

Analysis of catchments response to severe drought event for improved water resources

Manta Devi Nowbuth*
*Faculty of Engineering,
University of Mauritius
Email: mnowbuth@uom.ac.mu*

Anousha Saiboo
Mauritius

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Abstract

Drought is a natural hazard that is a normal part of climate in all regions of the world. It can result in serious economic, social and environmental impacts, if not properly managed. Consequently, there is a need to take precautionary measures to prevent problems associated with mismanagement of drought events. In this study, two catchments namely the Grand River South East and River Cascade of Grand River North West, have been analysed so as to better understand their response to dry spells. Three methods were initially selected namely; Flow Duration Curve, Low Flow Frequency Curves and the Base Flow Index. The second step in this study was to perform more in depth drought. The Run Sum analysis method and the Low Flow Frequency Analysis using Weibull Distribution were used to characterise the drought event. The analyses firstly noted that the two catchments under study responded differently to rainfall events. The Low flow frequency analysis was used to identify a threshold value, below which dry conditions were considered. The run sum analysis method was a sound method which indicates in advance the coming of dry spells, and this can help in better management of water resources, especially for an island.

Keywords: Drought, Low Flow analysis, Run Sum Analysis, Island, Drought Indexing

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INTRODUCTION

Drought is a complex phenomenon which manifests itself in different parts of the hydrological system and at different spatial and temporal scales. As a drought develops and subsequently decays, there may be considerable variation in timing, intensity and duration of stream flow depletion between nearby catchments. Drought implies scarcity of water which adversely affects various sectors of human society for example agriculture, hydropower generation, and the water supply industry. A combination of droughts or sequence of droughts with human activities may lead to desertification of vulnerable arid, semiarid and dry sub humid areas whereby soil structure and soil fertility are degraded or disappear. The prime cause of drought is the occurrence of below normal precipitation which is affected by various natural phenomena. Moreover, increased public and agricultural water demand during droughts exacerbates the strain on surface water resources leading to conflict between abstractors and need to protect the in-stream environment. In developed humid and sub-humid areas the damage caused by droughts is mainly monetary whereas in developing areas with arid or semi-arid climates, drought threatens the very livelihood of people. However, improved monitoring and management of water resources and understanding of the development of droughts can mitigate the impact of droughts. However, any such impacts could be addressed better with an improved scientific understanding of the spatial and temporal controls, on how catchments responds to drought conditions.

In 1998, Mauritius experienced a severe dry spell which was characterised by a high deficit in rainfall. The dry spell started at the beginning of the November 1998 and ended in January 1999, provoking serious drought conditions in the country and affecting all sectors in the island. This paper analyses how two particular catchments have responded to that drought event, with a view of obtaining a better understanding of how drought events can be managed in the future.

LITERATURE REVIEW

The importance of rainfall data analysis for planning of surface water resources systems, and the need to monitor river flows for management of droughts, is increasingly being recognised. A study was carried out by Fry *et al.*, (2003) to identify most suitable methods for analysing dry spell conditions in rivers located in southern Africa. Four methods were studied in detail, namely; Low Flow Frequency Analysis, Run-Sum Analysis, Runoff accumulation analysis and the Ranking of flows and compared with extremes.

The low flow frequency analysis or commonly known as the flow frequency analysis method is widely used in hot tropical climate like Mauritius (Fetter, 1994). This is a graphical based technique for estimating the probability that a year records an annual minimum flow less than a given critical flow. Flow frequency curves are frequently used for assessing the severity of extreme events, and have applications in economic studies where the risk of an event occurring in a given design project can be calculated from the curve and use in cost-benefit analysis (Tallaksen *et al.*, 1997). The slopes of the low flow frequency curves reflect the

effect of groundwater storage on the flow variability. Permeable catchments having steeper flow frequency curves than impermeable catchments. This graphical method also provides a sound basis for identifying the minimum value, below which dry conditions can be assumed.

