Variation in Cattle Numbers, Rainfall Amount and Land Availability in Tlokweng Sub District, Botswana

A Modelling Approach to Livestock Management

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by
Masego Ayo Mpotokwane

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DECLARATION

I declare that this thesis has been composed by me and that the work which it embodies has been done by me and has not been included in another thesis. Where data from secondary sources have been used, they have all been duly acknowledged.

Signed ____________________

Date 13th August 1999

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Most of all, I give thanks to God the Almighty for all that I have achieved.

Dedication

This thesis is dedicated to Limpet my wife, Lila my daughter and Phodiso my son for their love and support at all times.

Contents

List of Tables

List of Figures

List of Equations

List of Plates

List of Appendices

Abstract

This study describes and analyses cattle management in Tlokweng Sub District. Two methods were used. The two are households' interviews and a system dynamics STELLA model called the Rain Land Cattle model, which was adapted from the 1990 Braat and Opschoor model.

Ninety households, 61% of the 1991 households in the study area, were interviewed. All the households had arable fields and fifty nine percent had cattle. The Rain Land Cattle model uses 52 parameters to predict several cattle management factors, which include rainfall, stocking rate, total grazing area and livestock water availability. The model explored the use of parameters to relate water availability to grazing area and show the seasonality of the water source. Sixty two percent of the household had access to an ideal livestock water source. Cattle graze from the 5000 hectares of arable area for four months after harvesting. This seasonal grazing, optimises the uses of the grazing resource in the small sub - district. The model simulated a 5 and 20 percent permanent grazing land loss. Such a grazing land loss, increased the stocking rate, decreased the carrying capacity and cast doubt on sustainable cattle production. The model shows that the stocking rate is chronically greater than the carrying capacity. Most households acknowledged that there was land pressure due to the loss of grazing land.

A drier climate scenario will lead to a loss of seasonal grazing, reduced livestock water, which will increase cattle emigration and cause cattle management problems. The model is exploratory; it needs to be validated. It is easily understood, adaptable to other communal areas, and identifies the most influential factors in cattle

management. The livestock water parameters functioned reliably in the model. Based on the understanding of the cattle management derived from this study, more fenced grazing land is unlikely to improve the cattle management in the area.

Chapter 1. Introduction and Background

Introduction

Chapter 1 provides the background to the research. It is divided into six sections. The first section describes the research problem in some detail. The second section is an account of the rainfall pattern in Botswana with emphasis on the variability of the pattern. Section 3 introduces the land tenure system in the country and highlights the land tenure problem. A chronological descriptive account of the major events in the development of the livestock sector since 1895 follows. Section 5 discusses a selection of four government policies, which were developed between 1972 and 1991, to address aspects of cattle management. The sixth section outlines the research aims, objectives and hypotheses.

1.1 The Research Problem

Botswana faces the challenge of attaining good livestock management in communal rangelands where there is variable rainfall, increasing livestock numbers and competing demands for communal land. This research concentrates on cattle management in a communal area.

1.1.1 *The Attractiveness of the Cattle Sub Sector*

Cattle production in Botswana is a lucrative and attractive venture because:

i) Botswana's beef exports enjoy high prices from the European Union (EU) which are 24 percent above the next best in the world (Fidzani 1993). This preferential pricing enabled revenue from beef exports to almost quadruple between 1970 and 1976 when the number of cattle slaughtered increased by only 50 percent (Cooke, 1985).

ii) the national abattoir pays producers per kilogram of animals slaughtered. Because of the generally low cold dressed mass per animal, farmers hold large herds in order to earn a good income

iii) livestock do better than crops during a drought. They can be relocated to take advantage of differences in forage and water availability and it is more resilient to drought than crops. In some cases a crop failure increased the cattle sales as a source of rural incomes

iv) the government subsidises a number of livestock services such as vaccinations, borehole repairs, and supplementary feed during drought. In the past agricultural loans were written off due to widespread cattle deaths following a severe drought. The subsidies cost the government up to 55 percent of their input into the agricultural sector (Fidzani 1993).

v) a tax rebate allows losses incurred in the livestock sector to be off set against profits in the non-agricultural sectors

vi) cattle are an accepted form of payment for services and goods and, in some cases, collateral for loans. The size of a field or expected crop harvest is not acceptable collateral.

vii) there are limited investment opportunities in rural areas outside the cattle sub sector (Ministry of Agriculture, 1993).

Because of the attractions of the cattle sector, it is reasonable to expect that the cattle population will fluctuate between a maximum during good rainfall years and a minimum during poor rainfall years, as has been the case since the early 1920s (Figure 1.1).

1.1.2 *The Livestock and Population Trends*

Figure 1.1 shows that the cattle population in Botswana has increased from 500 000 in 1921 to about 3 million in 1996. The increase has been temporarily checked by

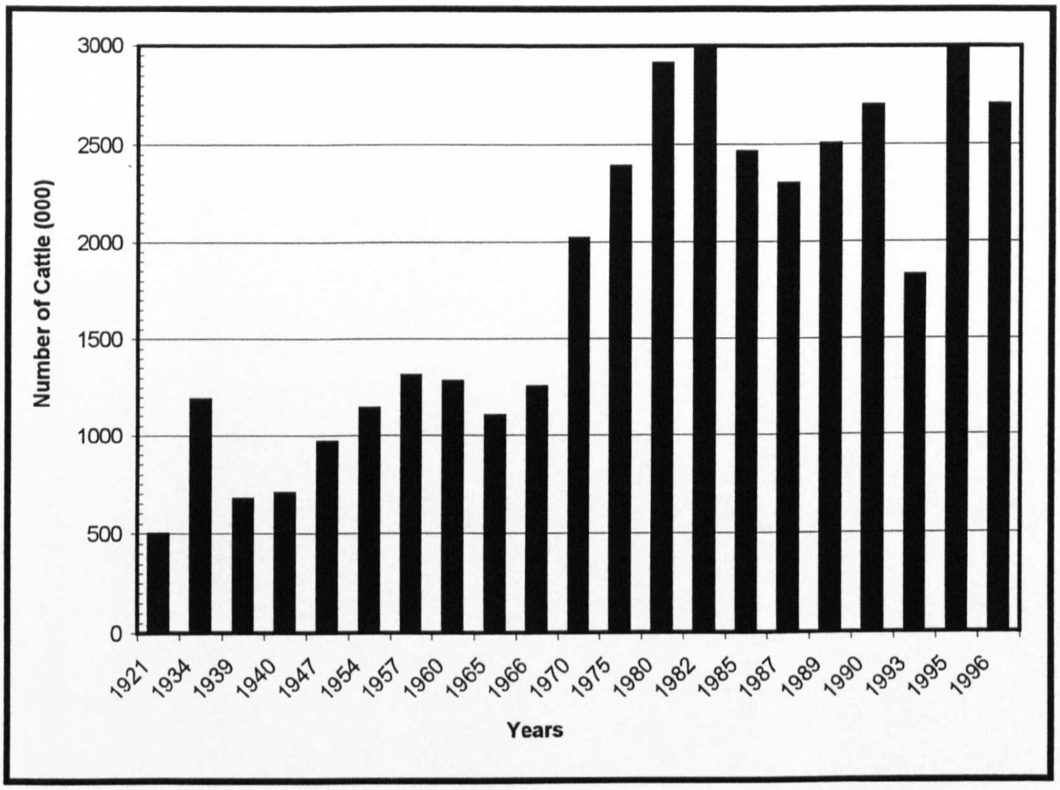

Figure 1.1. Number of Cattle in Botswana 1921 - 1996[1]

Sources: Roe, 1980 (1921 and 1947); Ministry of Agriculture, 1990 (1965 to 1987); White, 1993 (1934, 1939,1940, 1954,1957, 1960, 1990); Ministry of Agriculture, 1995 (1989 and 1993); Times, 1997 (1995 - 1996)

disease outbreaks (1978 Foot and Mouth Disease and 1995 Contagious Bovine Pleuro Pneumonia) and drought in 1957, 1965-66, 1982-1987 and 1993 and, to a limited

[1] The years are not evenly spaced because of paucity of data

extent, offtake, that is sale of animals. At the national level the cattle numbers have reached a plateau but fluctuate due to climatic factors. Botswana's cattle production is extensive therefore more cattle mean more land is required unless intensification of production may somehow be achieved.

Although the number of cattle has increased their relative significance has declined since 1921 (Figure 1.2). The decline was mainly due to the increase in the number of goats. The livestock diversification is welcome as goats are browsers which complement, rather than compete with, cattle for forage during most years.

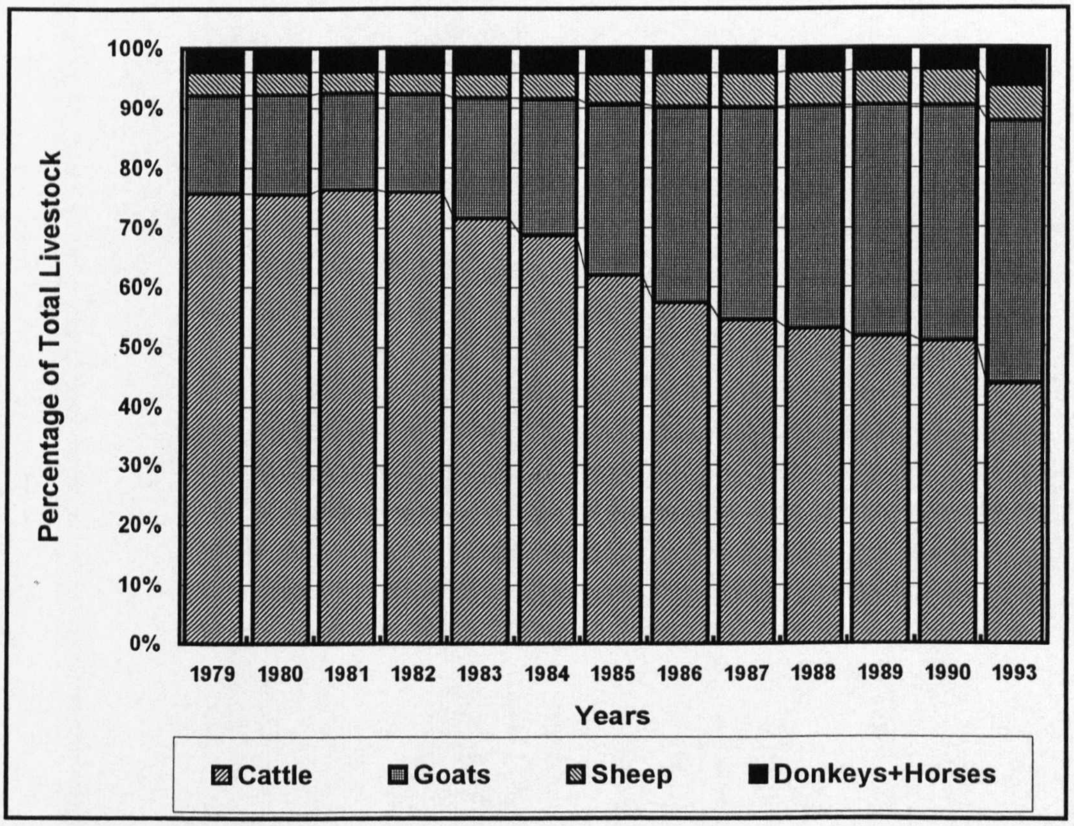

Figure 1.2. Significance of Different Livestock in Botswana 1979 - 1990 and 1993
Source: Adapted from Ministry of Agriculture 1995:40

A rapid population growth rate of 3.1 percent to 3.3 percent per annum between 1971 and 1981 (Ministry of Finance and Development Planning 1991:9) has declined marginally to 2.8 percent per annum recently (Ministry of Finance and Development Planning 1994:57). Though the country has a low human population relative to its area of 582 000 km^2, 70 percent of the country is covered by the Kalahari sand. Most people live in the eastern part of the country where localised land pressure is consequently most severe. The eastern part of the country has the most intense landuse competition. Some land that was used for grazing is taken up by non- grazing uses. For example, in Kgatleng District non-grazing landuses have encroached into grazing areas (Mpotokwane, 1986). Such a development occurs in most communal rangelands throughout the country. The present study looks at the extent to which land availability can contribute to cattle management problems. When the grazing land diminishes higher stocking rates result.

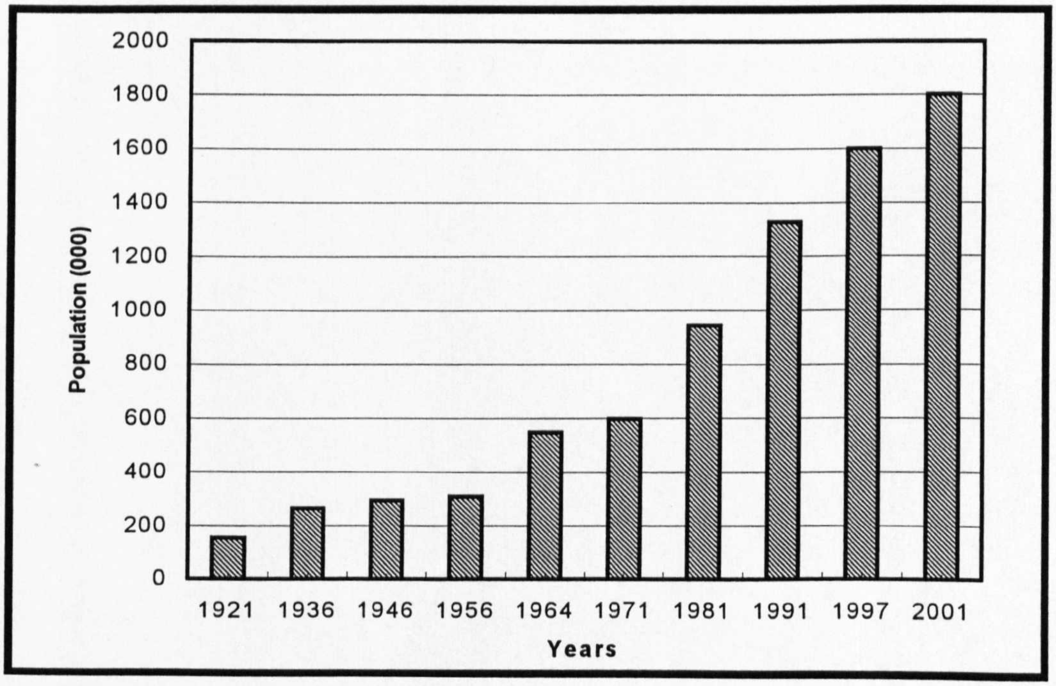

Figure 1.3. Population of Botswana - 1921 to 2001 (estimates 1997 and 2001)[2]

Sources: Ministry of Finance and Development Planning, 1991:9; Moyo *et al.*, 1993:35; Ministry of Finance and Development Planning, 1994:57

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[2] There is a 10 year gap between census 1936 to 1956, and 1971 to 1991.

1.1.3 *Extensive Livestock Management in the Communal Areas*

Botswana's livestock production is divided between the traditional (communal) and the modern (commercial) areas. The commercial areas have ranches and are generally viewed as an example of good management practise although there are reservations about that opinion (Ministry of Agriculture, 1995:7). There is communal grazing in the traditional sector which is characterised by poor productivity, low rates of inputs, low offtake and has been the least receptive to livestock management improvements in the country (Ministry of Agriculture, 1991). Eighty five percent of the national cattle herd is found in the communal areas (Ministry of Agriculture, 1995). Because of the low offtake rate and the tendency to keep large herds which stand a better chance of recuperation after a drought, communal areas are believed to be overstocked, overgrazed and undergoing degradation. The communal rangelands are overstocked at the beginning of a drought when there is not enough forage and water for the numbers available. But they are understocked during a subsequent good rainfall year when the low cattle numbers due to the drought, cannot fully exploit the abundant forage. This suggests that the relationship between cattle numbers and the ability of an area to support them is in a state of flux rather than fixed. Section 3.4 discusses whether rangeland degradation is taking place in Botswana's communal areas.

The Botswana government has been trying to improve livestock management in communal areas. The government's view is that communal use is amenable to resource abuse (Tsimako, 1993). Official stocking rates, based on the Potential Carrying Capacity (PCC) exist for the whole country (Figure 3.1). The PCC is based on an assessment of an area's forage production *vis a vis* the forage required for animal survival (see Section 3.3. for a detailed discussion). In most districts the stocking rates are commonly higher than the PCC (Table 1.1). A long term record of the number of cattle held in a place over time shows how many cattle an area can hold. Local management strategies, which are not shown on small scale PCC maps for a country, enable useful adaptations which will make a PCC value alone, irrelevant.

Table 1.1 Example of Commonly Used Stocking Rates and Potential Carrying Capacity (Ha LSU^{-1})[3] by Region 1980 - 1984

Districts or Region	Stocking Rate 1980	Stocking Rate 1984	PCC
Southern			
Barolong	4.2	6.6	12
Ngwaketse South	8.9	15.8	16-21
Ngwaketse North	12.9	10.0	16-21
Gaborone			
South East	4.1	4.0	12
Kweneng South	12.9	21.6	16-21
Kweneng North	4.1	1.2	12-16
Kgatleng	8.3	9.0	12-16
Central			
Mahalapye	10.8	11.1	12-16
Palapye	5.5	6.0	16-21
Serowe	n.a	n.a	12-21
Mmadinare	6.9	7.9	21
Francistown			
Tutume	n.a	n.a	12-21
Tati	4.2	5.1	21
Maun			
Ngamiland West	n.a	n.a	12-16
Ngamiland East	n.a	n.a	12-16
Chobe	n.a	n.a	8
Western Botswana			
Gantsi	n.a	n.a	16-21
Kgalagadi	7.0	13.5	21-27

Source: Arntzen 1989:72

Examples of such management strategies include livestock movement to access local key resources. Further, the PCC assessment should include a consideration of the most limiting factor in the production system which for most parts of Botswana is the

[3] The number of hectares needed to satisfy the forage requirements of one livestock unit, is higher for areas with low primary productivity. Therefore in Table 1.3 Gantsi, 16-27 Ha LSU^{-1} , has a lower primary production than Chobe, 8 Ha LSU^{-1}. 4.2 Ha LSU^{-1} is a higher stocking rate than 12 Ha LSU^{-1}

availability of livestock water. Consequently the thesis incorporates the livestock water component into the assessment of Carrying Capacity. The PCC is affected by the change in the land available for grazing. Since we recognise the significance of local management strategies which include livestock movement to key resource areas, PCC should be viewed as a dynamic feature, due to the variable rainfall, to which cattle adjust by moving from one place to another. When such movement is limited by competing landuses, pressure increases on the grazing and water resources in the communal areas.

1.1.4 *The Need for A Dynamic Study of Cattle Management*

The appropriateness of the theoretical tools of analysis used for cattle management in areas with variable climates in general and specifically in Botswana is discussed (see Chapter 3). A school of thought which suggests that flawed tools of analysis have been used for sometime has gained momentum (Behnke *et al.*,1993; de Queiroz, 1993: Scoones, 1995b). The school argues that fixed carrying capacity does not apply in areas with variable rainfall as cattle move at different times of the year and from one rainfall season to the next to take advantage of the varied resource availability. Different rangelands complement each other. Without the cattle mobility the natural resource base may be destroyed during low rainfall years. Rangelands have variable rainfall and fluctuating forage. A generically derived PCC consequently has limited relevance because fixed use of the land and a steady forage production does not occur. Given the variable climate and the present extensive cattle management in Botswana's communal areas, larger grazing areas will be required if the national herd grows beyond its present population. Cattle mobility is restricted due to the land pressure in most communal areas due to competing landuses. Therefore short distance movement and sedentary livestock management prevail. The short distance movements are critical to the effectiveness and the efficiency of the management system. Efficiency refers to movement being done at the right time to benefit the cattle and effectiveness refers to good management output that is healthy animals with low mortality. The management output will depend on the household's objective. A subsistence household's objective is to minimise livestock losses during drought and obtain the most from a given area of land.

An appropriate Potential Carrying Capacity should consider an area's local conditions. Some relevant factors to be taken into account include the prevailing methods of cattle management, the availability of livestock water, and the complementary or otherwise of its land use activities. Such an assessment should be area specific. There is no record of such an area specific assessment being carried out in Botswana. This study contributes an aspect of such an area specific study in the form of a model. The model is based on the relationship between annual rainfall, the amount of grazing land available at local management level and the number of cattle. It takes into account the local management practices which enable an area to hold a given number of livestock. For example, cattle graze off the stubble left in the arable areas after the harvest. The availability of the stover during the dry season, winter time, is strategically significant as it coincides with the time when the forage on the open grazing land is either dry and thereby of poor digestibility, or depleted. The model can be easily adapted to other communal areas in the country.

One argument from the new school of thought is that the number of cattle kept in an area over the long term is the true carrying capacity of the given its management practices. If that is the case, livestock numbers could be used to monitor the use of a rangeland and whether degradation is taking place. If cattle numbers are maintained degradation is absent. A significant decline in cattle numbers that cannot be explained as a policy measure may indicate a decline in carrying capacity and therefore rangeland degradation. However, a simplistic examination of livestock numbers though necessary will not be an adequate and conclusive indicator of rangeland degradation. Further evidence is necessary to establish the existence of degradation. Such evidence includes, among others, the soils properties, forage species composition and quality, surface water availability and crop production. The further evidence was beyond the scope of this study.

1.2 Rainfall in Botswana

1.2.1 *Sources, Variation and Uncertainty of Botswana Rainfall*

Botswana straddles the Tropic of Capricorn (23.5°S), and has a semi-arid climate. There are three sources of rainfall viz.:

i) the Inter Tropical Convergence Zone (ITCZ)

ii) the moist Maritime air from the Indian Ocean

iii) the Atlantic Air.

During favourable rainfall years the effects of the southern most swing of the ITCZ may be experienced in the northern and north eastern parts of Botswana while during other years effect is minimal. The north has the highest and the least variable rainfall. The source of moisture for most rainfall experienced in the east of Botswana is the Indian Ocean. Botswana is on the leeward side of the Drakensberg, a mountain range on the eastern part of Southern Africa. Because of the mountain barrier and the distance from the source, the rainfall is very variable. The Atlantic Air brings rainfall to the western part of the country. It is the least assured (Cooke, 1979) of the three sources. The Atlantic Air is associated with the cold Benguela Ocean current. Like other western parts of sub-continents at similar latitudes, (18^0S - 27^0S), western Botswana is the driest part of the country. Because the effect of the three moisture sources is marginal, Botswana's rainfall is spatially and temporally variable both in amount and seasonality of occurrence (Cooke, 1979; Arntzen and Veenendaal, 1986). Figure 1.4 shows the spatial distribution and variation of the annual rainfall in the country.

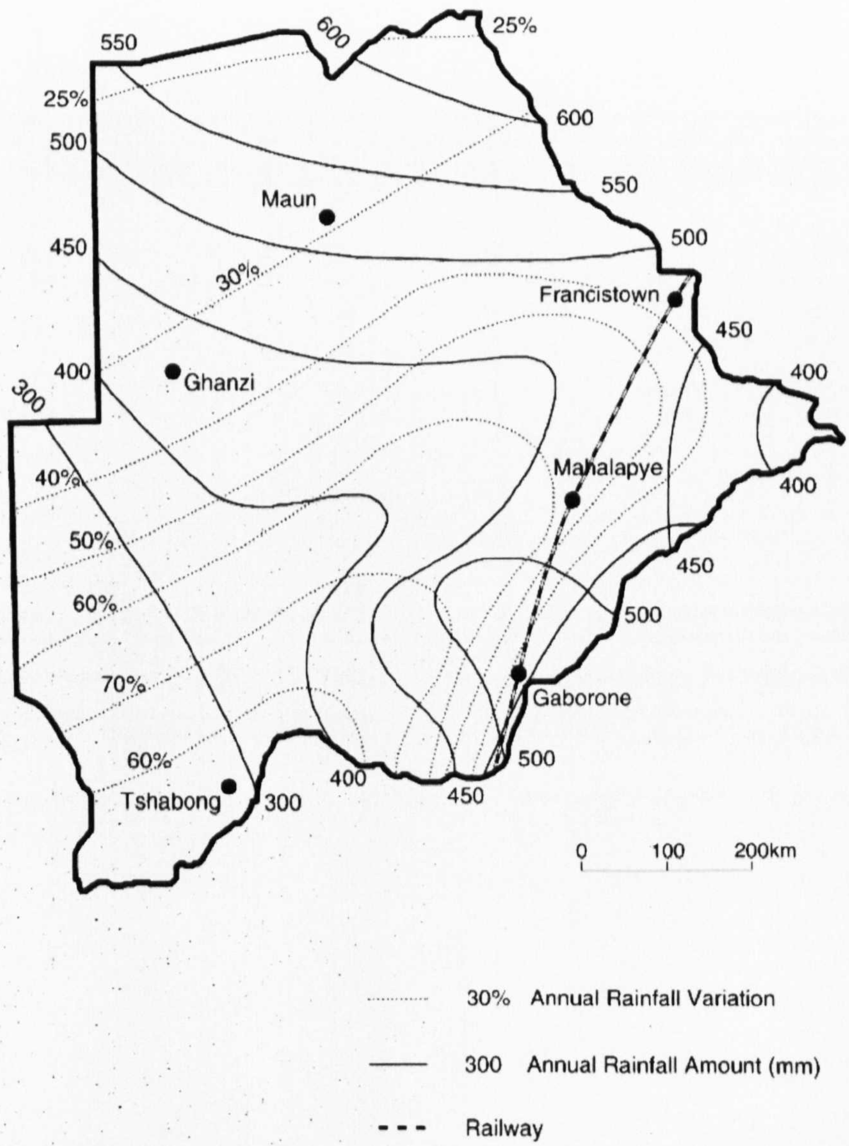

Figure 1.4 Botswana Annual Rainfall Amount and Percentage Variation

High intensity and short duration local showers are frequently experienced. For example Gaborone once experienced 192 mm. of rainfall, that is almost half its mean annual rainfall, in one day (Bhalotra, 1985). The north receives the highest rainfall, over 600 mm, and the south west receives the lowest, less than 300 mm. The mean annual rainfall variation is between less than 25 percent in the north and more than 70 percent in the south west. There is a negative correlation between the amount and the annual variation of rainfall. The higher the rainfall variation the greater the risk of a drought. Section 2.3 discusses the annual rainfall variation of at three stations, Gaborone, Mochudi and Lobatse in the eastern part of the country (Figure 2.1). The three have a trend of high and low annual rainfall years which indicates the cyclical nature of drought.

1.2.2 *Definitions and Occurrence of Drought*

Drought is an endemic hazard in Botswana. Drought is defined variously according to the different uses of water. There is a hydrological drought, socio-economic drought, agricultural drought and meteorological drought. These definitions are not always mutually exclusive. Wilhite and Glantz (1985 and 1987) detailed the various definitions. A meteorological drought is the degree and duration of dryness. The definition is location specific. For example a meteorological drought in Britain is defined as "*fifteen days none of which received as much as 0.25 mm of rainfall*" which contrasts with "*annual rainfall of less than 180 mm*" which is the definition in Libya (Wilhite and Glantz, 1987:15). The definitions show that Libya has a lower rain expectation than Britain. In India, a meteorological drought is declared when the "actual seasonal rainfall is deficient by more than twice the mean deviation". Tyson (1987:75) defined drought in South Africa as where the rainfall is "*below the 20th* *percentile of the annual total"*. Vogel's (1994:4) definition of a drought in South Africa " *a period in which only 75 percent of average rainfall is received and a disaster drought is experienced when 70 percent or less of average rainfall is received in two (or more) consecutive seasons*" is less frugal than Tyson's.

Agricultural drought is a moisture deficit which is significant enough to cause a crop failure. This takes into account that the crop moisture requirements vary according to the stage of the crop's development and its type. A Crop Moisture Index (CMI) shows the evapotranspiration (ET) deficit weekly. The variation between the expected ET and the actual ET gives an indication of the drought conditions for specific areas. A socio-economic drought is "*when precipitation is not sufficient to meet the needs of established human activities*" (Wilhite and Glantz, 1987:18). This contains features of the other definitions of drought, such as agricultural drought on which most human uses depend.

A hydrologic drought is "*a period during which streams are inadequate to supply established uses under given water management system*" (Wilhite and Glantz, 1987:17). The brief discussion above suggests that the concept of drought may pose some ambiguity. One or a few heavy showers may be adequate to fill a dam, but would not be distributed well enough for a good crop harvest. Drought for livestock management encompasses both adequate supply of water, which tends to be critical, and forage.

Due to the significance, frequency and widespread nature of drought in Botswana, Sandford (1979) worked out the probability of drought occurrence for different parts of the country. He defined drought as "*the rainfall induced shortage of forage brought about by the inadequate or badly timed rainfall*" (Sandford, 1979:34). The definition recognises that a shortage could be influenced by the past rates of use rather than climate *per se*. Sandford drew up three drought classes:

i) moderate - up to 15 percent deficit of livestock forage experienced

ii) severe - between 15 and 50 percent deficit

iii) disastrous - deficit in excess of 50 percent

Based on the rainfall records for a number of localities the drought classes shown in Table 1.2 were derived. Localities in the western part of Botswana have a higher frequency of drought occurrence than those in the eastern part of Botswana. The demand based definition highlights two significant factors for the present study. The severity of drought is dependent on the livestock numbers. The case for the reduction of livestock during drought seems to be vindicated by this argument, at this point. We shall explore other arguments later. Secondly supplementary provision of livestock feed, where possible, ameliorates the severity of the drought.

Table 1.2. Frequency of Three Drought Classes at Six Localities in Botswana

Locality (See Fig. 1.4)	Moderate	Severe	Disastrous
Gaborone	1 in ≥2 yrs.	1 in ≥5 yrs	1 in ≥ 50 yrs
Mahalapye	1 in ≥2 yrs	1 in ≥5 yrs	1 in ≥ 50 yrs
Francistown	1 in ≤ 2 yrs	1 in ≤ 4 yrs	1 in ≤ 50 yrs
Maun	1 in ≥ 16 yrs	1 in ≥33 yrs	not applicable
Ghanzi	1 in 11 yrs	1 in ≥25 yrs	not applicable
Tshabong	1 in ≥ 6 yrs	1 in ≥11 yrs	1 in ≥50 yrs

Source: Adapted from Sandford, 1979: 38

Though Sandford's definition is useful, the assumption that a region has got a normal or median annual rainfall is difficult to apply in areas with variable rainfall. But the definition allows us to incorporate management factors because it looks at the previous use of grazing resources in an area.

1.3 Land Tenure and Land Use Pattern

Botswana can be divided into two broad soil groups. The two groups, the sandveld in the west and the hardveld in the east, cover approximately 80 and 20 percent of the country respectively. These two soil groups form the template upon which the land tenure shown by Figure 1.5 is based.

1.3.1 *Freehold*

This is land where there are exclusive ownership rights in perpetuity. Five percent of the country is zoned freehold (Ministry of Finance and Development Planning, 1991) most of which is commercial arable farms and livestock ranches. The other freehold zones are found in towns. Freehold land has a high market value. Owners of freehold land guard against intrusion into their land holding.

1.3.2 *Stateland*

Presently 25 percent of the country is stateland (Ministry of Finance and Development Planning, 1991). Stateland is land held by the government as a bequest to the nation. This category contains National Parks, Game and Forest Reserves, some Wildlife Management Areas (WMA's) and pieces of land reserved for future use. Some stateland, which has very good grazing land, has been encroached upon by cattle farmers whom the government has failed to remove (Kalahari Conservation Society, 1989). The failure is an unwelcome precedent that threatens the integrity of the country's land tenure system in the future.

1.3.3 *Communal (Tribal) Land*

Seventy percent of the country is Tribal land. The amount available has decreased as some parts were developed into TGLP farms and a third of the Wildlife Management Areas. Individuals acquire a free piece of land for farming, settlement, or other uses in the Tribal land. Land Boards allocate land guided by the Tribal Land Act of 1970. Allocation confers the right to use, but never to own, tribal land. Revocable leases for periods of 50 or 99 years may be arranged on Tribal land. Practically, the lease holder's right to use is almost in perpetuity since lease periods are both renewable and inheritable. Tribal land has far more security of tenure than what the Tribal Land Act (1970) allows.

The Tribal land's continued existence and sustained production is vital for the Botswana's traditional livestock sector. The communal area holds 85 percent of the country's cattle (Ministry of Agriculture, 1995), 97 percent of its goats and 85 percent of its sheep and is used for extensive crop production by about 66 percent of the traditional farmers (Ministry of Finance and Development Planning, 1991:240).

Mixed farming areas are found within the communal areas. These are areas where farmers rear cattle alongside crop production to optimise the use of labour and access to free surface water (Arntzen, 1990). Mixed farming areas, which are vital for small farmers, are under pressure from competing landuses such as crop production and increasing human and cattle population. The Tlokweng Sub-District Tribal Land has been a mixed farming area since the 1920's because of land shortage situation.

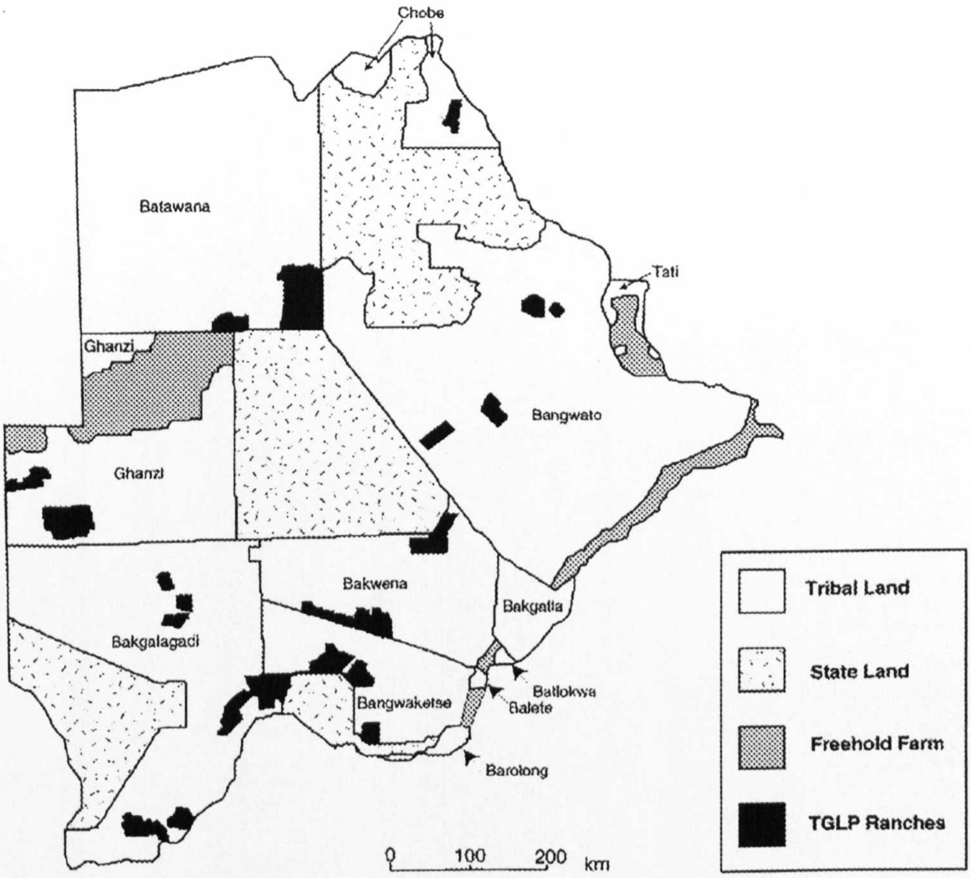

Figure 1.5 Botswana Land Tenure
Source: Arntzen and Veenendaal, 1986:13

1.3.4 *Some Land Use Issues that Affect Cattle Management*

Botswana has allocated 39 percent of its land to National Parks, Game Reserves and Wildlife Management Areas (WMAs). Most WMAs are in stateland. Given the extensive nature of agricultural landuse, a conflict with wildlife has emerged in a number of regions. Lands, a group of arable fields, and cattleposts, unfenced livestock rearing areas, were traditionally kept apart to avoid crop damage by livestock. The separation has faded as settlements expand due to population increase (Arntzen, 1989).

1.4 Development of the Livestock Sector and Consequences

Section 1.1.2 presented the increase in the livestock in Botswana. This section lists and briefly discusses developments that led to the herd growth. The developments are divided into pre and post independence eras. Most of the Sections 1.4.1 and 1.4.2 are based on three sources (Roe, 1980; Arntzen, 1989; White, 1993) unless specified otherwise.

1.4.1 *The Pre Independence Era (c 1895 - 1965)*

i) 1895/6 - the rinderpest epidemic of during which 95 percent of the national cattle herd died

ii) 1905 - establishment of the veterinary department

iii) 1919 - hut tax was introduced to tax cattle owners according to their herd size

iv) 1930/40 - groundwater development programme

v) 1934/35 - a national abattoir, later called Botswana Meat Commission, (BMC) was established at Lobatse

vi) c1948 -1960s- accelerated borehole drilling along trek routes to the abattoir

vii) 1955 -1962 - the Colonial Development Corporation developed a number of fattening and breeding ranches. Ranches in the north of the country failed but those in the south (at Molopo and Lobatse) were a success. The national abattoir was refurbished to expand its capacity and increase its efficiency.

viii) 1955 - the establishment of the European beef market which led to the expansion of veterinary services and the introduction of cordon fences to control livestock movement hence control livestock diseases.

ix) 1961 the colonial government launched the Livestock Industry Development Programme, which provided boreholes to reduce pressure on existing communal water sources and to encourage destocking

x) 1960 to1965 - drought and many[4] cattle died

xi) 1965 onwards - drought recovery measures introduced; these included Drought Relief, private livestock borehole drilling which reduced government's involvement

1.4.2 *The Post Independence Era (1966 to date)*

i) 1966 -1970 good rainfall period. Diamonds were discovered and their subsequent mining boosted national economic development

ii) 1970 - The Tribal Land Act was introduced. It transferred the land allocation power from the chiefs to the newly established statutory bodies called Land Boards. Effectively the traditional land management structures collapsed (Schapera, 1943)

iii) 1971 - following the success of the pre-independence ranches, more were allocated, at Ghanzi and Molopo

iv) 1972/3 - Livestock Development Plan 1 (LDP1) was launched during which more ranches were developed (see Section 1.5.1)

v) 1975 - three developments took place. Firstly, Botswana signed the Lome Convention that gave Botswana's beef exports preferential access to European Community market. Secondly, the Tribal Grazing Land Policy (TGLP) (see

[4] Between 1964 and 1966, the cattle population decreased by 430 304 (Campbell 1979:103)

Section 1.5.2) was launched to control and improve livestock management in communal areas. Lastly, the Cooperatives were strengthened. Cooperatives were run by the government to promote livestock marketing and group purchases of livestock feed and vaccines in rural areas

vi) 1977-81 - the LDP 2 was launched to fund the TGLP's commercial ranches

vii) 1978 - Foot and Mouth Disease outbreak followed by the closure of access to the European Community market

viii) 1979 - the launch of Services to Livestock Owners in Communal Areas (SLOCA) to enable the communal area farmers to improve livestock management. Through SLOCA, service centres and livestock input supply points were developed. SLOCA has recurred in the subsequent three five year National Development Plans

ix) 1981 - The Communal First Development Areas (CFDAs) were launched to concentrate development impetus into selected parts of communal areas in each district in order to accelerate rural development. It was not restricted to livestock development

x) 1982 – the second diamond mine was opened and the increased economic boom that followed diverted attention away from agriculture and the livestock sector

xi) 1983 - a second abattoir was opened at Maun, in the North West District

xii) 1986 - the launch of the National Land Management Project (LDP3) to promote improved livestock management in communal areas and to support diversified agricultural activities

xiii) 1989 - the Agricultural Sector Assessment report, by the Ministry of Agriculture, identifies overgrazing and degradation as important issues in livestock management. It singled out the TGLP farms as a contributory factor

xiv) 1990 - two significant events took place in the livestock sector. Firstly, a third abattoir was opened at Francistown. The total national slaughter capacity at the three BMC abattoirs reached 1450 cattle per day (Ministry of Finance and Development Planning, 1991). The abattoirs are operating below capacity. In 1997/98, 162 000 cattle were killed (http://www.gov.bw/19990309) which is about half of the national slaughter capacity. Secondly, the National Conservation Strategy (NCS) was launched. "*Degradation of rangeland pasture resources*" (Republic of Botswana 1990:4) was one of the four main environmental issues to be addressed by the strategy. The NCS describes the livestock sector as one of the eight "*main sustainable development opportunities based on natural resources which require support from government*" (Republic of Botswana 1990:5). The NCS is reviewed in detail in Section 1.5.3

xv) 1991 - The National Policy on Agricultural Development (NPAD) was launched. The policy is discussed in detail in Section 1.5.4

xvi) 1995 - an outbreak of cattle lung disease (Contagious Bovine Pleuro-pneumonia). About 300 000 cattle were killed to control the spread of the disease. Government compensated the livestock farmers in the affected area at a total cost of P250 Million[5] (Times, 1997).

[5] The value of Botswana's currency Pula (P) fluctuates, it was P1.00 =£ 0.1357 on 9th February 1999.

1.4.3 *Trends in the Livestock Sector*

Sections 1.4.1 and 1.4.2 show that livestock management concerns have dominated the development of the sector for sometime. Cattle mortality was reduced when the veterinary services were introduction 100 years ago. The reduced mortality, alongside other factors, led to the growth of the national cattle herd to an episodic maximum of 3 million shown in Figure 1.1. Except for periodic droughts, such as 1982 to 1987, when the national herd declined from 3 million to 2.3 million, (Figure 1.1: Ministry of Agriculture, 1990), the livestock population has not decreased significantly. The offtake rate in the communal sector is 8 percent (Ministry of Agriculture 1990:8), which is low when compared to 20 percent in the commercial areas (Mosienyane 1992). Since communal areas hold most of the livestock in the country (see Section 1.3.3) the national livestock herd is not reduced. The two ideas that have dominated the development of the livestock sector are drilling boreholes and fencing grazing areas. The government has encouraged diversification to small stock because they are resilient to drought. Indications are that the diversification is taking place because goats increased from about 20 percent of the livestock population in 1979 to 50 percent in 1993 (Figure 1.2).

1.4.4 *Pressure on Land Resources*

Some communal grazing areas, especially in mixed farming zones in the eastern part of the country, have lost land to arable lands. Mpotokwane (1986) studied land use change using sequential aerial photographs and found that fifty eight percent of the arable land increase between 1950 and 1982 encroached into a predominantly grazing area in the north east of Kgatleng District. Arntzen (1989) did not see arable encroachment as a cause of overgrazing in Kgatleng and around Palapye, but acknowledged that the conversion of communal land to freehold and leasehold led to local land pressure in some districts (Arntzen, 1989). Loss of grazing land contributes significantly to cattle management problems in communal areas.

1.5 Policies Affecting Livestock Development

In order get an insight into the government's efforts to improve cattle management in the country, four policies launched between 1972 and 1991 are reviewed. The first two were livestock development policies. The last two affected the livestock sector extensively but were not developed exclusively for the sector.

1.5.1 *The First Livestock Development Plan (LDP1) 1972*

The First Livestock Development Programme 1 was to provide controlled expansion of cattle production into the Statelands (see Section 1.3.2) in the west of the country in order to relieve pressure on the rangelands in east. The expansion would be made possible by the provision of borehole maintenance crews and other technical extension teams for the cattle management infrastructure. LDP1 was also to provide 70 breeding sheep and finishing ranches. Trek routes, paths with water and kraals along which livestock are driven for long distances without losing condition, were to be provided between the production areas and the national abattoir. The sponsors, the International Bank for Reconstruction and Development (IBRD) and Swedish International Development Agency (SIDA), requested that the LDP1 should improve the management of communal areas and provide new ranches without disadvantaging the poor and that the project should be economically viable (Cooke, 1985; White, 1993). Essentially the LDP1 was an attempt to demonstrate the benefits of fenced ranches as an improved livestock management technique.

The project failed. Four reasons were given for its failure. Firstly it was carried out in areas where transport, telecommunications and technical support staff were not easily accessible. Secondly the beneficiaries failed to make the expected transformation from cattlepost managers to modern ranch managers hence several ranches were merely managed as fenced cattleposts. Thirdly the government failed to control stock numbers within the ranches (Devitt, 1982 b), using the Agricultural Resources Conservation Act. Moupo (1992) recently observed that the Act has no history of being implemented. Lastly the absence of full time resident ranch managers constrained effective management (White, 1982). There were limited positive benefits. The Artificial Insemination facilities provided were made accessible to farmers in remote areas and there was employment generation in the newly established farms (Kjaer-Olsen, 1982).

1.5.2 *The Tribal Grazing Land Policy (TGLP) 1975*

As a sequel to the Livestock Development Project 1, the government introduced TGLP to tackle poor livestock productivity in the communal areas and the allegedly widespread overgrazing due to a growing livestock herd size on a relatively dwindling land resource base (Tsimako, 1991). The TGLP was also to address the issue of social equity by offering the large herd owners, those with over 400 animals, an opportunity to move out of the communal areas to fenced ranches. It was envisaged that the small herd owners left in the communal areas would have more room for their livestock, just like it had been envisaged for LDP1. Livestock management in the recommended 6400 hectares ranches was expected to be better than in the communal farms. Each ranch had a water source.

Although TGLP farms are now a part of Botswana's land use, it is widely accepted that their objectives have not been attained (Ministry of Agriculture, 1991; Tsimako, 1991). Several reasons have been cited for the failure. Seven are highlighted in this section. Firstly the TGLP policy designers wrongly assumed that there were unoccupied pieces of land on which TGLP farms could be demarcated. Some farms, especially in the Central and Kweneng districts, were demarcated on already inhabited land (Tsimako, 1991). Due to conflicts with the existing land users, some ranches were not developed. By December 1990, 501 TGLP ranches, ranging from 4 000 to 11 763 hectares were demarcated in six districts. Only 66 percent of the demarcated ranches were ever allocated and developed (Tsimako, 1991). Secondly, when a farmer did not succeed in drilling for water, subsequent ranch development was not possible. Thirdly some farmers were not able to raise money to contribute to the farm's development. Fourthly there was lack of cooperation amongst some development group members, called syndicates, which resulted in protracted arguments that delayed development. Fifthly, the 1978/79 and the 1981/82 to 1986/87 drought incapacitated some farmers just when they intended to move their livestock into ranches (Tsimako, 1991). Where the ranches were occupied, they were heavily stocked and subsequently overgrazed (Tsimako, 1991) just like the LDP1 farms. Occupancy of a ranch *per se,* did not bring about better livestock management. The management of the TGLP ranches has not been better than that found in the communal grazing areas despite the credit facilities and advice that the farmers received from government (Ministry of Agriculture, 1991). Lastly the TGLP farmers enjoy dual grazing rights (Ministry of Agriculture, 1991). Dual grazing rights means that the farmers graze cattle in both the ranch, to which they have exclusive access as lessees, and the communal rangeland, where they have a birthright. Dual grazing is a both a symptom and cause of the TGLP failure. It shows that the TGLP farmers' cattle management has not improved as envisaged. Dual grazing caused the failure in the expected reduction of herds in the communal areas because cattle from the TGLP ranches return to the communal areas. On the contrary, dual grazing increased the land pressure in the communal areas since the returning cattle had less grazing land because some of it was lost to TGLP farms.

1.5.3 *National Conservation Strategy (NCS) 1990*

The NCS was launched to operationalise Botswana's commitment to Sustainable Development. The strategy has two goals:

i) "*to increase the effectiveness with which natural resources are used and managed, so that beneficial interactions are optimised and harmful environmental effects are minimised*

ii) *to integrate the work of the many sectoral ministries and interest groups throughout Botswana, thereby improving the development of natural resources through conservation, and vice versa*" (Republic of Botswana, 1990:2).

A body called the National Conservation Strategy Coordinating Agency (NCS Agency) was formed to implement the NCS. Although the NCS goals are ideal they are difficult to attain. Botswana's traditional management groups which were localised have collapsed (Schapera, 1943) and in their place are less effective centralised sectoral structures. The integration of natural resource management and conservation is difficult between government sectors. Two examples highlight the problem. The essential coordination between ministries, such as the Ministries of Local Government Lands and Housing, which designates and allocates land for different uses, and the Ministry of Agriculture, is not always easy. The NCS and the National Policy on Agricultural Development (Section 1.5.4.) are a good example of the poor coordination between the two ministries. The two policies were launched a year apart but none refers to the other despite the obviuos linkages between them. The second example is the NCS Agency. In 1993 it was observed that the NCS Agency did not have the expertise and political influence to function as a clearing house for Environmental Impact Assessments specifically and natural resource management issues in general. It was recommended that the Agency should be independent so that it could develop expertise and be directly accountable to the Office of the President, to give it some political influence (Takirambudde, 1993). To date the NCS Agency is still in the Ministry of Local Government Lands and Housing where it is an advisory body to government departments. Its relationship with line ministries, and the authority it has to implement the NCS, are nebulous. The problem, in the present author's view, is that over time the government sectors have developed expertise and political influence which they are reluctant to share or relinquish. But consultation between sectors is a hurdle that natural resources management faces because the issues are multifaceted. Botswana's livestock management is not immune to the impasse.

The NCS policy document makes tentative recommendations about the improvement of livestock management. It states "*Of all the issues this* (livestock management) *is* *recognised to be the most difficult to resolve. Whilst many of the solutions have generally been known for a considerable long period of time, they run counter to traditional customs. Thus implementation progress is likely to be slow.....Legal reforms will continue to present problems. However the government is committed to continuing to devise legislation which will lead to improvements in the management of both rangelands and livestock. In addition, continued attention will be paid to finding politically acceptable ways of improving the enforcement of the Tribal Land Act and the Agricultural Resources Act*" (Republic of Botswana 1990:9-10). The tentativeness of the recommendation suggests that the NCS Act has succumbed to its fate. It shows a lack of political will to enforce Acts such as The Agricultural Resources Act of 1974. The latter Act is well equipped to control the use of the range resources, amongst others. It empowers the Agricultural Resources Board, the implementing body housed in the Ministry of Agriculture, to issue orders for the maximum number of stock which can be kept at a place and to confiscate excess stock from an overstocked area. It is doubtful that the Act has ever been implemented (Moupo, 1993). Takirambudde (1993) noted that environmental law in Botswana is poorly implemented because it is scattered in various Acts, administered by ministries with little coordination between them, costly to enforce, has manpower shortages and the laws are not widely known. It is difficult to see how the NCS Agency will overcome the problems which cause lack of implementation, as an advisory body. Meantime, management problems will continue in the livestock sector.

1.5.4 *The National Policy on Agricultural Development (NPAD) 1991*

The government launched the NPAD to address a range of development problems in the agricultural sector. The policy objectives are:

i) "to provide adequate and secure livelihoods for those involved in agriculture

ii) to increase agricultural output

iii) to increase food self sufficiency

iv) to conserve agricultural land resources

v) to meet the employment demands of a growing labour force (Ministry of Agriculture 1991:4).

The NPAD accepts that Botswana is not suitable for crop production and that there has been a notable deficit in food production due to the erratic rainfall, especially during the flowering stage of crop plants (Ministry of Agriculture 1991). The government adopts an economic position about food production, that "*self sufficiency made possible by high cost, heavily subsidised production is not what government is seeking*" (Ministry of Agriculture, 1991:20). Consequently it recommends food security to replace the objective of self sufficiency in food production.

The policy emphasises the need to address the problem of low productivity in the livestock sector. It highlights the issue of land (mis) management and suggests to '*allow farmers, where feasible, to fence livestock farming land either as individuals, groups or communities to improve productivity of the livestock sub - sector*' (Ministry of Agriculture, 1991:41). The NPAD states that "*through fenced grazing areas individuals or communities will be able to control stocking rates, disease and plan better their breeding and marketing programmes*" (Ministry of Agriculture, 1991:41). The availability of livestock water will be a prerequisite for fencing. Therefore those presently with water rights, may be given priority to fence areas around their communal water source for exclusive use. There is no recommendation to ban dual grazing rights within the policy framework (Ministry of Agriculture, 1991). The NPAD revisits the Tribal land livestock management problems which the TGLP failed to address, or exacerbated, sixteen years ago. The NPAD is a public statement of the government's tenacious faith in fencing as a panacea to communal rangeland mismanagement despite the negative results from the TGLP and LDP1. Chapter 3 critically appraises the theoretical basis of the government's enduring faith and introduces the theoretical framework of this thesis.

By June 1996, five years after the launch of NPAD, none of the communal land was fenced and the criteria for the selection of land to be fenced were not confirmed. The delayed implementation is normal. The TGLP farms were allocated ten years after the policy launch (Tsimako, 1991). However there are indications that the NPAD will be thoroughly investigated before it is implemented. A national Agricultural Sector Policy Implementation Committee was formed to coordinate the studies prior to the implementation of the policy. A technical committee, which comprised the two ministries most likely to be involved, was established to look at the fencing aspect. At this stage it remains to be seen whether the NPAD will succeed.

1.5.5 *Conclusion on Livestock Policies*

Fencing, an unsuccessful solution to livestock management before, has been revisited through the NPAD. However the delayed implementation of the NPAD affords a chance to develop a method to assess the viability of livestock management areas deemed suitable for fencing. The present study uses information on the history of rainfall, changes in landuse, livestock holding, and household management strategies to understand and analyse the cattle management in Tlokweng Sub - District.

1.6 The Research Aims, Objectives and Hypotheses

1.6.1 *The Research Aims*

The research has two aims.

The Research Aim 1

To describe and evaluate the sustainability of subsistence cattle farmers' management strategies in a communal land in the Tlokweng Sub District.

The Research Aim 2

To develop a system dynamics model to describe and monitor the cattle management in the study area which can be easily applied to similar areas elsewhere.

1.6.2 *The Research Objectives*

Four research objectives were identified.

Research Objective 1

To describe the pastoral management practised by households within the study area in terms of livestock holding, access to pastoral resources of water and grazing at various times of the year, response to shortage of grazing and water resources and livestock movements.

Research Objective 2

To develop a conceptual model of the cattle management for the study area.

Research Objective 3

To fit the conceptual model of the cattle management into the Rainfall Land Cattle model that is derived from the Braat and Opschoor model of 1990.

Research Objective 4

To assess the medium term sustainability of pastoral production in the study area, given the number of cattle, the rainfall changes and the change in land availability. The study will also assess the likely impacts of the fencing component of the National Policy on Agricultural Policy.

1.6.3 *The Research Hypotheses*

Three hypotheses were drawn.

Hypothesis 1

Subsistence cattle management in the communal areas of Tlokweng Sub-District is opportunistic and its success depends on the effectiveness and the efficiency of implementing the chosen management strategies.

Hypothesis 2

Land availability is considered the major limiting factor for subsistence cattle management in Tlokweng Sub District.

Hypothesis 3

The Rainfall Land Cattle model can be used to describe and assess cattle management in the study area under recent climatic conditions and under possible drier conditions.

Summary

The households accumulate cattle due to the interplay of financial, social and biological considerations. After increasing from the late 1960's to the early 1980's, the national cattle population fluctuates due to rainfall availability and disease outbreaks. Rainfall is variable and drought is endemic. The government's view is that cattle management in the communal areas is poor, unresponsive to change and detrimental to the natural resource base. The view is reinforced by the comparison of communal and commercial areas. To date policies to improve the productivity of cattle in the communal areas have in the large part been unsuccessful. Wrong tools of analysis were used to understand and solve communal cattle management. Through an investigation of cattle management in a small communal area, the present research seeks to establish how land availability, rainfall amount, and management strategies affect cattle management. A model will be developed to show the relationship of these three facets of cattle management in Tlokweng sub district. The model emphasises the dynamic aspects of cattle management.

Chapter 2 Description of the Study Area

Introduction

Chapter 1 discussed the landuse pattern and the pressures on livestock management at the national level. This chapter discusses the landuse pattern and livestock management pressures in the study area, Tlokweng Sub District. It also describes the rainfall, soils and vegetation units in the study area. Finally, it justifies the selection of the study area.

2.1 Location of the Study Area

The study area, Tlokweng Sub-District (*alias* Batlokwa Tribal Land) is located within the South East District (Figure 2.1), the smallest of Botswana's ten administrative districts (Table 2.1).

Table 2.1 Area, Population and Population Density (person km^{-2}) of Botswana Districts

District	Area (km^2)	1991[1] Population	Pop Density (person km^{-2})
Central	145 750	463 797	3.2
Chobe	20 750	14 166	0.7
Ghanzi	115 000	24 719	0.2
Kgalagadi	106 000	31 134	0.3
Kgatleng	7 650	57 770	7.6
Kweneng	36 800	170 437	4.6
Ngamiland	109 850	94 534	0.9
North East	5 400	108 598	20.1
South East	1 500	203 104	135.4
Southern	27 000	159 027	5.9
TOTAL[2]	575 700	1327 286	1.4

Sources: Field, 1978:67 (Area); Central Statistics Office, 1993 (Population);
(Population Density = 1991 Population/ Area)

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[1] Central, North East, South East and Southern Districts include an urban population totalling 316 642
[2] District areas were rounded off which led to the area of Botswana being less than 582 000 square kilometres

Figure 2.1 Administrative Districts in Botswana
Source: Ministry of Finance and Development Planning, 1991

The area of the district is 1 492 km^2. It has two communal lands, Batlokwa and Balete Tribal lands, which are 215 km^2 and 670 km^2 in area respectively. The communal land is about 60 percent of the district's area. The rest of the sub district is made up of two urban areas of Gaborone and Lobatse and several commercial farms (Republic of Botswana, undated). The South East district has the highest population density in the country and by inference, the greatest land pressure. The presence of Gaborone city, a fast growing commercial and industrial hub, and Lobatse town, exacerbates the land pressure within the district. The South East district is bordered by the Republic of South Africa, and Southern, Kweneng and Kgatleng districts.

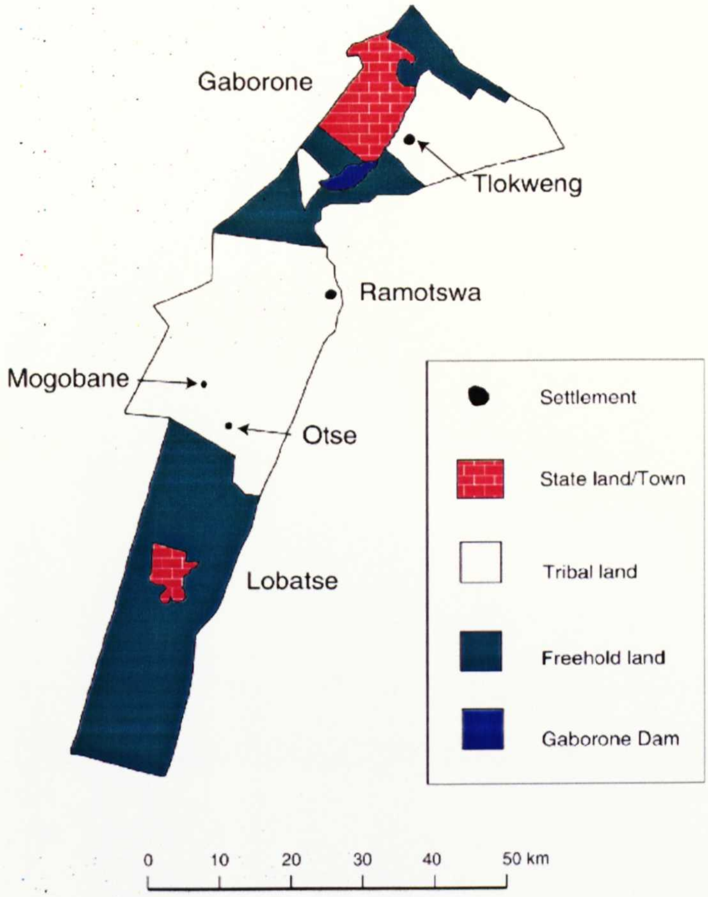

Figure 2.2. The South East District Land Tenure
Source: Department of Town and Regional Planning, 1995

2.2 A Historical Perspective of Tlokweng Sub District Land Pressure

In 1887 Batlokwa[3] settled in the present Gaborone City[4], then called Moshaweng, after migrating from South Africa (Schapera 1943 (a); Kgosi[5] Monare, personal communication, 1996.). They initially located their arable fields across the Notwane River in the present day Tlokweng village. Shortly afterwards they relocated their village to the same side of the river as the fields area because they feared a flood could interrupt their movement between the two. Moshaweng continued as a grazing

[3] Batlokwa are the people from Tlokweng Sub-District.
[4] Gaborone city is named after the chief Gaborone of Batlokwa.
[5] Kgosi is chief

area. Their land claim then extended into the Kgatleng and Kweneng district and some of the present freehold farms south of Gaborone City (Kgosi Monare personal communication 1996). The historical land claim of approximately 500 km^2, is more than double the area of their present territory.

Between 1894 and 1897 the British South Africa Company (BSA Co.) asked for a strip of land through Gaborone on which to build the railway line from South Africa to present day Zimbabwe (Colclough and McCarthy, 1980). Kgosi Sebele of Bakwena[6] gave them more land than they needed for the railway to deprive Batlokwa of their grazing land. Batlokwa had been allied to Bakgatla[7] against Bakwena in an inter tribal feud (Kgosi Monare, personal communication, 1996). After the land purchase, the BSA Co. allowed Batlokwa cattle to graze in Gaborone for a grazing fee of 15 shillings a household per annum (Botswana National Archives, DCG 1/8). Because the BSA Co. got more land than they needed, they sold the excess land to European settler farmers who established a freehold area. The freehold area became known as the Gaborone Block (Colclough and McCarthy, 1980:14). The Gaborone Block farmers did not allow Batlokwa cattle to graze on the land and even complained that their farms were devalued by the proximity to Batlokwa land (Botswana National Archives, S 94/7).

The land pressure intensified when the Gaborone Block grazing area was not accessible and Batlokwa repeatedly complained about the land shortage to the

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[6] Bakwena are the people from Kweneng District
[7] Bakgatla are the people from Kgatleng District

Resident Commissioner. In 1931 he suggested that they should move to Molopo, in southern Botswana, where there was adequate land for their 6000 herd of cattle. The Resident Commissioner further suggested that the BSA Co. would buy their small land and pay their resettlement cost at Molopo. Batlokwa turned down the offer (Botswana National Archives, S 94/7). In 1933 the Batlokwa Reserve was established (Colclough and McCarthy, 1980; Schapera, 1943 a) east of the Notwane river and a boundary fence was built along the river to separate the Reserve and the Gaborone Block. Batlokwa intensified complaints about their alienation from what they regarded as their grazing land.

2.2.1 *Alleviation of Land Pressure in Tlokweng Sub District*

Due to the land pressure Batlokwa livestock repeatedly trespassed into European farms (Mosothoane, 1976). In 1939 a desperate farm owner eventually succumbed to the incessant pressure and consented to sell off Fairfield farms (Figure 2.9) to Batlokwa for £2000.00. The Batlokwa chief imposed a £5 levy (Schapera 1943 (a)), or £3 according to Kgosi Monare (personal communication 1996), on each household to raise money to purchase the farm. Subsequently two other farms, Clent (16 km^2) and Almond Hill, also known as Majeadikgokong (20 km^2), were purchased (Figure 2.9). Each household contributed £30 (Kgosi Monare, personal communication 1996), for the purchase of the latter two.

Although the Batlokwa Reserve, including the arable fields' area, was believed to have the capacity to carry 3780 cattle, Schapera (1943 a) reported it to be carrying 5531 cattle. Despite being noted for its outstanding ability to recover from overgrazing and drought, Schapera (1943 a) noted that the reserve was overstocked. The following five measures were taken to relieve the land pressure:

i) concessions were given to graze cattle, which belonged to those who worked in Gaborone, in the Gaborone Block farms

ii) 1200 to 1800 cattle were to be moved to graze the stubble at Odi lands after the harvest

iii) the livestock water points were spread out

iv) Batlokwa were encouraged to use grazing in the Kgatleng and Kweneng Reserves (Schapera, 1943 a).

v) in 1928 a drift fence was put up to separate the 5000 ha. of arable fields from grazing in order to optimise the use of the land between grazing and arable land (Plate 1). The drift fences are part of the land management system within the study area.

According to the Tribal Land Act, Batlokwa like all other Batswana, are free to keep their livestock in any part of the country. In practice it seldom occurs.

Plate 1 A drift fence separates the arable area (left) from the grazing

2.2.2 *Recent Land Pressure from Gaborone City*

Just before the country's independence in 1966, Botswana established its capital town at Gaborone (Plate 2) because of the nearness to the then reliable water supply along the Notwane River[8]. The population of Gaborone has grown beyond predictions and Tlokweng has been one of the two main recipients of the spill over from the growth in the form of demand for residential land (Swedeplan, 1995 a). The other recipient is Mogoditshane, to the west of Gaborone. The South East District is under pressure due to the land demands of the growing city of Gaborone and it's associated landuses.

Plate 2 A view of Gaborone from the study area. Picture was taken about 10 km from Gaborone.

[8] Subsequently the Notwane Dam ($141 x 10^6 m^3$) became inadequate for the demands of Gaborone city. Two supplementary dams Bokaa Dam ($18.5 \times 10^6 m^3$) and Nnywane Dam ($2.3 x 10^6 m^3$) have been developed since the drought of 1981/2 to 1986/87. Letsibogo Dam ($100 x 10^6 m^3$) about 400 kilometres north of Gaborone is expected to provide more water to the city from 1999 (Khupe 1996:134).

The Gaborone land pressure problem has been accentuated within the last 20 years (Department of Town and Regional Planning, 1996). Like Gaborone, the population of Tlokweng has grown rapidly (Table 2.2). It is most likely that Tlokweng population

Table 2.2 Population of Gaborone and Tlokweng 1971 to 1991

Settlement	1971	1981	1991
Gaborone	17 713	59 657	133 468
Tlokweng	3 906	6 653	12 501

Source: Republic of Botswana, 1993:8,67.

growth is strongly influenced by the influx of people from Gaborone. Tlokweng has developed into a dormitory village for some Gaborone workers. For example, **Lengana,** which is a residential area mostly occupied by Gaborone workers, has developed on the eastern outskirts of Tlokweng village (Makepe[9] personal communication 1996). The residential area which did not exist on the 1989 aerial photographs of the village, developed during the last 10 years. The **Lengana** area used to be a grazing area and its conversion to residential use was a direct loss to pastoral farming. Recently Tlokweng Land Board suspended Tlokweng residential land allocation, as there were too many applications for practical consideration. Another land demand comes from The Greater Gaborone Area plan. If implemented, the plan will take over significant areas of present grazing land, which will further aggravate land pressure (Department of Town and Regional Planning, 1996). Industrial land demand has also been felt in Tlokweng and its surrounding areas. Due to land pressure within the sub-district land speculation developed. For example, between 1982 and 1995, the Land Board allocated 46 dairy farms with a total of over 30 ha., (see Appendix 1). Only three of the 46 dairy farms allocated were operational in 1996. The sudden interest in dairy farms was speculative. The Land Board suspended further dairy farm sites allocation as it deemed the Tribal Land to be too full to accommodate any more dairy farms (Makepe, personal communication 1996). Land hoarding has been observed in other landuses as well (Swedeplan, 1995 a and b). Land speculation and hoarding occur because owners of developed land hope to receive lucrative government compensation when their land is obtained for national projects like roads.

Natural resources in the sub- district, such as fuel wood, are also under pressure. Gaborone residents and institutions collect fuel wood from the sub-district. It is expected that the shortage of fuel wood will grow to 46 000 tonnes by the year 2010 in the South East district as a whole (Swedeplan, 1995 a). Households in other districts adapt to fuel wood scarcity by reducing the number of meals cooked per day and switching to other fuels and using less preferred tree species (Kgathi *et al.*, 1994). Within Tlokweng sub-district switching to less preferred tree species is unlikely due to the limited resource base. Reducing the number of meals cooked per day may lead to poor family nutrition.

2.3 Rainfall Characteristics for Gaborone, Mochudi and Lobatse

Figure 2.3 to Figure 2.5 show the annual rainfall for the three localities (Figure 2.1) nearest to the study area. The localities have similar rainfall trends. They are characterised by rainfall peaks in the mid 1950's, late 1970's and early 1990's. The trend is similar to that of southern Africa described by Tyson (1987).

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[9] Mr Makepe was interviewed as the Chairman of the Tlokweng Land Board during the field work

The rainfall year shown in Figures 2.2 to 2.4 is divided into five seasons (see Table 2.3) based on Vossen (1987). October to December is the early rainy season, January to February and March to April are mid and late rainy seasons respectively. May to June is the early dry season and July to September is the late dry season. Rain during the early rainy season enables the households to plough early and the early development of grass. It is also provides surface livestock drinking water, though that also depends on the nature of the rainfall. The mid rainy season rainfall is necessary to prevent plant and grass seedlings from wilting. It also coincides with the seed stalk development and flowering stages of the grass (Hendzel, 1981). The late rain is

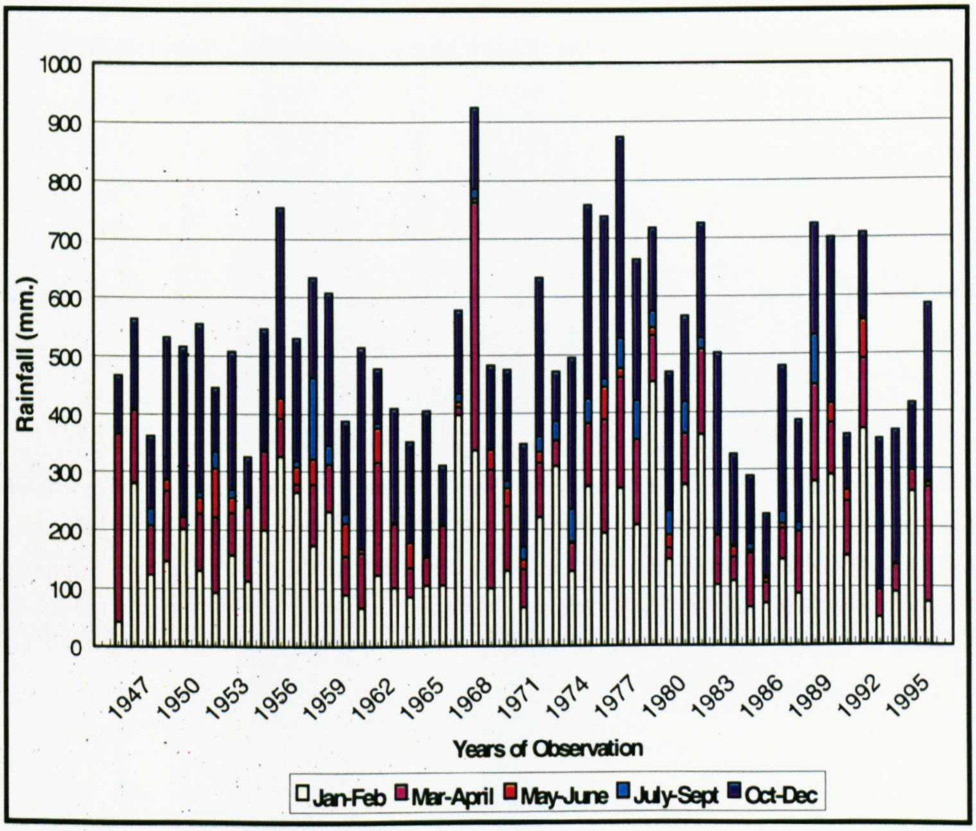

Figure 2.3 Gaborone Rainfall 1945 to 1995
Source: Adapted from Botswana Meteorological Services, 1996.

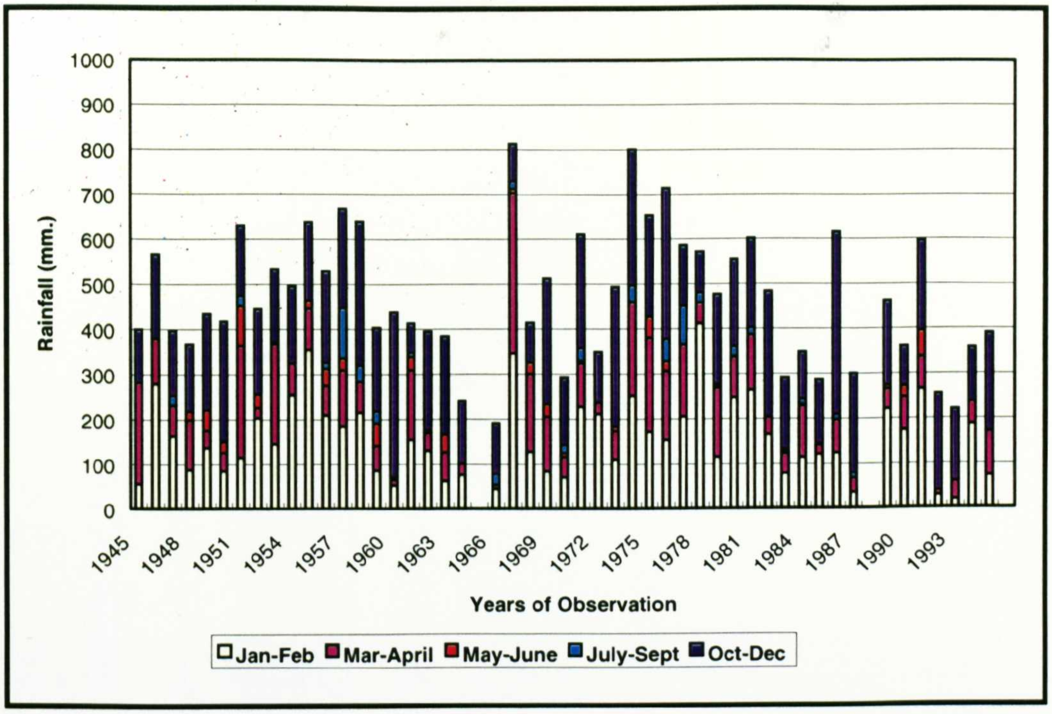

Figure 2.4 Mochudi Rainfall 1945 to 1995
Source: Adapted from Botswana Meteorological Services, 1996.

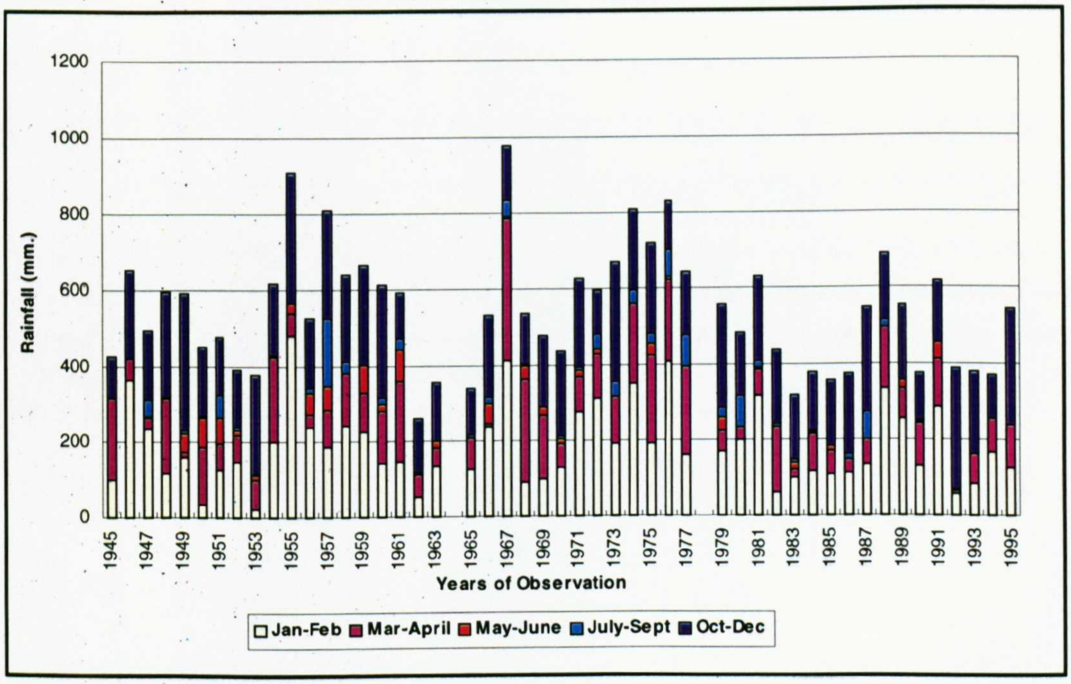

Figure 2.5. Lobatse Rainfall 1945 to 1995
Source: Adapted from Botswana Meteorological Services, 1996.

dry season (winter) rainfall, which is of low value to crops and not useful for forage production either. Both the spatial and the temporal rainfall variations influence the production of livestock and crops. A series of good rainfall years leads to an increase in cattle numbers. Crops benefit most when the rainfall occurs throughout the season. The annual grass species, which are common in Botswana, do well even from abundant late rainfall. The length and severity of the annual dry season, which depends on the amount of rain during the early and late dry season, is critical for livestock condition and survival (Vossen, 1987).

In addition to the countrywide spatial rainfall variation shown in Figure 1.4, the local rainfall varies temporally, seasonally (Bhalotra, 1985). Table 2.3 shows the rainfall seasonal coefficient of variation for Gaborone, Mochudi and Lobatse.

Table 2.3 Coefficient of Variation for Seasonal and Annual Rainfall, 1945 to 1995, at Gaborone, Mochudi and Lobatse

Months and Season Description		Coefficient of Variation (CV) (%)		
Months	Description	Gaborone	Mochudi	Lobatse
Jan - Feb	Mid rainy	56.4	59.2	56.0
March - April	Late rainy	71.0	78.9	67.9
May - June	Early dry	123.1	143.4	133.1
July - Sept	Late dry	142.5	168.1	149.8
Oct - Dec	Early rainy	37.8	42.8	35.4
Jan - Dec	Calendar year	29.7	37.7	32.9

Source: Calculated from Department of Meteorological Services, 1996.

