HYDROCLIMATIC TRENDS, SEDIMENT SOURCES AND GEOMORPHIC RESPONSE IN THE BELL RIVER CATCHMENT, EASTERN CAPE DRAKENSBERG, SOUTH AFRICA

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ABSTRACT

The Bell River in the Eastern Cape Drakensberg of South Africa has shown recent signs of channel instability as evidenced by avulsion, sinuosity reductions, gradient steepening and general channel instability. Analysis of rainfall data did not provide evidence for progressive long term change in rainfall pattern for the catchment. However, annual and seasonal rainfall cycles with variance peaks every 16-19 years were found, from which it can be inferred that flood events following years of below average rainfall may cross the threshold limit for channel stability. Channel instability is often followed by a major flood event after sustained low rainfall periods, a sequence referred to as the Flood and Drought Dominated Regimes by Warner (1987). Evidence presented also indicates an increase in catchment erosion in the past century with attendant sediment production increases to the channel. This may be due to catchment land use and management practices (following settlement by commercial farmers) superimposed on long term climatic changes. The conclusions are that catchment and channel processes are inseparable, and that disequilibrium in the catchment will be transferred to the channel.

Introduction

Instability in river channels can result from two groups of factors acting within the fluvial system, catchment factors and channel factors (Baker, 1977). Together they determine channel form and process within a spatial and temporal context. The morphology of a stable river channel has been related to the flow discharge and sediment load that is conveyed through it (Schumm, 1969; Lewin et al, 1988), these in turn are the response to catchment processes. For example, Schumm (1969) developed a qualitative model demonstrating the direction of morphological response in terms of sinuosity, gradient, form ratio and so on to particular combinations of discharge and sediment yield. Any process that alters either catchment hydrology or sediment yield can be expected to result in channel instability.

A changing rainfall regime may be responsible for causing channel change and instability in a river system (Warner, 1987; Eybergen and Imeson, 1989; Harvey, 1991). Warner (1987) related channel change in the MacDonald river in Australia to a climatically related shift in the sediment and hydraulic regime coupled with land use changes, while Harvey (1991), working in the north west of England, indicated that climatic changes are important both in terms of catchment processes (runoff and erosion on hillslopes) and the resultant channel processes (magnitude and frequency of flow events and sediment regime). Australian work has also pointed to the occurrence of periodic drought and flood dominated regimes during which there is a shift in channel processes between accretion and erosion (Erskine and Warner, 1988).

Land use changes have been shown to impact on both hydrological processes and sediment yield (Smith, 1982; Higgs, 1987; Lewin et al., 1988; Prosser, 1991, Thorne, 1991) and hence may trigger channel instability. Knighton (1989) has demonstrated how an increased sediment load resulting from tin mining induced marked changes in channel morphology in a Tasmanian river. Channel instability could also be triggered by an increased sediment load resulting from accelerated erosion in the catchment associated with poor land management. Debano and Schmidt (1989) have described the delicate interrelationship that exists between catchment hydrology, soil erosion and catchment condition as affected by grazing management and related activities.

River channel changes can be explained therefore within the context of changing energy environments (Warner, 1987) which are absorbed by the system through a series of channel adjustments (Simon, 1988). Most work on river channel changes in recent years has concentrated on either climatic changes (Erskine, 1986), or anthropogenic influence (Knox, 1977; Beaumont, 1978; Park, 1981). This paper examines the evidence for short term climatic change and land management as factors contributing to channel instability in the Bell River in the Eastern Cape Drakensberg of South Africa.

Evidence for instability in the Bell River can be seen in the form of meander cutoffs and channel widening, resulting in a shift from a meandering to a straighter, divided channel (Dollar, 1992; Rowntree and Dollar, in prep.). An examination of sequential aerial photographs for 1952, 1969 and 1975 and field surveys in 1991 showed the development of a series of meander cutoffs and general channel instability. As a result there has been a 8% reduction in sinuosity over a 20 km length of channel between 1952 and 1991.

It is hypothesized that channel change in the Bell River has been the result of either changes in the rainfall regime over the Bell River catchment or increased sediment loads resulting from changes in land use, or land management, since occupation by commercial farmers in the middle of the last century. This paper examines these hypotheses in turn and evaluates the evidence available.

The Study Area

The Bell River in the Eastern Cape Drakensberg forms part of the headwaters of the Orange river drainage system (Figure 1). It drains a mountainous catchment with an area of approximately 424 square kilometres. The altitude of the catchment ranges from 1720 metres (a.m.s.l) to 3001 metres. The mean annual rainfall ranges from 700 to 1300 mm, with precipitation concentrated in the summer months of October to March. The catchment has been used extensively for grazing by commercial farmers since the 1870s (Hugo, 1966). Floodplain areas are cultivated to produce fodder for livestock.

The geology of the area forms part of the Karoo Sequence. Pink, massive, fine grained, Clarens Sandstones outcrop in the lower catchment; compact amygdaloidal lavas of the Drakensberg basalts (Du Toit, 1912; Pemberton, 1978) comprise the upper slopes and higher lying regions. Soil depth on the steeper slopes of the upper catchment is limited, but deep soils form on the colluvial and alluvial sediments of the footslopes and floodplain areas. These represent significant sediment stores that can be remobilised by gullying or channel migration.

Many of the south facing slopes in this area of the Drakensberg are thought to have been under the influence
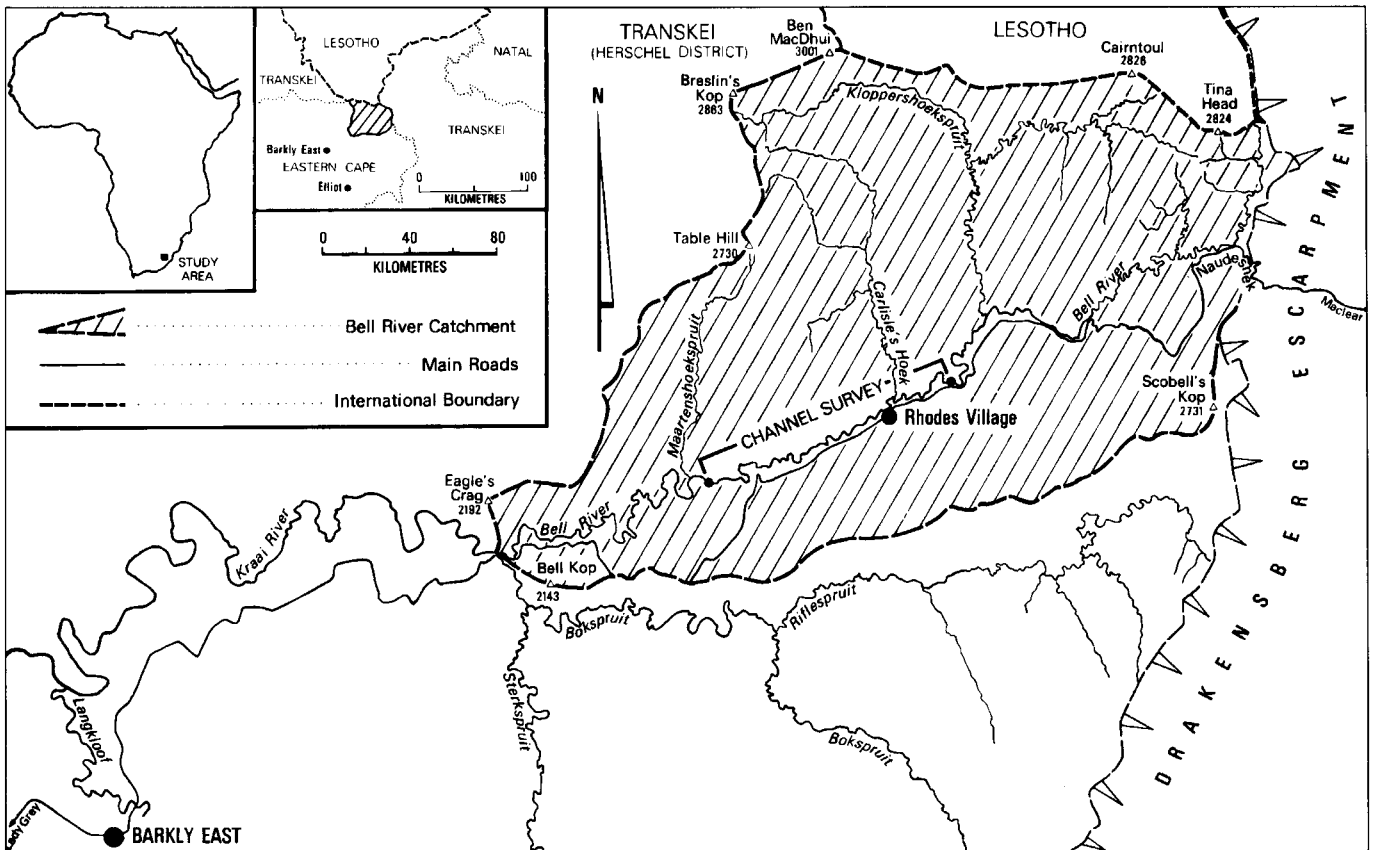
FIGURE 1: Study area