The run-sum analysis method (Tallaksen *et al*, 2004) also commonly known as a threshold level analysis method, and allows drought events to be described in more detail by determining both duration and deficit volume of the event (Figure 1). Accordingly, droughts are defined as flows below a predetermined threshold. Thus continuous runs of flow less than the threshold are identified and statistical analysis of drought characteristics are carried out. The characteristics of drought are:

- Duration of drought, d - length of time for which the flow remains below threshold level
- Severity or deficit, s - cumulative volume of flow deficit over duration of drought
- Magnitude - the average volume of water deficit over the drought duration

The run off accumulation time is the time required to accumulate a given volume of water at a site on a river. The estimated time to accumulate the mean annual runoff is on average one year (Raghunath, 2006). This is a relatively simple approach, which is developed as a mean of comparing the current flows to historic quantities. It is used as a part of the assessment of ongoing droughts and to illustrate past droughts. Each day from the start of the hydrological year, the flow values are accumulated to find the total volume of runoff to that point in due course. Then, the accumulated daily flow volumes are ranked and is assigned an exceedance probability using $P = i / (1+N)$. Appropriate curves of accumulated flow are then created for a set of probabilities of exceedance by interpolation between ranked data. The data for any years can be examined against the curves and the probability of the flow volume for the year can be determined.

The ranking of flows and comparison with extremes method is a relatively simple type of presentation of data in which monthly flows are compared both graphically and statistically, to historic minima, maxima and means. This method can be used to examine past drought events and evaluate ongoing droughts. Flows for period of five years are compared with extremes and monthly mean flows derived from preceding period of historic data. This method also includes tabulation of monthly flows summed over several months as percentage of long-term means and ranking of the values in relation to historic data.

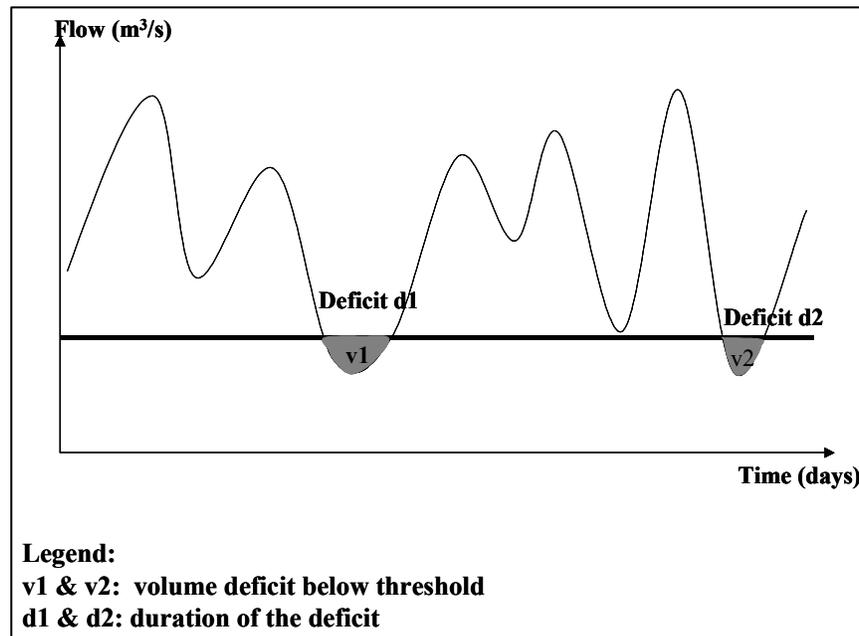


Figure 1: Run Sum Analysis of river flow data

WATER RESOURCES IN MAURITIUS

Over the last 20 years, the increasing water demand has pressurised fresh water bodies of the island (Proag, 1995; Ramjeawon, 1994). Water is used for industrial, commercial and domestic purposes. Rainfall distribution over the year indicates that in general February and March are the wettest months. The rainy season ranges from December to April, while the dry season extends from September to November. Mauritius with an area of about 1865 km² receives an average annual rainfall of 2100 mm, equivalent to 3900 Mm³ of water. Most of this rainfall is received in summer especially during cyclonic periods that extend from December to April. Mean annual rainfall varies from 1500 mm on the eastern coast to 4000 mm on the Central plateau and 800 mm on the western coast (Hydrological Year Book, 2000). There are about 256 operational rain gauges in Mauritius. The size and shape of the watersheds result in heavy rainfall producing flashy floods with very sharp peaks lasting only a few minutes. During such floods, a large fraction of runoff is lost to the sea. Flows in surface streams/rivers vary from a few litres per second to more than 500 m³/s. There are about ten reservoirs each of capacity 70 Mm³ and about 340 surface water abstractions points.