A high value shows a big seasonal rainfall variation. At each locality, the seasonal rainfall varies more than the annual rainfall. A good crop, or forage production, depends on rainfall that is seasonally well distributed rather than an annually even amount. Each of the localities has an annual rainfall coefficient of variation of at least 30 percent, which is the lowest CV found in rangelands (Ellis, 1995). The seasonal variation increases from the early rainy season to the late dry season. Most seasons' coefficients of variation exceed 30 percent, which shows a high variability (Table 2.3). Table 2.4 compares the seasonal rainfall between any two of the three localities.

Table 2.4 Linear Regression Correlation Coefficient for Seasonal and Annual Rainfall, 1945 to 1995, at Gaborone (Gab), Mochudi (Moch) Lobatse (Lob)

Months and Season Description		R^2 values		
Months	Description	Gab - Moch	Gab - Lob	Moch - Lob
Jan - Feb	Mid rainy	0.564	0.564	0.524
March - April	Late rainy	0.586	0.589	0.381
May - June	Early dry	0.718	0.554	0.527
July - Sept	Late dry	0.724	0.695	0.646
Oct - Dec	Early rainy	0.504	0.268	0.209
Jan - Dec	Calendar year	0.573	0.410	0.351

Source: Calculated from Department of Meteorological Services, 1996.

A high R^2 value tells us that the rainfall of two localities is similar while a low R^2 value is vice versa. The biggest difference between the localities was for Gaborone - Lobatse and Mochudi - Lobatse during the early rainy season when there was the least regression correlation coefficient. This tells us that the two set of localities have a big contrast in the rainfall amounts. There was less contrast between Gaborone and Mochudi for the early season rainfall. The late dry season was least variable for all the localities which means that each of the three localities was consistently dry, or wet, between 1945 and 1995. The mid rainy season had the most uniform pattern of rainfall with R^2 values of around 0.5 between each of the two localities compared. Overall there was a closer correlation between seasonal rainfall of Gaborone and Mochudi than there was between Gaborone - Lobatse and Mochudi - Lobatse. The same pattern occurred for the annual rainfall. Of the three localities Gaborone and Mochudi are nearest to each other while Mochudi - Lobatse are furthest apart.

2.4 Soils in the Study Area

The study area has eight soil mapping units on four main landscape units (Figure 2.6). The most extensive soil unit is the Ferric Luvisols on which most of the grazing takes place throughout they year. All soils in the study area are marginally suitable for sorghum, in particular, and arable agriculture in general. The common limitation is moisture availability. Crop yields on the marginally suitable land are 40 to 60 percent lower than the potential but still good enough to justify agriculture. It would cost a considerable amount to improve the arable production output in the study area (Huesken *et al.,* 1989).

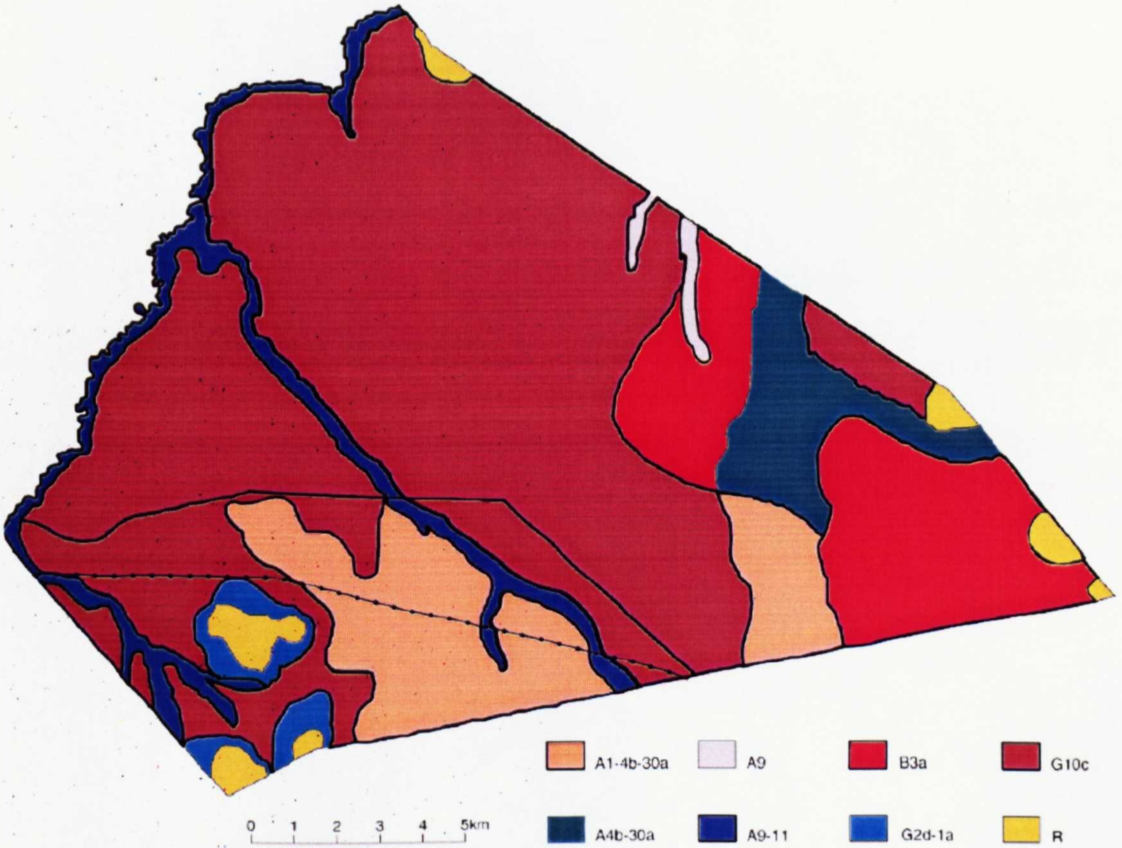

Figure 2.6 Soils in Tlokweng Sub District

Soil Map Legend

Main Unit	Map Unit Code	Soil Name and Occurrence	Soil Description	Main Landuse
Soils on Alluvial Deposits	A1- 4b-30a	Complex of Pellic Vertisols, Calcic Cambisols and Vertic Gleysols; found on slightly high ground	moderate to very deep; clay loam to clay; poor or imperfectly drained calcareous; Calcic Cambisol dominant	arable
	A4b- 30a	Calcic Cambisols and Vertic Gleysols; found on terrain like A1-4b-30a	moderate to very deep; sandy clay loam to clay; imperfect to poorly drained	arable
	A9	Calcic Luvisols; found on valley floors and lower footslopes	deep to very deep; sandy clay loam to clay; imperfect to moderately well drained; calcareous	grazing
Soils on Alluvial Deposits	A9-11	Calcic Luvisols and Ferric Luvisols; found on higher parts of the Notwane river and Maratadiba valleys	moderately deep to very deep; sandy clay loam and sandy clay to clay; moderately well to well drained; calcic in lower elevations and ferric on higher ground	grazing
Soils on Gabbro - Basic Igneous Rock	B3a	Chromic Luvisols; found east of the study area on gabbro rock	very deep; sandy clay loams to sandy loams; well drained; well developed clay subsoil	grazing

Soil Map Legend (continued)

Main Unit	Map Unit Code	Soil Name and Occurrence	Soil Description	Main Landuse
Soils on Acid Igneous and meta morphic Rocks	G2d-1a	Ferric Luvisols and Eutric Regosols; found on steep slopes	moderately deep; sandy loam to sandy clay loam; moderately well to well drained; susceptible to erosion	no known use
	G10c	Ferric Luvisols; found on most flat plains	deep to very deep; sandy loam to sandy clay loam; well drained; not susceptible to erosion due to flat location; most extensive unit in the study area	arable, grazing and settlement
Soils on Steep Hills, Ridges and Escarpments	R	Shallow Soils; found on hills and ridges	very shallow; rocky	not suitable for most uses

Source: Adapted from Huesken *et al.,* 1989.

2.5 Vegetation Units and Biomass Production Estimates

The study area has four general vegetation units (Timberlake, 1980; Powell, personal communication, 1996). Figure 2.7 shows the distribution of vegetation units whose characteristics are summarised in Sections 2.5.1 to 2.5.5.

2.5.1 *(Unit A) Heavily used Terminalia sericia Tree and Shrub Savanna*

Unit A is between the southern drift fence and the Gaborone – Border road. It includes the settlements Mmamogofu, Terateng and Radipotsane (Figure 2.9). It is similar to Unit B (Section 2.5.2) but has lower vegetation cover which is most likely due to the clearance of vegetation for use as fencing material for the homesteads and the drift fence (Powell, personal communication. 1996).

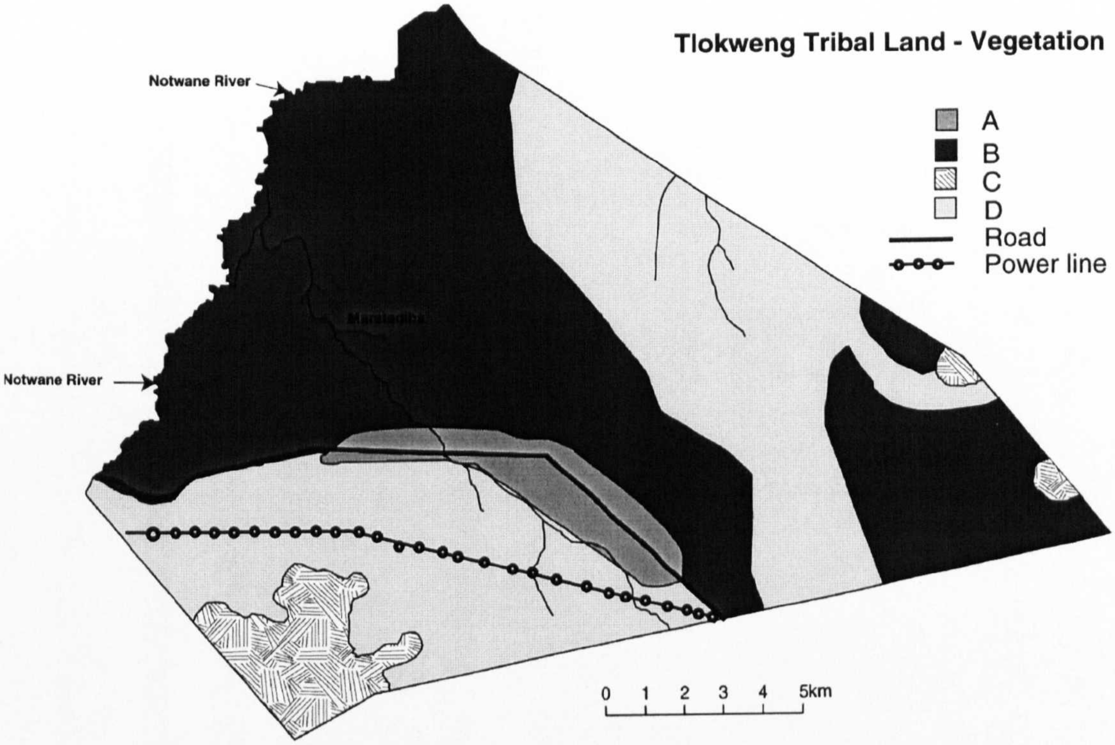

Figure 2.7 Vegetation Map of Tlokweng Sub District
Sources: Timberlake, 1980; Powell, personal communication, 1996

2.5.2 *(Unit B) Terminalia sericia Tree and Shrub Savanna*

The unit is the most extensive in the study area. It consists of open woodland with a dominance of Terminalia sericia, together with Acacia erubescens, Acacia tortilis, Acacia tenuispina and Boscia albutrinca (Powell, personal communication, 1996). Timberlake (1980) described the unit as predominantly Acacia erubescens and Terminalia sericea Woodland and Tree savanna. The unit is invaded by Aristida congesta which signals overgrazed or denuded and trampled areas (Field 1976:76).

2.5.3 *(Unit C) Hills*

The woodland species found are Combretum apiculatum, C. zeyhiri, Terminalia sericea, and Dichrostachys cinerea. They occur with the grasses Eragrostis rigidior, Aristida congesta and Tricholaema monachne. The units in the northern part of the study area are mostly used for grazing and wood gathering. It has less forage than each of units A, B and D.

2.5.4 *(Unit D) Acacia tenuispina Shrub Savanna*

Some good grazing grasses such as Chloris virgata, Eragrotis rigidior Setaria sp., Botriochloa insculpta are abundant. Other less desirable grazing species such as Tragus berteronians, Aristida stipitata, Dactyloctenium and Perotis patens also occur. The vegetation unit is found in the predominantly arable land use area. The grass species occur in the interstices of the arable fields and on some ley and abandoned fields.

2.5.5 *Biomass Production Estimates for Unit B and Unit C*

Table 2.5 and Table 2.6 show the distribution of trees, bush and grass in the

Table 2.5 Percentage Probability of Minimum Annual Biomass Production in kg Ha^{-1} for Different Vegetation Forms in Unit B of the Study Area

		Bush		Grass	
Probability	Trees	Upper	Lower	Under Canopy	From Canopy
100	108	128	115	69	644
75	315	371	334	133	1651
50	527	620	558	311	2462
25	774	911	820	1189	3153
0	903	1062	956	1705	3587
Average	539	634	571	711	2365

Source: Adapted from Powell, personal communication, 1996.

vegetation units B and C, respectively. The data indicate the expected forage availability in the study area. There were no data for the other two vegetation units.

Table 2.6 Percentage Probability of Minimum Annual Biomass Production in kg. Ha^{-1} for Different Vegetation Forms in Unit C of the Study Area

		Bush		Grass	
Probability	Trees	Upper	Lower	Under Canopy	From Canopy
100	128	151	128	13	552
75	308	364	308	35	1203
50	424	501	424	167	1524
25	545	644	545	383	1844
0	625	738	625	505	2178
Average	420	496	420	212	1496

Source: Adapted from Powell, personal communication, 1996.

2.5.6 *Interpretation and the Significance of the Biomass Production Tables*

The data for the biomass production is based on a 30 year period (Powell, personal communication, 1995). Table 2.5 and Table 2.6 show the minimum possible biomass produced at each percentage probability level. The likelihood of specific biomass production is related to the rainfall. One hundred percent probability means that the forage is produced at all times while 0 percent means that the biomass was never produced. Therefore the range 0 to 100 percent represents the minimum possible biomass production between the least and the most likely scenarios, respectively. The highest probability, which is the least biomass, shows what will be produced during the worst rainfall year, which is during a drought. The lowest probability is the biomass that will be produced during the highest possible rainfall. The contrast between the low quantity of grass under, and a relatively higher quantity away from bush and tree canopy, confirms the negative relationship between grass and trees in a savanna area as the two compete for moisture (Wijngaarden, 1985).

2.6 Description of Grazing Land Units and Grazing Practice in the Study Area

Six landuse units were identified during the fieldwork as described in Sections 2.6.1 to 2.6.6. The landuse units are identified in Figure 2.9.

2.6.1 *The Road Reserve*

The road that runs through the study area has a 60 metre wide fenced reserve over a total distance of about 10 kilometres (Plate 3).

Plate 3 Road Reserve grazing during the early dry season

The tarred road within the reserve is 10 meters wide therefore about 50 hectares of grazing land is available. The road becomes a key grazing area immediately after the early rains since the bush on its sides is cleared as a traffic safety measure, which encourages a vigorous growth of grass and shrubs shortly after the early rains. Consequently it is always the first area of green when the runoff from the paved road surface concentrates in the lower end of the road shoulder on either side of the tarmac. There are seventeen farm gates along the fence on either side of the road. The gates enable Terateng, Mmamogofu and Radipotsane farmers to move their cattle across the road to the Mmamogofu water point or other grazing areas. The gates are often left open to enable cattle to pass through unaccompanied but the cattle also get into and remain within the road reserve. Despite the road safety problems, the road reserve is a popular grazing area. None of the households accepted that they use it, because they know the danger livestock pose to motorists, but during the fieldwork livestock were seen along the road reserve most of the time. Goats walk through the four strands of fencing into the road reserve. However goats seldom stay long within the road reserve because there is less browse than outside the reserve.

2.6.2 *The Homesteads Area*

The homesteads area is the unit where the farming community dwelling compounds are located (Plate 4) and where the livestock are kept. It is found either side of the road reserve. The area has multiple uses. Grazing occurs between the dwelling units most of the year. Most households have a small homestead garden, commonly less than 1 ha., which is called **lesope**. It is individually fenced to prevent crop destruction by livestock. **Lesope** is near enough to the homestead to enable the owner to collect food without going the long distance from the homestead to the main field, **tshimo**. The vegetation in the homestead has signs of deterioration due to overuse. Aristida congesta (**seloka**), a poor invader grass, is dominant. Acacia tortilis (**mosu**) and Dichrostachys cinerea (**moselesele**) shrubs, which are low browse value shrubs and indicative of a deteriorating grazing area (Field, 1978) are abundant.

Plate 4 Dwelling unit found in the homesteads area

Pods of both shrubs were an important part of the livestock diet in May-June during the year of the fieldwork. Most water points, including Mmamogofu, are located in the homesteads area (Figure 2.8). Therefore it is a livestock watering area. In general livestock within Mmamogofu, Terateng and Radipotsane mostly use the grazing within the homestead area south of the main road. The homesteads area to the north of the road, that is Mabowaneng and Ramokobetwane area, has more grazing land and is used by most livestock in the study area.

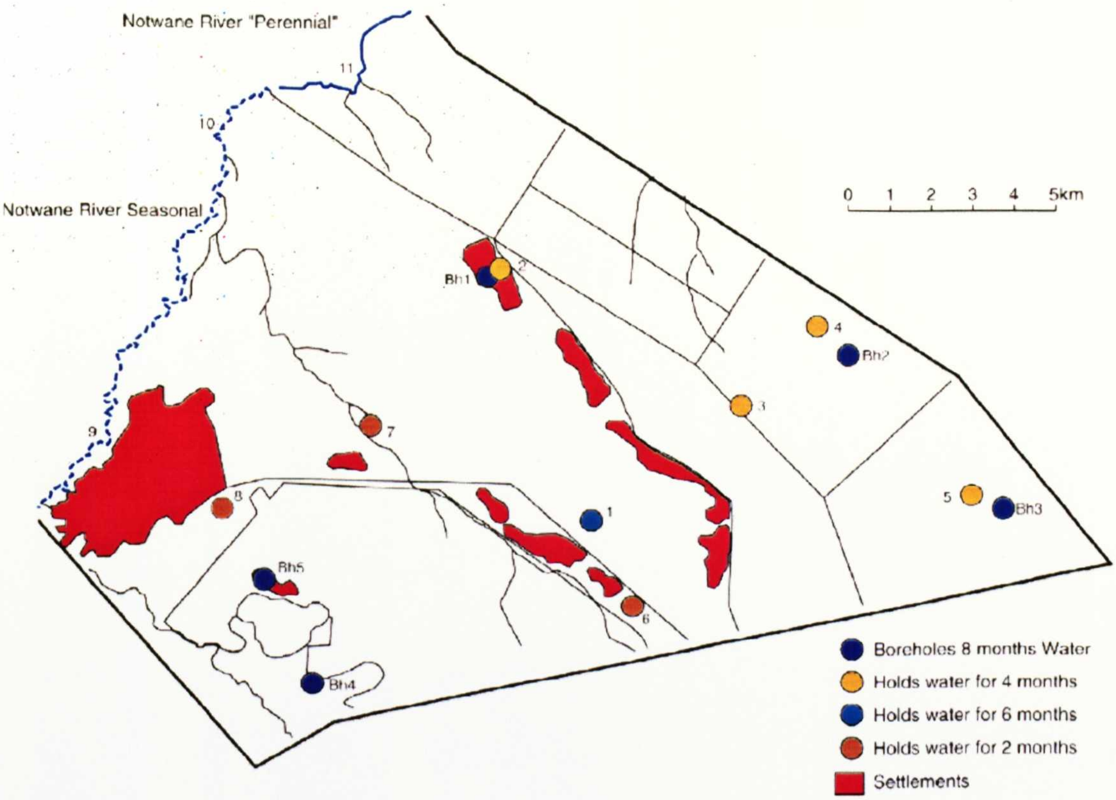

Figure 2.8 The Livestock Water Points Tlokweng Sub – District

Key to Water Points Names in Figure 2.8

Boreholes	*Waterholes*	*River*
Bh1 Mmakgama	*1 Mmamogofu / Lephala*	*9 Seasonal Notwane River*
Bh2 Steve's Syndicate	*2 Mmakgama*	*10 Seasonal Notwane River*
Bh3 Morui	*3 Hekeng*	*11 Perennial Notwane River*
Bh4 Mabutswe Syndicate	*4 Peterose*	
Bh5 Mabutswe Village	*5 Modipe*	
	6 Terateng	
	7 Letlapeng	
	8 Tlokweng	

2.6.3 The Arable Area

Two blocks of arable area totalling 5000 hectares are fenced. One is north and the other south of the road reserve. The field owners' exclusive use rights are suspended between the end of the harvest and the beginning of the ploughing when the arable area becomes communal grazing. During harvesting, the grain stalks are left standing so that they can be grazed off. The arable area could be grazed anytime between the end of June and beginning of November or December, depending on the completion of harvesting and the commencement of the ploughing season. During a drought or when the crops fail due to a poor seasonal distribution of rainfall, the livestock graze the wilted crop. The arable area has good forage (Plate 5).

Plate 5 Good forage in arable area before cattle were allowed to graze in the area

The grass grows between the arable fields and on some abandoned or fallow fields. Urochloa species (**phoka**), Schimidtia pappophoroides (**tshwang**), Eragrostis rigidior (**rathathe**) were observed within the arable area. Digitaria milanjiana (**namele**) occurs along the stream. The grasses indicate that the grazing is in a good condition (Field 1976). The grass and the grain are a strategic forage buffer during the dry period and drought. Cattle production in the area is sustained by a combination of natural forage and crop residues. The livestock farmer's view, that the study area has fewer droughts than other parts of the country, suggests that three factors mutually reinforce each other to ameliorate the drought effects. The three are the stubble grazing after the harvest, the existence of palatable grasses in the arable and the fact that Batlokwa choose to keep limited numbers of livestock per household. Batlokwa hold 9.8 cattle per household which was the second lowest in the country in 1993 (Ministry of Agriculture, 1995:68). This is because of the limited grazing land in the Tlokweng Sub – District.

2.6.4 *Majeadikgokong or The Tribal Farm*

Section 2.2 detailed how Batlokwa purchased the three farms Fairfield (840 Ha.), Almond Hill (2000 Ha.) and Clent (1600 Ha.) to extend their grazing land (Figure 2.9). Fairfield is now used as an arable area and the latter two together are called Majeadikgokong or simply the Tribal Farm.

Majeadikgokong has abundant and quality forage, two boreholes and at least three semi permanent water sources. Ideally Majeadikgokong is additional grazing land for all in Batlokwa Tribal Land. In 1996 eleven households had settled their livestock in the area. Other livestock farmers gave two reasons why they did not find the area attractive to settle in. They argued that the place was too far from Tlokweng village. Batlokwa maintain a strong affinity to their only village. Secondly predators, from the nearby Modwe and Modipe hills, were a nuisance to livestock and those without the means to control the predators or with small livestock herds, were reluctant to expose their livestock to the risk. Despite the reservations about settling in the Tribal Farm, some farmers regard it as a fall back point during drought. Tlokweng Land Board's allocation of permanent cattleposts and boreholes in the area will ultimately exclude such short-term users. The third hindrance is the awkward location of arable land between the homesteads and the farm. The arable area is a barrier to free access.
The northern boundary of the Tribal Farm is the boundary between the South East and Kgatleng districts. The boundary fence is in a poor condition, allegedly vandalised by livestock farmers from Kgatleng who want to graze or water their cattle in the Tribal

Farm area. A few farmers suggested that due to the poor condition of the northern boundary it is very risky to keep cattle in Majeadikgokong as they stray into Kgatleng district easily. The southern boundary, the arable area's northern drift fence and the eastern, the international boundary with South Africa, are well maintained. According to Kgosi Monare (personal communication, 1996), Majeadikgokong has been converted to Tribal Land, therefore it is no longer a privately owned Tribal farm. If that is the case, the Tribal Land Act (Republic of Botswana, 1970) permits land in the farm to be allocated to anybody in the country. It was not possible to confirm the land tenure status of the farm.

2.6.5 *Tlokweng Village*

Tlokweng village is important for livestock management in two ways. Some households keep their livestock, especially goats, at the village and the livestock graze on the fringes of the village, including along the Notwane river frontage, which historically was an important grazing zone for Batlokwa. The seasonal Notwane River, which has an annual discharge of 34.10×10^6 m^3 (Department of Town and Regional Planning, 1996), is the boundary between the village and Gaborone City. The boundary fence is poorly maintained and livestock easily cross into Gaborone City where the Gaborone City authorities impound them and release them only after the owners have paid a release fee. Households cite easy access to water and better use of limited labour resource as the main advantage for keeping livestock at the village. Secondly, the village is a strategic fallback source of livestock water during the dry season even for those who keep livestock elsewhere. Five households carted livestock water from Tlokweng to other parts of the study area using own transport.

The local authority provided a bulk water supply point from which water can be drawn for a paltry fee of P0.40 per 210 litres container, which was seldom collected.

2.6.6 *Other Settlements*

Settlements in the sub district which include Mathothwane, Mabowaneng Terateng Mmamogofu Egepeto, are shown in Figure 2.9.

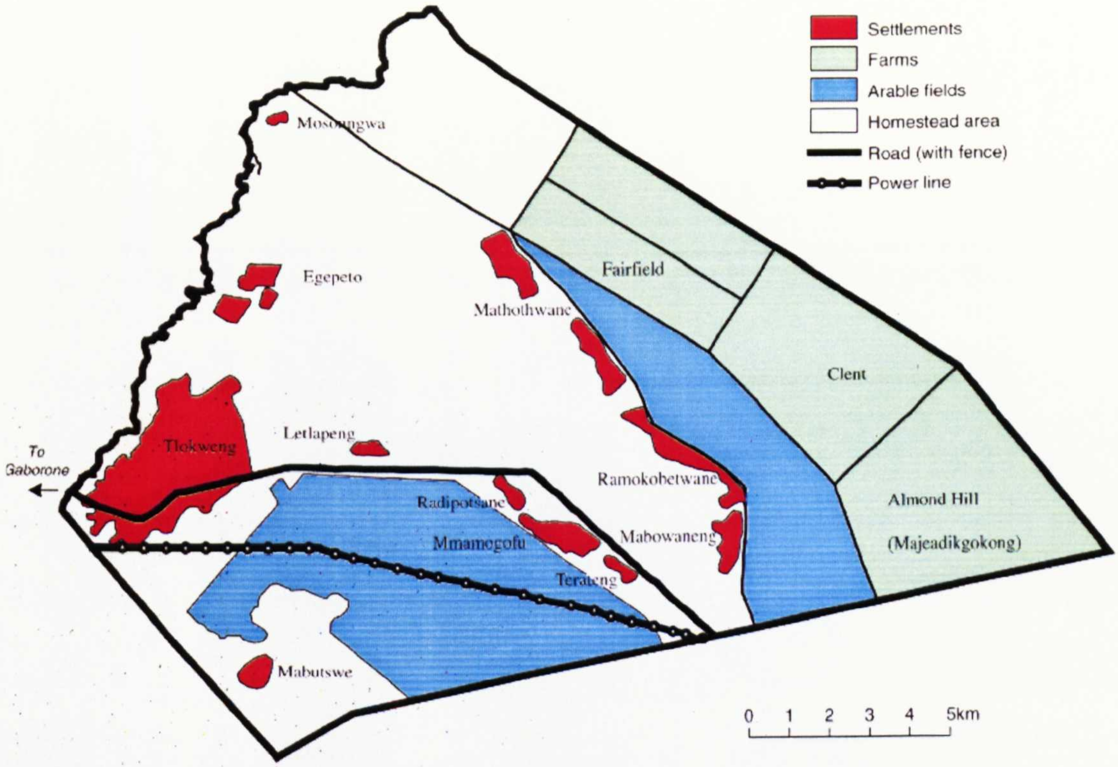

Figure 2.9. Settlements and Land Use in the Tlokweng Sub District

Most of the localities have a small population and are often seasonally settled. Some **masimo** at localities north of Tlokweng are outside the drift fence and therefore are individually fenced. There are a few permanently resident livestock at Egepeto compared to Mmamogofu and Majeadikgokong (Kgamanyane[10], personal communication, 1995). This is because Egepeto is a significant short term cattle

[10] B E Kgamanyane was the Veterinary Officer in charge of the study area at the regional headquarters during the survey

grazing point. The main attraction for livestock around Egepeto during the dry season and drought periods, is the 'ephemeral flow' along the seasonal Notwane River. The flow, an effluent discharge from the Gaborone City sewage ponds into the Notwane River, is a source of livestock water and nurtures a perennial belt of riverine vegetation. Farmers were reluctant to reveal that their livestock drank the sewage water called **metse a matala**, which literally means green water. Households that do not have an option water their cattle from the dirty water. Households were reluctant to accept that they watered cattle from the sewage water because they knew the water could be hazardous. Those who accepted that they moved cattle to Egepeto, emphasised access to the perennial riverine forage and downplayed access to the green water, or accepted it as inadvertent. Respondents had reservations about Egepeto as a fallback grazing area for three reasons. Firstly the cattle went astray when they got together with herds from other localities during a drought. Secondly like at Tlokweng village, livestock moved across Notwane River into Gaborone and were impounded by the city officials for trespassing into the livestock free zone. Thirdly the cattle drink the over flow water from the sewage ponds. Khupe (1996), a Gaborone City Council official, conceded that the sewage discharge into Notwane river is used for livestock watering and noted that the ponds provide a reasonably high standard of treatment. He did not however indicate whether the water was safe for livestock watering. It is most unlikely because the Gaborone City Council has public notices around the sewage ponds that advise against the use of the sewage waste for watering livestock.

2.7 Rationale for Choice of Study Area

The study area was chosen for the following five reasons.

i) **Land Pressure** - the South East District is the smallest in the country. It is under pressure to satisfy its own population's land demands and those of Gaborone City and Lobatse town. Land pressure on cattle production is represented through an assessment of the grazing land loss, which is ideal for a model that has land availability as one of its parameters.

ii) **Compactness** - the bounds of the study area are clearly demarcated by an international boundary, Kgatleng district (Figure 2.1), Gaborone City, and neighbouring freehold farms (Figure 2.2). The compactness of the area is advantageous for the exploratory study because it enables a spatially holistic view of cattle management units which was preferred over arbitrarily carving out an area within a big district.

iii) **History of Mixed Farming** - the study area has a long history of mixed farming where management methods that have been successfully tried and tested.

iv) **National Policy on Agricultural Production and Development (NPAD)** Mmamogofu and or Majeadikgokong have been tentatively identified for the establishment of the envisaged NPAD communal grazing farms in Tlokweng sub district (Tsimako[11], personal communication 1995). By looking at the cattle management in the study area, it is possible to assesses the feasibility of the communal farms zoning as recommended by the NPAD

v) **Logistics** - for an exploratory study with a limited budget and personnel, it was imperative to choose an area where the logistics can be managed by one researcher. The Tlokweng sub district is easily accessible and traversed.

2.8 Comparison of Study Area with Agropastoral Areas in Rest of the Country

After justifying the choice of the study area in the previous section, this section shows how representative the study area is compared to other agropastoral areas in the country. This is done because the method developed in Chapter 6 should be suitable for use in the rest of the country.

i) **Land Pressure**

It was established that the South East district is the smallest in the country and is therefore subject to one of the highest land pressures on its natural resources within the country (Arntzen and Veenendaal 1986). The pressure is exacerbated by the land demands from the capital city. Other communal areas in the country have comparable land pressures due to similar processes, though at a lower magnitude.

ii) **The History and Nature of the Mixed Farming Area**

Mixed farming has developed due to land pressure and landuse competition in a number of hardveld communal areas. The study area's history of successful mixed farming started with arable fencing in 1928. In other parts of the country, mixed farming areas are not as compact, organised and successful as

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[11] B Tsimako was the Senior Research Officer at the national headquarters of the Ministry of Agriculture during the survey.

in the study area. The Tlokweng sub district pastoralists keep their cattle close to Tlokweng village while in other districts cattle are kept some distance away from the villages. The compact mixed farming system practised in the study area may be the future pattern to be seen in communal grazing areas elsewhere in the country.

iii) **Potential for Implementing the National Policy on Agricultural Development Fencing**

Mmamogofu and possibly Majeadikgokong, are potential areas for the development of communal ranches as suggested by the NPAD (Tsimako, personal communication, 1995). Other communal areas have been earmarked for fencing country wide, for example Kaka in the Central District and around Kakhea in the Southern District (Tsimako, personal communication, 1995). Therefore methods used to assess the management of the pastoral system in the study area should be transferable to other potential areas.

iv) **Rainfall Characteristics.**

The study area has a mean annual rainfall of 520 mm. for 1945 to 1995, which is close to the mean for the country and can be regarded as the secondary maximum found in the south eastern part of the country (Ministry of Finance and Development Planning, 1991). A 40 percent annual variation is typical for most of the hardveld (Ministry of Finance and Development Planning, 1991). Though the 30 percent annual coefficient of variation in the study area is less than the 40 percent for most of the country's hardveld, 30 percent is the minimum for areas with highly variable rainfall that is frequently associated with large deviations from the mean (Ellis, 1995). The study area's rainfall is therefore regarded to be representative of rangelands in general and to some extent that of other communal areas within the country.

v) **Cattle Holding and Herd Composition**

The study area is within an agricultural district with the second lowest average number of cattle per farm (Ministry of Agriculture, 1995). This implies that the average cattle holding per household is lower than in other parts of the country, a factor that several respondents emphasised. Most characteristics of the cattle herd composition compares well with other districts but the study area has a significantly high percentage of heifers, almost double that found in most districts (Ministry of Agriculture, 1995). Commercial herds have a high number of heifers (Fidzani, 1993) therefore in that respect the study area is similar to commercial areas. Most households in the study area have both livestock and arable fields, therefore it is an agropastoral area.

vi) **Accessibility and Compactness**

Tlokweng Sub-District is easily accessible because it is compact, which was important to limit the logistical intricacies for this study. Communal areas in the bigger districts in the rest of the country are not as compact and easily accessible.

Summary

This chapter introduced and described the characteristics of the study area. The study area has a temporally variable annual rainfall. The biomass (forage) production varies according to the rainfall. The arable fields, from which cattle are grazed during the dry season, are located on the best soils of the study area. The study area has a history of high land pressure because it is within the smallest district in the country, near to Gaborone City and there is an intense land use competition with agricultural uses. The competing landuses include freehold areas and Gaborone City, which are out of bounds but are frequently trespassed by cattle. The processes responsible for land pressure in the study area are similar to those found within other communal areas in the country which makes it possible to extrapolate the methods used to study cattle management in the study area to other communal areas. Due to the land pressure, the study area developed a mixed farming dating back to the 1920s which optimises the use of its limited natural resources. Six complementary land use areas that are used by livestock at different times were identified. The chapter introduced the cattle management system in the study area.

Chapter 3. Theoretical Framework of the Study

Introduction

The theoretical framework for the study takes into account two main characteristics of the study area. The area has variable rainfall and practises communal livestock management. Both are characteristics of rangelands. Based on the two characteristics, the theoretical framework is developed around four aspects of cattle management. First the rainfall, forage and cattle numbers interact in a defined pattern with rainfall as the driving mechanism. Secondly, competing landuses in the communal area reduce the available grazing land due to increased land pressure. Thirdly, livestock water availability plays a significant factor in determining the carrying capacity because it is a limiting factor to livestock production in rangelands. Lastly, new thinking in rangeland management is a useful starting point for studying cattle management in rangelands.

3.1 Traditional and New Thinking in Livestock Management

About sixty percent of Africa's ruminant livestock population is found in arid and semi arid rangelands (Scoones, 1995). The two rangelands types occupy 37 and 18 percent of Africa's land area (Sandford, 1995) respectively. The rangelands are therefore the main areas of concern when studying the effects of Africa's livestock production upon the environment. For a long time, the prevailing belief was that livestock production in the semi arid areas of Africa destroyed the natural vegetation. Under colonial rule most African pastures were deemed overstocked to the point of destruction (Stafford Smith, 1996). The belief was borne out by seemingly valid observations such as the lapses in vegetation cover, the high number of livestock normally held by pastoralists, the high mortality rates during the drought and the extensive areas of grazing land used by migratory livestock. The subsistence herd owners' migratory lifestyles were regarded as inefficient use of the range and also blamed for rangeland degradation (United Nations Sudano Sahelian Office, 1994 b). Predictions were made suggesting that the rangelands will collapse. However the predictions made about the time it would take to irreversibly destroy the range have not materialised. For example in 1947 a veterinary officer described the South East District, Botswana, as so overstocked that it would collapse (Botswana National Archives, V.8/1-4). More than fifty years the district is still productive.

The Sahelian drought of 1968-74 provided some apparent credibility to the assertion that cattle herders caused rangeland degradation. Donors responded by financing projects to change the prevailing pastoral systems in order to halt the degradation. Picardi (1975) criticised the investments in veterinary services and water for aggravating the effects of the drought. Picardi's criticism was questioned by Sandford (1995) who argued that veterinary and water development programmes aid efficient opportunism by the enabling better spatial use of grazing land units (Sandford, 1995). The thrust of the development efforts according to the traditional thinking was to reduce stocking levels, privatise the grazing areas and sedentarise the herders. Despite the conviction that overstocking was the source of all evils, attempts to improve the efficiency of pastoralists' utilisation of the range were hardly successful (Horowitz and Little 1987; Sandford 1995; Stafford Smith 1996.). In the wake of failures to improve the rangelands and the unfulfilled prophecies about the rangeland collapse, an alternative explanation about the rangeland characteristics and how they function was opportune. A popular view was that wrong tools of analysis had been used (Behnke and Scoones, 1993; Scoones, 1995 b). The relevance of the carrying capacity to rangeland degradation was questioned and other ways of looking at rangeland's characteristics and productivity were suggested (Scoones, 1995 a; Stafford Smith, 1996; Tainton *et al.*, 1996). Some of the new thinking is that a rangeland and its livestock population will recover from drought (Barrett, 1989). Therefore the oscillation of cattle numbers is a characteristic of a rangeland's variable productivity and not a symptom of the rangeland's imminent collapse (Behnke *et al.*, 1993; Scoones, 1995 b). The early efforts to develop cattle management concentrated on making pastoralists sedentary but the current approach is to incorporate the socio economic characteristics of the pastoralists' for an effective and holistic management intervention (United Nations Sahelian Office, 1994 b). Table 3.1 summarises the old and new thinking about pastoral development.

Table 3.1. Summary of the Old and New Thinking About Pastoral Development

Area	Old Thinking	New Thinking
Objectives	focus on commodity production and livestock production	focus on livelihoods and pastoral development
Range management	open range improvement using legumes, fodder trees paddocking and restrictive movement through fences	focus on **key resources** improvement, rehabilitation, creation of **mobility** and flexibility no fences
Planning	blueprint development planning	flexible, adaptive planning with local involvement and a recognition of **uncertainty**
Drought	normal year development plan based with drought relief separated	drought proofing and integrated **safety nets provision** - focus on tracking i.e. de/restocking supplementary feeding, etc.
Tenure	fixed tenure regimes; privatisation or exclusive communal conflict issues largely ignored	**flexible tenure**: complex mix of overlapping and integrated regimes. Focus on conflict negotiation, mediation and arbitration
Institutions and administration	service delivery package through centralised extension services Extension worker for technical delivery	pastoral organisations or local management issues Extension workers as institutional organisers

Source: Scoones, 1995 a: 34

The main themes in new thinking are key resources, mobility, uncertainty, safety net provision and flexible land tenure. Some of the new thinking in livestock management studies for semi arid and arid areas may not be very new (Scoones, 1995 a), as shall be shown later in this section, but they highlight principles which offer hope for more effective livestock policy formulation.

Communal management systems were traditionally regarded as having poor production in comparison to the ranches (Sandford, 1995) which led to an emphasis on the ranch as the ideal land tenure for improved livestock management. We now regard the traditional systems to be more productive than ranches per unit area although traditional systems have higher stocking rates and diverse livestock uses. The latter difference is not a recent discovery. Forty three years ago Stoddart and Smith (1955) noted that higher stocking density produced more per hectare but less per animal than lower stocking density. Communal areas have high stocking rates because of the difference in production (Biot, 1993) which is discussed in Section 3.4.3. Reference to the carrying capacity without specifying the user's objective is criticised because the users objectives determine the different carrying capacities (Sandford, 1995). Forty three years ago, when carrying capacity was commonly used to refer to the ecological carrying capacity (see Section 3.2.3) Stoddart and Smith (1955) discussed the significance of differentiating between the economic and ecological objectives of production (see 3.2.3).

Rainfall and forage production in semi arid areas fluctuates more than in a temperate region. An annual rainfall coefficient of variation of 30 percent divides the non equilibrium from equilibrium systems (Sandford, 1995). Equilibrium systems are uniform while non equilibrium systems are variable (see 3.1.1). New thinking is that the productivity of the variable non equilibrium ecosystem should be optimised. Due to the spatial heterogeneity of semi arid areas, it is more productive to adopt a flexible livestock management strategy where livestock move from one area to another to optimise the diverse resources (Sandford, 1995). Sedentary management is not optimal for semi arid areas because it requires a lot of inputs such as water that could be costly and in the long term even detrimental to a rangeland.

Agropastoral production is promoted as the most profitable landuse in areas of transition from cattle to crop farming based on rainfall availability (Scoones, 1995 a). The integrated landuse offsets the grazing land loss by offering crop residue as security for livestock during the dry season and drought. However Abel *et al.*, (1987) dispute the advantage of using crop residues to feed animals in the Southern District, Botswana. They argued that 1400 tons of forage was lost to arable farming during a season of low rainfall (Abel *et al.*, 1987:59). They seem to argue for an abandonment of arable farming in this area in favour of full time pastoral farming. The present study presents an opposite view about agropastoral farming in the Tlokweng Sub District in Botswana.

3.1.1 *Equilibrium and Non Equilibrium Areas*

The variable rainfall in semi arid and arid areas causes the primary and secondary production to vary which determines the characteristics of pastoral systems. In principle the bigger the inter annual and intra seasonal rainfall variations, the greater the resultant forage variation. Table 3.2 summarises the characteristics of equilibrium and non equilibrium areas. The instability of pastoral systems in African rangelands has been well documented (Sandford, 1983; Ellis and Swift, 1988; Behnke and Scoones, 1993; Ellis *et al.*, 1993; Tainton *et al.*, 1996).

Table 3.2 Characteristics of Equilibrium and Non Equilibrium Systems

Characteristics	Equilibrium System	Non Equilibrium System
Environment	Uniform - high and consistent rainfall	Variable - low and erratic rainfall
Floristic Structure	Comprised of perennial plants	Comprised largely of annual plants
Forage flow	Relatively constant and predictable	Variable and unpredictable
Driving forces	Grazing and fire, 'management driven' - level of management input determines response, e.g. stocking rate, fire frequency, etc.	Moisture availability, 'event driven' - chance and contingency of non biological (e.g. rainfall) and biological (e.g. grazing) events determine dynamics
Balance between plants and animals	Stable - negative feedback determines equilibrium position	Plant and animal populations fluctuate widely- 'non equilibrium'
Appropriate models	Succession (range condition), stable isoclines, relatively simple dynamics	State and transition, complex dynamics
Stability	Stable and non resilient	Unstable and resilient
Management control	Strong	Weak
Management complexity	Manipulative to reduce heterogeneity 1. sedentary-camping, rotation and regulation of animal numbers 2. Manipulative-aim to maximise stability and uniformity 3. Control selection	Exploitation of heterogeneity 1. Migratory-transhumance to exploit resource heterogeneity 2. Opportunistic and flexible - aim to maximise production while reducing risk 3. Allow selection

Source: Tainton *et al.*, 1996: 283

Although unstable in the short term, in the long term non equilibrium systems are stable enough to enable predictions about their productivity. Non equilibrium systems have loosely connected ecological components therefore they are less likely to be affected by a change to one. But when the low connectivity of the components is improved, such as the effect of introducing fences on a grazing area, the non equilibrium system may become stable but less resilient (Tainton *et al.*, 1996). Four points need to be highlighted about non equilibrium grazing systems. They experience a low and erratic rainfall. The animal and plant population oscillate in response to the rainfall. They are characterised by a weak, opportunistic and flexible management approach which includes population migration to exploit the heterogeneity of an area. "*Environmental variability seldom allows the system to equilibrate*" (Tainton *et al.*, 1996:289). On the contrary, equilibrium systems are characterised by uniform rain and forage production in which management practices, such as grazing intensity, influence the amount of forage available (Tainton *et al.*, 1996).

3.1.2 *Livestock Mobility in Non Equilibrium Areas*

Variation of the available fodder is part of a natural cycle in areas with variable rainfall (Abel, 1993; White, 1993). Livestock managers in areas with variable rainfall move their herds from one patch to another in order to exploit the variation in the forage and water availability (Scoones, 1995 c; Sandford, 1983). Areas that provide such water and forage are called key resource areas. Livestock managers choose a stocking rate that best suits their intended management strategy (Sandford, 1982 and 1983). They could hold many cattle and take advantage of good rainfall years but risk heavy losses during a drought. Such a strategy is opportunistic. Opportunistic farmers vary the number of livestock according to the availability of water and grazing resources. Opportunism connotes activities, such as supplementary feeding, which enable an area to support as much livestock as possible. Opportunism depends on the timely response to changes in resource availability and access to key areas. Alternatively farmers may hold limited stock numbers which will not be badly hit during bad rainfall years (Sandford, 1983; Abel and Blaikie, 1989; Scoones 1992 b).

Such a strategy is conservative. A conservative stocking rate does not take advantage of the best years but minimises the livestock losses during bad years.

A study on cattle management should consider the grazing areas used during the seasonal or periodic wet and dry periods. Such grazing areas explain how the farmers adapt their management strategies in an area. Sandford (1983) used three hypothetical areas in a region with low and variable rainfall, to illustrate the advantages of livestock mobility. He made four assumptions for his study.

i) The three areas labelled A B and C in Table 3.3 to Table 3.5, have an average annual rainfall of 400, 300 and 500 mm respectively. The average rainfall is the base for each scenario.

ii) Rainfall determines the number of cattle that can be kept in an area. There is no supplementary feeding. One millimetre of rainfall provides adequate forage for one animal for a year, therefore 400 mm will be enough to sustain 400 animals in a year.

iii) Livestock die if they do not get enough food. They eat only as much as they need to survive when there is excess forage.

iv) The three year period represents the whole cycle of rainfall oscillations possible within the area.

Based on the four assumptions, three scenarios shown in Table 3.3, Table 3.4 and Table 3.5. Scenario 1 shows the baseline of the hypothetical cattle management landscape where each area experiences the same amount of annual rainfall, therefore there is no advantage for livestock mobility. The carrying capacity is 1200 cattle each year. Scenario 1 is likely to occur in equilibrium areas.

Table 3.3. Scenario 1 Constant Annual Rainfall and No Livestock Mobility

Area	Rainfall (mm.) and no. of animals kept			Animals kept in worst year
	Year 1	Year 2	Year 3	
A	400	400	400	400
B	300	300	300	300
C	500	500	500	500
Total	1200	1200	1200	1200

Source: Sandford, 1983.

Scenario 2 (Table 3.4) represents a uniform change in rainfall for each area between years. In Year 2 a 50 percent increase from Year 1 rainfall was experienced which led

Table 3.4. Scenario 2 Variable Rainfall Highly Correlated Between Areas

Area	Rainfall (mm.) and no. of animals kept			Animals kept in worst year
	Year 1	Year 2	Year 3	
A	400	600	200	200
B	300	450	150	150
C	500	750	250	250
Total	1200	1800	600	600

Source: Sandford, 1983

to a total carrying capacity of 1800 animals which was the best in all the three scenarios. The Year 3 rainfall is 66.6 percent less than that of Year 2 that led to a total carrying capacity of 600 animals, the lowest carrying capacity in all the three scenarios. Despite depicting both the worst and the best cases of carrying capacity levels for all the scenarios in Years 2 and 3 respectively, there was no advantage to be gained from livestock mobility in Scenario 2 because the changes between the areas are uniform and simultaneous. Scenario 2 is likely to occur in equilibrium areas.

Scenario 3 (Table 3.5) best illustrates the advantages of livestock mobility in areas with variable annual rainfall. Year 1 is the status quo as in Scenario 1. During Year 2 Area A has a surplus carrying capacity of 200. The surplus occurs because 600 mm of

Table 3.5. Scenario 3 Inter Annually Variable Rainfall Not Correlated Between Areas

Area	Rainfall (mm.) and no. of animals kept			Animals kept in worst year
	Year 1	Year 2	Year 3	
A	400 *400*	600 *400*	200 *200*	200 *400*
B	300 *300*	300 *300*	450 *300*	450 *300*
C	500 *500*	250 *250*	500 *500*	500 *250*
Total	1200 *1200*	1150 *950*	1150 *1000*	1150 *950*

Source: Sandford, 1983.

Note: *Italics* represent number of livestock kept in each area without mobility.

rainfall is experienced in an area with 400 animals. In the same year Area B is at carrying capacity while Area C carries 250 animals less than its capacity. Area A absorbs 200 animals from the deficit of Area C, leaving 50 animals to perish. The total carrying capacity for Year 2 is 1150, which is 50 less than the combined capacity of the three areas. In Year 3 Area A has a deficit of 200 animals, Area B has a surplus of 150 animals and is able to absorb 150 of the 200 animals deficit from Area A. Area C is at carrying capacity.

From the hypothetical cattle management landscape in the Tables 3.3, 3.4 and 3.5, Scenario 1 shows no mobility. Scenario 2 represents temporal variation in a spatially homogeneous area. It shows both the maximum and the minimum number of animals that can be kept within the three scenarios. In Year 2, 1800 animals were kept and in Year 3 it decreased to 600, a third of the maximum. Scenario 3 shows the effect of temporal and spatial variation of rainfall. The number of animals than can be held fluctuates less than that in Scenario 2, a minimum of 950 and a maximum of 1200. The lower fluctuation of cattle numbers in Scenario 3, compared to Scenario 2, shows the advantages of livestock mobility where there are spatial differences. A closer look at Scenario 3 shows that the difference between maximum number of animals that can be kept without livestock mobility, and those kept with mobility, is 250 animals. During the worst year the difference between the number of cattle that can be kept when they are mobile and when they are not, is 200. The example implies that mobility reduces the cattle mortality during a bad year and maximises cattle holding during a good year. Mobility enables livestock to be moved out of areas with low rainfall to take advantage of the increased carrying capacity in areas with high rainfall.

White (1993) showed hypothetical cattle management landscape scenarios for Botswana with an illustration similar to that of Sandford (1983) (Table 3.6).

Table 3.6 Hypothetical Variation in Stocking per Livestock Water Zones in Botswana

Livestock Water Zone	Rainy Season Stocking				Min Stocking per Livestock Water Zone
	Late Dry Early Wet	Mid Wet	Late Wet Early Dry	Mid Dry	
Seasonal water	500	2500	4500	1000	500
Permanent Water	1500	3000	3000	2000	1500
Riverine	4000	3000	1500	3000	1500
Total Capacity	6000	8500	9000	6000	3500

Source: White 1993:9.

White contrasts a hypothetical sandveld zone with seasonal water, a hardveld zone with permanent water and a seasonal riverine grazing zone. The words sandveld and hardveld were omitted for brevity in Table 3.6. Each livestock water zone has four livestock water seasons, which are Late Dry Early Wet, Mid Wet, Late Wet Early Dry and Mid Dry seasons. White leaves the interpretation of the seasons in Table 3.6 to the reader. The Late Dry Early Wet refers to a dry spell at the end of the rainy season followed by early rains in the subsequent season. In contrast, a Late Wet Early Dry is a wet spell at the end of the rainy season followed by delayed rain in the subsequent rainy season. Mid Wet and Mid Dry seasons occur when a wet or a dry period respectively, is sandwiched by contrasting beginning and end of the rainy season. A Mid Wet season implies a very long dry season between the rainy seasons.

Late Wet Early Dry season carried most cattle, 9000, most of which (4500) used the sandveld area with seasonal water. This is because seasonal water sources are available when the end of the rainy season is wet. The hardveld with permanent water was most attractive during a Mid Wet season and a Late Wet Early Dry season. The permanent water source is needed in the Mid Wet season to reduce the effects of a long dry season. The riverine area was popular during the Late Dry Early Wet season when the rivers are flowing and have the earliest sprouts of vegetation. The sandveld with seasonal water carried the least cattle population for all the seasons, 500, during the Late Dry Early Wet season. With cattle movement the sandveld with seasonal livestock water zone carried the highest number of cattle, 4500, during the Late Wet Early Dry season. This shows that mobility enables the seasonal water area to carry 4000 more cattle. Compared to the other livestock water zones, the permanent water area carried 1500 more cattle and the riverine area carried 2500 more due to mobility. Table 3.6 reinforces the understanding of the advantages of livestock mobility in non equilibrium areas. It shows that the rainfall seasonality influences the maximum number of cattle held at a place in time.

3.2 The Concepts of Grazing Capacity (GC) and Carrying Capacity (CC)

Grazing Capacity and Carrying Capacity are vital and frequently used concepts in livestock management and yet remain nebulous and ambiguous. They are used in a number of different ways. The definitions of the two concepts are reviewed in the next two sections and the differences highlighted.

3.2.1 *Definitions of Grazing Capacity*

The definitions of Grazing Capacity and Carrying Capacity in Boxes 3.1 and 3.2 are based on Bartels *et al* (1993:89 - 103) except where otherwise specified.

Box 3.1 Grazing Capacity Definitions

1) Grazing Capacity is sometimes a synonym for carrying capacity.
2) Maximum stocking rate possible without inducing damage to vegetation or related resources.
3) Maximum animal numbers which can graze each year on a given area of range, for a specific number of days, without inducing a downward trend in forage production, forage quality, or soil.
4) Total number of animals which can be sustained on a given area based on the total forage resources available, including harvested roughage and concentrates.
5) Grazing capacity (or livestock carrying capacity) is the number of stock of a given class or classes, expressed in livestock units or head, which a rangeland unit will support for the period of grazing (or feeding) allowed.
6) Total number of Animal Unit Months (AUMs[1]) produced and available for grazing from a pasture unit, grazing allotment, the total ranch or other specified land area.
7) Maximum stocking rate possible without inducing damage to the soil, vegetation or related resources or deleteriously affecting grazing animal response. To be accurate must consider factors such as annual fluctuations in forage production, kind or mix of animal species, season and system of grazing, and grazing distribution
8) The maximum stocking rate of an animal type with specific production objective that a certain land unit can support on a sustainable basis during a defined grazing season.
9) Grazing Capacity is a purely topological quality which relates to the food resource, vegetation (Zonneveld, 1995).

[1] the amount of forage consumed per month by a cow weighing 454 kg or equivalent weight of other type of livestock (Bartlett *et al* 1993:103)

3.2.2 *Definitions of Carrying Capacity*

Box 3.2 Carrying Capacity Definitions

1) User specified quality biomass of a particular species (such as cattle) for which a particular area can supply all energy and physiological requirements over a long but stated period under specific management objectives.
2) Maximum number of animals of given species and quality that can survive through the least favourable environmental conditions in a given ecosystem within a stated time interval, usually one year.
3) Stocking rate at the optimum grazing pressure.
4) Number of stock which a range will support for a definite period of grazing without injury to the range.
5) Point where the rate of production of forage equals the rate at which that forage is consumed.
6) Maximum stocking rate possible, which is consistent with maintaining or improving vegetation related resources. It may vary from year to year on the same area due to fluctuating forage production.
7) Maximum capacity of a land unit for supporting animals during the time of greatest stress to them in the year (FAO, 1991).
8) Density of stock at equilibrium with the range conditions providing maximum sustained offtake - it is equivalent to the grazing capacity. The density is less than the maximum possible (Caughley, 1976:217)
9) includes the grazing capacity (a physical land attribute), climatic hardship, endemic diseases, resistance to soil erosion, chorological influences such as the effects of accessibility, availability and walking distance to drinking water, and other factors (Zonneveld, 1995). Zonneveld (1995) summed the carrying capacity into Equation 3.1.

Equation 3.1 Carrying Capacity

$$CC = \frac{(Ph \times ph \times nh) + (Pb \times pb \times nb)}{R} \times f_1 \times f_2 \times f_3 \ldots f_n$$

where: CC is Carrying Capacity
Ph is production of forage by the herbaceous layer
ph is proper use factor for the herbaceous layer
nh is corrective factor for nutritive value in the herbaceous layer
Pb is production factor of forage in the form of browse
pb is proper use factor of forage in the form of browse
nb is correction factor of the nutritive value of browse
R is forage requirement of specific animal type
f1, f2, f3,...fn is multipliers for relevant chorological and other land qualities such as hardships, accessibility and abundance of predators

A number of observations can be made about the definitions of carrying capacity and grazing capacity. The two concepts are so inter related that they are at times equated. Both definitions relate to the number of animals supported by a piece of land, or available natural resources on which animals depend. In that respect the dividing line between the two can be blurred. FAO (1991) differentiated carrying capacity from grazing capacity by arguing that carrying capacity does not refer to landuse on a sustained basis, and is therefore not relevant to the FAO's Land Evaluation framework. FAO's definition of the grazing capacity does refer to the sustained use of an area. Some of the definitions, such as carrying capacity definitions 2,4,6,7 and grazing capacity definitions 3 and 9, refer to time over which animals can be supported or over which the land is expected to support animals. Both definitions refer to a maximum number of animals and the use of land without damage, which suggests a ceiling beyond which livestock will damage a rangeland. Equation 3.1 provides the pivotal difference between the two concepts. The grazing capacity is a physical attribute and carrying capacity is a land quality[2] made of several attributes such as access and availability of drinking water (Zonneveld, 1995). Zonneveld compares the human carrying capacity, where attributes such as accessibility and distance to water, fuel, and various food resources including the market, are added together to come up with the physical suitability of a land.

Zonneveld's definition of carrying capacity provides the best differentiation between carrying capacity and grazing capacity. For the present study, grazing capacity refers to forage availability in relation to the herbivore demands, which is a physical attribute. Carrying capacity is made up of grazing capacity and the number of animals on the land now and previously. The availability of livestock water is added to the grazing capacity to refine the carrying capacity concept.

3.2.3 *Ecological and Economic Carrying Capacity*

The definition of carrying capacity is further complicated when it is sub divided into ecological and economic carrying capacity. The sub division shows that production managers could stock at or near the maximum stocking rate also called the subsistence stocking density. The subsistence stocking density is the point at which animals are kept near the starvation point which checks against further population growth. When the carrying capacity is just below the starvation point of the livestock, it is variously called the ecological carrying capacity, the potential carrying capacity, the maximum carrying capacity or the environmental carrying capacity. Alternatively the stocking

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[2] The concept of land quality in Land Evaluation refers to a factor that determines the suitability of a land for some human use. A quality which does not enable human use is a limitation (Zonneveld 1995:105)

rate may be lower than the ecological carrying capacity. The animals' performance is better when stocked below the ecological carrying capacity. A stocking rate that is below the ecological carrying capacity is called the economic carrying capacity (Bartels *et al*, 1993:92). African subsistence livestock producers tend to stock near to the ecological carrying capacity and the commercial livestock produces near to the economic carrying capacity. Caughley (1979) argues that there is equilibrium between the number of animals and the quantity of vegetation along a curve called the zero isocline. The ecological carrying capacity is where there is the maximum number of animals that can be supported by a given quantity of forage, which is the highest point of the zero isocline. The economic carrying capacity is one of the points below the ecological carrying capacity along the isocline. Caughley (1979) cautions against the use of the word overpopulated to describe the point when the economic capacity is being exceeded. Caughley's work describes situations where a few other factors, such as land pressure from competing landuses, come into play when looking at population and forage interactions.

The objective of livestock production is to obtain a harvest over a long period, a Sustainable Yield (SY). The harvest could be money, milk, meat, blood, skins or draft power or any combination of the six items. A yield is sustainable if the yearly harvest can be obtained without forcing the population to decline. At the ecological carrying capacity the harvest potential is limited due to two reasons. The rangeland holds the maximum population possible therefore the herd has a zero potential growth rate. If only the interest is to be harvested, the population can not be harvested without a population decline. Secondly the improvement in the fecundity and survival rate necessary to bring about an increased population, which can be harvested, is achieved by lowering the population density.

Overgrazing can be identified for both carrying capacities as ecological and economic overgrazing. Ecological overgrazing is when the level of grazing pressure exceeds the maximum sustainable yield (MSY) of the range, whereas economic overgrazing is the grazing level which is above the optimal grazing pressure (Perrings, 1990:8). The optimal grazing pressure is the point where the best outputs for commercial livestock production, for example beef, are obtained. Caughley (1976) referred to the number of cattle at the optimal grazing pressure as the optimal stocking density. Wilcox and Thomas (1990:132) described the MSY in western Australia as "*the stocking rate which can not be exceeded while maintaining the rangeland in a stable condition*". The stable condition was a set of points which relate the stocking rate to the range condition. Any point beyond the MSY caused the grazing resource and or the livestock to deteriorate.

Ecological overgrazing can be differentiated into two, the current and the fundamental ecological overgrazing (Barrett, 1984; Perrings, 1990). The current overgrazing refers to a condition which is likely to be redressed within a relatively short time while the fundamental overgrazing is "*the stochastic equilibrium level of grazing pressure in excess of the maximum sustainable yield of the range*" (Perrings 1990:8). The definition shows that the degree of overgrazing may fluctuate unpredictably (stochastic), as expected in rangelands due to the variable rainfall. Fundamental ecological overgrazing is a relevant concept in areas where subsistence stocking level exists. In reality fundamental ecological overgrazing is unlikely to occur since livestock die off when there a shortage of grazing thereby restoring the balance between the grazing pressure and the sustainable yield of the range. In rangelands there is also the possibility that drought induced grazing shortage will cause a decrease in the herdsize, thereby preventing the occurrence of herds large enough to cause the ecological overgrazing. On the other hand economic overgrazing occurs when the grazing pressure exceeds the optimal grazing pressure (Barrett, 1989; Perrings, 1990). Both Barrett (1989) and Perrings (1990) argue that the optimal grazing pressure is determined by the profitability (economics) of using a rangeland. They show that the concepts of carrying capacity and stocking rate are conceptually useful tools to address the issues of ecological carrying capacity, economic carrying capacity and the related overstocking. A discussion of the work of Barrett and Perrings follows in Section 5.2.

3.2.4 *The Context of Carrying Capacity and Grazing Capacity in Communal Rangelands*

Given the problems with the definition of carrying capacity and grazing capacity discussed earlier, there is reason to doubt the relevance of carrying capacity in Africa's communal rangelands. Stafford Smith (1996) argues that carrying capacity is a farcical concept with limited applicability in areas where the annual coefficient of variation of rainfall exceeds 30 percent and proposes that it should be replaced by the concept of non equilibrium dynamics. He dismisses the relevance of carrying capacity because it is difficult to determine the stocking rate in communal livestock systems in Africa where the livestock have several uses. While accepting the limited relevance of the carrying capacity concept in variable climates, Stafford Smith (1996) cautions against optimism that subsistence systems are resistant to land degradation. He argues that tolerance in communal systems is not evidence of resilience, which may decline as evidenced by less than normal quantity or quality of forage, following a drought of limited severity.

The Botswana government has been battling to convince subsistence pastoralists in the country that rangeland degradation exists and that it is caused by heavy stocking (Republic of Botswana, 1990). The prevalent view among Botswana pastoralists is that a lack of rainfall, or the occurrence of drought, causes a shortage of grazing (Mpotokwane and Mogalakwe, 1987). The pastoralists' view is reinforced by the occurrence of lush vegetation after the rains. Such a blind trust in nature's resilience develops because tolerance is mistaken for resilience. By highlighting the time of greatest stress, the FAO's (1991) definition of carrying capacity accounts for the fluctuations of forage availability in response to the non-equilibrium rainfall pattern which equates carrying capacity to a conservative stocking rate.

Botswana has a map showing the potential carrying capacity values, also called the carrying capacity, for parts of the country (Figure 3.1). Section 1.1.3 shows that the stocking rate in most districts exceeds the potential carrying capacity. The finding that stocking rate exceeds the grazing capacity in most districts in Botswana highlights the suspicion about the limited relevance of the official grazing capacity figures for the management of livestock in communal areas. If such figures were relevant, then the doom scenario for the country's rangeland would have been realised. It has not been the case.

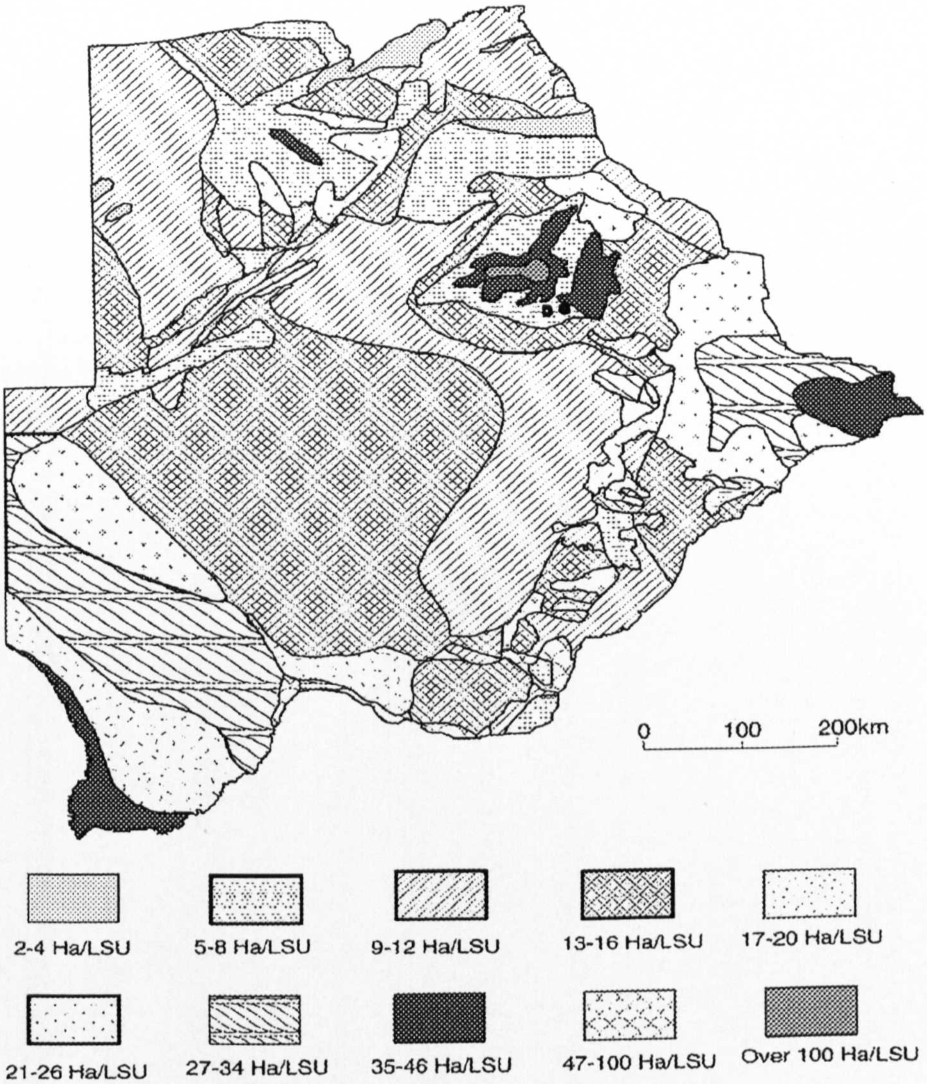

Figure 3.1 The Potential Carrying Capacity of Botswana
Source: Arntzen and Veenendaal, 1986:36.

The fixed definition of the grazing carrying capacity does not take into account the type of livestock and their potential to adapt within their habitat. For example, indigenous cattle in semi arid areas can take 25 to 45 litres of water once every three days while the temperate zone cattle introduced into tropical conditions would require 60 to 90 litres every day (FAO, 1991). The different water requirements show that the carrying capacity for the two species would be different when the livestock water availability is taken into account. Similar adaptations occur for forage intake. Another adaptation is the movement of cattle which optimises the use of the forage and water resources within the area. Livestock mobility was discussed in Section 3.1. At this point it is relevant to point out that livestock mobility complicates the efficacy of grazing capacity measurements as much as the objective of the production (Section 3.4.3).

Due to their low grazing capacity, rangelands which occupy extensive areas of land in southern African savanna are used for livestock production. The ranches tend to be large scale, for example 3000 hectares (Walker *et al.*, 1978). In Botswana, the demarcated Tribal Grazing Land Programme ranches varied in size between about 4000 hectares and 11000 hectares (Table 3.7). The largest farms were in the driest

Table 3.7. The Size of Tribal Grazing Land Policy (TGLP) Ranches in Botswana

District	Ranch Area (Ha.)
Ngwaketse	6400
Kweneng	6400
Central District	3960 – 8890
Kgalagadi	8104 - 11050
Ghanzi	6156 - 7488
Ngamiland	4050 - 7600

Source: Adapted from Tsimako, 1991:7-14.

part of the country, where the grazing capacity was lowest. One of the NPAD policy proposals is to take into account the variation between grazing capacity rather than follow the unrealistic fixed ranch size model which was recommended for the TGLP farms (Ministry of Agriculture, 1991). The livestock density, availability of grazing land and the grazing capacities between the east and the western part of Botswana are different.

Communal rangelands grazing capacity and carrying capacity have two functions. They establish the relationship between the animals forage demands and the available forage. However the relationship varies according to the management of the ecosystem in question. Secondly, given the variations of the relationship between livestock and forage, albeit its weaknesses, carrying capacity is a useful for livestock management. Despite the problems with definition for use in a variable system, the concepts can be improved upon.

3.2.5 *Towards Definitions of Grazing Capacity and Carrying Capacity for Communal Rangelands*

An ideal definition of carrying capacity for communal rangelands should have five features.

i) It must state the **production goal**. Communal livestock producers obtain a number of products from their livestock as opposed to the ranches, which are a monoculture. Communal rangelands focus on the highest output per land unit and therefore keep large herds while ranches concentrate on the highest output per animal and keep few animals in order to maintain a healthy range.

ii) The **acceptable minimum resource condition** and the **time** over which the acceptable resource condition should be assessed must be specified (Leeuw and Tothill, 1990 and 1993). The proper use factor (FAO, 1991) indicates a recommended use level. Rangeland changes take place all the time but it is not easy to say at which point they signal the deterioration of the rangeland. Ideally the assessment time should occur over a long period to include sustainability, which is the present production or use level that should not impede the future use of the rangeland. However carrying capacity alone is not enough to identify the causes of rangelands change over time since many factors act simultaneously (Hulme, 1996; Odada *et al.*, 1996).

iii) It must reflect the **temporal and spatial characteristics** of the rangeland as far as practical or possible given the mapping scales. The definition would thus incorporate the different resources available for use at different times. For example Abel *et al.* (1987) observed that when the grass biomass was low, browse became a significant source of forage for livestock in Ngwaketse District of Botswana. However browse does not maintain the condition of cattle as effectively as grass (Abel *et al.*, 1987). Although it would be relevant to include the value of browse when we calculate grazing capacity for communal areas, it would not be practically relevant for commercial production where the objective is to get the highest output per animal as was discussed in the earlier parts of Section 3.3. Browse enables livestock to survive during the drought or dry season therefore. The spatial characteristic of a rangeland includes the use of different areas during different times of the year.

iv) A carrying capacity definition should indicate the **availability, reliability** and **accessibility** of livestock water within a given rangeland (see also FAO, 1991:47). Existing grazing capacity definitions and assessments are solely based on the forage quantity and quality. Some definitions refer to land resources in general, which seem to imply that livestock water availability is not a constraint. When an animal has insufficient water it reduces the dry matter intake. When they walk a long distance to watering points, the daily grazing time is reduced which also reduces their dry matter intake (Nicholson, 1986).

v) It is appropriate for the grazing capacity and carrying capacity definition to take into account the **mobility of the livestock** by considering the grazing orbit of herds within an area. The grazing orbit is *"a circle centred on the home of an animal that is* *grazed by the animal throughout the year"* (FAO, 1991:135). Grazers in rangelands move from one area to another to select the best forage (Scoones, 1992 a; b). Several grazing orbits define the outer circle of the mosaic of grazing orbits.

3.2.6 *Livestock Water Management Strategies in Semi Arid Areas*

Households in semi arid areas, adjust the water intake of their cattle according to the availability of water. When there is inadequate water, the common strategy is to reduce the frequency of livestock watering as the distance to the water increases (Author's fieldwork). Less regular watering enables livestock to alternate their time between grazing and watering. The effect of a two and a three day watering schedule on cattle was investigated by Nicholson (1986). He concluded that the overall cost to animal productivity was small but significant and lists the benefits of a three day watering schedule as to:

i) enable cattle to exploit grazing which is further afield of the watering point

ii) save on labour, water and fuel when engines are used to pump water

iii) save on forage intake as low water intake reduces the livestock's appetite to feed

iv) reduce the potential erosion as cattle move less to the watering point

While all the above are plausible, it is questionable that households in the study area had the savings (ii) to (iv) in mind when they decided on watering strategies. The highest priority amongst the households' management strategy was to increase access to grazing (Author's fieldwork). The Rain Land Cattle model integrates the physical and the social aspects of decision making in order to come up with a simulation from which a sound analysis of the problem could be made.

3.3 The Interaction of Rainfall, Forage and Cattle Numbers

3.3.1 *Rainfall and Forage Production*

Several authors have studied the direct relationship between rainfall and forage production (Gils, 1984; Wijngaarden 1985; FAO 1992; Leeuw and Tothill, 1993). Wijngaarden (1985) developed formulae for the rainfall and forage relationship in semi arid Kenya.

Equation 3.2 is corrected for proper use factor[3], and loss through decay and trampling. The equation tells us that when there is a low perennial grass cover there will be low available grass forage produced under the same rainfall and soil conditions. Where annuals dominate, the grass cover at the beginning of the rainy season is always low and therefore of less relevance to the subsequent production.

Equation 3.2. Calculation of Available Grass Forage based on Annual Rainfall

$GA = 6.2 \times R \times PGC$ where: 6.2 is constant used for deep poorly drained soils; 5.4 and 2.7 are the constants used for deep well drained soils and shallow well drained soils, respectively GA is available grass forage (kg km^{-2}) R is annual rainfall (mm) PGC is perennial grass cover (percentage)

Source: Wijngaarden 1985:97.

Equation 3.3, has been corrected for utilisable browse[4] and forage fraction[5]. It shows that the available browse decreases as the shrub cover percentage increases. When the woody percentage of the rangeland is high, the percentage cover by perennials is

[3] Proper use factor is the ratio of forage which can be removed (grazed) without damaging the potential for future production through accelerated erosion, nutrient depletion, physical soil degradation or undesirable vegetation changes (FAO 1991:89)
[4] Utilisable browse is the browse within a height that can be reached by browsers
[5] Browse forage fraction is the percentage of browse species in a region which the ungulates forage from. Not all browse is forage.

always low. The bushes are more efficient in extracting moisture from the ground hence the maxim that bush encroachment causes a decline in the production of a rangeland. Wijngaarden (1985) and Walter (1994) explore the development and existence of competition between shrubs and grass in some detail. When there is a low percentage woody cover, the perennial grass cover varies considerably. This is because the woody cover sets a maximum limit to the cover by perennial grasses. Because the limit is high in wetter climates, Wijngaarden (1985) suggests that the limit is set by the competition for available moisture.

Equation 3.3 Calculation of Available Browse from Shrubs based on Annual Rainfall

$BAS = R \times (-4.535 + 8.751 \times SC + 0.0179 \times SC_2 - 0.0056 \times SC_3 + 0.000055 \times SC_4)$
where:

BAS is available browse from shrubs (kg km^{-2})
R is annual rainfall (mm)
SC is shrub cover percentage, represented as SC = 2%; SC_1 = 10%; SC_2 = 20%; SC_3 = 30%; SC_4 = 40%

Source: Wijngaarden 1985:98-99.

Dry matter production can be predicted based on the annual rainfall using Equation 3.4.

Equation 3.4 The Simple Model for Total Dry Matter (TDM) Production based on Annual Rainfall

$y = a + bx$ where:

y is Total dry matter production
a is constant value as per Table 3.8
b is constant value as per Table 3.8;
x is mean annual rainfall (mm yr^{-1}).

Source: FAO 1991:87

Using the equation, the estimated TDM production for Sudan Zambezian is1000 kg ha^{-1} that for the Karroo- Namib is1220 kg ha^{-1} and the Mediterranean produces 2220 kg ha^{-1}. These estimates were found to be within the normal range found of each region (see Walter 1994) despite the crudeness of the model. The model does not account for differences in soil and temperature for example. Equation 3.4 is used in tandem with Table 3.8 to predict herbage or herbage and browse in different ecological regions in Africa. Table 3.8 also shows the mean annual rainfall range. Van Gils (1984) explains how the constants in Table 3.8 were derived.

Table 3.8. Mean Annual Rainfall and Constants Used in Formula for Arid and Semi Arid Areas

Region	Type of Forage		Rainfall mm yr^{-1}	Constants	
	herbage only	herbage + browse		a	b
Mediterranean		+	20 - 900	-200	4.4
Sahelo Sudanian	+		200 - 1400	100	2.6
Semi arid Kenya	+		50 -400	-180	6.3
Semi arid Kenya		+	50 - 400	-400	10.0
Sudan Zambezian	+		200 - 800	0	2.0
Karroo - Namib	+		50 - 500	-100	4.8
East + South Africa	+	+	500 - 800	-200	8.5

Source (FAO, 1991:88)

Wijngaarden (1985) observed that in a savanna the combined rainfall from the last two or three seasons had a more significant influence on perennials than the current season's rainfall. His observation was similar to those made by Vossen (1990) on the influence of rainfall on cattle mortality. The influence of rainfall on cattle can be extrapolated to infer the availability of forage. The two observations show that for a more accurate estimation of total dry matter the previous year's rainfall amount should be included.

