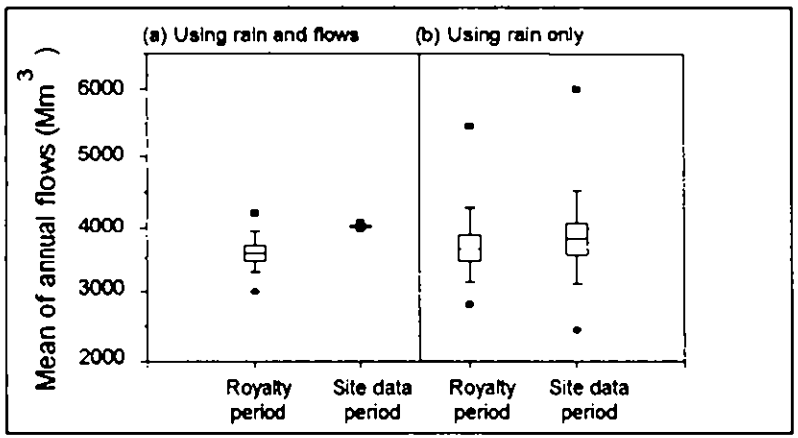
Sub-basin E



Cumulative flows:Koma Koma



Cumulative flows:Seaka



Cumulative flows:Oranjedraai

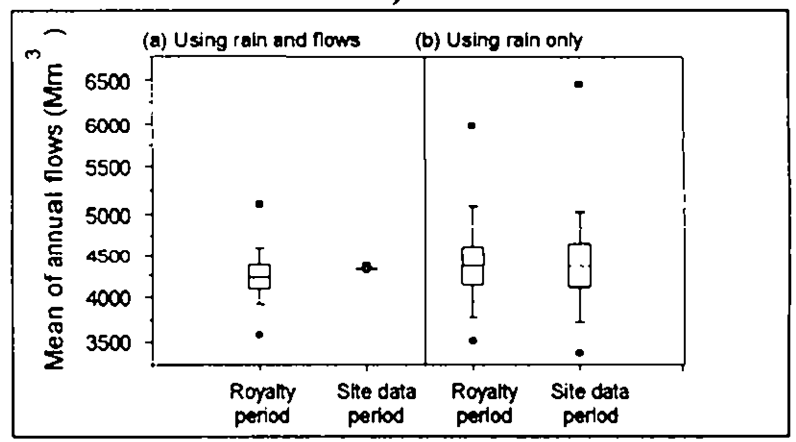
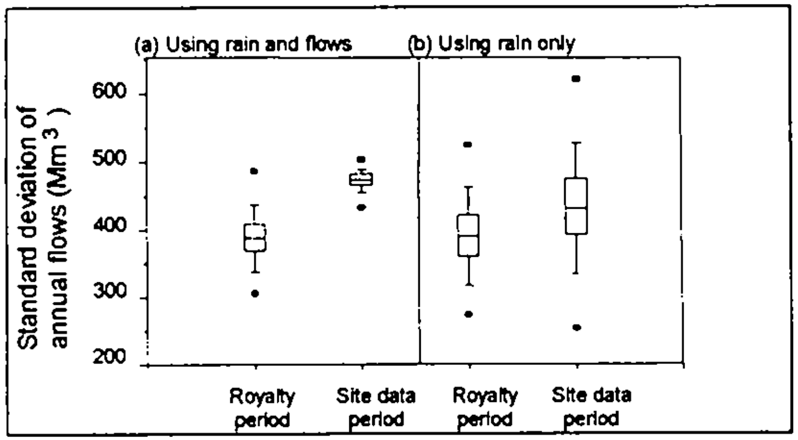


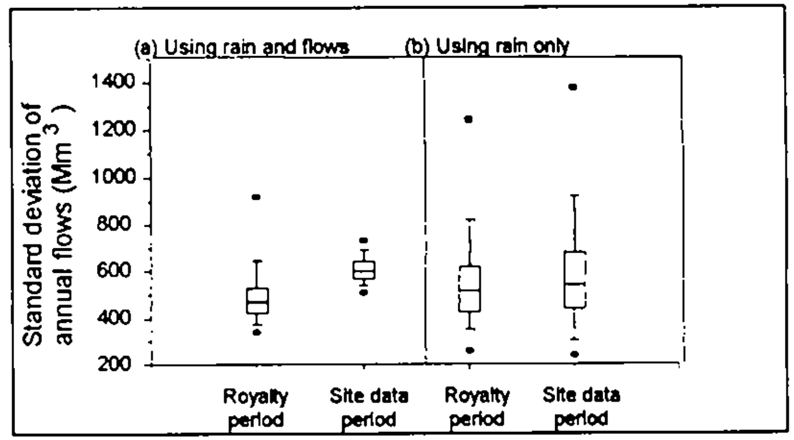
Figure A.1 cont.