Mauritius experienced its most severe drought from November 1998 to December 1999, and this showed a need for an effective drought management operation as from the month of March, just after the expected rainy periods. Rainfall data was analysed in two parts; first the rainfall data during the dry period was analysed and then the cumulative rainfall data during the normally wet period (November-

January) for different stations were analysed. There were compared to the long term mean data (from 1955 to 1999), obtained from the Meteorological Services for the whole island. Moreover, the winter rains from May to October which represent one third of the annual rainfall were also compared to the long term average rainfall. Finally, frequency analysis of annual rainfall data for the last 120 years for the rainfall station of Savinia was carried out so as to compute return periods of events. The first three months of the wet season (November to January) the cumulative rainfall was only about 27% of the long-term mean. During the normally wettest months of the year (February and March) rainfall was below the normal, which amounted to about 57% of the long-term mean. Winter rainfalls from May to October, which normally represent one third of the annual rainfall, were about 77 % of the long-term mean. The rainfall was less than the normal and amounted to about 50 % of the long-term mean over the western region. The overall observation made was that the most affected area was the Northern region with a 39% deficiency and the least affected region was found in the East with a 62% deficiency. Groundwater resource which depends significantly on recharge from rainfall was also affected. The local water authority had set up a drought management committee (Bhowruth, 2002), to manage this situation as best as possible.

THE STUDY AREA

For the purpose of this study, the response of two catchments to rainfall events were analysed. Grand River South East (G.R.S.E) and River Cascade, a tributary of Grand River North West (G.R.N.W.) were chosen as the two catchments for the purpose of this study. The Grand River South East basin (Figure 2) is the largest and longest river in the island, covering an area of 164 km² and a length of 27.67 km and consists of a large number of tributaries. The GRNW is gauged at several stations, but data were analysed for two particular gauging stations which are coded as E07 and E008a. These two stations were considered since the hydrological year book (2000) considered that these two stations reflected the true flow system of the river. Moreover, there is a major diversion of water to feed La Nicolière Reservoir from station E008a, so a combination of the two stations E07 and E008a would give a good analysis of the response of the whole catchment.

The catchment Grand River North West (Figure 3) consists of 113.93 km² area and is fed by River Seche, River Mesnil, River Plaines Wilhems, River Terre Rouge, River Profonde and River Cascade. Since it has many tributaries, River Cascade is selected and the river is least affected by diversions.