of Quaternary periglacial activity (Hanvey et al., 1986; Lewis and Hanvey, 1991). The associated sediments range in particle size from large boulders to fine sand. Due to their unconsolidated nature and high sand and gravel content, these sediments are highly erodible once the protective vegetative cover has been removed (van Rheede van Outshoorn, 1988). In contrast, north facing slopes consist of colluvial deposits typical of southern Africa (see Watson et al., 1984 for a full description), which produce generally finer material (< 2 mm).

Vegetation in the catchment is dominated by climax grassveld of *Themeda-Festuca Alpine Veld* (Acocks, 1988). The vegetation tends to be short and dense and ranges from sour to mixed grazing. The dominant species of this vegetation type is *Themeda triandra*. Acocks (1988) writes that the main effect of mismanagement of this veld is a change to a more woody *Karroid False Fynbos* as has been noted in several parts of the Bell River catchment.

The second grassveld type is Cymbopogon-Themeda Veld (Acocks, 1988) occurring predominately in the lower lying regions of the catchment along the valley floors. The dominant species is Themeda triandra, with *Eragrostis chloromelas triandra* and *Microchloa caffra* increasing with grazing pressure.

Rainfall Trends

The first hypothesis put forward to explain channel instability was a change in rainfall regime over the catchment. Tyson (1986) demonstrates the cyclical nature of the pattern of South African rainfall, especially for the summer rainfall regions in the north east of South Africa. In this region there is a distinct seasonality within each year, as well as alternating wet and dry cycles between years. Variance peaks in the region of 18-22 years are common, with most peaks occurring close to 18 years (Dyer, 1975; Dyer and Tyson, 1977). Similar cycles are

experienced elsewhere in southern Africa (Mazvimawi, 1989). Tyson (1978) showed how decades 1916 to 1925, 1936 to 1944, and 1954 to 1963 experienced above average rainfall, whereas the decades in between experienced below average conditions.

Research in southern Africa to date has shown that no long term increase or decrease in rainfall can be discerned for regional data series over the period of rainfall records (Louw, 1965; Tyson and Dyer, 1975; Dyer 1982; Tyson, 1986; Dent et al., 1987; Vogel, 1988), but that it is possible for individual stations and therefore, by inference, particular localities or small catchments to show a climatic trend which may be either positive or negative (Brook and Mametse, 1970). It may be possible therefore for the Bell River catchment to have experienced such a progressive trend in rainfall.

Research on southern African rainfall trends has focused on annual data series, with little attention paid to seasonal or daily data. From research in Australia, Erskine (1986) showed that changes in the seasonality of rainfall rather than annual changes may trigger instability. Time series for annual, seasonal and daily data are all considered in the present paper.

Methodology

Numerous methods of analysis have been used to describe climatic change (Brooke and Mametse, 1970; Dyer 1975, 1982; Lindesay, 1984; Tyson, 1986, Dent et al., 1987). No single method for determining climatic variability appears to be dominant in the literature. The methodology applied depends on the type of rainfall series used, the length of data series, and most importantly, the type of information and statistical parameters required from the data series. For the present study a methodology was devised that would determine whether there had been any medium term changes in annual, seasonal and daily rainfall
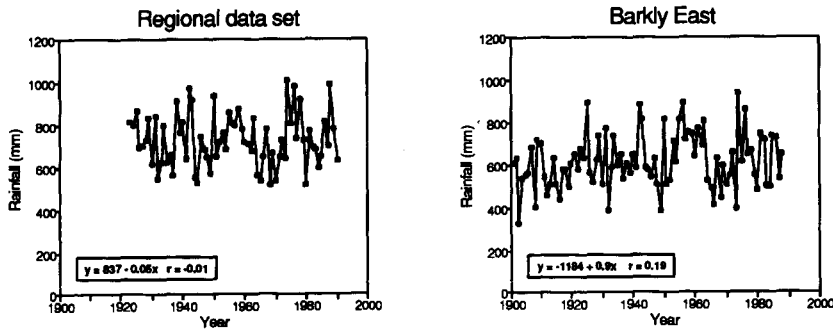
FIGURE 2: Rainfall chronology for regional data set (1923-1900) and Barkly East (1901-1989)
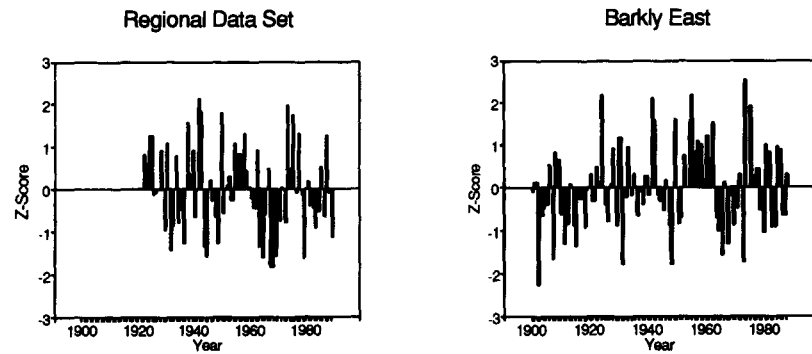

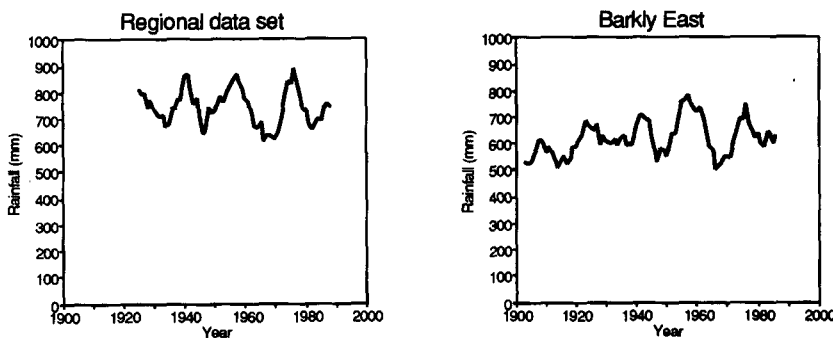FIGURE 3: Standardized anomaly index for regional data set (1923-1900) and Barkly East (1901-1989)

FIGURE 4: Five year moving average for regional data set (1923-1900) and Barkly East (1901-1989)

over the Bell River catchment. The methodology varied for the three time series and will be described in the appropriate sections.