Comparison of observed and simulated standard deviations for several representative basins

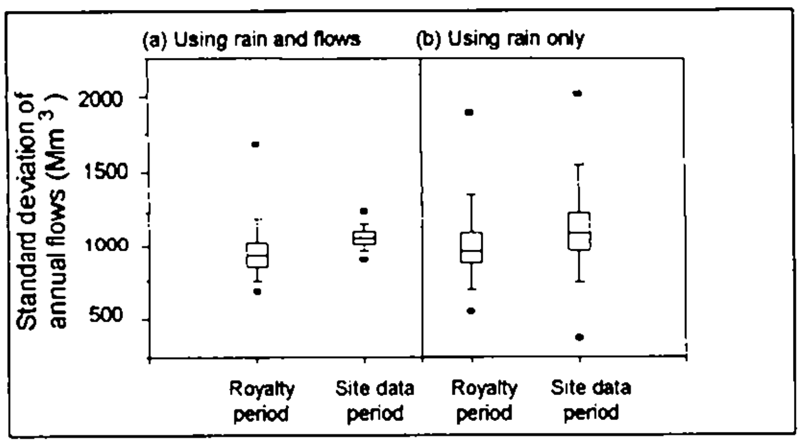
Sub-basin A



Sub-basin B



Sub-basin C



Sub-basin D

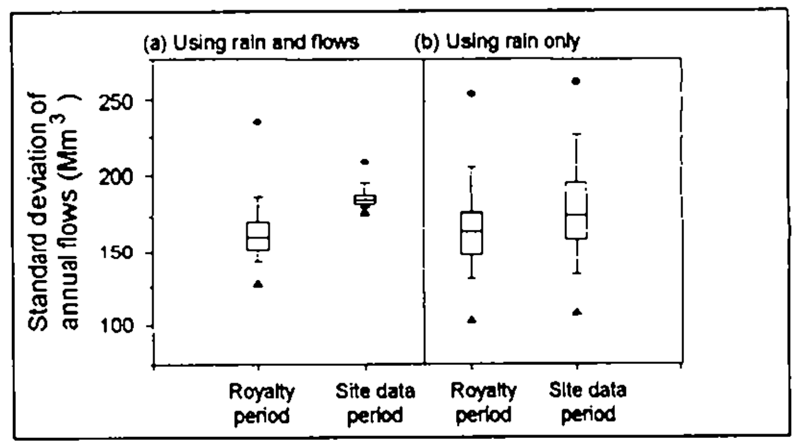
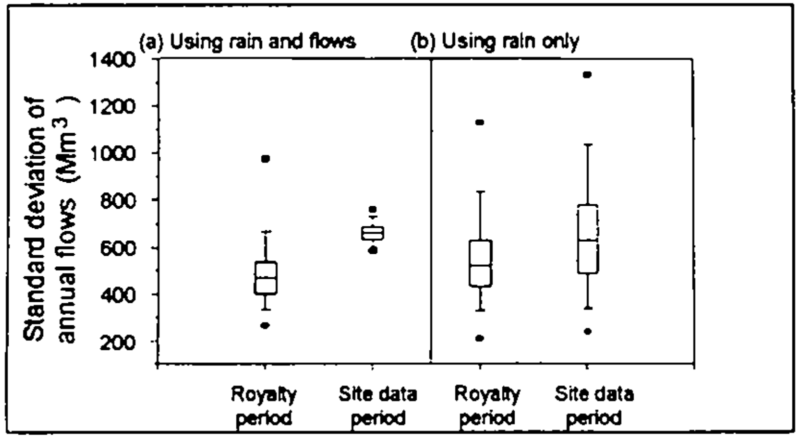