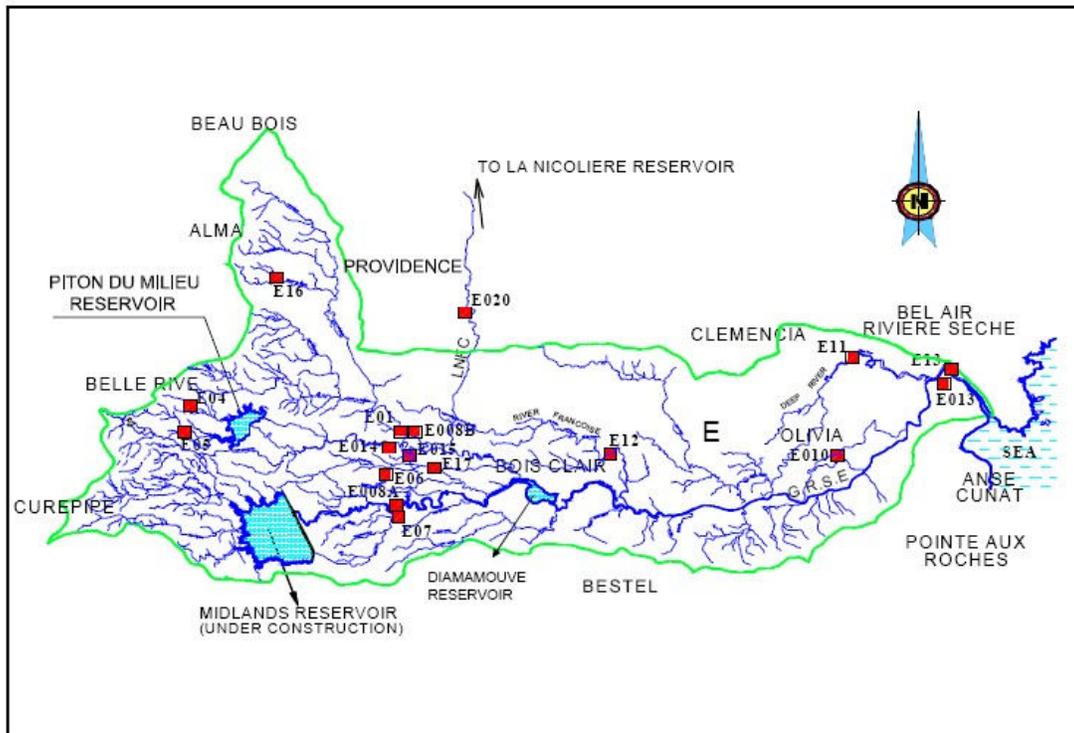


Figure 2: Catchment Grand River South East

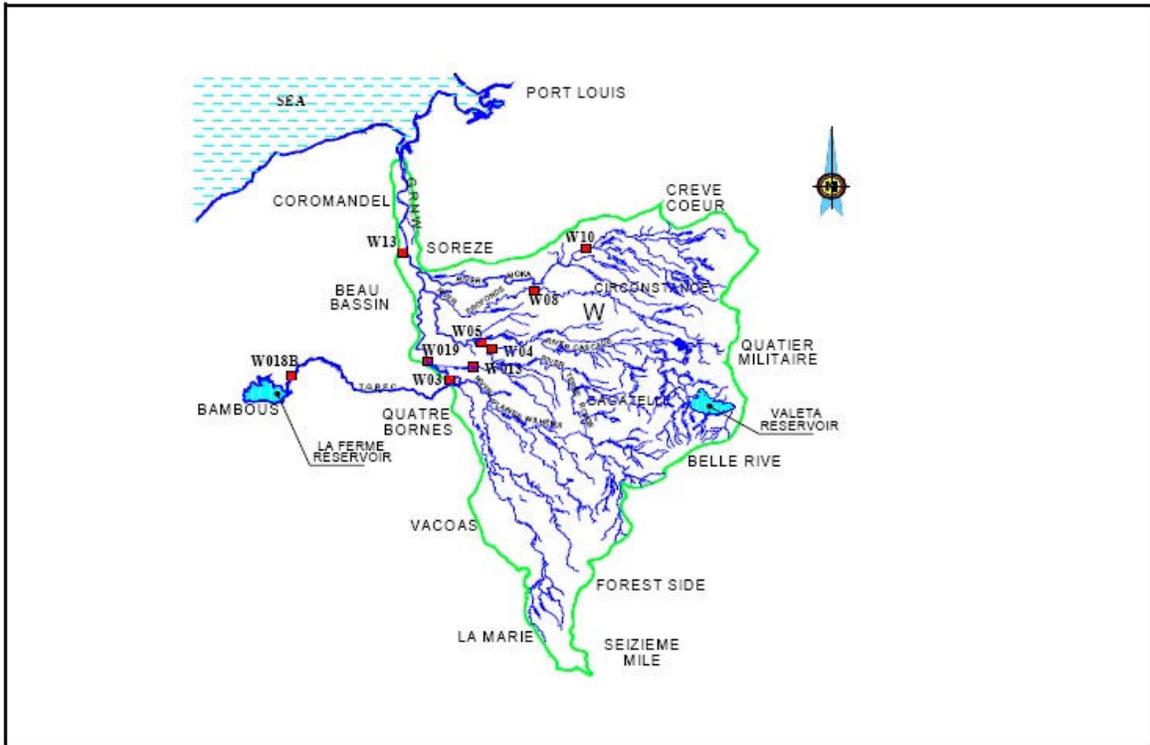


Figure 3: River Cascade within the Grand River North West catchment

DATA ANALYSIS

The first stage of this analysis was to study the response of the two catchments to rainfall events. Flow Duration Curve, Low Flow Frequency Curve and Base Flow Index methods were used to describe the flow patterns of different catchments. In the second stage, the response of the catchment to the 1998/1999 drought event was analysed in detail, using Run sum analysis and Low flow frequency analysis methods.