Leeuw and Tothill (1993) reviewed the TDM production estimates for West Africa, Kenya and Zimbabwe for different rainfall conditions as shown in Table 3.9.

Table 3.9 Estimated Total Dry Matter (TDM) Production (tonnes DM Ha^{-1}) based on Annual Rainfall

Region and Water Holding Capacity (WC) of the soil	Annual Rainfall (mm.)			
	200	400	600	800
West Africa	0.65	1.1	1.7	2.2
Zimbabwe WC100 mm	0.5	1.7	2.2	2.5
Zimbabwe WC 200 mm	0.7	2.6	3.2	3.7
Kenya	1.1	2.3	2.6	-

Source: (Leeuw and Tothill, 1993:79)

As expected, the TDM production increases with rainfall, but not in a simple linear relationship. Leeuw and Tothill (1993) observed that Kenya had a higher TDM production than West Africa due to the higher soil fertility, the greater water holding capacity of the soils and the lower evaporation rates because of the altitude. The soils could influence the rangeland production in West Africa by as much as 50 percent (Leeuw and Tothill, 1993).

Whenever generic relationships are used, variations of the rangeland production due to differences on a finer scale are disguised. Such differences include soils, rainfall, slope and vegetation cover. The history of use influences the TDM produced in an area. Heavily used areas will experience a decline in TDM production even with a constant rainfall. This finding concurs with that of Wijngaarden (1985) as shown in Equation 3.2, FAO (1991). Because rainfall can be used predict forage production, it is concluded therefore that it can be indirectly used to predict ungulate population.

3.3.2 *Ungulate Population Growth Patterns*

Caughley (1976) wrote on the relationship between wildlife ungulate population and their food resource. He observed that when introduced to an unoccupied area, the ungulate population grows as long as there is unlimited access to the food resource base. When the population is low in relation to the food resource base, the ratio of resources to animals is at its maximum level (Caughley, 1976). As the population increases the per capita food declines. The per capita food decline leads to a decrease in the animal population until an equilibrium is reached at a new resource population level that is lower than the initial peak. Caughley called the upsurge in population numbers in the initial stages the eruption and the subsequent decline the crash. The intensity of grazing prior to a crash may be detrimental to the vegetation's structure because overpopulation, called overstocking in rangeland management, is most likely to occur.

The eruption and the crash are followed by dampened oscillations as the population and food resources find a new equilibrium. The vegetation and herbivore population relationship best depicts the oscillation summed up by the logistic growth equation, Equation 3.5.

Equation 3.5 The Population Logistic Growth Curve

$$\frac{dN(t)}{dt} = r_m N(t)\left(1 - \frac{N(t-T)}{K}\right) \text{ where:}$$

N is the number of animals in the population
t is time over which the relationship is observed to change
r_m is the intrinsic rate of population growth rate
T is time lag between a change in resources per head and the populations dynamic reaction to that change
K is carrying capacity size of the population

Source: Caughley, 1976:210.

The equation shows that the population increase over time [dN(t)/dt] is the rate of the intrinsic population growth [r_mN(t)], which is the population's biological capacity to grow, multiplied by the complement of the proportion of the carrying capacity size [1-N(t-T)/K] which the population reached at a given time (t – T) (Caughley, 1976). N(t-T) shows the population density when the vegetation is altered and a new equilibrium sets in.

Three observations, which form the theoretical basis of the present study, can be drawn from Equation 3.5. The intrinsic population growth, which is the difference between birth and death rates, influences the population dynamics. The available forage, influences the population's growth through the carrying capacity. Lastly, the carrying capacity, which determines the food resource available for a livestock population, is determined by the rainfall within a rangeland.

3.3.3 *Rainfall and Cattle Population Dynamics in Botswana and Zimbabwe*

Vossen (1987; 1989; 1990) conducted a key research on the influence of rainfall on both crops and cattle output at regional and national level in Botswana. His work on cattle is relevant to the present study.

The length of the annual dry season in Botswana could be anything between four months, for a late end and early start of the next rainy season, and nine months for an early end and late start of the next rainy season. He classified the rainy season into early, mid and late season (Table 2.3). Each month's rainfall was analysed on a 10 day basis for 10 months between September and June during a rainfall season. He found that the 10 day rainfall analysis explained 86 percent of the inter annual crop yield variation as opposed to 75 percent by the seasonal rainfall.

For livestock production, Vossen (1989) took into account the rainfall for the previous two seasons and that of the current season. Eighty one percent of the inter annual herd size variation was accounted for by the weighted sum of the rainfall of the present, the previous and the season two years ago. Using a wide range of meteorological data, Vossen (1989) proposed three measures to assess the livestock rainfall relationship. The three measures were:

i) **The Rangeland Cattle Water Requirements (RCW)**

The RCW indicates the extent to which rainfall provides adequate moisture for both healthy forage and livestock drinking water. Livestock drinking water can only be provided when the water supply is in excess of the vegetation demands.

Equation 3.6 The Rangeland Cattle Water Requirement (RCW)

$RCW = PET \times C_f$ where:

PET is potential evapotranspiration
C_f is the rangeland cattle factor, which is the fraction of PET to be met by rainfall to satisfy both the requirements of rangeland vegetation and livestock drinking water

Source: Vossen, 1989:88

ii) **The Total Water Stress (WS)**

The Total Water Stress (WS) in Equation 3.7, is the difference between the water demand to satisfy the forage production and the water supply from both the rain and the soil moisture buffer. The ideal situation, where there is no water stress, occurs when the Rangeland Water Requirement is less than the moisture at the beginning of the 10 day period, plus the rainfall during the 10 day period, that is [$WS \leq 0$ when $RCW<(ASRi + RRRi)$]. When the RCW exceeds the sum of the moisture buffer at the beginning of the rainy season and the rainfall during the 10 day period, that is [RCW > (ASR_i + RRR_i)] then WS > 0, which shows water stress.

Equation 3.7 The Total Water Stress (WS)

$$WS = \sum_{i=a}^{i=b} \left[(C_f \times PET_i) - (ASR_{i-1} + RRR_i) \right] \text{ where:}$$

WS is water stress
i is number of 10 day rainfall observation period. Usually it refers to the whole rainy season from September to June but it could represent a shorter period
a,b is beginning and end of period of observation, respectively.
C_f is rangeland cattle factor
PETi is potential evapotranspiration for decade i
ASRi $_{-1}$ is actual soil moisture reserve at the end of the previous decade. There is no moisture reserve at the beginning of the first decade, thus ASRi = 0
RRR_i is rainfall during decade i
ASR_i is Actual Soil Moisture Reserve ($C_f \times PET_i$) - (ASR_{i-1} + RRR_i)

Source: Vossen, 1989:190

In simple terms, the equation shows what happens when neither the soil moisture buffer nor the rainfall is adequate for the forage and water required by cattle. The cattle are expected to lose condition due to the water stress and may ultimately die.

iii) **The Livestock Performance Index (LPI)**

The LPI shows the extent to which the Rangeland Cattle Water Requirement (RCW) is satisfied, or not satisfied, as percentage. The LPI is derived from the comparison of the RCW and the WS as shown by Equation 3.8.

Equation 3.8 The Livestock Performance Index (LPI)

$$LPI = \frac{RCW - WS}{RCW} x \ 100 \qquad \text{where:}$$

RCW is The Rangeland Cattle Water Requirements
WS is The Total Water Stress

Source: Vossen 1989:189 and 1990:192.

When WS ≤ 0 there is no water stress and when WS > 0 shows there is water stress. A Livestock Performance Index of 100 percent shows absolute water stress which can be expected during a severe drought when almost all the Rangeland Cattle Water Requirement is not met. Based on the LPI, Vossen (1989) explained the cattle death rate for different agricultural regions in Botswana based on the present, previous and the season two years ago. He derived regression equations similar to the Equation 3.9 for six agricultural regions.

Equation 3.9. Regression Equation for Cattle Death Rate of Southern District 1978/79 – 1985/86

$$D = 81.11 - 0.30\,(LPI_{MJ-2}) - 0.47\,(LPI_{-1}) - 0.27\,(LPI_{o})$$ where:

D is death rate
LPI_{MJ-2} is Livestock Performance Index two years ago
LPI_{-1} is Livestock Performance Index previous season
LPI_{o} is Livestock Performance Index present season

Source: Vossen 1990:194.

Vossen (1989; 1990) found that the cattle death ratio was accounted for by the LPI of the present and the previous two seasons in five out of the six agricultural regions studied. All the districts had a negative regression coefficients to show that the death rate increased when the season qualities worsened. The positive intercept represents a high death rate when there was no rainfall, which confirms that rainfall affects cattle mortality hence, population dynamics. The relationship between cattle and rainfall is the basis of the Rain Cattle Land model developed in Chapter 6. Vossen (1989, 1990) did not study other factors that affect cattle population such as epidemics, sales, economic factors and government policy.

Scoones (1990; 1993) studied the population dynamics in six communal areas in central and southern Zimbabwe for the period 1896 to 1990. He described half the areas studied as "drier" and the other half as "wetter". Zimbabwe has a higher rainfall and more complete cattle records than Botswana. He noted that the cattle population decreased because of epidemics, destocking policy, war and drought and increased when the cattle dips were operational, destocking abandoned and during good rainfall years (Scoones, 1993). He described the cattle data for the six study areas between 1920 and 1990 by the logistic growth Equation 3.10 that is similar to Equation 3.5.

Equation 3.10 Logistic Growth Model Used for Zimbabwe Cattle Data

$N_{t+1} + N_t + H = rN_t - rN_t^2/K$	where:

r is intrinsic rate of population growth (births versus deaths)
N_t is population at a given time (time t)
N_{t+1} is population a year after the given time (time t + 1)
H is harvest + sales
K is ecological carrying capacity

Source: Scoones 1993:67.

The Equation 3.10 shows that the cattle population depends on the intrinsic population growth rate less a factor of that growth rate based on the ecological carrying capacity. The equation explained 30 to 60 percent of the population growth, ($R^2 = 0.3$ to 0.63) with a standard error of up to 52 percent. During drought, also called shock years, the mortality rates were high (25 percent) and density independent which means that during a drought cattle will die irrespective of how many there are in an area. During the non drought years, the mortality rate was low, 2 to 4 percent, and density dependent. This means that when there is no environmental stress the number of cattle influences their mortality. The birth rate, on the other hand, was always negatively related to the cattle density during both drought and non drought years. This means that the birth rate was density dependent (Scoones, 1993:70). A density dependent variable is influenced by the number of the animals in an area, while a density independent variable is not. In practice it is more difficult to attribute, for example, high mortality to one cause such as lack of rainfall. Different impacts will be realised in areas with the same amount of rainfall and different species population density. Scoones (1993) found that the actual carrying capacity estimates in communal areas, as reflected by the stocking rates, were higher than the officially recommended carrying capacity of 7.2 Ha LSU^{-1}. He concluded that the official carrying capacity was based on the economic carrying capacity for a beef production ranch which was not relevant to a communal area where livestock have multiple uses. Because the stocking rates were persistently above the official carrying capacity it showed that the area was resilient. The resilience was due to the cattle movement between different habitats to offset the imbalances between the number of animals and forage production and maintain the stocking rates above the government recommended levels (Scoones 1993).

3.3.4 Dynamic Relationships and Modelling

Up to this point we highlighted the flux in the forage and livestock population relationship due to the spatial and temporal variability of rainfall in rangelands. The challenge for modelling is to select a time scale that captures the flux in a manner most relevant to management. A coarse spatial or temporal resolution with useful outputs is preferred to a model output with fine spatial or temporal resolutions which do not relate to cattle management. For example, it will not be useful to model rangelands at a temporal scale below the seasonal forage availability changes and the annual calving rate.

The other challenge is to identify a spatial scale that reflects the functional significance of the landscape units which provide key resources within the management system. The Preference Index (PI) objectively defines the functional significance of a unit. The PI is the extent to which a unit is used in relation to its availability (Scoones, 1993). Normally cattle should spend more time on a large grazing unit than on a small grazing unit. When PI < 1 it means that the unit is avoided, PI = 1 means the unit is used in proportion to its availability and PI > 1 means the unit is preferred (Scoones, 1993). The PI was not used in the present study. The cattle in the study area, grazed in the arable area during the dry season. The Rain Land Cattle model, described in Chapter 6, assumes that the arable area is preferred.

3.4 Rangeland Degradation and Productivity in Botswana's Cattle Sub Sector

This section defines and discusses the issue of rangeland degradation, and critiques the productivity analysis for communal areas and ranches in Botswana.

3.4.1 *Definition of Rangeland Degradation*

In Botswana rangeland degradation is associated with overstocking (Ministry of Agriculture, 1991) but seldom defined. This is because rangeland degradation is difficult to define. Abel and Blaikie (1989:113) defined rangeland degradation as "*an effectively permanent decline in the rate at which the land yields livestock products under a given system of management*". Based on their definition it is difficult to conclusively show rangeland deterioration in a semi arid area because a poor rangeland condition can be reversed. A further difficulty arises when for example rangeland species change due to heavy grazing is regarded as an improvement to the rangeland as was the case in the Southern District of Botswana (Abel *et al.*, 1987). Rangeland degradation is a continuous process (Abel and Blaikie, 1989) and like soil erosion, it maybe accelerated by the nature of rangeland use. This suggests that acceptable limits of rangeland degradation may be defined.

3.4.2 *The Existence of a Rangeland Degradation in Botswana*

The number of cattle in Botswana has increased since the 1900's as shown in Figure 1.1. The cattle sub-sector is a significant source of income for rural households and the national economy (Colclough and McCarthy, 1980: Ministry of Agriculture, 1991; Ministry of Finance and Development Planning, 1991). Concern has been raised about the impact of the growth of livestock numbers on the rangeland resource especially grazing (Schapera, 1943: Cooke, 1979: Ringrose and Matheson, 1986: Arntzen and Veenendaal, 1987: Perkins and Thomas, 1993). There is a view that the country has too many cattle which cause overgrazing (Ringrose and Matheson, 1986) and rangeland degradation (Queiroz, 1993). Most concern is about the communal grazing areas where over seventy five percent of Botswana's livestock is kept. The prevalent view is that communal grazing areas are overexploited by individual herd owners along the lines suggested by the Tragedy of the Commons (Abel and Blaikie, 1987; Ministry of Agriculture, 1991).

Forage varies in areas with variable rainfall (Abel *et al.*, 1993) which led White (1993) to argue that there is no rangeland degradation in Botswana. De Queiroz (1993) has challenged White's view. White (1993) bases his view on three points. The first point is based on Biot's finding that Botswana's hardveld will not show any significant decrease in forage production for 400 years (Biot, 1993). De Queiroz (1993) questioned Biot's finding and argued that the decreased infiltration when the clay sub surface layer found in most hardveld soils is exposed, causes a decrease in forage production which is rangeland degradation. Secondly, White (1993) viewed the increase in the nationwide meat output per animal between 1966 and 1990 as evidence of lack of rangeland degradation. De Queiroz (1993) disputed White's interpretation and pointed out that the increase in meat production was due to a decrease in the stocking rate, due to an increase in grazing land when the borehole technology became available. To support his argument, de Queiroz quoted the Kgalagadi District where an increase in cattle population from 36 500 to 62 400 between 1960 and 1990 was accompanied by a decreased stocking rate from 47 to 51 Ha LSU^{-1}. To further support his argument, de Queiroz (1993:9) argued that despite the improved veterinary care and livestock marketing facilities, there was no improvement in the average dressed carcass weight, which de facto indicated a decrease in the rangeland's ability to produce livestock products. De Queiroz (1993:11-13) observed that the reduced concentration of phosphorus around pans, which are an important nutrient cycling pathway in the Kalahari, was due to reduced wildlife numbers as veterinary cordon fences were put up. He argued that the reduced concentration of phosphorus was a sign of ecological degradation to the Kalahari ecosystem caused by the livestock sector. De Queiroz's last point is contentious. The decrease in phosphorus obviously has an indirect effect on cattle in the Kalahari ecosystem. Although cordon fences have an impact on wildlife (Pearce, 1993), they are not the main source of decline in the number wildlife in the Kalahari. Spinage and Matlhare (1992) hold a view that does not support de Queiroz on the dynamics of large herbivore population in the Kalahari. This discussion shows that de Queiroz and White had different conclusion about the existence of rangeland degradation despite using the same definition of rangeland degradation. Recently Sefe *et al.*, (1996) found that people's increased dependence on natural resources during drought in North Central Botswana, triggered off a process of resource overuse which gradually leads to degradation and desiccation. Stocking rate and rainfall variation are important variables in the rangeland degradation process. The number of cattle and the rainfall variability are inextricably intertwined as was outlined in Section 3.3.

3.4.3 *The Productivity of Ranches versus Communal Areas in Botswana*

The Botswana government holds the view that herds under communal management are less productive than those in the commercial sector, mostly ranches (Ministry of Agriculture, 1991; Mosienyane, 1993; Rennie *et al.*, 1977). Table 3.10 shows the disparity in the productivity of the communal areas (cattlepost) and commercial areas (ranches).

Table 3.10. Cattle Productivity under Cattlepost and Ranch Management in Botswana

Trait	Cattlepost	Ranch
Calving Percentage	47.3	74.8
Calf Mortality (%)	10.7	8.5
Weaning (%)	42.5	68.4
Weaning mass (kg)	123.5	180.4
Post Wean Weight Gain (7 – 18 months) (kg)	89.7	105.9
Mass of Weaner calf/cow/year (kg)	52.5	123.4
Mass of 18 month calf/cow/year (kg)	90.6	195.8

Source: Behnke, 1985:111

But the government also finds that "*at least on the basis of performance indicators such as calving percentage, offtake and mortality rates, the commercial sector is technically, and not necessarily economically, more efficient than the traditional / communal sector. To determine economic efficiency between the two production systems will require data on costs of production, resource use efficiency with/ without subsidies, etc.*" (Ministry of Agriculture, 1991:8). It has been observed that cattle in Botswana's communal areas have a higher productivity per hectare than ranches, while the ranch herds produce better per animal (Abel and Blaikie, 1989; Behnke, 1985; Ministry of Agriculture, 1991; Scoones, 1995 a). Experiments showed that a stocking rate of 4 ha per livestock unit produced a live mass gain per hectare of 15.7 kg $year^{-1}$compared to 12.9 kg $year^{-1}$ at a stocking rate of 8 ha. per livestock unit (Abel and Blaikie, 1989). The results showed that as the stocking rate increases per hectare productivity increased similarly. In order to obtain high production per hectare, the communal areas have higher stocking rates than the government's recommended stocking rates (Abel, 1993). In general the stocking rate in mixed farming areas is almost double that in the commercial ranches. For example, 7.5 Ha LSU^{-1} compared to 13.9 Ha LSU^{-1} (Arntzen, 1990) or 6 Ha LSU^{-1} in the communal areas compared to 12.5 Ha LSU^{-1} on ranches (Abel and Blaikie, 1989).

Behnke (1985) argued that differences in production between the two systems reflect the multi purpose use that communal livestock are put to such as draft, home slaughter, and milk production against the ranch herds which are usually limited to a single purpose use. The comparison between communal and commercial areas is therefore lopsided because it looks at all the produce for the ranch against part of the produce from the communal area (Behnke, 1985). Further to the lopsided comparison, the existence of dual grazing rights (see Section 1.5.2) means that the condition of livestock in a ranch reflects the combined benefit of access to both the ranch and the communal grazing (Abel and Blaikie, 1989). On the other hand the poor condition of livestock in the communal areas reflects the disadvantages of dual grazing in the communal rangeland and not the poor productivity of communal grazing *per se*. From Sections 1.4 and 1.5 we know that the ranch has not been widely successful and its management is not necessarily different from that in the communal areas. Another source of inaccuracy in the comparison is that most ranch data are based on experimental farms which are managed differently from a ranch (Behnke, 1985). When biological data from a producer's ranch are used, the difference in production with the cattleposts is less stark (Behnke, 1985:113). Meaningful economic comparisons between the two systems are difficult due to difficulties with consistent valuation of certain social benefits from and inputs to livestock in the communal sector (Behnke, 1985).

3.5 The Contribution of the Study to Cattle Management

This study makes seven contributions to cattle management studies, and practice, which are discussed in Sections 3.5.1 to 3.5.7.

3.5.1 *Relationship Between Grazing Capacity, Carrying Capacity and Number of Cattle*

Section 3.2 discussed the differences between grazing capacity and carrying capacity. It was pointed out that carrying capacity should include other physical attributes and not be limited to the availability of forage. Livestock water is critical to the livestock's survival and well being. The present study combined the livestock water availability and the carrying capacity to derive an index about both the grazing capacity and the livestock water availability within a rangeland called the Carrying Capacity Water Availability Ratio (Section 4.3.6). The potential for cattle management and production is more accurately depicted when the livestock water availability is included. A static grazing capacity has limited practical relevance for rangelands where there is a significant temporal and spatial variation of forage production. Livestock take advantage of the rangeland's temporal and spatial variations by moving between key areas. The research models the variation in rainfall from year to year and the subsequent herd population dynamics. In that respect the present study serves two purposes as a strategy for future cattle management. It is a methodology for monitoring livestock dynamics in a local cattle management area. Secondly it can be used to predict livestock water holding under different rainfall scenarios. Prediction leads to proactive management.

Communal land grazing areas in Botswana are declining due to competition with other landuses. The present study models the grazing land available from year to year by incorporating the decline in the available land which occurs due to landuse competition in the area. The decline in the available grazing area causes a decrease in the carrying capacity in response to the increase in the stocking rate. It is realistic to consider both the herd size growth and the decline in the available grazing land because the communal grazing land is not fixed.

Vossen's (1990) study of births, deaths and rainfall's contribution to herd growth in Botswana, did not include a dynamic model. Braat and Opschoor (1990) modelled cattle numbers in relation to rainfall at the national level (Section 5.5). The present study takes the herd dynamics monitoring a step further by simulating the interactions between the annual herd growth, communal grazing land loss and the annual rainfall at a local level.

3.5.2 *The Definition of Carrying Capacity and Grazing Capacity*

The possible confusion between carrying capacity and grazing capacity was discussed in Section 3.2. The present study draws a dividing line between the two definitions for Botswana's communal areas. Grazing capacity is regarded as a physical measure that relates the available forage to the livestock demands while Carrying Capacity is a broader concept that includes other land attributes such as the presence of predators, pests and competing herbivores. In this study only livestock water availability (Section 6.7.5) and the seasonal use of the arable area (Section 6.5.1) were included in the carrying capacity.

3.5.3 *New Thinking in Rangeland Management*

The new thinking in rangeland management emphasises heterogeneity, livestock mobility, use of key resources and local scale management strategies. Existing maps and studies of livestock management (Field, 1973; Ministry of Agriculture, 1991; Ministry of Finance and Development Planning, 1991) do not have the temporal and spatial resolution necessary to implement the new thinking in rangeland management. The present study demonstrates possible temporal and spatial resolutions at which to implement the new thinking in pastoral management. It contributes towards implementing new thinking in rangeland management. The methodology is adaptable to other communal areas in Botswana, rather than being a prescriptive procedure, and is readily applicable to all areas at all times. For example, some rangelands may not have an arable area into which livestock move at a particular time of the year. Although it was not part of the present study, it is possible to measure the grazing capacity at the different spatial and temporal scales used in the model. For example, the three communal grazing areas in the present study, which are arable land, riverine and homesteads are expected to have different grazing capacities. The arable area's grazing capacity varies between normal and drought years when the animals are allowed to graze the wilted crops. Similarly the grazing capacity of the riverine area will fluctuate.

The livestock water availability variation is measured by the rainfall variation. This study develops a methodology which can be used for continuous monitoring of cattle, rainfall, grazing land and livestock water availability. The approach would provide data required to implement cattle management policies for the new thinking in rangeland management.

3.5.4 *System Dynamics Modelling*

The study uses system dynamics (see Section 5.4) to represent a pastoral system. The characteristics of the communal cattle management system, such as grazing land loss, arable area grazing, variable rainfall trend are comparable to other parts of the country. The model developed is generically applicable to the rest of the country. The study therefore contributes to systems dynamic modelling of cattle management in communal areas in Botswana. System dynamics modelling is an appropriate approach to problem solving since it involves the use of positive and negative loops to represent a system, which in most cases are based on widely understood principles. The method considers many issues that are part of the problem studied instead of the single issue approach. Life problems are rarely based on a single issue approach. System dynamics is realistic because it is a holistic approach. Cattle management issues in the communal areas are multi faceted.

3.5.5 *The Carrying Capacity Water Availability Ratio (CCWA Ratio)*

The study explores the use of the CCWA ratio (Section 6.7.6) which combines the available livestock water in an area to the carrying capacity of the area. The water availability measure is based on the number of water points and their water holding under different rainfall conditions (Section 4.3.3). Above average rainfall increases both the grazing capacity and the number of livestock water points which improves the CCWA ratio. The opposite happens during below average rainfall. The CCWA ratio measure devised is admittedly exploratory and the measurements of water availability can be improved. However the index is logical and consistent and improves on the carrying capacity which seldom refers to livestock water availability.

3.5.6 *Sustainability of Pastoral Management Strategies*

The present study simulates rainfall prediction, land availability, livestock water availability and the corresponding herd dynamics. By implication it can show the sustainability of a communal grazing area. When calibrated, the model used in the present study would predict how a pastoral system would cope with environmental shock and stress. The long term ability to cope with drought (shock) and high stocking rates (stress) indicate the sustainability of cattle management in an area.
The discontinuous cattle numbers data in the study area, which were also for a short period, were of limited reliability when assessing the sustainability of pastoralism. However the potential for an accurate output exists when reliable data are available. In that respect the model serves as a template for data collection.

An immediate issue, which the present study addresses, is how feasible the policy of fencing communal areas will be for the Tlokweng sub district. It is used to assess the effect of fencing under different rainfall scenarios, matched to different land loss and stocking rates. The assessment is based on how the communal water resources are used and the relation between the stocking rate and grazing capacity. If there is limited communal livestock water, it will be controversial to fence them in as high stocking rates will be exacerbated when part of the communal land is privatised.

The present study integrates the pastoral households' views of the physical facts about rainfall, cattle numbers and land availability, to explain the management choices.

3.5.7 *Informed Policy Making*

The study enables informed policy decisions to be made based on monitoring the stocking densities, use of the grazing land, household management strategies, and livestock water availability. Since it serves as a template for data collection as well as policy analysis, the study enables similar communal areas to be monitored and useful data to be collected for the future management of the areas. Policy making for cattle management in Botswana in general has so far been based on aggregate cattle data that do not indicate the main management factors responsible for the dynamics of cattle, land availability, rainfall and livestock water availability. New thinking in livestock management emphasises spatial variability of grazing areas, mobility of livestock and the temporal and spatial; complementarity of the grazing patches and livestock water sources. Chapter seven deals with the household perceptions of the complementarity of the different areas. It also shows the model simulations that indicate the livestock patterns that can be expected under different rainfall trends.

Summary

The theoretical framework of the research is based on the new thinking about rangeland management. Carrying capacity and grazing capacity are defined. Though they overlap and are often confused, they are separated for the purposes of the study. The CCWA is introduced to refine the carrying capacity. The degradation debate on rangelands is reviewed within the context of Botswana. It was shown that it is difficult to show the existence of rangeland degradation. The study shows the interaction between rainfall, grazing land availability, number of cattle and livestock water availability. The relationship is shown by a systems dynamics modelling. The issue of spatial and temporal scale was highlighted but not resolved within the present study. The seven areas in which this study contributes to cattle management are spelt out.

Chapter 4. Methods Used for the Study

Introduction

This chapter consists of four sections. Section 4.1 describes the methods used to collect the household data. Section 4.2 reviews the statistical procedure used to break the rainfall data into the components used to predict rainfall. Section 4.3 introduces and details the procedure for the livestock water accessibility and Section 4.4 discusses the strengths and weaknesses of the three methods used in the study.

4.1 The Household Interviews and the Questionnaire

4.1.1 *Household Interviews*

Ninety agropastoral households (HHs) were interviewed in the study area.

The purpose of the interviews was to establish the extent and magnitude of households' livestock ownership and to study the households' livestock management practices in the study area. The researcher conducted most of the interviews. A research assistant did a few after he was trained and observed before he could administer any interviews unsupervised.

4.1.2 *Sampling Procedure*

The study was conducted in five localities within the Tlokweng Sub - District, in the South East District (Figure 2.9). The five were purposively sampled because they are in the region most likely to be affected by the NPAD. The five localities were Radipotsane (code 06-208); Mmamogofu (code 06-204); Ramokobetwane (code 06-210); Terateng (code 06-205); Mabowana (code 06-209). The locality codes used were based on the National Census maps. The localities are classified as lands (CSO, 1993), which means areas where arable cultivation took place. The localities were the strata from which households (HHs) to be interviewed were drawn.

The HHs to be interviewed in each locality were randomly identified from the Central Statistics Office (1991) map. During the 1991 national population census, a metal plate was tagged at a prominent position to identify each household. The metal plate was inscribed with the three numbers. One number was for the enumeration district, another for the locality code and the third for the individual household number. For example, the number 06-204-35 means that the household is in the Enumeration Sub - District 06 that is Tlokweng Sub - District, locality 204 which is Mmamogofu and is household number 35. Using tags was a convenient, systematic and objective way to sample. Table 4.1 summarises the number of households for each locality against the sample size per locality. The intended sample size was 100 households.

Table 4.1. The 1991 Number of Households (HHs) and Sample Size per Locality in the Study Area.

Locality Name	HHs in 1991 (%)	Sample Size (%)
Mmamogofu	63 (43)	38 (42)
Terateng	15 (10)	11 (12)
Radipotsane	22 (15)	09 (10)
Mabowana	13 (09)	09 (10)
Ramokobetwane	33 (23)	23 (25)
Total	146 (100)	90 (100)

Source: Central Statistics Office, 1991; Fieldwork

The Census map is based on the households that existed at each locality in 1991. Some HHs no longer existed in 1996 and new ones were added since then. Most tags were found somewhere within the inhabited compounds. A few tags were seen at abandoned compounds. Some households did not have tags either because they were newly built or, for other reasons, the tag had disappeared. A replacement method was determined beforehand to deal with situations where a tag was not seen or where a tagged homestead was abandoned. The replacement method is described as part of the steps in the sampling procedure.

The Steps in the Sampling Procedure

i) Households within each locality were randomly selected. The households within each stratum, locality, were a simple random sample, except for Radipotsane where all HH were enumerated (see vii).

ii) The sample was taken proportionally to the size of the population for each locality selected. Table 4.1 shows the proportional representation of the sample. The initially intended sample of 100 was reduced to 90 HHs because Radipotsane, which was the last to be enumerated, did not have enough HH for the required number.

iii) Random numbers were used to choose the HHs to be sampled for each locality. Only random numbers within the range of the HH numbers in the locality were used. For example when a random number 134 is drawn, for a locality with 40 households, a new random number was selected.

iv) Households were identified by looking up the numbers of the HH tags which were chosen in the sample. In the event where not all the HH selected for the sample could be located, procedures (v) and or (vi) were followed.

v) Each HH which did not have a tag, was allocated a serial numbers out of which a random draw was made in accordance with the expected frequency of HH number for the locality

vi) The replacement procedure for missing HH was:

- to add 1 to the sample number which needs to be replaced

- if still needs substitution subtract 2 from the resultant number in (i) above
- if further replacement is needed subtract 1

It was never necessary to go beyond the third tier of action for replacement

vii) In Radipotsane there were not enough HH for the required sample of 14 HH, (15 percent of 90). It was necessary to reduce the sample size from 14 to 9, which was virtually all the HH in the locality.

viii) All HH, including those who did not own livestock, were eligible to be sampled. This was necessary in order to understand the context of agropastoralism in the area

ix) At each HH, the respondent was an adult, that is over 18 years, and preferably the owner of the HH. Where the head of the HH was absent repeated calls were made to locate him/her. Inadvertently in a few cases the respondent was not the owner of the HH.

x) All but one of the pre - selected HH accepted to be interviewed. The HH whose respondent did not oblige to the interview was replaced using the method described in (vi) above.

The total sample size is considered adequate for inferences about management issues in the study area. Care should be taken however when disaggregating observations to individual localities for two reasons. Firstly only Mmamogofu had over 30 respondents and secondly although the localities are separate, functionally they are a unit in several respects, as shall be shown in Chapter 7.

In addition to the sample for the Questionnaire interview, other people were identified during the survey for in - depth discussions on the pastoral management in the area (Table 4.4). The choice was based on recommendations from people who know the area or was based on the researcher's assessment. Informal discussion were held with individuals who had been formally interviewed and many others who were not part of the sample but live in the study area. The information from the questionnaires and the in - depth discussions, was used for the conceptual model and the Rain Land Cattle model, which are discussed in Chapter 6.

4.1.3 *Review of the Questionnaire*

A structured questionnaire (Appendix 2) was used for the interviews. The questionnaire was tested during a pilot survey at Letlapeng, a locality within the Sub - district. Some amendments were made after the pilot study. The questionnaire consists of eight parts. Parts 1 to 3 and 8 were administered to all respondents. Parts 4 to 7 were administered to households who hold livestock, (that is those who look after somebody else's livestock) or those who own and look after their livestock. The questionnaire parts are individually described below.

Part 1 Identity of Respondent

The age of the respondent and their relationship to the head of HH were recorded. Names were not recorded in order to give respondents some anonymity that was deemed necessary for the respondents to be free during the discussion. However as the interviewer introduced himself by name, most respondents gave their names too and some insisted that their names should be recorded. Though not required, the respondents names were noted on the questionnaire and they proved useful when cross checking information about the livestock holding against the official governments records. As the fieldwork progressed the researcher came to know the respondents by name as well anyway. It was important to find out how long the respondent had lived in the area because it determines their familiarity with the area.

Part 2. Pastoral Production Units (PPU's) Background

One question was asked to determine the HHs livestock holding. Although the information on the number of sheep, donkeys and horses was obtained, HHs held so few that they were ultimately excluded from the data analysis. The other question asked for the locality code and name, which were obvious from the code, but both were used as cross checks. The third question was used to find out if some or all livestock were kept elsewhere away from the study area.

Part 3. Household Involvement in Arable Agriculture

It is common for Botswana cattle owners to be agropastoralists. They view cattle rearing and crop production as complementary activities and a safeguard against drought. In a single year of drought, crops are likely to fail but cattle may lose weight without dying. Most arable fields in the study area were located in an enclosed area. In the study area HHs have a peculiar system where they hold three fields as described in Section 2.6.2. An attempt to record the hectarage of **lesope** and **segotlo** fields during the survey was not successful. Households knew the size of the **tshimo** reliably because government extension worker had measured fields during the last ploughing season as part of a government aid package through which farmers were paid for the cost of ploughing their fields. When in doubt, the farmers quickly referred to the official record of the field size. Alternatively the farmers were encouraged to say how much they were paid for ploughing, from which it was possible to work out the size of the field.

Part 4. Grazing Management Strategies

The context of the five questions in this section was not intuitive to the respondents. The interviewer had to explain the context. For example respondents confused a drought and the seasonal dry season. Therefore it was necessary to differentiate between the annual dry season and drought, although there was a forage shortage during both. A drought was defined as a prolonged period of forage and water shortage that lasts for a year or more during the rainy season. The annual dry season was the winter season. The respondents were asked to describe the characteristics of the other areas that livestock used during periods of drought.

Pre - coded responses, derived from the pilot study, were used for Questions 15 and 16. Question 17 was ultimately found redundant as it was answered during the responses in Question 16.

Part 5. Livestock Water Management Strategies

Part 5 was covered by seven questions. One part deals with water during the dry season and drought and its characteristics. During the dry season livestock water is not freely available, therefore a question about the cost of livestock water was included. The water obtained from non communal sources was classified on how often it is available (reliable), how easily it is available (convenient) and how much it costs to maintain, purchase, or buy (cost) in the opinion of the user. Question 24 cross checked Q21 for consistency on water costs.

Part 6. Livestock Movement as a Management Strategy

Questions 25 and 26 were not filled out because the individual herd movements could not be recorded on a questionnaire. Individual herds were not followed either. A general picture of the movement of cattle herds was drawn based on the average distances between water points from a central location of the five localities. A discussion on livestock movement takes place in Section 4.1.6. Question 27 validated Question 7. For example, a HH might not hold livestock in other areas and yet livestock may move temporarily to some areas for grazing. On the other hand, a HH which has kept cattle elsewhere may confirm where their cattle are grazed.

The questions 28 to 31 investigated the respondent's perception of changes in livestock movement within their grazing area. Question 32 and 33 probed the respondents' view of the significance of livestock movement in the area. Questions 34 to 36 dealt with the respondents' perception of the adequacy of livestock movement in the area. The Questions 28 to 36 were not restricted to livestock owners since all people in the area could hold a view on livestock movements.

Part 7. Household Livestock Outputs and Herd Utilisation

Question 37 to 40 established the household's herd utilisation pattern for the past 12 months. The pattern indicated the HHs' livestock uses. Detail was obtained about the HHs' sale of livestock, offtake, which is an important aspect of livestock management. Questions about milk quantity were abandoned because when the survey took place most cows were not milked therefore it was not possible to measure the milk amount consistently. Livestock draught power was not used in the area therefore the question on draught power was irrelevant.

A record of calves during the past 12 months (Question 41) was collected where possible. But the data were sporadic and therefore overall doubtful. The data were difficult to reconcile with the official livestock statistics although the reliability of the cattle data from the government is not beyond doubt either.

Part 8. Fencing Aspect of the National Policy on Agricultural Production (NPAD)

The questions 43 and 44 solicited views on the possible effects of the NPAD. The other five questions, Question 45 to 49, were used to find out how the respondents view the problems of livestock production in their area and what they felt could be done to solve their problems. The later questions were important because the HHs and national policy makers may have different perceptions. Questions 46 and 48 were to find out if the respondent thought there was a land or cattle problem in their area. The contrast between the responses to Questions 46 to 48 gave an opportunity to capture the locals' view of the problem. The interpretation to Question 46 to 48 is related to Question 28 to 36.

General Remarks

The administration of the questionnaire was successful. All the ninety questionnaires were used for the analysis. The questionnaire was a compromise between an open ended and a pre coded structure. Open ended questionnaire answers for a big sample may be too varied and difficult to handle. On the other hand, a pre coded questionnaire can be restrictive when a variety of responses are possible. A blend of open and pre coded responses was considered ideal in this case.

4.1.4 *Analysis of Questionnaires*

The Data Structure

The questionnaires were given serial numbers to identity them and make it easy to refer back to the questionnaires. The questionnaire data was processed in two stages. Firstly similar responses were given a numerical code. The code book is attached in Appendix 3. The code book has four columns which are the questionnaire number, the field number, the field code and the response code. The questionnaire number identifies each questionnaire. It is a serial number between 1 and 90. After the questionnaire numbers there is the question number. The question number is the number of the question on the questionnaire. There were 49 questions therefore the question numbers are 1 to 49. The next column on the code book is the field number which shows information about the questions. A question may have one or more field numbers. Question 6, was sub divided into three field numbers to represent information on cattle, goats and sheep. There were 80 fields for the 49 questions. The sub division meant that a coded answer might not be easily related to the question number without reference to the code book. The next column shows the field code is the abbreviated form of the question. For example, the Question 6 field codes were cattle, goats and sheep. MS Access restricted the field code names to eight characters, hence some field codes such as "lngthstay" for length of stay, were abbreviated. The last column shows the response code given to similar responses. For example the response "yes" was coded 1 while "no" was coded 2. Numerical responses, such as number of cattle owned, the actual number given was used as a response code. The responses obtained for each field were coded according to their variation. In cases when there were many different responses for a field, such as Question 12, they were grouped before coding. In such a case it was necessary to obtain an overview of the variety of the responses before they were coded so that logical codes which adequately represent the variety were used. It was necessary for the codes to these varied responses to be revised several times to suit the analysis of the questionnaire for each field. For example, in Question 18 Field 28, some cattle water sources in the questionnaire turned out to be not as popular as others. The responses with a low frequency of occurrence were categorised as others, while those with a very high frequency were subdivided so that they could stand out. The response codes used are the outcome of an iterative process. After the questionnaire data entry into Microsoft Access, it was converted to Minitab for better statistical analysis. The coded questionnaire data is appended as Appendix 8.

Questionnaire Outputs

The questionnaire outputs were Minitab cross tables. The cross tables were either constructed directly from the field codes (Table 4.2) or classified further. The further classification reduced the low frequencies which occur in Table 4.2 or was used to change the field codes into headings suitable for the cross table. Table 4.3 shows that the reclassified output is easier to read than the output of Table 4.2. The Minitab reclassification of data was done using a the following Minitab function:

Original Code → Manipulate ⇒ Code ⇒ Use Conversion Table → New Code

The age of respondents in Table 4.3 was coded to show code 1 for 20 to 40 years old; code 2 for 41 to 60 years; code 3 for 61 to 80 years; code 4 for 81 to 100 years and code 5 for 100 to 120 years old. The compact format of the Table 4.3 was preferred to the lengthy and cumbersome output of Table 4.2. The locality codes are explained in Section 4.1.2 and the code book.

Table 4.2 Minitab Output Data Showing Respondents Age and Locality

Rows: Age Columns: Locality

Age	204	205	208	209	210	All
23	0	1	0	0	0	1
31	0	0	0	0	1	1
35	1	0	0	0	0	1
39	1	0	0	0	0	1
42	0	0	0	0	1	1
46	1	0	0	0	1	2
47	1	0	0	1	0	2
48	0	0	1	0	0	1
49	0	0	0	0	1	1
50	1	0	0	0	0	1
54	1	1	0	1	0	3
55	0	0	0	0	1	1
56	2	0	0	0	0	2
57	1	0	0	1	1	3
58	0	0	0	0	1	1
60	3	1	0	0	0	4
61	1	0	0	1	0	2
62	2	0	1	1	0	4
63	0	2	2	0	2	6
64	2	0	1	0	1	4
65	3	1	0	0	0	4
66	2	0	0	1	0	3
68	0	0	0	0	2	2
69	1	0	0	2	0	3
70	2	0	3	0	2	7
71	3	1	0	0	3	7
72	0	1	0	0	0	1
73	1	0	0	0	1	2
74	1	0	0	0	0	1
75	2	1	0	0	0	3
76	0	0	0	0	1	1
78	0	1	0	1	0	2
80	3	0	0	0	1	4
82	1	0	0	0	1	2
84	1	0	0	0	0	1
87	0	1	0	0	0	1
89	0	0	0	0	1	1
93	0	0	0	0	1	1
94	0	0	1	0	0	1
106	1	0	0	0	0	1
All	38	11	9	9	23	90

Table 4.3 Reclassified Output Data Showing Respondents Age and Locality

Age	204	205	208	209	210	All
1	2	1	0	0	1	4
2	10	2	1	3	6	22
3	23	7	7	6	13	56
4	2	1	1	0	3	7
5	1	0	0	0	0	1
All	38	11	9	9	23	90

4.1.5 *In - Depth Interviews*

In addition to the formal interviews, about twenty five in-depth interviews (Table 4.4) were conducted. In-depth interviews explored detailed issues that could not be captured through the questionnaire. They were also conducted as a follow up to issues raised in the questionnaire interviews or those that may not emerge elsewhere.

Table 4.4 The In-depth Interviewees and Subject of the Interviews

Interviewee	Subject of Interview
Batlokwa Chief Monare Gaborone	Batlokwa history with emphasis on the development of the land problem
Mr Bogatsu - Retired Government borehole operator	Borehole location, ownership and management in the study area
Mrs Pilane – Secretary of the Mmamogofu Water Development Project	The water development scheme, prospects and problems
Mr Makepe – Tlokweng Land Board Chairman (Mr Matlapeng) - Land Board Member	The land Board operations in the study area and the land issues of the study area
A farmer in Mmamogofu A farmer in Majeadikgokong	Check the respondents perceptions (which includes the Mmamogofu farmer) of cattle farming, in the study area and iron out some of the apparent contradictions
Mr Baruti - Livestock Officer at Department of Animal Health and Production office at Gaborone	The study area fell within the officer's area of jurisdiction. He was interviewed on the Livestock Statistics for the study area and livestock production issues in the study area

Table 4.4 continued

Interviewee	Subject of Interview
Ms George -District Officer Lands Mr Kabagambe – District Physical Planner Ms Khudu – District Physical Development Officer	Land Allocation and an overview of the land development in the subdistrict. The land speculation issue was brought up as shown in the Appendix 1
Dr Cavric - Department of Town and Regional Development (DTRP)	The official interviewed had just written a draft of the Tlokweng Village Development Plan
13 Herdboys	Several herdboys were interviewed individually, and as a group, about herding strategies and problems such as drought. They discussed the cattle movements in the study area. The herdboys information was used to cross check the questionnaire respondents information

4.1.6 *Livestock Movements and Livestock Water Points*

One aspect of household management strategies to be studied was to determine the pattern of livestock movements through which cattle cope with the variations in the available resources in the study area and around. McCabe (1985), Abel *et al.* (1987) and Scoones (1990) studied livestock movements in rangelands by following the herd and recording how they use the different landscape or ecological units. Their approach was attempted in the study area but later abandoned for four reasons. Firstly, it emerged that the cattle movements in the area were restricted by fences and generally similar. Secondly, the cattle are not herded in the sense of being followed around. When such cattle are followed around their routine movements are influenced which gives a different picture from their usual pattern. The fact that the researcher was alien to the cattle made the distortion worse. To avoid disturbing the cattle, we tried to visit them at different times of the day to establish their pattern of movements. Even that was difficult because different herds could not be easily isolated at different times of the day. Thirdly, it appeared that the most significant patterns were those from one season to the other rather than the daily movement. Movements during the dry season were characterised by convergence to water points and arable fields for stubble grazing. The different movements are described in detail in Section 2.6. Fourthly the majority of the households did not kraal cattle overnight therefore it was difficult to round them up and make them available for monitoring.

The researcher went to the other localities of the sub-district to find out which cattle use them. In most cases people knew where the livestock came from, whose they were, and would say with some certainty when and why people brought their livestock into an area. Due to the reasons discussed above, livestock movement is represented as a general pattern rather than movement per head. The study settled for general observations of livestock movements supplemented by informal discussions with herd boys. Some of the data on where and why livestock moved, was collected through the questionnaire.

4.2 Statistical Procedure for Gaborone Rainfall Decomposition

The seasonal and annual characteristics of rainfall were described in Section 2.3. This section shows how the rainfall was analysed for trend. Rainfall prediction is important but quite complex in semi arid rangelands. The historical pattern of rainfall for fifty years between 1945 and 1995 was studied in order to understand the trend of rainfall in the study area. Once the trend is known, the rainfall pattern can be predicted. The rainfall prediction, which is an important part of the Rain Land Cattle model described in Chapter 6, is done in two stages. Stage 1 is the rainfall decomposition described in Sections 4.2.1 to 4.2.3. Stage 2 uses the output of rainfall decomposition as an input for the Rain Land Cattle model described in Chapter 6.

4.2.1 *Time Series Analysis for 1945 to 1995 Gaborone Rainfall*

The 1945 to 1995 rainfall data are assumed to have some characteristics that will be repeated in the future, assuming no climatic change. The assumption suggests the data are stationary. A stationary data series is characterised '*in part by a finite mean and a finite variance about the mean which do not change with historical time*' (Jenkins and Watts, 1968:61). We observe that the Gaborone annual rainfall between 1945 and 1995 varies from year to year, it always wanders back to the mean therefore the Gaborone rainfall does not increase or decrease significantly over time. Secondly a stationary time series enables prediction between any two points of the data series irrespective of the origins of the data series (Gottman, 1981). The latter characteristic means that the data series covariance is only a function of the lag between the two points (Gottman, 1981).

Time series data consist of a trend, a cycle and a stochastic element, or noise (Burroughs, 1992). In some cases the data may be made up of only a trend and a stochastic element. The trend is for all practical purpose the mean. It can be determined through the least squares method of regression analysis for rainfall amount against time. A cycle is the spectral waves within the data. Cycles are seldom detected from the raw data, but can be observed after spectral decomposition when its components, which are the phase, amplitude and frequency, are calculated (Gottman, 1981). A cycle maybe deterministic or non deterministic. A deterministic cycle has a memory, through which past events can be used to reliably predict future occurrences. Non deterministic cycles do not have a memory and hence are unreliable for prediction. A deterministic cycle's spectrum peaks at one particular frequency whilst a non deterministic cycle repeats over several frequencies.

The stochastic element, or the noise, is the residual after the trend and the cycles have been removed from a series. Noise distorts the data's spectral signal which makes accurate prediction difficult. Noise in meteorological data can be attributed to two sources, errors in measurement and the non coherent background variability of weather over time (Burroughs, 1992). Bhalotra (1985) suggested that the noise in Botswana's rainfall data are caused by the paucity of records, unreliable data due to changes of recording site locations and unevenly distributed rainfall recording stations. Therefore predicting rainfall will be difficult.

4.2.2 *Fourier Analysis Method and Results*

Fourier analysis, also called spectral or harmonic analysis, is a technique that detects the sinusoidal wave patterns, or cycles, which are often buried in a data series, by using a series of sine and cosine functions (Burroughs, 1992). The data are broken like light to the different colours which make it up (Gottman, 1981) but which would not normally be visible. The oscillations explain the variance of a time series by showing the spectral power of the different data values that are often not intuitively discernible from the data. Spectral analysis, and time series analysis using moving averages and autoregression, were used to decompose the Gaborone rainfall into components parts which could be used to reconstruct the original rainfall trend. Spectral analysis breaks the data into spectral frequencies, also called periodic functions. The periodic function is a cycle whose peak to peak distance is the period. Equation 4.1 shows how the periodic function is derived. The period of the cycle is the time taken for behaviour to repeat itself (Gottman, 1981:9), which may be measured in any time units. The period is measured in years in the present study therefore the frequency in this case tells us how many years it takes to repeat a specific rainfall characteristic, be it very low or very high rainfall.

Equation 4.1. The Calculation of the Periodic Function

$$f(t) = f(T + t) \text{ where:}$$

f(t) is periodic function
f is frequency
t is time
T is period (1/f)

Source: Gottman, 1981:14

The rainfall was observed for 50 years, which represents (t). The complete formula used to decompose the Gaborone rainfall data is shown in Equation 4.2.

Equation 4.2 Fourier Decomposition

$$X(t) = \bar{X} + \sum_{n=1}^{n=N/2} \left[A_n \sin\left(\frac{2\pi t}{P}\right) + B_n \cos\left(\frac{2\pi t}{P}\right) \right]$$

where:
$\bar{X}$ is mean of series
X(t) is data series under study
A_n is coefficient for sine wave
B_n is coefficient for cosine wave
N is total number of harmonics (integers 1 to N/2)
P is fundamental period
t is time at which harmonic is reached

Source: Burroughs 1992:175: Jenkins and Watts, 1968.

In Equation 4.2 the coefficients An (cosine) and Bn (sine) show the wave amplitude which is the shape of the cycle. The mean of the data is the least square estimate for the data series. The harmonics are multiples of frequencies (n/N) where the total number of harmonics is given by N/2 (see Table 4.5). The power, or variance, of each harmonic is the sum of the sine and cosine functions

Table 4.5 Meaning of Frequency, Harmonics and Years out of 50

Years out of 50	Frequency (Fraction)	Frequency (Years)	Harmonic
1	0.02	1 in 50	1
5	0.1	5 in 50	5
10	0.2	10 in 50	10
25	0.5	25 in 50	25

The Table 4.5 shows that Harmonic 1 means an occurrence frequency of 1 in 50 years and Harmonic 25 is 25 years in 50 years , which is equivalent to a frequency of 1 in 2 years.

4.2.3 Results of the Gaborone Rainfall Time Series Analysis

Based on the principles of Fourier analysis, the Gaborone rainfall data was decomposed into a periodogram shown in Figure 4.1.

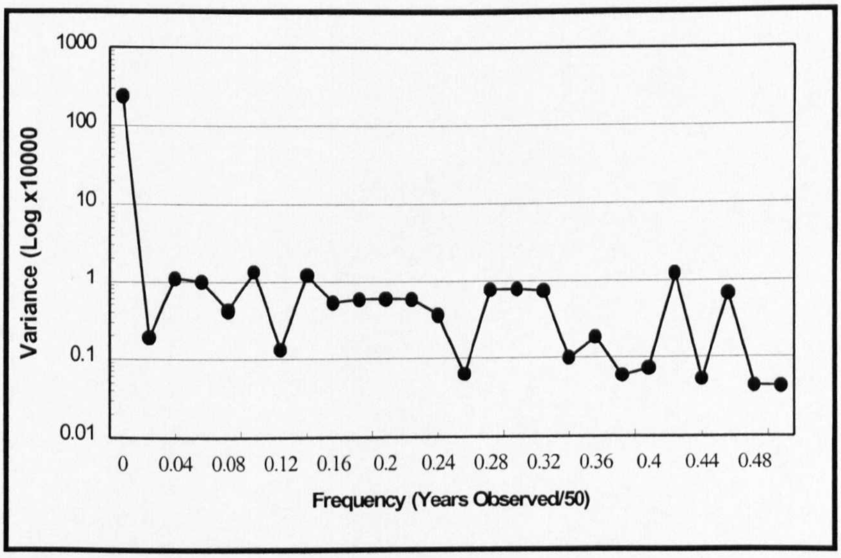

Figure 4.1 Gaborone Rainfall Spectrum 1945 to 1995

Removing the Trend

The rainfall was regressed against time to obtain a trend value of 520 mm which is the dominant spike in Figure 4.1. The trend value has a low standard deviation of 2.12.

The trend value, the mean, was deducted from the annual rainfall data for Gaborone. Visual inspection shows that the pattern of the rainfall values, after the removal of the trend, is similar to the one before the removal of the trend, but with more negative values in the earlier (Figure 4.2). However the periodogram of the rainfall cycle in Figure 4.2 had no variance at zero frequency and consisted of two thin spikes, one at frequency 0.1 and the other at 0.42. both with a power of around 8000. It had a wide peak between frequencies 0.28 and 0.3 with a power of 4000 units. Because the cycle has both spiky and a broad peak, it represents the continuum between a deterministic and a non deterministic trend (Gottman, 1981:98) which further confirms the observation that after the removal of the trend the remainder of the data is predominantly noise.

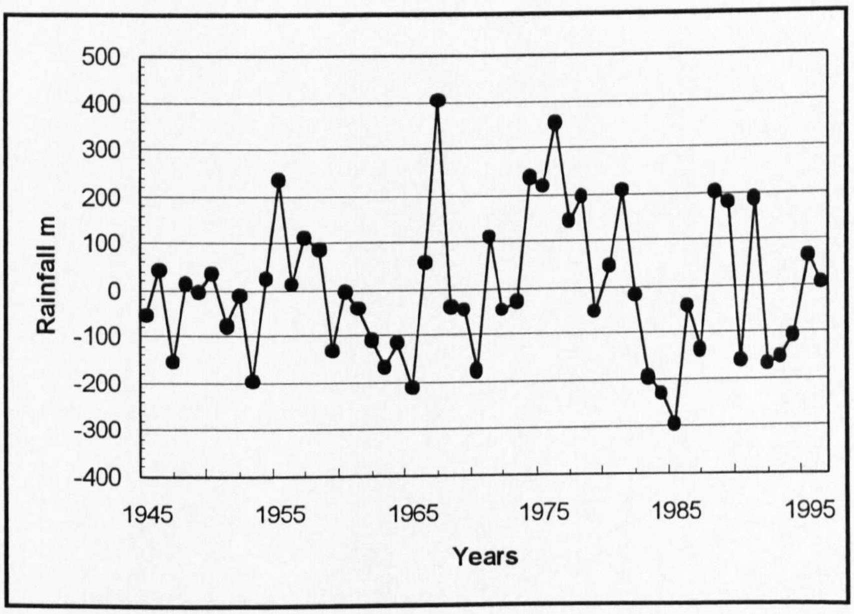

Figure 4.2 Gaborone Rainfall Less the Trend (1945 to 1995)

Table 4.6 summarises the periodogram values for the trend shown in Figure 4.2. An attempt to remove the trend shown by the peaks yielded anomalous residuals with more spectral power than the original series which confirmed that the spectral analysis had reached its furthest point and what remained was mostly noise.

Table 4.6 Summary of the Spectral Variance for Gaborone Rainfall Less the Trend (1945 to 1995)

Frequency	Trend of the Variance
0.04 to 0.1	around a variance value of about 10 000
0.14 to 0.24	generally stable variance after a decline from around 10 000 variance units
0.28 to 0.32	stable trend with similar values to those found at the frequency range of 1.4 to 2.4
0.34 to 0.40	low value variance trend at about 1000 variance units
0.4 to 0.5	highly variable trend oscillating between 1 000 and 10 000

The values of the detrended rainfall suggest that it was noise because its mean is next to zero (-0.43) and the phases for the rainfall at that stage do not show a distinct trend. The Autocorrelation function[1] (ACF) declines to zero after lag 2 (Table 4.7).

Table 4.7 Autocorrelation Function (ACF) for Gaborone Rain Less Mean 1945 - 1995

Lag	ACF	Lag	ACF
1	0.27	7	-0.02
2	0.12	8	-0.12
3	-0.00	9	-0.03
4	-0.18	10	-0.00
5	-0.09	11	-0.06
6	-0.12	12	-0.03

The ACF value at lag 1 (0.27) is not significantly different from 0 since it is less than 0.28, which is the cut off point for significant lag values for 50 data items according to the Bartlett's formula $\left[\left(2/\sqrt{N}\right) = 0.28\right]$ (Gottman 1981:67). Other values for the ACF are essentially zero. It was concluded that the rainfall data have a linear, or

[1] Autocorrelation assumes that a data series consists of correlated neighbouring values. The Autocorrelation function

almost a linear, trend superimposed on a stochastic element (Box and Jenkins, 1970; Gottman, 1981).

The Autoregressive Process

Moving averages were used to decompose the time series further. In this case, since it was not easy to remove the spectral peaks after detrending the data, an autoregression was opted for. The Auto Correlation Function dips to zero after lag 2, therefore the series best approximated by an Auto Regression of Order 2 (AR2) with 3 steps ahead as described by Gottman (1981). An AR2 means that the model uses the past two years data to forecast the third year. AR process with steps enables the forecasting to be recursive, initially using estimates of the ACF coefficients and then incorporating the realised outputs as true data. The formula for the process is shown in Equation 4.3. Using Equation 4.3 with the values of a_1 and a_2 as 0.27 and 0.12 respectively, and those of a_3 and a_4 values as 0.57 and 0.18 respectively, the detrended data were auto regressed with three steps, as the most suitable model to depict the data series trend.

Equation 4.3 The Auto Regressive Equation with 3 Steps Forward

$$\hat{X}_{t+3} = \left(a_1\hat{X}_{t+2} + a_2\hat{X}_{t+1} + \ldots + a_3\hat{X}_{t+1}\right) + \left(a_3X_t + a_4X_{t-1} + \ldots + a_2X_{t+1}\right)$$

where:

$\hat{X}_{t+3}$ is the estimate for a given period + 3 steps (time) forward

a_1, a_2 is auto correlation coefficients for lag1 and lag 2

a_3, a_4 is auto correlation coefficients for the second use of data which has incorporated the initial estimates into the true data

$Xt-1$ is the real data one step back

Source: Gottman, 1981:273

The Autoregressive component (Figure 4.3) was removed from the detrended rainfall data to obtain the residual.

The Residual

The residual is the last component after detrending. The periodogram of the residual had a peak at frequency 0.42 that persisted from the previous stages. The frequency 0.42 represents an occurrence of 1 year in 2.38 years, which tells us that there was a high frequency disturbance over the normal cycle, which was stochastic, in 1 out of 2.38 years. The frequency could explain the occurrence of an unusually wet year during a drought spell and vice versa. The residual was removed from the stochastic component using a moving average of the order 3.

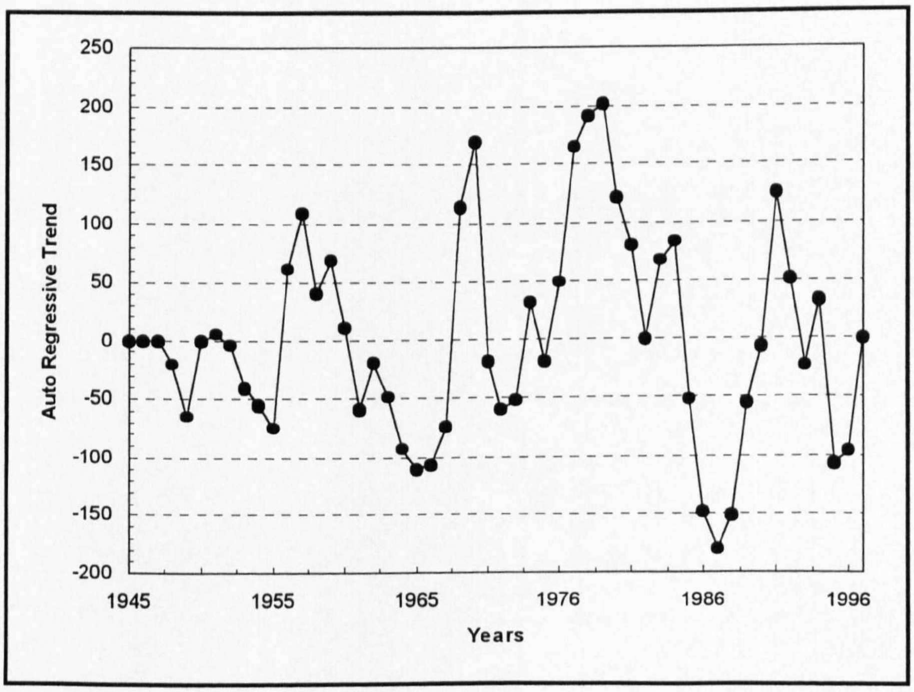

Figure 4.3 The Auto Regressive Process (Order 2 with 3 steps) for Gaborone Rainfall 1945 to 1996

The statistical procedure shows that the rainfall consists of four components which are the Mean, the Autoregressive trend, the Moving Average and the residual (stochastic). Section 4.4.2 discusses the accuracy of the rainfall decomposition procedure.

4.3 The Livestock Water Availability Index Procedure

The rainfall decomposed according to the method in Section 4.2 is used to determine the livestock water availability. Existing definitions of grazing capacity and carrying capacity (Section 3.2) do not include the availability of livestock water hence they are more readily suitable for temperate regions, where livestock water is not a limitation, than for semi arid conditions. Lack of livestock water is a constraint to the use of rangelands in semi arid regions. The Rain Land Cattle model, described in Chapter 6, integrates the livestock water availability into the carrying capacity.

The rainfall amount for the current and last year, known as RF Weighted in the model, (Section 6.4.5), was grouped into three classes which are represented by the rainfall multiples in Table 4.8.

Table 4.8 Rainfall Description, Amount (RF Weighted) and Multiple in the Model

Rainfall Description	Rainfall (mm.)	Rainfall Multiple
Below Normal	< 675	0.5
Normal	675-975	1.0
Above Normal	>975	1.5

The rainfall figures in Table 4.8 were based on the assumption that if the mean annual rainfall is 520 mm, then the mean for RF Weighted [520 + (0.5 x 450)] is 780. A range that straddles the annual mean, 450 - 650 mm, equivalent to a RF Weighted range of 675 - 975 mm, represents the normal annual rainfall range. Values which are more than 975 mm are Above Normal and those less than 675 are Below Normal.

4.3.1 *Identification of the Water Sources Holding Capacity*

Sixteen water points were identified in the field and classified according to their water holding during a normal season. The livestock water sources which were repeatedly mentioned during the interviews, were identified and monitored for water holding during the fieldwork. The observations were supplemented by information gathered from the in-depth interviews. This type of information gathering was necessary as the average rainfall during the fieldwork year could not be extrapolated beyond that year. Table 4.9 shows the water holding, which is defined as the number of months during a normal rainfall year when a water point can be expected to hold water.

Table 4.9 Types of Livestock Water Sources; Based on 1995 Observations

Map Code	Category	Water Source Name	Water Holding	Frequency
Bh1 - Bh5	1	Boreholes (Table 4.14)	8	5
11		Perennial Notwane		1
1	2	Mmamogofu/Lephala	6	1
2	3	Mmakgaila	4	4
3		Hekeng		
4		Peterose		
5		Modipe		
6	4	Terateng	2	5
7		Letlapeng		
8		Tlokweng		
9		Seasonal Notwane		
10		Seasonal Notwane		

The water holding is discussed in Section 4.3.2. The map codes are used to identify the water points in Figure 2.7, and Figure 4.4 to Figure 4.7. Frequency is the number of water points of a certain water holding, in the study area. The water sources were grouped according to their water holding into four categories. Category 1 is the highest water holding and Category 4 is the lowest water holding. Water source name is the name of the water source used by the people in the study area. Table 4.9 shows the characteristics of the livestock water sources. Boreholes in Category 1 are described further in Table 4.14. The "perennial" Notwane River holds water for eight months and was counted as one water source. Mmamogofu, also known as Lephala, (Plate 6) is a natural pool that was deepened and is now commonly regarded as a dam. Modipe and Hekeng, Category 3 sources, are disused burrow pits[2] while Mmakgaila and Peterose are natural water collection points with an impermeable surface. Terateng and Tlokweng are culverts. Letlapeng is a silted dam site and "seasonal Notwane" is an area where the river dries up. Its 10 km length was regarded as two water sources based on a 5 km radius.

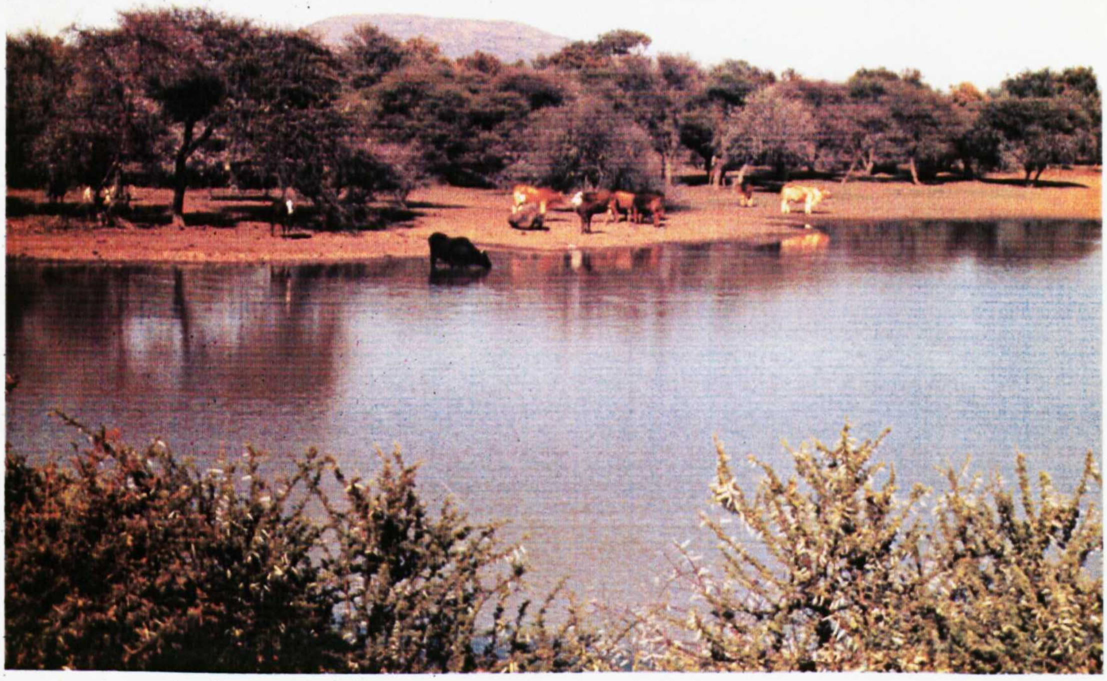

Plate 6 Cattle watering at Mmamogofu, which holds water for six months

[2] a burrow pit is an abandoned hole, which was dug to collect aggregate, into which rain water collects.

4.3.2 *Determining the Livestock Water Holding from the Rainfall Multiple*

It was assumed that livestock water is not a limiting factor for cattle management during the four months rainy season and therefore the critical water holding is the 8 months dry period. Table 4.10 shows the 8 months is divided into four time groups of 2, 4, 6 and 8 water holding months. In reality the water holding months are continuous rather than discrete, therefore they were modified into water holding bands. Table 4.10 shows how the Rainfall Multiple influences the livestock water holding (see Section 6.7.3) by changing the water holding capacity of a livestock water source. The principle used in Table 4.10 is that water holding improves during an above normal rainfall, which is represented by a Rainfall Multiple of greater than unity.

Table 4.10 The Resultant Livestock Water Holding for Varied Annual Rainfall.

Water Holding in Normal Year	Water Holding Bands	Resultant Seasonality for Rainfall Multiple		
		0.5	1.0	1.5
2 months	≤2	1.0	2.0	3.0
4 months	>2 to ≤4	2.0	4.0	6.0
6 months	>4 to ≤6	3.0	6.0	9.0*
8 months	>6 to≤ 8	Exogenous Sources		

(* *the water holding of 9 is equivalent to the maximum of 8 months*)

The water holding deteriorates during a below normal rainfall year, which is represented by a Rainfall Multiple of less than unity. The product of the water holding band and the rainfall multiple is the resultant seasonality. In reality the situation is more complicated because:

i) the water holding period may be staggered due to the variable timing of the rainfall

ii) the wet season may have periods of livestock water shortage contrary to the assumption that it has an adequate supply of water throughout

Both circumstances (i) and (ii) are not represented in the determination of the water holding months in this study.

The resultant seasonality varies between a minimum of 1, when a 2 months water holding source has below normal rainfall, and a maximum of 9.0, taken to be the maximum of 8 months when a 6 months water holding point has above average rainfall. The change in the number of water sources due to rainfall is discussed in Section 4.3.3 (see Table 4.11).

4.3.3 *Number of Livestock Water Points During a Rainfall Season*

This section shows how the change in the number of livestock water point is represented for different rainfall amounts. The number of water points influences the stocking density around water points. During a dry year there is a high stocking density around the fewer livestock water points than during a wet year, and vice versa. In the study area, the stocking density varies during a dry year due to differences in livestock water accessibility. For example, boreholes are not accessible to all livestock. When convenience (represented by the distance livestock walk to a water point) is accounted for, the stocking density picture becomes more difficult to generalise. Expected distribution of livestock water points during the different rainfall conditions is shown on Table 4.11. The table shows there are fewer livestock water points during a below normal rainfall year than during the normal and above normal rainfall years. This is because all livestock water points hold water for a shorter period during a below normal rainfall year. The exception is boreholes and the "perennial" Notwane River, which are Category 1 water points, whose source is exogenous to the rainfall simulated in the model. The Category 1 livestock water points hold water for the whole dry season at all times. The water points which hold water for two months during a normal rainfall year, Category 4 livestock water points dry up during a below normal year.

Table 4.11 The Number of Livestock Water Points During Different Rainfall Occurrences

Water Points Category and (Frequency)	Livestock Water Holding Months for Different Annual Rainfall											
	Below Normal Rainfall				Normal Rainfall				Above Normal Rainfall			
	2	4	6	8	2	4	6	8	2	4	6	8
1 (6)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2 (1)	✓	✓	×	×	✓	✓	✓	×	✓	✓	✓	✓
3 (4)	✓	×	×	×	✓	✓	×	×	✓	✓	✓	×
4 (5)	×	×	×	×	✓	×	×	×	✓	✓	×	×
Total (16)	11	7	6	6	16	11	7	6	16	16	11	7

Notes: ✓ Water source available; × Water source not available

A total of seven livestock water points, the least number in the study area during the above normal rainfall year, hold livestock water for eight months. All water points (16) hold water for four months during the above normal rainfall year. This contrasts with the 11 and 7 livestock water points which hold water during the normal and below normal rainfall years, respectively. The six water points which hold water for 8 months, do not change much between the different rainfall years because they have exogenous sources. Mmamogofu Dam, the only category 2 water source, holds water throughout the dry season during the above normal rainfall. This water source was desilted in 1995 through a government assisted scheme. The fact that households referred to it as a perennial source of livestock water confirmed its significance. Though the changes in the frequency and water holding of water points during the different rainfall years shown in Table 4.11 are simplified, the underlying relationship is valid.

4.3.4 *Ideal Number of Water Points in the Study Area*

The distribution and seasonality of the livestock water points can be measured against an ideal scale. It was assumed that during below normal rainfall at least 50 percent of the livestock water points should hold water for four months of the dry season. From Table 4.11, we know that 7 livestock water points hold water for 4 months of the dry season during a below normal rainfall season therefore 9 water points do not. A Chi - square test was done to find out whether the observed distribution was significantly different from the expected distribution of livestock water points. The null ($H\phi$) and alternative (H_1) hypotheses for the number of water points which hold water for 50 percent of the time during a period of below normal rainfall were drawn as follows:

$H\phi$ **is** Observed number of water points = Expected number of water points

H_1 **is** Observed number of water points ≠ Expected number of water points.

Table 4.12 shows the result of the Chi square.

Table 4.12 Chi Square for the Number of Livestock Water Points for Different Rainfall Occurrences

	Water points			
Description	No Expected	No Observed	[Sum $(Exp - Obs)^2$]/E	χ^2
≥ 50% of time	8	7	1	0.25
< 50% of time	8	9	1	

Source: Fieldwork

A χ^2 of 0.25 is less than the critical value of 6.64 ($\rho = 0.01$; at 1 d.f.) therefore $H\phi$ cannot be rejected in preference of H_1. The finding means that the number of livestock water points during a below normal rainfall year was not statistically different from an ideal distribution. We therefore conclude that the study area does not have a shortage of livestock water points during a below average rainfall year. This conclusion based on the Chi square test is likely to mislead because access to some sources is restricted.

4.3.5 *The Livestock Water Months (LW Months)*

This study developed a measure called the LW Months (Equation 4.4) to represent the total livestock water holding in the study area (see Livestock Water Equation 6.5).

Equation 4.4 The Livestock Water Months (LW Months) for the Study Area

$$\text{LW Months} = \sum\left[\text{Seasonality}\begin{pmatrix}\text{Boreholes} + \text{Cat2} + \text{Cat3} + \text{Cat4} + \\ \text{Notwane Seasonal} + \text{Notwane Perennial}\end{pmatrix}\right] \quad \text{where:}$$

LW Months is Livestock Water Months
Cat2 is 6 months water holding sources
Cat3 is 4 months water holding sources
Cat4 is 2 months water holding sources
Notwane Seasonal is 2 months water holding sources
Notwane Perennial is 8 months water holding sources
Boreholes is 8 months water holding sources

The LW Months, which shows months of water holding, is minimum when the least amount of rainfall is experienced and maximum when the highest amount of rainfall is experienced. The temporal scale at which the LW Months is measured influences the accuracy of the LW Months. The LW Months will be more precise on a fine temporal scale than a coarse one. The same is true, to some extent, with the spatial scale. The LW Months fluctuates from one year to the next with the rainfall and the Rain Land Cattle model reflects the variation. The LW Months was used to calculate the Carrying Capacity Water Availability Ratio (CCWA Ratio).

4.3.6 *The Carrying Capacity Water Availability Ratio (CCWA Ratio)*

In simple terms the CCWA Ratio measures the available livestock water per livestock unit. Equation 4.5 shows a two step procedure to derive the CCWA Ratio. Step 1 derives the LW Months Density, which is the number of water months per area of grazing. LW Months Density can be related to the number of livestock units per hectare.

Equation 4.5 The Carrying Capacity Water Availability Ratio (CCWA Ratio)

Step1. $\text{LW Months Density} = \left(\frac{\text{LW Months}}{\text{Total Grazing Area.}}\right) = \left(\frac{\text{LW Months}}{\text{Hectares}}\right)$

Step 2. $\text{CCWA Ratio} = \left(\frac{\text{LW Months Density}}{\text{Carrying Capacity}}\right)$

Therefore: $\left(\frac{\text{LW Months}}{\text{Hectares}} \times \frac{\text{Hectares}}{\text{LSU}}\right) = \left(\frac{\text{LW Months}}{\text{LSU}}\right)$

where:

LW Months is Livestock Water Months
CCWA Ratio is Carrying Capacity Water Availability Ratio
LSU is Livestock Units
Ha is Hectares

A high LW Months Density is when there are many LW Months per small area. It occurs when an above average rainfall is experienced and represents good livestock water availability. A low LW Months Density occurs when there are few LW Months per area, which is during below average rainfall years. Other factors that could affect the LW Months such as soil characteristics, local relief, evaporation are not accounted for in the Equation 4.5. Step 2 introduces the CCWA Ratio, to relate the LW Months Density to the carrying capacity. Because the LW Months Density measures how many water months there are per area, and the carrying capacity measures the number of livestock units per area, it is possible to calculate the number of water months per livestock unit.

Table 4.13 shows the meaning and limits of the CCWA Ratio for this study. The CCWA Ratio may change through two ways. Firstly, it deteriorates when the LW Months Density declines either due to the increase in the grazing area or decline in the rainfall. On the other hand, the CCWA Ratio improves when the grazing area decreases or the rainfall improves.

Table 4.13 The Limits of the CCWA Ratio in the Study Area

LW Months Density	CC Ha LSU^{-1}	CCWA Ratio	Remarks
104.17	9.96	10.46	Poor LW Months density, worst CCWA Ratio
123.13	14.06	8.76	
97.6	15.34	6.36	Good LW Months density, good CCWA Ratio
113.08	16.26	6.96	
92.82	14.98	6.20	
91.44	16.03	5.70	Best LW Months Density, best CCWA Ratio

Secondly, the CCWA Ratio deteriorates when the CC for a given LW Months Density improves. An improved CC implies more LSU per area. If the LW Months Density does not improve with the CC many LSU share the water supply which may lead to a water shortage. According to Table 4.13 the best CCWA Ratio of 5.7 LW Months LSU^{-1}, was obtained when the CC was 16.03 Ha LSU^{-1}, which occurred with the best LW Months Density of 91.44 Ha LW Months. The worst CCWA Ratio, 10.46 LW Months LSU^{-1}, occurred with a poor LW Months Density of 104.17 Ha LW Months and the CC was 9.96 Ha LSU^{-1}. The annual rainfall changes and the grazing land loss affect the CCWA Ratio. The variable rainfall causes the CC to fluctuate and the grazing land loss affects both the CC and the LW Months Density. The CCWA Ratio values shown in Table 4.13 are only valid for this study. Different figures should be determined for each study area.