Four stations in and around the Bell River catchment were chosen for statistical analysis (Table 1). These stations – Rhodes Police (1973-1990), Malpas (1923-1983), Funnystone (1923-1986) and Barkly East (1901-1990) – were chosen on the basis of length of record, proximity to the catchment and reliability of data. Although Barkly

TABLE 1: Summary Statistics, Rainfall Series.

VARIABLE	FUNNYSTONE	MALPAS	RHODES POLICE	BARKLY EAST
Date	1923-1986	1923-1983	1973-1990	1901-1990
Altitude (m)	1850	1800	1820	1780
Sample size	64	61	18	90
Mean (mm)	811	694	708	618
Median (mm)	807	689	700	606
Mode (mm)	793	685	692	633
Standard deviation (+mm)	158	141	117	127
Maximum (mm)	1150	1004	921	942
Minimum (mm)	535	412	534	327

East lies some 50 km east of the catchment, and receives considerably less rainfall, it was the only station whose data extended to the beginning of the century. Augmented data for these stations was supplied by the Computing Centre for Water Research (CCWR).

Annual rainfall

Analysis of the annual rainfall series included the development of a synthesised regional data set, the application of linear regression to the time series data in order to establish any long term trends (Dent et al. 1987) and a standardised anomaly index (Katze and Glantz, 1986; Hulme, 1990) and moving mean to establish short term variability.

The degree of correlation between the four annual series was found using Pearson's product moment correlation coefficient. High correlations were found between all four stations (Table 2), justifying the generation of a synthesised regional data series for the three stations Rhodes Police, Malpas and Funnystone. The procedure used was as follows. Firstly, simple linear regression was performed to establish the relationships between pairs of stations and hence to extend the data set for all three stations over the full period of record. Secondly, for each year the regional average rainfall was found for the three stations. This synthesised data set formed the basis for further analyses of climatic change. Barkly East was not used in the regional data set as it is further away from the catchment area and may therefore not be sufficiently representative. Separate analyses were carried out on this data set.

Linear regression was performed on the regional data set and the Barkly East data set to establish whether or not there was any linear trend in rainfall through time. The results are given in Figure 2.

TABLE 2: Regression Analysis, Bell River Rainfall Stations (0.05 Significance Level).

VARIABLES	REGRESSION EQUATION	CORRELATION COEFFICIENT
Rhodes Police on Funnystone	Y = 232.25 + 0.55 X	0.83
Rhodes Police on Malpas	Y = 316.68 + 0.55 X	0.78
Funnystone on Malpas	Y = 136.29 + 0.98 X	0.86
Rhodes Police on Barkly East	Y = 330.40 + 0.59 X	0.70
Malpas on Barkly East	Y = 207.10 + 0.76 X	0.73
Funnystone on Barkly East	Y = 222.58 + 0.92 X	0.78

Standardized Anomaly Indices (SAIs) (Eq. 1) were calculated for the two annual series. This index allows comparison of annual totals based on the standardization of rainfall using a z-score. Results are given in Figure 3.

SAI (z-score) = Yearly Total - Historical Mean (Eq. 1)

Historical Standard Deviation

A five year moving average was used as a method of smoothing the data series, allowing the identification of wet and dry periods. The results are given in Figure 4.

Seasonal rainfall

The data were divided into summer and winter rainfall series using the following procedure. Firstly, for each year the percentage monthly rainfall was calculated. The mean percentage monthly rainfall for the entire series was then determined (Table 3). From Table 3 clear breaks are apparent between September and October and March and April. October to March were designated summer or wet season months and April to September winter or dry season months. The summer months produce on average more than 70% of the yearly rainfall.

Simple linear regression analysis was performed separately on the summer and winter rainfall for each rainfall station. In this manner it was possible to identify the

TABLE 3: Seasonal distribution of rainfall

| MONTH | MEAN MONTHLY PERCENT | | | SEASON |
	Rhodes Police	Malpas	Funnystone	
October	10.43	8.84	9.08	Wet
November	12.10	10.42	11.43	Wet
December	12.64	13.18	12.70	Wet
January	13.18	15.07	14.19	Wet
February	13.53	13.67	12.78	Wet
March	11.74	12.89	13.26	Wet
April	6.88	7.40	7.91	Dry
May	3.78	4.93	5.32	Dry
June	3.38	2.18	2.86	Dry
July	2.27	2.66	2.50	Dry
August	3.77	2.99	3.09	Dry
September	6.30	5.14	4.89	Dry

presence of progressive trends in seasonal precipitation. The results are summarised in Figure 5.

Daily rainfall

Daily rainfall data were analyzed to determine whether there was any significant difference between the magnitude and frequency of daily events between wet and dry years of rainfall, and hence by implication, between wet and dry cycles. Daily data was obtained for three stations, Funnystone (1923-1986), Malpas (1927-1972) and Rhodes Police (1973-1990). The designation of wet and dry years was based on the regionalised data set, wet years being those which recorded above average and dry years below average rainfall.

For each rainfall station the frequency of daily rainfall depths of 10 mm or greater were tabulated according to the classes specified in Table 4. Separate distributions were derived for wet and dry years. Rainfall events recording less than 10 mm were excluded as it was assumed that these would have been of minor significance in terms of flooding and erosion (Stocking and Ellwell, 1976; Rowntree, 1988).

Results

Annual rainfall

Long term variability in regional rainfall can be seen from Figure 2. Although there is considerable variation from year to year there is no significant trend in the rainfall series. This finding conforms with results obtained by other southern African researchers. Thus even at this very local scale there is no progressive trend in rainfall.