Characteristics of the two catchments

Comparison of the flow duration curves for GRSE and River Cascade of Grand River North West, indicated that the GRSE had a more stable flow regime, recording higher discharge. The mean flow of GRSE was $2.04 \text{ m}^3/\text{s}$ and the mean flow of River Cascade was $0.7 \text{ m}^3/\text{s}$. The flow duration curve for GRSE (Figure 4) indicates that 37% of the time the flow in this river was above the mean flow, while for River Cascade (Figure 5), it can be noted that only 26% of the time the flow in this river exceeds the mean flow. The Base Flow Index method noted that groundwater contribution was more significant for GRSE, with a BFI of 0.098 as compared to 0.053 for River Cascade. A threshold value was noted for both flow duration curves, below which drought conditions will be assumed. This threshold

value was Q90, being 0.62m³/s for GRSE and 0.2 m³/s for River Cascade. This threshold value was used in the rum sum analysis method to predict any imminent drought conditions and to evaluate the severity of the drought event. The low flow frequency analysis indicated that the mean low flow for River Cascade had a return period of 1.9 years whereas that of GRSE catchment had a return period of 2.5 years, once again confirming the more stable flow regime of GRSE.

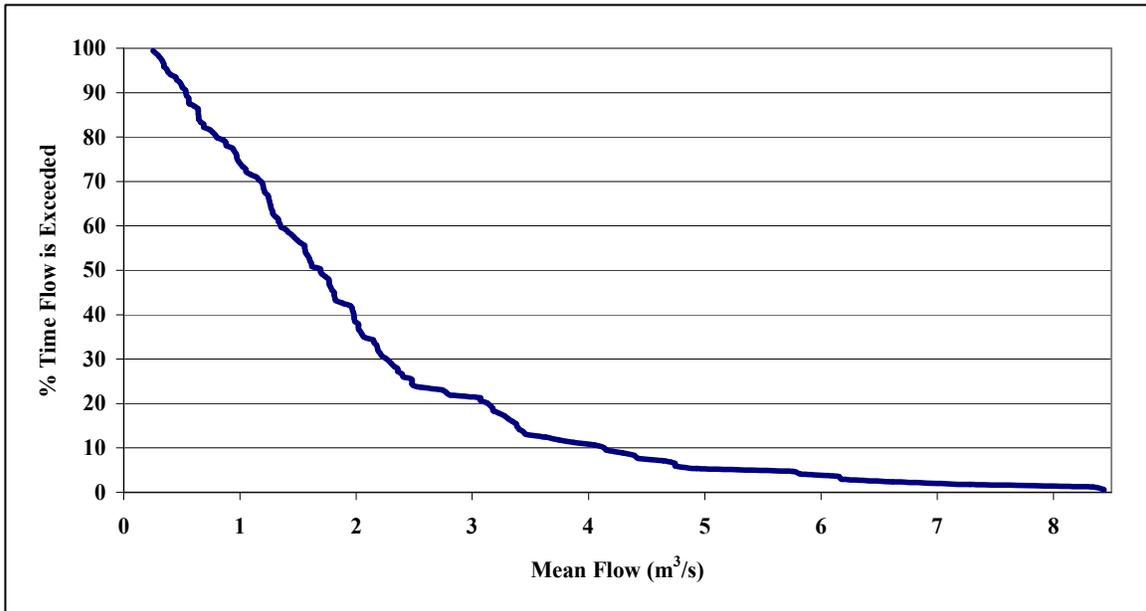


Figure 4: Flow duration curve: GRSE

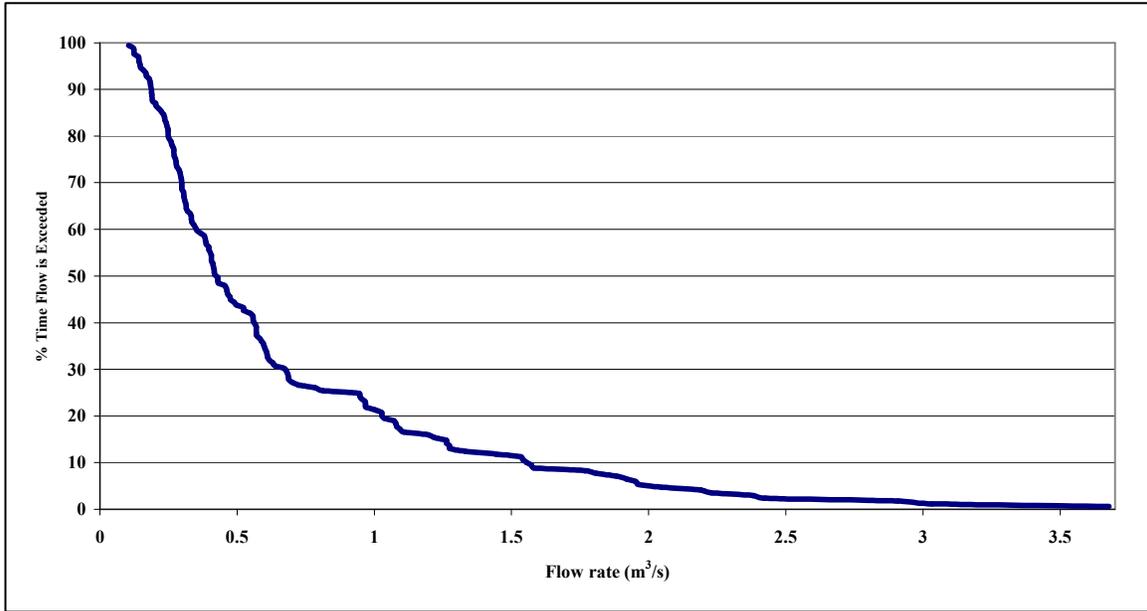


Figure 5: Flow duration Curve: River Cascade (GRNW)

Response of the catchments to the 1998/1999 drought event