The CCWA Ratio in this study is exploratory for two reasons. Firstly, like the CC that it seeks to improve, it is a mathematical average for conditions that are usually more varied in the field. Secondly, in this study it is based on an estimated livestock water holding capacity from which we infer the quantity of water available rather than a measurement of the water quantity. However, it can be improved by including data from detailed rainfall observations and water holding capacity for the different water sources.

4.3.7 *Livestock Water Points Access and Availability*

Cattle have unrestricted access to most livestock water sources in the study area except boreholes. Table 4.14 shows the identity, ownership and use of the boreholes.

Table 4.14 Borehole Identification, Operation and Nature of Use

Map Code	Borehole Name.	Ownership	Main Use
Bh1	Mmakgama	Syndicate	Livestock
Bh2	Steve's Syndicate	Syndicate	Livestock
Bh3	Morui	Private	Livestock
Bh4	Mabutswe Syndicate	Syndicate	Livestock
Bh5	Mabutswe Village.	Local Government	Mixed

Source: Fieldwork

Three of the five boreholes are owned by a syndicate. A syndicate is a borehole management organisation, developed in the Kgatleng District, whose rationale is to supply funds to manage a borehole and introduce some accountability (Peters, 1994). The local authority runs one and the fifth is privately owned and operated. Four of the five boreholes are used mainly for livestock watering and the local authority operated borehole has mixed use. Access to syndicate boreholes is through the syndicate membership or payment of a fee for watering rights. The membership and watering rights fees were administered with laxity such that herds for non members were allowed to water as long as they were with the herd of a recognised paid up member. None of the boreholes had a register of the number of cattle watered per member, hence it was difficult to establish how many cattle watered per borehole. It was even more difficult to establish how many cattle water in the open communal water points such as Mmamogofu dam. Consequently this study assumed that the cattle were evenly spread amongst the water points when calculating the CCWA Ratio. An even spread of livestock is expected when points are equally accessible.

The water available from a livestock water point can be viewed from two positions, its water holding capacity and the number of water points available. The water holding capacity was described in Section 4.3.1. The water holding of a livestock water point can be more accurately determined over a long period through empirical observations of several variables such as the hydrology, geology, local topography, rainfall, land cover, landuse. Such observations were beyond the scope and means of this study. The three rainfall categories used adequately represent the annual variation in the number of livestock water points in the model but would not show the seasonal variation which may be critical in livestock management. Secondly, water availability can be represented as the number of livestock water points shown in Table 4.11 where fewer water points implies a scarcity of livestock water than many water points.

4.3.8 *Water Source Convenience*

A convenient water source is near to the cattle. A distant water source is inconvenient because grazing time and energy are lost in an effort to reach the water. In the study area convenience also means the ease with which a place can be reached. Due to the fences, some water points are difficult to reach.

Table 4.15 shows the indicators of convenience used for the different water sources in the area. Table 4.15 should be studied alongside Figures 4.4 to 4.9 that show isolines 1 kilometre apart around each water source. The isolines measure the reported spheres of influence, hinterlands, for each water point.

Table 4.15. Convenience of Cattle Water Sources in the Tlokweng Sub - District

Sources (Code on Map)	Indicators of Convenience
Mmakgama (Bh1)	• hinterland up to 10 kilometres from south eastern border of sub - district • easily accessible
Steve's Syndicate (Bh2)	• cut off from most of the study area by the northern arable fields shown in Figure 2.9
Morui (Bh3)	• a 3 kilometre hinterland shown on map
Mabutswe Syndicate (Bh4)	• limited access, about 3 km, due to southern arable fields shown in Figure 2.9 • used by some Mmamogofu and Terateng livestock
Mabutswe Village (Bh5)	• mixed use, discourages livestock watering • up to 4 km sphere of influence
Perennial Notwane (11)	• maximum of 21 km hinterland therefore distance constraint for Mabowana cattle, for example • concerns - "filthy" water and cattle stray into Gaborone city or Kgatleng District
Seasonal Notwane (9 and 10)	• maximum of 16 km from the eastern edge of study area to the river • Tlokweng village partly obstructs access to source for water users away from the village. • cattle stray into Gaborone city
Mmamogofu (1)	• centrally located - about 10 km radius to the borders of the sub - district • unobstructed access for cattle from all directions
Mmakgaila (2)	• used 5 km around source • fields - grazing boundary location therefore risk of cattle damage to crops
Hekeng (3)	• at gate between grazing and arable; popular during seasonal grazing, 5 kilometres radius
Peterose (4) Modipe (5)	• cut off from most of the study area by the northern arable fields • 3 kilometre hinterland
Terateng (6) Letlapeng (7) Tlokweng (8)	• a 3 kilometre hinterland shown on map • used by Letlapeng residents within 1 kilometre radius • used by livestock kept at and around Tlokweng • about 4 kilometre hinterland

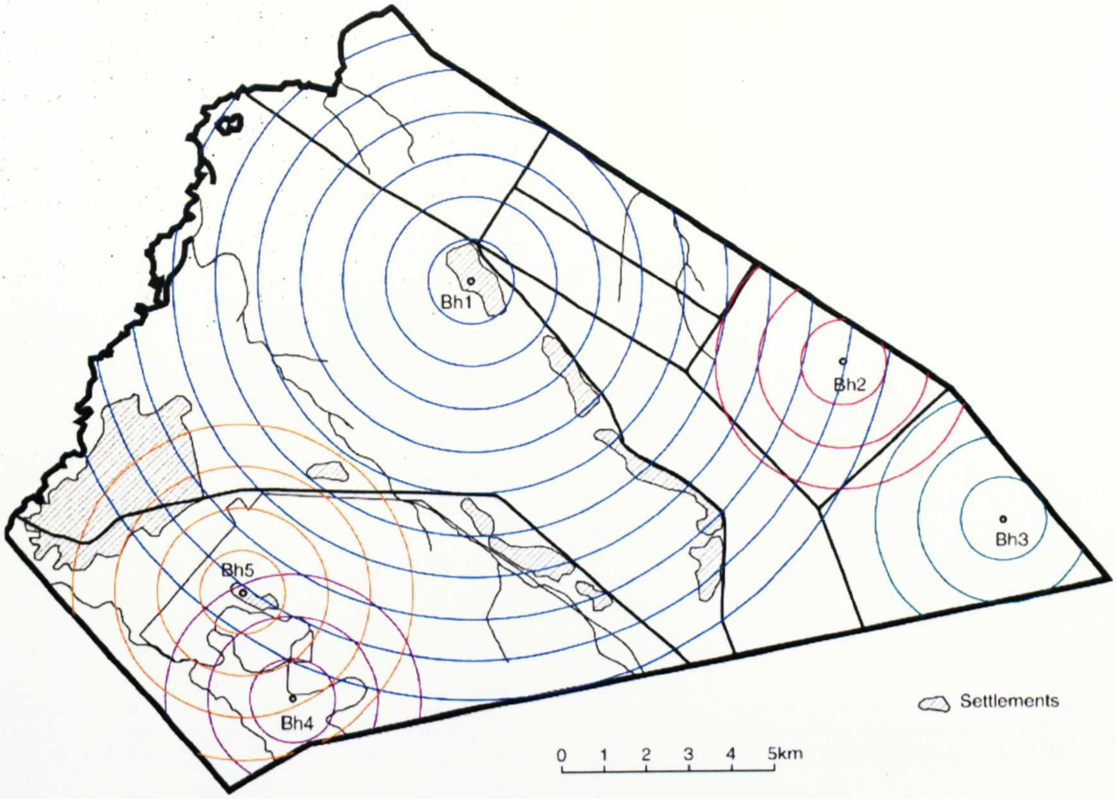

Figure 4.4 Isolines from Boreholes in Tlokweng Sub - District

Note: 1 kilometre isolines

Source: Fieldwork

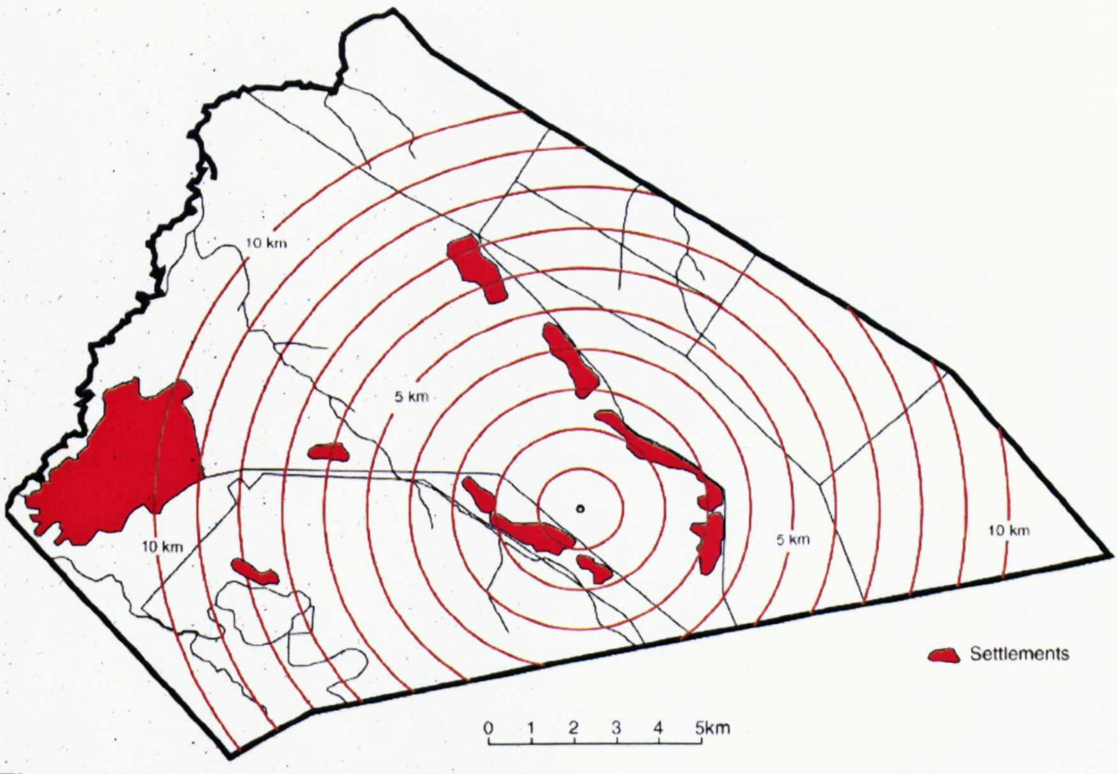

Figure 4.5 Isolines from Mmamogofu Water Source in Tlokweng Sub - District

Note: 1 kilometre isolines

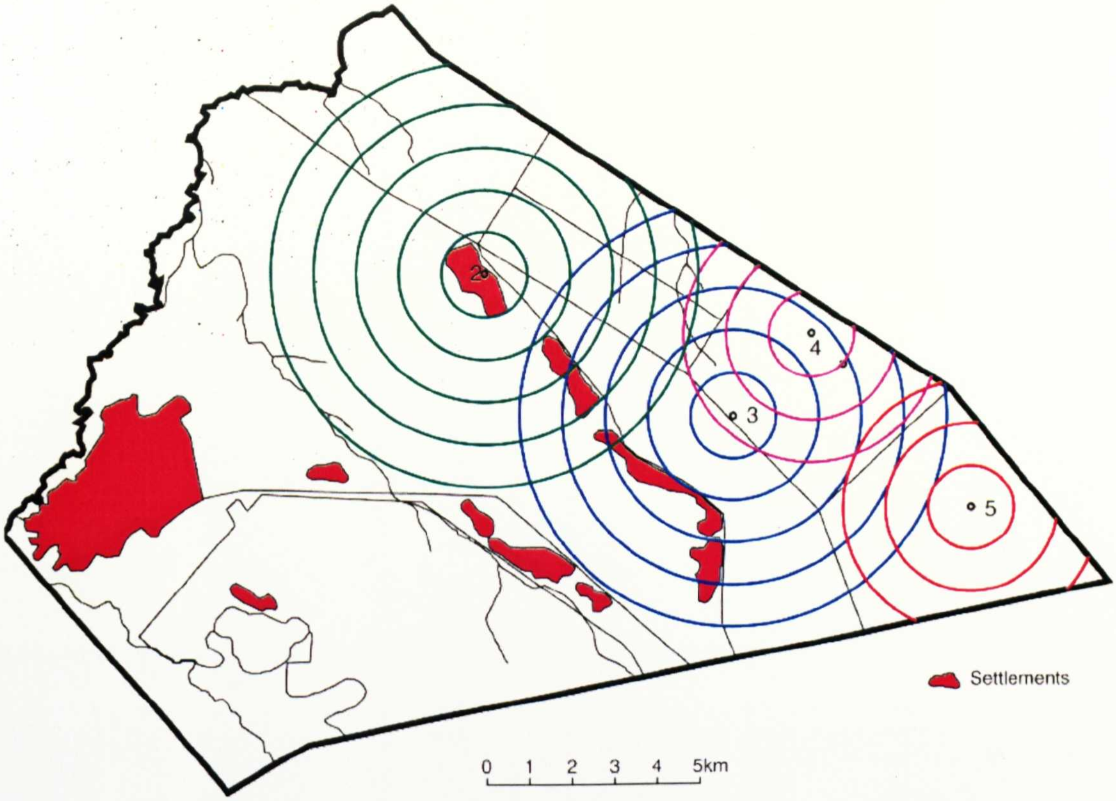

Figure 4.6 Isolines from 4 Months Water Sources in Tlokweng Sub - District
Note: 1 kilometre isolines

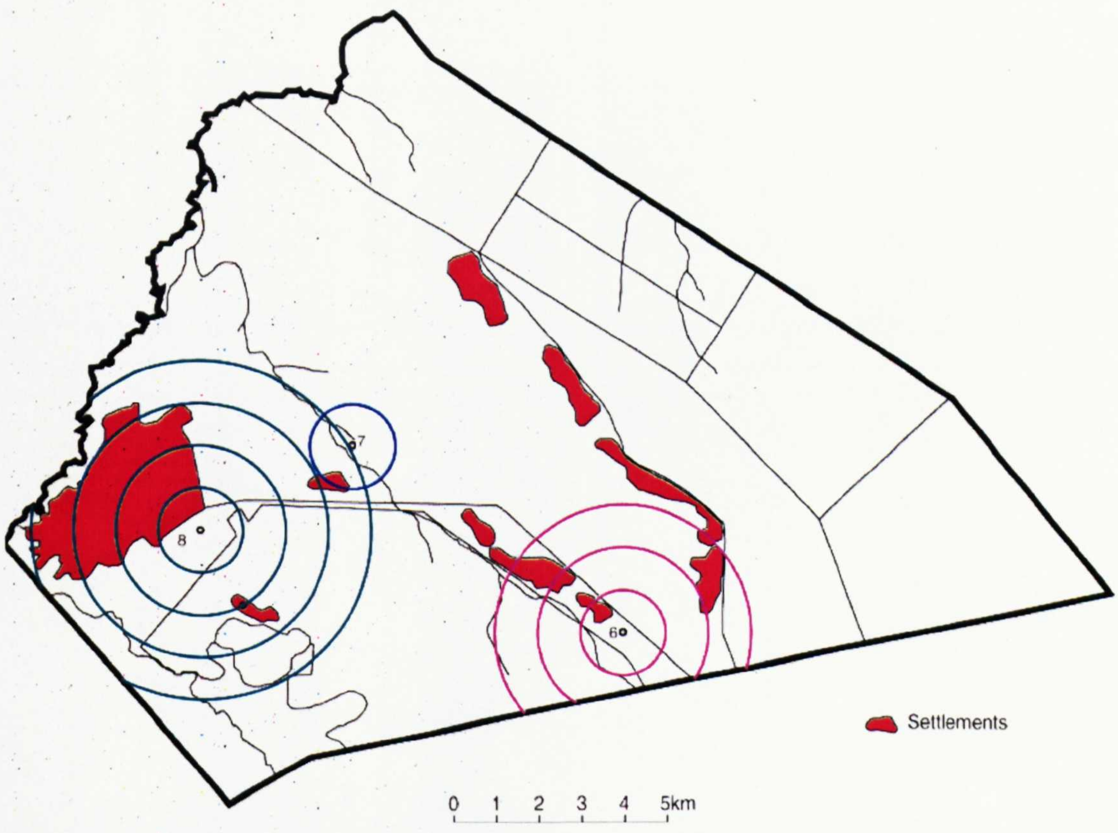

Figure 4.7 Isolines from 2 Months Water Sources in Tlokweng Sub - District
Note: 1 kilometre isolines
Source: Fieldwork

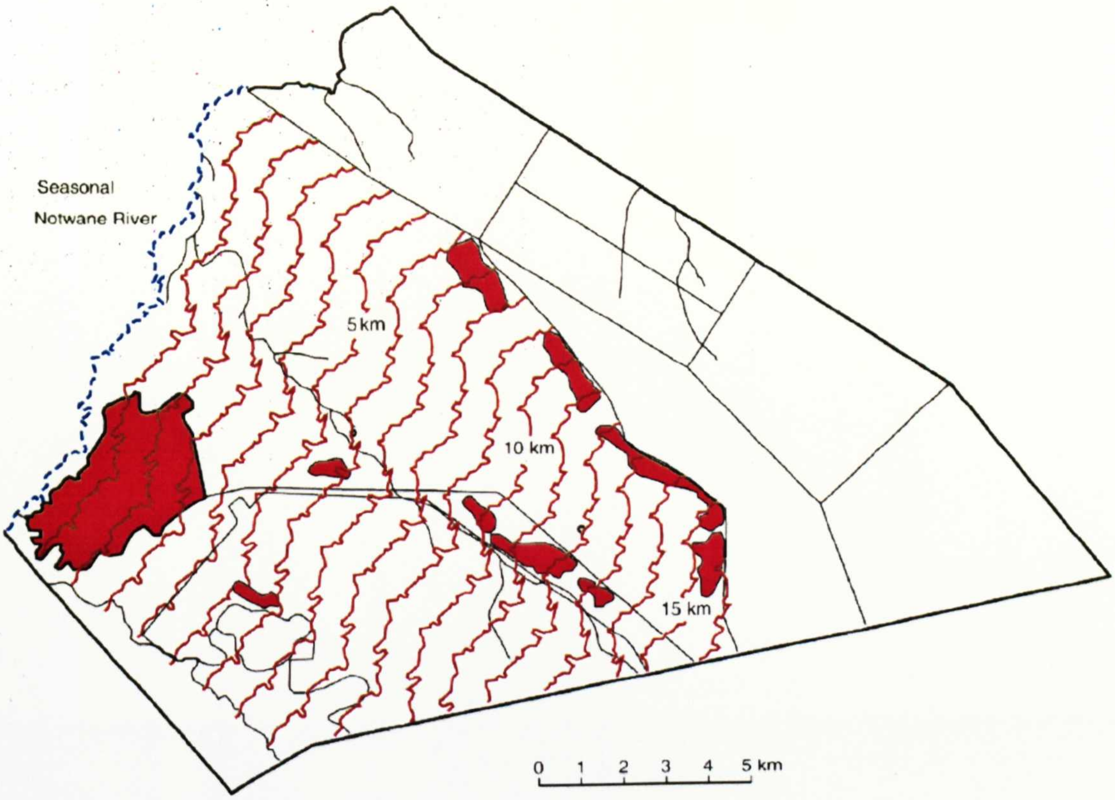

Figure 4.8 Isolines from the Seasonal Notwane River
Note: 1 kilometre isolines
Source: Fieldwork

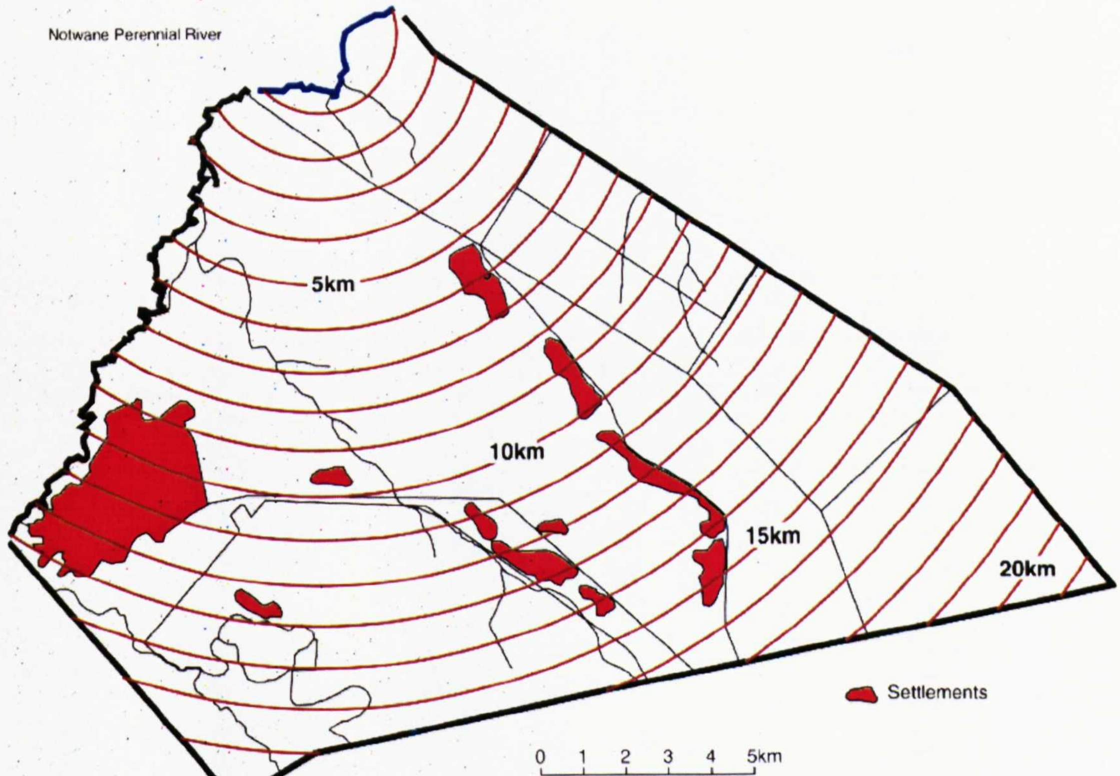

Figure 4.9 Isolines from the Perennial Notwane River
Note: 1 kilometre isolines
Source: Fieldwork

4.4 Critique of Methods Used

This section evaluates the methods described in Sections 4.1, 4.2 and 4.3.

4.4.1 *Field Data Methods*

The researcher personally conducted most of the questionnaires therefore the data were consistent. The accuracy of livestock holding data is always difficult to verify. This is because livestock are like personal savings the size of which individuals are reluctant to divulge. However in some cases the government livestock annual records showed the individual's livestock holding which verified the livestock numbers given by households during the interview. In general, though the exact number of livestock owned were difficult to verify, those who claimed livestock ownership could be easily verified in most cases. Some of the evidence used to confirm livestock ownership was the presence of an actively used kraal and feeding pans. The information supplied during questionnaire interviews was cross checked for verification during in - depth interviews with the herd boys. The same was done for other sources wherever possible. Government officials' views were confirmed through officially published documents wherever possible, otherwise the views were accepted as given.

The pattern of livestock movements observed and reported was taken to be accurate enough for the temporal and spatial scale of the study. This was because during the interviews similar descriptions were given about the cattle movements. The researcher observed some of the cattle movements. Respondents watering from the same borehole sources, especially syndicate members, were consistent about the livestock water costs. Non syndicate members reported varied fees most likely because they did not pay their dues regularly.

4.4.2 *The Accuracy of the Rainfall Decomposition*

The statistical procedure for decomposing the 50 year rainfall, which was discussed in Section 4.2, is the first step towards modelling the rainfall in Chapter 6. After the trend was removed, the Gaborone rainfall had a stochastic component which was more amenable to auto regression rather than spectral analysis. The three components removed from the rainfall data, the trend (Mean), Autoregressive component and the residual also called the stochastic element, were used as inputs to model rainfall in the Rain Land Cattle model described in Chapter 6.

To assess the accuracy of the rainfall decomposition, the decomposed components were reconstituted to obtain the observed rainfall. The difference between the reconstituted rainfall and the observed rainfall shows the accuracy of the decomposition procedure. The reconstituted rainfall was within a 10 percent error in 73 percent of the cases, which suggests that the statistical method used was good. Figure 4.10 shows the accuracy of the statistical procedure for the entire period. The results of Figure 4.10 have been summed up in Table 4.16. A negative error means that the reconstituted rainfall was less than the observed rainfall and a positive error means the opposite. The nine years with an error percentage of 20 percent and above had both a relatively low mean rainfall and standard deviation compared to the other years. This means that the biggest decomposition inaccuracy was associated with low rainfall years. Although the years with a higher rainfall mean were associated with the least accuracy errors, the error increases with the standard deviation, which represents the rainfall variation from year to year.

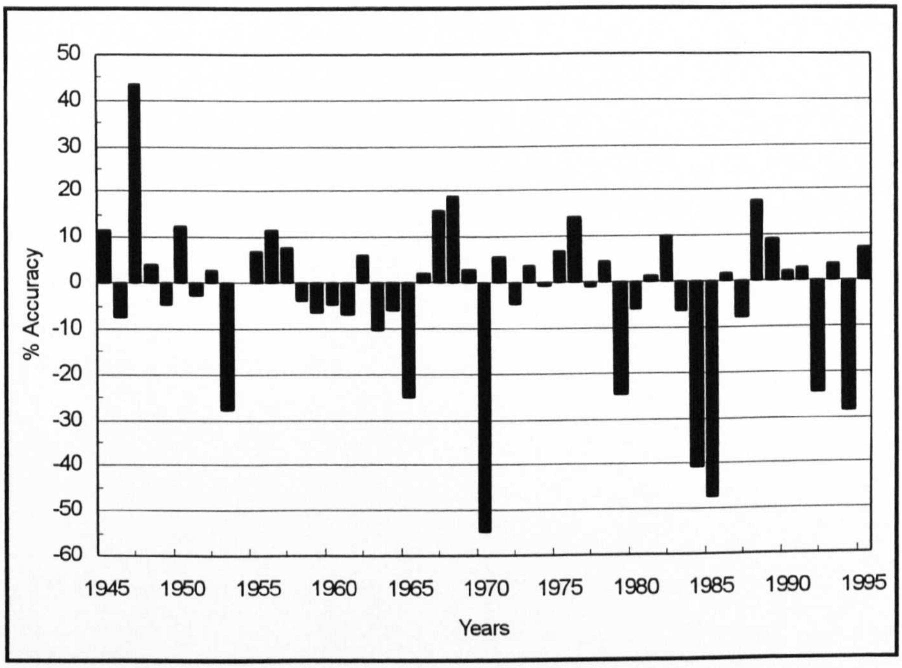

Figure 4.10 The Accuracy of Gaborone Rainfall Decomposition

Table 4.16 Summary of Rainfall Decomposition Errors

Years	N	% Error	Comment
1946, 1948, 1949, 1951, 1952, 1954, 1955, 1957 – 62, 1964, 1966, 1969, 1971 – 75, 1977, 1978, 1980, 1981, 1983, 1986, 1987, 1989 – 1991, 1993, 1995	33	up to 10 %	Approximately 50% of the errors were positive and the other 50% were negative. Mean 551.45 mm, S.D. 120.3, min 328.1 mm, max 756.9 mm
1945, 1950, 1956, 1967, 1968, 1976, 1982, 1988	8	More than 10% but less than 20 %	All errors were positive. Mean 631.95 mm, S.D. 183.45, min 465.5 mm, max 923.8 mm
1953, 1965, 1979, 1992, 1994	5	More than 20% but less than 30%	All errors negative. Mean 374.34 mm, S.D. 67.2, min 309.1, max 414.7 mm
1947, 1970, 1984, 1985	4	More than 40%	Three years positive error and one year negative error. Mean 305.5 mm, S.D. 62.7, min 223.9 mm, max 362.0 mm
Total	50	No accuracy errors 30% to 40%. Only three years with >40% errors	50% of the errors were positive and the other 50% negative. Mean 520.1 mm, S.D. 156, min 223.9 mm, max 923.8 mm

However the decomposition errors were more likely due to the sudden changes in the rainfall trend rather than the individual years. The prediction accuracy shows that the rainfall decomposition under predicted for low rainfall years more than it over predicted, therefore the reconstituted rainfall is likely to show more severe rainfall deficit during low rainfall years than is actually the case. Of the ten years with a prediction error below 5 percent, none had less than 400 mm rainfall and seven had above 500 mm annual rainfall. This proves further that the rainfall decomposition was more accurate for high rainfall years than for the low rainfall years. The latter confirms the higher prediction error for low rainfall years, most of which were under predicted.

4.4.3 *Carrying Capacity Water Availability Ratio Procedure*

The CCWA Ratio procedure is exploratory therefore subject to further development. But it provides a good opportunity to improve the GC and CC concepts. The accuracy of the CCWA Ratio may be questioned because seasonal rainfall is more likely to influence water holding than annual rainfall on which it is presently based. Seasonal rainfall is more difficult and uncertain to simulate than annual rainfall. It is possible to have more categories for RF Weighted (Table 4.8) and livestock water holding which may increase the accuracy but it would not represent the CCWA Ratio more precisely.

Summary

This study used three methods, the household interviews, the rainfall decomposition procedure and the derivation of the Carrying Capacity Water Availability. The methods were described in this chapter. The household interviews are used in Section 7.6. to give a picture of the management decision at the household level. The rainfall is the driving variable in the model and the Carrying Capacity Water Availability Ratio integrates the livestock water availability measure with the carrying capacity. Six maps show the distribution of the livestock water sources and Table 4.11 shows the variation in their number according to the rainfall. The Rain Land Cattle model, which is described in Chapter 6, integrates the data from the interviews, the rainfall decomposition components and the CCWA Ratio method described in this chapter. Chapter 5 discusses the use of models in cattle management studies.

Chapter 5. Review of Selected Cattle Management Models in Africa

Introduction

This chapter introduces models in general. It reviews six models that have been used to study aspects of cattle management in African rangelands. They are classified into bio - economic, static and system dynamics models. Five of the six models used are based on Botswana. One of the Botswana models, the Braat and Opschoor model, was adapted into the Rain Land Cattle model in Chapter 6. System dynamics modelling, which was introduced in Section 3.5.4, is discussed with an example of pastoral management in North Africa.

5.1 A General Introduction to Models

Coyle (1997:5) defines a model as "*simply a means by which we attempt to represent some aspect of the external world, in order to be able to influence, control or understand it more effectively*". The above definition shows two aspects of models that are relevant for the present study. Firstly, models simplify phenomena that are otherwise difficult to understand. Therefore models are selective and do not represent several aspects of the real world. Secondly, models are used for management. The Rain Land Cattle model in Chapter 6 is based on these two aspects. Forrester (1961:123) described a model as a "*statement of a law of behaviour*". The description suggests that models are based on regular and predictable behaviour. Prediction is an important aspect of modelling.

Two factors, the purpose and scale of model, determine what and how much a model will show. A model whose purpose is to show water will exclude detail which has little relevance to water. The smaller the scale the less the detail that will be shown and only those aspects which are relevant to the purpose of a model will be shown.

5.1.1 *Types and Uses of Models*

There are three types of models which are hardware, conceptual and mathematical models (Huggett, 1993). The order of the listing represents an increase in the level of abstraction respectively.

There are two kinds of hardware models, iconic and analogue. Iconic models, also called scale models, differ from the real world only by the scale. They are either bigger or smaller than the real world objects they represent. A small scale representation of a building is an example of an iconic model. Many life size features will be omitted in the small scale model of a building. Analogue models use other materials and symbols to represent objects, for example a map. Just like iconic models analogue models also vary in size from the object represented (Huggett, 1993).

Conceptual models *"express ideas about components and processes deemed to be important in a system and some preliminary thoughts on how the components and processes are connected"* (Huggett, 1993:6). Conceptual models, and indeed other models, can be used to develop a hypothesis (Forrester, 1969; Huggett, 1993). In that respect, a conceptual model can be used both to systematically arrange a body of knowledge for further analysis and as a tool of analysis. A conceptual model can be developed so that an operational version can be used to simulate the real world. Therefore how well a model performs can be measured by how closely a model simulates reality. Table 5.1 shows attributes, advantages and disadvantages of conceptual methods. The table shows that conceptual models can be words or more abstract diagrams. The Forrester diagram is an example of system dynamics modelling.

Table 5.1 Types of Conceptual Models and Their Uses

Model Design	Attributes	Advantages	Disadvantages
Words	verbal description	supplement all kinds of conceptualisation	complexity difficult to convey and can be cumbersome
Pictures	illustrations using natural elements	conveys information on composition and spatial characteristics	lack temporal and mathematical inferences
Black box diagrams	uses boxes to represent system components and arrows to show linkages	emphasise throughputs of matter and energy and does not show what happened in the boxes	lack mathematical inferences and no detail on what happens in the black boxes
Computer flow diagrams	sequential order of computations shows order of environmental processes	components can change in space and time	the flow charts may not show what happens in each box and uses rudimentary symbolic language
Forrester Diagrams	computer flow charts with state variables shown by valves, auxiliary variables as circles; flows represented as arrows, causal relationship as broken arrows; sources and sinks denoted as clouds. The models have feedback loops	interactions more obvious, rate equations, components, sources, and sink	Forrester is an example of many picture languages with bewildering variety of symbols which is non standardised, as one moves from one pictorial system to another there is a need to learn a new picture language The symbols should not be more important than the understanding of the system

Source Adapted from Huggett, 1993:8

The mathematical model is the third type of model. It represents relationships as flows of quantities, mathematical symbols and equations. Mathematical models are the highest level of abstraction which uses the formal symbolic logic of mathematics (Huggett, 1993). But even they can be used to show plausible outputs that may not necessarily be accurate when historical records are examined (Forrester, 1961). Indeed mathematical models may show the outcome of some previously unrealised and yet plausible occurrence. Such mathematical models will nevertheless be useful if they are able to explain how a system works. Their prediction inaccuracies could be due to the inadequacies of the data used. Though ideal for accurate predictions, mathematical models are often data hungry. When it is difficult to provide the data they need, especially at an exploratory level, they tend to be inaccurate. However the difficulty is not a deterrent to using mathematical models because as we indicated earlier models may be used to develop research hypothesis as well.

The purpose and scale of a model are relevant when assessing a model's ability to simulate reality. A general model will not show detail and a model will only be good in dealing with aspects for which it was designed.

5.1.2 *Modelling Cattle Management in Communal Areas*

This section answers the question why it was considered necessary to model the dynamics of cattle management in Botswana's communal areas using the Rain Land Cattle model. The model is discussed in detail in Chapter 6.

The theoretical basis for this study, which was described in Chapter 3, highlighted the interaction of rainfall, forage and livestock as the basis for modelling cattle numbers in an area. The three other influential factors are grazing land, livestock water and household management decisions. The household management decisions are more difficult to incorporate into a model than the physical factors of grazing land and livestock water. The Rain Land Cattle model offers an opportunity to experiment with the range cattle management scenarios outside reality. The scenarios are conducted without the risk of damaging the rangeland, cattle or the households' ability to sustain themselves (Chapter 7). The implications of the scenarios to cattle management are examined (Chapter 8). Once a sound understanding of the cattle management factors is established, proactive management is possible. Proactive management pre-empts undesirable consequences.

The dynamics of cattle and rangelands physical and management factors in general were discussed in Chapter 3 and Section 4.3. System dynamics modelling, described in Section 5. 4, enables the dynamism of cattle and rangelands to be simulated using a manageable number of variables. The level of simulation detail will depend, among other factors, on the power of the computer in use. Computers extend the capability and speed with which we are able to simulate different scenarios using a wide range of variables. The choice of the simulation time interval, the length of simulation period, the number of variables whose behaviour will be altered to produce a varied outcome, depends on the research objective and the experience of the person setting up the model (Roberts *et al.*, 1983).

The Rain Land Cattle, which is developed in this study (Chapter 6), depicts the communal cattle management system. A system is a collection of interacting elements that function together for some purpose (Roberts *et al.*, 1983). The elements of the communal cattle management system for the model are the rainfall, grazing land, cattle, cattle water resources, and the agropastoral households who own and manage the cattle. Given the variability of the rainfall and the dependence of the production system on the rainfall pattern, the main characteristic of the management system is the fluctuations in forage and cattle production. The Rain Land Cattle model is based on the subsistence system, as outlined in Sections 1.1.3, 1.3.3 and in Chapter 2. Livestock production is geographically widespread in Botswana, where it often competes with other landuses for land and water. The Tlokweng sub district is used as a case study from which to establish the credibility of the modelling approach, which integrates the household management strategies. Once the approach is established, the method will be available for use in other localities. The model can help to pre-empt land use conflicts and reinforce the complementary role of cattle management.

5.2 Bio- Economic Models

Bio - economic models are models which combine the characteristics of the biological system and that of the economic system.

5.2.1 *Perrings' Model*

The theme of Perrings' study was to investigate the decline of agricultural productivity in low income countries with a variable climate. Perrings used rainfall and national livestock regeneration rates data from Maun, Botswana, to generalise about "low income countries in Sub-Saharan Africa" (Perrings, 1990:1). The model shows that herd size and rangeland cover are sensitive to climatic oscillations. It looks into the use of monetary instruments as policy measures to solve the overgrazing problem.

5.2.2 *Some Concepts in the Perrings Model*

Perrings defined maximum sustainable yield (MSY) of the range as the *point where the net rate of depletion of the range is equal to the maximum rate of its regeneration* (Perrings, 1990:6). The definition shows the significance of the rainfall to rangelands. Low rainfall results in a slow range regeneration rate. However, Perrings takes the argument further to show that the use of the range is dependent on the carrying capacity. The maximum regeneration rate of the range occurs when the range operates at half the maximum carrying capacity as shown by the Equation 5.1 because it is not overused.

Equation 5.1 Maximum Range Regeneration Rate (MRRR)

$\beta t_m = k_t = 1/2k_c$ where:

βt_m is maximum rate of regeneration of the range
k_t is current carrying capacity
k_c is maximum carrying capacity of the range

Source: Perrings, 1990:5-6

Perrings acknowledges the effect of livestock disease, which is unrelated to rainfall, on the growth of the livestock herd. The management of a range by controlling the number of animals determines the difference between the net depletion of vegetation and the natural rate of regeneration. This observation is pertinent for the current study where the number of animals is considered a vital parameter to monitor, and hence control, in order to manage the range effectively. Grazing pressure (x_t/k_t) is a function of the herd size and the carrying capacity and in reality overgrazing is expected to cause a decline of the herd size. Ideally when the CC is low the herd size should be kept low in order to reduce the grazing pressure and avoid depletion of, or damage to, the rangeland.

Perrings differentiates between ecological and economic overgrazing. Ecological overgrazing is of two types, the fundamental and the current. Fundamental overgrazing occurs when the stochastic equilibrium level of grazing pressure exceeds the level of grazing pressure corresponding to the maximum sustainable yield of the range. The stochastic equilibrium level of grazing is a continuous though varied level of grazing pressure. Fundamental overgrazing represented by Equation 5.2, is a long term phenomenon

Equation 5.2 Fundamental Overgrazing

Fundamental Overgrazing = $\alpha x_t/k_t > x_m/k_m$ where:

α is at infinity
x_t is herd size at time t
k_t is carrying capacity at time t
x_m is herd size corresponding to the maximum sustainable yield
k_m is maximum range regeneration rate

Source: Perrings, 1990:8

In contrast to the Fundamental Overgrazing in Equation 5.2, current overgrazing is short term (Equation 5.3).

Equation 5.3 Current Overgrazing

Current Overgrazing =$x_t/k_t > x_m/k_m$ where:

x_t is herdsize at time t
k_t is carrying capacity at time t
x_m is herd size corresponding to maximum sustainable yield
k_m is maximum range regeneration rate

Source: Perrings, 1990:8

Persistent current overgrazing may become fundamental but is not a sufficient condition for fundamental overgrazing. This is because the range recovers when favourable rainfall periods occur, or when the herd size is reduced as livestock starve to death when the rangeland is depleted. The Equation 5.3 tells us that the current overgrazing occurs when the present level of grazing pressure exceeds the maximum sustainable grazing pressure. If the herd size exceeds the carrying capacity of the range in one year, it is not a mandatory precondition for the decline of the carrying capacity in the subsequent year. In practice it means that the carrying capacity variability from one year to the next may be expected but it does not necessarily signal the collapse of the range when, for example, a year with good rainfall follows a bad one.

Although Perrings chose to deal only with the current overgrazing in his study, the difference between fundamental and current overgrazing encapsulates the main characteristics of Africa's rangelands. This is because one year's forage deficit should be seen against the previous years situation and several years forage deficit will have a strong impact on the range and hence livestock production.

Economic overgrazing is where the "*actual level of grazing pressure exceeds the optimal level of grazing pressure*" (Perrings, 1990:12). Equation 5.4 shows economic overgrazing.

Equation 5.4. Economic Overgrazing

$$\xi_t = \left(\Psi_t / \Psi_t^*\right) - 1$$

where:

ξ_t is economic overgrazing
Ψt is index of grazing pressure i.e. (carrying capacity / Herdsize)
Ψt^* is optimal level of grazing

Source: Perrings 1990:12

The optimal level of grazing defines the upper bounds for the grazing pressure. The bounds of the optimal grazing pressure are defined by the relative prices of using the range. When the marginal costs of livestock and carrying capacity relative to the marginal benefit of offtake are such that it is economic to mine the range, then the optimal level of grazing will be greater than the maximum sustainable grazing pressure which would result in fundamental overgrazing (Perrings, 1990). In simple terms this means that where there are no costs for using a rangeland and when very good prices are paid for livestock, such as found in Botswana, there is a financial incentive to maximise the profit even if it involves mining the rangeland. It is not clear from Perrings study for how long the range can be mined. But it is known that the livestock population in a range that is being mined will eventually collapse, thus ecologically redressing the balance. The optimal grazing pressure maximises the expected returns over a long period. At the household level optimal production is the maximum level of farm productivity that is represented by Equation 5.5.

Equation 5.5 Optimal Policy for a Rural Farm Household

$W(u_t, x_t, k_t) = p(u_t) - c(x_t). - r(k_t).$

where:
W is welfare in the rural cattle economy
p is constant slaughter price applied to offtake at time t
c is constant cost of livestock maintenance for herd size at time t
r is constant cost of carrying capacity at time t (e.g. grazing fee)
u_t is offtake at time t
x_t is herd size at time t
k_t is carrying capacity at time t

Source: Perrings 1990:14

The equation shows that the level of optimal grazing pressure is determined by the difference between the costs of livestock maintenance and of using the range compared to the income from selling the livestock. When the cost of using the range is not realised by the livestock producer, the optimal grazing pressure will be greater than the maximum sustainable grazing pressure (Perrings, 1990:12). The latter argument is used to call for a tax on the resource use in order to limit the level of use below the maximum sustainable grazing pressure, hence reduce the risk of denuding the rangeland. However Perrings acknowledges that implementing the optimal policy would be difficult because herdsize is influenced by risk, which is not catered for in the formula. Other possible difficulties with the formula are the livestock uses beyond the meat value, and those benefits whose economic value is not easily determined. It is difficult to see how rangeland use can be taxed in Botswana since it would be politically unacceptable.

5.2.3 *Barrett's Model*

Barrett's model, like that of Perrings, discussed the relationship between herd size and the range. But Barrett goes further to look at why overgrazing persists during drought. After differentiating between the three different schools of thought which seem to represent the evolutionary stages in understanding the relationship between carrying capacity and the herd size, Barrett chooses to dwell on the resilience model. The three schools of thought are:

i) the equilibrium model which states that carrying capacity is fixed and herd numbers will eventually settle to it

ii) the degradation model which argues that the carrying capacity of an area gets destroyed irrevocably

iii) the resiliency model which argues that there is an interplay between herd size and carrying capacity which enables herd size to be adjusted to the carrying capacity.

Barrett (1989) looked at the resiliency model which agrees with the new thinking on rangeland management (Section 3.1). Herd management can be represented by Equation 5.6.

Equation 5.6 Herd Management Equation in the Resiliency Model

$$Ht = rHt(1-Ht/Kt)-ht$$

where:
Ht is herd size at a given time
Kt is Environmental capacity
ht is harvest rate
(Ht = Kt) is an equilibrium between herdsize and environmental capacity

Source: Barrett, 1989:4

Barrett illustrated the continuous fluctuation between carrying capacity and herd size with a sheep population that stabilised at one third of the carrying capacity. The effect is described as the optimal approach to a steady state and was likened to the effect of introducing ungulates to a previously unoccupied area. It is noted that where a new population is introduced to a previously unoccupied area, the population will increase rapidly and continuously first until it has overshot the carrying capacity after which it will crash. Thereafter the sheep population will fluctuate around a long term average as discussed in Section 3.3.2.

Barrett's economic model argues for the control of ecological variables, mainly carrying capacity, through economic tools. He also observed that it was possible to control the carrying capacity through the increased water points, reseeding, fencing off heavily grazed areas, irrigation and weeding off noxious vegetation (Barrett, 1989:5).

He discusses the pastoral society's social profit, summarised in Equation 5.7. The profit is depicted as the relative cost and price of producing herds, just like Perring's description in Equation 5.5. The pastoral society benefits as long as the returns from the herd are greater than the cost of maintaining the herd. Barrett argues that when the cost price ratio is large, the optimal grazing pressure is small. On the other hand an increase in the discount rate leads to a decline in the optimal grazing pressure.

Equation 5.7. Pastoral Society's Social Profit

Social Profit = ph_t - cH_t
where:

ph_t is constant unit net price of the harvest ($p>0$)
cH_t is constant unit cost of maintaining the herd ($c>0$)

Source: Barrett, 1989:5

Like Perrings, Barrett discussed ecological and economic overgrazing. Barrett argued that it was optimal to stock above the range's grazing capacity after a drought and below the capacity during a drought. He proposed three management options to overcome overgrazing in the arid and semi arid areas. The management options are:

i) the need to issue exclusive grazing rights, similar to the ones in the traditional society which are often rendered ineffective by the governments bureaucracy and imposed controls (Barrett, 1989:15)
ii) privatisation of grazing rights which may include issuing grazing permits
iii) taxation on the livestock sold (income) and the number of livestock held.

Barrett's recommendations, like those of Perrings, are based on economic considerations which in Botswana are not politically acceptable.

5.3 Static Models

This section describes two static models. Static model parameters do not have feed back loops found in a system dynamics model (Section 5.4).

5.3.1 *Abel's Land Degradation Model*

Abel (1993) combined a livestock sub model and a soil erosion sub model to show the likely effects of reducing the cattle numbers in a communal rangeland. The erosion sub model was adapted from the Soil Loss Estimation Model for Southern Africa (SLEMSA). Abel's model was based in the Central District, Botswana.

5.3.2 *The Livestock Sub Model*

Abel's Livestock sub model had five inputs.

i) Rainfall

The rainfall amount and variability is the main driving force for variation in the livestock productivity and stocking rates.

ii) Stocking Density

The 1983 stocking density was derived from aerial livestock counts and official statistics. Official government cattle figures were used for the other years between 1978 and 1988. The livestock unit (LSU) was derived by multiplying the given cattle number by 250/350. Non cattle biomass was estimated at 8 percent of the cattle biomass and added to the total cattle biomass.

iii) The Carrying Capacity

The published stocking density figures from research around Botswana were used. The figures were regressed against the rainfall for the current and the previous seasons (Abel, 1993). The equation of the relationship was used against the rainfall pattern in the area to produce expected variations in stocking density over time. For comparison, two stocking strategies were used, the Recommended Stocking Rate (RSR) which is the governments official rate and the Current Stocking Rate (CSR) which obtains in the communal areas. The CSR was always higher than RSR.

iv) Calving Rate, Calf Weight Gain and Survival

The officially published figures for calving rate and survival were used. Calf weight gain data, obtained from ranches, was adjusted to show the effect of abstracting milk for human consumption which is a common practise in the communal areas, but not in the research stations.

v) Milk Production and Offtake

Milk production data from Pelotshetlha in the Southern District, which had been extensively studied before (see Abel *et al.*, 1987), was used to estimate the relationship between rainfall and milk production at the RSR. Pelotshetlha is a communal area believed to be better managed than other communal areas in the country.

5.3.3 *The Erosion Sub-Model*

A previous study by Biot, developed the erosion sub model for the study area. Cattle data were collected from low level (120 metres above the ground) photographic surveys. Thirty metre long slopes, which fall within a soil type, were identified from a

1:50 000 topographic sheet base map, along transects which were 5 kilometres wide. The number of cattle counted from these low flights was used to estimate the vegetation consumed, hence calculate the removed vegetation. The density of animals at a specific time could be calibrated against the existing agricultural census of the same period of the year (Abel, 1993:185). The vegetation cover during the growing season was calculated by measuring the remaining grass at the end of the growing season and adding to it the estimate of what would have been eaten by the livestock during the season. The annual forage production was plotted against rainfall. A close relationship that compared well with what was observed under similar climatic conditions in Zimbabwe (Abel, 1993) was observed. Using the relationship CSR and RSR grass cover curves were produced.

5.3.4 *The Results of Abel's Model*

The most important result of the model is the relationship between soil loss and vegetation cover (Figure 5.1). It found a maximum curvature line between soil loss and percentage energy interception, where the latter depends on the amount of vegetation cover. The figure shows that when less than 30 percent of the rainfall energy is intercepted, the gross soil loss index (tons Ha^{-1} yr^{-1}) increases significantly. The point of significant increase in the soil loss represents the maximum curvature line. Beyond the point of maximum curvature, the soil loss is insensitive to the change of cover and the different rainfall amounts (Figure 5.1). The finding implies that beyond the point of maximum curvature, the stocking rate, which influences the vegetation cover, had no effect on the amount of soil loss which therefore rules out destocking as a measure to reduce land degradation. Abel (1993) found that a mean

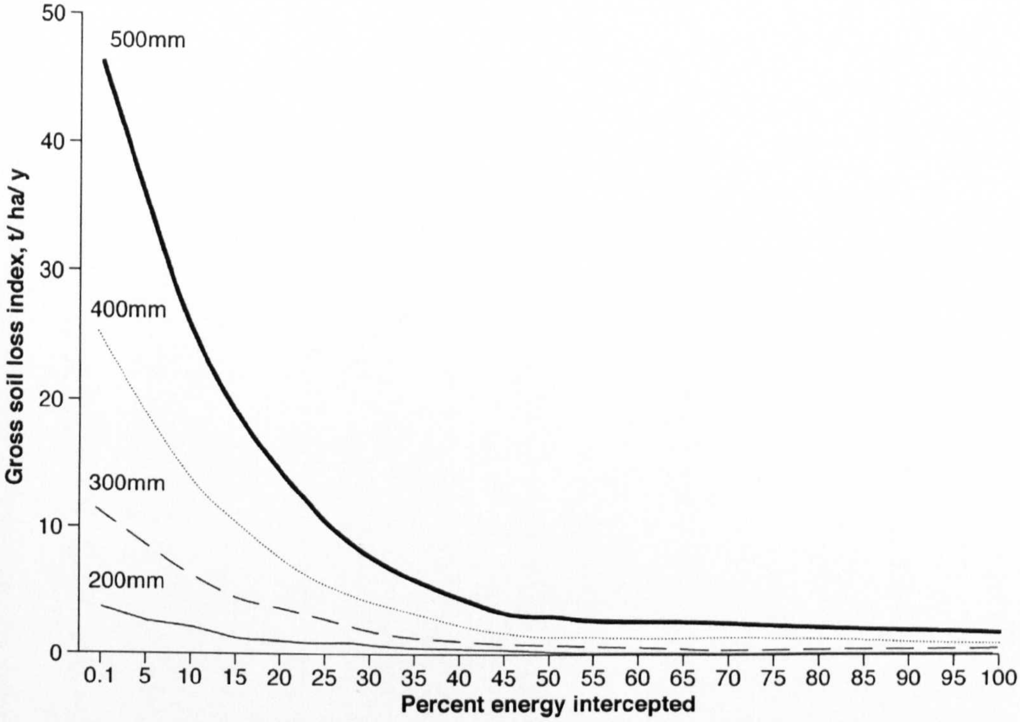

Figure 5.1. Gross Soil Loss and Cover in Relation to Rainfall

Source: Abel, 1993:189.

soil cover of 51 and 73 percent, for current stocking rate and recommended stocking rate respectively, had similar soil losses. But "*if the effective cover of both systems proved to be in reality 20% lower than the estimate, so that the recommended stocking rate remained above but the current stocking rate moved below the point of maximum curvature in the cover – soil loss curve, the difference in rates of soils loss between the two systems would rise greatly" (*Abel, 1993:188 - 189). In addition to the finding on soil loss, the study confirmed that the production of livestock per hectare in communal areas was higher than that found in the commercial areas and research farms. However the production per livestock unit is higher for the commercial areas. Overall this vindicates the high stocking of the communal areas.

Based on the findings of the soil loss model, it was concluded that there would be no significant soil loss for Botswana for another 400 years under the present stocking rates (Biot, 1993). This implies that the present stocking rates even in the communal areas do not cause any significant damage to the soil within the foreseeable future. The high stocking rates are seen to be a reasonable strategy based on the production objectives of the communal pastoralists.

The model does not say what the possibility of a species composition change is, which may occur without a decrease in cover form. Such a change may have negative effects on the quality of grazing. Secondly, it is not clear to what extent the model can be generalised to other areas. Thirdly should there be higher stocking densities, which would cause a bigger loss of grass cover in other parts of the country, the soil loss could be drastically different to that simulated by the model. It is also not clear how the model carries over the adverse effects of droughts from the previous years. Drought years have a cumulative effect which should be looked at within the context of the previous years as argued by Vossen (1987) for example.

5.3.5 *Ellis and Swift*

Ellis and Swift (1988) studied a non equilibrium system (see Table 3.2) in Turkana, Kenya, which had an annual rainfall of between 200 and 600 mm. The area experienced about 50 percent biomass variation between a drought and non drought year. They were interested in understanding the relationship between forage availability, livestock mortality, and the management strategies used by pastoralists to alleviate the effects of drought. Ellis and Swift (1988) developed a model (Figure 5.2) to describe the plant livestock interaction during droughts of varying duration and frequency in non-equilibrium areas. They found out that a single year of drought had a limited effect on livestock dynamics compared to the debilitating effect of a multi year drought. A multi year drought will cause the livestock population to decrease by

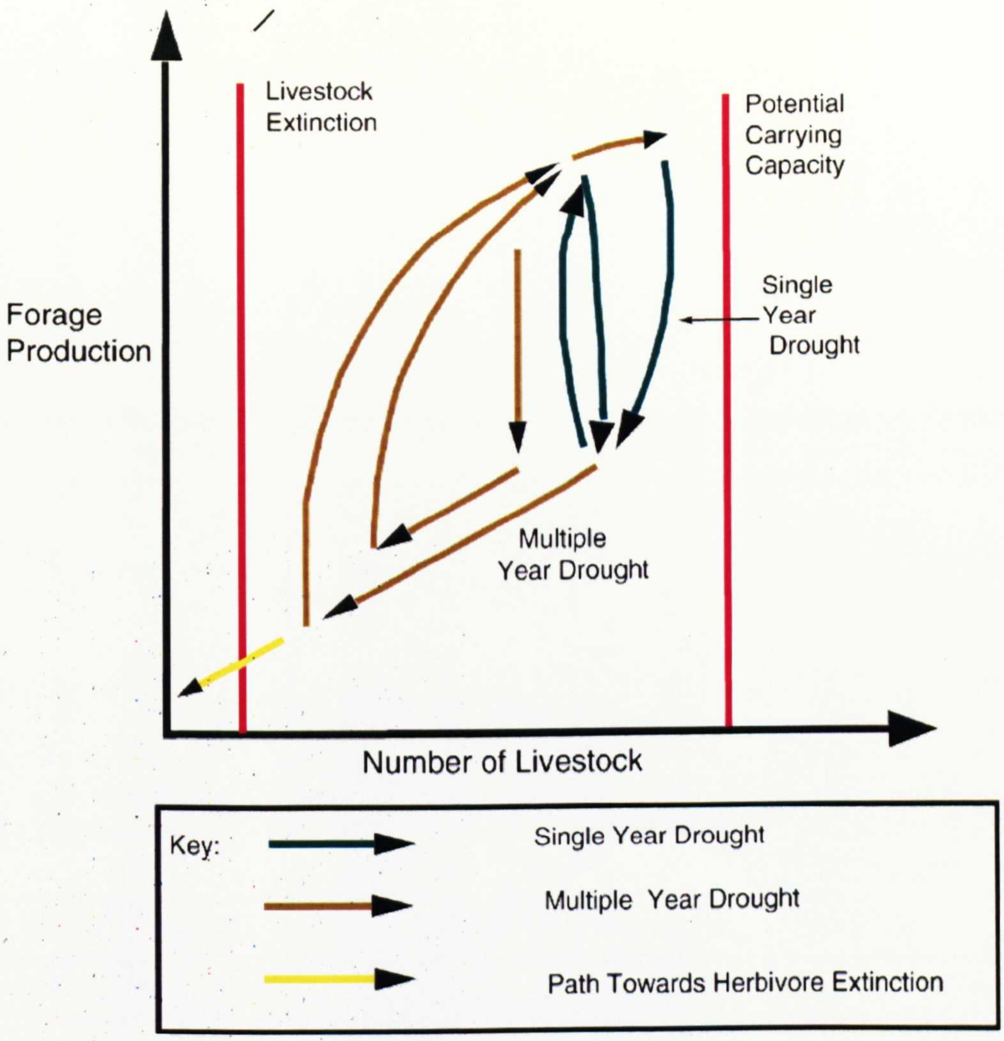

Figure 5.2. Plant Herbivore System at Disequilibrium.
Source: Tainton *et al.,* 1996:290

a magnitude which is weakly related, or not related, to the livestock density prior to the drought (Ellis and Swift, 1988: 456). Because the density of the livestock has minimal influence on the livestock mortality, non equilibrium areas are density independent. Density independent means that the population of cattle depends on the seriousness of drought rather that the stocking density. The livestock condition is determined by the quality, not just the quantity, of the forage consumed. The model demonstrates the effect of external factors on the dynamics of cattle population. Five observations can be made from this finding. During a single year drought the livestock population remains constant, though the animals may lose condition, but during several years of drought the population declines as the forage production is reduced significantly. Secondly, the animal population grows slowly throughout the years, but never reaches the theoretical ecological carrying capacity, shown on the diagram as the Potential Carrying Capacity. Thirdly, the frequent long term droughts which are severe enough to cause increased herd mortality, do not lead to livestock extinction. This is because as the drought progresses, pastoralists migrate to other areas, or livestock adapt by feeding on less preferred forage such as browse, thereby attenuating the physiological effects of the drought (Behnke and Scoones, 1995; White, 1993) and improving their chances of survival. Also the high livestock mortality during the early stages of a drought reduces the stocking rate and thereby redresses the imbalance between forage and livestock numbers. A quasi stable condition between the livestock and the available forage is created, which prevents further livestock losses as the drought progresses. Fourthly, forage production (P) is highly responsive during years of good rainfall and livestock numbers are never high enough to have a negative effect on the vegetation (Tainton *et al.,* 1996:289). Lastly recovery of forage is linked to that of livestock. During a single year drought, though the forage decreases significantly there is only a small decrease in the livestock numbers. A multiple year drought causes a significant decline in both the forage and the livestock population level.

In summary Ellis and Swift point out two main issues about livestock management in semi arid areas. Firstly drought is part of the system and secondly livestock mobility and adaptation are important.

5.4 System Dynamics Models

System dynamics modelling deals with continuously changing (dynamic) functionally interconnected elements of the environment (Moffatt, 1991). A system dynamics model captures the change. Because the change is continuous, it is often necessary to define the time differences over which the change will be simulated. The difference in time used for simulation, also called time steps or simulation time interval, is represented as dt or Δt.

The definition of the simulation time interval depends on two factors, the appropriate time differences according to the nature of the inputs and the outputs of the model. For example, the Rain Land Cattle model (Chapter 6) used a dt of one year for most outputs. Although rainfall can be observed hourly, weekly, monthly or seasonally, the annual rainfall was used because cattle reproduce once a year. However the arable land availability was simulated on a shorter dt than one year because arable land is available for four months each year. Secondly, the value of dt is influenced by the likelihood of errors in estimating outputs. There are two possible errors caused by the value of dt, the truncation and rounding off errors (Huggett, 1993). Truncation errors cause a difference in output between dt and smaller dt. The difference in the output is because the simulation uses segments to fit a continuous time curve (Moffatt, 1991; Huggett, 1993; Hannon and Ruth, 1994). Therefore the smaller the dt value the less the truncation error. The rounding off errors occur because each model calculation is rounded off to two significant figures. When a small dt is used to calculate outputs for one year, for example, four calculation per year for a dt of 0.25 instead of one calculation when dt is 1, the rounding off errors increase (Huggett, 1993). The definition of dt is therefore a compromise between reducing the truncation and the rounding off errors. The choice of dt also takes into account computing time and cost, both of which increase when dt is reduced (Forrester, 1961; Moffatt, personal communication, 1998).

A system dynamics model has a conceptual boundary that defines its organisational autonomy (Dent and Anderson, 1971:3) from the rest of nature. The boundary for the Rain Land Cattle model was taken to be the sub district border. The cattle production system in Botswana has four levels. The highest level is national cattle production which is followed by the commercial and communal production level. The districts' level is the third hierarchy and the local level, which in this case is the sub district, is the fourth level. The hierarchies are interconnected. Each system in a model consists of interacting elements called parameters. A parameter has a specific role in a system. Examples of parameters in the Rain Land Cattle model are rainfall, land, number of cattle, grazing capacity and area of grazing land. The parameters are functionally linked. For example the rainfall affects the grazing capacity.

A system dynamics model consists of links and feedback loops. A link is a connection between two parameters. It can be positive or negative. A positive link between A and B shows that an increase in A leads to an increase in B. Negative link shows that more of a value in a parameter will lead to less output in the next or vice versa. Figure 5.3 is a causal diagram. A causal diagram shows how the parameters are linked in a model. In Figure 5.3 A - B is a negative link and B - A is a positive link. Links in system

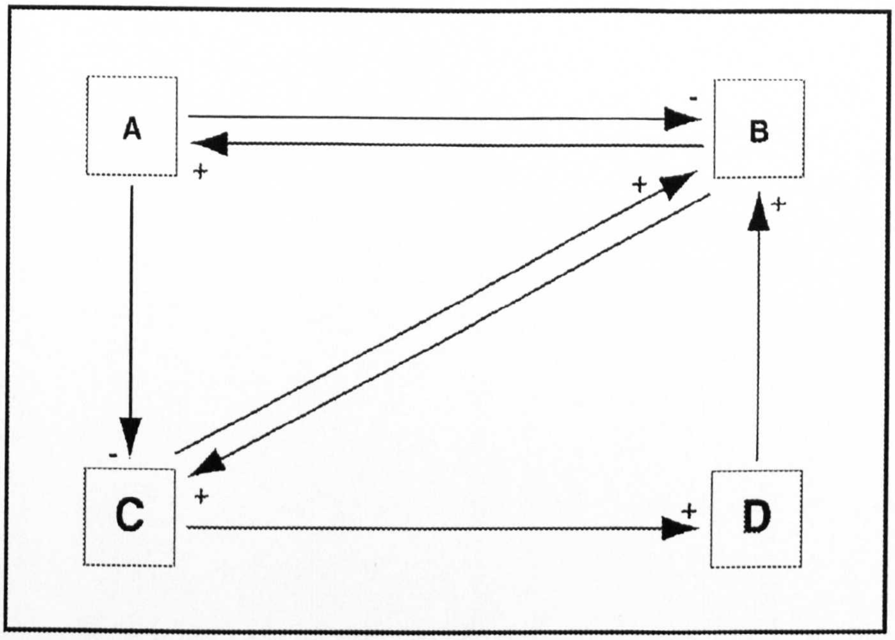

Figure 5.3 A Hypothetical Causal Diagram to show Links and Feedback Loops

dynamics models can be interconnected in a closed circuit to form a feedback loop. The link A - C - B – A in Figure 5.3 is a feedback loop. As with links, feedback loops can be negative or positive. A negative loop is made of links with an unequal number of like signs or any other combination of links with unlike signs. A positive feedback loop consists of positive links or an equal number of links with like signs, which could be positive or negative. Figure 5.3 has thirteen feedback loops, eight of which are negative and five are positive (Table 5.2). A positive loop reinforces an effect whilst a negative loop establishes an equilibrium within the system (Hannon and Ruth, 1994; Moffatt, 1991). Negative feedback loops are self limiting while positive loops have no upper bound (Picardi, 1975). Figure 5.3 would therefore be characterised by a strong self limiting mechanism which is associated with the negative feedback loops. A self limiting model's outputs are limited within specified bounds. However the number of negative feedback loops *per se* is not sufficient basis to assess the extent of the self limiting aspects of a model. The sensitivity analysis often tells us more about the controlling parameters in a model than what the number and types of feedback loops would.

Table 5.2 Description of Links and Feedback Loops in Figure 5.3

Feedback Loop	Description of Links	Feedback Loop Sign
1	A - B - A (-;+)	Negative
2	A - C - B - A (-;+;+)	Negative
3	A - C - D - B - A (-;+;+;+)	Negative
4	B -A -B (+;-)	Negative
5	B -C - B (+;+)	Positive
6	B - A - C - B (+;-;+)	Negative
7	B - C- D - B (+;+;+)	Positive
8	B - A - C - D - B (+;-;+;+)	Negative
9	C - B - C (+;+)	Positive
10	C - B - A - C (+;+;-)	Negative
11	C - D -B - C (+;+;+)	Positive
12	D - B - C - D (+;+;+)	Positive
13	D - B - A - C- D (+;+;-;+)	Negative

5.4.1 *Types of Parameters Used in System Dynamics Models*

The system dynamics parameters described below are classified according to their functions. They are based on Stella (**S**tructural **T**hinking **E**xperimental **L**earning **La**boratory). The parameter examples are based on the Rain Land Cattle model

i) Level

A level is the basic building block for a system dynamics model. It represents accumulated stocks (model outputs) into or out of which materials flow. Levels in the Rain Land Cattle model are Cattle, Delayed Rainfall values, Delayed Stocking Rate and Permanent Grazing. The materials stored in a level are equal to the initial value to which is added the quantity's rate of change over time (Equation 5.8). For each level an initial value is stated and maintained throughout as the basis for level calculations. Levels in Stella are represented by rectangles called stocks (see Figure 6.2).

Equation 5.8 The Calculation of a Level in a System Dynamic Model

$K = J + dt \times R$ where:
K is quantity at present time
J is initial quantity
dt is difference in time between K and J
R is rate of change in quantity

Source: (Pugh, 1973:2)

ii) Rates

A rate, also called a flow rate, determines the inflow to, or outflow from, a level. In Equation 5.8, R represents rate. A rate may be constant or calculated at different times. For example, the parameter Births in the Rain Land Cattle model (Figure 6.2) depends on the number of cattle at the present time and the birth rate (Births = Cattle x BI Rate). Rates are used as decision functions when modelling management decisions (Forrester, 1961). A rate is connected to a stock, level, by a converter with a tap sign.

iii) Constants

A constant may be a fixed number such as PCC = 12.5 Ha LSU^{-1}, or it may depend on another input where it varies around a constant number such as BI Rate = 0.235 x R1 in Figure 6.2.

iv) Graphical Functions

Graphical functions are used when the independent variable (input) in a model has an observed relationship, or one based on known estimates, with a dependent variable, output (Hannon and Ruth, 1994:13; Moffatt, 1991:25). The graph fixes the relationships, which do not change during the modelling process but allows interpolation between known values.

Examples of graphical functions in the Rain Land Cattle model are R1 (Section 6.6.3), R2 (Section 6.6.4), Stocking Factor (Section 6.5.7) and the Botswana Range Condition Index (Section 6.4.4). Graphical functions can be distinguished in the model diagram by a tilde (~) in their converters.

v) State variable

The state variable is the main driving variable for most processes in the model. It describes the condition of the system (Hannon and Ruth, 1994). In the Rain Land Cattle model, Rainfall and the Range Area are state variables.
A level or an auxiliary may represent a state variable, as in the case of Range Area and Rainfall.

vi) Auxiliaries

An auxiliary is a variable which is not a rate, level, constant or state variable. An auxiliary determines the flow of quantities and changes over time. In general it facilitates the operation of the model in ways not offered by the other variables. Forrester (1961:78) describes auxiliaries role *"as to assist but they remain incidental to rate equations"*. They help to reduce the complexity of rate equations or operations (Coyle, 1977: 32). A good example of auxiliaries in the Rain Land Cattle model are the parameters Notwane S'snal, Cat 2, Cat 3 and Cat 4. They could have been incorporated in the RF Weighted parameter earlier, but the equation would have been cumbersome and unwieldy. Because the auxiliaries reduce the complexity of rates, the two are complementary.

vii) Connectors and Flows

A connector is a single arrowed line which either joins converters, levels to converters and converters to rates. In Figure 6.2 there is a connector between the variables cattle and offtake. A connector can not link directly into a level, except through a rate. A flow is a conduit represented by a double arrowed line that links a rate and a level. A flow may carry quantities being modelled from, or to, outside the boundary of the system of interest. A cloud symbol on the flow pipe represents areas outside the boundary. A model will not have any further information about the "clouded" area. For example the Rain Land Cattle model can not provide any further information about the cattle sold.

5.4.2 *Picardi's Study of the Sahel*

Background

The 1970's drought in the Sahel, prompted the United States Agency for International Development (USAID) to commission a study on the methodology and data requirements for a major alternative development possibility. A multidisciplinary team from the Massachusetts Institute of Technology (MIT) carried out the study. Picardi's work, later submitted for a doctoral thesis, was a part of the team's output. Picardi's study was based on system dynamics modelling where a change in one parameter leads to a ripple effect throughout the entire system and back to the source of the change. The art in systems modelling is to capture the chain of causalities in as much detail as possible using the least number of variables possible to explain the change (Meadows and Robinson, 1985).

Objectives of Sahel Study

Picardi (1975) conceptualised the problem in the Sahel to be in two forms, which are:

i) the human problem - famine leading to declining livestock and human population

ii) the ecological problem - desiccation as the top soil is scoured away leaving a pebbly desert pavement (Picardi, 1975:19).

Desertification and famine are the core of Picardi's work from which he drew two hypotheses.

Hypothesis 1- the problem of desertification and recurring famine in the Sahel can be studied through system dynamics modelling. The approach enables us to understand the fundamental causes and discover ways of combining the Sahel's human and ecological resources to achieve a more acceptable behaviour mode of the system

Hypothesis 2- the problem behaviour of the ecological pastoral system, that is desertification and the recurring famine, results primarily from processes at work within the system. Furthermore, a solution to the situation involves much more than the conventional programmes proposed to date. It is perceived that a trade off exists between the pastoralists population level and their way of life (Picardi 1975:24-25).

Picardi chose the Tahoua administrative district in Niger as a case study. The study region has semi-desert to desert conditions with an annual rainfall of 100 to 650 mm. The cattle move south to stubble graze in the harvested arable fields and then move north to the rangelands after the rains. The area is predominantly pastoral. The Zebu, the main cattle species, is adapted to the harsh conditions in the area. Picardi (1975) noted that he used the system dynamics modelling approach because it was:

i) broad based therefore it can encapsulate the complexity of the entire Sahel system,

ii) quantitative therefore outputs could be easily communicable,

iii) generic rather than specific problem oriented therefore widely applicable to the Sahel

iv) based on a 150 years time span over which ecological problems can be reversed

v) less sensitive to reasonable numerical data uncertainties and discrepancies, which was vital given the paucity of data for the entire Sahel region.

5.4.3 *Brief Description of Sub Models in Picardi's Model*

Picardi (1975) used three sub models SAHEL2, ECNOMAD3, SOCIOMAD in increasing order of detail and complexity, to study the Sahel problem. Sahel2 is presented in Figure 5.4. ECNOMAD3 and SOCIOMAD are shown in Appendices 4 and 5 respectively.

SAHEL2

SAHEL2 shown in Figure 5.4 defines the ecological problem. It details the Sahel's physical and ecological system (Picardi, 1975:45). It is the core of Picardi's work based on the population, livestock and rangeland (soil) of the area studied. Figure 5.4 shows how the different aspects of population, livestock and rangeland interact in Sahel2.

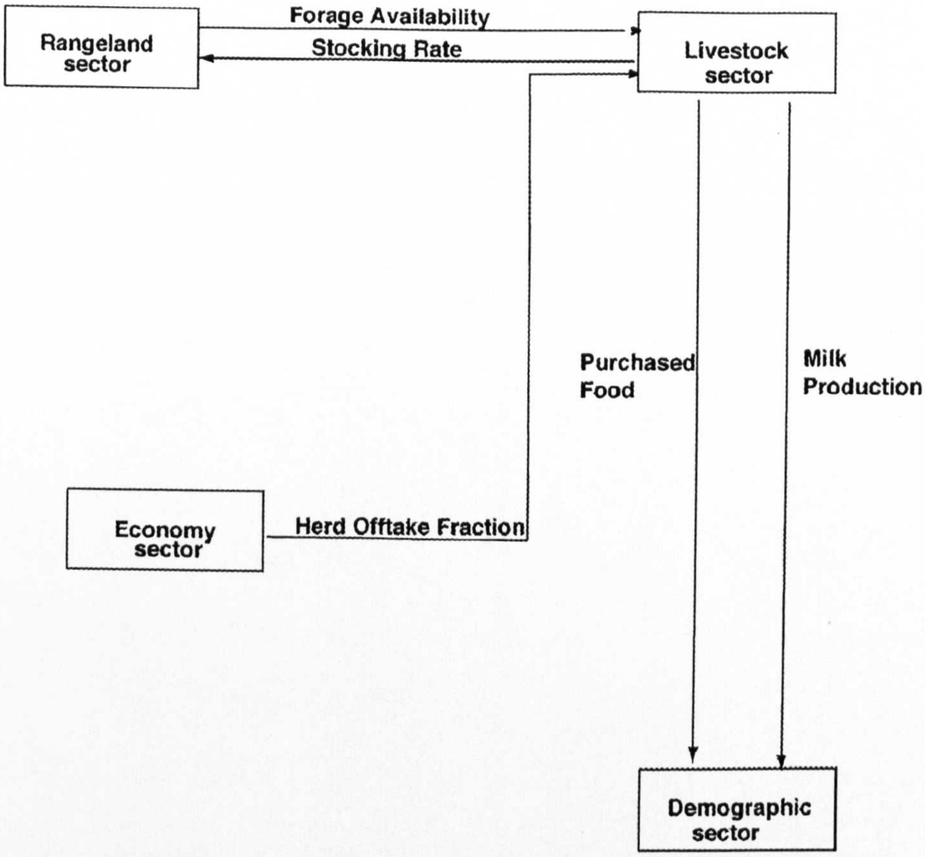

Figure 5.4. Sahel 2

Source: Picardi, 1975

The features of SAHEL2 model (Figure 5.4) are summarised below:

i) the amount of forage used by livestock within a period of time which is called the forage utilisation intensity, links the rangeland and the livestock sectors

ii) the possibilities for the sale of cattle, the offtake rate, links livestock sector with the rest of the economy

iii) rainfall was classified an exogenous factor to the model because functionally it is not affected by any of the interactions in the system but remains an important input into the system.

iv) the population is wholly dependent on milk, meat and the money from the sale of cattle for its sustenance.

v) warfare and public health were exogenous controls on human population.

vi) veterinary services reduced livestock death rate while well digging increased the number of days spent in the Sahel which discouraged livestock movement. Both had a detrimental effect on the rangeland since they increased the forage utilisation intensity. Both veterinary services and well digging were exogenous factors to the livestock sector.

vii) public health services reduced the population death rate and warfare increased the death rate.

viii) high forage utilisation intensity leads to increased soil degradation and a decline in the forage production potential. Picardi (1975) argued that unless the livestock population decreased there would be a long term decline in the area's ability to hold cattle. This was because the recovery of grass is a long term process complicated by soil damage (Picardi, 1975).

ix) the only positive loop for the livestock and human population sectors was the calving rate and the birth rate respectively. The sectors' negative loops are easily weakened (Meadows and Robinson, 1985) which causes the system to deteriorate (Picardi, 1975).

ECNOMAD3

ECNOMAD3 (Appendix 4) investigated the social and economic values that form the basis for the pastoralists' behaviour. Marginal utility, the increase in the benefit from a service or a good similarly as its availability increases, was used to explain both the fertility and offtake rate. Because children are an important source of labour and future social security in the pastoral society, they have a high marginal utility hence the pastoral households have a high fertility rate. On the other hand the marginal utility of purchased food, social infrastructure and the goods, determines how many animals a household sells. Households with a higher utility for purchased goods sold more livestock than those with less utility under similar conditions. However a high marginal utility for milk reduced the offtake. Social infrastructure is the herdsize needed to protect against complete cattle loss during a drought (see Appendix 4). Where there is a high marginal utility of the social infrastructure, the fraction of the herd offtake is low. Households with a high social infrastructure herd have a low marginal utility of purchased goods, and therefore will most likely have a low offtake.

SOCIOMAD

SOCIOMAD investigated the social and economic policies under which sustainable rangeland usage could be attained (see Appendix 5). The main findings are summarised as four points below:

i) benign neglect simulations led to such severe rangeland deterioration that intervention became necessary

ii) increasing the cattle prices to stimulate offtake, had the opposite result as pastoralists sold fewer cattle to get their consumer goods, hence stocking levels increased. Offtake only changed when their society's level of expectations was raised in which case the increased offtake was not in response to the rainfall patterns

iii) overall, accumulating cattle as social infrastructure improves the herd's chances of survival during a drought (Picardi, 1975)

iv) steep taxation for high stocking was considered to enforce low stocking rates. Apart from the likely problems with implementation, taxation did not show decreased stocking during simulation. When the pastoralists stayed for a shorter period within the Sahel than usual, the vegetation in the Sahel improved. But then the pastoralists responded by increasing their herdsize to take advantage of the vegetation, which caused overgrazing in the long term.