The Standard Anomaly Indices plotted in Figure 3 demonstrate clear, alternating cycles of wet and dry rainfall periods. The five year running mean (Figure 4) shows a similar relationship, with the smoothed curves showing wet and dry cycles more clearly. Peaks occurred at intervals of around 16-19 years, concurring with the analysis of Dyer (1975) and Tyson and Dyer (1975).
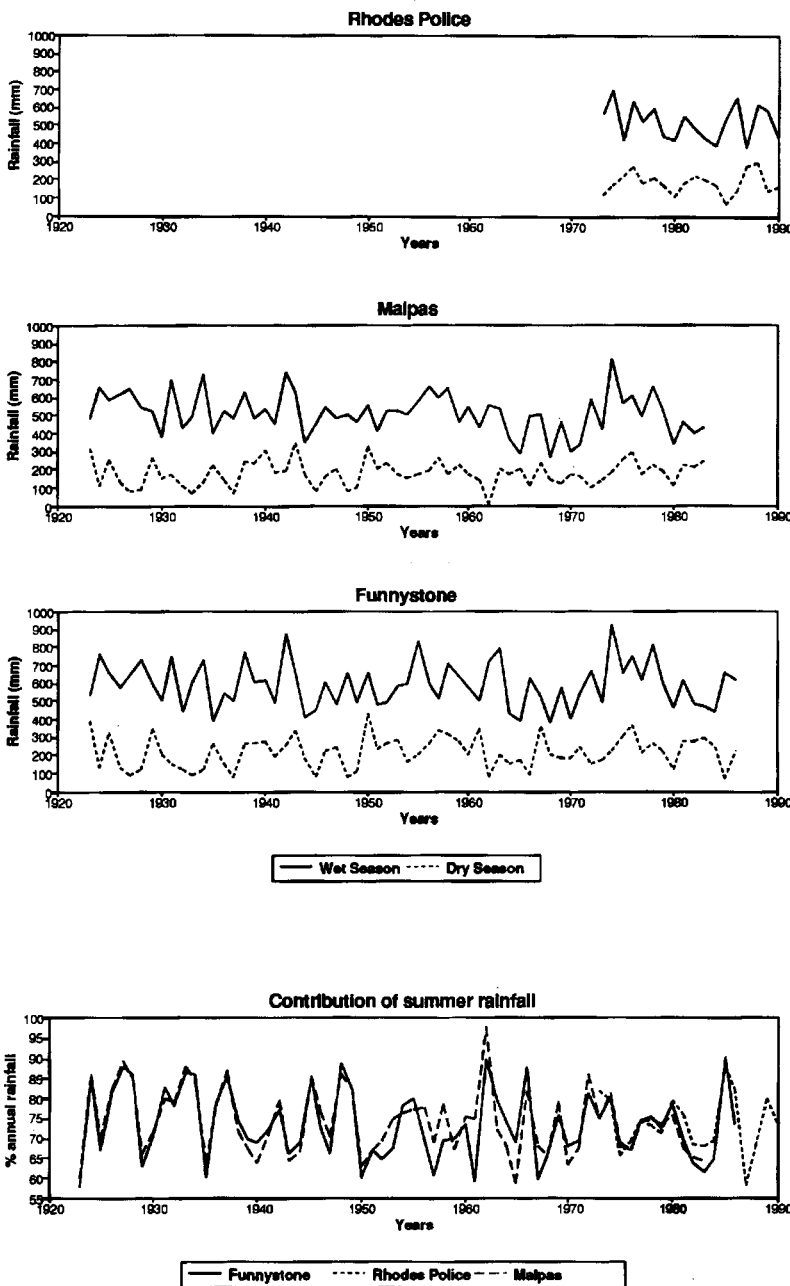

FIGURE 5: Seasonal rainfall chronology for Rhodes Police (1973-1990), Malpas (1923-1983) and Funnystone (1923-1986)

TABLE 4.   Percentage distribution of daily rainfall

PERCENTAGE FREQUENCY OF DAILY RAINFALL AMOUNTS: average of all three stations		
CLASS LIMITS (mm)	DRY SEASON	WET SEASON
10-19.9	69.5	68.5
20-29.9	20.3	21.7
30-39.9	6.6	6.3
40-49.9	2.6	2.1
50-59.9	0.9	0.8
60-69.9	0.3	0.2
70-79.9	0.0	0.1
80-89.9	0.0	0.3
90-99.9	0.0	<0.1
Total	100.0	100

Clearly then, for the annual series, climatic fluctuations rather than progressive climatic trends dominate the rainfall pattern of the Bell River catchment. The length of these periods and the distribution of maximum and minimum rainfall are the important themes in the rainfall pattern. Similar relationships have been found in Australia and have been termed Drought Dominated Regimes (DDR) and Flood Dominated Regimes (FDR) (Warner, 1987), though in this case the cycles extended over much longer time periods.

Seasonal rainfall

As in the annual series, no evidence could be found to suggest a progressive trend in the seasonal data (Figure 5). Even though the slopes of the expressions showed weak positive and negative slopes, these were statistically insignificant at the 0.05 level.

Daily rainfall

The frequency distribution of daily rainfall data shows interesting trends (Figure 6 and Table 4). Although the percentage frequency distribution is similar for the wet and dry years, both the absolute frequency of events and the magnitude of extreme events is greater for the wet periods. It is clear that wet and dry years result from changes in the frequency of daily events across the full range, rather than a percentage shift towards higher magnitude events. Wet periods also produce infrequent higher intensity events which, although insignificant in terms of their overall contribution to rainfall, may be important in terms of geomorphic thresholds and channel change.

Summary

The evidence presented has indicated the following:

a) no long term progressive trend exists in the annual rainfall series for the Bell River catchment, concurring with work by previous authors (Dyer, 1982; Tyson, 1986; Vogel, 1988);

b) no long term progressive trend exists in the seasonal rainfall series for the Bell River catchment;

c) distinct wet and dry cycles are apparent from the data, with peaks every 16 to 19 years;

d) wet years are the result of an increase in the frequency of daily events rather than the magnitude of the events, but infrequent high magnitude events occur during wet periods.
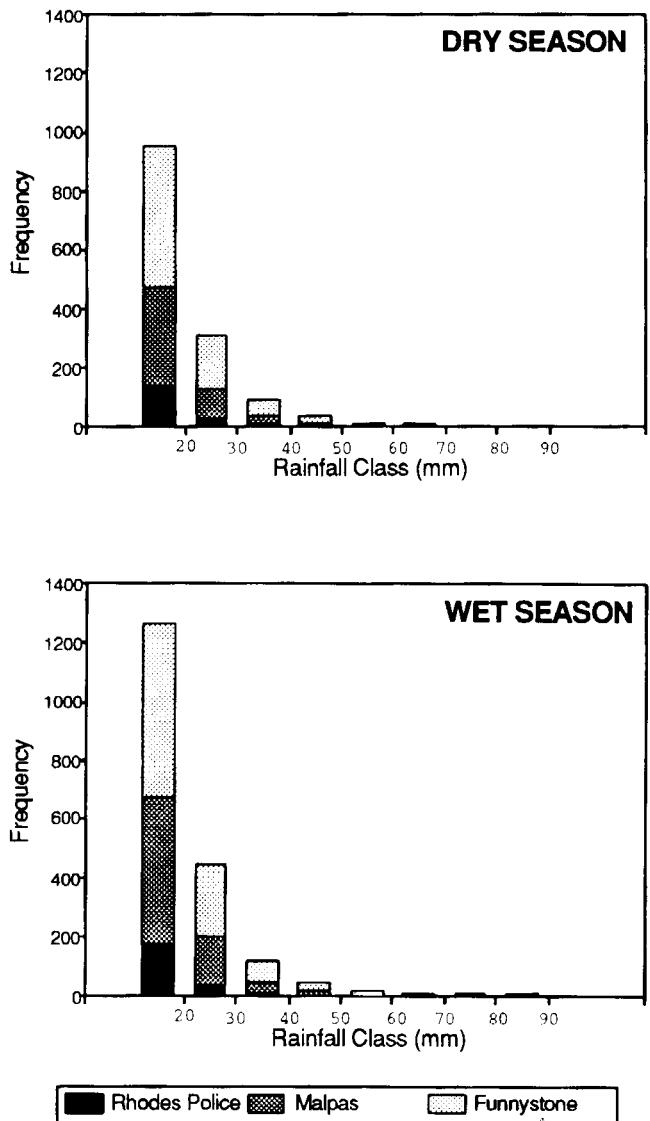