The Run Sum analysis was used to analyse the response of the catchments to the 1998/1999 drought event. The storage deficit, the cumulative and drought deficit were calculated for the period 1991-2005 (Figures 6 & 7) to better highlight the response of the events to the drought event. The local water authority base their analysis of drought conditions on a threshold of 30% of the long term mean flow. For GRSE the 30% long term mean flow was 0.61 m³/s for GRSE and for River Cascade it was 0.202 m³/s. These thresholds were used, as it did not vary much for the identified Q90 value from the first analysis, Q90 being 0.62m³/s for GRSE and 0.2 m³/s for River Cascade. The analysis showed that for River Cascade drought conditions were recorded for 1998/1999, with a deficit of 0.0123 m³/s whereas for GRSE no drought conditions could be recorded. Similarly, it was noted that the duration of this drought for River Cascade was 1 year and the severity is 3.4 x 10⁻¹⁰ m³/yr, giving an indication of the amount of water which should have been stored had there been no dry spell. Based on the 30% threshold value, the results obtained confirmed the fact that the catchment Grand River South East was more resistant to drought event. However, drought conditions did prevail during the 1998/1999 period, and this may question the threshold value being used for monitoring drought, Q90 may be too conservative a value.

The run sum analysis method can also be used for analysing daily flow, monthly and yearly river flow data. The use of average daily data which resulted into larger

sample size and greater relationship. Thus the daily analysis picked out the more persistent periods of low flows (Figures 8 & 9). As can be observed from Figures 7 to 10, the threshold value is very determining in predicting dry spells or the coming of a drought event. So for drought monitoring, the analysis suggested that daily data based upon a more realistic threshold will yield more indicative information.