Picardi used the Tragedy of the Commons to explain the management problems in the Sahel. He argued that the individual pastoralist's short time horizon objectives were not compatible with conservation in the Sahel. An individual's conservation efforts were unlikely to be successful in a commonage hence there was no incentive for conservation. But he also noted that privatisation of the commonage would not necessarily instil a conservation ethic.

5.4.4 *Policy Sets and Trade Off for Decision Making*

Given the multiplicity of possible objectives for pastoral production in the Sahel, a combination of objectives called policy sets was simulated. In some cases the policies conflict and trade-offs were necessary. The policy sets that Picardi considered are summed in Table 5.3.

SOCIOMAD policy set simulation for the sectors population, rangeland and cattle were graphically illustrated for the period 1972 to 2070 (Picardi, 1975). Policy Set 1 performed poorly throughout. Policy Set 2 needed supplementary feeding which could be at a high cost to the community, a trade off. Policy Set 3, is an improvement to both Policy Sets 1 and 2, smoothed out the variation of livestock numbers. Policy Set 4 introduced veterinary services which made high offtake rate possible. Policy Set 5 increased the wealth target of the population in order to encourage them to maintain the high offtake rather than implement a forced destocking. Policy Set 6 added health improvement, which increased the population and spread out the wealth generated in

Table 5.3 Policy Sets for SOCIOMAD

Policy Set	Comments	Implementation Suggestion
1) Continue as at present	Rangeland almost completely destroyed	Strict control of grazing intensity
2) Direct Stock Control	Sudden large destocking, population starvation, exodus and social insecurity	Add supplementary feeding based on long term sustainable stocking rate
3) Direct control supplementary feeding	Inefficient herd management, no increase in per capita offtake rates	Add veterinary and herd management program
4)-direct stock control: - supplementary feeding: - veterinary and herd management	large forced offtake rate, little improvement in per capita welfare	Add increase intrinsic offtake
5) -direct stock control:- supplemental feeding:- veterinary and herd management:-increased material wealth aspirations	little improvement in per capita health, high cost of supplemental feed	Add health, nutrition, family planning and education programs to policy set 5
6) Direct stock control:- supplementary feeding: veterinary and herd management:-increase material wealth aspirations:-health, nutrition, family planning, decrease social importance of cattle	per capita wealth increase not sustained, high population and out migration, high cost of supplemental feed	Add economic policies to increase present values of stock and decrease value of feed to policy set 5
7)-direct stock control:- supplementary feeding: veterinary and herd management:-increase material wealth aspirations:-economic phasing, price and evaluation policies	little improvement in health and nutrition, large initial destocking	Add health, nutrition, family planning and education programmes to policy set 7
8)-direct stock control;- supplementary feeding:- veterinary and herd management:-increase material wealth aspirations:-economic policies - health, nutrition, family planning education	large periodic population out migration, per capita wealth not sustained, large initial destocking	None

Source: Picardi, 1975:194-195

Policy Set 5. Policy Sets 7 and 8 introduced economic features to reduce the costs of supplementary feed and increase the benefits which enable the individuals' personal wealth to accrue.

Picardi (1975) considered the trade-offs not to be necessarily the most relevant to pastoralists or government officials decision making in the Sahel, but as an exercise in decision making (Picardi 1975:209). He concludes that population growth is the biggest trade off for personal wealth development in most cases and therefore argues for population control. When there is a maximum population pressure in the region, out-migration takes place.

5.4.5 *Validity, Sensitivity and Robustness of Picardi's Model*

Validity describes how the stochastic variation and numerical uncertainty affects the model. The rainfall pattern causes the stochastic variations and the numerical uncertainty is due to the paucity of data. Picardi correctly argued that the model should be evaluated on how well it reflected the dynamics of a problem and not how well it replicates the details of the system in which the problem behaviour occurs. Because the models deals with non-linear systems with complex dynamic structures the validations have not been statistically based (Picardi, 1975). The model represented the dynamics of the system well for the simulation time span. The structural validity is the extent to which the model is based on parameters with a valid functional and causal relationship. This involves matching the levels of details of interacting sectors and understanding the mechanisms that are responsible for the system's behaviour. Because the model used established theories on how the pastoral system works, rather than establish new ones, it was regarded to be structurally valid to the extent that complexity and detail were kept to manageable proportions (Picardi, 1975). Emphasis was placed on the structural validity of the model rather than the accuracy of the numerical outputs.

Sensitivity analysis was carried out on parameters whose value was estimated. They were subjected to variations outside reasonable limits to observe if absurd outputs were realised. Examples of such parameters were the cultural parameters in ECNOMAD3. Most did not cause a significant response in the model. However Picardi concludes that the sensitivity analysis can not be conclusive without the verification in the ground, which was not done.

The robustness of the model's inferences tells us how much trust we can put on a model's outputs given a variety of uncertain operational circumstances. A robust model can be generalised without losing the ability to infer from its outputs (Picardi, 1975). Soil, population, livestock growth patterns offtake trends and desired wealth behaviour were simulated under six rainfall patterns. The model's social and ecological causal factors did not change drastically in the Sahel and therefore the output behaviour did not show stochastic perturbations (Picardi, 1975). This confirms that the model is robust with respect to rainfall, hence the qualitative trade offs are real (Picardi, 1975).

5.5 Braat and Opschoor's Model

Braat and Opschoor (1990) used a system dynamics model to answer the question how much livestock Botswana could support in the future. They described their model as a study of "*relationship between rainfall, range area, grazing capacity and cattle* *herd development. Other factors such as competitive browsing by smallstock (sheep and goats), competition between wildlife and cattle, and alternative investment opportunities may well be relevant in evaluating the uncertainties, risks and effectiveness of management strategies but were excluded from the model*" (Braat and Opschoor, 1990:155).

Braat and Opschoor's model, the national model, predicted the size of the national herd in response to a national annual rainfall pattern. Sections 5.5 and 5.6 discuss the parameters and the causal structure of the Braat and Opschoor model, respectively.

5.5.1 *The Parameters Used In the Braat and Opschoor Model*

This section briefly describes the parameters used in the Braat and Opschoor model. The parameters in the Braat and Opschoor model are a subset of those in the Rain Land Cattle model, which are discussed in detail in Chapter 6. To avoid repetition, the Braat and Opschoor parameters are only discussed in brief here.

5.5.2 *Range Area*

The range area is the total land on which cattle forage. It also called grazing area. The Braat and Opschoor model assumed that more range area means more forage. The range area was based on land with access to water, either boreholes or hand dug wells. The use of grazing land with access to water shows the significance of water in a semi arid rangelands. The model simulated a policy option to increase the range area. The policy was based on the assumption that more boreholes would create more grazing, which was a realistic proposition for Botswana's cattle development then (see Section 1.4).

Two types of grazing were defined. Theoretical grazing is all land within an administrative district that is not built up, cropland, National Park and Reserves or Wildlife Management Area and stateland. Borehole based grazing, or actual grazing, is the 6400 hectares around each borehole to which the water rights holder had de facto grazing rights. Table 5.4 shows that the borehole based grazing was smaller area than the theoretical grazing area. The Braat and Opschoor model used the borehole based grazing. Additional grazing shows the grazing which could be added when additional water points are established. Braat and Opschoor observed that some districts had no space for additional grazing.

Table 5.4. Types and Areas of Grazing (km^2) in Botswana by District

District	Type of Grazing Area (km^2)		
	Theoretical	Borehole based	Additional
Kgalagadi	42 500	7 040	700
Ghanzi	20 700	2 560	4 600
Southern	25 100	25 100	-
Kweneng	31 000	22 120	8900
Ngamiland	51 350	17 350	17 000
Central	100 000	62 400	26 320
North East	2 300	2300	-
Kgatleng	7 400	7400	-
South East	475	475	-
Chobe	4750	3 520	-
National	285 575	150 165	57 520

Source: Braat and Opschoor, 1990:158

5.5.3 *Stocking Rate (ST Rate)*

The model calculates the stocking rate annually. It is expressed conventionally as hectares per livestock unit, (Ha LSU^{-1}). Low stocking rate refers to many hectares of grazing used by few cattle and a high stocking rate is the opposite. The stocking rate is commonly compared to the ability of land to support animals, the Potential

Carrying Capacity or simply the Carrying Capacity. The meaning of Carrying Capacity was explored in Section 3.2.2.

5.5.4 *Potential Carrying Capacity (PCC)*

The Potential Carrying Capacity (PCC) is the amount of land needed to support a livestock unit (LSU). According to Section 3.2.2, PCC is closely related to the grazing capacity. Table 5.5 shows the stocking rate, Potential Carrying Capacity, number of cattle and the area of the range on which the Braat and Opschoor model was based. The Kgalagadi district, which is in the sandveld has the lowest PCC and Chobe in the north has the highest[1] PCC. The South East district, which is in the hardveld, has a PCC which is between the two extremes. The PCC figures tend to correspond to the annual rainfall (see Figure 1.4).

Although the livestock unit (LSU) was used for both stocking rate and PCC, Braat and Opschoor did not define a LSU in their model. The definition of a LSU varies. Field (1978) defined 1 LSU as 500 kg in Botswana and FAO (1991) used 250 kg live weight for Tropical Livestock Unit (TLU). It was assumed that Braat and Opschoor used 1 LSU for 450 kg of animal live weight (Arntzen and Veenendaal, 1987) to determine the national PCC average of 11.5 Ha LSU^{-1}. Evidence from the average cold dressed mass per cattle, around 200 kg (Ministry of Agriculture, 1991), suggests that most cattle in Botswana's communal areas have a mass of less than 450 kg. This means that the total LSU will generally be less than the actual number of animals.

[1] A low PCC shows that many hectares are used per a LSU while a high PCC is the opposite.

Therefore when the number of cattle is not converted to LSU, it creates a higher stocking rate than when the conversion is done. Other uses of the rangeland such as the collection of thatching grass and loss through bush fires which may limit the availability of grazing land, were not included in the model.

Table 5.5 Cattle, Range Area, Potential Carrying Capacity (PCC) and Stocking Rate (ST Rate) of Botswana Districts in 1980

District	Cattle (000)	Range Area (km^2)	PCC (Ha. LSU^{-1})	ST Rate (Ha. LSU^{-1})
Kgalagadi	59	7040	40	11.9
Ghanzi	43	2560	21	6.0
Southern	33	25100	14	7.5
Kweneng	252	22120	12	8.8
Ngamiland	255	17350	10	6.8
Central	1174	62400	16	5.3
North East	141	2300	24	1.6
Kgatleng	110	7400	12	6.7
South East	23	475	10	2.1
Chobe	5	3520	8	70.4
National	2395	150165	11.5(a)	n.a.

Source: Adapted from Braat and Opschoor, 1991:156-159

Notes: (a) The National PCC is not the average of the listed PCC values but an estimate derived from other calculations

5.5.5 *Rainfall*

The model used an "average" annual rainfall of 450 mm for the country. The rainfall was both cyclic and variable. The model represents the cyclic nature (trend) by a cosine wave function, called sine (Figure 5.5). The rainfall trend is part of a cycle that repeats in about 15-17 years (Braat and Opschoor, 1990). The variable nature of the rainfall was represented by an erratic function. The erratic function is combined with the sine wave and the mean rainfall to obtain the total rainfall. The detail on how Braat and Opschoor derived the sine and erratic values is sketchy.

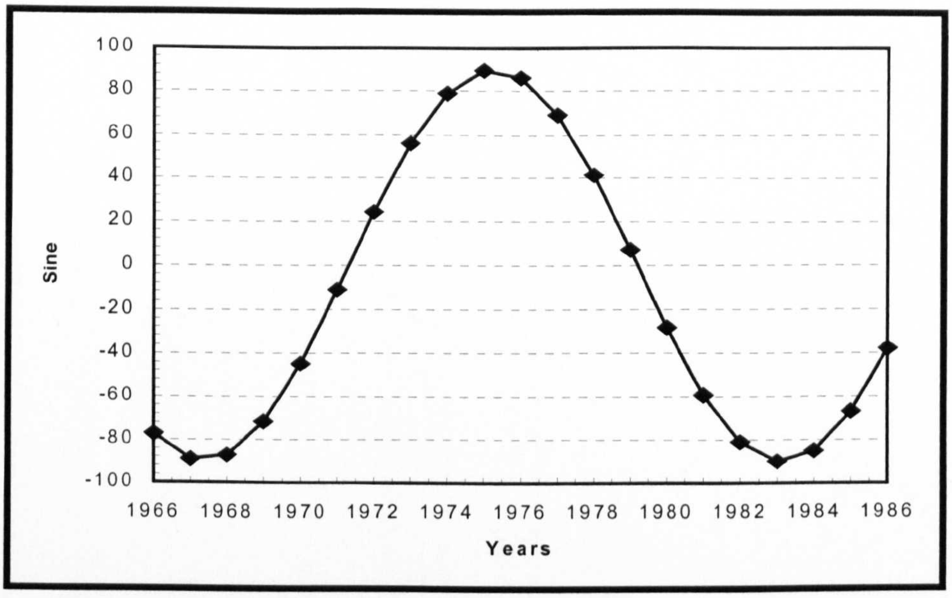

Figure 5.5 The Sine used in the Braat and Opschoor Model
Source: Based on Braat and Opschoor, 1990:163.

5.5.6 *Grazing Capacity (GRACAP), Rainfall Factor (RF Factor) and Stocking Factor (ST Fact)*

The Grazing Capacity is the actual carrying capacity from year to year. The model represented it as the combined influence of the rainfall and the stocking rate on the country's PCC. A comparison of the PCC and the GRACAP indicates the grazing pressure in an area. The GRACAP exceeds the PCC when an area is heavily stocked and the GRACAP is less than the PCC in lightly stocked areas. The RFF Weighted represents this year's and last year's rainfall. The national average annual rainfall was set at 450 mm.

Figure 5.6 shows the influence of rainfall on the grazing capacity. When the RFF Weighted is less than 450 mm the RF Factor is less than unity and it is greater than unity when the RFF Weighted is above average. The RF Factor represents the influence of the accumulated rainfall (RFF Weighted) on the GRACAP. The RF Factor shows that low rainfall reduces the GRACAP, that is it makes it more than the

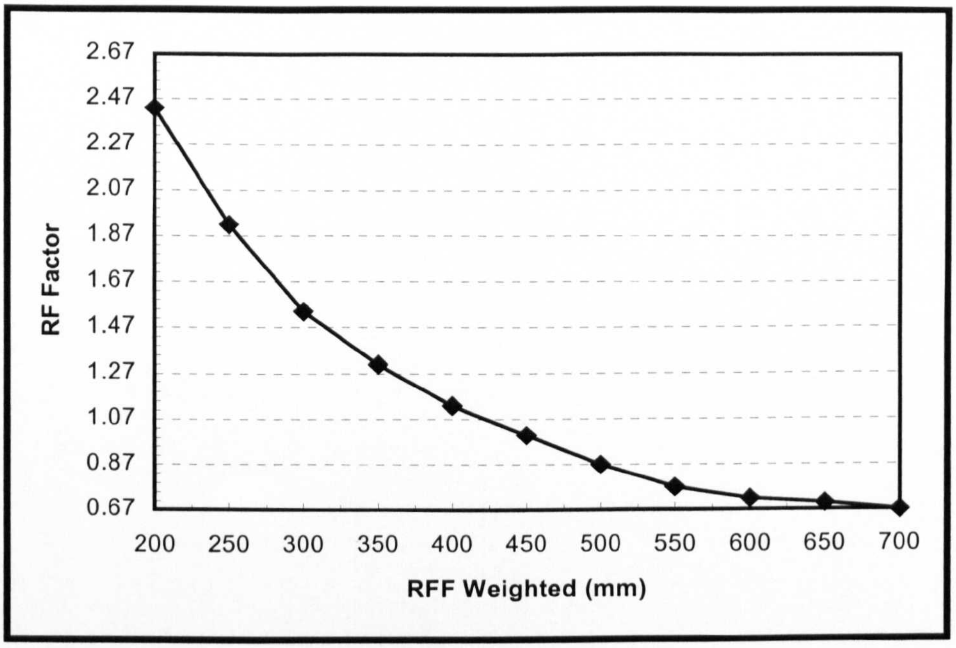

Figure 5.6 The Influence of Rainfall on Grazing Capacity
Source: Braat, personal communication, 1997 b

PCC (11.5 Ha LSU^{-1}) and higher rainfall increases the GRACAP, that is makes it less than 11.5 Ha LSU^{-1}.

Like the rainfall, the stocking rate influences the GRACAP through the ST Fact (Figure 5.7). A stocking rate that is higher than the PCC causes the GRACAP to decline and a lower stocking rate improves the GRACAP. When the stocking rate is equal to the PCC, the ST Fact is at unity. Therefore when the stocking rate is high the ST Fact will be more than unity and vice versa.

Braat and Opschoor argue that high stocking rate or a long period of less than average rainfall leads to a depletion of the grazing and the appearance of rangeland "scars"(Braat and Opschoor, 1990).

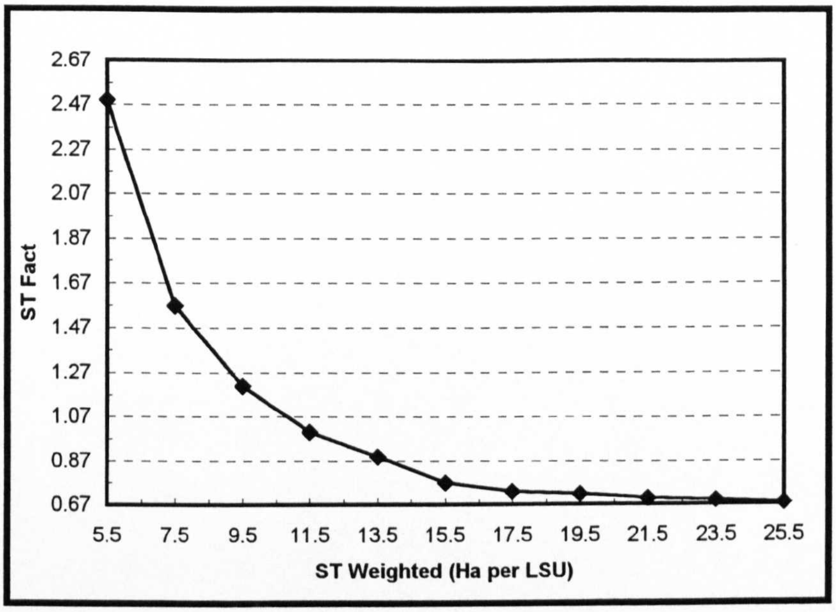

Figure 5.7 Influence of Stocking Rate on the Grazing
Source: Braat, personal communication, 1997 b.

5.5.7 *The Erratic Parameter in the Braat and Opschoor Model*

The erratic parameter simulates the stochastic manner in which the annual rainfall fluctuates. It was constructed from a Stella built in function, Normal. The function has an input structure {Normal (mean, standard deviation, seed)} (Stella Manual Part 1.). The structure shows that the erratic factor is a series of normally distributed random numbers with a given mean, standard deviation and seed. The mean and the standard deviation values may be specified differently from the standard normal distribution of mean, 0, and the standard deviation of 1.

The Structure of the Erratic Function

Braat (personal communication, 1997 a) stated that the erratic function in the model was between -75 and +75. It is not clear why those threshold values were used. Several combinations of the mean and standard deviation give an erratic parameter value of -75 to +75. Figure 5.8 shows the pattern of the erratic function used by Braat and Opschoor.

The national model was reconstructed and rerun to replicate the results obtained by its authors. There was a very good fit ($R^2 = 98.4$) between simulated rainfall and observed cattle numbers which showed that rainfall could be used to predict the number of cattle. Similarly there was a good fit for observed and simulated cattle numbers ($R^2 = 88.0$). There was a poor fit between the observed and rerun rainfall figures. Overall it was not possible to get a good fit of the rainfall figures Braat and Opschoor got for their model from a rerun. The best fit for simulated versus the actual

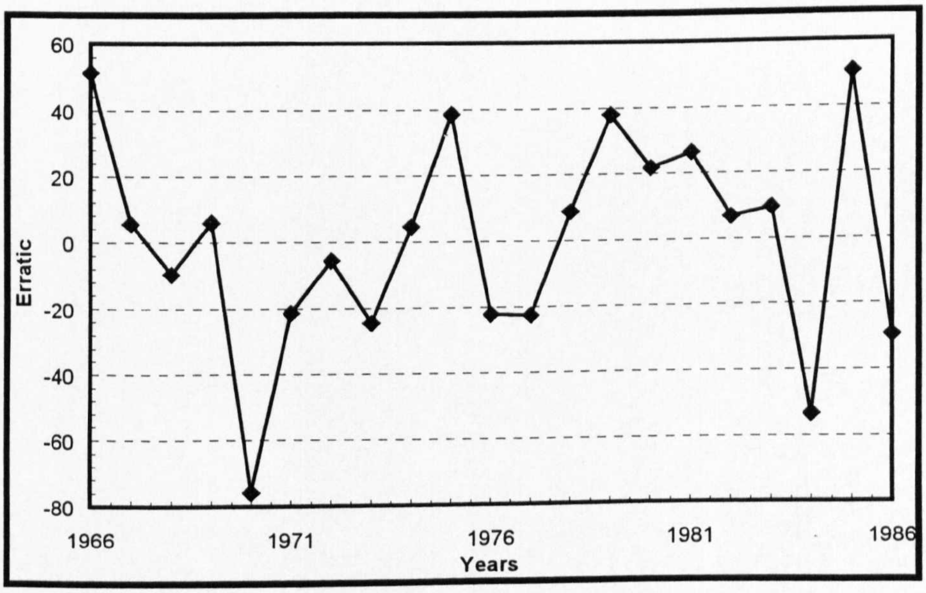

Figure 5.8 The Erratic Component of Rainfall
Source: Based on Braat, personal communication, 1997 (a): Braat and Opschoor 1990:163

rainfall was $R^2 = 45.8$. It was difficult to get a very good fit for rainfall because it is stochastic. The acceptable goodness of fit in stochastic models is lower than that for deterministic models

The Mean and the Standard Deviation in the Erratic Parameter

Increasing the value of the mean in the erratic factor causes an increase in the total rainfall by the same magnitude. For example an increase of 105 units in the mean of the erratic factor will cause an increase of 105 mm in the rainfall amount. On the other hand a change in the value of the standard deviation will cause a proportional change in the erratic parameter as a whole. Therefore an increase of 10 units for the standard deviation of the Normal translates to an equivalent change in the erratic value. The change has minimal effect on the total rainfall. However a decrease in the standard deviation of the normal causes a decrease in the standard deviation of the rainfall, which means it becomes less variable from year to year. Understanding the impact of the variation of the erratic component is important for simulating rainfall change in the Rain Land Cattle model.

The Seed in the Erratic Parameter

Table 5.6 show that the seed has no clear influence on the rainfall and the erratic values. The seed for national model was set at 1.

Table 5.6 The Effect of Seed in the Erratic Parameter in Braat and Opschoor Model

Change in Seed Value	Rainfall Amount		Erratic Amount	
	Mean	Standard Deviation	Mean	Standard Deviation
1 to 5	-4.7	-2.36	-3.95	-4.04
5 to 10	+5.89	+6.51	+5.96	+2.8
10 to 15	-5.94	+5.52	-5.32	+2.87
15 to 50	+6.36	-14.87	+4.79	-0.94
50 to 100	-7.06	+6.5	-4.58	-6.48
100 to 1000	+6.49	-8.04	+3.67	+4.92

When the seed value is not stated different erratic values, hence annual rainfall patterns, are generated with each model run. In order to replicate rainfall values, the seed must be stated. Braat and Opschoor did not state what seed value they used for their model. The effect of the value of the seed on the rainfall and erratic mean was investigated using the fixed values for the normal mean and standard deviation.

5.5.8 *Cattle*

Cattle refer to the national herd. Braat and Opschoor's figures were based on the Ministry of Agriculture's figures (Braat and Opschoor 1990). The figures may vary between sources. For consistency it is best to stick to one source. The national herd oscillated between 1 million and just over 2 million between 1966 and 1986.

5.5.9 *Births and Deaths*

In principle during a drought, the death rate increases while the birth rate decreases, and the trend is reversed during a good rainfall season. Figure 5.9 shows the influence of the GRACAP on the birth rate.

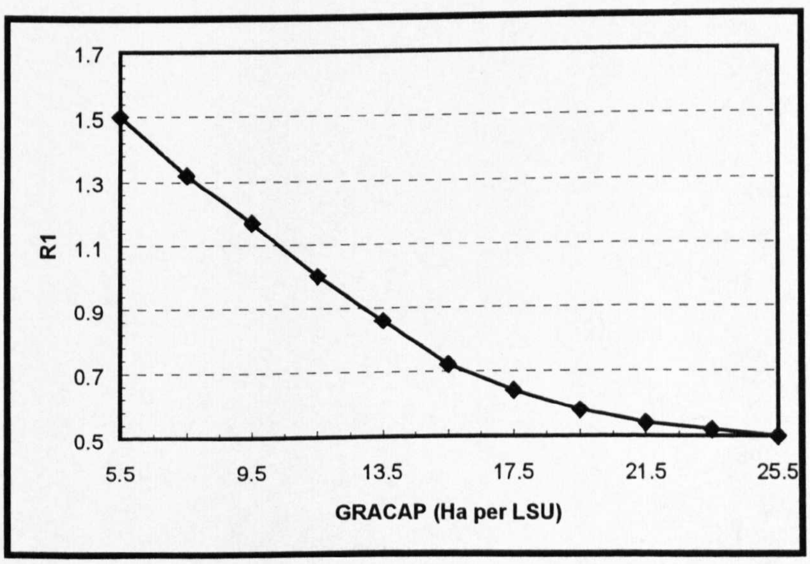

Figure 5.9 Influence of Grazing Capacity on Birth Rate in the Braat and Opschoor Model
Source: Braat and Opschoor 1990:161.

The cattle birth and death rates are based on observations made countrywide by the Ministry of Agriculture (Braat and Opschoor, 1990). Vossen (1987) studied the relationship between cattle death rates and the nature of the rainfall season in Botswana (see Section 3.3.3). Based on his findings the death rate was 14.4 percent in an overstocked region, 12.8 percent for a region at PCC and 10.7 percent for an understocked region (Vossen 1987:27). If we use the region stocked at PCC as the base with a value of 1, the overstocked region will be equal to 1.156 and the understocked region equal to 0.836. Braat and Opschoor seem to have used Vossen's findings to set the limits of the Death Influencing Factor. The Death Influencing Factor (R2), in Figure 5.10, is at unity when the GRACAP is equal to PCC.

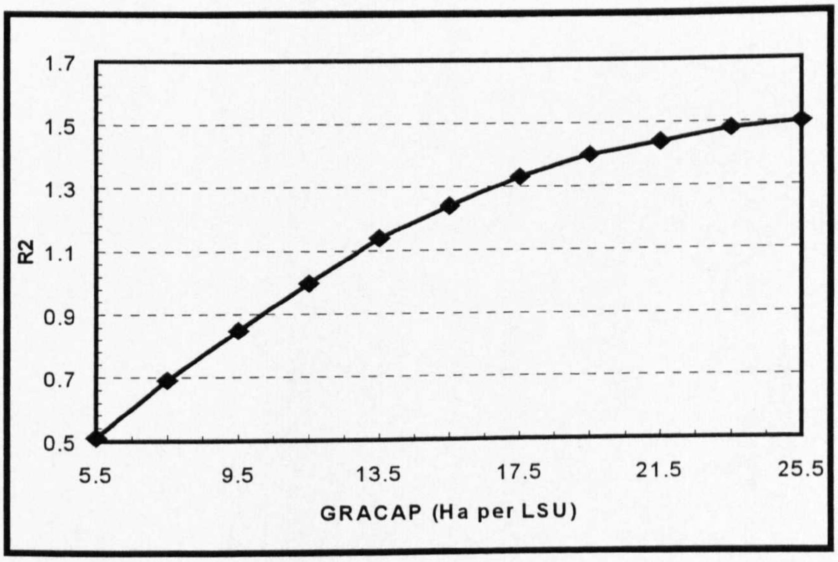

Figure 5.10 Influence of Grazing Capacity on Death Rate in the Braat and Opschoor Model
Source: Braat and Opschoor 1990:162

R2 increases when the GRACAP is smaller than the PCC, that is a bigger value than 11.5 Ha LSU^{-1}, and vice versa. The relationship shows that the death rate increased when a grazing land has more cattle that its PCC. The explanation for the increased deaths is that livestock will not have adequate forage when the GRACAP is smaller than the PCC. The opposite effect is true for the Birth Rate Influencing Factor (R1). When the GRACAP is smaller than the PCC, the R2 value decreases which leads to a low birth rate. The opposite is true when the GRACAP is higher than the PCC.

5.5.10 *Purchase*

The purchase represents cattle that are brought into the country from outside.

5.5.11 *Management Policies*

Braat and Opschoor were interested in showing the effect of increased offtake and increased range area on the livestock sector in Botswana. Increased offtake will reduce the national herd, especially in the communal areas where most of the cattle are in Botswana. The communal livestock sector has a lower offtake rate than the commercial sector (Ministry of Agriculture, 1991) because communal farmers only sell cattle during household emergencies rather than as part of a maintenance strategy (Fidzani, 1993). Increasing the national range area is feasible in the sandveld where unused potential grazing areas may be tapped when boreholes are sunk to provide water. But most of the best grazing areas are already taken and new areas will have poorer grazing quality than the existing ones. Braat and Opschoor (1990) endorsed the latter observation in their model appraisal.

5.6 The Causal Structure of The Braat and Opschoor Model

Section 5.4 introduced links and loops in system dynamics models. Braat and Opschoor (1990) did not describe the causal structure of their model. The present study identified six loops in the Braat and Opschoor that are shown by the causal diagram Figure 5.11.

Loop 1. <u>Stocking rate - Grazing Capacity- Deaths- Cattle - Stocking rate</u>

The loop is negative because an increase in stocking rate leads to a decrease in grazing capacity; a decrease in grazing capacity leads to an increase in the death rate; and an increase in deaths leads to a decrease in the number of cattle or herd size.

Loop 2 <u>Stocking rate-Grazing Capacity- Births- Cattle- Stocking rate</u>

Loop 2, is similar to Loop 1, but in this case it represents births rather than deaths. It has a negative causal loop because of the one negative link between stocking rate and grazing capacity described in Loop 1 above. The births and cattle have a positive link and so does cattle and stocking rate.

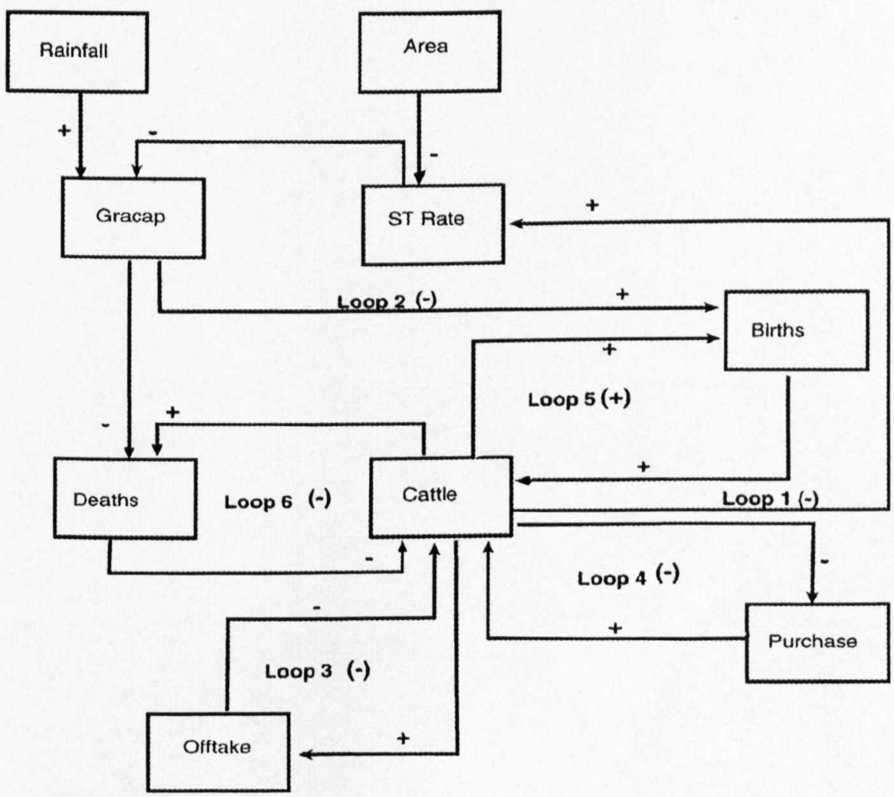

Figure 5.11 The Causal Diagram for the Braat and Opschoor Model

Loop 3 **<u>Cattle -Offtake - Cattle</u>**

As the national cattle number increases there was an increase in the offtake and with increased offtake, the cattle number will be reduced hence a negative link therefore Loop 3 is negative.

Loop 4. **<u>Cattle-Purchase- Cattle</u>**

Purchases of cattle from outside the country increase when there is a decrease in the numbers within the country. In turn an increase in the national herd leads to a decrease in the number of purchases whilst an increase in the purchases will lead to a growth of the herd size. The loop is negative.

Loop 5 **<u>Cattle - Births - Cattle</u>**

Loop 5 is the only positive loop in the model. It shows that more births will cause an increase in the herdsize which in turn leads to more births or vice versa.

Loop 6 **<u>Cattle - Deaths - Cattle.</u>**

Increased deaths will lead to a decline in the number of cattle and more cattle leads to more deaths. The loop is negative.

The interaction of the links described in the six loops above leads to changes in the rainfall, number of cattle and the other model parameters. Table 5.7 lists all the parameters shown by model structure in Figure 5.12. The classification used for the parameters in Table 5.7 is based on the description found in Section 5.4.1. The parameters for each type, such as Auxilliary, are alphabetically arranged.

Table 5.7 Types of Parameters used in the Braat and Opschoor Model

Parameter	Type	Unit Measurement
Birate	Auxiliary	percent
Erratic		random number
GRACAP		km^2 LSU^{-1}
NDRate		percent
POLICY1		percent
Ratio		ratio
RFF Weighted		mm
Sine		degrees
ST Rate		km^2 LSU^{-1}
St Weighted		km^2 LSU^{-1}
PCC	Constant	km^2 LSU^{-1}
R1 and R2	Graphical Function	ratio
RF Factor		ratio
Stfact		ratio
Cattle	Level	millions
Delayed Rain		mm
Delayed ST Rate		km^2 LSU
Parameter	Type	Unit Measurement
Range Area	Level (or state variable)	km^2
Births	Rate	number of cattle
Del RFf		mm
DRAIN1		mm
Inrate		km^2 LSU^{-1}
NatDeath		number of cattle
Offtake		number of cattle
Outrate		km^2 LSU^{-1}
POLICY2		percent
Purchase		number of cattle
Rainfall	State Variable	mm

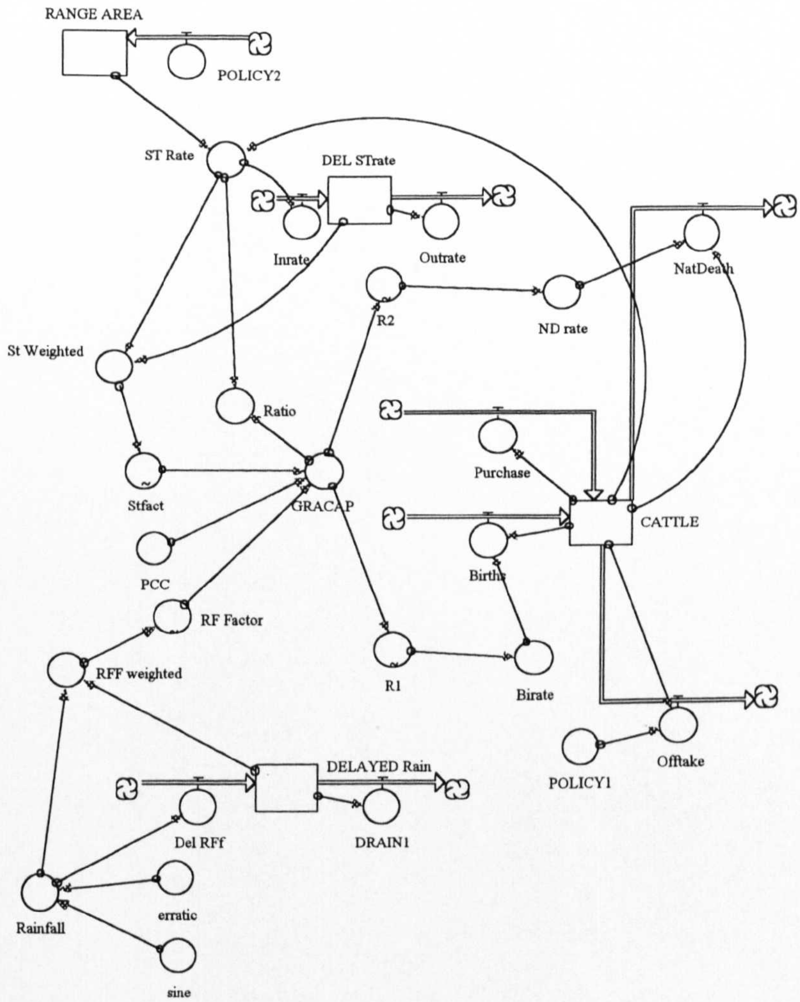

Figure 5.12 The Structure of the Braat and Opschoor Model
Source: Braat and Opschoor 1990: 163

5.6.1 *Findings of the Braat and Opschoor Model*

Braat and Opschoor found that *"even though several initial conditions are not known and the rainfall table function can only generate historical data every other year the simulated herd development follows historical data rather closely"* (Braat and Opschoor, 1990:164). They observed that the model predicts a sustainable national herd size of around 2.3 million cattle. A simulated average Ratio of fifty five percent suggests that the rangeland is permanently under stress. In the long term, when the offtake is increased, the simulated ratio is above 100 which shows a rangeland that is not under stress. The model found that as more boreholes were opened, the increased grazing area led to a decrease in the stocking rate. It also found that offtake was an effective way to control stocking rates. The annual rainfall influences the productivity of cattle. One year with less than average rainfall has limited effect on the cattle numbers but several below average years will cause an increase in cattle mortality.

5.6.2 *Significance of the Braat and Opschoor Model*

The model shows a GRACAP which is persistently smaller than the PCC since the Ratio was always above 100, which indicates a rangeland that was under stress. The finding means that there are more cattle in an area than what it is believed to be able to hold. Drought caused a drop in the cattle population but even the most severe and prolonged drought does not lead to cattle extinction. Ellis and Swift (1988) made a similar conclusion in Kenya. Increased offtake reduces the number of cattle. The majority of communal households are known to sell cattle only when there is a pressing household need and not as a management strategy (Fidzani, 1993). In reality increasing offtake depends on the household's willingness to sell and the capacity of the national abattoirs, which was increased in 1990 (Section 1.4.2). The Braat and Opschoor model excludes the influence of other livestock that jointly use the range with cattle. The omission may not drastically alter the conclusions of the study since Braat and Opschoor did not convert the number of cattle to Livestock Units (LSU) which means that the model over represents cattle as LSU. Though the model is a methodologically sound way to simulate rainfall, cattle and land interactions the national average rainfall was too coarse for the district level stocking rates and PCC because of the variability of rangelands noted in Section 3.2.

Summary

The six models described in this chapter, deal with various aspects that emphasise new thinking in cattle management in rangelands. The bio - economic models emphasise the financial controls, the static models show how rainfall affects forage. System dynamics models simulate a system using links and loops, which are either negative or positive. System dynamics is attractive for management intervention studies because when each link and loop is described functionally, parameters that can be used for effective management intervention are identified. Modelling cattle management enables experiments and proactive management with minimal negative effects on the rangeland. The chapter introduces the Braat and Opschoor model, which is the basis for the Rain Land Cattle model that will be discussed in the next chapter.

Chapter 6. The Rain Land Cattle Model

Introduction

This chapter describes the Rain Land Cattle model, which is developed in this study. The model contributes to studies on local cattle management in communal areas of Botswana. The model is expected to apply outside the communal areas. The chapter consists of eight sections. Section 6.1 describes the conceptual model on which the Rain Land Cattle model is based. Section 6.2 is a detailed analysis of the causal structure of the model. Section 6.3 explains how rainfall, the main driving parameter in the model, is simulated. It also defines the rainfall scenarios which are obtained from the model. Sections 6.4, 6.5 6.6 and 6.7 describe and justify the equations and parameters in the Rainfall, Land, Cattle and Livestock Water sub - models respectively. A full list of the parameters is presented in Appendix 6. Section 6.8 draws the differences between the Braat and Opschoor model and the Rain Land Cattle model.

6.1 Conceptual Model of Cattle Management in Tlokweng Sub District

The conceptual model (Section 5.1.1 discusses a conceptual model) on cattle management in Tlokweng Sub District, from which the Rain Land Cattle model is derived, is shown in Figure 6.1. The conceptual model is developed for the present study based on the results of the questionnaire and in – depth interviews. Other questionnaire findings are presented in Section 7.6. The conceptual model shows that crop production and other livestock, such as goats and donkeys, are not included in the management scenarios. The management activities are in two categories, those affecting small and those affecting large herds. The management considered deals with

with grazing areas, livestock water sources and household management factors. Each management factor is characterised according to the number of cattle observed.

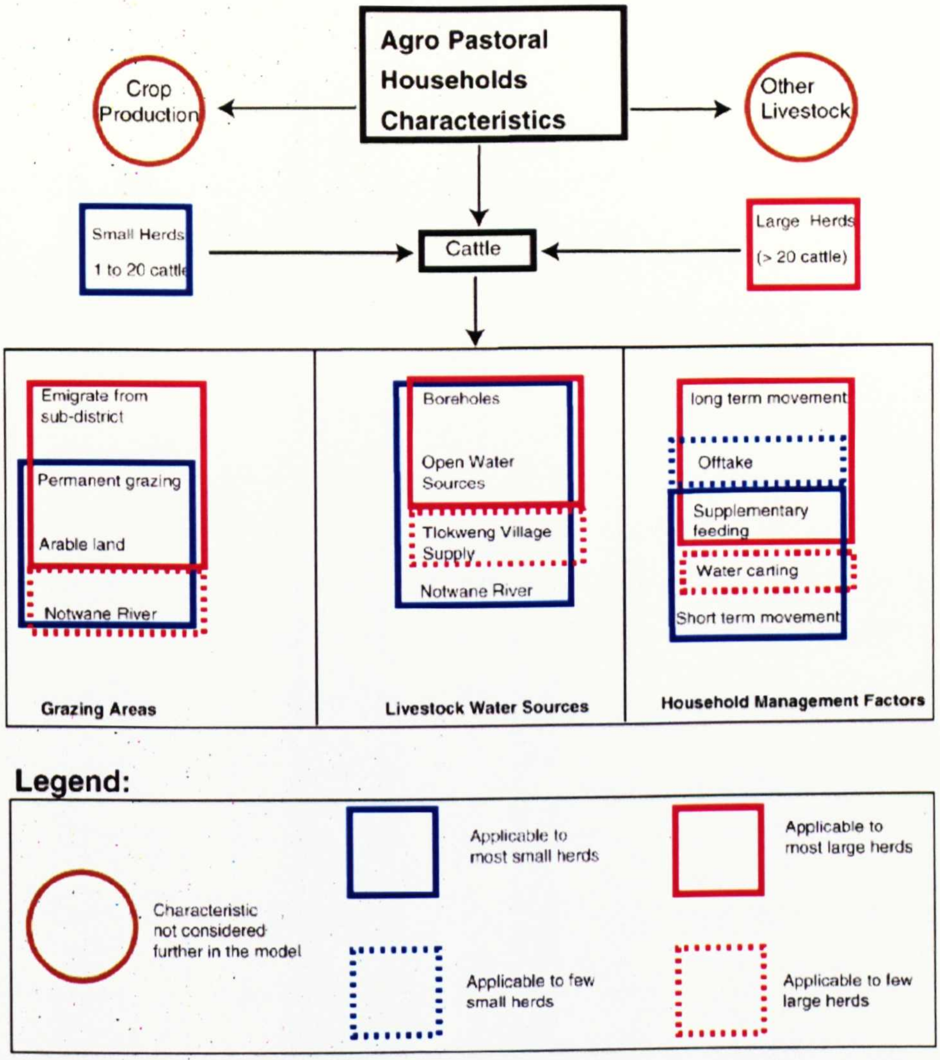

Figure 6.1 Conceptual Model of Cattle Management on Tlokweng Sub District

The number of cattle involved in the different management factors was classified into "most" or "few". The classification was based on the numbers observed in the study area and those reported by the respondents. The conceptual model shows that few large herds and most small herds graze along the Notwane River. Small and large herds use the permanent grazing area and the arable (seasonal) grazing area. Large herds emigrate from the sub district on a long term basis but small herds do so on a short term basis. Both households with small and large herds practise supplementary

Boreholes are popular livestock watering places during the dry season or drought, but many small herds also water from the Notwane River. Carting water from Tlokweng village for livestock is more popular with small cattle herd owners than the large herd owners. Small herds water from several sources depending on the availability, nearness and the cheapness of the water source in relation to the livestock grazing. Large herds are watered mostly from boreholes. Large cattle owners sell cattle regularly but small herd owners do not.

After the conceptual model has defined the broad scope of the Rain Land Cattle model, the rest of this chapter discusses the model in detail.

6.2 The Causal Structure of the Rain Land Cattle Model

Before discussing the causal structure of the Rain Land Cattle model, Figure 6.2 shows a diagram of the model. When compared to Figure 5.12, which shows the Braat and Opschoor model from which it is developed, Figure 6.2 has more parameters and linkages. The discussion of the Rainfall, Grazing, Cattle and Livestock Water sub - models in Sections 6.2.1 to 6.2.4 shows the detail about the parameters in Figure 6.2. The sections also explain the causal structure for each sub - model. To appreciate the discussion of the causal structure for the sub - models and their interactions fully, it will be useful to refer to Figure 6.2 for the complete picture of the model parameters. Section 5.4 will refresh the understanding on how links and loops operate. Causal relationships used to describe the loops are generalised. For example it is generally expected that more cattle mean more births.

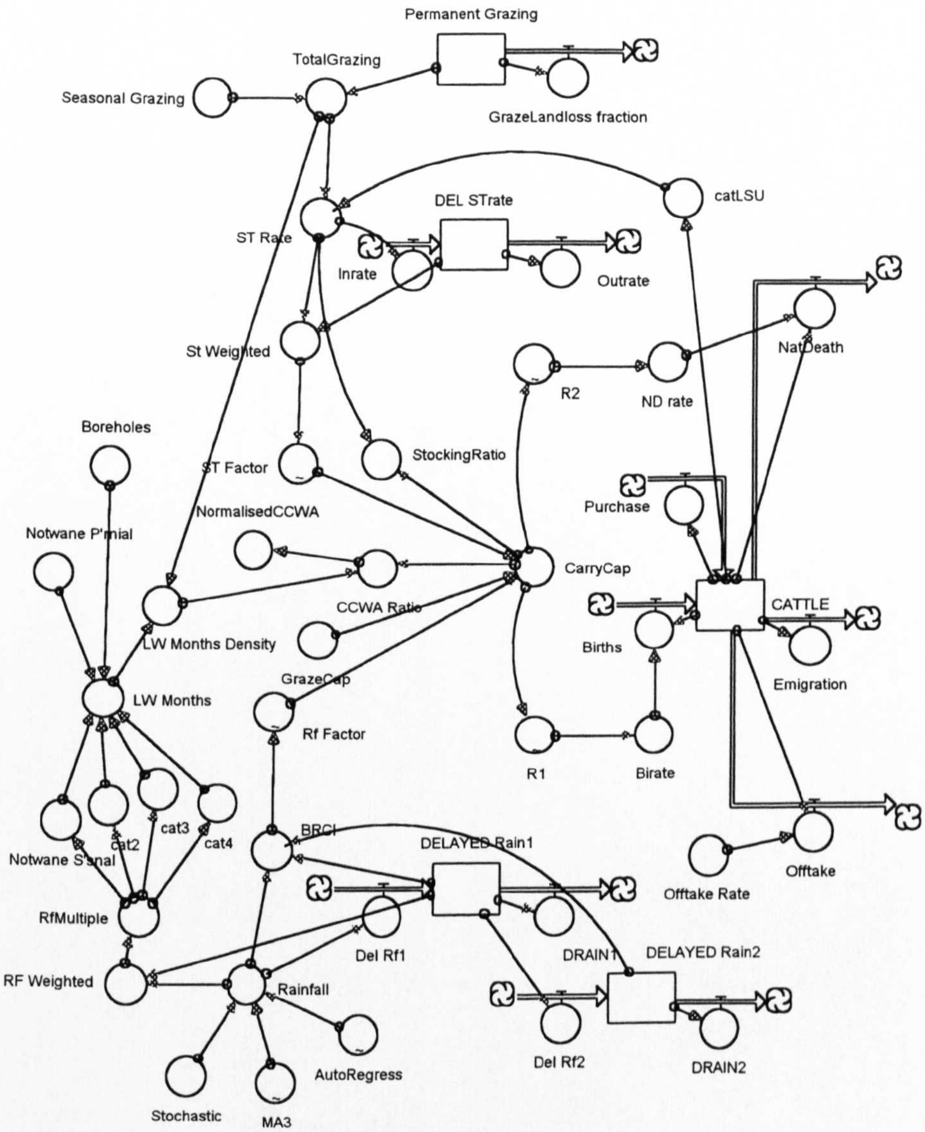

Figure 6.2 The Structure of the Rain Land Cattle Model

6.2.1 *The Rainfall Sub - Model*

The Rainfall sub - model (Figure 6.3) deals with all the rainfall parameters in the model. Rainfall, the main driving force for the model is an exogenous model parameter because it is given and not changeable by any of the cattle management processes. The Rainfall sub - model consists of three parameters, the Stochastic which has a mean and standard deviation, the RF Weighted and Botswana Range Condition Index (BRCI) (Section 6.4.4), which represent the rainfall in the past year and previous year. The causal diagram for the sub - model has three positive loops. Loop R1 shows that a high Stochastic mean leads to a high rainfall and vice versa. In turn a high rainfall has

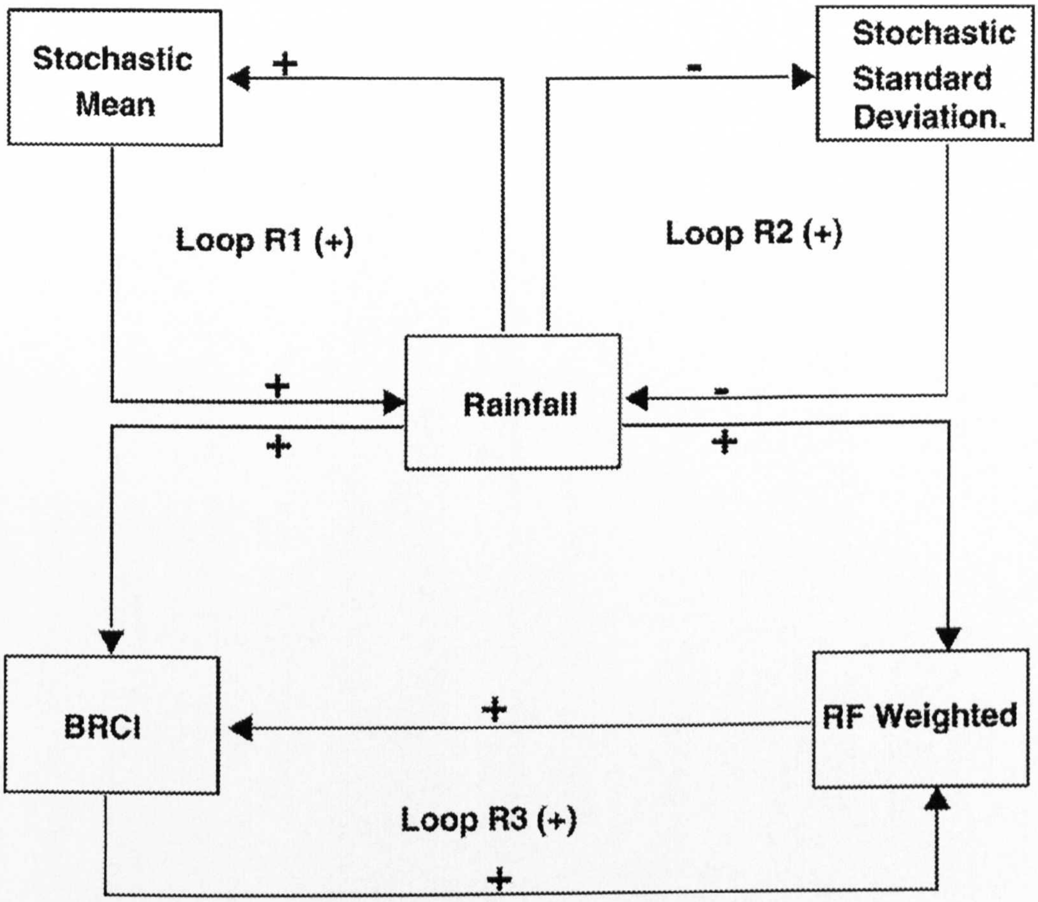

Figure 6.3 The Causal Diagram for the Rain Sub - Model

a high Stochastic mean. Loop R2 shows that a low Stochastic standard deviation leads to a low rainfall and a high Stochastic standard deviation leads to a high rainfall. This is because in areas with a high rainfall there is a low rainfall variation and vice versa. The two negative links between the rainfall and the Stochastic parameters form a positive feedback loop. Loop R3 shows that a high RF Weighted will lead to a high BRCI and similarly a high BRCI leads to a high RF Weighted. But the RF Weighted and BRCI are not linked back to the Rainfall because they represent rainfall during the past years which in this model plays no part in the present year's rainfall.

6.2.2 *The Grazing (Land) Sub - Model*

The Grazing sub - model (Figure 6.4) shows the availability of grazing land in the communal system.

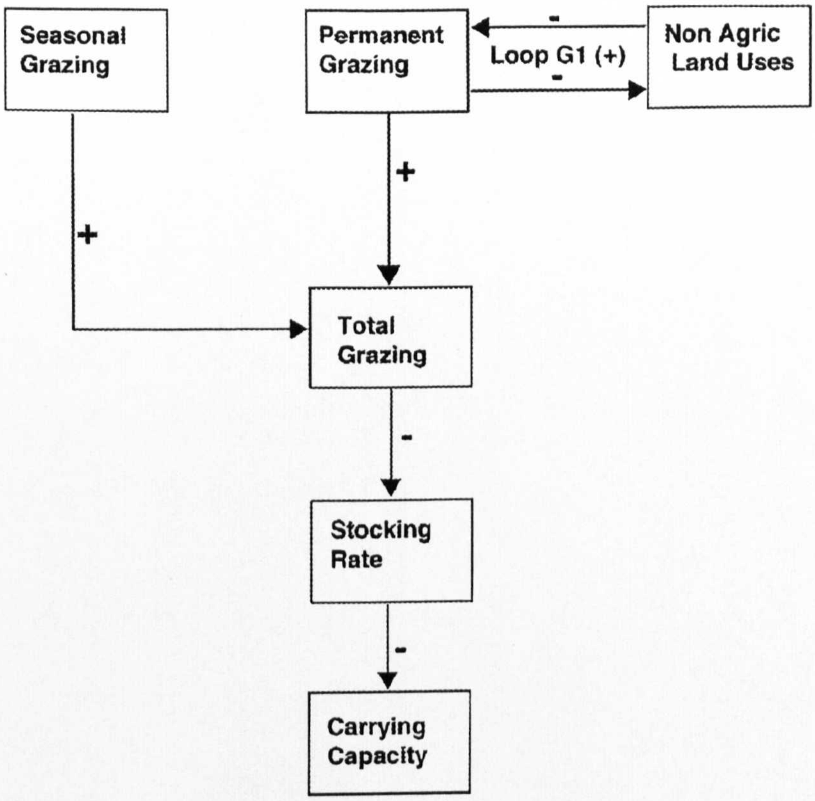

Figure 6.4 The Causal Structure for the Grazing Sub - Model

The sub - model consists of six parameters which are Seasonal, Permanent Grazing, Total Grazing, Stocking Rate, Carrying Capacity and Non Agricultural landuse. Stocking rate is the number of cattle in a grazing area. Non Agricultural landuse is exogenous to the model. The sub - model has one positive loop, Loop G1, which is made of two negative links between Permanent Grazing and Non Agricultural Land uses. Two negative links make a positive loop. The links between the two are negative because more non agricultural land uses, mainly settlement, will cause a decrease in permanent grazing and vice versa. The area of Permanent Grazing declines mainly due to the expansion of settlement in the Tlokweng sub-district. The seasonal grazing in the model is fixed but in reality it increases marginally at the expense of permanent grazing. The total grazing increases when the permanent or seasonal grazing increases and vice versa. Therefore there is a positive link between total grazing and permanent or seasonal grazing. More total grazing (Ha) will reduce the Stocking Rate (Ha LSU^{-1}), which means the link is negative. A high stocking rate, the number of cattle in an area, will reduce the carrying capacity and vice versa, therefore the link between the two is negative.

6.2.3 *The Cattle Sub - Model*

The cattle sub - model (Figure 6.5) has six parameters, which are Births, Deaths, Offtake, Purchase, Emigration and Cattle.

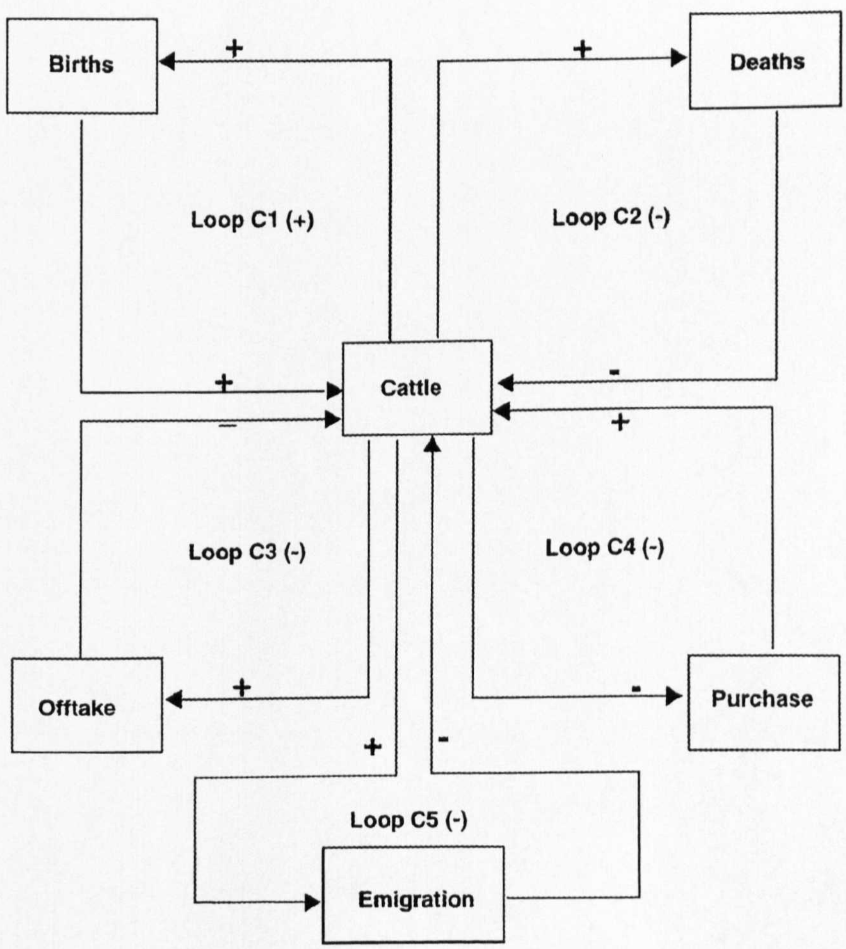

Figure 6.5 The Causal Diagram for the Cattle Sub - Model

The sub - model has five loops. Four of the five loops (C2 to C5) are negative and one (C1) is positive loop. Loop C1 shows that other things being equal, cattle births and numbers positively reinforce each other, that is more cattle means more births or more births means more cattle and vice versa. Loop C2 is negative because as the number of cattle increases, the number of deaths increases proportionally and a high number of deaths cause the cattle population to decline. Loop C3 is negative because an increase in offtake causes a decline in the cattle population and when the cattle population increases the offtake increases accordingly. This is because when there are many cattle, farmers have enough cattle to sell while retaining the breeding herd or a critical minimum herd. The negative Loop C4 shows that when the cattle population in the study area is high, there will be a decrease in the livestock purchases from outside the area and when the purchase rate increases the number of cattle increases too. Lastly, Loop C5 shows that many cattle in the area leads to a high emigration, a positive link, which reduces the number of cattle in the area, a negative link. A negative and a positive link form a negative loop.

6.2.4 *The Livestock Water Sub - Model*

The Livestock Water Sub - Model (Figure 6.6) does not have any loops. It is made up of three positive links between the four variables RF Weighted, Number of Water Sources, Livestock Water Months and the Carrying Capacity Water Availability (CCWA) Ratio. Further detail on the livestock water and its related concepts can be found in Section 4.3 and Section 6.7. In the sub - model, as the RF Weighted increases, the number of water sources increases, which increases the water availability and the CCWA Ratio in turn increases. The relationship between the parameters shows parameters shows that more rainfall results in higher CCWA Ratio. A high CCWA Ratio indicates that the rangeland's ability to sustain livestock has improved.

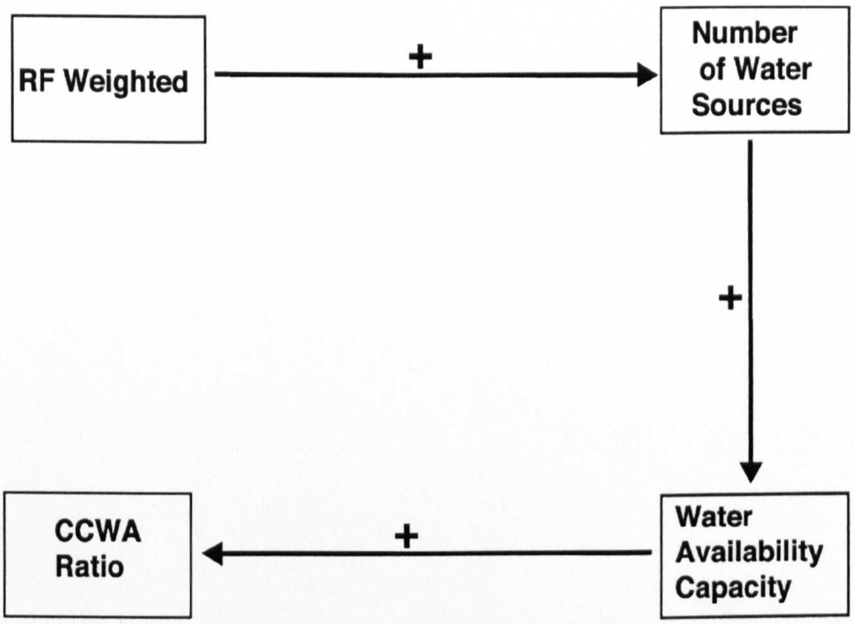

Figure 6.6 The Causal Diagram for the Livestock Water Sub - Model

6.2.5 *The Interaction of the Four Sub - Models*

The four sub - models, namely Rainfall, Grazing Land, Cattle and Livestock Water interact in the main model as shown in Figure 6.7. Five negative loops were identified. Loop M1 links the Cattle (C) and Grazing (G) sub - models. A decrease in the number of cattle leads to decreased grazing pressure, which in turn leads to an increase in the number of cattle. This is because as the grazing pressure increases, each animal has less grazing land to forage from, which implies less forage. An increase in the grazing pressure causes a drop in the cattle population as there is less forage for each animal. Loop M2 links Cattle, Livestock Water and Cattle. It shows that an increase in cattle leads to a decrease in livestock water and limited livestock water availability will lead to a low cattle population. The positive and the negative link make a positive loop.

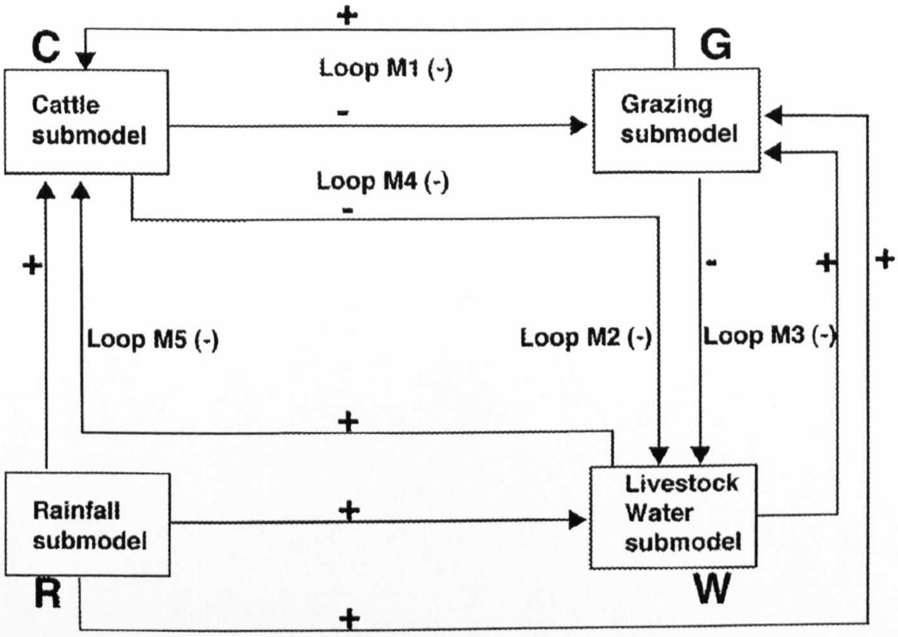

Figure 6.7 The Causal Diagram for the Interaction of the Sub - Models

Just like the lack of availability of forage in Loop M1 will increase cattle mortality, in Loop M2 a shortage of livestock water will increase cattle mortality. Loop M3 links Grazing, Livestock water and Grazing. The links shows that increased livestock water opens more grazing, which is a positive link. But a large grazing area diminishes the water sources, which is a negative link. The Loop M4 connects Cattle (C), Livestock Water (W), Grazing Land (G), Cattle (C). It shows that more cattle will lead to less livestock water, a negative link. Like Loop M3, more livestock water enables more grazing to be used, or vice versa, which is a positive link. More grazing land increases the number of cattle in an area which is a positive link. Loop M4 has two positive links and one negative link therefore it is negative. The last loop, M5, links Cattle (C), Grazing (G), Livestock Water (W) and Cattle (C) sub - models. The loop shows that more cattle will lead to less grazing land, which is a negative link. More grazing land leads to less available livestock water and limited livestock water causes a decrease in cattle population. Link M5 is positive. Rainfall, the main driving force of the model, has a positive link to each sub - model which shows that its abundance or scarcity has a directly correlated impact the sub - models.

6.2.6 *Observations on the Causal Structure of the Model*

The structure of the model is best understood through the sub - models. Table 6.1 summarises information about the loops for the sub - models. Figure reference number (Figure Ref. No.) in Table 6.1 indicates the diagram from which the information was obtained. The sub - models are made up of nine loops, five of which are negative and four are positive. Negative loops check the reinforcement of the effect of positive loops. Within each sub - model there are further links between parameters.

Table 6.1 Number and Sign of Loops in the Rain Land Cattle Sub - Models

Sub - Model Name	Figure Ref. No.	No and Type of Loops		Total No of Loops
		(+ ve) Loops	(- ve) Loops	
Rainfall	6.3	3	0	3
Grazing	6.4	0	1	1
Cattle	6.5	1	4	5
Livestock	6.6	0	0	0
Four sub - models	6.7	4	5	9

6.3 The Simulation of Rainfall in Stella

The rainfall for 1945 to 1995 was decomposed into four components using Minitab as described in Section 4.2. The four components outputs obtained were:

i) the annual rainfall mean for the period 1945 to 1995, which is 520 mm;

ii) the 2nd order auto regression with 3 steps described in Gottman (1981:272-277);

iii) a 3 year moving average, after the removal of the Autoregressive component;

iv) a stochastic component.

It was assumed that the Autoregressive, the Moving Average and the Mean will be the same in the long term as for the 1945-1995 period because the rainfall data are stationary. The Autoregressive and the Moving Average were used as time dependent graphical function inputs in Stella, to show the rainfall trend. The annual rainfall mean, 520 mm, was input as a constant to calculate the rainfall. Because the rainfall data are stationary, the simulations have a trend that oscillates around a long term mean of about 520 mm. The Stochastic parameter was the source of variation for the predicted annual rainfall in the model. The mean and standard deviation of the Stochastic parameter were varied to show different rainfall scenarios.

6.3.1 *The Stochastic Component of Rainfall in the Model*

An in - built Stella function called Normal, was used to define the stochastic component of rainfall in the model. The function generates random numbers with a given mean and standard deviation. The Stochastic component has a normal distribution, zero mean (the actual stochastic rainfall mean of was -0.7.) and a standard deviation of 117.2. A seed of 1000 was used in the simulation. A seed is a number between 1 and 32767 which enables the random stream of numbers to be replicated (Stella II Technical Documentation, 1993). It is necessary to be able to use the same stream of random numbers because varying streams of numbers would inadvertently vary the outputs.

6.3.2 *Varying the Mean and Standard Deviation (SD) of the Stochastic Parameter*

Varying the mean and the SD of the stochastic parameter created eight rainfall scenarios. A rainfall scenario in this context is a the temporal pattern obtained from a given set of conditions. The conditions refer to the values set for the mean and the standard deviation. The scenario closest to the realisation of the observed rainfall parameters is called the Base Run. It is the point to which the model is calibrated or standardised. Table 6.2 shows the settings for the Stochastic parameter when simulating annual rainfall. Figure 6.10 to Figure 6.13 depict two scenarios alongside the Base Run for comparison. The main points about each scenario are discussed in Sections 6.3.4 to 6.3.7. Section 6.3.8 summarises the effect of varying the mean and the standard deviation of the stochastic.

Table 6.2 The Setting of the Mean and Standard Deviation (SD) of the Stochastic Parameter Used to Simulate Rainfall Scenarios

Scenario	Stochastic Mean and SD	Brief Description of the Scenario
Base Run	Mean 0 SD 117.2	Mean and SD as in Observed Rainfall
1	Mean100 SD200	Increase Both
2	Mean150 SD250	Mean and SD
3	Mean-50 SD50	Decrease Both
4	Mean-100 SD0	Mean and SD
5	Mean-50 SD150	Decrease Mean and
6	Mean-150 SD250	Increase SD
7	Mean100 SD17.2	Increase Mean and
8	Mean200 SD-117.2	Decrease SD

6.3.3 *Comparison of Base Run and Observed Rainfall - The Prediction Error*

The first stage in dealing with the simulated rainfall was to establish a Base Run, which is the closest simulation to the observed data. The Base Run was altered to reproduce different scenarios discussed in Sections 6.3.1 to 6.3.7. Figure 6.8 shows the difference between the observed and the Base Run, which is simulated rainfall. Figure 6.9 shows the prediction error that was calculated using Equation 6.1. Eye examination of Figure 6.8 suggests that the observed and simulated rainfall have a similar trend but with a marked difference in rainfall amount. The prediction error (Figure 6.9) was highest in

(Figure 6.9) was highest in 1983 to 1985, where there was an over prediction of 77 to 97 percent. The biggest under prediction was 55.4 percent in 1967, when the Base Run predicted 411 mm for an actual rainfall of 923 mm. The positive mean prediction error of 9.11 shows that the overall tendency was to over predict.

Equation 6.1 The Prediction Error

$$\frac{P - A}{A} \times 100 \quad \text{where:}$$

P is Base Run prediction for 1945 to 1995
A is Actual rainfall for the period 1945 to 1995

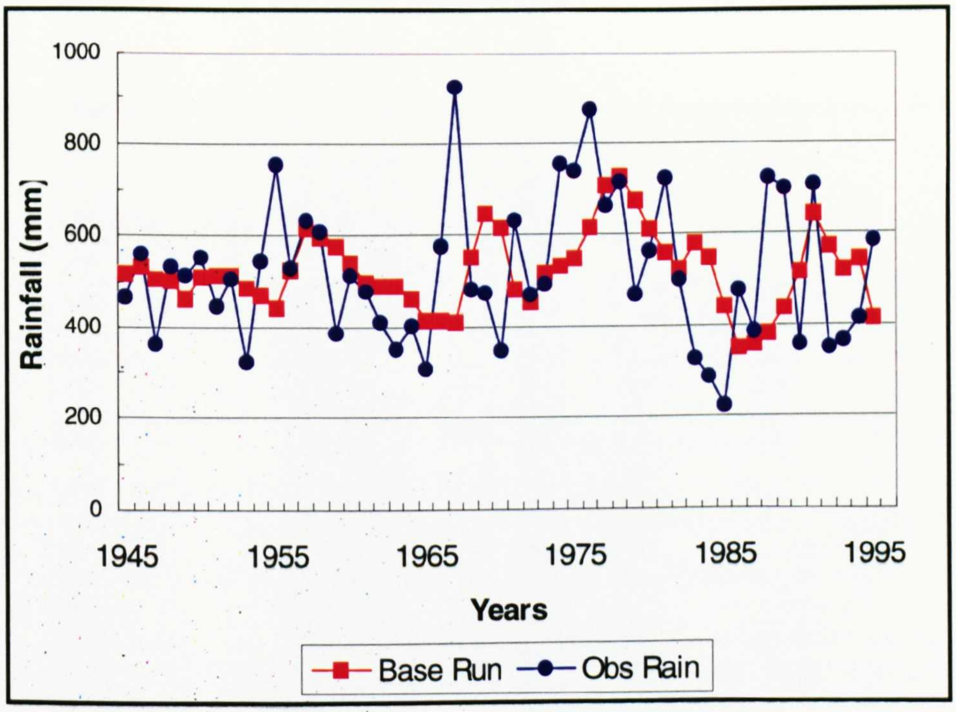

Figure 6.8 The Base Run and Observed Rainfall for Gaborone 1945 to 1995

The coefficient of variation of the prediction error is very high, 388 percent. This is expected given the highly variable annual rainfall, and it means that it is difficult to accurately predict the annual rainfall amount. This means that the model shows a good trend but not necessarily and accurate prediction of the year to year annual rainfall variations. The prediction errors are normally distributed (not significantly different from normal at $p > 0.05$) therefore there was no bias in the Base Run prediction.

Figure 6.9 shows the prediction errors.

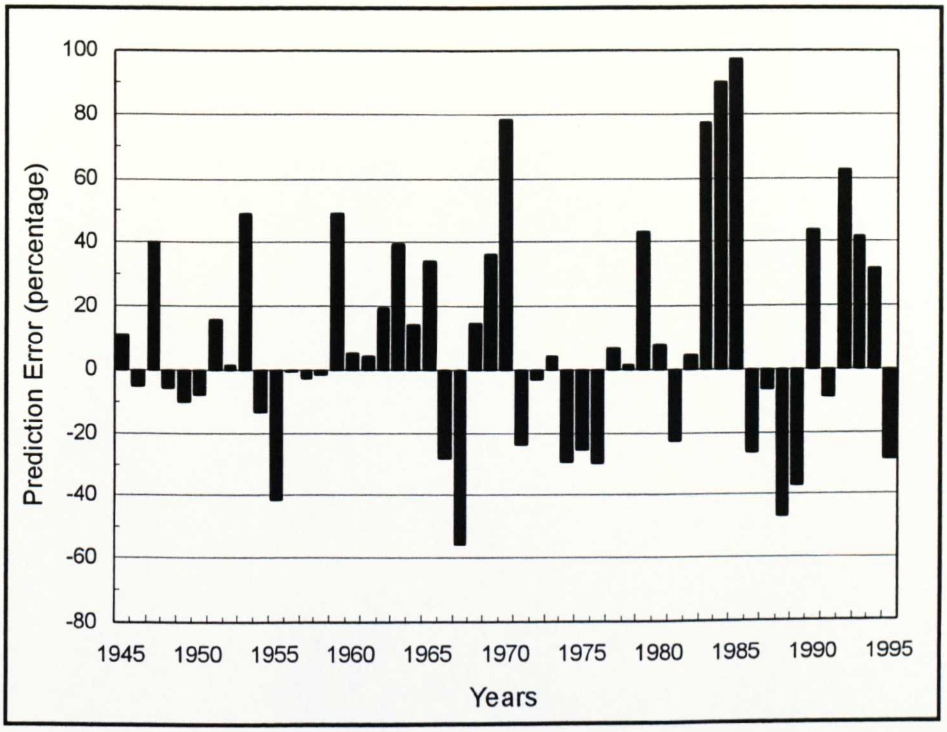

Figure 6.9. The Rainfall Prediction Error (Percentage) 1945 to 1995

6.3.4 *Discussion of Scenario 1 and Scenario 2 Outputs*

Figure 6.10 shows Scenarios 1 and 2 which represent a progressive increase in both the Mean and Standard Deviation (SD) of the stochastic parameter of the model.

Both scenarios show a higher mean annual rainfall than the Base Run. In Scenario 1 although the mean rainfall is higher, the Coefficient of Variation (CV) remains the same as for the Base Run. A further increase in Mean and SD in Scenario 2 leads to almost 14 percent increase in CV. An increase in the CV means more erratic annual rainfall. An initial increase in both the minimum and maximum annual rainfall values in Scenario 1 is followed by a decrease in the minimum rainfall in Scenario 2. The latter scenario depicts a severe drought occurrence that alternates with very high rainfall

rainfall years. Scenario 2 has the highest annual maximum and the second lowest minimum rainfall of all the eight scenarios depicted in this study.