FIGURE 6: Daily percentage fequency distributions for three rainfall stations: Rhodes Police, Malps and Funnystone

The hypothesis that channel instability in the Bell River could have been induced by a progressive long term change in rainfall can be rejected on the above evidence. It is highly probable, however, that the timing of major channel changes is related to short term cyclical changes in rainfall and to the occurrence of high magnitude rainfall events. The coincidence between these phenomena and observed channel change will be examined below.

Flow variability

Flow records were not available for the Bell River itself, only for the Kraai River, 180 km downstream. The weir (no. D1H011 – Lat 30° 49' 50" S, Long. 26° 55' 17" E) records discharge from an area of 8688 km², 20 times that of the Bell River catchment. Due to their mountainous nature, however, the Bell and neighbouring Bokspruit Rivers contribute a high percentage of flow to the Kraai system (Middleton et al., 1981). Records were available from 1965.

Monthly flows were correlated against monthly rainfall for the separate rainfall stations in the Bell River catchment. The degree of correlation was found to be quite high, 0.77, 0.75 and 0.78 for Rhodes Police, Malpas and Funnystone respectively, indicating a good correspondence between rainfall and hydrological response. All correlations were
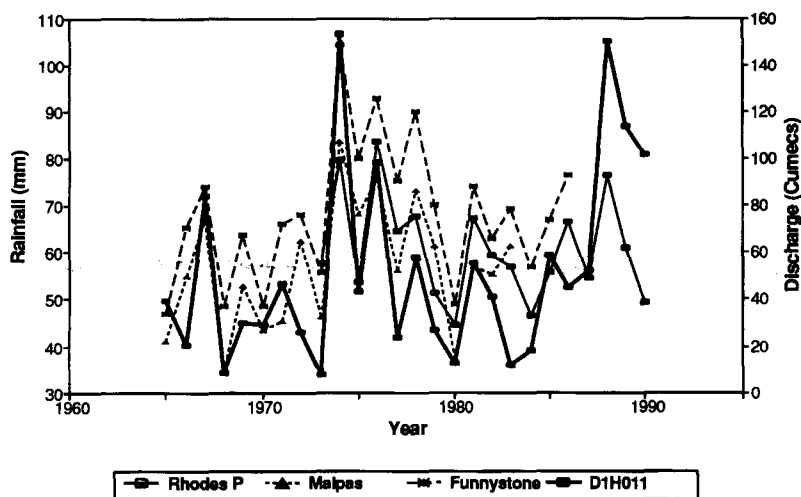
FIGURE 7: Relationship between mean annual discharge and mean annual rainfall for D1h011, Rhodes Police, Malpas and Funnystone

Sediment sources

The second hypothesis put forward to explain channel instability in the Bell River is that it is the result of an increased sediment load due to a change in catchment management over the last 100 years. Any increase in the rate of sediment delivery to the channel must be the result of accelerated erosion in the catchment.

Methodology

Soil erosion surveys and ground surveys were undertaken firstly to assess the extent of gully erosion in the catchment and the degree to which erosion had increased over time and, secondly, to give an estimate of the volume of material which has been lost from the gully systems.

significant at the 0.05 probability level. The relationship between annual flows and annual rainfall is shown in Figure 7. There is a close correlation between rainfall experienced in the Bell River catchment and the flow pattern of the Kraai River. Thus a rainfall peak in 1974 was accompanied by a flow peak in 1974, and low rainfall period of 1984 was accompanied by a low flow in 1984. These results all give support for the use of the Kraai flow records to indicate temporal changes in hydrological response in the research area.

TABLE 5: Flood Peaks in the Kraai River exceeding 500 m³s⁻¹ (1965-1989)

DATE	PEAK DISCHARGE (m³sec⁻¹)
February 1972	2016
March 1974	904
February 1976	582
March 1976	1186
September 1987	1094
October 1987	1665
February 1988	1797
April 1988	518

Major flood events (500+ m³s⁻¹) recorded for the Kraai river since 1965 are given in Table 5. These are expected to reflect the simultaneous occurrence of floods upstream in the Bell River. The significance of these events for channel change can now be assessed.

Evidence from aerial photographs and field surveys showed that major channel straightening occurred between 1969 and 1975 and in 1988. Major rainfall and flood events occurred in 1972, 1974 and 1976 after a sustained period of below average rainfall (see Figures 2, 3 & 4), referred to as Drought Dominated Regime (DDR) by Warner (1987). From conversations with farmers it would appear that major channel adjustment occurred in 1974, primarily in response to a series of floods experienced in the catchment.

The Drought Dominated Regime of the early 1980s (Figure 3 and 4) was broken by a series of high rainfall and flow events in 1987 and 1988 (Table 5). Once again, after a sustained period of low rainfall, high rain and discharge events were responsible for further channel straightening in 1988.

Soil Erosion Mapping

The use of aerial photography to map erosion in the Bell River catchment was the most cost effective, objective method to monitor rates of erosion and to determine whether soil erosion had increased in the catchment. The technique used had to satisfy the following criteria (based on Morgan, 1980): the survey method should be simple, objective and provide quantitative information, it should enable both rapid and inexpensive study and temporal monitoring of erosion for a given area. Black and white panchromatic aerial photographs of the catchment were available for 1952, 1969 and 1975 at scales of 1:30 000 1:20 000 and 1:50 000 respectively. The photographs were all taken during the winter months, ensuring a similar vegetation cover.

Although the classification of the South African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS, 1981) has been used extensively to map soil erosion in southern Africa (Weaver, 1989; Rowntree et al. 1991), this system was inappropriate for use in the present survey. The dense vegetation cover of *Cymbopagan Themeda Veld* and *Themeda-Festuca Alpine Veld* made it impossible to determine sheet and rill erosion with any degree of accuracy although field evidence indicated their presence. Moreover the scale of the photographs precluded the accurate definition of smaller erosion features such as slumps and rill erosion, a problem also experience by Garland and Broderick (1991).

The only features that could be accurately identified were incised channels and gulleys. These corresponded roughly to the G3-G5 classification of SARCCUS (1981). The method used to map erosion features was similar to that adopted by Keech (1969, 1980) and Garland (1982). Erosion features were traced from the photographs on to transparent film and then transferred to a base map. Sequential surveys were performed either side of a ground survey carried out in 1991.

The aerial extent of erosion in 1991 was mapped in the field using the classification system given in Table 6. Two shapes of gulley were identified, V shaped gulleys and U shaped gulleys. Due to the size of the catchment (424 km²) and the mountainous terrain, it proved impossible to ground survey the entire area in detail, but most of the catchment (80% of the areal extent) was visited or viewed from high points.