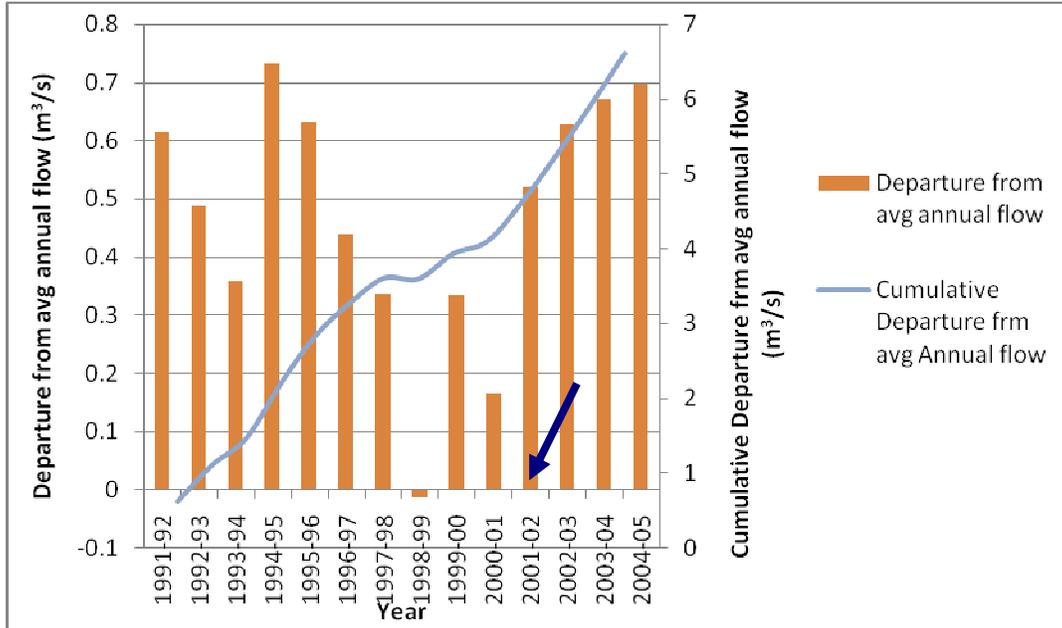


Figure 6: Departure from long term annual average flow River Cascade – only 1998/1999 detected

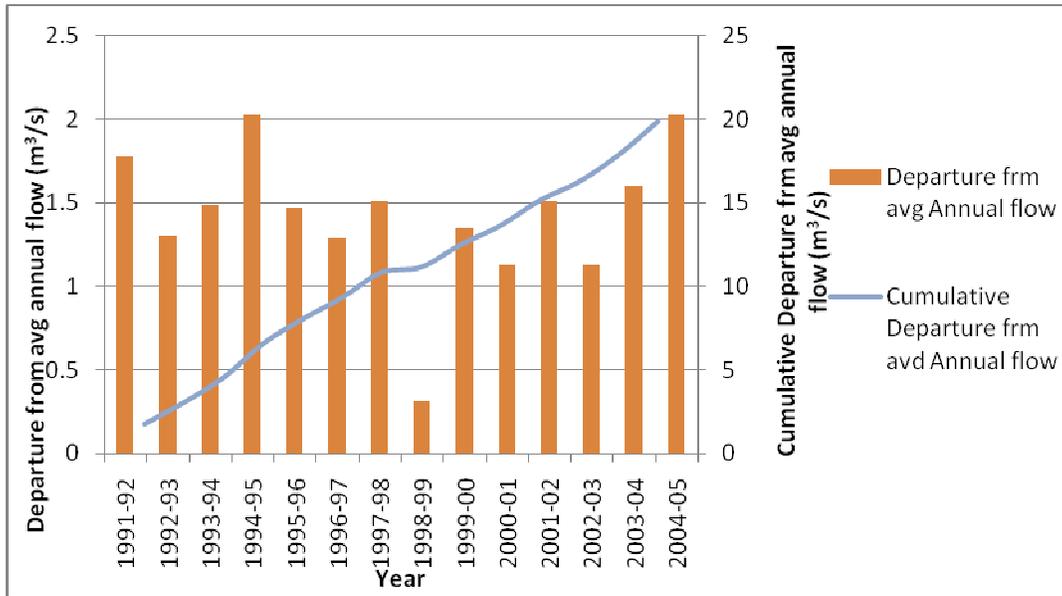


Figure 7: Departure from long term annual average flow GRSE – nothing detected 1998/1999 detected