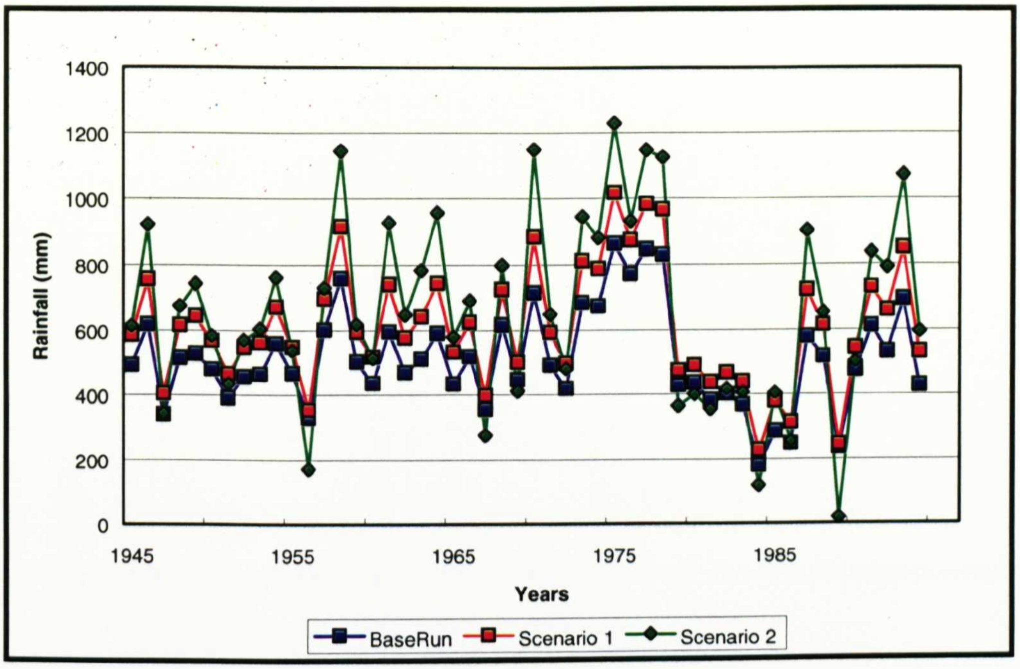

Figure 6.10 Scenario 1 and 2 - Rainfall Simulation and Base Run

6.3.5 *Discussion of Scenario 3 and Scenario 4 Outputs*

Figure 6.11 shows Scenarios 3 and 4, which represent a progressive decrease of the mean and standard deviation of the stochastic component, respectively. The effect of the decrease is a lower mean annual rainfall than the Base Run, and a decrease in the CV. The two effects mean a low but more reliable rainfall from year to year. Their CV of 21 and 22 percent, is lower than 30 percent, which is the cut off point for areas with variable rainfall. Coefficient of variation lower than 30 percent are not characteristic of semi arid areas where the lower the rainfall the higher the rainfall variability. A progressive decrease of the mean and standard deviation of the Stochastic parameter leads to a higher minimum and a lower maximum rainfall than the Base Run, which show reduced variability and imply a low agricultural risk.

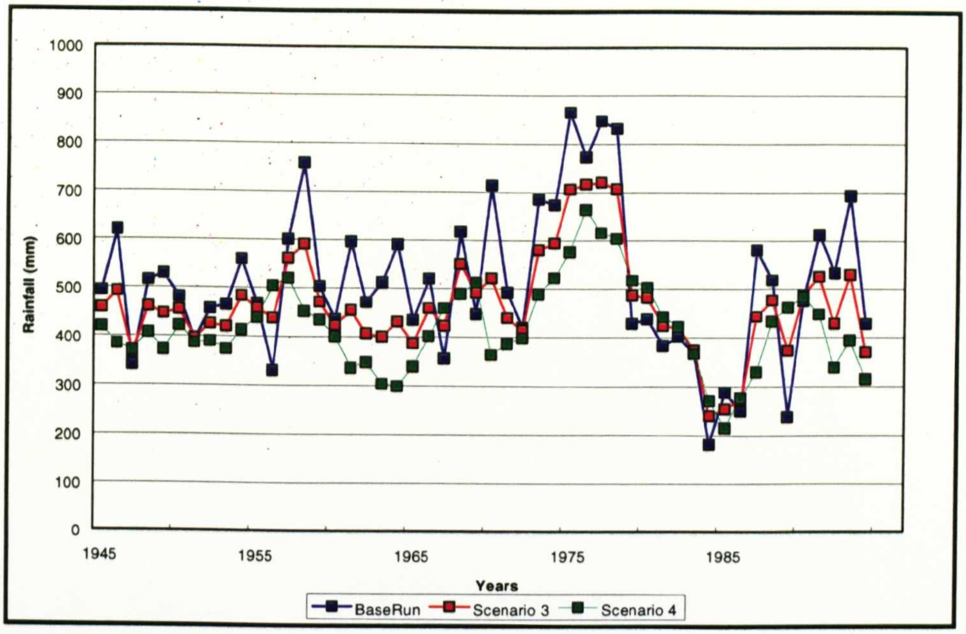

Figure 6.11. Scenario 3 and 4 - Rainfall Simulation and Base Run

6.3.6 *Discussion of Scenario 5 and Scenario 6 Outputs*

Figure 6.12 depicts Scenario 5 and 6, which represent a progressive decrease of the mean and an increase of the SD of the Stochastic parameter, respectively.

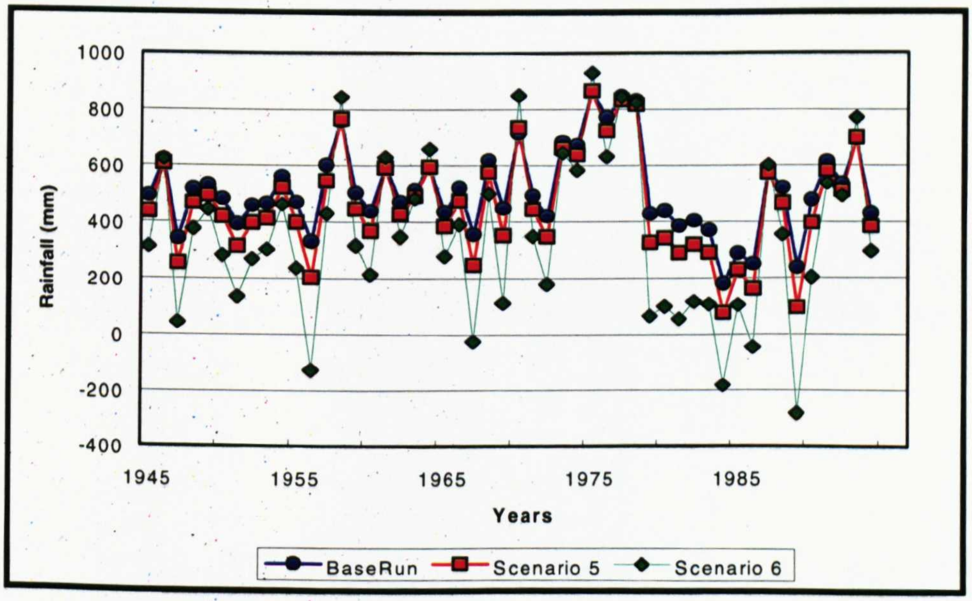

Figure 6.12. Scenario 5 and 6 - Rainfall Simulation and Base Run

The scenarios simulate a bigger decrease of the mean and a bigger increase of the SD, than Scenario 3 and 4 (Table 6.3). Scenario 5 simulates a lower mean annual rainfall with a higher CV than the Base Run. The CV increases to 40 percent for Scenario 5 and doubles to 81 percent for Scenario 6. The mean annual rainfall in Scenario 6 is lower than that in Scenario 5 and the two are almost always less than the annual rainfall Base Run. The higher CV predictably goes with a higher annual rainfall SD. Scenario 5 depicts the third lowest annual rainfall of the eight scenarios in this study and Scenario 6 has the lowest minimum rainfall. The two scenarios show that when the Stochastic parameter has a low mean and high SD, a low and very variable annual rainfall is simulated. Scenario 6 has five years with an apparent absurdity of below zero rainfall which, alongside several near zero mean annual rainfall, represent extreme aridity. The range and inter quartile range of Scenario 5 and Scenario 6 are equivalent to those of Scenario 1 and Scenario 2 respectively because the difference between the value of the mean and that of the standard deviation in both cases is equal.

6.3.7 *Discussion of Scenario 7 and Scenario 8 Outputs*

Scenarios 7 and 8 (Figure 6.13) simulate a progressive increase in the mean and decrease in the SD of the Stochastic parameter. As expected the scenarios are the opposite effect of Scenarios 5 and 6. Scenarios 7 and 8 have a higher mean annual rainfall than the Base Run. The lower CV represents a more reliable rainfall pattern than that the Base Run. The minimum rainfall of Scenarios 7 and 8 is higher than that found in the Base Run. However the annual maximum rainfall for Scenario 7 is equal to that of Base Run. Like Scenario 3 and 4, the annual rainfall for Scenarios 7 and 8 is not typical for areas with variable rainfall because their CV is less than 30 percent.

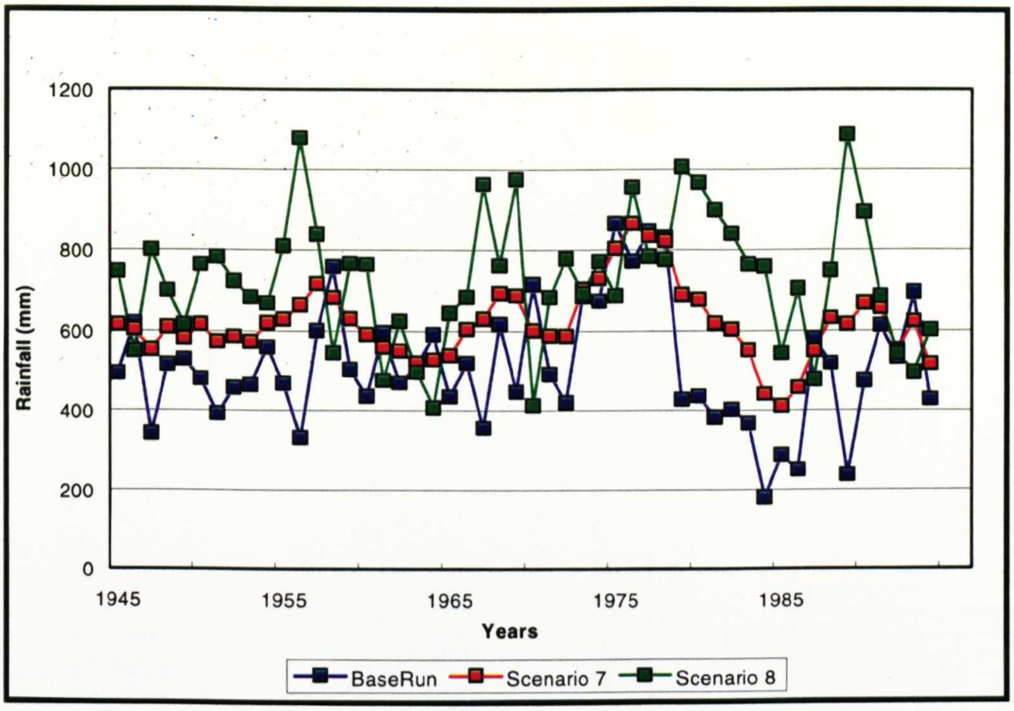

Figure 6.13. Scenario 7 and 8 - Rainfall Simulation and Base Run

6.3.8 *The Effect of Varying the Mean and SD of the Stochastic- A Summary*

The mean of the Stochastic parameter influences the annual rainfall amount simulated. Increasing the mean increases the annual rainfall amount and decreasing the mean has the opposite effect. The standard deviation of the Stochastic parameter influences the SD and the CV of the annual rainfall. When the SD of the Stochastic parameter is increased, the standard deviation and the CV of the annual rainfall increased. When the SD of the Stochastic parameter is decreased, the standard deviation and CV of annual rainfall decreased. The standard deviation and the mean of the Stochastic parameter were used to vary the simulated annual rainfall for the study area.

Table 6.3 Simulated Rainfall Scenarios - Results and Comments

Scenario	Mean	CV	SD.	Min.	Max.	Summary of Scenario Output
Base Run	521.8	30.1	154.5	352.7	728.4	Mean and SD of Stochastic same as Observed Rainfall
1	610.4	30.3	185.2	229.1	1018.4	Simulation shows higher mean rainfall than Base Run. Scenario 2 simulates higher drought likelihood than Base run.
2	653.5	43.9	287.2	19.6	1229.5	
3	467.3	22.2	103.8	240.1	722.2	Scenarios show more reliable rainfall than Base Run in almost all years
4	420.8	21.6	90.9	216.3	664.5	
5	460.4	40.2	185.2	79.1	868.4	Scenarios show most unreliable rainfall and Scenario 6 depicts a very severe drought with -280.4 mm of rainfall.
6	353.5	81.2	287.2	-280.4	929.5	
7	619.6	14.8	91.8	412.1	865.7	Scenarios show more reliable and higher mean rainfall than Base run.
8	728.9	22.4	162.9	408.5	1088.3	

6.4 The Parameters and Equations in the Rainfall Sub - Model

This section presents the equations used for the rainfall sub - model parameters.

6.4.1 *Rainfall*

Rainfall Equation 6.1 shows how rainfall is calculated for the model.

Rainfall Equation 6.1 Rainfall

Rainfall = 520+AutoRegress+MA3+Stochastic where: Rainfall is the simulated annual rainfall 520 is the Mean for the 1945 to 1995 Gaborone rainfall AutoRegress is Auto Regressive component of the rainfall MA3 is Moving Average of the order 3 Stochastic is the Stochastic element of the rainfall simulation

The formula shows that the rainfall is made of four parts, which are:

i) mean of 520 mm calculated from the historical rainfall whose trend is used for prediction in the model;

ii) the Autoregressive ,explained in the Section 4.2 (see Appendix 8);

iii) a Moving Average of the Order 3 (see Appendix 8); and

iv) the Stochastic.

6.4.2 *The Stochastic Parameter*

Sections 6.3 to Section 6.3.8 discussed the effect of the Stochastic parameter on the simulation of annual rainfall in detail. The Stochastic parameter in Stella is a set of normally distributed numbers with a mean, standard deviation and seed, in that order. The Rainfall Equation 6.2 defines the Stochastic parameter with a mean 0, standard deviation of 117.2 and a seed of 1000.

Rainfall Equation 6.2 The Stochastic

Stochastic = NORMAL (0,117.2,1000)

The range within which the mean and standard deviation were varied, to obtain the different annual rainfall scenarios, is shown in Table 6.3

6.4.3 *Delayed Rainfall*

There are two Delayed Rainfall parameters in the model, Delayed Rain1 and Delayed Rain2. Both are level equations. Appendix 7 shows how a level equation is calculated. Delayed Rain1 is the sum of the present and past year's rainfall.

Rainfall Equation 6.3 Delayed Rain1

DELAYED Rain1(t) = DELAYED Rain1(t - dt) + (Del RF1 - DRAIN1) * dt where:

DELAYED Rain1 (t) is the delayed rainfall at the present time (t)
DELAYED Rain1(t - dt) is delayed rainfall a year ago (t - dt)
Del RF1 is the inflow which is rainfall this year
DRAIN1 is the outflow which is rainfall last year
dt is simulation time interval (see Section 5.4)

Rainfall Equation 6.4, is the Delayed Rain2 equation. From Figure 6.2 it can be seen that the Delayed Rain1 value is connected to Delayed Rain2.

Rainfall Equation 6.4 The Delayed Rain2

DELAYED Rain2(t) = DELAYED Rain2(t - dt) + (Del Rf2 - DRAIN2) * dt where:

DELAYED Rain2(t) is rainfall two years ago
DELAYED Rain2(t - dt) is rainfall three years ago
Del Rf2 is the inflow, which is Delayed Rain1 during the previous year or rainfall two years ago
DRAIN2 is the outflow, which is rainfall three years ago
dt is simulation time interval

From the Delayed Rain1 and 2, the RF Weighted and the Botswana Range Condition Index (BRCI) are derived, respectively.

6.4.4 *Botswana Range Condition Index (BRCI)*

The Botswana Range Condition Index measures the rainfall effect on the range. It is the combined effect of rainfall in the present year and the past two years. The combination of the rainfall amounts is derived from the Botswana Range Condition Index (Vossen 1987: McLeod, 1990) which was used to show that the number of cattle is based on the annual rainfall for the past three years. Equation 3.9 is an example of how Vossen used the BRCI. Rainfall Equation 6.5 shows that BRCI is the sum of all of the present year's, half of last year's and one quarter of the previous year's rainfall.

Rainfall Equation 6.5 Botswana Range Condition Index (BRCI)

BRCI = (8*Rainfall+ 4*DELAYEDRain1 + 2DELAYEDRain2)/8 where:

BRCI is the cumulative effect of present, past and previous year's rainfall on the range
Rainfall is present year rainfall
DELAYEDRain1 is rainfall during last year
DELAYEDRain2 is rainfall during previous year

6.4.5 *Rainfall Weighted*

The Rainfall Weighted Rainfall Equation 6.6 is the sum of the present year's rainfall and half of last years.

Rainfall Equation 6.6 RF Weighted

RF Weighted = (Rainfall + 0.5* Delayed Rain1) where:

Rainfall is the present year's rainfall
Delayed Rain1 is last year's rainfall

Rainfall Equation 6.6 shows the consequences of soil moisture storage for surface water availability in the Rain Land Cattle model. It is assumed that the rainfall affects the livestock water sources for two seasons only. The Rainfall Weighted has three bands, which are < 675, 675 to 975, and > 975 mm. The bands represent "Below Normal", "Normal" and "Above Normal" rainfall respectively (Section 4.3.2).

6.5 The Parameters and Equations in the Land Sub - Model

6.5.1 *Seasonal Grazing*

Seasonal grazing is available from the two blocks of fenced arable land in the Tlokweng Sub-District, which together measure 50 km^2. The field owners' exclusive rights cease after the harvest and are replaced by the community's livestock grazing which continues until the beginning of the ploughing season. The duration of seasonal grazing varies from year to year according to the time of harvest and the onset of the rains, hence the commencement of ploughing. Generally, seasonal grazing is available for the four months between June and September before the rainy season is expected to commence in October. The model incorporates seasonal grazing as a Stella in - built function, **Step,** which switches the seasonal grazing land availability on and off on a four monthly basis.

Land Equation 6.1 Seasonal Grazing

Seasonal Grazing = STEP(50,1945.5)-STEP(50,1945.83)+STEP(50,1946.5)-STEP(50,1946.83)+STEP(50,1947.5)-STEP(50,1947.83)+..............where:
Seasonal Grazing = Area of grazing land available in the arable area STEP is a Stella function, in this case defined as [STEP (Area of Land, Time)] It allows 50 km^2 of arable land to be available for 4 months grazing every year

The Land Equation 6.1 shows that the arable area is used for grazing every four months in a year, which is from June to September. Each month is represented by 1/12 = 0.083 of a calendar year in the model equation. The availability of arable area grazing is represented by [12 months x (0.83-0.5)] = 3.96 months which is rounded to 4 months. The first set of numbers in the equation (50, 1945.5) indicate that 50 km^2 is available from June (month 0.5) in 1945. The second set of numbers (50,1945.83) show that grazing ceases to be available in October (month 10 x 0.0.83 = 0.83) in 1945. The "+ STEP" stands for when the 50 km^2 becomes available and the "-STEP" stands for when it ceases to be available. The initial "+" symbol is not shown in STEP (50, 1945.5). In all other cases [+STEP (50, 1945.5), -STEP (50, 1945.83)] means that the 50 km^2 is available for grazing from the 6th month (0.5 x 12 months of 1945), and ceases to be available from the 10th month (0.83 x 12 months 1945). The Figure 6.14 shows how the step function switches the arable land grazing on and off for four months on the sixth month of each year.

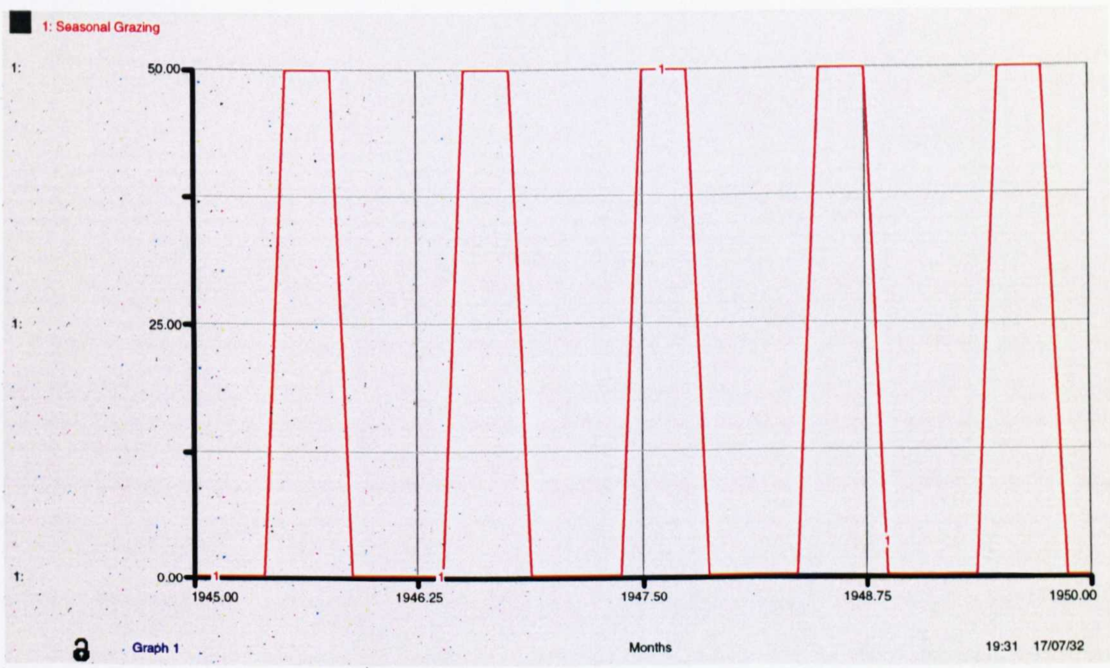

Figure 6.14 The Step Function Output for Arable Land Grazing 1945 to 1950

The cattle graze the maize and sorghum stalks and the grasses from the fallow fields and the interstices of the fields. During the fieldwork it was noted that cattle grazed the crop residue first and they switched to the grass only after the crop residue was depleted.

6.5.2 *Permanent GrSazing*

Permanent grazing is obtained from a 100 km^2 stretch of land classified as mixed grazing on the landuse map of the study area. Other landuses such as residential, *masope* and dairy farms occur in the permanent grazing and their development reduces the land available for grazing according to the land loss fraction (Section 6.5.3). The Land Equation 6.2 shows how permanent grazing is calculated in the model. It is a level equation.

Land Equation 6.2 Permanent Grazing

Permanent Grazing (t) = Permanent Grazing (t - dt) + (- Landloss fraction) * dt where:

Permanent Grazing (t) is the present area of permanent grazing
Permanent Grazing (t - dt) is the area of permanent grazing one time step ago, last year
Landloss fraction is the rate at which the grazing land is lost
dt is simulation time

Land Equation 6.2 states that the present area of Permanent Grazing is equal to that 1 year ago, less the land loss multiplied by the simulation time (dt), which is 1 year. Briefly, the Land Equation 6.2 tells us that permanent grazing is the present grazing area less the land lost over a specific time. Because some permanent grazing is lost to non grazing uses, in the long term the area of permanent grazing declines.

6.5.3 *Land Loss Fraction*

Between 1963 and 1996, 1547 hectares of permanent grazing was converted to residential land as a result of the growth of Tlokweng village (Department of Town and Regional Planning, 1996:80-81). The mean permanent grazing land loss for that period was estimated at 47 hectares per year, which represents about 0.47 percent of the current grazing land. Using a fixed land loss fraction is a simplification because different rates of permanent grazing land loss have occurred due to the expansion of

Tlokweng village. The biggest expansion, 49 Ha yr^{-1}, was between 1980 and 1996 and the least, 28.8 Ha yr^{-1}, was between 1963 and 1971 (Department of Town and Regional Planning, 1996). Other sources of permanent grazing land loss are *masope* and dairy farm allocations. Between 1982 and 1995 about 30 ha. of land was allocated to dairy farms (see Appendix 1). Further dairy farm allocations were subsequently suspended (Makepe, personal communication, 1996). The average grazing land loss due to dairy farm allocation of 2 Ha. yr^{-1} was added to the Tlokweng village growth to make 49 Ha yr^{-1}. It was not possible to establish, from the land allocation authorities, how much other land had been allocated non grazing land use. It was assumed that about 1 Ha yr^{-1} was allocated for other purposes on average which maybe lower than real. The 0.5 percentage (0.005) used to simulate the permanent grazing land loss fraction considered other losses. It is therefore an acceptable approximation of the land loss. The model assumed that the land loss is at a fixed rate. It is most likely to increase given the demand for land described in Section 2.2.2.

6.5.4 *Total Grazing*

Total grazing is the sum of the seasonal grazing and the permanent grazing less the land loss. Land Equation 6.3 shows the total grazing. The total grazing fluctuates

Land Equation 6.3 Total Grazing

TotalGrazing = (Seasonal Grazing + Permanent Grazing)*100 where:

Seasonal Grazing as shown in Land Equation 6.1.
Permanent Grazing as shown in Land Equation 6.2

seasonally because of the seasonal grazing. As the permanent grazing declines over time, the total grazing is reduced as well. When other parameters are held constant, a decline in Total Grazing leads to increased stocking rate. The total grazing area is converted from square kilometres to hectares by multiplying by 100.

6.5.5 *Stocking Rate (ST Rate)*

Land Equation 6.4 shows the stocking rate, which is the number of cattle per grazing unit area normally expressed as Ha LSU^{-1}. It indicates livestock pressure on the land. In this study the number of cattle was converted to Livestock Units (LSU) by a factor of 0.7 as recommended in Arntzen and Veenendaal (1986:39). In Botswana a livestock unit is 450 kg, but it may also be 500 kg (Field, 1978:89). The Ha LSU^{-1} measure is used in rangeland studies because the forage consumed by an animal is relative to its body weight (FAO, 1991).

Land Equation 6.4 The Stocking Rate

ST_Rate = TotalGrazing/CatLSU   where:

ST_Rate is Stocking Rate (Ha LSU^{-1})
TotalGrazing as shown in Land Equation 6.3
CatLSU is number of cattle * 0.7

6.5.6 *Delayed Stocking Rate (DEL ST Rate)*

The Land Equation 6.5 is a level equation (see Appendix 7).

Land Equation 6.5 Delayed Stocking Rate (DEL ST Rate)

DEL ST Rate(t) = DEL ST Rate(t - dt) + (Inrate - Outrate) * dt   where:

DEL ST Rate(t) is the delayed stocking rate at the present time (ST Rate)
DEL ST Rate(t - dt) is the delayed stocking rate two years ago
Inrate is the stocking rate last year, as inflow
Outrate is the stocking rate two years ago, as outflow
dt is one year

It states that present (t) DEL ST Rate is equal to the DEL ST Rate an instant ago, (t - dt), which is last year, plus the difference between Inrate (last year's Stocking Rate) and Outrate (stocking rate two years ago) multiplied by the simulation time (dt). It shows that the stocking rate in any given year includes the cumulative effect of that in the previous year. In cattle management terms, the DEL ST Rate affects the forage availability during the current and the subsequent year.

6.5.7 *Weighted Stocking Rate (ST Weighted)*

The Land Equation 6.6 shows that the weighted Stocking Rate is the sum of the present and half of last year's Stocking Rate.

Land Equation 6.6 Weighted Stocking Rate (ST Weighted)

St_Weighted = ST_Rate+(0.5* DEL_ST Rate) where: St Weighted is Weighted Stocking Rate ST Rate is Present Stocking Rate as shown in Land Equation 6.4 DEL ST Rate is Delayed Stocking Rate as shown in Land Equation 6.5

The effect of present grazing is always passed onto the following year(s). During a dry year, a soil water deficit is created which will have to be overcome before the soil can be saturated with water that is available to plants. The opposite, a soil moisture reserve, occurs following a wet year. The delayed effect of rainfall on cattle production was discussed in detail in Sections 6.4.3. Sustained intense grazing, which is associated with high stocking rates, causes a decline in forage production during the subsequent years because the grass seed is destroyed, and annuals damaged by grazing at the wrong time (Hendzel, 1981) or the plants being uprooted. Tacheba and Mphinyane (1993) report a decrease in both plant matter production and desirable species, and an increase in non desirable species on heavily stocked ranges in eastern Botswana. Their finding shows that a rangeland's species quality decline occurred alongside a decline in the forage quantity.

6.5.8 *The Stocking Factor (ST Fact)*

The Stocking Factor is a graphical function that converts the effect of the weighted stocking rate (ST Weighted) to the CC. When the Grazing Capacity (12.5 Ha LSU^{-1}) is equal to the mean stocking rate, the mean ST Weighted is 12.5 x 1.5 = 18.75 Ha LSU^{-1}. The mean ST Weighted therefore represents the ST Factor value of 1 because it will not cause the CC to deteriorate or improve. When all the other parameters are held constant, a high stocking rate decreases the CC, which increase the ST Factor values, and vice versa. Land Equation 6.7 shows how the ST Factor values of the graph Figure 6.15 are derived.

Land Equation 6.7 The Calculation of the ST Factor

$$\frac{1}{\text{ST Weighted} / 18.75}$$ where:

ST Weighted is as shown in Section 6.5.7
18.75 = 1.5 * Mean Stocking Rate of 12.5 Ha LSU^{-1}

Appendix 6 shows the coordinates of the ST Factor graph when the ST Weighted is set between 10 and 25 Ha LSU^{-1}. Stella automatically determines the ST Weighted graduation between 10 Ha LSU^{-1} and 25 Ha LSU^{-1}. The ST Factor graph (Figure 6.15) shows the relationship of the ST Factor and ST Weighted. Two characteristics of the relationship can be observed. Firstly the ST Factor graph is negatively skewed because a high stocking rate (a small ST Weighted) increases the ST Fact, which decreases the CC. Secondly the graph has a gentler slope towards the low ST Weighted values (big ST Weighted) than the high ST Weighted values. This is because as the stocking rate declines, its marginal influence on the CC declines. Eventually a very low ST Weighted will have no influence on the CC.

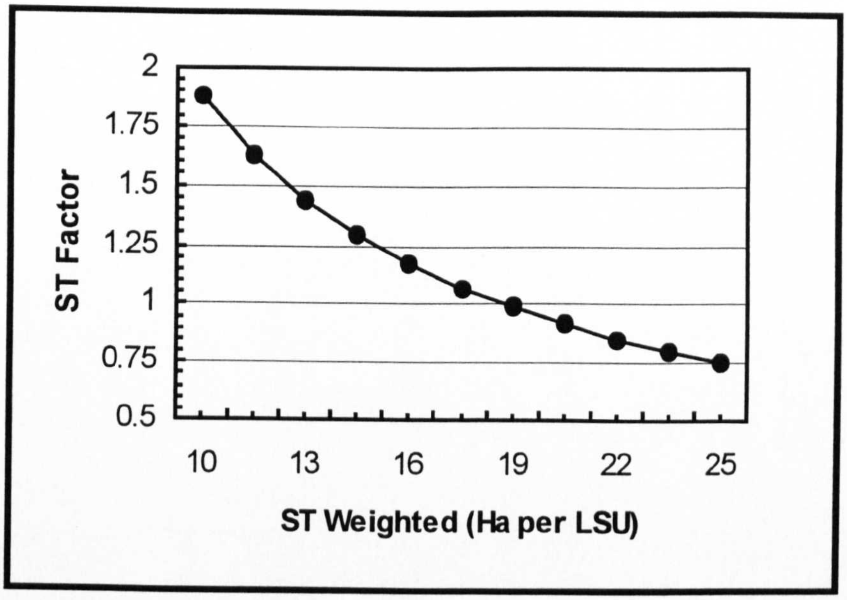

Figure 6.15 The Stocking Factor in the Rain Land Cattle Model

6.5.9 *The Range Factor*

The Range Factor converts the influence of the Botswana Range Condition Index (BRCI) into the Carrying Capacity. The mean rainfall for the 1945 to 1995 period (520 mm) was used as the mean BRCI. The mean BRCI equals to a Range Factor value of 1, or unity. When the BRCI is less than the mean, the Carrying Capacity deteriorates therefore the Range Factor increases, and vice versa. The Range Factor value is calculated using Land Equation 6.8.

Land Equation 6.8 Calculating the Range Factor

$$\text{Range Factor} = \frac{1}{\text{BRCI}/520} \quad \text{where:}$$

BRCI = Botswana Range Condition Index
520 = Mean for 1945 to 1995 rainfall

Stella assigns the graduation when the BRCI range is set at100 to 950. Based on the Land Equation 6.8 the coordinates of the Range Factor shown in the Appendix 6 were obtained. Figure 6.16 shows the graph of the Range Factor coordinates in Appendix 6. The Range Factor graph is negatively skewed. When the BRCI is small, there Range Factor is big and CC deteriorates. In practice a small BRCI value occurs when there is poor rainfall which causes a soil moisture deficit and poor grazing availability. The graph in Figure 6.16 flattens towards the big BRCI values because of a decline in the

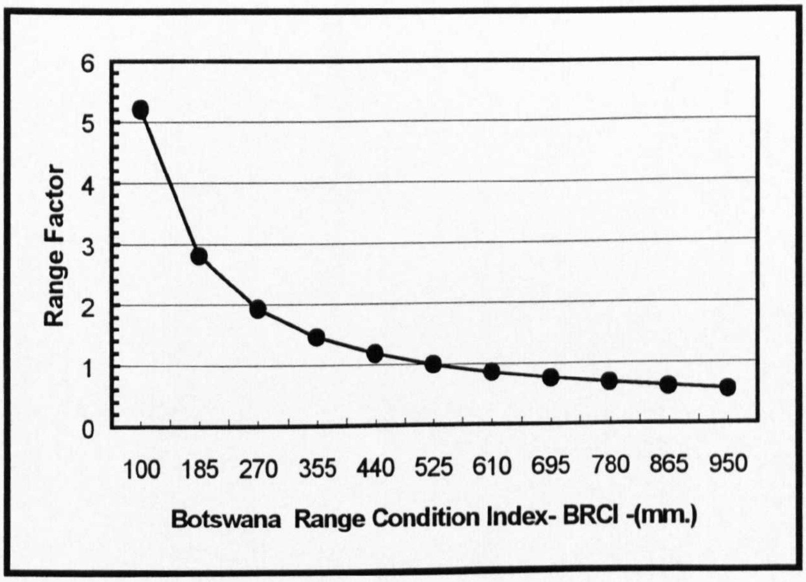

Figure 6.16 The Range Factor for the Rain Land Cattle Model

marginal utility of the Range Factor. The flat graph means that for a low BRCI, more rainfall is needed to improve the carrying capacity, the grazing condition, than for a high BRCI. But once at field capacity, additional rainfall has a declining marginal utility. In reality, when the soil is at field capacity, further rainfall is lost as runoff which is of limited utility for the Carrying Capacity.

6.5.10 *Grazing Capacity (GC) and Carrying Capacity (CC)*

A detailed discussion of the concepts of GC and CC was done in Sections 3.2.1, 3.2.2 and 3.2.3. Sometimes the GC is referred to as PCC, in contrast to the Actual Carrying Capacity, which refers to the CC. The Grazing Capacity is the amount of grazing land available to animals without destroying the productivity of the area. The GC is based solely on an average figure when the forage production fluctuates from year to year. Because the GC figures used in livestock management are based on "average" rainfall, the variety of grazing areas is often masked by the mapping scale. Determining a mapping scale to reflect the variety of grazing areas accurately is infinitely difficult because cattle select grass at a larger scale than the one at which it is ever mapped (Dillon, 1968). The GC value used in the model is based on Field (1978).

The Carrying Capacity is the ability of a grazing area to support livestock based on the combined effects of the past and present rainfall and stocking rates. The model calculates the CC as shown by the Land Equation 6.9. The Land Equation 6.9 shows that the Carrying Capacity is the sum effect of the Range Factor and the Stocking Factor. When BRCI is more than the three year mean of 520 mm (520 + 0.5 x 520 + 0.25 x 520), the Carrying Capacity improves.

Land Equation 6.9 The Carrying Capacity (CC)

CarryCap = ((RF Factor*GrazeCap)+(ST Factor*GrazeCap))/2 where:

CarryCap is the Carrying Capacity
RF Factor is the Range Factor (see 6.5.9)
ST Factor is the Stocking Factor (see 6.5.8)
GrazeCap is the Grazing Capacity of 12.5 Ha LSU^{-1}

When the BRCI is less than 520 mm the Carrying Capacity deteriorates[1], that is becomes less than 12.5 Ha LSU^{-1}, such as 20 Ha LSU^{-1}. When the St Weighted exceeds the mean GC for two years, (12.5x 1.5) 18.75, the Carrying Capacity deteriorates, that is becomes lower than 12.5 Ha LSU^{-1}, such 20 Ha LSU^{-1}. The opposite is true when the ST Weighted is less than the GC.

The response of the Carrying Capacity to the combined changes of the ST Factor and the Range Factor compares to the aboveground net primary productivity formula used by Rodriquez and Jameson (1988:89). The Rodriquez and Jameson formula shows the aboveground net primary productivity as the combined effect of the rainfall in the current and previous years and the standing crop in the previous year. The ST Factor and Range Factor in the Land Equation 6.9 are comparable to the standing crop in the previous season and the present and previous year's rainfall, respectively, in the Rodriquez and Jameson formula.

6.5.11 *Stocking Ratio*

The Stocking Ratio (Land Equation 6.10) is an index that compares the Stocking Rate to the Carrying Capacity. When the Stocking Rate is equal to the Carrying Capacity, the Stocking Ratio is 100. A Stocking Ratio greater than 100 shows that the stocking rate is lower than the CC which means that there are few animals in an area capable of

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[1] What does a decrease in GC, Stocking Rate or CC mean?
A decrease in Grazing Capacity means that an animal needs more land to obtain adequate forage to subsist on than it did previously e.g. from 10 Ha LSU^{-1} to 20 Ha LSU^{-1}. A decrease in Stocking Rate means fewer animals on a piece of land than before e.g. from 10 Ha LSU^{-1} to 20 Ha LSU^{-1}. A decrease in Carrying Capacity means that an animal needs more land to supply adequate forage and other requirements to subsist on than before, e.g. from 10 Ha LSU^{-1} to 20 Ha LSU^{-1}.

holding more. For example, when the stocking rate is 40 Ha LSU^{-1} in an area with a Carrying Capacity of 20 Ha LSU^{-1}, the Stocking Ratio will be 200 percent.

Land Equation 6.10 The Stocking Ratio

Stocking Ratio = (ST_Rate/CarryCap) x 100 where:
Stocking Ratio is Index of stocking level in relation to the Carrying Capacity
ST_Rate is Stocking rate as explained in Land Equation 6.4
CarryCap is Carrying Capacity as explained in Land Equation 6.9

A Stocking Ratio less than 100 percent shows that the stocking rate is greater than the CC which means that there are many animals in area capable of holding fewer than what it is holding. For example when the stocking rate is 20 Ha LSU^{-1} in an area with 40 Ha LSU^{-1}, the Stocking Ratio will be 50 percent. A Stocking Ratio greater than 100 shows a lightly stocked rangeland and that less than 100 shows a heavily stocked rangeland.

6.6 The Parameters and Equations for the Cattle Sub - Model

Cattle numbers were obtained from the Department of Animal Health and Production at the Ministry of Agriculture in Gaborone. The department compiles livestock data per cattle crush during the yearly vaccination campaigns. The 1980 to 1995 cattle numbers and herd composition data are temporally and spatially discontinuous. The most complete data series was for 1988 to 1996, but the 1995 data are missing. The number of goats, sheep, donkeys was available though they are not used in the model.

6.6.1 *Changes in Cattle Population*

The cattle population changes directly in response to five parameters which are birth rate, death rate, offtake rate, emigration and purchase. The birth and death rates are discussed in Sections 6.6.2 to 6.6.4.

The questionnaire and in - depth interviews established that some cattle emigrate from the study area. They emigrate when the owners feel that the herds are too big for the limited grazing in the small sub district. In principle, large herds are more likely to emigrate than the small herds (Section 7.6.2). Five percent of the households with cattle emigrated which shows that emigration is not a common management strategy. Several respondents reported that some households who emigrated during the drought lost more cattle than those who remained in the area did. Emigration is simulated by Cattle Equation 6.1.

Data for cattle sales were investigated during the fieldwork. Sales represent the outflow from the system. A record of cattle sold at the Tlokweng *Kgotla*, the traditional court, between March 1994 and November 1995 was obtained. Local butcheries buy most of the slaughter cattle from the *Kgotla*. The *Kgotla* records showed an average sale of 12 animals per month from the sub district and another 3 per month from outside. The total *Kgotla* sales for 1994 was 170, which is 16.6 percent of the sub district's herd. The offtake of 16.6 percent is almost double the 8 percent national average offtake in the communal area (Ministry of Agriculture, 1991). Arntzen and Veenendaal (1986:xix) estimate that 2.5 percent of the sub-district's herd, which is 26 animals per annum based on the current cattle population in the district, are slaughtered at the Gaborone abattoir. Some of the animals sold at the *Kgotla* are taken to the Gaborone abattoir for slaughter but others change hands between households within the sub district. Since 1994 was a third consecutive year of below average rainfall, it is possible the 1994/1995 *Kgotla* sales were higher than normal because the farmers wanted to alleviate losses. Although the *Kgotla* sales data indicate the magnitude of sales they may be higher than usual due to the drought (Section 7.6.5). It was appropriate to use 8 percent, the national offtake rate for communal areas (Mosienyane, 1992), which is half of the Kgotla offtake rate. The *Kgotla* records show that 3 animals were purchased from outside the study area per month. Given the study areas population of about 1500 cattle, the 3 animals represent a 2.4 percent purchase rate, which was used in the model. It was difficult to confirm this figure due to the drought. The 1993 agricultural survey recorded a purchase rate of 0.1 percent for the district (Ministry of Agriculture, 1995). The Cattle Equation 6.1 shows how the parameters Purchase, Offtake and Emigration were derived.

Cattle Equation 6.1 Purchase, Offtake and Emigration

Purchase = 0.025*CATTLE Offtake = Offtake_Rate* CATTLE Emigration = 0*CATTLE

The three equations are structurally similar. In each case the number of cattle multiplies the percentage of cattle purchased, sold (offtake) or moved out of the area (emigration) to get the number that is purchased, sold or which emigrates.

The Cattle Equation 6.2 shows how the cattle population grows. The equation was used in Appendix 7 to show how to calculate a level equation. This equation has two inflows (Births + Purchase) and three outflows (Offtake, NatDeath, Emigration).

Cattle Equation 6.2 Number of Cattle

CATTLE(t) = CATTLE(t - dt) + (Births + Purchase - Offtake - NatDeath - Emigration) * dt where:
CATTLE(t) is the number of cattle this year CATTLE(t - dt) is the number of cattle last year Births is the number of cattle born last year (inflow) Purchase is the number of cattle bought last year (inflow) Offtake is the number of cattle sold last year (outflow) NatDeath is the number of cattle which died last year (outflow) Emigration is the number of cattle moved out study are in a year (outflow) dt = one year

The Cattle Equation 6.2 shows that the present number of cattle equals to the cattle population plus births and purchases last year, less the offtake, natural death and emigration. The initial number of cattle used in the model, 1000, was based on the observed cattle numbers between 1987 and 1995.

6.6.2 *The Birth Rate*

The Birth Rate for this study was calculated from the 8 years data from the Department of Animal Health and Production (Table 6.4). The BRCI is calculated from the annual rainfall as described in Section 6.4.4. The Birth Rate is expressed as a percentage of the herd. It is affected by the Birth Rate Influencing Factor, R1, which depends on the CC. When the Carrying Capacity is good, such as 5 Ha LSU^{-1}, the Birth Rate is high. When the Carrying Capacity is poor such as during a drought, the Birth Rate is low because cows are not physiologically fit to calve and the number of cows is reduced due to increased mortality. Research elsewhere in Botswana shows that cows with weight of 300 kg have a 69 percent calving rate while those with a weight of 450 kg have a 79 percent calving rate.

Table 6.4 Birth Rates and Rainfall in Tlokweng Sub District 1988 - 1996

Year	Birth Rate (%)	Rainfall (mm)	BRCI
1988	29.52	723.7	570.6
1989	23.65	699.9	655.6
1990	23.66	360.6	534.2
1991	23.18	707.5	590.6
1992	18.03	353.7	472.8
1993	20.30	368.2	419.9
1994	21.82	414.7	389.0
1995	20.02	584.6	491.9
1996		527.2	527.6

Sources: Botswana Meteorological Services, 1996 (Rainfall); Department of Animal Health and Production, 1996 (adapted for Birth Rates).

A 30 kg increase in cow weight during the breeding period, increased the calving rate by 9 percent and a weight gain of 50 kg increased the calving rate by 13 percent (Animal Production Research Unit, 1976). The Rain Land Cattle model translates this finding into the relationship between Carrying Capacity and Birth Rates using the Birth Rate Influencing Factor (Section 6.6.3). A cubic regression equation (Cattle Equation 6.3) relates the birth rate to the BRCI in Table 6.4.

Cattle Equation 6.3 Regression Equation for Birth Rate and the Botswana Range Condition Index for the Study Area

$$\text{Birth Rate} = 528.491 - 3.07 \times \text{BRCI} + 6.07^{-3} \times \text{BRCI}^2 - 3.9^{-6} \times \text{BRCI}^3$$

Where $R^2 = 0.604$

According to Cattle Equation 6.3, when the BRCI is 520 the Birth Rate will be 25.04 percent. The mean Birth Rate in Table 6.4 is 22.88, rounded off to 23 percent, which is less than the 25.04 percent derived from the equation. The model used a Birth Rate of 25 percent as a base value.

From the cow weight and birth rate discussion in the previous paragraph, more rainfall means healthier animals. The data from the study area does not show the rainfall influence on the birth rate beyond the 723 mm rainfall. It is unlikely that births will continue to increase beyond the 723 mm rainfall because of five factors. Firstly, the low levels of management in the communal areas reduce the marginal benefits of increased rainfall. Secondly, the cows are expected to reach their biological limit to calve. Thirdly, the limited grazing land prevents further extensive landuse. Fourthly, high stocking rates limit the individual animals increased output in preference for increased output per land unit. Lastly, because the rainfall in the study area oscillates, long term birth rates are likely to oscillate as much.

The Birth Rate in the model was determined by a base percentage (25%) which is altered by the Birth Rate Influencing Factor (R1). Cattle Equation 6.4 shows how the births are calculated in the model.

Cattle Equation 6.4 Births

Births = Birate*CATTLE where:

Births is the number of cattle born
Birate is the percentage Birth Rate for the herd (25 percent)
CATTLE number of cattle

6.6.3 *The Birth Rate Influencing Factor (R1)*

The Birth Rate Influencing Factor (R1) is a graphical function that translates the effect of the CC onto the birth rate in the model. The Birth Rate in Table 6.4 oscillates between 18 and 30 percent due to the rainfall. When the CC is equal to the GC of 12.5 Ha LSU^{-1}, the Birth Rate Influencing Factor (R1) will be 1. When the Carrying

Capacity deteriorates the Birth Rate also deteriorates therefore the R1 value becomes smaller. The range of the Carrying Capacity for the area was set between 5 to 30 Ha LSU^{-1} based on the outputs of the Rain Land Cattle model.

The coordinates of the CC and R1 based on the Cattle Equation 6.5 are shown in the Appendix 7. Figure 6.17 shows the R1 graph based on the coordinates in Appendix 7.

Cattle Equation 6.5 The Calculation of the Birth Rate Influencing Factor (R1)

$$R1 = \frac{1}{GC/CC} \quad \text{where:}$$

R1 is the Birth Influencing Factor
GC is 12.5 Ha LSU^{-1}
CC is Carrying Capacity value between 5 and 30 Ha LSU^{-1}

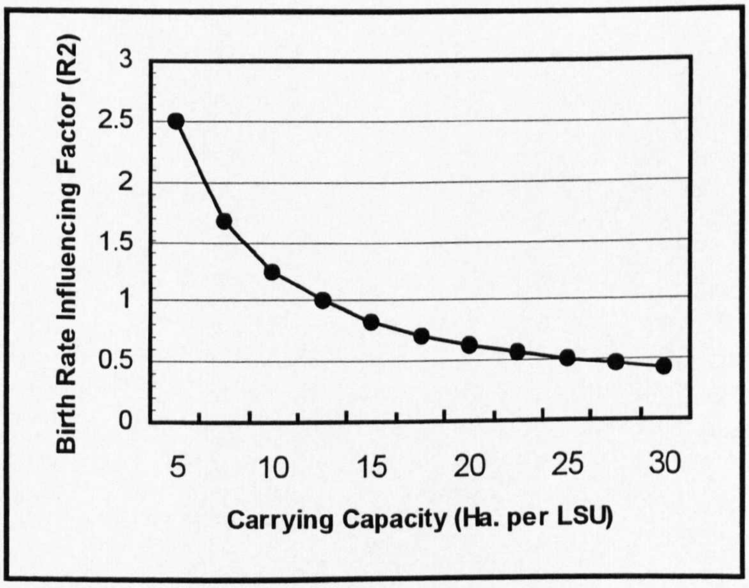

Figure 6.17 The Influence of the Carrying Capacity on the Birth Rate (R1)

The graph is negatively skewed because when the Carrying Capacity is good (a low figure) the R1 is high, and vice versa. The influence of the Carrying Capacity on the R1, hence Birth Rate, declines as the Carrying Capacity deteriorates. Consequently the R1 graph has a steep slope when the CC is high and a gentle slope when the CC is low.

The varied slope shows that marginal utility of the CC on the R1 declines as other factors, such as the cows calving limit, become influential. The R1 is multiplied by the average Birth Rate of 25 percent to get Birate, which fluctuates according to the CC. When a big R1 value is multiplied by the Birth Rate it increases the Birate and a small R1 reduces the Birate.

6.6.4 *The Death Influencing Factor (R2)*

Like the Birth Rate, the Death Rate is influenced by the Carrying Capacity through the Death Influencing Factor (R2). When the CC deteriorates the Death Rate increases and when the CC improves the Death Rate decreases.

This study area had no cattle death data which could be used to set the death rate the same way the birth rate was determined in Section 6.6.2. Therefore Vossen's work on death rates, rainfall and stocking rates (Vossen 1987; Vossen 1990) was used to determine the Death Rate values for this study's model. Vossen (1987) established a Rainfall Area Cattle Index (Cattle Equation 6.6), to show the relationship between average annual rainfall, available grazing area and cattle numbers for agricultural districts in Botswana. The index indicates the cattle forage availability. A low index

Cattle Equation 6.6 Rainfall Area Cattle Index

(RA)/C = (Ri x Ai)/Ci. where:

(RA)/C is the Rainfall Area Cattle Index
Ri is average seasonal rainfall for an area
Ai is estimated grazing area available for cattle
Ci is total number of cattle during a given year
i is area of study

Source: Vossen 1987:25.

shows forage shortage and a high index indicates abundance of food. Using the Cattle Equation 6.3 in areas with similar rainy seasons, Vossen (1987) found that heavily stocked areas had a higher death ratio than lightly stocked areas. Table 6.5 shows the effect of the Range Area Cattle Index on death rate.

Table 6.5 The Death Rate and Rainfall Cattle Area Index for Three Localities in Botswana

Locality	Death Rate (%)	(RA)/C	Observation
Mahalapye	14.4	25	Heavily stocked
Kweneng	12.8	100	at Carrying Capacity
Western	10.7	600	Lightly stocked

Source: Adapted from Vossen 1987:27.

Scoones (1993) confirmed Vossen's finding in communal areas of Zimbabwe where the cattle death rate was density dependent when there was no environmental stress (see Section 3.3.3). A density dependent death rate is influenced by the stocking rate. From Table 6.5, if the stocking rate at Carrying Capacity is 12.5 Ha LSU^{-1}, a heavy stocking rate is 5 Ha LSU^{-1} and a light stocking is 30 Ha LSU^{-1} (Figure 6.18). The relationship between the RA/C and the Death Rate can be represented by Figure 6.18. Figure 6.18 shows that as the stocking rate increases the Death Rate increases and vice versa. But the RA/C and Death Rate do not have a straight relationship. The Death Rate between Mahalapye and Kweneng differs by 1.6 percent when the Rainfall Cattle Area Index differs by 75, which contrasts with a 2.1 percent Death Rate difference when the Area Index differs by 500 between Kweneng and Western districts. These differences give a Death Rate to Range Cattle Area Index ratio of 1:47 and 1:24 respectively. The different ratios show that the Death Rate is more sensitive to a change in the forage availability within a heavily stocked area than within a lightly stocked area.

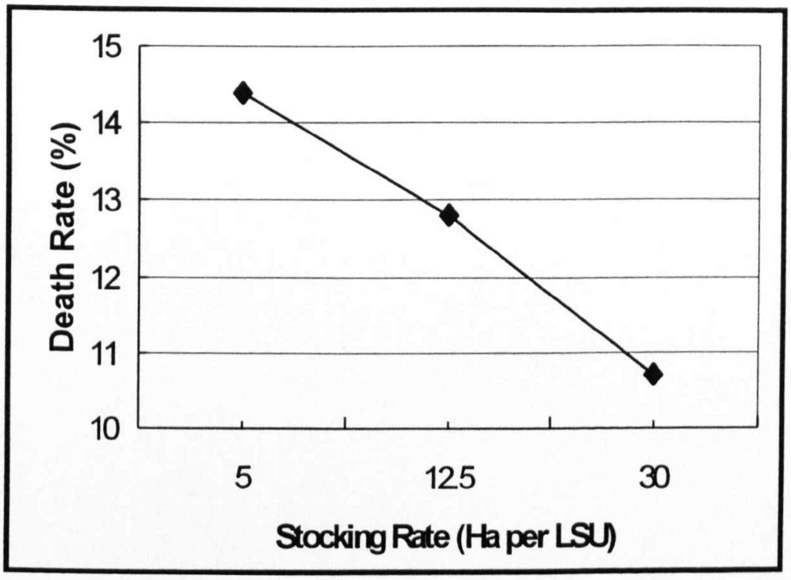

Figure 6.18 The Death Rate at Three Stocking Rates
Source: Adapted from Vossen 1987:27.

Rainfall, which directly determines the forage availability, is a limiting factor for cattle mortality. All the regression equations which Vossen (1990:194) derived for the Livestock Performance Index (LPI), had a negative slope to show that the Death Rate worsens with an increased shortage of the cattle water requirements (Section 3.3.3). The contribution of the rain towards the cattle mortality depends on a combination of management and natural factors. Some of the management factors are the availability of supplementary feeding, timely cattle sales at the beginning of the drought, and timely cattle movement out of an affected area (Vossen 1990).

The Cattle Equation 6.7 was used to calculate the R2 values for the Carrying Capacity values between 5 and 30 Ha LSU^{-1}.The Carrying Capacity and R2 coordinates from the Cattle Equation 6.7 were a straight line which did not represent R2 and Carrying

Capacity relationship envisaged in Figure 6.18. They graph was smoothed to get a curvature in the coordinates.

Cattle Equation 6.7 Calculating the Death Influencing Factor (R2) values

$$R2 = \frac{1}{GC/CC} \quad \text{where:}$$

R2 is the Death Influencing Factor
GC is 12.5 Ha LSU^{-1}
CC is Carrying Capacity

A Carrying Capacity decline causes R2 to increase and an increase in the CC causes R2 to decline. In Figure 6.18 a high stocking rate is associated with a low carrying capacity and vice versa, consequently, Figure 6.19 which shows the Death Rate and the stocking rate, is negatively skewed. In contrast to Figure 6.18, Figure 6.19 which shows the Death Rate and the carrying capacity, is positively skewed. This means that in Figure 6.19, when the CC is at Grazing Capacity, R2 is at unity and when the Carrying Capacity is below 12.5 Ha LSU^{-1}, R2 increases.

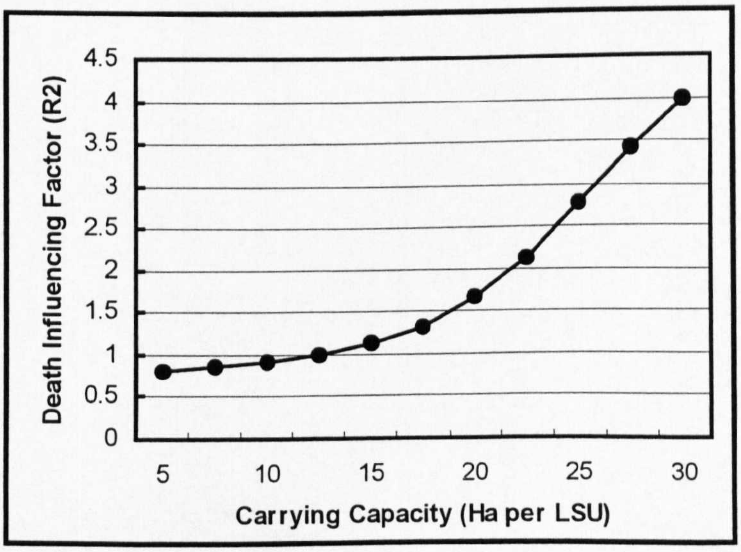

Figure 6.19 The Influence of Carrying Capacity on the Death Rate

When the Carrying Capacity is above 12.5 Ha LSU^{-1}, R2 decreases. A poor Carrying Capacity increases the death rate more than a good Carrying Capacity reduces it. Hence the R2 graph has a steep gradient for the low Carrying Capacity and a gentle gradient for the high Carrying Capacity.The communal areas national average Death Rate of 10 percent (Mosienyane, 1992) was used for the natural death rate (ND Rate) in the Cattle Equation 6.8.

Cattle Equation 6.8 The Natural Death Rate (ND Rate)

NatDeath = CATTLE*ND Rate where:
NatDeath is the number of cattle deaths CATTLE is the number of cattle ND Rate is the Natural Death Rate

To get the annual number of deaths, the 10 percent is multiplied by the R2 value. Multiplying the Death Rate by a big R2 increases the deaths and multiplying by a small R2 decreases the deaths.

6.7 The Parameters and Equations for the Livestock Water Sub - Model

6.7.1 *The Rainfall Multiple*

The three Rainfall Weighted bands in Section 6.4.5 convert the rainfall into the Rainfall Multiple as shown by the Livestock Water Equation 6.1.

Livestock Water Equation 6.1 The Rainfall Multiple

RF Multiple =IF (RF Weighted1>975) THEN (1.5) ELSE (IF (RF Weighted1<675) THEN (0.5) ELSE (1)) where:
RF Multiple is the influence of the RF Weighted on the livestock water categories

After the conversion, the Rainfall Multiples 0.5, 1.0 and 1.5 represent below normal, normal and above normal rainfall, respectively. The Rainfall Multiples are used to change the water holding for the livestock water categories as explained in Sections 4.3.2 and 6.7.2.

6.7.2 *The Livestock Water Holding*

This section discusses the derivation of the livestock water holding equation. The availability and seasonality of a seasonal livestock water source in response to rainfall was introduced in Section 4.3. The water holding for the different sources during an average rainfall season were summarised in Table 4.4. Livestock Water Equation 6.2 determines the water holding for the four water holding categories. Sections 4.3.2 and 4.3.3 complement the Livestock Water Equation 6.2.

Livestock Water Equation 6.2 Seasonal Livestock Water Sources

Notwane_S'snal = IF (RF Multiple = 0.5) THEN (2*2*0.5) ELSE (IF (RF Multiple =1.0) THEN (2*2*1) ELSE (2*2*1.5))

Cat2 = IF (RF Multiple = 0.5) THEN (1*6*0.5) ELSE (IF (RF Multiple = 1.0) THEN (1*6*1) ELSE (1*6*1.5))

Cat3 = IF (RF Multiple = 0.5) THEN (4*4*0.5) ELSE (IF (RF Multiple = 1.0) THEN (4*4*1) ELSE (4*4*1.5))

Cat4 = IF (RF Multiple = 0.5) THEN (3*2*0.5) ELSE (IF (RF Multiple = 1.0) THEN (3*2*1) ELSE (3*2*1.5)) where:

Notwane S'snal is seasonal Notwane River - 2 sources - 2 months average water holding
Cat2 is Category 2 water source - 1 source - 6 months average water holding
Cat3 is Category 3 water source - 4 sources - 4 months average water holding
Cat4 is Category 4 water source - 5 sources - 2 months average water holding

Livestock Water Equation 6.2 shows how the model determines the water holding for three water sources; the seasonal Notwane River and the Category 2 sources, Category 3 sources, Category 4 sources. The seasonal Notwane River and the Category 4 sources hold water for two months, the Category 3 sources hold water for four months and the Category 2 sources hold water for six months. The equation does not include Category 1 sources and the perennial Notwane River, which hold water for eight months, which in the model is the whole dry season. The equation structure for each seasonal livestock water source is similar. The seasonal water holding per source is determined by (Frequency x Water Holding x RF Multiple). Frequency is the number of livestock water sources per category, for example, there is one Category 2 water source. Water holding is the number of months over which the source holds livestock water following average rainfall conditions (see Table 4.4). The RF Multiple, defined in Livestock Water Equation 6.1, changes the water holding in response to the RF Weighted. When the RF Weighted is 1000 mm, the effect on Category 3 sources will be [4 (water points in the category) x 4 (average water holding months for category 3 sources) x 1.5 (Rainfall Multiple for over 975 mm rainfall) = 24]. Since Category 3 has 4 water sources, the water holding per source is 24/4 = 6 months. In this example, the RF Weighted of 1000 mm improved the water holding of the Category 3 water sources from 4 to 6 months. The procedure in Livestock Water Equation 2 applies to seasonal livestock water sources only. The simulated rainfall in this study does not affect the perennial sources.

Most perennial sources (Livestock Water Equation 6.3) are boreholes with low groundwater recharge rates that are difficult to assess (Beekman *et al.*, 1996). The perennial sources in the model are not connected to the RF Multiple as their recharge time frame would be out of scale with the other model outputs.

Livestock Water Equation 6.3 Perennial Livestock Water Sources

Boreholes = (5*8) Notwane P'rnial = 1*8 where: Boreholes is the 5 boreholes in the area Notwane P'rnial = Perennial section of Notwane River equivalent of one source

The perennial livestock water sources are assumed to have water for eight months, hence in the Livestock Water Equation 6.3 the water source frequency is multiplied by the 8 months supply.

6.7.3 *The Livestock Water Months*

As discussed in Section 4.3.5, the Livestock Water Months is the livestock water holding for all sources. Livestock Water Equation 6.4 determines the LW months.

Livestock Water Equation 6.4 Livestock Water Months (LW Months)

LW Months = (Boreholes + Notwane P'rnial + Cat2 + Cat3 + Cat4 + Notwane S'snal) where: LW Months is the total months water holding for all the water sources in an area Boreholes is the 5 boreholes in the area Notwane P'rnial is the perennial section of Notwane River equivalent 1 source Cat2 is Category 2 water source - 1 source - 6 months average water holding Cat3 is Category 3 water source - 4 sources - 4 months average water holding Cat4 is Category 4 water source - 5 sources - 2 months average water holding Notwane S'snal is seasonal Notwane River - 2 sources - 2 months average water holding

At normal rainfall the LW Months is 76. A LW Months above 76 occurs when there has been an above average normal rainfall and that less than 76 shows below normal rainfall.

6.7.4 *The Livestock Water Months Density*

The Livestock Water Equation 6.5 measures Livestock Water Months Density which is the distribution of the livestock water per area. The LW Months Density is measured in Ha LW Months^{-1}. The LW Months Density, discussed in Section 4.3.6, is influenced by both the LW Months and total grazing.

Livestock Water Equation 6.5 The Livestock Water Months Density (LW Months Density)

LW Months Density = (Total Grazing/LW Months) where:

LW Months Density is the distribution of the total water holding per area
Total Grazing is the are of the grazing land
LW Months is as shown in Livestock Water Equation 6.4

6.7.5 *The Carrying Capacity Water Availability Ratio (CCWA Ratio)*

The Carrying Capacity Water Availability Ratio shown by the Livestock Water Equation 6.6 represents the average number of animals (LSU) per available water points. The implications of changes in Carrying Capacity and LW Months Density to the CCWA Ratio were discussed in Section 4.3.6. Equation 4.5 details derivation of the CCWA Ratio. Livestock Water Equation 6.6 shows how the CCWA Ratio is calculated.

Livestock Water Equation 6.6 The Carrying Capacity Water Availability Ratio (CCWA Ratio)

CCWA Ratio = LW Months Density/CarryCap where:

CCWA Ratio is the Carrying Capacity Water Ratio
LW Months Density is Livestock Water Density (see Livestock Water Equation 6.5)
CarryCap is the Carrying Capacity

A high figure means a low CCWA Ratio and vice versa which makes the CCWA Ratios counter intuitive. The Normalised CCWA Ratio (Livestock Water Equation 6.7) improves the perception of the ratio. The Normalised CCWA converts the CCWA Ratio so that a high Normalised CCWA Ratio value represents a high CCWA Ratio and vice versa.

Livestock Water Equation 6.7 Normalised Carrying Capacity Water Availability Ratio (Normalised CCWA)

Normalised CCWA = (1/CCWA Ratio) *100 where:
Normalised CCWA is the CCWA Ratio which is made to look intuitive CCWA Ratio is the Carrying Capcity Water Availability Ratio

6.8 Differences Between the National and Local Model

The national model (Braat and Opschoor Model) has twenty nine parameters while the local model (Rain Land Cattle model) has forty nine. Most of the additional parameters in the local model are for the Livestock Water Sub - Model which was not in the national model. Sections 6.8.1 to 6.8.4 detail the differences between the two models per sub - model.

6.8.1 *Differences in the Rainfall Sub - Model*

i) **The Rainfall Trend** - in the local model the trend was represented by a Moving Average and an Auto Regressive while it was represented by a sinusoidal function in the national model. The rainfall trend in the Rain Land Cattle model is much closer to the observed trend for the fifty year period (1945 to 1996) than the national model's sinusoidal curve is to twenty year (1966 to 1986) rainfall trend used by Braat and Opschoor.

ii) **Delayed Rainfall** - the Rain Land Cattle model has two delayed rainfall parameters. One is linked to the Carrying Capacity and the other is linked to the livestock water availability. Each of the delayed rainfall parameters has a weighted rainfall formula. The Braat and Opschoor model has one delayed rainfall parameter linked to the Carrying Capacity. The latter model uses the present and last years rainfall for the Carrying Capacity while the Rain Land Cattle model uses the present, past and previous year's rainfall.

iii) **Range Factor** - a fundamental difference between the two models is the interpretation of the Rainfall weighted values used in the Range Factor graphical function. The RF Weighted values in the Braat and Opschoor model are based on a ratio of 0.67:0.33 for the Range Factor equal the annual rainfall figures. The Botswana Range Condition Index in the Rain Land Cattle model uses the ratio of 3:2:1 for present, last and previous year's rainfall.

6.8.2 *Differences in the Grazing Sub - Model*

iv) **Seasonal Grazing** – the local model has a management function that represents seasonal grazing as a STEP function. The parameter is not used in the national model.

v) **Permanent Grazing** - like the seasonal grazing the permanent grazing is only used in the local model. Its nearest equivalent in the nation al model is range area.

vi) **Grazing Land Loss** - The local model simulated a permanent grazing land loss while the national model simulated addition to the range area through the development of additional boreholes.

vii) **Conversion of Cattle to Livestock Units** - the local model converts cattle to the conventional livestock units (LSU) before determining the stocking rates, stocking factor and Carrying Capacity. The national model does not. Confusion could arise due to non conversion. For example Braat and Opschoor use GC in Ha LSU^{-1} and stocking rates in Ha LSU^{-1} yet they did not convert cattle numbers to LSU. For consistency it is advisable to convert cattle to livestock units.

viii) **Stocking Factor** - the national model used equal weights between the present and last year's stocking rates to calculate the weighted stocking (ST Weighted). The local model uses a ratio of 1:0.5 for present and last years stocking. Consequently the local model's unity value is greater than the Grazing Capacity for the area. The weightings are subject to verification but the argument for unequal weights for stocking rate in consecutive years is stronger than that for equal weights because over time the grazing recuperates.

ix) **Terminology on Carrying Capacity and Grazing Capacity** - the national model used Grazing Capacity and Potential Carrying Capacity. The local model used Carrying Capacity and Grazing Capacity. The justification for the use of Carrying Capacity and Grazing Capacity in the local model was made in Section 3.2. Although interchanging the terms is not fundamental to either model's outputs and performance in this case, it is a potential source of confusion when the two models are compared.

6.8.3 *Differences in the Cattle Sub - Model*

x) **Emigration** - the local model included the parameter Emigration because farmers move cattle out of Tlokweng sub district to other parts of the country as a management strategy. The parameter was not relevant at the national level because cattle do not emigrate from Botswana to neighbouring countries.

6.8.4 *The Livestock Water Sub - Model*

None of the parameters in the livestock water sub - model occur in the national model. The national model shows the significance of livestock water by suggesting that the range area increases when new boreholes are opened (Braat and Opschoor, 1990) hence reducing the stocking rates. In the local model livestock water is incorporated into the definition of the Carrying Capacity of an area as the Carrying Capacity Water Ratio.

Summary

Chapter 6 describes the Rain Land Cattle model, its causal structure and how the model parameters are derived and function. The parameters' equations are described in detail. Some of the values used in the equations are subject to validation but the principles on which they are based are explained in each case. The validity of the principles used to determine the values is paramount and should be borne in mind when interpreting the model outputs in the following chapters. A model that simulates functionally valid relationships may make poor predictions because of problems with data availability. For example, if the graphical functions R1 and R2 are a plausible relationship between the Carrying Capacity and Birth and Death rates respectively, the model provides a good basis on which accurate data could be used. In that case the parameters R1 and R2 are a useful finding about the relationship of parameters which influence the cattle management system in Botswana.

Chapter 7. Results of the Study

Introduction

The results of the study are divided into two, the Rain Land Cattle model results, and the questionnaire results. The former are the macro aspects of the study and the latter are the micro aspects. The model results used four of the eight rainfall scenarios in Section 6.3.5 to 6.3.9 whose coefficient of variation was appropriate for rangelands to simulate number of cattle, rainfall amount, carrying capacity, grazing land loss, grazing, land pressure, and the effects of cattle management strategies. The questionnaire results described the interviews with ninety households and in-depth discussions held on cattle management and land availability.

7.1 The Definition and Meaning of the Base Run

The Base Run for the study area was defined by the parameter settings in Table 7.1.

Table 7.1 The Base Run Parameter Values used in the Rain Land Cattle Model

Name of Parameter	Parameter Setting	Comment
Stochastic Factor	(0, 117.2, 1000)	(mean, s.d., seed)
Rainfall Mean	520 mm	
Initial Cattle Herd	1000	
Birth Rate	23 percent	
Death Rate	10 percent	
Grazing Capacity	12.5 Ha LSU^{-1}	
Offtake Rate	0.08 percent	
Seasonal Grazing	50 km^2	four months a year
Permanent Grazing	100 km^2	x landloss fraction
Grazing Land Loss Fraction	0.005 x Permanent Grazing	
Purchase rate	0.025 percent	
Emigration	0 percent	
R1	min 0.038	at 35 Ha LSU^{-1}
	max. 2.9	at 7.5 Ha LSU^{-1}
R2	min 0.58	at 2.5 ha LSU^{-1}
	max. 5.0	at 35 Ha LSU^{-1}
Range Factor	min 0.5	at 1650 mm
	max. 5.0	at 200 mm
ST Factor	min 0.5	at 50 Ha LSU^{-1}
	max. 0.3	at 5.0 Ha LSU^{-1}

The term "Base Run" refers to a simulation model where the parameters have been calibrated to reproduce a past pattern of behaviour. In this case the Rain Land Cattle model reproduces the rainfall amount and number of cattle in Tlokweng sub – district. The derivation of the parameters used in the model is explained in Chapter 6. Figure 7.1 shows the Base Run number of cattle and rainfall for 1945 and 1995. The Y axis has two scales whose origin is not zero. Simulation begins at 1945 because the rainfall data used are from 1945. The number of cattle increased from 1000 in 1945 and fluctuates between 1435 and 1871 most of the time while the rainfall fluctuates between 352 and 728 mm per annum.

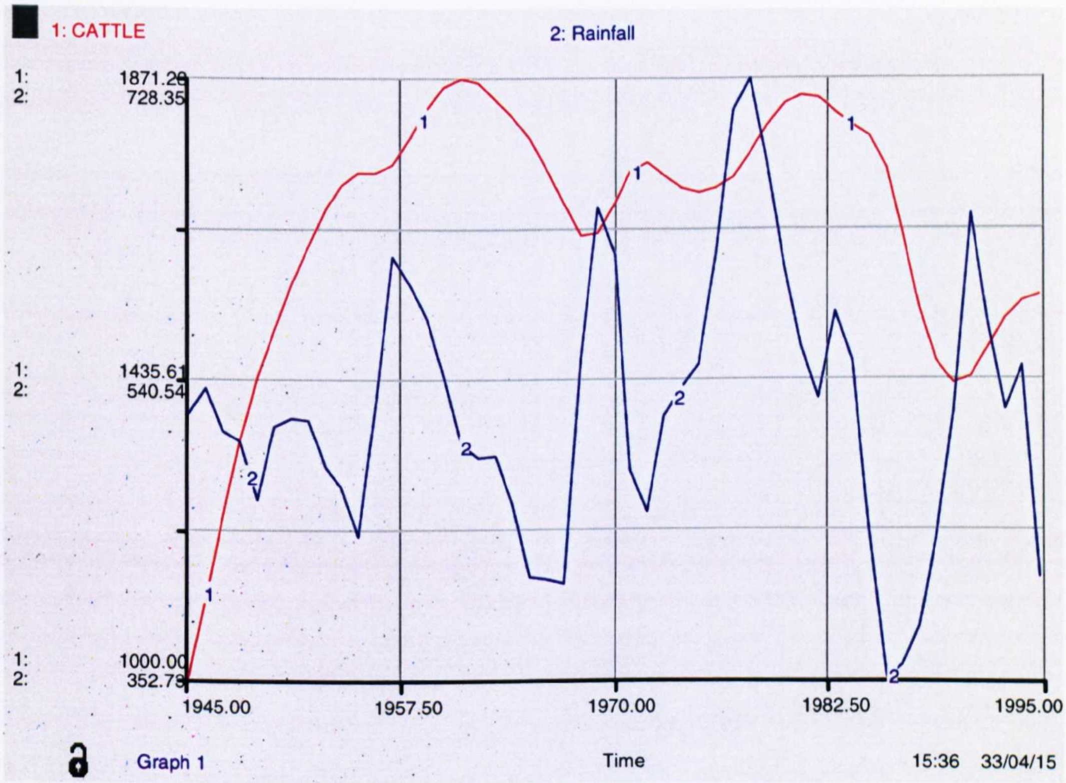

Figure 7.1 Base Run - Rainfall and Number of Cattle 1945 to 1995

Figure 7.2 compares the predicted and observed cattle within the period 1980 to 1996.