The data obtained from the surveys for the four dates were entered onto a GIS (PC\ARCINFO). The distribution of erosion at each date is shown on Figure 8. The length of erosion features was calculated from the PC\ARCINFO data base, the results are given in Table 7.

Ground surveys

During the 1991 field survey four large gulleys and incised channels that were prominent on the aerial photographs were surveyed in more detail so as to obtain an estimate of the volume of sediment produced. The location of these gullies is shown on Figure 8d. Width, depth and cross-section shape were recorded for three points along the length of each selected feature as given in Table 8. The data on gully length by size category collected during the field survey in 1991 was used to estimate the volume of material produced from the gully network by that date. This probably gives an underestimation of the total sediment delivered to the channel as it does not account for sediment generated by sheet wash and rilling.

was 22 m wide and 10 m deep. The volume of sediment produced from all gully systems up to 1991 was estimated at 1.7×10^6 m3. This does not include sediment produced from the hillslopes by rilling and sheet wash which was observed during ground truthing to be widespread in the catchment. The gully systems provide an efficient network for transporting this additional sediment into the channel so that sediment delivery ratios should be high.

TABLE 7: Length of incised channels and gulleys, 1952 to 1991

DATE	ERODED LENGTH (km)	INCREASE IN LENGTH (km)	SOURCE OF DATA
1952	33.3	—	aerial photography
1969	40.5	7.2	aerial photography
1975	47.7	7.2	aerial photography
1991	122.2	74.5	ground survey

TABLE 8: Dimensions of selected gulleys, Bell River catchment

GULLY SITE	POSITION	TOP WIDTH (m)	DEPTH (m)	BOTTOM WIDTH (m)	ASPECT
Park Gate	Top	14.8	13.1	9.3	North
	Bottom	7.2	3.3	5.3	
Monard	Top	3.0	3.8	1.5	South
	Midslope	21.5	9.5	15.0	
	Bottom	10.4	5.1	7.7	
Commonage	Top	5.8	3.6	2.70	North
	Midslope	5.3	2.2	4.50	
	Bottom	16.3	8.0	7.8	
Mertoun	Midslope	7.0	3.3	3.8	South

TABLE 6: Erosion Classification System used for Erosion Mapping in the Bell River Catchment 1991.

TYPE	APPROXIMATE SIZE depth (m)	width (m)	DESCRIPTION
1			Un-incised channels
F			Finger gullies: generally recent features found on steep hillslopes
2	<2	<3	Slightly incised channels
3	2-<5	<10	Moderately incised channels
4	>5	<10	Severely incised channels

Results

Temporal changes in gully erosion since 1952

An analysis of the erosion features delineated in Figure 8 (Table 7) indicates that by 1952 there was already severe erosion in the catchment, with 33.29 km of gullies and incised channels, but that erosion has clearly increased in the catchment since then. An increase in total length of gullies of 14.4 km or 69 % was recorded over the 23 year period up to 1975. Most of this increase has been in the middle and lower sections of the catchment where there are deep colluvial soils. It should be noted that deep gulleys are often found adjacent to, or in cultivated fields. Aerial survey work showed that there was no increase in the area of cultivated land after 1952. Even though the classification used to determine the erosion in 1991 is not directly comparable to the survey of aerial photography, it is clear from Figure 8 and Table 7 that there are still significant, active gulleys in the catchment delivering sediment to the channel.

The considerable size of the larger gully systems can be appreciated from Table 8. At the site of maximum development, the Park Gate gully was nearly 15 m wide and 13 m deep, the Monard gully
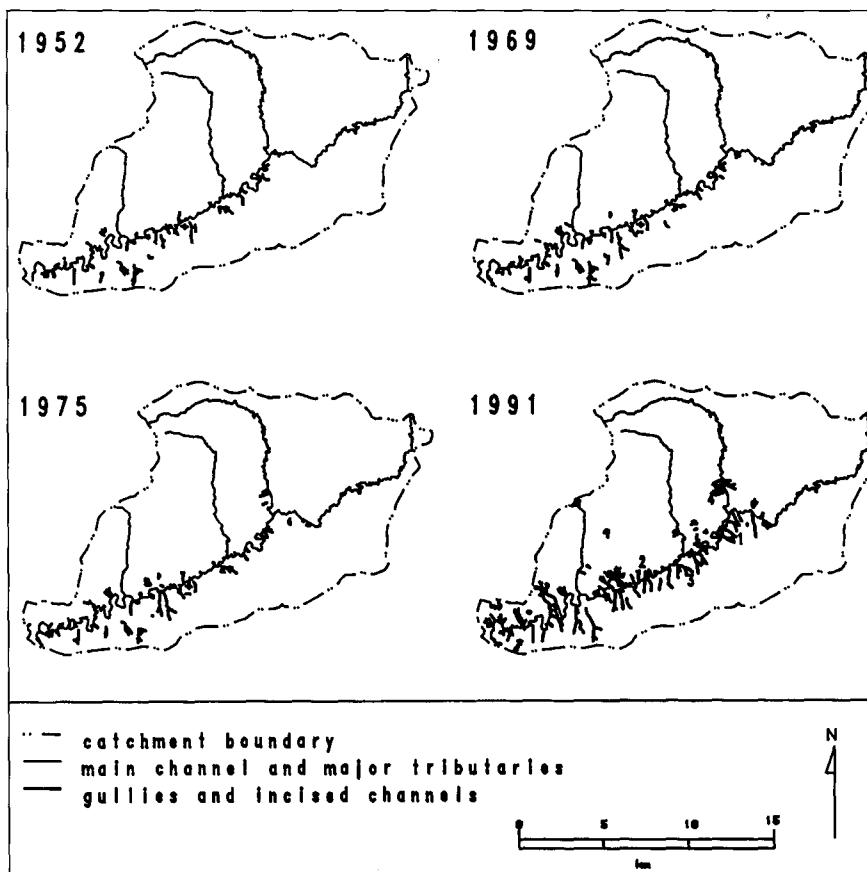

FIGURE 8: Changes in gully erosion, Bell River catchment. Gully survey sites are shown on the 1991 map: 1. Park Gate, 2. Monard, 3. Commonage, 4. Mertoun

The size distribution of sediment produced from the gully systems depends on their source material. Gulleys on the south facing slopes produce generally coarse material with a great heterogeneity (boulders, cobbles, gravels and sand). Those on the north facing slopes produce material predominantly in the sand and silt range. The coarser eroded material often formed small alluvial fans at the base of the gulley systems. These act as sediment storage zones which are likely to be mobilized in medium to high flows.

Initiation of erosion

Although erosion mapping has shown that gully extension has continued since the 1950s, further evidence is required to date the initiation of significant accelerated erosion. Fence posts provide one source. A number of fences stretch across deep gulleys as shown in Plates 1 and 2, leaving fence poles suspended in mid-air, some with soil still attached. It was concluded therefore that gully incision occurred after fencing. According to local farmers fencing was started in the early 1900s and continued until the 1970s. Major gully incision must have taken place within the last 90 years.

A combination of evidence from aerial photographs and fence posts thus points to the recent nature of many of the major gullies, incision having been initiated between 1900 and 1952. Given the significant volumes of sediment produced by these gullies, the implications for channel instability are considerable.