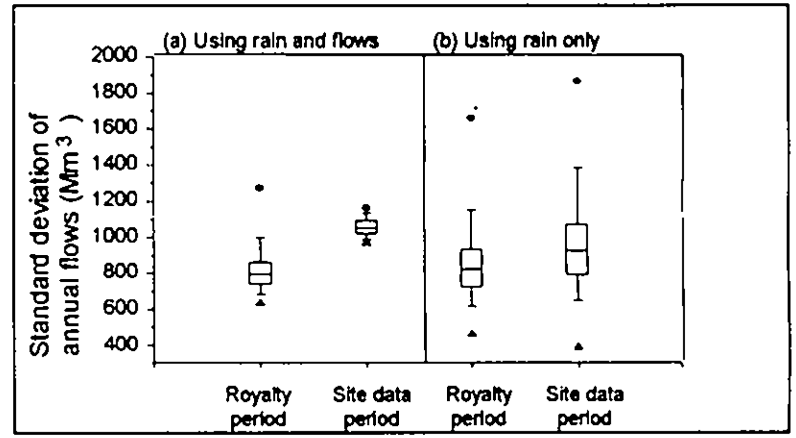
Figure A.2

Comparison of observed and simulated standard deviations for several representative basins

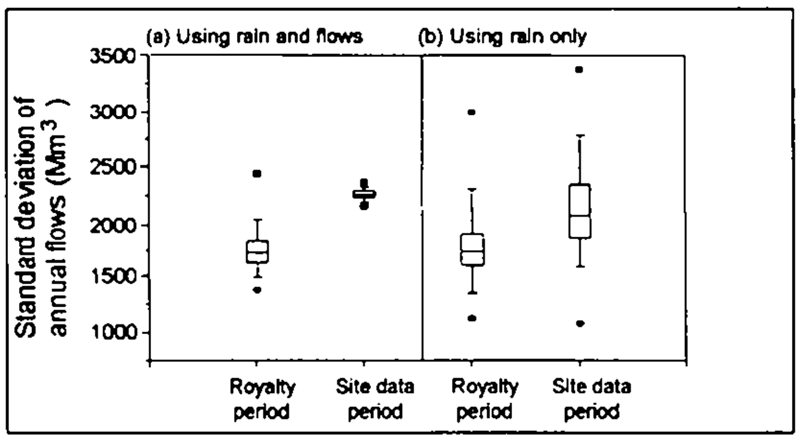
Sub-basin E



Cumulative flows:Koma Koma



Cumulative flows:Seaka



Cumulative flows:Oranjedraai

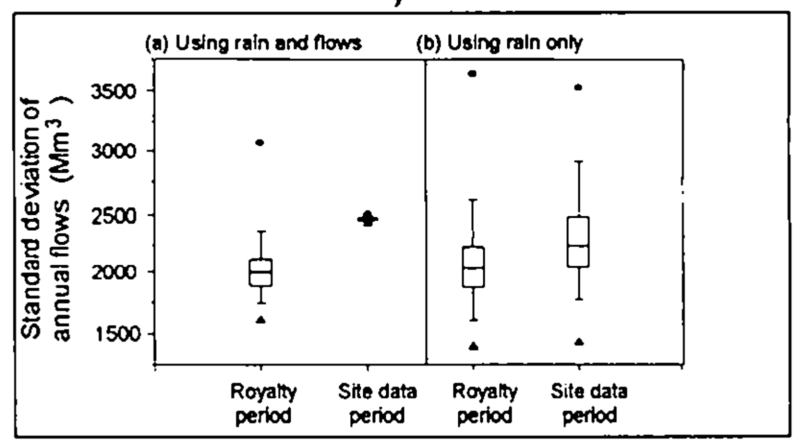