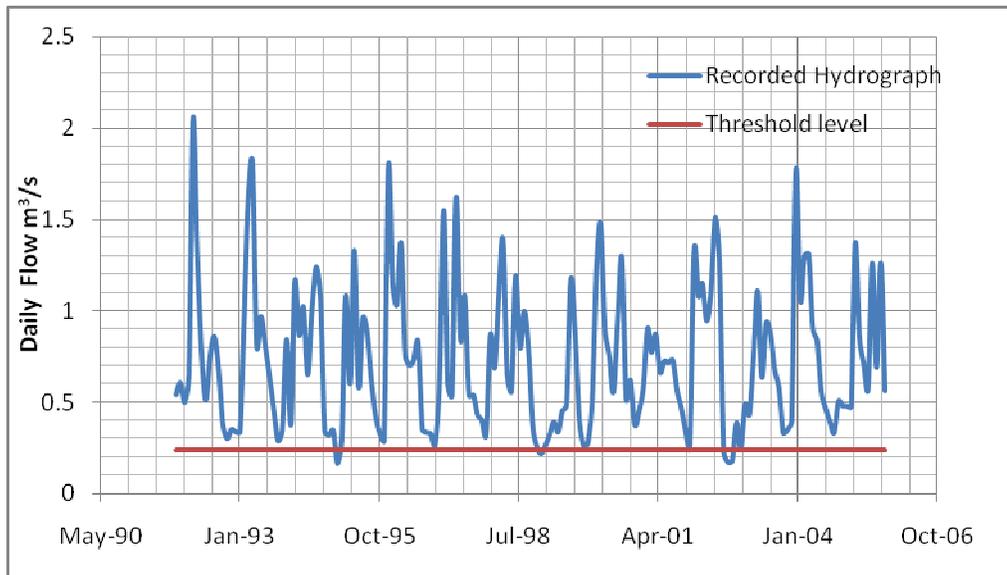


Figure 8: Drought evaluation on daily flows (GRSE)

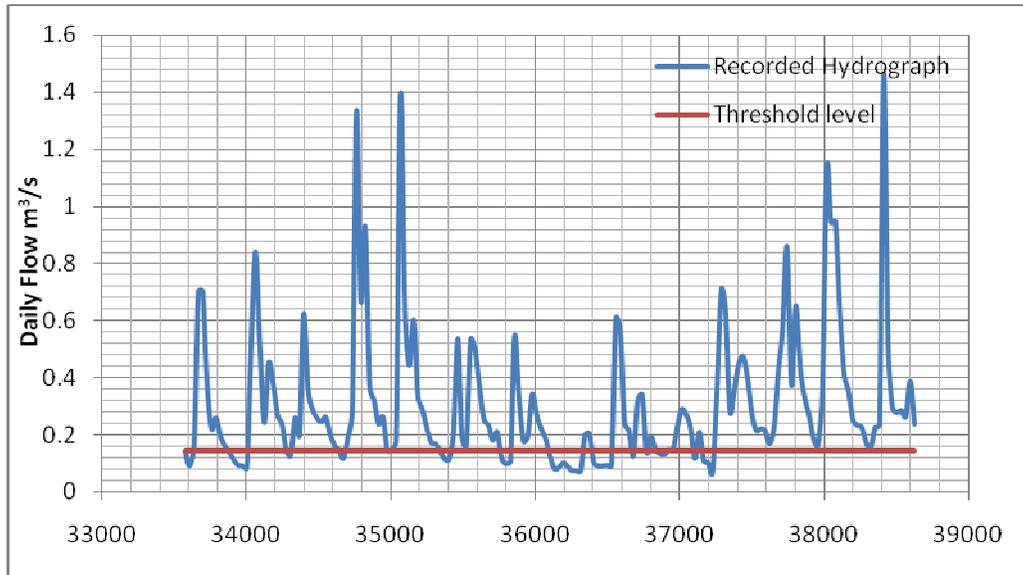


Figure 9: Drought evaluation on daily flows (River Cascade)

Next step was to use the low flow frequency analysis and predict the low flow conditions at different return periods for both rivers. For this Weibull - Extreme Value Type III (Chow, Ven Te, 1988) probability distribution was applied for predicting the return period. The results (Table 1) indicate that GRSE has a more stable flow regime than River Cascade.

Return Period	Projected Flows (m ³ /s)	
	Grand River South East	River Cascade
25	0.3766	0.2933
50	0.4060	0.3211
75	0.4242	0.3423
100	0.4375	0.3597
125	0.4481	0.3746
150	0.4570	0.3876
175	0.4646	0.3993
200	0.4713	0.1237

Table 1: Prediction of low flows at various return periods

CONCLUSION

This study has highlighted some pertinent issues. Firstly the 30% long term average flow rate which corresponds closely to the Q90 value, used to monitor dry spells looks to be too high. There is a need to use a more realistic value. Secondly there is a need to study each catchment in detail, since each one has a different type of flow regime, and their vulnerability to dry spells is likely to vary accordingly. The prediction of the coming of drought event is sounder when daily river flow rate data is being used. The Run-Sum analysis not only give an indication of the volume deficit but also on the duration and severity of the impacts of the dry spells, and this method is likely to help significantly in better water resource management during such periods. The low flow frequency analysis is a very good indicator of the vulnerability of a river, and again this type of analysis will provide for improved water resource management. The methods highlighted can be used to get a clear insight of the capacity and characteristics of catchments, and this will significantly help to identify appropriate and timely measures that need to be taken for different catchments during drought periods.

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