The hypothesis that sediment delivery to the channel has increased over the recent past can therefore be accepted. The possibility that this increase is linked to catcment management will now be assessed.

PLATE 2:   Suspended wooden fence pole, Bell River catchment. Soil is still attached to the bottom of the post.

Catchment Management: changes since the 1900s

The evidence presented above indicates that the initiation of severe gully erosion occurred between 1900 and 1950, that is during the half century following settlement by commercial farmers and the introduction of stock farming into an area previously sparsely populated by indigenous peoples. The implication is that land management practices caused serious degradation of the veld and consequent soil erosion. An assessment of land management is presented below.

The Bell River catchment is situated in the sour to mixed veld area of South Africa. Sour veld is characteristic of high altitudes, low temperatures and humid conditions. It provides a good ground cover, but is palatable only during the summer growing season. In contrast, sweet veld, found in warmer drier areas, remains palatable throughout the year, but does not provide such a good cover (Tainton, 1988). Stock farming is the dominant agricultural practice in the area. Alluvial and colluvial soils in the valley bottoms and foot slope areas are cultivated in places, mainly under the fodder crop lucerne.

Three information sources were used to reconstruct the history of land management in the area. The first was the government statistical registers from 1891-1981[1] from which stock numbers for the Barkly East District were extracted. This was the smallest aerial unit for which census data was available. After 1981 the census boundaries changed so that data after this date are not compatible with that for the earlier period. The second source of information was a questionnaire survey carried out amongst
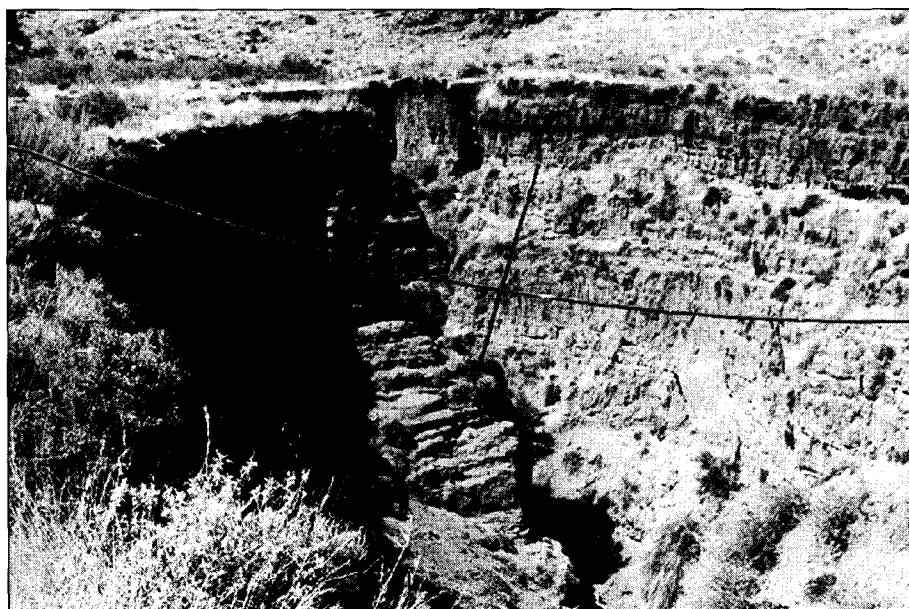
PLATE 1:   Park Gate gully showing suspended fence line

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[1]   The following statistical sources were consulted. For full details see Dollar (1992). Cape of Good Hope Statistical Register for 1905, Statistical Register of the Colony of Cape of Good Hope 1894 1907–1911, Union of South Africa, Agricultural Census 1918–1934, Union of South Africa, Report on Agricultural and Pastoral Production 1936–1957, Republic of South Africa, Report on Agricultural and Pastoral Production 1959–1981.

farmers within the research area. Farmers were often reluctant to answer questions and few could give an accurate historical perspective, but the more willing respondents furnished useful information concerning current practices. The third source of information was the district agricultural extension officer.

Degradation of grasslands can be caused in three main ways, firstly by the adoption of an inappropriate grazing strategy (Teague 1989), secondly by stocking at rates above the carrying capacity of the veld (Danckwerts 1989) and thirdly through the misuse of burning (Danckwerts and Teague 1989, Trollope 1984, Bode 1991). These will be considered in turn for the Bell catchment.

The grazing strategy recommended for sour veld areas is that of High Utilisation Grazing and Non Selective Grazing (HUG/NSG). This allows for heavy utilisation of the veld for a short period so as to prevent the favouring of less palatable species. It requires that stock be rotated around or between farms and has come to replace continuous grazing over a wider area which tends to lead to selective utilisation of the most palatable species. The Bell River catchment includes over 60 farm units which were originally operated as separate enterprises under the ownership or management of one farmer. These relatively small farms each encompassed a limited range of veld type, for example either high mountain grazing or valley bottom lands, restricting the opportunities for stock movement and rotational grazing. Presently many farmers own between 3 to 6 farms, both within the catchment and also elsewhere in the wider region. There is thus a greater opportunity to practice rotational grazing both within a single farm unit and between farm units. Adequate fencing is also a pre-requisite for controlled grazing. As noted above, the main period of fencing was between the 1900s and 1970s.

The general feeling amongst farmers and the agricultural extension officer was that veld condition in the catchment have improved significantly over the last 30 years due to the adoption of improved grazing strategies and to a reduction in the overall stocking rate. By implication, grazing strategies used before this time were perceived as contributing to general degradation of veld and soils in the area.

Changes in stock numbers for Barkly East District over the period of record are illustrated in Figure 9. Sheep make up by far the largest stock numbers, followed by goats and cattle; in Figure 9 sheep, goat and cattle numbers have been combined to give equivalent large stock units (6 sheep or goats are equivalent to one large stock unit). It can be seen

from the graph in Figure 9 that stocking rates were high in the late Nineteenth Century, reached a peak in the 1920s and thereafter declined gradually. This regional trend is thought to reflect that in the Bell River catchment itself; the agricultural extension officer believed that stock numbers in the catchment had declined by about 300 % over the last 30 years.

The decrease in stocking rates after the 1920s may have reflected an increasing awareness of conservation issues amongst farmers, but was probably also the result of economic circumstances. For example, in the earlier part of the period wool was extremely profitable, but after the Wall Street Crash of 1929 wool prices plummeted (Davenport 1987). Roux and Opperman (1986), writing on the Karoo, note a corresponding decline in sheep numbers from the mid 1930s.

In order to give an indication of the impact of these stocking densities on veld condition and erosion, it is necessary to make a comparison with the estimated carrying capacity of the land. Tainton (1988) defines carrying capacity as the area of grazing land required to maintain an animal in good productive condition for a year without vegetation or soil degradation. Although there is much argument as to how grazing capacity should be derived, guidelines have been set out by the Department of Agriculture based on conventional wisdom. The recommended stocking rate for the Barkly East District has been given by Dohne Agricultural Research Centre as 6.5 ha per large stock unit. For an area of 3644 km^2 this results in a recommended total stock number of 56 081 large stock units (lsu) for the district. When this figure is compared to actual stock numbers as given in Figure 9 it can be seen that in the 1920s, with total stock numbers of 140 000 lsu, the land was overstocked by 2.5 times. By the 1980s the numbers were down to 80 - 90 000 lsu which is still above the recommended rate. It is thus apparent that, even allowing for some underestimation of true carrying capacities, there is strong evidence that Barkly East District was significantly overstocked in the past and may still be so today, despite the decline in numbers.