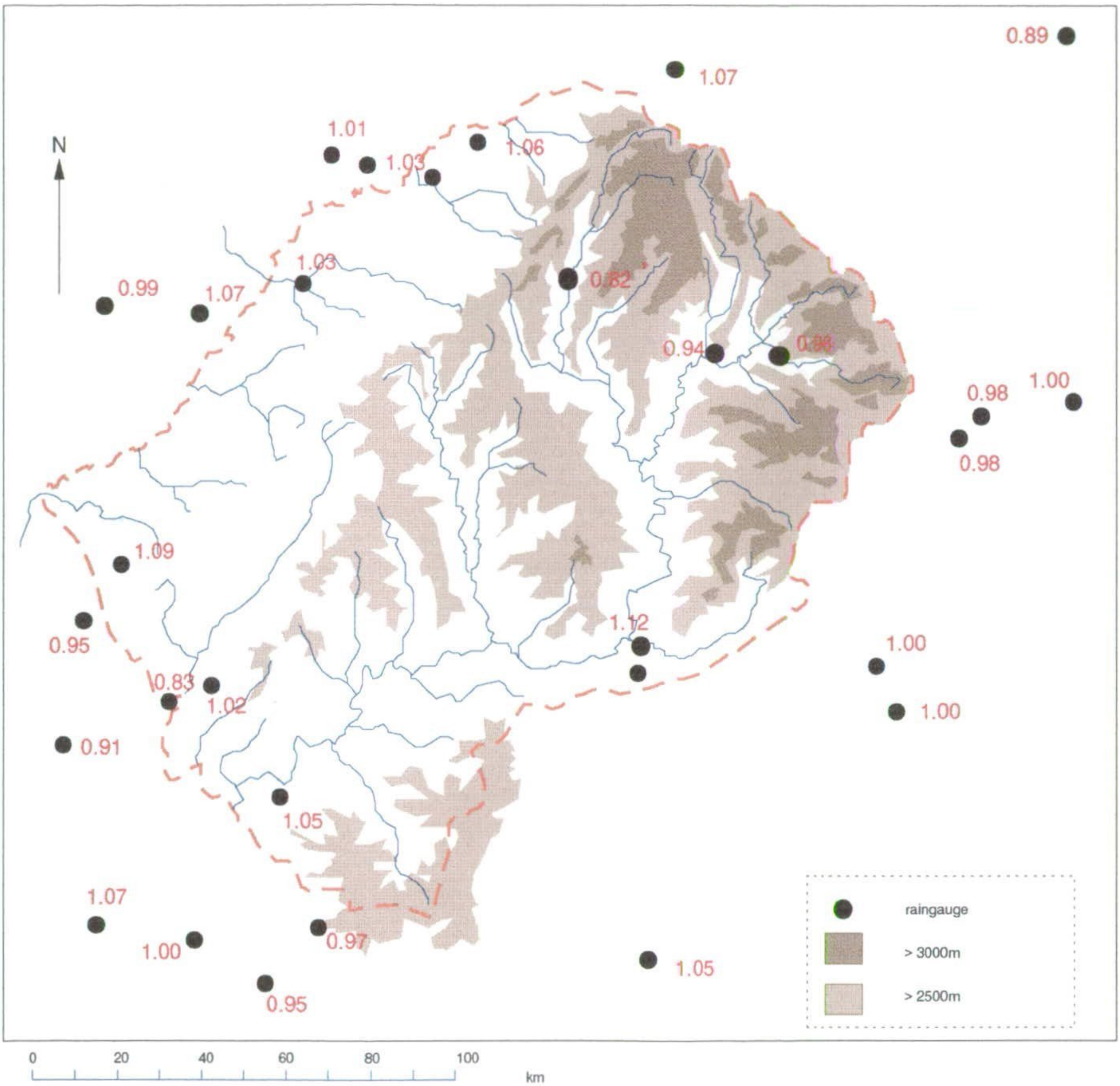


Figure A.2 cont.

Ratio of mean annual rainfalls in the periods 1930 - 1966 and 1967 - 1992 (based on infilled annual records)



* Insufficient annual values for reliable long term means

Figure A.3

Comparison of modelled flows for Oranjedraai
with estimated flows for Aliwal North (1930 - 1991)