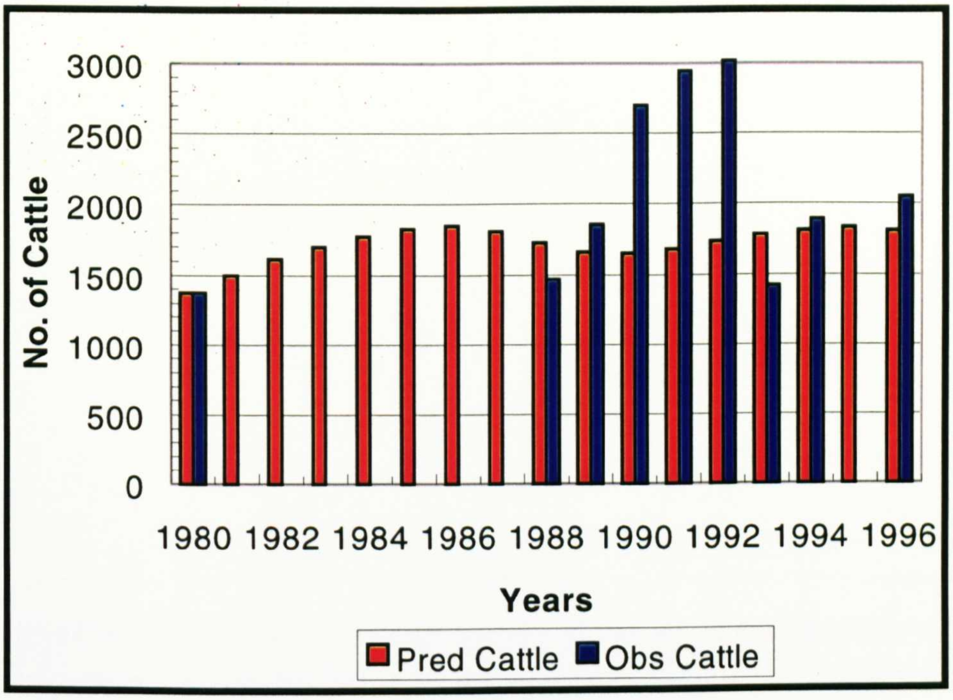

Figure 7.2 Predicted (Pred) and Observed (Obs) Number of Cattle 1980 to 1996 in Tlokweng Sub - district

Source: Veterinary District Office, personal communication, 1996: Veterinary Officer, personal communication, 1997. (Both for observed number of cattle)

There were no observed cattle data for 1981 to 1987, and 1995. Between 1990 and 1992 there were more observed cattle that those predicted. The observed cattle population doubled between 1988 and 1992. The growth is unlikely to be through natural herd growth alone. The above average (723, 700, 360, 707 mm) annual rainfall between 1988 and 1991 (Figure 7.3) would attract cattle from other regions into the area. Some households move cattle in and out of the Tlokweng sub - district (see Section 7.6.2) in response to the changes in climate. Given that the model does not predict cattle movement in and out of the study area, the seven year observed cattle data gap between 1981 to 1987 which had below average rainfall, it is difficult to make a firm conclusion about the accuracy of cattle prediction in Figure 7.2. Between 1990 and 1992, the number of observed cattle was almost double that predicted but

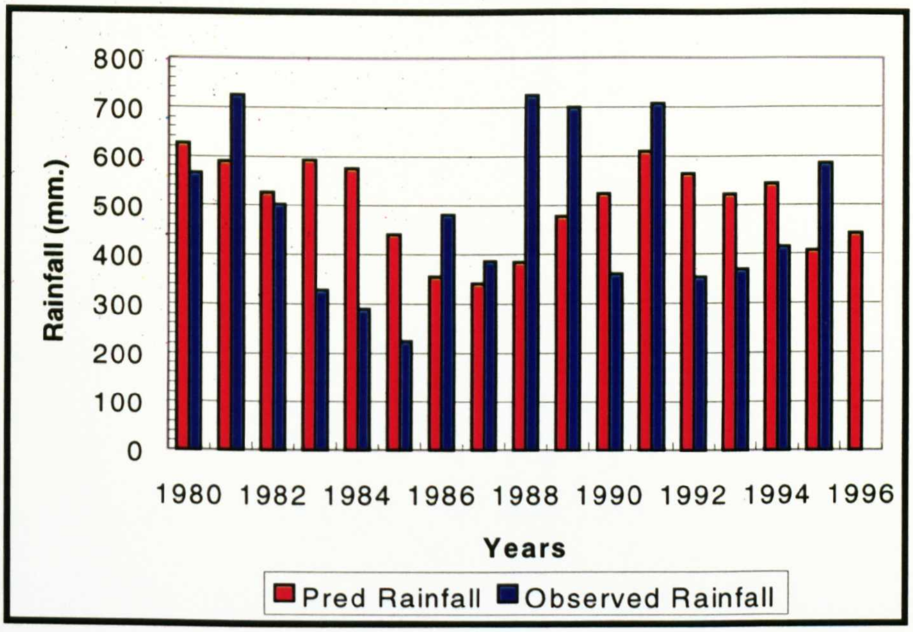

Figure 7.3 Predicted (Pred) and Observed (Obs) Rainfall -Gaborone 1980 to 1996
Source: Botswana Meteorological Services, 1996. (Observed rainfall)

during the other years the number of observed and predicted cattle were within the same order of magnitude. It is not clear how much confidence to place on the observed cattle figures in Figure 7.2. The Department of Animal Health and Production collects the cattle data yearly during the vaccination campaigns to which most farmers bring their cattle. Often the cattle go to the same locality every year. The number of cattle in Figure 7.2 is from two official sources. The records were from compiled from between 3 and 6 localities. Even if unreliable, the figures are accepted for this exercise because they are the basis for official cattle management plans in the sub - district. Figure 7.3 shows the observed and the simulated rainfall for the period 1980 to 1996. The predicted rainfall was more than the observed rainfall in 1983 to 1985, 1990, and 1992 to 1994. These were years when the observed rainfall was less than 520mm, the mean annual rainfall. The peak rainfall years between 1988 and 1991 coincide with a high population of observed cattle but with a lag effect such that the number of cattle exceeds 2000 only in 1990. The lag shows the delayed rainfall effect that was incorporated into the model through the Botswana Range Condition Index.

The meaning of Stocking Rate (ST Rate), Carrying Capacity (CC) in the model are as explained in Section 6.5. This section explores the Base Run pattern for the Stocking Rate and the Carrying Capacity. The behaviour of the two, which are on the same scale for easy comparison, is illustrated by Figure 7.4.

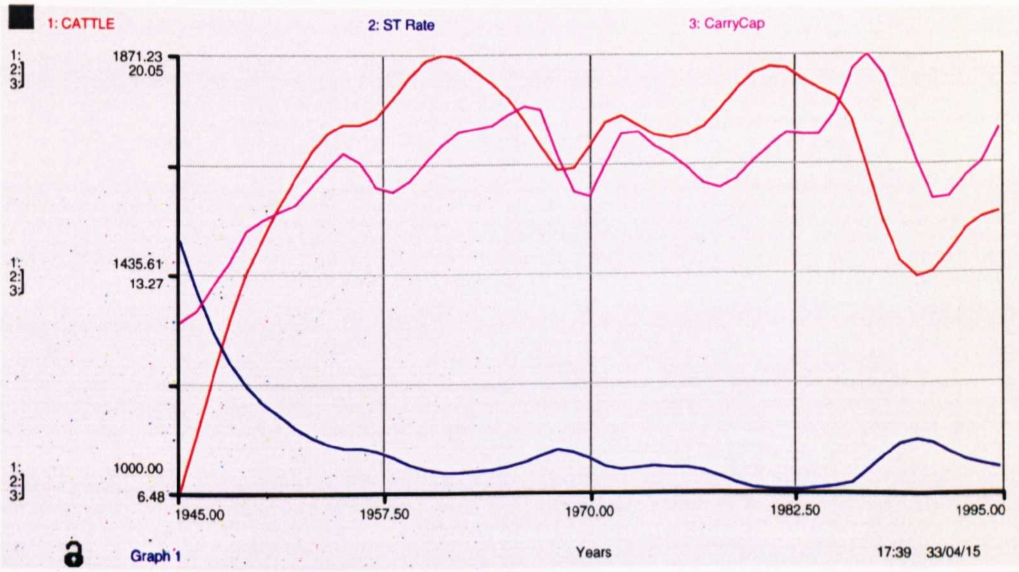

Figure 7.4 Base Run - Number of Cattle, Stocking Rate and Carrying Capacity, 1945 to 1995

The number of cattle was added to the graph to show the context of the comparison. The initial 3 years pattern should be disregarded because they show the effect of the delayed rainfall. The ST Rate is higher than the CC most of the time. When defining the research problem in Chapter 1, it was pointed out that where the stocking rate exceeds the CC, it is taken to be prima facie evidence of overstocking and poor cattle management of the communal areas. This section, which defines the Base Run, also shows that it is difficult to establish the validity of the cattle predictions due to the paucity of observed cattle data. The prediction shows that the Stocking Rate is always higher than the Carrying Capacity.

7.2 Sensitivity Analysis

Sensitivity analysis measures how a change in a parameter affects the output of a model. The model's output is measured in relation to a parameter base value. Based on the response of the model's output to a change in parameter values, the sensitivity of the parameters was divided into three classes (Table 7.2).

Table 7.2 The Definition of the Sensitivity Classes

Output response to 1 percent parameter change	Sensitivity Class
More than 0 but less than 1 percent	Not sensitive
1 – 2 percent	Sensitive
Over 2 percent	Very sensitive
No response	Not relevant

A difference of 20 percent in output, for a parameter set at 30 percent of the base value, means that a 1 percent parameter increase causes 0.7 percent output value increase, therefore the parameter is not sensitive. The most and least influential parameters in a model are identified through the sensitivity analysis. The Rain Land Cattle model has forty nine parameters all of which interact, and could be outputs, during simulation. A series of simulations were undertaken to determine the sensitivity of several of the parameters. Section 7.2.1 is an example of how the sensitivity of the rainfall amount to changes in the rainfall mean was determined. Table 7.3 summarises the sensitivity of birth rate and death rates, number of cattle stocking rate and other output variables, to the rainfall, grazing capacity, grazing land loss and offtake as input parameters.

7.2.1 *Rainfall Patterns Based on Variations of the Mean*

Figure 7.5 shows the trends when the rainfall mean is set at five different values. It is

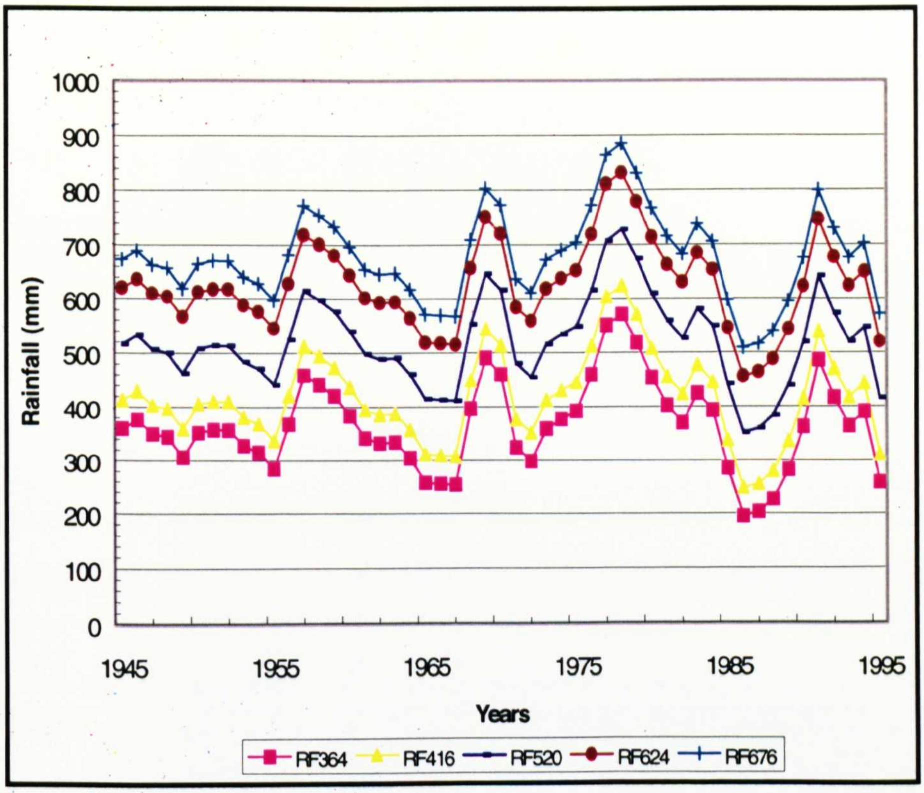

Figure 7.5 Sensitivity of the Rainfall Mean

an example of how the sensitivity analysis was done for each variable in Table 7.2. The first two values, RF 364, RF 416 which stand for a rainfall mean of 364 and 416 mm respectively, represent 70 and 80 percent of the mean rainfall of 520 mm. The last Two. RF 624 and RF 676, represent 20 and 30 percent above the mean. The rainfall is sensitive to the variation of the mean which means that a 1 percent change in the rainfall mean in the model causes 1-2 percent variation in the rainfall. A rainfall mean of 364 mm (RF364) simulates the least rainfall and 676 mm (RF676) simulates the highest rainfall.

7.2.2 *Summary of Model Parameters' Sensitivity*

Table 7.3 summarises the sensitivity of some parameters in the model. The stochastic parameter causes changes to the rainfall as dealt with in Sections 6.3. The sensitivity classes are explained in Table 7.2. "Not relevant" means that the input variable has no influence in the output parameter considered. Rainfall, the driving parameter in the model, affects the number of cattle and consequently the stocking rate. The number of cattle and the stocking rate are both very sensitive to variations in the grazing capacity and offtake which shows that the grazing capacity is fundamental to the model. The two cases where the sensitivity of the grazing capacity changes after 12.5 Ha LSU^{-1} show the influence of the grazing capacity values set in the model.

Table 7.3 The Sensitivity of the Model Parameters

Output parameter	Input Parameter (varied by 1 percent)			
	Rainfall	Grazing Capacity	Grazing Land Loss	Offtake
Birth Rate	Not sensitive	Sensitive when GC > 12.5 otherwise not sensitive	sensitive	Not sensitive
Death Rate	Not sensitive	sensitive	sensitive	Not sensitive
No of Cattle	sensitive	Very sensitive	sensitive	Very sensitive
Stocking Rate	sensitive	Very sensitive	sensitive	Very sensitive
Carrying Capacity	Not sensitive	sensitive	Not sensitive	Sensitive
LW Months	Not sensitive	Not relevant	Not relevant	Not relevant
LWM Density	Not sensitive	Not relevant	Not relevant	Not relevant
CCWA Ratio	Not sensitive	Sensitive when GC > 12.5 otherwise not sensitive	Very sensitive	Not relevant
Total Grazing	Not relevant	Not relevant	Very sensitive	Not relevant

7.3 Simulation of Erratic Rainfall Scenarios

In this section, Rainfall Scenarios 1 and 2 represent a higher and more erratic rainfall than the Base Run. Rainfall Scenarios 5 and 6 represent lower and erratic rainfall than the Base Run. Table 6.3 shows the parameter settings for the rainfall scenarios. Figure 7.6 to Figure 7.13 which show simulated number of cattle, deaths, births and rainfall are all at different Y axis scales because Stella determines the scale automatically. Although the scale can be determined manually, and possibly set uniformly for all the diagrams, it would make it difficult to see the variations from one simulation to another.

7.3.1 *High and Very Erratic Rainfall Scenarios*

The number of cattle and rainfall for a fifty year simulation period for Scenario 1 is shown in

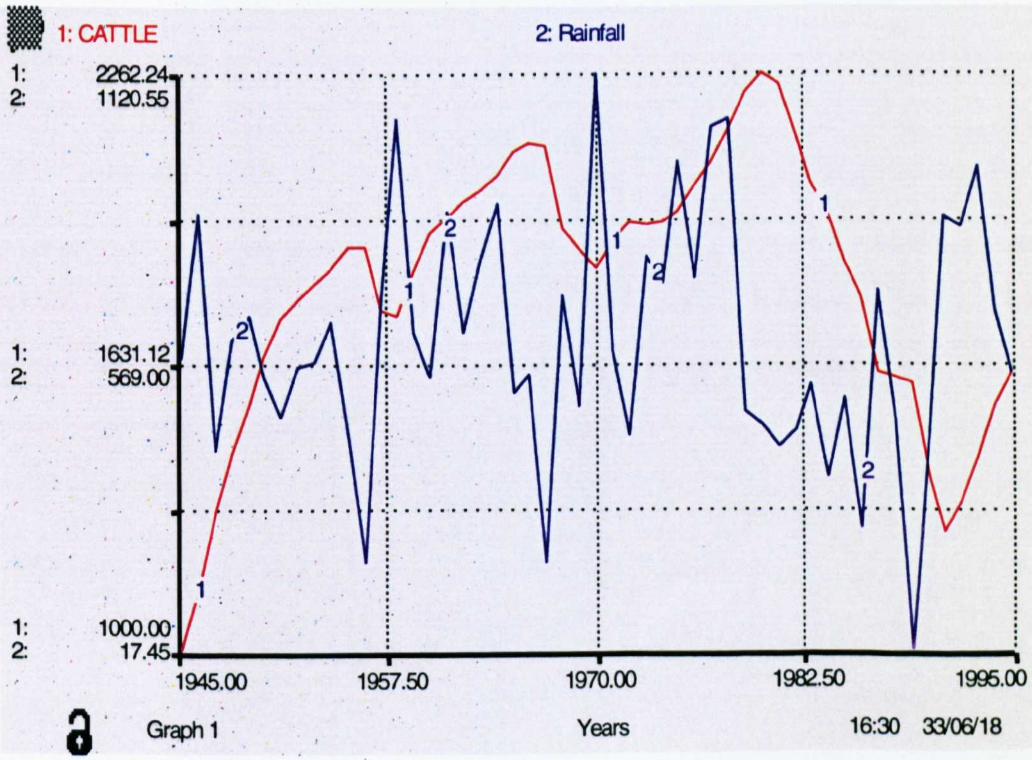

Figure 7.6 Scenario 1 - Rainfall and Number of Cattle 1945 to 1995

Cattle increased from the initial 1000 in 1954 to a maximum of 2262 in 1980. The rainfall declined to a minimum in 1989 followed by a low cattle figure in 1991. The maximum number occurs in 1980, which is 2 years after the peak rainfall, because the number of cattle responds to the Botswana Range Condition Index (Section 6.4.4). Figure 7.7 simulates Scenario 2 whose cattle population has a similar trend to that of Scenario 1. Scenario 2 simulates slightly more cattle than Scenario 1 because it has

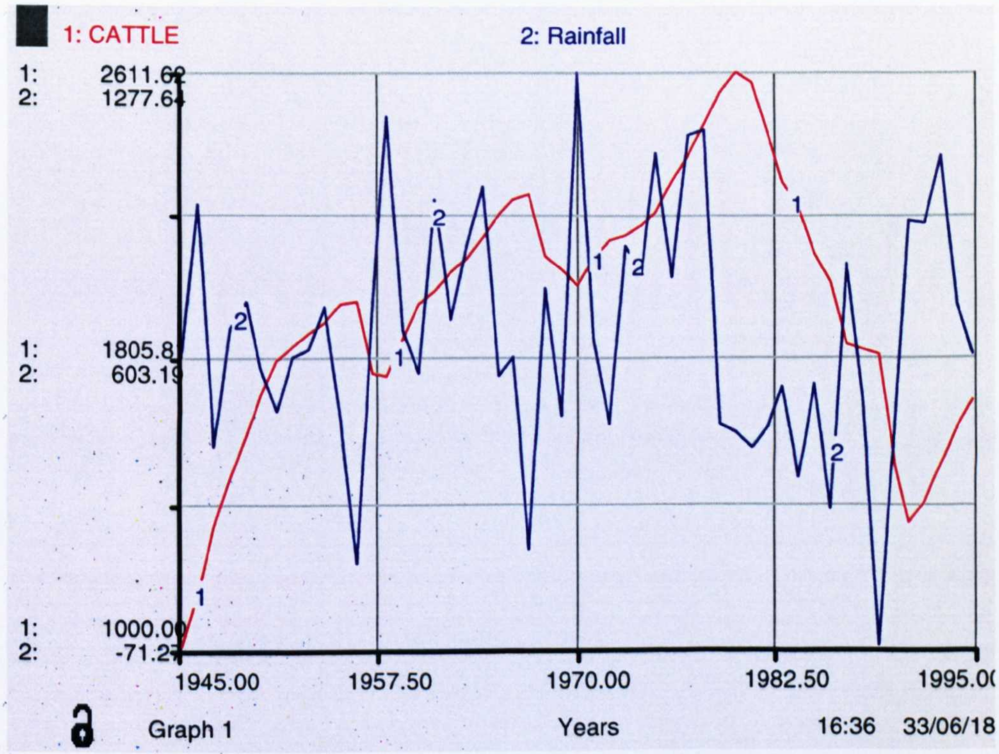

Figure 7.7 Scenario 2 - Rainfall and Number of Cattle 1945 to 1995

more rainfall even though it has a bigger standard deviation. The simulated births and deaths for Scenario 1 and 2 are closely comparable because the standard deviation of the rainfall is similar, 200 and 250 respectively (Table 6.2). A closer look at the cattle trends shows that cattle deaths (Figure 7.8) follow the rainfall pattern in an inverse order to the births, and both show a lag due to the BRCI as explained earlier. A high mortality, above 200 deaths per annum, was simulated for both Scenario 1 and 2 after periods of rainfall shortage during 1955 to 1957, 1965, 1968, and intermittently between 1980 and 1990 (Figure 7.8). Figure 7.8 confirms the high cattle mortality during a drought but also shows that a when the rainfall is highly variable, such as 1978 to 1990, the death rate will be high and the birth rate declines.

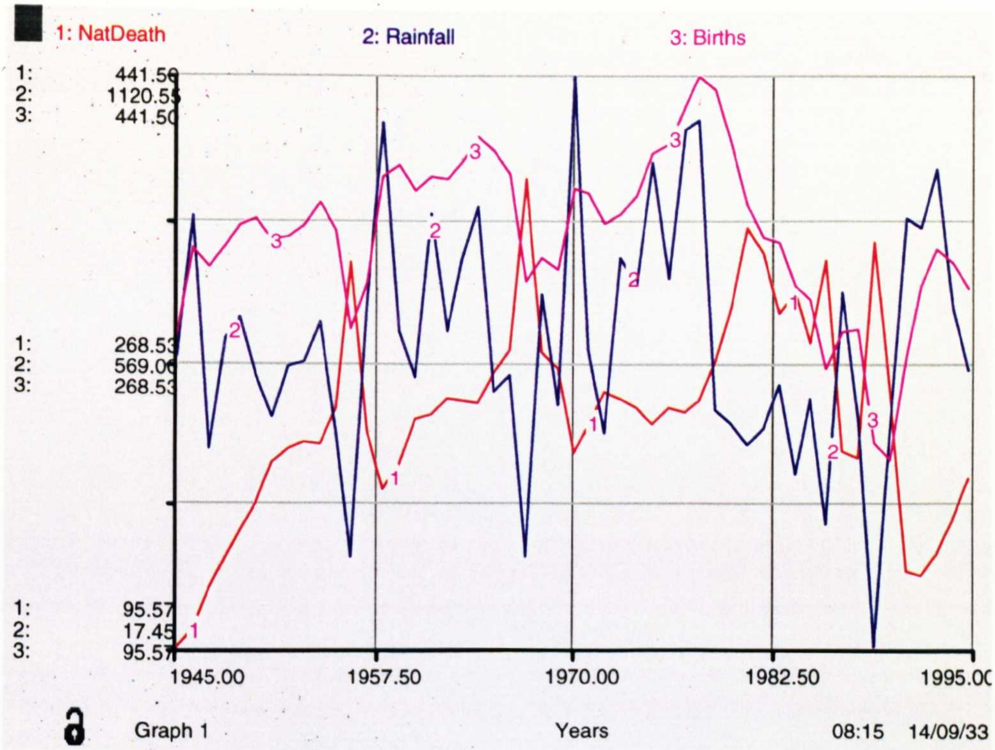

Figure 7.8 Scenario 1 Cattle Deaths, Births and Rainfall

Figure 7.9 shows a decrease in the Carrying Capacity and an increase in the Stocking Rate as the number of cattle increases from the initial 1000 to a peak of 2664 in 1980. Except for the first two simulation years, which should be ignored because they show the effect of the model initialising its equation, the Stocking Rate is always more than the Carrying Capacity.

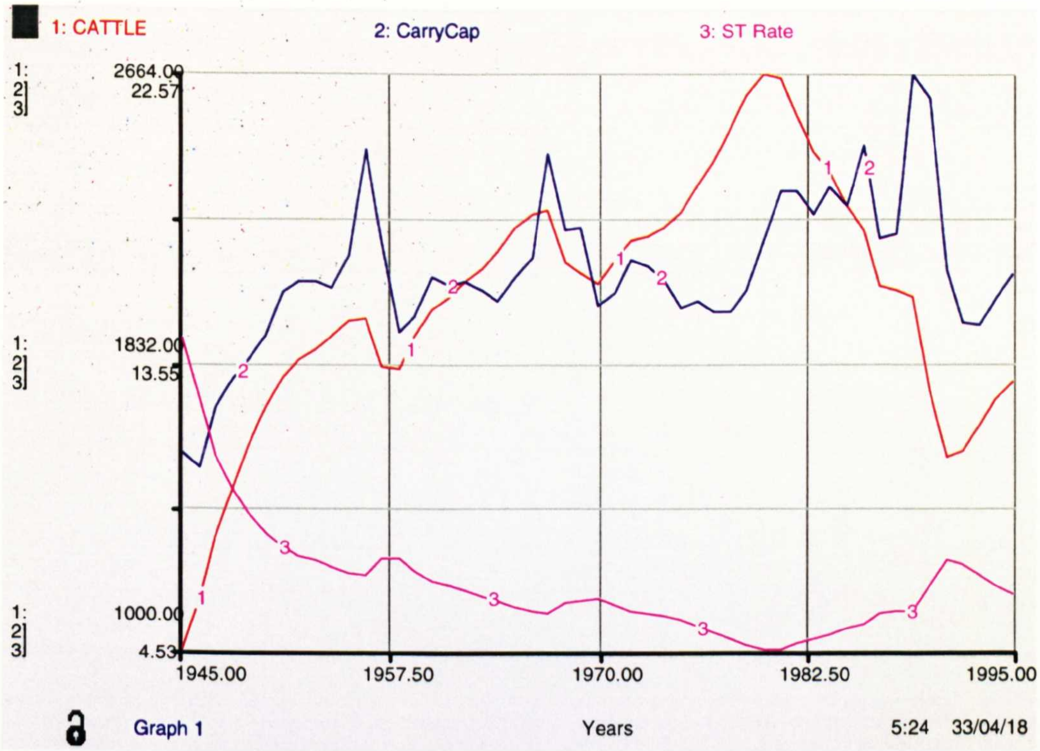

Figure 7.9 Scenario 2 - Number of Cattle, Carrying Capacity and Stocking Rate 1945 to 1995

The Stocking Rate decreases as the number of cattle declines towards the end of the simulation period. The number of cattle had decreased between 1990 and 1995 despite the annual rainfall increase, which is seemingly contradictory. This was because the cattle population responds to the Botswana Range Condition Index rather than the rainfall. Due to the low rainfall (Figure 7.7) from 1979 to 1990, except 1987, the BRCI is also generally low but rises after 1991. The implication of the finding is that when a drought occurs in an area with many cattle from the previous years of good rainfall, the CC declines first due to the high stocking rate before the number of cattle declines through mortality.

7.3.2 *Low and Very Erratic Rainfall Scenarios*

The model simulates fewer cattle for Scenarios 5 and 6, which represents drought years, than for high rainfall years. Rainfall influences the simulated number of cattle through the BRCI. Figure 7.10 simulates a more variable and lower cattle population than either Figure 7.6 or Figure 7.7.The low rainfall mean causes the low cattle population and the variable rainfall causes the cattle population to vary.

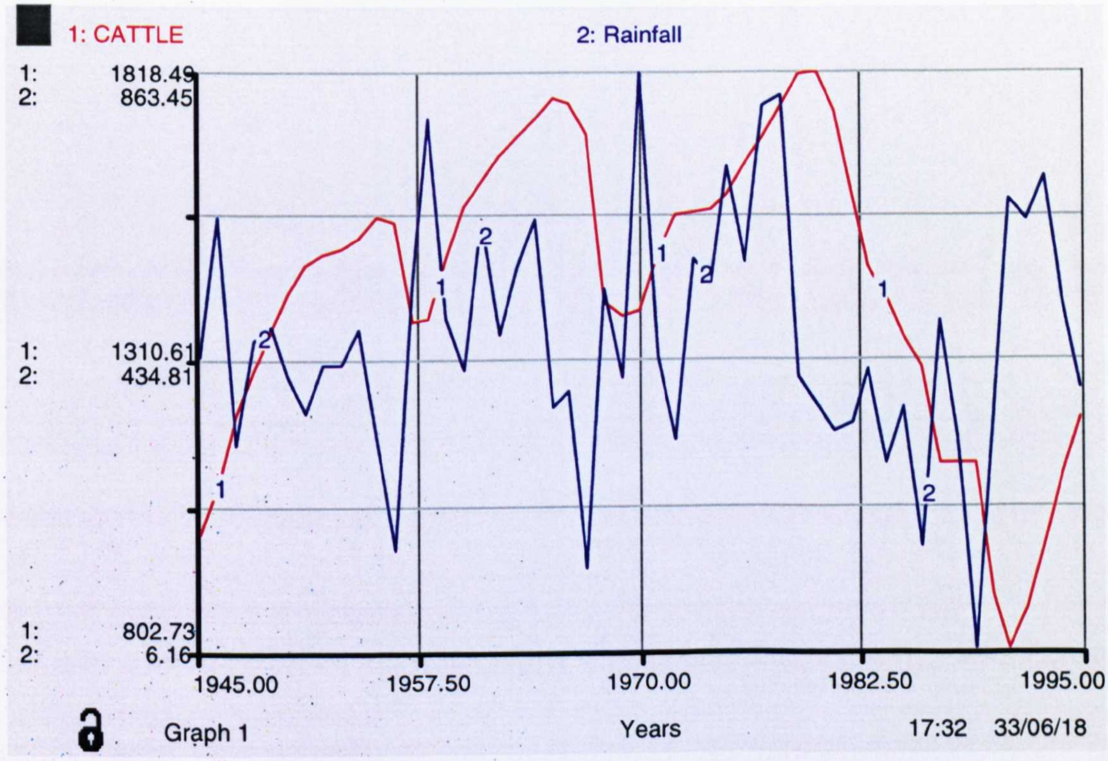

Figure 7.10 Scenario 5 - Rainfall and Number of Cattle 1945 to 1995

The delayed response of the cattle population to the rainfall variation is evident once more. Although Scenario 5 simulates a low cattle population, it is persistent despite the very low rainfall. The scenario shows the resilience of cattle numbers, even without simulating for supplementary feeding which would increase the livestock resistance and hence their persistence. The pattern for Birth and Deaths in Scenario 5 are shown in Figure 7.11. The deaths have five distinct peaks in 1956, 1967, 1980 to

1981, 1986 and 1989. The last four peaks occur during a decline in the rainfall, while the first two are within troughs during a below average rainfall period.

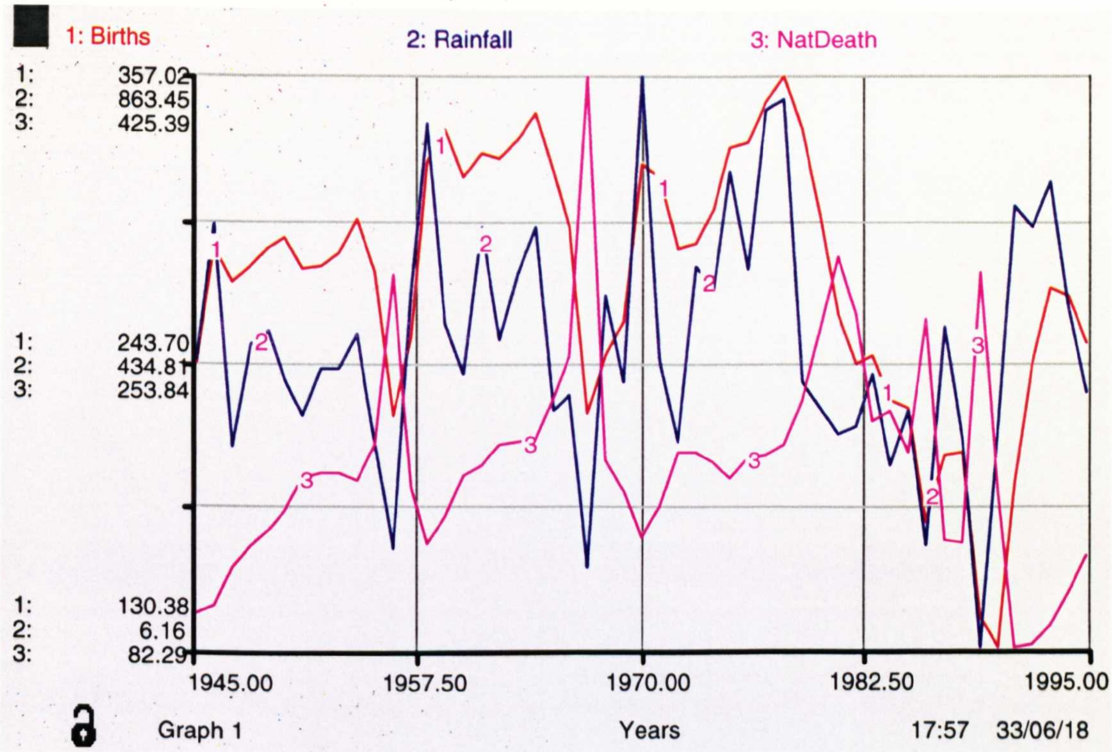

Figure 7.11 Scenario 5 - Number of Cattle, Births and Deaths 1945 to 1995

The highest deaths in 1967 occur because there were many cattle when the rainfall decreased. This shows the devastating effect of a drought when cattle numbers have built up. The births show a less dramatic variation than the deaths, which means that a low and variable rainfall affects the cattle population more through mortality rather than births. In reality this means that individual years of an alternating pattern of high and low rainfall are not conducive to building a big herd though the herd will not be decimated.

Figure 7.12 shows the Scenario 6 cattle population and rainfall amount. As the rainfall mean decreased and the variability increased further than in Scenario 5, the cattle population trend is simplified to three peaks, and decline to about 64 cattle.

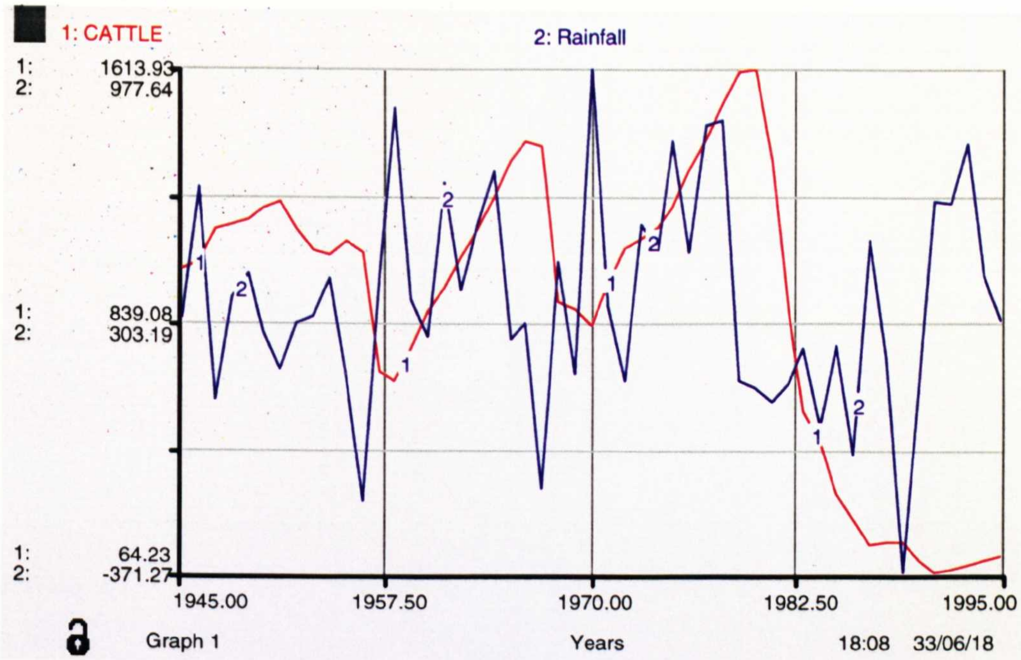

Figure 7.12 Scenario 6 - Number of Cattle and Rainfall Amount

The least rainfall is simulated as a negative figure, which means extreme aridity because negative rainfall does not exist. The cattle population crash in the late 1990s follows a declining and fluctuating rainfall trend. Scenario 6 simulated a practically depleted cattle herd between 1984 and 1990. Practically such a herd would take a long time to recover since there would be too few cattle to enable the herd to recuperate quickly.

The Carrying Capacity in Figure 7.13 has three spikes which show a poor Carrying Capacity, that coincides with high Death Rate shown in Figure 7.11. Scenarios 5 and 6 are comparable hence the comparison between Figure 7.11 and Figure 7.13. As previously, Figure 7.13 shows a lower stocking rate than the CC at virtually all times, except when the herd was virtually depleted. The simulated CC and stocking rate occur because the fluctuating rainfall does not allow the herd to build yet it enables the CC to improve, reinforced by the low stocking rate.

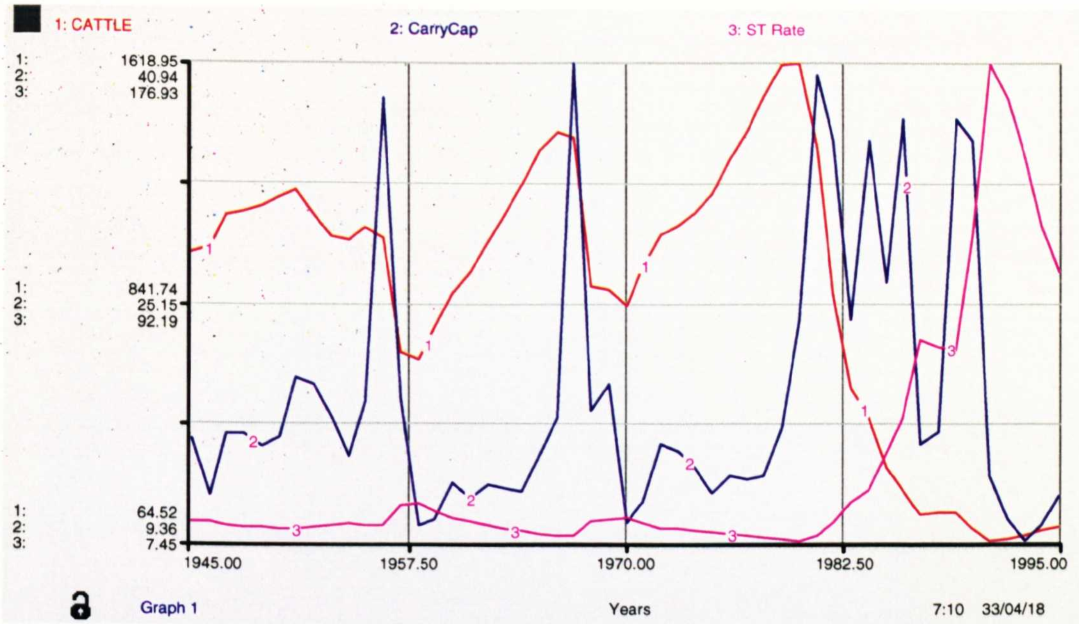

Figure 7.13 Scenario 6 - Number of Cattle, Carrying Capacity and Stocking Rate

If the extreme aridity simulated in Scenario 6 were to occur in Tlokweng Sub - district, and there were no such management interventions as supplementary feeding, the simulated cattle depletion and the relationship between CC and stocking rate would take place.

7.4 Grazing Land Loss Scenarios

The basis for the simulated grazing land loss was discussed in Section 6.8.3. In this section, the effect of present and accelerated land loss scenarios on cattle management is explored.

7.4.1 *Present Land Loss*

At the present permanent grazing land loss of 5 percent, it is predicted that 1397 ha. of total grazing land will be lost in thirty years between 1995 and 2025 (Table 7.4).

Table 7.4 Predicted Cattle, Total Grazing, ST Rate, Grazing Land, Carrying Capacity and ST Weighted - 1995 to 2025 - Based on 5% Land Loss at Base Rate

Year	Cattle	Total Grazing	ST Rate	C Capacity	ST Weighted
1995	1000	10 000	14.29	13.44	21.43
2000	1442	9 752	9.66	14.14	14.87
2005	1741	9 511	7.80	16.23	11.81
2010	1820	9 276	7.28	17.01	10.96
2015	1822	9 046	7.09	17.21	10.66
2020	1768	8 822	7.13	17.19	10.68
2025	1736	8 603	7.08	17.19	10.62

Starting with 1000 cattle in 1995, the stocking rate increased from 14.36 Ha LSU^{-1} to 7.08 Ha LSU^{-1} in 2025 when the number of cattle was 1746. The 50 percent increase in the stocking rate was due to a 75 percent increase in cattle and 14 percent decrease in the grazing land. The inevitable conclusion is that the main factor for the increase in the stocking rate was the increase in the number of cattle rather than the grazing land loss. The stocking rate is persistently higher than the carrying capacity except in 1995, which was the initialising year in this case. The grazing land loss accentuates the disparity between the simulated stocking rate and the carrying capacity. The CC decreased from 13.41 Ha LSU^{-1} to 17.19 Ha LSU^{-1}. As discussed in Section 6.5.9, the CC shows the effects of both the stocking rate and the rainfall. The predicted rainfall (not shown in Table 7.4) for 1995 to 2025 is above the mean. Therefore the decrease in CC should be due to the stocking rate. Simulations for a longer period than that shown in Table 7.4 show that the disparity between the stocking rate and the carrying capacity increases.

7.4.2 *Accelerated Land Loss*

When the grazing land loss was predicted using 10 and 40 percent of the permanent grazing for 1995 to 2025, it led to a decrease of 2603 and 7061.42 hectares respectively. The decrease of grazing land influences cattle management. When all other factors are held the same, the model predicted fewer cattle for a 40 percent grazing land loss than for a 10 percent land loss (Figure 7.14).

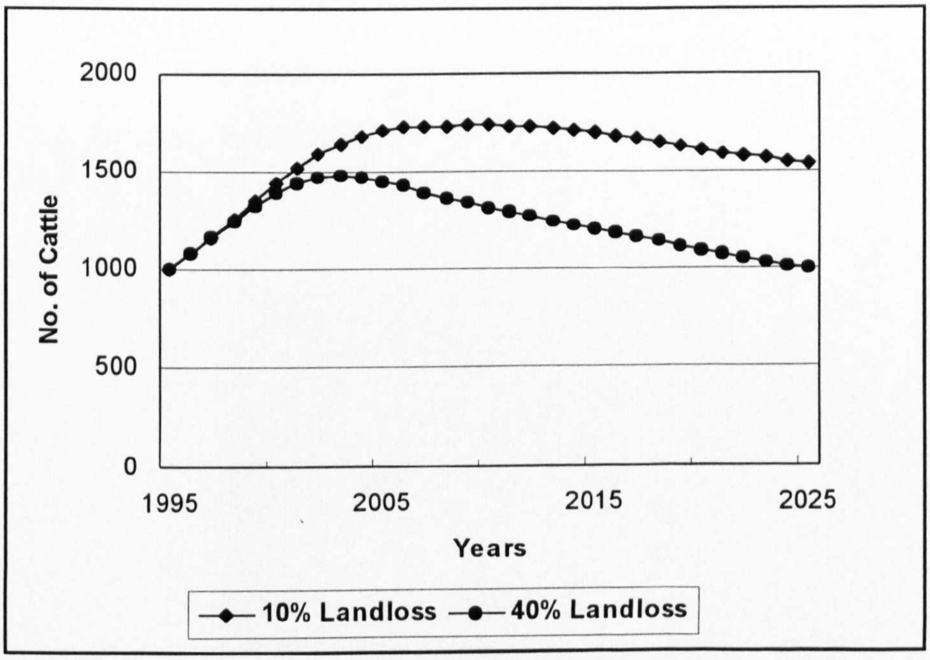

Figure 7.14 Number of Cattle at 10 and 40 percent Land Loss 1995 to 2025

This was because to determine the CC the model integrates the birth and death rate factors. There was 36 percent less cattle when a grazing land loss of 40 percent was simulated than for a 10 percent grazing land loss. The simulations show that the grazing land loss decreases the ability of the remaining grazing land to hold cattle. However the CC difference between 10 and 40 percent land loss was modest because the CC is not sensitive to land loss. In practice cattle management measures are taken to enable the reduced land to hold the same number of cattle, if not more.

The simulated stocking rates between 1995 to 2025 differ as much as the number of cattle for the two land loss rates (Figure 7.15). The number of cattle decreased by 35.5 percent while the stocking rate increased by 37.5 percent. Table 7.3 indicates that the number of cattle and the stocking rate are sensitive to land loss. The increase in the stocking rate, when both the number of cattle and the total grazing land decrease, shows that the grazing land decrease was mores significant than the decrease in the number of cattle.

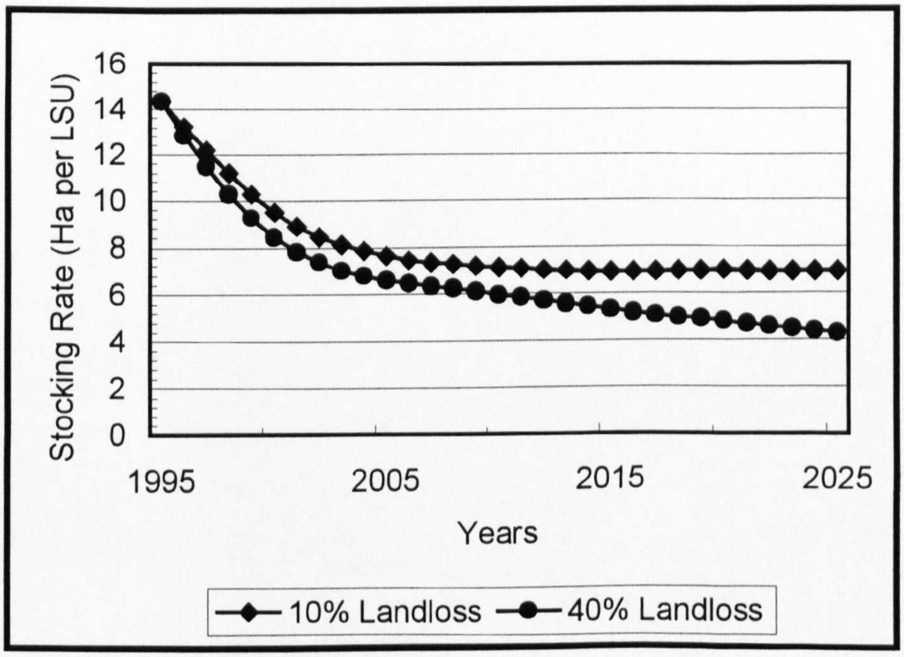

Figure 7.15 The Stocking Rate for 10 and 40 percent Land Loss - 1995 to 2025

Figure 7.15 shows that the Stocking Rate at 10 percent grazing land loss is marginally higher than that simulated at 40 percent permanent grazing land loss. The explanation for the similarity in the stocking rates between 1945 and 1995 is that the ratio between the LSU and the area of the available grazing land, which is the stocking rate in the model, is similar for the two land loss simulations. Because the stocking rate is of the same magnitude, it shows that over the long term the stocking rate in the area is stable notwithstanding the fluctuations discussed earlier. Only major events like a drought, causes drastic changes to the stocking rate. Other possible sources of sudden change are emigration, purchase of livestock and their sale outside the area.

7.5 Livestock Water

Sixteen water sources were used to simulate the livestock water availability in the study area. Six sources were dependent on exogenous rainfall sources. The procedure for determining the number of months during which a water point will be expected to hold water was described in Section 4.3. Section 7.5.1 assesses and interprets the meaning of the variation of water points.

7.5.1 *Variation in Water Points*

Table 4.4 shows the water holding and Table 4.6 shows how the water holding fluctuates. Using the Base Run rainfall, The LW Months is simulated in Figure 7.16.

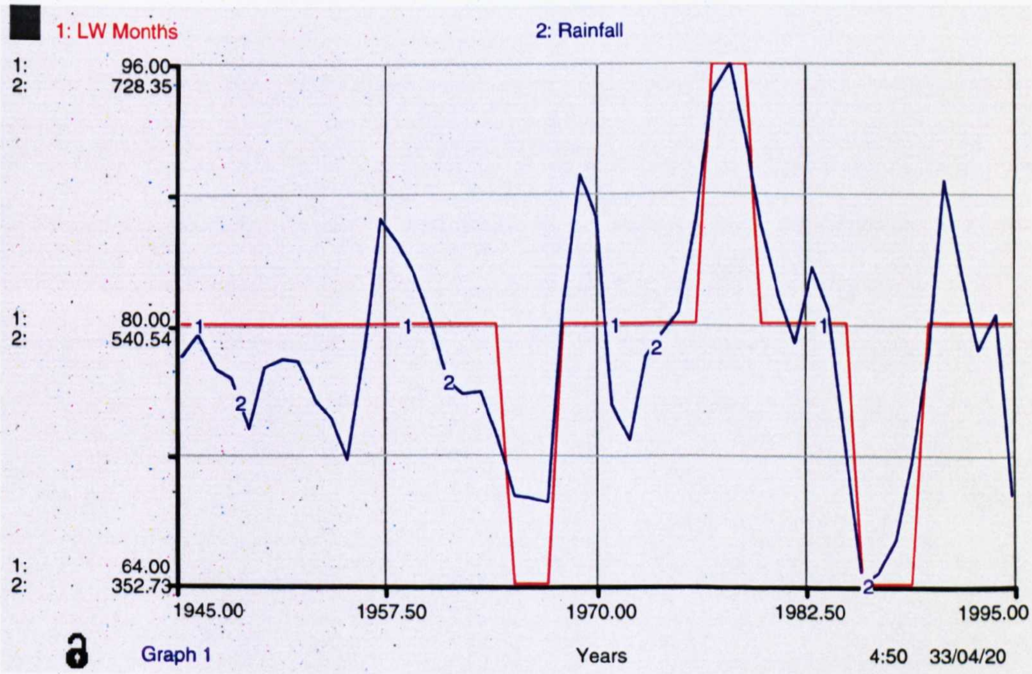

Figure 7.16 The Livestock Water Months (LW Months) and Annual Rainfall

The Figure 7.16 simulates the total livestock water holding fluctuates between 64, 80 and 96 LW Months. For most years the LW Months was 80. It decreased to 64 when the rainfall was about 400 mm and increased to 96 when the rainfall was about 700 mm. The LW Months graph is flat shaped, rather than irregular like the rainfall, because the LW Months parameter classifies the rainfall into three bands.

7.5.2 *Effect of the Livestock Water on the Carrying Capacity Calculations*

The Rain Land Cattle model integrates the carrying capacity and the LW Months into the Carrying Capacity Water Availability Ratio, CCWA Ratio, (see Section 4.3). This section discusses the meaning of the CCWA Ratio. The CCWA Ratio improves the relevance of the Carrying Capacity. The CCWA (see Equation 4.5) shows how much water is available per a LSU. Figure 7.17 shows how the CC and the CCWA interact at Base Run.

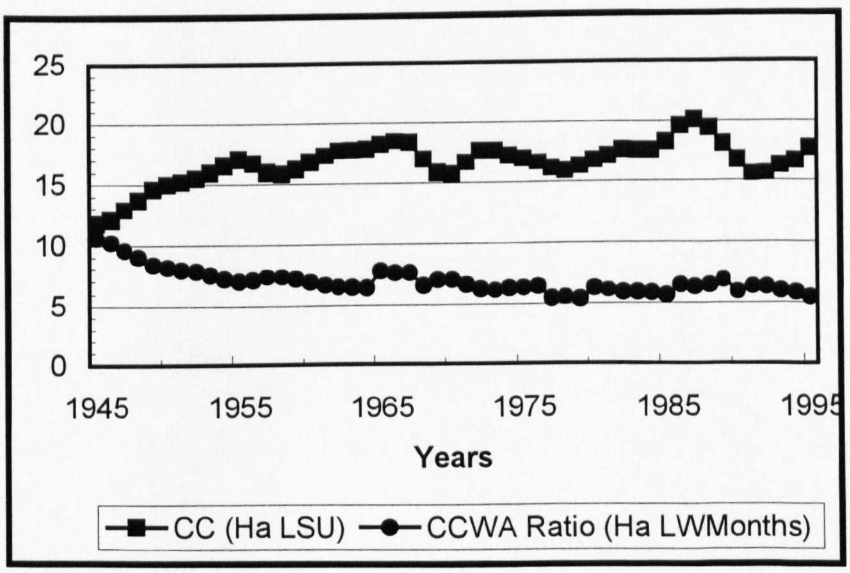

Figure 7.17 The Carrying Capacity and the Carrying Capacity Water Availability Ratio at Base Run

Both the CC and the CCWA Ratio decreased from 1945. A decrease in the CCWA Ratio means less Livestock Water Months per livestock unit. The CCWA Ratio trend is inevitable because an increase in cattle implies that more LSUs share the available water resource. One of the ways to reverse the decline in the CCWA Ratio is to introduce perennial water sources. The other way is to reduce the number of cattle, possibly through a higher offtake rate.

7.5.3 *Expected Consequences of Borehole Use in the Study Area*

Table 7.5 shows the yield, water rest depth and borehole depths of three boreholes in the study area. The location of the boreholes is shown in Figure 4.4.

Table 7.5 Data for Three Boreholes in Tlokweng Sub - district

Borehole Characteristics			
Map Code (Figure 4.4)	Yield ($m^3\ hr^{-1}$)	Water Rest Depth (m)	Depth (m)
Bh1	1.95	20.44	161.65
Bh2	3.42	54.29	73.2
Bh5	3.44	18	56.73

Source: Water Apportionment Board Secretary, personal communication, 1996.

The borehole yield is the volume of water that the borehole extracts per given time. The figures in Table 7.5 are based on tests made when the borehole is commissioned. The yield may have subsequently changed. The water rest depth is the water level observed during a test period. The borehole water is extracted from the ground water level. The water rest depth increases during drought. For example, between 1985 and 1996, the ground water levels in Kanye fluctuated by about 5 metres (Beekman *et al.*, 1996). The levels also vary spatially. Wells 25 km apart showed a variation of 80 metres at the same well fields (Beekman *et al.*, 1996). The boreholes in the study area are less than 20 kilometres apart (Figure 4.4). The borehole depth is the depth of the bore from which a borehole draws water. It is usually greater than the water rest depth unless the borehole is about to dry up. Ongoing countrywide research on groundwater recharge rates indicates that the recharge rate is slow and uncertain (Beekman *et al.*, 1996). There was no recharge rate data for boreholes in the study area but it is expected to be as low as for the rest of the country. In the long term therefore depending on boreholes may not be sustainable because of their low recharge rates.

7.6 Household Characteristics and Grazing Practice

The characteristics of the household management strategies in the area were studied as described in Section 4.1. Ninety four percent of the respondents in the sample were over 45 years old and 71 percent had lived in the study area for over 30 years. The length of stay in the area was relevant because the longer respondents have been in the area, the more experience they have with the livestock management issues of the area.

7.6.1 *Livestock and Arable Field Ownership*

The livestock and arable field holding described in this section is based on the household questionnaires. All households sampled had an arable field and 87 percent of the households owned 1-10 hectares (Table 7.6). A Chi - Square test showed no significant difference between the number of households with 1-5 hectares and the number who own cattle in the four herd size categories of 0; 1-5; 6-10 and above 10 cattle ($\chi^2 = 3.72$; $\rho = 0.01$; d.f. = 3).

Table 7.6 Number of Households with Given Cattle and Arable Fields Sizes

HH with given Cattle herdsize	HH with given field size		
	1- 5 Ha.	> 5 Ha.	Total HH
None	24	13	37
1 – 5	12	0	12
6 –10	10	4	14
> 10	13	14	27
Total HH	59	31	90

There was also no significant difference between ownership of goats in similar herd size categories and the number of households with 1-5 hectares of arable land (χ^2 = 2.88; ρ = 0.01; d.f. = 6). The two findings suggest that the minimum arable field ownership is not a consistent indicator for an agropastoral household livestock holding. It was not possible to confirm the Chi - square relationship of livestock holding against the other field size classes due to the small number of households in those field holding categories.

Thirty-seven households had no cattle and twenty-six had no goats (Table 7.7). Nineteen households had no livestock and 46 had both goats and cattle. Eighteen households with goats had no cattle and 7 with cattle had no goats. The goat herd sizes were significantly different from the cattle herd sizes (χ^2 = 19.9; ρ = 0.01; d.f. = 5). The main difference in herd sizes was with the small herds, especially the 11-20 herd size category, where there were more households with goats than those with cattle.

Table 7.7 Number of Households with a Given Livestock Herdsize

Cattle	Goats Herdsize					Total
Herdsize	None	1-5	6-10	11-20	>20	HH
None	19	4	6	5	3	37
1-5	2	1	6	3	0	12
6-10	3	1	0	5	5	14
11-20	1	0	2	3	3	9
>20	1	1	3	4	9	18
Total	26	7	17	20	20	90

7.6.2 *Cattle Movement During Drought*

Table 7.8 shows two characteristics of the households' cattle management during drought, the locations where cattle water and the source of the cattle water. Some households move their cattle to watering locations outside their locality and others do not. Farmers take their cattle to Egepeto, Diphiring, Batlokwa Farm and Village (Tlokweng) which are within Tlokweng sub - district (Figure 2. 9). Others take their cattle outside the district to Kgatleng, Kweneng and Central districts (Fig 2.1). Normally the watering localities during the drought, which are shown in Table 7.8, are also the grazing areas.

Table 7.8 Cattle Water Sources during Drought – Recorded per Household (HH)

Cattle Locality	Source of Water						Total HH
	Borehole	Dam	River	Village	Other	N/A	
Egepeto	1	1	3				5
Diphiring	1		1	1			3
Batlokwa Farm	1						4
Village	1		2				3
Kgatleng	4						4
Kweneng	2				1		3
Central	2						2
Don't Move	20	2	1	4	2		29
N/A						37	37
Total	35	3	7	5	3	37	90

Source: Fieldwork

A Chi-square test, using a 2x2 matrix, (Table 7.9) was used to determine whether there was a significant difference between the movements of small and large herds. A small herd class was 1-20 cattle and a large herd was over 20 cattle. Using Equation 7.1, there was no significant difference between the small and large herds movement ($\chi^2 = 0.04$: $\rho = 0.01$: d.f. = 1).

Table 7.9 A 2x2 Contingency Table to Determine the Significance of Cattle Movement by Herdsize Ownership

Herdsize	Don't Move	Move	Total
Small	(A) 20	(B) 15	35
Large	(C) 9	(D) 9	18
Total	29	24	53

Source: Fieldwork

Equation 7.1 The Chi-square Determination for a 2x2 Matrix

$$\frac{n\left(|AD - BC| - n/2\right)^2}{(A+B)(C+D)(A+C)(B+D)}$$ where:

n = total number of individuals in the two samples (herdsize categories are treated as separate samples)

A, B, C, D = frequencies in each of the cells indicated in Table 2.5

Source: Edbon 1985:68

The Chi - square test also showed no significant difference between cattle movements within the sub-district and those to another district. The two test results imply that large herds are as likely to move as are small herds, and both are equally likely to be destined within or outside the sub-district. The conclusion is counter intuitive for two reasons. A large herd is more likely to move outside the sub-district because it is constrained by the limited grazing in the small sub-district more than a small herd. Secondly, a household with a large herd has better resources to set up in a new area than one with a small herd. For example, one household moved out of Tlokweng Sub-District with 65 cattle and subsequently spent P65 000 to drill and equip a borehole in the sandveld of the Central District. Borehole watering is essential in the sandveld where surface water sources are rare. Cattle movements could be long or short term based on the household's intentions. Such intentions are reversible. For example, when a household fears it may lose more cattle in the destination area than in Tlokweng sub-district, it will return before its intended sojourn is over. During the survey we met farmers whose intended long term absence from Tlokweng were cut short when they experienced more cattle deaths than they had expected. Long term cattle movements were mostly destined outside the sub - district while short term movements were within the sub - district. A short term cattle movement may be seasonal, for example during the dry season, or periodic, such as during a drought. The short term cattle movements last the duration of the drought.

7.6.3 *Use of Livestock Water Sources*

The thirty five households who use boreholes (Table 7.5) are almost equally split between those that move and those that do not. However households with large cattle herds were significantly dependent on boreholes during drought ($\chi^2 = 30.2$; $\rho = 0.01$; d.f. = 3). The latter finding about large herds, contrasted with that for small herds, where the households choice of cattle water sources was not significantly different from an ideal distribution amongst four other sources, that is dams, river and village and other ($\chi^2 = 10.37$; $\rho = 0.01$; d.f. = 3). This means small cattle herd owners management did not show preference for any source. Their choice was influenced by proximity to a source but the households with large herds chose boreholes because they have water all the time.

Four water source ownership categories were found in the study area (see Table 4.5). These were communal, private, syndicate (see Section 4.3.7) and local government. Communal sources such as dams and the river were accessible to all within the area. Private sources have restricted access. Local government sources belong to the district council. More large herd owners used boreholes as syndicate members, (10 out of 16), than the small herd owners (7 out of 19). The finding suggests that large herd owners are better placed to pay for borehole ownership than the small herd owners who frequently depended on hired water rights per animal watered. It is less risky, and possibly cheaper, for a large herd owner to be a syndicate member because their cattle are guaranteed access to water. Those who hire water are not guaranteed access. The

Notwane River is the second most popular cattle water source after boreholes. The use of the river was discussed in Section 2.4.6. Water cartage from the village was discussed in Section 2.4.5.

7.6.4 *Reliability, Convenience and Cost of a Water Source*

The household's views were solicited on the three water source qualities namely, reliability, convenience and cost. Table 7.10 summarises the household's assessment of their cattle's water source.

Table 7.10 Household Views on Livestock Water Quality During Drought

View on Livestock Water Quality	Cattle Water Sources (a)						Total HH
	B	D	R	V	O	N/A	
Reliable Convenient Not Costly	25	-	2	4	2	-	33
Reliable Not Convenient Not Costly	5	-	5	1	-	-	11
Reliable Convenient Costly	2	-	-	-	-	-	2
Reliable Not Convenient Costly	2	-	-	-	-	-	2
Not Reliable Convenient Not Costly	-	2	-	-	1	-	3
Other	1		1	-	-	-	2
Not Applicable	-	-	-	-	-	37	37
Total number of Households (HH)	35	2	8	5	3	37	90

Source: Fieldwork
(a) B = Borehole; D = Dam; R = River; V = Village; O = Other; N/A = Not Applicable

A reliable source supplies water throughout a drought period. Convenience is used to assess the distance cattle walk to a water source. It is convenient for cattle to walk a short distance from the grazing area to the watering source. Though convenience refers to distance, which can be objectively measured, when a nearby source dries up the assessment becomes relative. This is because a household will drive its cattle to a further source which they would still regard as convenient. Convenience therefore means that the households accept to drive cattle over increased distances. Like convenience, the cost of cattle watering is based on an objective measurement. But the household's view on whether a source is costly depends on a subjective judgement that includes affordability and willingness to pay. Affordability depends on factors such as the household's other sources of income, and the number of cattle owned. The willingness to pay is directly related to the risk of livestock losses. A household will be most willing to pay for water when there is a high risk of livestock losses. The study used the household's views on the water qualities as given (Table 7.10) and did not explore factors which influence the households' view.

An ideal livestock water source is reliable, convenient and not costly. Sixty two percent of the households with cattle characterised their cattle drought water source as ideal (Table 7.10). Seventy six percent of households with ideal sources use boreholes. Tlokweng village is the second ideal livestock water source. Four of the five households who hauled cattle water from the village during drought described it as an ideal source. The fifth household said that hauling cattle water was tedious, therefore not ideal. The latter household hauled 520 litres of water daily for 18 cattle and 16 goats during a drought. This contrasts with one of the other four households which hauled 1000 litres of water daily for 35 cattle and 10 goats. The latter household classified the village as an ideal water source because the water was clean. The five households used their own transport, or that of a relative, to haul water and their views did not include transport costs. None of the households without own transport carted water from the village to water cattle. They only watered goats. It cost P10.00 to cart a 210 litres drum of water from the village to any point in the study area. The cost of carting water was a deterrent to those who had to hire transport.

Ten households, five of whom used the river and the other five used boreholes, described their water sources as not convenient. The river was not convenient because of the dirty water and the risk of cattle going astray as mentioned in Section 2.4.6. Twenty percent of the borehole users classified their source as not convenient because they were too far from the grazing areas. The majority (77 percent) of the households that used boreholes in the sub - district regarded the boreholes as convenient. Households in the study area adapted to the long distance to water sources during a drought by watering cattle on alternate days to allow them more grazing time. Nicholson (1986) studied a 2 to 3 day cattle watering schedule in Ethiopia, where grazing was 21 kilometres away from the water source. He concluded that the 2 to 3 day watering schedule enabled cattle access to a larger grazing area than when they were watered daily. In the study area the maximum distance to a water source was 20.5 kilometres to the perennial Notwane River (Figure 4.9).

Four households that watered from boreholes regarded the water sources as costly. Three of the four households had 3, 4 and 6 cattle and the fourth had 60 cattle. The ones with 60 and 6 were syndicate members and paid a fixed fee of P100.00 and P80 per annum respectively. The main grievance in the former case was the variable maintenance costs while in the latter case it was the high per capita cost for the small herd. The example demonstrates the variation of household views on water source quality and cost.

When the quality of each water source was considered individually, 91 percent of the households with cattle regarded their water source as reliable, 71 percent regarded it convenient and 87 percent regarded it not costly. Only 7.5 percent regarded the sources as costly and 25 percent regarded them as not convenient. The households' water quality ratings show that overall the cattle water sources in the study area have positive qualities.

Three conclusions can be drawn about the households' views on the qualities of cattle water. Firstly, a statistically significant number of households, most of which used boreholes, regarded the water sources as ideal ($\chi^2 = 21.59$; $\rho = 0.01$; d.f. = 2). To calculate Chi - square, livestock water qualities were grouped into three:

- reliable, convenient and not costly;
- reliable, not convenient, not costly;
- a combination of the other four livestock water qualities in Table 7.7 into: reliable + convenient + costly; reliable + not convenient + costly; not reliable + convenient + not costly; others. The three groups are in a hierarchical order.

Secondly, few households regard livestock water sources to be costly because they are willing to pay as much as necessary to avoid cattle losses. Thirdly, convenience is an important livestock water quality, but the household's willingness to drive its cattle a given distance to watering points is paramount. Therefore the distance between water points and grazing, though very important, is only part of the assessment criteria for convenience.

7.6.5 *Supplementary Feeding*

Table 7.11 shows the drought cattle management strategies used by households in the sub-district. The annual stubble grazing described in Section 2.4.2 is not included because practically all cattle take part in it, therefore it is not a distinguishing characteristic. Management strategies within a year, and from one year to the other, seldom occur in isolation, but rather as combinations represented in Table 7.11.

Table 7.11. Drought Cattle Management Strategies by Household Herdsize

Management strategy during drought	Households per Herdsize Category			Total
	Small	Large	No Cattle	Households
Supplement				
Only	21	4		25
+ sell	2	5		7
+ move and sell		2		2
+ move	1	1		2
Move only				
Long term	2	4		6
Short term	4	1		5
Do nothing	4	1		5
Not Applicable	1		37	38
Total Households	11	18	37	90

Source: Fieldwork

During a drought, 68 percent of the households supplement cattle food supplies and twenty eight percent of the households move their cattle to other areas. A Chi-square test shows a significant difference between households who supplement and those that do not ($\chi^2 = 53.31$; d.f. = 3; $\rho = 0.01$). There is however no statistically significant difference between the number of households with large or small herds who supplement, which implies that herdsize has no influence on the decision to supplement. The latter finding was partly surprising given that most supplementary feeding is purchased which should put large herd owners at an advantage over the small herd owners. The widespread supplementary feeding in the study area is because households depend on crop by products such as stalks and husk (**moroko**) for supplementary feeding. Since all the households have an arable field they therefore have access to a source of supplementary feed. Supplementation is a logical adaptation given the limited grazing in the study area. Though supplementary feeding is widespread, even during the years of average rain, five households reported that they do not supplement. A closer look at the five shows that they had a labour shortage and poor management. One household had most of its herd stolen and was left with just two. Two had three and five cattle respectively, which were seldom kraaled, that is put in a pen. The fourth had 15 cattle that were left to roam the sub-district and were only rounded for vaccinations. An elderly person, who had no herd boys, owned the fifth herd of 46 cattle. He argued that there was no need to supplement because cattle always recover after a drought. It is true that a large herd stands a better chance to recover from a drought than a small herd. However it is also possible that the study area may be less susceptible to a grazing shortage during drought than other parts of Botswana because of four factors. These factors are the arable area which is opened for all year round grazing when the crops wilt, the "perennial" river grazing belt, browse species to which cattle have adapted and Majeadikgokong Farm which often has good grazing. Despite the four options it is unlikely that supplementary feeding was never required.

Supplementary feeding in the area was combined with other strategies such as the sale of livestock usually to raise cash to buy supplementary feeding, and cattle movement to areas with better forage. One of the two households that combined supplementary feeding with cattle movement, moved 37 cattle to Kweneng District where 21 died in 6 years before the residual herd was returned to Tlokweng Sub - district. The other household kept its cattle in Kgatleng District during the good years but brought them into the study area during drought because they believed that the study area withstood drought better than Kgatleng District. Seven households sold part of their herd to obtain cash to buy supplementary feed. This means that during the early stages, or during a drought, cattle sales in the study area increase (Section 6.6.1). Another two households moved, sold and supplemented their livestock. Both households had large herds and moved within the sub - district, one to Majeadikgokong farm and the other to Diphiring. They sold part of their herd to buy supplementary feed. None of the households in the study sold livestock to reduce stocking levels. Therefore offtake is expected to be high during drought since households want to supplement not because they want to reduce the number of cattle.

7.7 Household Views on Grazing Land Management and Availability

The study area has intense land pressure (Table 2.1 and Section 2.2.2.) which is manifest through limited grazing land. Sixty three percent of the respondents accepted that there was shortage of grazing land in the study area. Most respondents, fifty eight percent, did not feel that there were too many cattle in the study area. Half of those who said that there was a shortage of grazing land did not feel that there was too much livestock in the area. The latter response pattern suggests that the respondents had adjusted the number of cattle held in the study area to the limited grazing land. About one third of the households in the sample, 29/90, said that the area held fewer cattle than before which suggested that as the grazing land diminished households reduced their cattle herd sizes. The reduced size of cattle herds was discussed in Section 2.2.1. The same twenty-nine respondents said that the area does not have too much livestock. The observation in the study area questions the commonly held belief that communal management leads to selfish individual tendency to maximise benefits irrespective of the consequences for the community at large (Panel on Common Property Resource Management, 1986). The cattle management views and practices within the study area, such as use of arable grazing after harvest, so far support the view that it is possible to have common property management without abuse. This is consistent with the view that good communal property management is possible when it is owned by a well defined community with established local representatives (United Nations Sudano – Sahelian Office 1994a). In the study area overseers look after the arable area fences in the study area. The local representatives determine when the cattle should be allowed into the arable area. Residents promptly report when livestock get into the arable area before harvesting has taken place.

The major adaptation to the study area's grazing land shortage is the availability of grazing in the arable area after the harvest. Sixty nine percent of the respondents felt that the movement of cattle into the arable area for grazing was a significant management strategy for the area. The strategy was deemed significant because it preserved forage in the arable area and enabled the study area to hold more cattle than would be possible without the arable area grazing.

7.8 Effect of Livestock Management Strategies

This section models the effect of five cattle management strategies in the study area. The five are arable land availability for short term grazing, increased water access at Mmamogofu, supplementary feeding, cattle emigration and purchase rates and offtake rates. The behaviour of the Stocking Ratio is discussed.

7.8.1 *Arable Land Availability*

Section 2.6.3 pointed out that the use of the arable land grazing after the harvest is an important cattle management strategy that has been practised by most cattle farmers in the study area since 1928. The Rain Land Cattle model (Figure 6.2) assumed that the grazing capacity of the arable land, seasonal grazing, and the permanent grazing area are equal. The assumption was pragmatic but most likely conservative. During fieldwork it was observed that the arable land had abundant forage at the beginning of the four month grazing period. There is therefore a strong case for the arable area's grazing capacity to be assessed separately from that of the permanent grazing area because it could be higher than that of the permanent grazing area. Unfortunately no meaningful forage production measurements could be made within one year's fieldwork because such measurements are liable to annual as well as seasonal fluctuations. During the fieldwork it was observed that a few farmers fenced off their arable fields individually which did not allow communal grazing to take place on their fields after harvesting. Other farmers expressed a desire to do likewise so that they could exclusively reserve grazing for their animals. If the trend gains momentum, which is likely, the future of the communal seasonal grazing in the study area would be in jeorpady.

The effect of the reduced permanent grazing, is simulated as "With and Without Arable", shown in Figure 7.18 and Figure 7.19. Figure 7.18 show a decrease in cattle and an increase in the ST Rate. The reduced availability of seasonal grazing should have a similar effect. The availability of seasonal grazing improves the ability of the study area to hold cattle and the model associates the availability of four months seasonal grazing with the ability to hold a higher number of cattle. Figure 7.18 shows the simulated cattle with or without seasonal grazing. The difference in simulation time was four months (dt = 0.25). A further increase in the number of cattle will be obtained when the seasonal arable grazing is available for longer than the four months used in the model or the grazing capacity of the seasonal grazing is higher than the

12.5 Ha LSU^{-1} used in the model. The higher number of cattle for the "With Arable" scenario in Figure 7.18 shows that the study area can hold more cattle when the arable grazing is available than when it is not available.

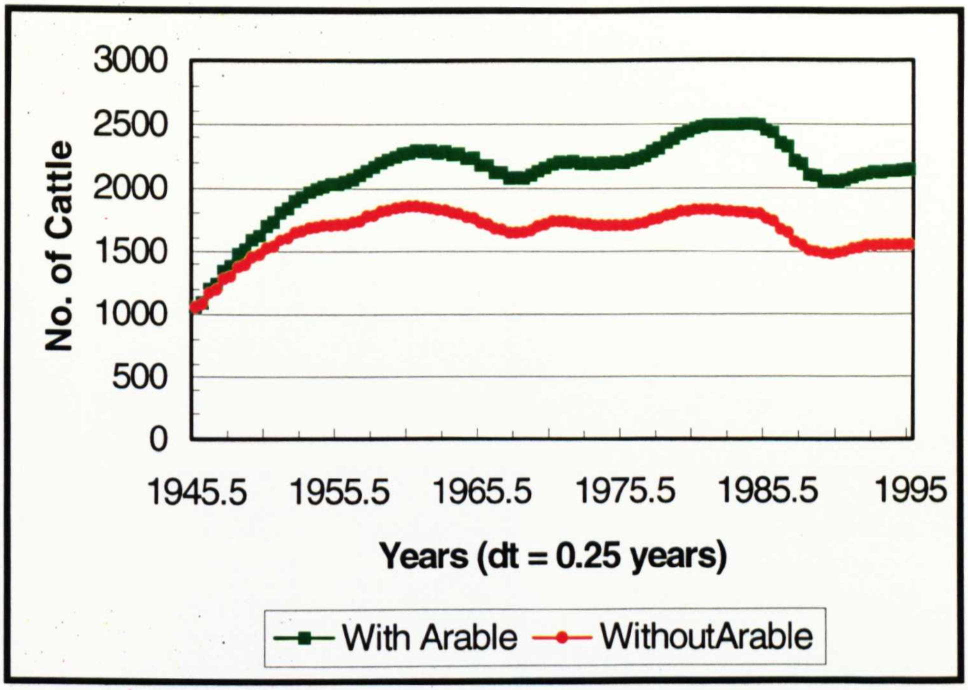

Figure 7.18 Number of Cattle With and Without Arable Grazing at Base Run

The seasonal grazing is used for more than four months when the rainy season starts late. Based on the rainfall data for 1945 and 1995, Gaborone had less than 50 mm rainfall in October, in 3 out of 5 years (Botswana Meteorological Services, 1996). In Figure 7.19, the carrying capacity with the arable grazing is higher than the carrying capacity without arable grazing. The difference, which is dampened because the varied carrying capacity is not taken into account, nevertheless reinforces the observation in Figure 7.18 where there were more cattle when the seasonal grazing is available. As with the carrying capacity there is a lower stocking rate when the seasonal grazing land is available. The combined effect of a higher Carrying Capacity and a lower Stocking Rate indicates better cattle management possibilities for the communal area.

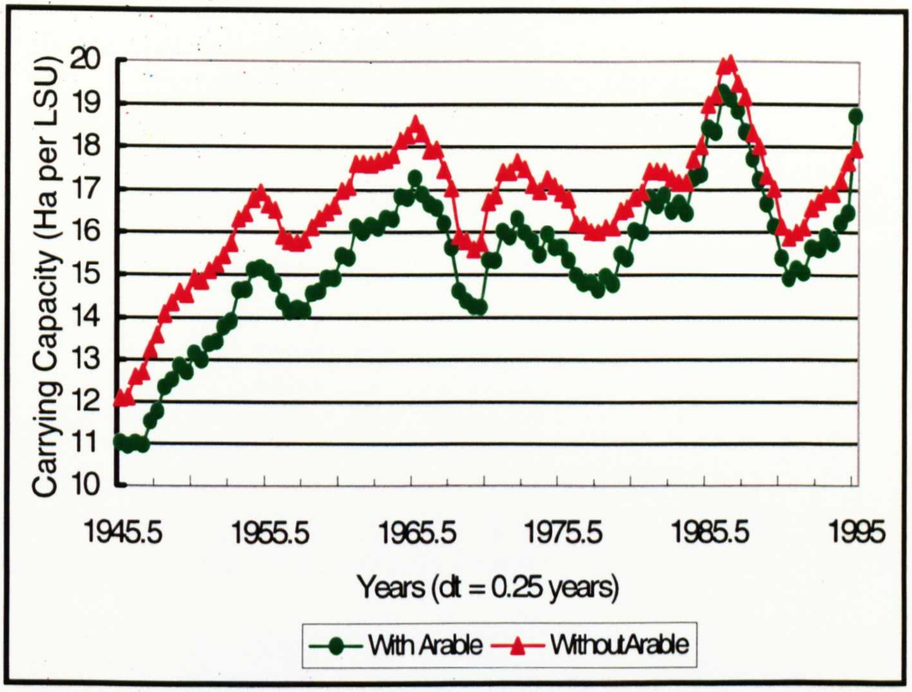

Figure 7.19 Carrying Capacity With or Without Arable Grazing at Base Run

The model has been able to demonstrate the role of seasonal grazing as a management strategy in the study area. During the interviews, the farmers indicated that they are aware of both the significance of the strategy and the risk of undermining its effectiveness by fencing individual fields. Individual field fencing is similar to the dual grazing rights discussed in Section 1.5.2 because a farmer who has fenced his/her field individually uses the communal arable grazing before they graze their cattle in the individually fenced field.

7.8.2 *Increased Water Availability At Mmamogofu*

The availability of livestock water is based on the amount of rainfall. However the dependence on the annual rainfall may soon change because the residents were working on the Mmamogofu Water Scheme. Water will be pumped from the River Notwane to the Mmamogofu grazing area reservoir with a capacity of about 80 000 litres. When operational, the Mmamogofu Water Scheme will be a permanent water source which would increase the perennial sources from five to six. The reservoir is located next to the Mmamogofu water point (Figure 4.5). The Mmamogofu Water Scheme would improve the Carrying Capacity Water Ratio of the area, reduce the distance cattle walk from Mmamogofu area to water at the Notwane River, and create long term sedentary grazing around the reservoir. There was no plan to distribute the water beyond the reservoir (Pilane, personal communication, 1996.) therefore the stocking rate in the permanent grazing area next to Mmamogofu will increase when the other water points dry up. This new water source will be especially important for watering livestock at the time when seasonal grazing is being used. The seasonality of its water source will be the eight dry months. The cattle at Mmamogofu and Ramokobetwane (Figure 2.8) would benefit from the reduced walking distances to the water points used which should increase the amount of time available for grazing (Nicholson, 1986).