The recommended stocking rates given above assume that the carrying capacity of the veld remains constant through time and therefore represents an average condition. Clearly the carrying capacity for any one year depends on the current rainfall and on the degree of degradation inherited from previous years. It is interesting to note that the high stock numbers at the beginning of the century coincided with an extended drought period which ended in the early 1920s (Figure 3 or 4). By the time the drought was broken the veld must have been badly degraded with a much reduced carrying capacity. The co-incidence during the following wet period of high rainfall with badly degraded veld would inevitably lead to a high potential for erosion. Fluctuations in stock numbers subsequent to the 1920s appear to be in phase with the climatic cycles noted previously, with higher stock numbers reflecting wetter periods. This apparent adjustment between stock numbers and a variable carrying capacity of the veld would have had far less serious consequences for erosion.

Controlled veld burning is carried out to improve veld condition, but out of season burning or too frequent burning can lead to a reduction in the strength of the grass sward
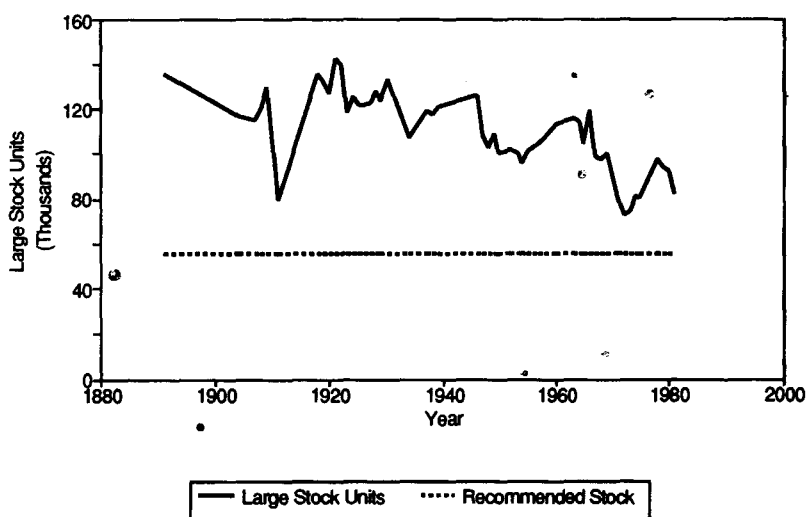

FIGURE 9: Stock figures, Barkly East Magisterial District: figure for large stock unit includes sheep, cattle and goats (six small stock units equal one large stock unit)

and an increase in runoff and soil loss (Danckwerts and Teague, 1989; Trollope, 1989; Barnes, 1989). It appears that veld burning in the Bell River catchment is carried out approximately every four years, though one farmer stated that he never burnt. No evidence was obtained to indicate that burning was a cause of erosion in this area so that the implications of burning regimes for veld degradation remain unclear.

In conclusion, it is highly likely that stocking densities well above the carrying capacity of the veld, coupled with poor grazing strategies, would have set the scene for widespread erosion and gully incision in the first half of this century. Once initiated, the cycle of gully erosion would be expected to proceed unchecked for many years until some sort of equilibrium was reached, despite any improvements in veld condition which may have occurred more recently in the catchment (Schumm *et al.* 1984).

Although evidence points to an anthropogenically induced increase in erosion in the catchment, it is none the less important to note that recent research has indicated the cyclical nature of gully incision in Southern African colluvial deposits which can be related to long term climatic shifts (Goudie and Bull, 1984; Botha, 1987; Bousman et al. 1988; Botha *et al.* 1992). If this were the case for the Bell River catchment, episodic sediment injections to the channel could maintain the channel in a continuous state of disequilibrium. The possibility that accelerated erosion in the catchment may be a response to recent anthropogenic influence superimposed on a longer term climatic cycle must not be discounted.

Conclusions

Two hypotheses explaining recent instability in the Bell River have been investigated. The first related to climatic change, the second to increased sediment production from the catchment in response to land management factors.

There is no evidence to suggest a change in the long term rainfall pattern in the Bell River catchment over the last 90 years. Climatic change cannot therefore be invoked as the cause of increased instability in the channel. However, due to the seasonality and cyclical nature of the rainfall, flood events following years of below average rainfall may cross the threshold limit for channel stability. It has been shown that channel straightening in the Bell River was concurrent with major rainfall and flow events occurring after a sustained period of below average rainfall, a sequence comparable to the Flood and Drought Dominated Regimes of Warner (1987).

The evidence presented from the sequential air photo surveys indicates that there has been significant erosion in the catchment which in turn would have increased the rate of sediment delivery to the channel, hence inducing instability. From 1952 to 1975 the length of eroded features (gulleys and incised channels) had increased by 14.4 kilometres. The existence of 33.29 kilometres of eroded features in 1952 means that severe incision must have occurred before that date. Evidence from fence poles points to gully incision between 1900 and 1950, coinciding with the settlement of the valley by commercial farmers practicing extensive grazing. Gully extension continues to the present day. These gullies, together with more extensive sheet erosion, have been shown to be significant sediment sources for the channel.

The increased erosion in the catchment over the last forty years or longer has been linked by the authors to the high stocking rates recorded during the first half of this century, often co-incident with drought. Such high rates,

well in excess of recommended stocking rates, would be likely to lead to degradation of the grass cover and to an increased erosion potential. From the available evidence the following scenario is presented.

1) Over-stocking and poor veld management practices occurred in the Bell River catchment at least in the first half of this century.

2) Accelerated erosion observed in the catchment was possibly the result of overstocking and poor veld management following European occupation.

3) Significant amounts of sediment have been injected into the Bell River channel during the past 90 years.

4) Channel instability has resulted from this sediment injection.

5) Due to declining stock numbers and better veld management, catchment condition has improved in terms of grass cover and percentage of palatable species. In some parts of the catchment this has led to a decline in erosion, and stabilization of some of the gullies and incised channels.

The importance of these findings in terms of channel change in the Bell River is as follows. On the one hand the absence of a progressive climatic trend eliminates one variable (climate change) that may have been responsible for triggering channel instability. On the other hand the observed increase in catchment erosion coincident with heavy grazing pressures supports the hypothesis that channel instability can be related to catchment management. Climate and management cannot be seen as independent factors, however. The relationship between wet and dry cycles of rainfall, together with the magnitude and frequency of the storm events, plays an important role in the hydrological response of the catchment in terms of both the runoff response and the precipitation/vegetation-erosion interaction. The cyclical nature of the rainfall coupled with increases in sediment inputs to the channel can be invoked to explain the channel instability observed over the last forty years.

It is clear that one cannot separate catchment processes from channel processes. Disequilibrium in the catchment will inevitably result in channel instability. The appropriate use and management of the catchment is therefore paramount in maintaining the geomorphic stability of river channels. An awareness of the cyclical nature of rainfall in the summer rainfall region of southern Africa can lead to a better understanding of the hydrological and sediment-ological processes in drainage basins and to more appropriate land management strategies.

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