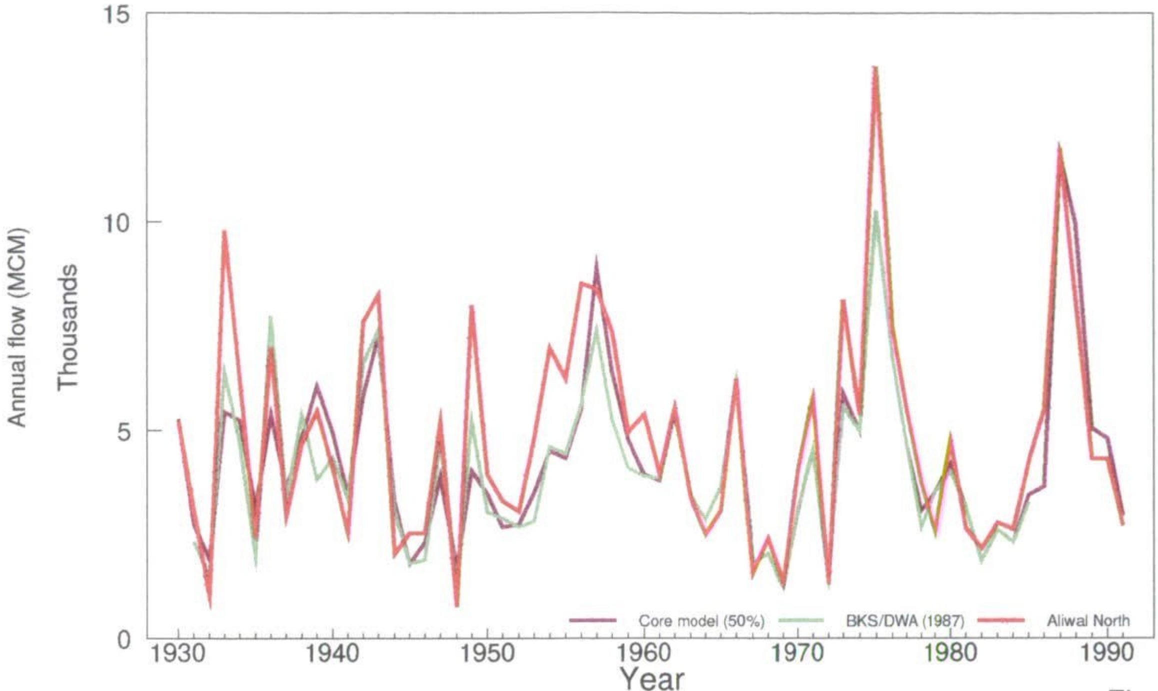


Figure A.4

Example of simulated flows for Oranjedraai (5 runs)

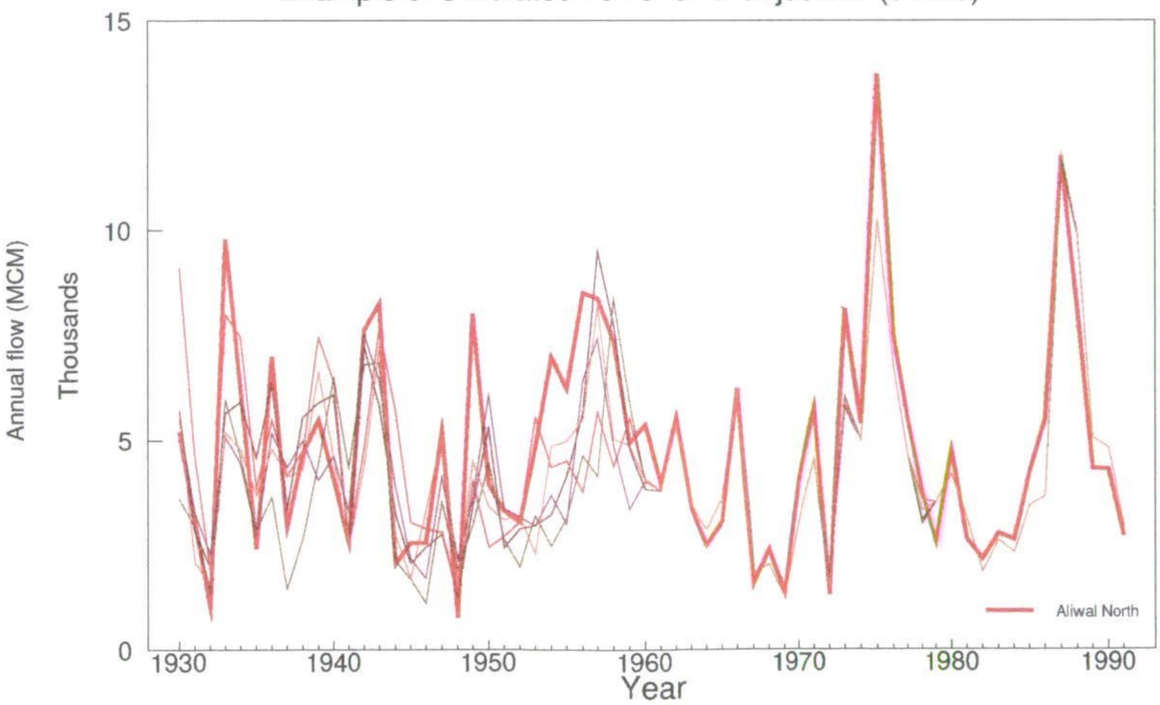


Figure A.5