The effect of the additional water on the livestock water availability was simulated using the Rain Land Cattle model. Two scenarios, "With and without water Project" were simulated. The water source has a seasonality of eight months, because it would be perennial, therefore it would increase the LW Months by as much. The LW Months Density pattern at Base Run is depicted by Figure 7.20. The pattern shows more water per area when the water project is operating than when it is not. In both cases Figure 7.20 shows that the LW Months Density improves, shown by the downward slope of the graphs, which means that there is less grazing area per water

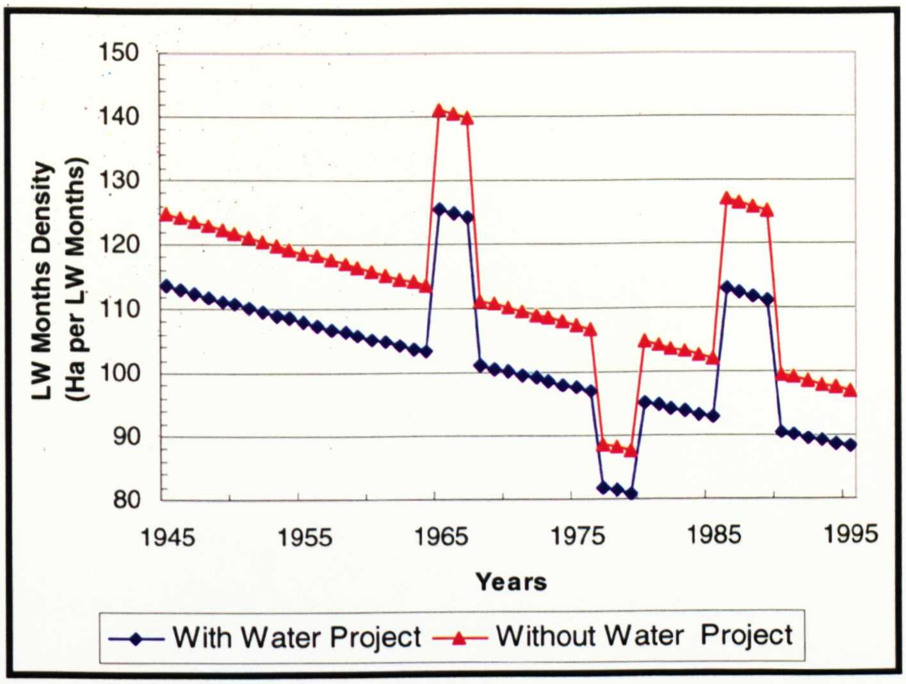

Figure 7.20 The Livestock Water Months Density With and Without the Mmamogofu Water Project

source. The improvement was due to the grazing land loss, which reduced the area of grazing land that a fixed number of water points serve, rather than an improvement in the rainfall. The peaks in LW Months Density1965 and just after 1988 represent a poor LW Months Density drought, and the trough in 1979 represents a good LW Months Density during a high rainfall period.

7.8.3 *Effect of Supplementary Feeding*

Section 7.6.5 noted that supplementary feeding was widespread in the study area. During the fieldwork it was not possible to determine how much and how regularly the supplementary feeding occurs. A herd of eight cattle may share a bucketful of a mixture of salt and husk. Other forms of supplementary feeding such as grass bales, harvested crop residue such as stalks, rumevite block and molasses are occasionally used. If the supplementary feeding were given in large quantities and for long periods, it would be possible to incorporate it into the model as a management parameter.

Although supplementary feeding was widespread its occurrence was sporadic and not easy to meaningfully incorporate into the model. Therefore the effect of supplementary feeding on cattle management in the study area was not included in the model and will only be referred to subjectively. The obvious impact of supplementary feeding is that it enables cattle to survive through a drought. It was also used to attract cattle back to the enclosure so that the owner can take stock of his herd. When used to mitigate the drought effect, supplementary feeding is similar to an increase in the carrying capacity of the model. It could be shown as an increment in the carrying capacity. In that case the carrying capacity increase would not be directly related to the rainfall in the area.

7.8.4 *Cattle Emigration and Purchase Rate*

Section 2.4.7 reported on cattle emigration as a management strategy. Figure 7.21 shows the number of cattle and how emigration is simulated in the model.

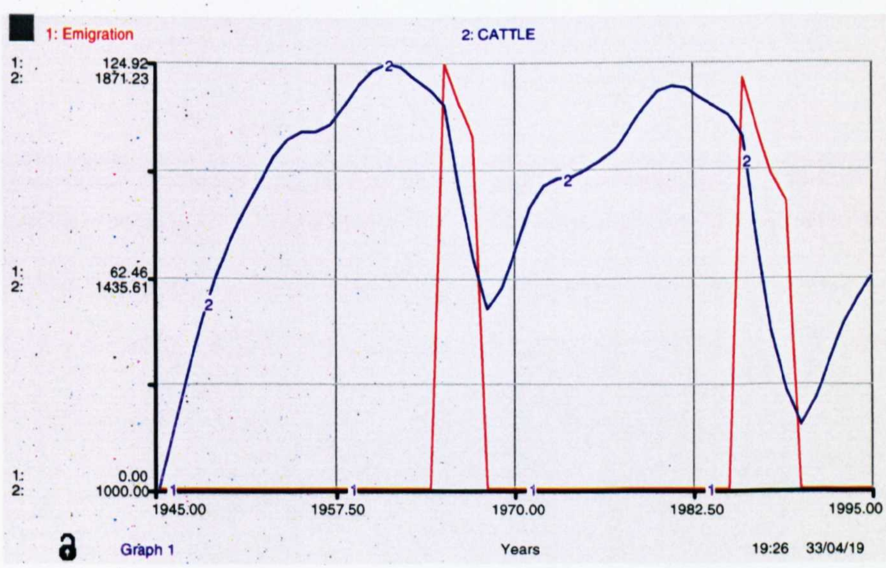

Figure 7.21 Number of Cattle that Emigrate and Total Number of Cattle

Seven percent of the households interviewed had moved their cattle permanently outside the study area during some very dry years. In most years cattle do not emigrate. When the rangeland condition is poor, represented in the model by a BRCI value of 450, seven percent of the cattle emigrate. The decline in cattle numbers when the rangeland is poor is a due to a combination of emigration and increased mortality. When cattle emigrate, the Stocking Rate decreases. The Rain Land Cattle model illustrates the benefit and extent of cattle emigration. At a larger spatial scale, it is possible to illustrate the benefit of cattle movement from one part of the study area to another. For example, at that scale it can be shown that when cattle move to the Notwane River grazing the stocking rate in areas with poor grazing at that time of the year is reduced. Reducing the stocking rate where grazing is inadequate in one part of the study area and increasing it at the Notwane River, enables optimal use of variable forage and water resources. Purchase rate was not reported but its effect is equivalent to cattle moving to graze in the study area from neighbouring Kgatleng district.

7.8.5 *Offtake Rates*

Figure 7.22 shows the cattle population "with offtake" and "without offtake".

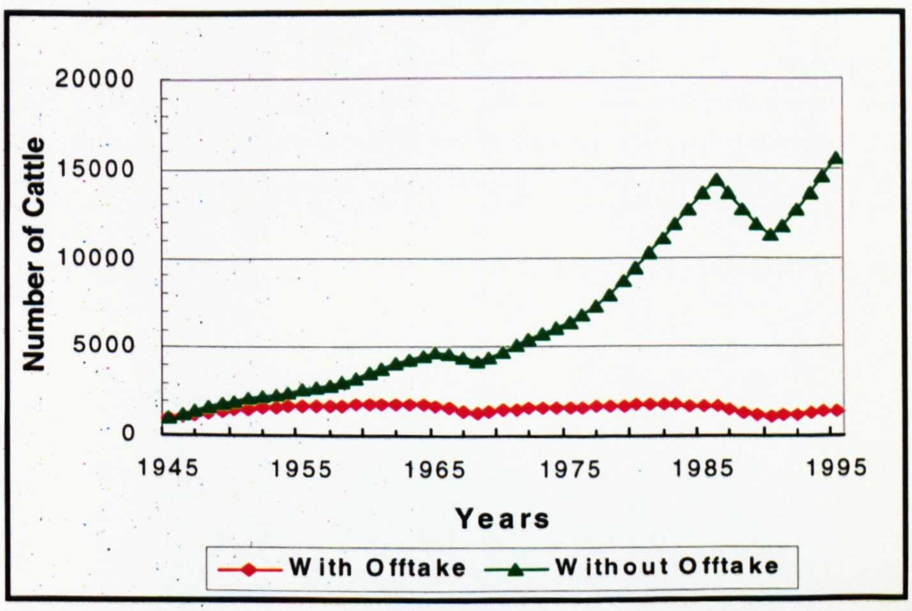

Figure 7.22 The Cattle Population with Offtake and Without Offtake

The subsistence households' offtake is sporadic and mainly influenced by households' demands, such as family ceremonies. The precise estimate of sales is difficult to undertake in a study of this nature. Figure 7.22 shows the number of cattle decreases significantly with regular sales of 8 percent per annum. The actual effect of the sales in the study area may be less than that shown by Figure 7.22 because households sell cattle irregularly. Without any sales, the model simulated the herd increase to 15 000 in the study area. In practise offtake reinforces the intermittent annual emigration rate, and together the two factors may be responsible for the removal of 15 percent of the livestock in the study area.

7.8.6 *Indication of Rangeland Pressure*

The rangeland pressure in the model is represented by the Stocking Ratio (Section 6.5.11), which compares the GC and the Stocking Rate which is shown in Figure 7.23.

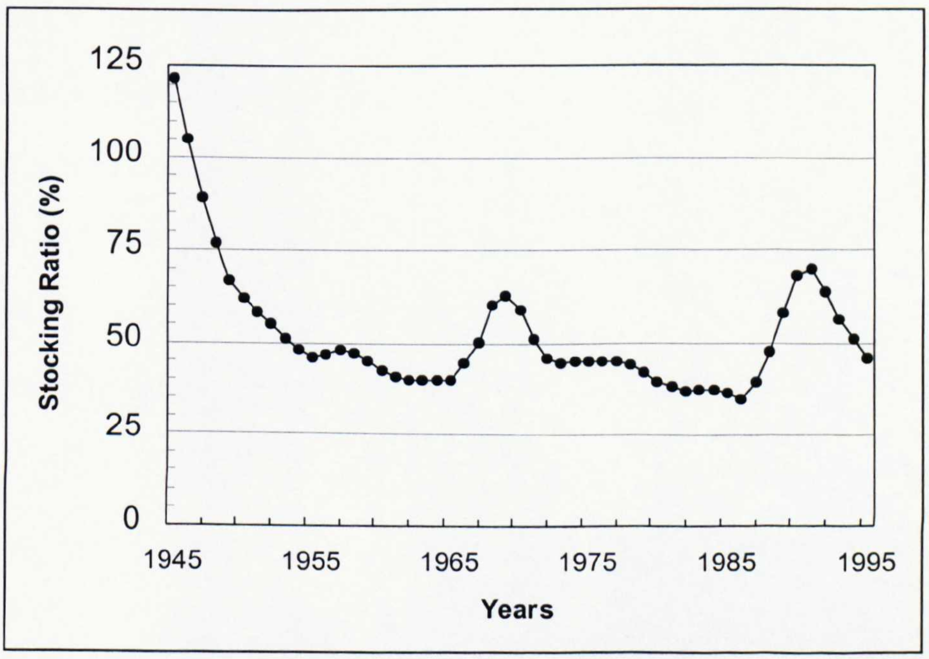

Figure 7.23 The Stocking Ratio at Base Run 1945 to 1995

The rangeland pressure indirectly indicates the cattle condition. A Stocking Ratio of 100 shows that the area is stocked at grazing capacity when there is no pressure on the rangeland. A Stocking Ratio above 100 shows the area has fewer cattle than it can carry and a Stocking Ratio less than 100 shows more cattle than the are can carry. The latter Stocking Ratio indicates the existence of rangeland pressure and in theory the cattle condition would deteriorate. Figure 7.23 indicates a Stocking Ratio that is persistently below 100 which suggests the study area has rangeland pressure most of the time except the first two years, which are initialising years in the computer simulation. The Stocking Ratio shows that the Tlokweng Sub - district rangeland is under stress most of the time. The situation prevails in the communal grazing areas throughout the country (Braat and Opschoor, 1990; Ministry of Agriculture, 1991). The low Stocking Ratio, despite 70 years of successful cattle management in the study area, illustrates the inherent flaw of Carrying Capacity and Stocking Rates as measures of the quality of cattle management which ignores opportunistic management interventions that often make big differences in semi arid areas. If taken literally this Stocking Ratio would indicate that the rangeland would collapse and the cattle will starve to death. We know it has not happened. The local cattle movements, supplementary feeding and other management techniques have prevented the collapse of the rangeland and the large scale death of cattle.

Summary

The simulated cattle population increases from an initial value of 1000. The Base Run simulated less cattle than what was recorded by the government officers in the study area. The disparity between the predicted and observed cattle data can be explained in three ways. First several parameters used in the model need to be validated. Secondly the rainfall trends are probabilistic and lastly, there could be irregularities with the cattle statistics used to validate the model. The reliability of the government cattle census was not verified during the study. The model predicted a higher stocking rate than the carrying capacity at all times. The finding confirms that the high stocking rates are common in the semi arid communal rangelands. The model shows a persistent cattle population, which characterises the area despite the high stocking rates. The cattle population trend is reinforced by opportunism. This chapter has demonstrated that the Rain Land Cattle model can be used to study cattle management factors in a communal area with variable rainfall. The model can also be used at a larger scale such as a district.

The questionnaire data and in - depth discussions showed that households are aware of the limitations of the study area for cattle management such as the shortage of grazing land and the long term effect of grazing land loss. Grazing land loss and the availability of seasonal grazing are significant cattle management factors. The local cattle movement into and out of the arable grazing is opportunistic management that enables the area to hold more cattle than that which would be predicted by the model.

Chapter 8 Discussion of the Results

Introduction

This chapter discusses the implication of the findings in Chapter 7. It appraises the performance of the model and looks at the future of cattle management in the study area. Specific attention is paid to the dry climate, likely due to El Nino, because it poses specific management problems simulated as Scenarios 5 and 6 in Chapter 7. The limitations of the study are discussed.

8.1 The Relevance of System Dynamics Simulation

The relevance of system dynamics model to cattle management in semi arid was alluded to in Chapter 5. Semi arid forage, water availability and cattle population vary according to the rainfall. The Rain Land Cattle model captures the variation. If the rainfall variation is predicted well, the variation in the forage and water availability and cattle population can be similarly predicted. If water availability and cattle population can be effectively predicted, the model provides an opportunity for proactive cattle management in different grazing areas. The cattle herd growth, rainfall trend and amount were predicted with varying degrees of success using the Rain Land Cattle model. It was easier to predict the rainfall trend than the rainfall amount because the latter is stochastic. The prediction accuracy for the number of cattle depends on the rainfall prediction. It also depends on how accurately the parameters such as death and birth rate and the death and birth influencing factors were calibrated. The birth rate was calibrated using data for eight years which represents one sixth of the rainfall observation period of the study. Equation 6.2 shows that factors other than rainfall contribute to the birth rate. The model does not account for those other factors. The death rate used was generic based on a national estimate. The accuracy of the number of deaths in the study area cannot be established since the area had no data on deaths.

System dynamics is a simple way to model cattle management systems. A system dynamics model uses links and loops based on observable parameters that are easy to measure. The links make it easy to perceive the interactions. The rainfall, area of grazing, number of cattle in the Rain Land Cattle model can be counted or measured. Even the grazing capacity, whose relevance is debated, is measurable.

8.1.1 *Grazing Strategy and Rainfall Variation*

The model shows the livestock movement between the permanent and seasonal grazing, which is the arable area. The seasonal grazing is a strategic grazing reserve during the dry season or drought which is critical for successful cattle rearing in the study area. The model however does not simulate the increased availability of seasonal grazing during drought when the crops fail.

It was not possible to measure the difference in the forage production for the permanent and seasonal grazing areas. The two grazing areas were assumed to produce the same amount of forage in the model simulations. The assumption was conservative for a number of reasons. Permanent grazing shows signs of rangeland deterioration (Section 2.6.2). The seasonal grazing is used for at least four months and rested for the rest of the year. The rest period is significant for the forage production in the seasonal grazing area. Hendzel (1981) observed four stages in the grass growth cycle around Gaborone. The stages are early growth, flowering, seed ripening and maturing and the dormant stage. Seasonal grazing occurs during the seed ripening and maturing and the dormant stages when the grass is not actively growing and has completed its food storage. Seasonal grazing therefore enables vigorous grass regrowth in the subsequent year. Based on this logic, the arable area is expected to produce more forage than the permanent grazing area.

Gaborone rainfall data were used for the model because the local rainfall data were not available. It is not clear how different the local rainfall would be from the Gaborone rainfall data. Although the rainfall data for Gaborone have a closer correlation to that of Mochudi which is geographically closer to Gaborone than that of Lobatse, it is not possible to conclusively state that distance always implies similarity of rainfall. Jackson (1985) described two places in Tanzania, which were less than ten kilometres apart, but with a persistently different rainfall amount. Though there could be a difference in the rainfall amount between localities in the study area, it is unlikely that the rainfall differences will significantly contribute to the livestock movement. The latter observation leads to the conclusion that livestock movement in the area is influenced by the landuse. The other significant factors are soil characteristics and relief. Both factors have not been simulated in the model.

Livestock movement and the amount and nature of rainfall determine the availability of livestock water, which influences the CCWA Ratio. The model does not account for the nature of the rainfall though it can be significant for both forage production and surface water retention. Gaborone has short duration storms (Bhalotra, 1985) hence the monthly rainfall variation is greater than the annual variation (see Table 2.3). The nature of the rainfall will affect the number of water points which in turn affects the CCWA Ratio.

8.1.2 *Household Management*

The Rain Land Cattle model aggregates the households' management strategies shown in the conceptual model (see Figure 6.1). There are three cattle management boxes in the conceptual model which are classified as grazing areas, livestock water sources and household management factors. Under the grazing management activities the model does not simulate the Notwane River grazing. The Notwane River frontage grazing was popular during drought years but the Rain Land Cattle model did not isolate the River frontage to show the change of landuse during drought. Instead the Notwane River grazing was modelled as part of the permanent grazing. Under the livestock water sources management activities, the model did not simulate the Tlokweng village water supply. The livestock water which households carted from Tlokweng village was represented as boreholes since they are the source of the village water supply. Under the household management factors, water carting and supplementary feeding were not represented in the model. Sixty eight percent of the households with cattle practise supplementary feeding during drought. Supplementary feeding was not included as a management parameter in the model though stubble grazing, which takes place from the arable area, is a form of supplementary grazing. Households do not cut the crop stalks for supplementary feeding after harvesting. They are left on the field to be grazed off by the animals.

8.2 Reliability and Validity of the Rain Land Cattle Model

Validity is how well a particular model simulates the natural processes of the phenomenon being studied (Picardi 1975:213). Validation is a *process by which we establish sufficient confidence in a model to be prepared to use it for some particular purpose* (Forrester 1961:115; Coyle 1977:181). Validation does not just prove the model is a true representation of the real world but shows the model's strengths, limitation and flaws. Forrester (1961:115) argues that "*the ability of a model to predict the state of the real system at some specific future time is not a sound test of model usefulness*". Forrester's point is that the ability of a model to predict should not be the only test of its usefulness. Comparing the observed and simulated outputs of stochastic models is unlikely to yield good results at all times and therefore may not be a satisfactory way to validate such models. More so in exploratory research observed data are limited which is a further constraint to the validation method. An assessment of the model will show the model's contribution to cattle management. Section 8.2.1 to 8.2.8 answers eight questions about the model (Britt 1997:134). A model may do well in some areas and not so well in others. The following discussion indicates the assessment of the model's performance in each of the areas listed as follows.

8.2.1 *Improved Perception of the Communal Grazing Problem*

The Rain Land Cattle model has demonstrated that the rainfall, livestock water, grazing land availability are some of the important parameters in a cattle management system characterised by feedback loops. Therefore intervention on a single item, such as destocking, can not adequately deal with cattle management if these other factors are ignored. If the destocking were to be followed by a drought there could be disastrous consequences as farmers with small herds may lose the breeding stock. Alternatively, if destocking is followed by a good rainfall season, farmers may regret that they did not take advantage of the abundant forage. The system dynamics approach suggests that a broader approach that looks at the most sensitive parameters in the model should be used for effective management. The model introduced the concept of Carrying Capacity Water Availability (CCWA) Ratio, as part of cattle management assessment criteria. Though the CCWA Ratio is exploratory, its contribution is significant because there are parts of Botswana with abundant grazing but scarce livestock water. By looking at the available water resources the CCWA Ratio improved the carrying capacity measure for management purposes. The CCWA Ratio approach is closer to reality than carrying capacity measure used before. The model shows that the carrying capacity is sensitive to the grazing capacity. This means that if the grazing capacity for the different patches grazed in an area can be determined, the carrying capacity measure will vary from that given when the different areas are generalised.

8.2.2 *Descriptive Realism*

The model improved the perception of cattle management in communal areas by dealing with parameters associated with different aspects of cattle management. Most parameters described in Chapter 6 have real world attributes or equivalent real world attributes, which can be seen or measured, and so makes it easy to diagnose the cattle management problem and identify the appropriate interventions. Such real parameters also enable us to see the limitation of the model clearly. For example, the use of an annual rainfall to determine the livestock water holding is limited because the water holding of the water sources depends not just on the annual rainfall amount but also on the nature of the rainfall. Because it uses parameters which are close to the real world, the Rain Land Cattle model has a high level of descriptive realism.

8.2.3 *Reproduction of Real Behaviour Model*

The simulated dynamism between rainfall and the number of cattle is close to the real life pattern even though it was difficult to say how close the prediction was to reality due to poor data availability (Figures 7.2 and 7.3). The diagram of the model in Section 6.2 can be constructed from an understanding of the general principles about the parameters in the system modelled. For example, the model loop that states that more rain means more cattle and less rain means less cattle (Figure 6.7) is easily understood. Another model loop that is easily understood is that the expansion of Tlokweng village causes a decrease in the available grazing (Figure 6.4). The model simulates the behaviour of a communal grazing system quite well as shown in Section 6.2 and the various model outputs in Chapter 7. The historical rainfall data was well reproduced (Figure 6.9). But the model's main strength was how well it reproduced the trend of the rainfall pattern.

8.2.4 *Model Transparency*

The model is easy to understand because its parameters use real names and the structure diagram clearly shows how the parameters link without a clutter of equations. This enables the day to day users to easily follow the linkages between parameters. When the model's outputs are easily perceptible, the model is transparent. The transparency helps to trace any fault the model may have. The model is attractive because a non professional readership will easily comprehend the flow diagrams since most links are obvious. Stella is a user friendly software that warns the user where elementary model construction errors are made.

8.2.5 *Relevance of the model*

The model deals with the interaction of critical cattle management factors in Botswana. The management factors are offtake, birth and death rates in response to rainfall and stocking rates, cattle emigration, seasonal grazing, land use dynamics and livestock water availability. The model is appropriate for cattle management in Tlokweng communal grazing area. Model simulations enable us to assess the various possible management options. For example, the impact of reduced grazing land and increased livestock water sources can each be simulated and conclusions drawn about their likely consequences. There are no hidden parameters and all the model parameters have been detailed fully in Chapter 6.

8.2.6 *Adaptation*

The research objective 2 (Section 1.6.1) states that the model should be adaptable for the study of cattle management systems in communal areas. The model parameters can be removed, added or altered based on the circumstances of the new area studied. For example, if the area has no seasonal grazing, the parameter is simply removed. Most communal areas in Botswana have characteristics shown by the model, including, a decreasing permanent grazing area, a number of livestock water sources which can be counted and whose water holding can be determined, cattle deaths and births that are affected by the grazing capacity. The model can be used for cattle production in a commercial area because they have most of the communal area's parameters such as grazing capacity and rainfall variation. There are differences such as pronounced supplementary feeding in commercial areas. The commercial areas have no land loss but instead seasonal grazing would be between different paddocks. Offtake is a very important cattle management parameter in a commercial area. Commercial areas have different quality of cattle from the communal areas. The model parameter "catLSU" (Figure 6.2) adjusts for differences in the quality of cattle.

8.2.7 *Correspondence to Real World Data*

The model used some parameters for which there were no ground based data such as:

- the correspondence between the rainfall and its contribution to the carrying capacity called the Range Factor
- the correspondence between the stocking rate and its contribution to the carrying capacity called the ST Factor
- the correspondence between the carrying capacity and its contribution to births and deaths, called R1 and R2 respectively
- the relationship between annual rainfall and livestock water holding for different water sources

Despite the lack of the real values of the above mentioned parameters, the model's predictions were within a reasonable order of magnitude against rainfall. The assessment for the number of cattle was difficult due to paucity of data. The model matched the annual rainfall trend for the fifty year rainfall data reasonably well. It was much easier to match the trend than it was to predict the stochastic annual rainfall.

8.2.8 *Predictive Ability*

The predictive ability of the model depends on the correspondence to real world data in Section 8.2.7. Since a number of sensitive parameters were not based on data measured in the field, the predictive ability of the model is limited. However if the model were used for cattle management, and field data were available, it is expected that the assessment of the model's predictive ability will improve. At present the inference on the model's predictive ability is based on its known ability to match the historical records. In order to assess how good the rainfall prediction was, a measure called the efficiency of the model in Equation 8.1 was used (Brandt ,1990). The efficiency of the model is expressed by R^2, like the coefficient of determination. The R^2 values for the efficiency of the model could range from negative infinity, when there is little agreement between the simulated and observed values, to positive one for a perfect agreement of the values (Brandt 1990).

Equation 8.1The Efficiency of the Model

$$R^2 = \frac{F_o^2 - F^2}{F_o^2}$$ where:

R^2 = the efficiency of the model
F_o^2 = Initial variance
F^2 = Sum of the squares of the residuals

Source: Brandt, 1990.

Initial variance shows how much the observed rainfall varies about its mean. It is calculated according to the Equation 8.2

Equation 8.2 Initial Variance of Observed Rainfall

$$F_o^2 = \sum_{t=0}^{t}\left(R_o(t) - \bar{R}_o\right)^2 \quad \text{where:}$$

$R_o(t)$ = Observed rainfall at time t

$\bar{R}_o$ = Mean of the observed rainfall over period of observation

F_o^2 = Initial variance

Source: Brandt, 1990

The variance of the simulated rainfall and the observed rainfall is calculated from the Equation 8.3.

Equation 8.3 Sum of Squares of Residual of Observed versus Simulated Rainfall

$$F^2 = \sum_{t=o}^{t}\left(R_o(t) - R_c(t)\right)^2$$

where:

$R_o(t)$ = Observed rainfall at time t

$R_c(t)$ = Simulated rainfall at time t

F^2 = Sum of squares of the residuals

Source: Brandt, 1990

model for the each rainfall cycle. The two periods 1945 to 1953 and 1982 to 1989, which were dry periods, had the best model efficiency of above 0.5. The other rainfall periods had model efficiency less than 0. The worst model efficiency was for 1963 - 71 which was a wet year.

Figure 8.1The Model Efficiency for Different Rainfall Periods

8.3 The Robustness of the Model

Robustness refers to how well put together a model structure is which gives rise to credible outputs despite the uncertainty of some of its parameters (Picardi 1975:215) and even when the parameters are subjected to change outside reasonable bounds. The model structure validity defined by Moffatt (1991:31) is similar to the model robustness defined by Picardi (1975). The robustness of the Rain Land Cattle model is considered for each sub model in Sections 8.3.1 to 8.3.4.

8.3.1 *The Rainfall Sub Model*

Each component of the sub model is functionally defined and justified (Section 6.5). The Delayed Rain1 and Delayed Rain2 may need to be determined more accurately based on the soil characteristics of an area, local climatic factors, and landuse variations. Similarly RF Weighted and Botswana Range Condition Index also need to be determined for specific localities. The model parameter that determines the variability of rainfall is the Stochastic. The coefficient of variation of the simulated rainfall for scenarios used to run the model was above 30 percent (Section 6.4). The standard deviation of the Stochastic determined the level of rainfall variability while the mean of the Stochastic determined amount of rainfall.

8.3.2 *The Grazing Land Sub Model*

This sub model captures the dynamics of the landuse in the study area with respect to grazing. The simulation is considered to represent the dynamics adequately because the seasonal grazing comes on and off every four months. The grazing land loss (Section 6.5.3) is difficult to simulate in the long term but 5 percent is realistic based on the available data.

The model resolved the debate about the meaning of grazing capacity and carrying capacity. Carrying capacity is simulated as a variable parameter that is influenced by the rainfall (Range Factor) and the stocking rate (ST Factor). Grazing capacity on the other hand is a static figure. The GC was taken as a baseline value around which the CC varied. The model used both because the grazing capacity figure is widely available. The model goes further to include the CCWA Ratio.

8.3.3 *The Cattle Sub Model*

The cattle sub model responds as expected to the fluctuations of rainfall and the land availability where high rainfall leads to more births and low rainfall leads to more deaths. However the Birth and Death Rate influencing factors are subject to calibration. The two factors are very sensitive to small changes and are therefore crucial to the predictive ability of the model. They were not conclusively determined in the Rain Land Cattle model. There were no cattle death data for the study area. Basing the birth rate and the death rate on rainfall alone is subject to an undetermined margin of error. The offtake and purchase rates used were for the country.

8.3.4 *The Livestock Water Sub Model*

The comments about the RF Weighted and the Stochastic, made under the rainfall sub model, are applicable to the livestock water sub model. The RF Multiple is subject to validation and improvement. The seasonality of a livestock water source is not just determined by the annual rainfall, but by short duration showers of high intensity which cause a high overland flow with limited percolation. Several factors determine the amount of overland flow such as the amount of vegetation cover, the soil type and the slope. None of these factors were used to estimate the livestock water holding ability of the seasonal water sources in the model. The livestock water availability figures should be viewed with these limiting factors in mind. Given that the model used the annual rainfall to simulate carrying capacity, as a proxy for forage production, any shortcomings with the livestock water availability is within the general accuracy level of the model.

8.4 The Possible Effects of Climate Change

This section considers how climate change may affect the study area because the model simulations in Chapter 7 are rainfall driven. Climate change is expected to have more pronounced effects on semi arid areas because they are marginal (Watson *et al.*, 1996:141). The consequences of climate change in Southern Africa rangelands have been studied recently (Hulme, 1996; Odada *et al.*, 1996; Watson *et al.*, 1996).

Climate change has been taking place for a long time in Southern Africa. Hulme (1996) shows the sub region's generalised rainfall trends from 1900/01 to 1995/96. The rainfall pattern was variable between 1900 to 1975 but declined from 1975 to 1995/96. The driest spell for the century was between 1991 and 1995. Within the latter period, the 1991/92 period was connected to the EL Nino Southern Oscillation (ENSO) which represents the climatic anomalies associated with the warming of the Pacific Ocean that are experienced in the low latitude areas (Hulme, 1996:11). The dry condition was broken and wet conditions experienced in 1995/96 for most areas. Throughout the century, the inter annual variability of rainfall was over 30 percent (Hulme, 1996). At the same time there was an increase in temperature at an average of 0.05^0 C per decade (Hulme, 1996). It is expected that the study area could get drier or wetter (Hulme, 1996) but the temperature will most certainly increase. Less rainfall, a drier scenario, would be more variable therefore there will be more frequent droughts while more rainfall means the opposite (Galvin and Ellis, 1996).

Given that both wet and drier periods could be associated with climate change, we concentrate on the effects of drier periods. A wetter period would present fewer hardships for cattle management than those associated with a drier period.

8.4.1 *Changes in Vegetation and Livestock Water Availability*

One of the major effect of climate change is the increase in extreme events such floods and drought (Watson *et al.*, 1996). Therefore a drier scenario should be perceived as extensive dry periods with higher temperatures interspersed by floods. Higher temperature will increase the loss of water through evapotranspiration hence there will be a moisture deficit which may cause the vegetation to wilt thus decreasing the available grazing. But the vegetation may adapt in several ways to a drier climate. Firstly the species may change from perennials to annuals. The study area may be experiencing the shift mentioned above as annuals dominate (see Section 2.5 and 2.6.2). Secondly it is expected that there will be an increase in the thorny bushes (Hulme, 1996). Bush encroachment would cause a direct loss in the productivity of the rangeland. For example, in 1994 Namibia was estimated to lose 34 000 tonnes of beef annually due to bush encroachment (Hulme, 1996:68). Thirdly the surface water sources would be reduced. The reduction of surface water sources would lead to an increase in the number of animals watered from boreholes and that would result in higher draw down borehole levels. When combined with a poor recharge rate likely due to poor rainfall, boreholes will become less reliable and may be unable to supply the increased livestock water demand. At the same time bare areas would grow around the few livestock water points from which an increased number of cattle would water (Hulme, 1996) and grazing areas without water would be lost.

Such bare areas will develop within and around settlements too. Tlokweng village is a fallback livestock management location for poor households. During a drought the village would not be able to support such households when it's grazing has been scarred. More large cattle owners would be encouraged to move their cattle out of the Tlokweng Sub District to the sandveld where extensive grazing areas will be available for their cattle during a drier climate. The movement would increase the geographical polarity between the small and large cattle owners with the Tlokweng

Sub District grazing area predominantly used by the small herd owners. During the fieldwork several households pointed out that the study area was not suitable for large herd owners because of the limited grazing.

8.4.2 *Arable Area Shrinkage and Significance of Grazing Land Loss*

A drier climate would reduce the significance of the arable area to the cattle grazing in the sub district. At present, when there has been inadequate rain for ploughing, the seasonal grazing is used all year round. If the rains fail after the seed germination and the seedlings wilt, the wilted crop is grazed off. A similar practise was observed in the Southern District of Botswana (Abel *et al.*, 1987). The Tlokweng Sub District arable area normally provides forage at a time when the permanent grazing is depleted. Under a drier climate it may not be available because it will not be ploughed. The loss of the seasonal grazing would increase the rangeland pressure the same way as the effect of grazing land loss discussed in Section 7.4.2. The arable area would also decrease directly as households give up cattle farming for more viable and less risky ventures such as intensive dairy farming or pig farming. Both are presently practised to a limited extent in the study area. The National Policy on Agricultural Development (Ministry of Agriculture, 1991) encourages both types of farming in areas where the farmers may get higher returns from them than from cattle farming.

8.4.3 *Permanent Movement from Tlokweng Village*

It is likely that under a drier climate some cattle farmers in the study area would move from Tlokweng village to stay permanently in the present farming areas. The move would enable them to sell their village homes to the Gaborone City land hunters which would reduce both the role of Tlokweng village as a fallback location during drought and the land available for cattle grazing in the sub district. Both the development of permanent settlement (Silitshena, 1982 a; b) and mixed farming areas (Mpotokwane, 1986; Arntzen, 1989) were observed in other districts of Botswana. None of these studies associated the development with changes towards a drier climate.

8.4.4 *Increased Need for Supplementary Feeding*

Both the need for, and consequently the cost of, supplementary feeding will increase during a drier period. Small herd owners are least likely to afford the supplementary feeding for their cattle. Since some households in the study area sell cattle during drought in order to get the money to buy supplementary feeding (see Section 7.6.5), they would have to sell more frequently because of low prices due to the poor cattle condition and the high frequency of drought occurrence. The small herd owners are likely to be the most disadvantaged because they have fewer cattle to sell before their herd is depleted.

8.4.5 *Use of Notwane River and Gaborone Sewage Water*

A drier climate would increase the strategic significance of the Notwane River grazing. Consequently more cattle would graze along the Notwane River and would stray or trespass into Gaborone City. There would be a need for close cattle herding, which according to the respondents was not common in the study area due to a shortage of labour. This may cause a conflict in the labour demands given the expected increased urban employment. Watering cattle from the perennial trickle off the Gaborone City Sewage ponds would increase. The long term health consequences for cattle which depend on the waste water are not certain.

8.4.6 *Increased Urban Employment*

Table 8.1 shows the employment situation in different parts of the country. The localities in Table 8.1 represent the country (national), urban area (Gaborone), district (Southern) and a village (Tlokweng).

Table 8.1 Type of Employment and Percentage Employment per Locality

Employment Category	National	Gaborone	Southern	Tlokweng
Employed by others	20.8	46.4	11.4	40
Self employed	2.2	3.2	1.5	1.9
Family Business	0.6	0.4	0.7	0.4
Lands, Farms Cattlepost	5.1	0.2	6.0	0.4
Seeking Employment	4.6	6.0	4.4	5.9
Total Economically Active[1]	33.3	56.2	24.0	48.4

Source: Central Statistics Office, 1993

The table shows that a higher percentage of Tlokweng's total population is economically active compared to the national or that in Southern District. The employment situation in Tlokweng compares closely to that in Gaborone. Because the study area is near to Gaborone and Lobatse, the Tlokweng village population is more likely to be formally employed than that of other rural areas in Botswana. During a drier period, the drift to urban employment is likely to be accelerated. The effects of urban incomes on the management of cattle are varied. Access to income would enable households with small herds to buy supplementary feeding which

[1] The Total Economically Active is the sum of all the percentages employed per a locality

would negate the earlier proposition that such households would not afford supplementary feeding. On the other hand cash income would enable households to diversify away from cattle in order to minimise risk due to climatic vicissitudes.

8.4.7 *Diversification*

One possible development due a drier period is the increased ownership of small stock, especially goats, which are more resistant to drought and use less water than cattle. Figure 1.2 shows that the trend has already been developing nationally. The increased number of goats would be suitable to the utilisation of browse rather than the grazing in the area. Although the introduction of goats would be economically efficient, mixing cattle with wildlife would be both economically and ecologically efficient (Watson *et al.*, 1996:148). A mix of wildlife and cattle rearing is unlikely in the study area because in dry areas wildlife requires extensive grazing areas and the study areas does not provide the requisite conditions. The other constraint is that the area does not have a history of a mixed wildlife and cattle land use. An instant switch is unlikely.

8.4.8 *Government Policy*

The above consequences of a drier period do not take into account government policy which plays an influential part in cattle management. It is difficult to predict changes in government policy as they could be politically motivated. The National Policy on Agricultural Development (NPAD) does not include the implications of climate change. If the NPAD recommendation on targeted subsidies (Ministry of Agriculture, 1991:39) were to be applied, supplementary feeding and livestock water provision would most likely be subsidised during a drier climate as has so far been the case during the past droughts. However it is questionable whether such a policy would be sustained in the long term.

8.5 Modelling the Consequences of a Drier Scenario

Some of the consequences of a drier scenario mentioned in Section 8.5.1 can be directly modelled in the Rain Land Cattle model. Table 8.2 summarises the modelling prospects for each of the consequences and shows that some consequences can be modelled directly or indirectly and others cannot be modelled at all. Those that can be modelled directly have a parameter that represents them on the model already. Those that can be modelled indirectly can be inferred using existing model parameters. For example bare areas can be represented through a Range Factor with a poor response to rainfall because bare areas are less attractive to the germination of grass (Vegten, 1981) even when there is adequate rainfall. Those consequences described as not modelled are not necessarily impossible to model. The label "not modelled" shows that the Rain Land Cattle model in its present form does not have a parameter to consider the consequence in question. Some of the consequences that are presently not modelled can be incorporated. For example, grazing in the Tlokweng village can be modelled by a grazing parameter that shows the characteristics of the Tlokweng village grazing. Though increased urban employment is a significant issue for a drier climate scenario, the Rain Land Cattle model did not model it.

Table 8.2 Modelling Consequences of a Drier Scenario in the Rain Land Cattle Model

Consequence	Modelling Prospects
Vegetation change and loss of livestock water	• vegetation loss can be modelled indirectly using the Rainfall and Stocking Factors • decrease in livestock water can be directly modelled through the Rainfall Multiple • bare areas can be represented as vegetation loss therefore they can be modelled indirectly • increased use of Tlokweng Village can not be included in the model at the present scale - a larger scale would be necessary which would show the village grazing as a separate grazing area • movement of large herds out of the area can be modelled directly as emigration
Arable land shrinkage and decreased significance	• can be modelled directly as loss of seasonal grazing
Permanent movement from Tlokweng village	• the cattle management consequence of the movement is the loss of the Tlokweng village grazing it is not included in the Rain Land Cattle model (see also (i) above)
Increased supplementary feeding	• effect of supplementary feeding is not modelled • increased sales can be directly modelled as offtake
Use Notwane River grazing and perennial water	• Notwane River Grazing is not modelled • Notwane River perennial water is modelled directly - its increased significance can be depicted relative to a decreased seasonality of boreholes
Increased urban employment	• not modelled
Diversification of animals	• increased browsing is significant, not just the change in stocking rates, but it is not modelled
Government policy	• subsidies for supplementary feeding not modelled

8.5.1 *Rangeland Variations*

Rainfall induced and man made variations of the rangeland and their effect on the production of grazers have been studied over time (see Section 3.1; Jones and Sandland, 1974; Vegten, 1981; Tacheba and Mphinyane, 1993). Seitshiro (1979) studied a rangeland in north east Botswana where the annual forage yield fluctuated between 4733 kg Ha^{-1} during a year of high rainfall and 1665 kg Ha^{-1} during a normal rainfall year. The studies show that the rangeland, rainfall amount and stocking rate in the semi arid areas are in a state of constant flux. The Rain Land Cattle model shows the fluctuation of rainfall, which causes forage fluctuation, and the effect of forage fluctuation on the number of cattle held in an area. The link between the rainfall and the number of cattle is based on the graphical functions Range Factor and ST Factor.

8.5.2 *Management Demands on the Land*

The main management concern for communal grazing areas in Botswana is their sensitivity and resilience. Sensitivity is the degree to which a given land system undergoes changes due to natural forces after some disturbance (Blaikie and Brookfield, 1987). The source of disturbance may be anthropogenic, natural or both. A grazing area may become more sensitive to the impact of grazing over time. It is argued that ecologically marginal areas are likely to become more eroded under sustained heavy grazing (United Nations Sudano Sahelian Office, 1994a). Resilience on the other hand is "*a property that allows a system to absorb and utilise, or even benefit from change*" (Holling cited in Blaikie and Brookfield, 1987:10). A high resilience system will remain unaltered by an impact within certain limits. The general effects of management on the resilience and sensitivity of an ecosystem is shown by Table 8.3. Resilience explains the relationship between natural resources and development in a semi arid environment where the weather is variable. Resilience has been equated to sustainability (Pearce *et al.*, 1992) which in the context of agriculture is "*the ability of an agro-ecosystem to maintain productivity when subject(ed.) to stress or shock*"

(Pearce *et al.*,1992:41). Stress is regular, predictable and maybe continuous while shock is irregular, unpredictable and discontinuous.

Table 8.3 Management Effect on Systems of Varying Resilience and Sensitivity

	High Resilience	Low Resilience
High Sensitivity	• easily degraded • responds well to restoration of land capability	• easily degraded • does not respond to land capability reparation
Low Sensitivity	• not easily degraded except through persistent very poor management • land capability restoration possible but may take a long time	• initially resistant to degradation • once threshold level is passed, land capability restoration is very difficult

Source: Adapted from Blaikie and Brookfield, 1987:11-12.

Botswana's annual water shortage during the dry season is stress. It is predictable. A drought is less predictable. It represents a shock event. A grazing area maintains its productivity if it is able to hold the same number and quality of cattle year after year. Historical records suggest that the study area once held about 6000 cattle, some of which had to be moved to neighbouring districts due to land shortage (Section 2.2). The 1992 official cattle count of 3017 is half of the 6000 once held. The decrease in the number of cattle in the area can be partly explained by the reduced grazing area. Grazing land has been lost to other landuses. Historical accounts of the landuse in the study area (Mosothoane, 1976; Schapera, 1943) show that the grazing area used to be more extensive than at present. About one third of the respondents reiterated the view that the study area holds fewer cattle than before because of the decrease in the grazing land (Section 7.7).

There was consensus among the respondents in the study that the study area was not easily affected by drought. Most small herd owners were reluctant to move out of the area during drought because they feared they would expose their cattle to drought in unfamiliar areas (see Section 7.7). The households' responses and the characteristics of the cattle production simulated by the Rain Land Cattle model show that the study area can be characterised as a high resilience low sensitivity landscape according to Table 8.3. The cattle population have survived and recuperated after drought in the past. The effectiveness of Tlokweng Sub District cattle management strategies is evident from the cattle population records. But questions maybe raised about the effectiveness of the management strategy in the future because of:

i) the grazing land loss;

ii) a trend, which is at its infancy, where farmers individually fence their fields;

iii) the governments interest in developing the NPAD; and

iv) the opportunity costs of cattle farming against other economic ventures in the subdistrict.

8.6 Grazing Capacity and Carrying Capacity in the Study Area

The model defined a sharp difference between grazing capacity and carrying capacity. Grazing capacity is a static concept while carrying capacity is dynamic. The model uses the static grazing capacity as a bench mark to define the fluctuations of the carrying capacity due to rainfall and the stocking rate.

8.6.1 *The Implication of Scale for Grazing Capacity and Carrying Capacity*

Carrying Capacity is affected by the Grazing Capacity, the rainfall and the stocking rates. The number of cattle is very sensitive to the grazing capacity parameter in the model.

The scale at which the variation of grazing capacity, the rainfall and the stocking rates is to be considered is significant since it determines how much detail will be shown. Cattle use the range at a larger scale than the one at which rangeland mapping is normally done. Rangeland maps represent cattle grazing units as homogeneous or at most heterogeneous complexes. As pointed out in Sections 3.2 and 3.3., semi arid rangelands are heterogeneous because the grazing and water resources are available at different times. Cattle in areas with variable rainfall adapt to the heterogeneous landscape by moving from area to area. The ideal scale for studying cattle management should highlight the significant grazing units, patches, which are used at different times and their complementarity. The product of such mapping is a cattle management map that may be based on a rangeland map. But such cattle management map scales will differ markedly from the existing rangeland maps. The level of detail at which the physical resources such as soils and vegetation are mapped determines the scale of rangeland mapping (Gils, 1984). To determine the relevant scale of a cattle management map, the Rain Land Cattle model suggests that a representative fraction such as a 1:50 000 map may be too small. The model does not show the movement of cattle to the river, for example. The significance of the cattle movement between the different patches should be considered, when determining the level of mapping detail necessary. The Preference Index, described in Section 3.3.4, can be used to determine the relevant scale of the study. Patches preferred by cattle should be investigated and mapped individually. That means the grazing capacity and carrying capacity maps will be necessary for each patch. It will be difficult to develop such large scale maps because they are not conventional and it is doubtful that adequate data bases exist to support mapping at such a scale in Botswana.

That means in a number of cases it will still be necessary to leave out the significance of the grazing patches when the grazing and carrying capacity calculations are calculated until such time that the areas have adequate data to represent the areas in detail. Therefore a compromise scale may have to be arrived at to enable the simulation of the grazing and carrying capacities.

8.6.2 *The Carrying Capacity Water Availability Ratio*

The Carrying Capacity Water Availability Ratio refines the carrying capacity in semi arid areas. Table 4.9 shows the limits of the LW Months, the CC and the CCWA Ratio and their implications. The LW Density is low when the CC is highest.

8.7 Further Data Requirements for the Model

The model was exploratory. One of the parameters that require calibration is the Range Factor. Pickup *et al.,* (1998) came up with a method to calibrate vegetation growth in semi arid areas under various rainfall occurrences using remote sensing. They looked at the vegetation growth vigour in areas near to, and away from, water points in five geographical areas over a period of eight years. The data were monitored at 1 hectare resolution between 1982 and 1995. The data was taken six to eight weeks after rains, during droughts when the cover was lowest and during the intervening periods. A ratio which calculates the vegetation's response in intensively grazed areas in comparison to that in lightly grazed areas, was devised. A decrease in the ratio suggests that the area is degrading since its ability to respond to the rainfall is declining. The method was tried in large Australian paddocks with areas between 110 km^2 and 460 km^2 (Pickup *et al.,* 1998). It is not clear to what extent the method will be applicable in a communal area, where the land use and pixels are mixed. Tacheba and Mphinyane (1993) looked at the response of an area to grazing in Central Botswana. Such studies will indicate the possible data collection methodology for data validation.

8.8 The Future of Cattle Management in the Study Area

The future of cattle management in the study area is bleak, as it is for several communal areas in eastern Botswana. A number of factors contribute to the bleak future.

We noted that large cattle owners have already been moving their cattle out of the area because of they feel the limited grazing constraint most. The trend will continue because of the land demand by the Gaborone residents on Tlokweng and the Tlokweng residents speculative land requests. Secondly, the Tlokweng Development Plan, which was drafted in 1996, will develop extensive areas of the present study area into non grazing uses (Department of Town and Regional Planning, 1996).

8.8.1 *Changes in Land Use*

The changes in land use, mainly the loss of permanent grazing, will reduce the grazing area and or cause cattle production to be marginalised. The Tlokweng Development Plan (Department of Town and Regional Planning, 1996) threatens the future grazing areas, cattle movement and even arable land.

8.8.2 *Uncertainties*

Although we assume that the area will undergo landuse changes and migration there is uncertainty because future government policies could affect the area considerably. One major source of uncertainty is whether the area will continue to be classified as a rural area. If the land tenure classification changes from rural to urban, which is a realistic supposition, the future of cattle management will be changed drastically. An increased urbanisation of the population may cause the households main source of income to move away from cattle investment to non cattle based activities.

8.9 Feasibility of Fencing the Communal Grazing

Several fences, described in Chapter 2, are found in the study area. The fences are part of a communal grazing management system developed and perfected over time. The fences are the management strategy for the whole community and not the preserve for a few households. The fences around the arable area are opened to allow cattle to graze in the area during the dry seasons (May to September) after which the cattle are put outside and the arable area closed to enable crop production during the rainy season. The National Policy on Agricultural Development (Section 1.5.4) accepts that communities can fence as found in the study area. "*The Government will* *allow farmers where feasible to fence livestock farming land either as individuals, groups or communities to improve productivity of the livestock subsector"* (Ministry of Agriculture, 1991:41). Given that in the past policies meant to develop cattle production encouraged individuals to fence land (see Sections 1.4 and 1.5), it is logical to interpret the position of the NPAD as encouragement of individual or group fences rather than community fences. That position means that the arable grazing area fences found in the area do not enhance the policy's objectives for cattle management. If the NPAD were to accept the present communal management it would enhance its efficiency which would be a positive step towards good cattle management. The alternative of fencing the Homesteads grazing area or the Tribal Farm, which are described in 2.4.2 and 2.4.4 respectively, is a not realistic based on the existing patterns of use in the area. The Homesteads area already has network of access roads, is densely settled, and its vegetation shows signs of degradation. The Tlokweng Land Board has allocated about ten cattleposts in the Majeadikgokong Tribal Farm. Two privately owned boreholes have been drilled in the Tribal Farm, therefore reverting to communal use is unlikely.

8.9.1 *Integrated Use of the Units in the Study Area*

In Chapters 2 and 6 it was noted that the Homesteads landuse area has several uses and that it was losing grazing land to other landuses. The predicted degree of grazing land loss showed increased livestock pressure on the land. Further loss of communal grazing land will accentuate the land pressure. There is no other unused land large enough to be fenced for group or individual grazing farms. The history and prevailing land use management of the area, is based on integrated and not exclusive land use. Exclusive use is unlikely to be accepted. The area resisted the establishment of the neighbouring freehold farms (see Section 2.2).

8.9.2 *Views from the Field Questionnaire*

Policy considerations such as equity, sustained use of land and increased livestock production can not be easily addressed in the study area. Presently the shared use of the arable area grazing land addresses the equity issue since all cattle, irrespective of the owners land holding, have access to the seasonal grazing. The seasonal grazing, supplementary feeding and moving cattle to the Notwane River or out of the study area, all contribute to the sustained use of the area. It is doubtful that cattle production can be increased under the present management style. Most households do not believe that there is scope for more cattle to be kept in the study area. They argue that the area can only maintain the present levels or experience a decreased production.

The response to the NPAD fencing was "*we already have fences in our area what we need is money to maintain the fences*". They felt that the management system where cattle moved into the arable area after harvesting was very good if only they could maintain the fences well. The NPAD fencing was subsequently dismissed as irrelevant. The respondents' view is supported by the research findings that the use of the arable grazing area is fundamental to the successful management of the area.

8.10 Limitations of the Study

Sections 8.10.1 to 8.10.4 present four limitations of the study.

8.10.1 *Data Availability and Suitability for Model Input*

At the beginning of the study, it was considered important that the data for the model should be readily available. This is because a data hungry model is constrained by the high cost of data collection which is not ideal for a country with considerable financial and manpower constraints. Data collection takes a lot of time. Despite the requirement for readily available data, the available data was limited. Chapter 6 detailed the availability of data used.

Cattle data are collected annually by the Department of Animal Health and Production in all districts in Botswana. The data show age and gender but they do not show deaths and sales. The cattle data used in the model were for a very short period (8 years) in relation to the length of the model simulations. The cattle data appeared to be of questionable reliability. National data were used for death rate which may not be an accurate representation of the situation in the study area. Vossen (1987) shows that the death rate varies significantly between districts and the country.

The Gaborone rainfall data was used. Gaborone is about 10 kilometres away from the study area. The rainfall data in Botswana are collected from a sparse network of stations which makes data interpolation necessary. In 1990, Botswana had 11 synoptic weather stations, 14 climatological stations and 25 rainfall stations (Ministry of Finance and Development Planning, 1991). The network of rainfall recording stations is denser in the eastern part of the country than in the west. Given the current network of stations, this was the best way to deal with the rainfall data. The effect of stocking rates on the ability of the rangeland to recover (ST Factor) is not easy to determine. It can only be established by long term research in different ecological regions. The effect of rainfall on the rangeland was based on the Botswana Rangeland Condition Index. The BRCI represents a good relationship between the rainfall and the rangeland in Botswana as noted in Section 6.4.4.

A recent detailed time series study (Department of Town and Regional Development, 1996) reviews the land use dynamics in the Tlokweng sub district. From the land use review it was possible to establish the grazing land loss trend. The annual land loss assumes that the land loss between two period of years is even.

8.10.2 *Effect of Excluding Cattle Biological Performance*

The model extrapolated the effect of the biological performance of cattle through the graphical factors Range Factors, Death and Birth Rate Influencing Factors. The biological indicators, such as weight loss for mortality and birth rate are not used. For the purpose of the model, indicators are dispensable. The model does not consider the different cattle cohorts based on age separately. They are all subsumed under the livestock unit.

8.10.3 *Rainfall Prediction*

Rainfall prediction for an area with variable rainfall is a difficult task because it is probabilistic rather than deterministic. This means that whatever figures are derived, they represent a very likely outcome based on the constraints imposed on the model. In this case the constraints were the trend that was defined by the Auto Regression and the Moving Average. The trend keeps the annual rainfall away from any random prediction. The rainfall prediction beyond the observed period assumes that the trend for the past 50 years is likely to be reproduced. It is reasonable to assume that the past rainfall trend is likely to be reproduced in the future because Tyson (1987) showed that the Southern African rainfall trend has a cycle of about 18 to 20 years. The stochastic nature of the rainfall, which is the main characteristic of a variable rangeland area, was the main source of deviation from the trend. Given that the number of cattle depends on the BRCI, rather than a single year's rainfall, the significance of the yearly rainfall variation is minimised.

It was difficult to predict the annual rainfall accurately. Rainfall in variable areas is unpredictable in reality. But it is useful that the model trends were well captured. Rainfall varies spatially and temporally in a semi arid area. This means that for example, if the model predicted Gaborone rainfall accurately, that would not necessarily apply to the rainfall in the study area as well. When considering the rainfall prediction accuracy, it is necessary to take into account the practical relevance of the accuracy in question. The spatial and temporal variations of the rainfall in semi arid areas militate against relatively low rainfall prediction accuracy. The annual rainfall prediction adequately fulfils the objective by measuring rainfall as a cattle management factor in the study area.

8.10.4 *Spatial Aspect in the Model*

The model has a limited spatial resolution but its temporal resolution is quite good. The spatial resolution is associated with the use of local variations in the resource availability. The temporal resolution enables us to look at the use of different resources at different times of the year. Opportunism in the study area has both a temporal and a spatial dimension.

The spatial units considered in the model are the arable area, the permanent grazing and the grazing outside the study area (emigration). The use of local units such as the Notwane River frontage, Tlokweng Village, and other localities is not considered. Livestock movement within the study area, is an important management aspect that was observed during fieldwork and reported by the interviewees.

Summary

The model performs well given its data limitations. It is however subject to further refinements and validation. It has a valid and robust structure. It is expected that the model can be easily adapted for similar areas elsewhere in Botswana. It can be used to show the future effects of a drier scenario. The future of cattle management in the study area is doubtful because of the government National Policy on Agricultural Development, the proposed Tlokweng Land Use plan and the land pressure from Gaborone City. Carrying Capacity and Grazing Capacity have been clearly defined in the model. The CCWA Ratio which was developed to refine the CC, shows that the CC and LW Density do not always go together. The measure is exploratory.

Chapter 9. Conclusions

Introduction

There are five conclusions. The first shows the efficacy of dynamic modelling in cattle management. The second summarises how the livestock water parameter, enhances the perception of carrying capacity in cattle management studies. The parameter is an innovation of this study. The second conclusion ties in with the third to discuss the sustainability of the cattle production in the study area. The fourth shows how the study addressed its objectives and the last conclusion looks beyond this study.

9.1 Dynamic Modelling for Cattle Management in Communal Areas

The theoretical framework (Chapter 3) discussed the relationship between cattle production and forage in order to explain how this model uses rainfall to simulate the number of cattle. The chapter introduced density dependent and density independent factors. The model's ST Factor is density dependent and the Range Factor is density independent. This shows that the model simulates cattle numbers through density independent and density dependent factors.

The study has demonstrated the usefulness of system dynamics modelling. System dynamics modelling considers the management factors together and over time. The alternative, a static study that isolates parameters for consideration without a time perspective, is further removed from reality and hence not likely to properly address the management issues at stake. The Rain Land Cattle model's dynamic output can be used to show the effect of individual parameters on the output over a short or medium term period. The longer the simulation the less likely it is to be realisable because of the inherent uncertainties. Therefore, except when using the 50 years historical data, the projections in the model were limited to 30 years.

The model indicated the need for continuous data collection to monitor livestock management factors. The best way to operate successfully is to use the present Department of Animal Health and Production annual data collection more diligently and add a few more enquiries such as cattle emigration. For example it is possible to ask households to indicate where their cattle were the previous year at each cattle census point. The government has proposed to tag cattle to identify those eligible for sale to the European Union export market (http://www.gov.bw). Such tagging will enhance continuous data collection.

The model indicates the significance of understanding the households' management strategies in cattle management intervention for communal areas. The study integrated the households management strategies, such as movement into the arable area after harvesting, with the physical aspects of the study area, such as grazing capacity and rainfall pattern, to demonstrate the biological factors of cattle births and deaths. This integrated approach is ideal for successful and relevant management intervention. Government policies are necessarily broad and should be followed by integrated local level studies before implementation.

This study also indicates that households' views can assist implementation of the National Policy on Agricultural Development policy. The households' view that the

National Policy on Agricultural Development should reinforce the existing fencing instead of introducing a new one is viable. During the fieldwork government's policy implementers were looking for areas to fence rather than identifying how the policy could blend into the existing fencing policy. The government policy implementers' preliminary selection of areas for fencing assumed that Majeadikgokong and Mmamogofu were available for fencing (Kgamanyane, personal communication, 1995: Tsimako, personal communication, 1996). Neither location is readily available. The other significance of the households' view is political. A politically unacceptable policy is unlikely to be successfully implemented.

The spatial and temporal scales at which the modelling occurs are paramount in a semi arid area because the local resources are heterogeneous. Planning that disregards the heterogeneity of water, forage and land use is unlikely to be successful. Many other studies show that the local cattle management should exploit the heterogeneity of the landscape (Sandford, 1983; Abel *et al.*, 1987; Abel, Dahlberg and White, 1993; Behnke, Scoones and Kerven, 1993; Scoones 1995b). The model found that the study area has a chronically higher Stocking Rate compared to the Carrying Capacity but the effect of the high stocking is reduced when cattle move into the seasonal grazing area. The National Policy on Agricultural Development argues in favour of fencing without regard for enhancing the exploitation of the heterogeneity of the landscape. The Lesotho government supports the exploitation of local heterogeneity through *maboella* grazing although recent developments have reduced the efficiency of the traditional grazing cycles (Sylla, 1995).

The scale at which management plans should be developed depends on the outputs likely from the process. For example, cattle production looks at the births and deaths which are both measured on an annual basis. Thus a solution time of one year will show these quite well. Secondly, the time scale depends on the efficiency between accurate information and cost of computing. When the simulation time is reduced, rounding off compounds errors and the cost of computer time increases (Moffatt, 1991; Huggett, 1993). The cost of computer time is not critical factor when using a fast computer. The spatial scale is a trade off between mapping possibilities and the significance of the grazing area to the animal which can be determined by the Preference Index (Scoones, 1990).

When taking into consideration the objective of this study and the cattle management practices in communal areas of Botswana, we conclude that the Rain Land Cattle Model can be assessed on five characteristics:

i) **Dynamic**

A dynamic model is sensitive to the changes in the parameters. Table 7.3 shows the sensitivity of the various parameters. The model's output responds to rainfall amount, land availability, grazing capacity and other parameters. A dynamic model also shows how a number of parameters interplay to influence the model's outputs.

ii) **Pragmatic**

The model operates at a scale which is useful for effective management. It is pragmatic because it is problem oriented. We indicated that its spatial scale is limited however, though it can be improved. But that will require more data which will also reduce the temporal scale of the model.

iii) **Compatible Data**

Most of the data used in the model are readily available, though its accuracy is subject to verification. Therefore the model is easy to run and affordable. It would be costly to collect the data specifically for the model, which would reduce the chances of the model being used by the established structures. The model can blend into the existing data collection procedures without further demands but enables better understanding, hence management, of the communal cattle production system which is prevalent in Botswana than has hitherto been the case.

iv) **Simple**

The model is easy to understand and intuitive. Most parameters use real names which are already part of the day to day language in cattle management. The loops and links are based on easily perceived relationships and principles. The model can be used for management after some limited training. Because the model is compatible with the existing database, it would be easy to integrate it into the present cattle management attempts in the country.

v) **Adaptable**

The model is adaptable. The model can be used to study cattle management in a farm or whole district. It can be used country wide to assess cattle management problems. Parameters can be added, removed or modified to suit the specific circumstances.

The model establishes that the size and quality of the grazing land, the availability of reliable water sources, complementary use of the diverse grazing resources and an active offtake policy determine the sustained cattle production. Designating the present communal grazing areas into farms as suggested by the NPAD is not feasible in the study area and, *ipso facto*, will not improve cattle management.

9.2 The Role of Livestock Water in Cattle Management

The relationship between the water sources and rainfall amount is more complex than that depicted by the Rain Land Cattle model. Botswana's rainfall, like in other semi arid areas, varies spatially and temporally (Bhalotra, 1995). The water that collects into an open water source during the rain depends, among other factors, on the intensity of the rain and not just the amount. The other factors which determine the water holding are topography, soils, geology, vegetation cover and sedimentation rate. The Ministry of Agriculture in Botswana considers sedimentation rate the major factor when looking at the dam design (Mphathi and Wah, 1994). The model has simplified the determination of the water holding. The simplification was necessary given the objectives of the study. The inaccuracies, or inadequacies, that result from the simplification cannot be determined at this stage. However the principle of relating Carrying Capacity to water availability is valid though it needs to be refined later.

The development of Mmamogofu Water Development Scheme will boost the reliability and sustainability of livestock water sources in the study area. The Mmamogofu Water Development syndicate had problems similar to those of the Tribal Grazing Land Policy, which were reviewed in Section 1.5.2. Some members' devotion to get the scheme off the ground was wavering and there were bureaucratic entanglements with the local government about the design details (Pilane, personal communication, 1995). When developed the water scheme will affect the landuse and future of cattle management in the area.

Table 9.1 shows the implication of the water availability for cattle management in Botswana. It generalises the outputs of the model for the study area to demonstrate the usefulness of the outputs to the rest of the country. When both the forage and the water availability are poor, wildlife takes over as the main landuse because wildlife is more efficient when water resources are limited. In semi arid areas the ideal situation, where both water and forage are accessible, is rare which is why opportunism is common. Conditions in Botswana ranches are nearest to the ideal. Communal areas have medium to low carrying capacity and medium to low livestock water density. Extensive use of the rangeland is necessary.

Table 9.1 The Implication of Livestock Water Months Density for Cattle Management in Botswana

Livestock Water Months Density	Carrying Capacity (Ha LSU^{-1})		
	< 10 Ha (High)	10 – 20 (Medium)	>20 (Low)
More than 140 (Poor)	Investment on water development justified due to the high quality of the rangeland	Water scarcity may limit full use of the grassland in a number of years	Cattle production unlikely due to the cost of improving the range and water availability. Competition with wildlife likely
100 – 140 (Medium)	Rangeland use without major water resource development possible	Water shortage unlikely and there is an opportunity for permanent ranch development	Good water availability. Requires maximum rangeland use
Less then 100 (Very Good)	Excellent water availability on very good rangeland. Best possible rangeland conditions.	Very good water available. Most ranches in the country are found on such areas	Excellent water available but supplementary feeding necessary due to poor rangeland

Source: Based on the Rain Land Cattle Model

Access to grazing land next to water points in the study area has so far been unrestricted. Restricting access to grazing land, which may occur under the National Policy on Agricultural Development, will increase the pressure on the forage resource in the area which in turn will squeeze out some of the poor households who cannot move out to other parts of the country. This would raise the issue of equity of access to natural resources and whether the National Policy on Agricultural Development is a just policy. Botswana's development is based on both equity and justice (Ministry of Finance and Development, 1991).

9.3 The Sustainability of Cattle Management

Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future (World Commission on Environment and Development, 1987). The Botswana government definition of sustainable development refers to concern about future production, efficient production and resilience to shocks (Ministry of Finance and Development Planning, 1991). Concern about the resilience of cattle to shocks is a prime concern in a semi arid area. Another aspect of sustainability is the conservation of agricultural land. The Agricultural Resource Board is responsible for "*controlling the use of agricultural resources*" (Ministry of Finance and Development Planning, 1991:245). The National Conservation Strategy (NCS) 1990, which was discussed in Section 1.5.3, commits Botswana to sustainable development. It was noted that the NCS is not expected to achieve much on cattle management. Section 1.5.4 reviewed the NPAD, which specifically addresses cattle management. This study contributes to the implementation of the policy. The brief introduction to this section shows that there is a commitment to sustainable development but there are doubts about sustainable cattle management.

Vegten (1974) observed that the grass cover decreased when bush encroachment increased in Kgatleng District. Section 8.4.2 showed the case for rangeland degradation due to bush encroachment in Namibia. Stocking (1995) found that soil erosion costs Zimbabwe US$ 10 - 80 per hectare of grazing land per annum. Biot measured the soil loss in exposed areas for Botswana (Section 5.3.4). Although Section 3.4.2 concluded that it was difficult to establish the existence of rangeland degradation in Botswana, measures such as bush encroachment indicate a decline in the rangeland productivity, which would affect the cattle. Bush encroachment and soil erosion can be used to measure rangeland degradation. This study accepts the measures. They can be incorporated as parameters into the Rain Land Cattle model. This study complements and supplements the static measures with a system dynamics approach that enables a holistic approach to the cattle management problem. Since the model in this study runs on time and different land units, data on the measurements of rangeland degradation will need to have a spatial and time context. Rates of soil erosion and bush encroachment in the different parts of the study area, will be needed. Presently the model assesses the sustainability of cattle management from:

i) **Grazing area land loss** – which is due to the expansion of non grazing land uses is a major threat. The grazing land loss due to rangeland degradation was not measured. It is therefore not part of the model.

ii) **Availability of the arable area** – is useful for the seasonal grazing and the agro - pastoral household economic welfare. The latter is not shown in the model.

iii) **Rainfall occurrence** – the severity and frequency of drought is a major factor in the cattle management system.

iv) **Size and heterogeneity of grazing area** - it is necessary for cattle to move over a sizeable area with varied grazing and water resources. The model showed that when the seasonal grazing decreased, the carrying capacity also decreased.

v) **Livestock water availability** - the livestock sector uses the highest volume of water in the country (Figure 9.1). The demand will decrease in relative terms to 23 percent by 2000, which will still be the highest, and as much as the demand in urban areas (Makosha, 1994). Because there is a dearth of surface water sources, most of the livestock water is from boreholes.

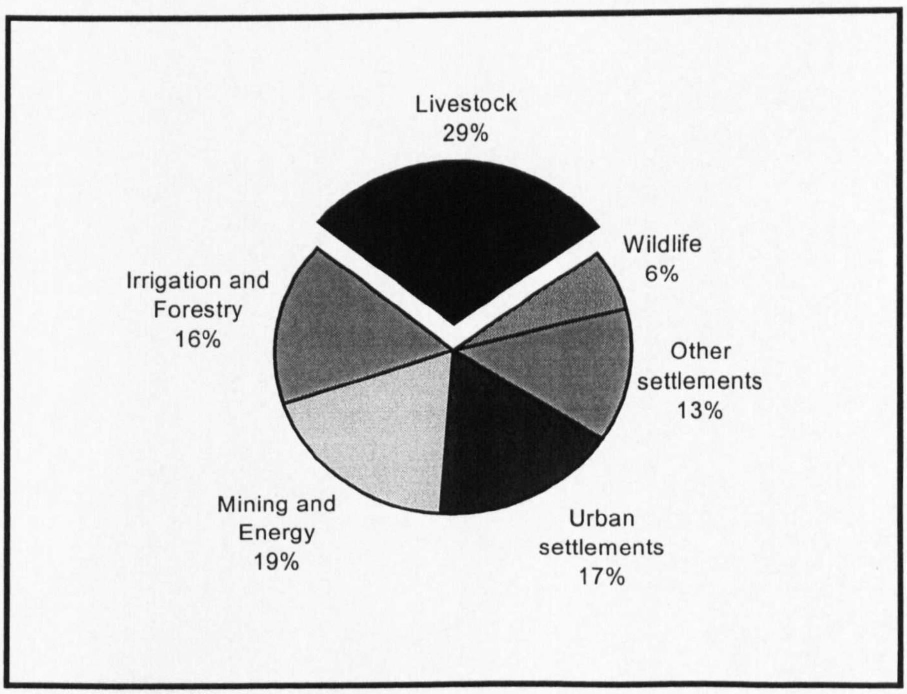

Figure 9.1 Botswana National Water Demand in 1990
Source: Makosha, 1994.

There are 14 000 boreholes in the country (Ministry of Finance and Development Planning, 1991). The sustainable rate of borehole water extraction in Botswana is undetermined. There is 100 000 million m^3 of groundwater, 1 percent of which is rechargeable (Khupe, 1994). In future, livestock water, not forage, will be a limiting factor for cattle management. The livestock water availability parameter in the model indicates areas with a water scarcity and those without.

Sustainable cattle management in the area depends on the household management practices which have been internalised over a long period of time. The critical management practise is the use of seasonal grazing but other practices are movement to the Notwane River and out of the district and supplementary feeding. The management strategies are opportunistic. The social responsibility of respecting the established norm of group fencing in the arable area is a critical factor to the sustainability of cattle management in the study area. If the norm disintegrates, Tlokweng sub - district is most unlikely to continue with the present cattle management practises. In Section 2.6 it was noted that the Land Board had allocated cattleposts and boreholes in a farm bought by the community to alleviate the grazing pressure. Although a few farmers were aware of the consequences of the Land Board action, most were not. The majority interviewed still believed that the Tribal Farm at Majeadikgokong was for Batlokwa and complained that it was trespassed by cattle from Kgatleng District. The Land Boards allocation of cattle post and boreholes has alienated most households with cattle who do not have a water point in Majeadikgokong especially during drought when Hekeng and Modipe water points are dry.

9.4 Integrating the Findings to Research Objectives

The rainfall prediction, household management strategies and the land use dynamics are well represented in the Rain Land Cattle model described in Chapter 6. The Rain Land Cattle model produced different scenarios for the sustainability of cattle management in Tlokweng Sub District. For most scenarios, cattle numbers fluctuate between 1 000 to 3 000. The number of cattle was arrived at despite uncertain values for some cattle management parameters. The model achieved the objectives of the study, which was to assess the sustainability of cattle management in the study area. Historically, the study area once held 6 000 cattle (see Section 2.2.1), but now holds only half the number. The decrease was caused by several factors the most important of which was the grazing land loss. The model captured the effect of the grazing land loss quite well to prove the research hypothesis 2 and research objective 4.

There is a strong case for efficient and effective (Brown, undated) application of the present cattle management in Tlokweng Sub District, rather than a new management. Brown's concepts, adopted from business operation, for cattle management in this study. Brown (undated) defined efficient management as doing things right in contrast to effective management, which is doing the right thing. This means effective describes what is done, a strategy, and efficient describes how it is done, operation (Table 9.2). An efficient strategy may be ineffectively implemented and vice versa. The cattle management system will survive when an effective policy is inefficiently managed, but an ineffective management will kill a system irrespective of its management efficiency (Brown, undated). Table 9.2 shows what a combination of the different strategies and operations mean for cattle management in the study area. Seasonal grazing in the arable area is an effective management strategy because the permanent grazing area is rested and cattle utilise the stalks left after harvesting the fields when there is no grazing elsewhere. Efficiency means making sure that the cattle are not in the seasonal grazing before harvesting or after ploughing. It also means the seasonal grazing is available for grazing after harvesting.

Table 9.2 Implications of Cattle Management Efficiency and Effectiveness in Tlokweng Sub District

Operation	Strategy	
	Effective	Ineffective
Efficient	• the timely availability of the seasonal grazing • enables seasonal and permanent grazing to recuperate • best long term prospect for cattle production	• no seasonal grazing • cattle move randomly to any grazing areas • deterioration of the grazing areas • cattle in poor condition and may die
Inefficient	• cattle enter seasonal grazing area after ploughing and before harvesting • poor crop harvest • poor forage in seasonal and permanent grazing area • cattle survive but vulnerable to future grazing shortage	• cattle graze anywhere anytime • grazing depleted quickly every season • poor rangeland recovery • crop damage in the arable area • cattle die quickly

Source: Adapted from Brown, undated.

During the fieldwork there were reports that cattle trespassed into the arable grazing before harvesting. When households fence fields for private use the communal management becomes ineffective. Another source of ineffectiveness is the permanent grazing land loss due to the allocation of non grazing land uses. The two sources of ineffectiveness in the seasonal grazing will cause the Tlokweng Sub District communal grazing to collapse, irrespective of the efficiency of the management. For example, the cattle management system will collapse if over half the seasonal grazing area is individually fenced, irrespective of how efficiently the cattle are kept out the arable area. This observation answers Hypothesis 1. Tlokweng Sub District has survived the land pressure todate because of the effectiveness of its cattle management strategy. When cattle enter the seasonal grazing at the wrong time, the cattle management strategy becomes inefficient. An inefficient and ineffective cattle management strategy will destroy the rangeland in the area, cause the death of many cattle and adversely affect the arable area. Table 9.2 shows that the effectiveness and efficiency of the Tlokweng Sub District's cattle management determines the sustainability of the system. Cattle farmers are aware of the effectiveness of their cattle management strategy and worried about the inefficiency that threatens its survival. Those with large herds have moved out of the study area because they stand to lose most. The small cattle owners' response will be a number of mixed strategies.

The findings that seasonal grazing is vital to the future of cattle production will reinforce the farmers' determination to preserve seasonal grazing. The passive resistance to individually fenced fields will change to a formal objection. However there will be a conflict between the 1928 traditional cattle management of communally fenced fields and the individual rights bestowed to the field owner by the Tribal Land Act of 1970 (see Section 1.4.2). The Tribal Land Act of 1970 gives the field owners the right to manage their land in the way they think will best suit their production goals. The other worrying factor to most farmers is the NPAD. If more fences are put up, the farmers fear that their land will be taken up by the few with access to water sources. Practically, during the study it was clear that the NPAD's best chances of success in the area is to reinforce the existing fencing policy rather than delineate new grazing areas. This finding meets the research objective 4. This conclusion is based on the findings of Sections 4.3 which shows the livestock water distribution, Sections 7.4 to 7.8, which shows the household management strategies and the simulated effects of the different strategies. The Sections 7.6 and 7.8 also address research objective 1.

A projection of 9 wet and 9 dry years was made from the 1982 - 1991 dry season, using the rainfall cycle for Southern Africa described by Tyson (1987) which is relevant to eastern Botswana (Cooke, 1978). The projection shows that a period of dry years is very likely during the first five years of the 2000's. This study will encourage the policy makers and households to reactivate the stalled development of Mmamogofu Water scheme. If the water situation in the study area is not improved, the impending dry period and land pressure will have severe negative consequences on the cattle production of the area. It is not recommended to introduce the NPAD fencing just before the likely drought, since it is likely to exacerbate the household's cattle losses. Data on livestock water availability should identify high risk areas in other parts of the country, when the dry period arrives. Those administrative districts which do not have access to the model can use the LW Months Density as a static measure indicated on a map. The concept is useful even when it is not on a dynamic model.

9.5 The Way Forward

The model demonstrated how a system dynamics model describes and assesses cattle management options in a communal area. A follow up study could look at how to integrate the model into a Geographic Information System (GIS) software. The integration would add a spatial dimension to the current temporal output. GIS outputs communicate the cattle management dynamics better than non spatial outputs. The resolution of GIS data should strike a balance between costly data collection, storage and manipulation, which is not useful for management on the one hand, and highly generalised but affordable data on the other, which are practically useless. Large districts, such as the Central District (see Table 2.1), would incur a high cost for data collection and storage if the scale were too large.

This study has four policy implications. Firstly, heterogeneous cattle producing landscapes should take advantage of their heterogeneity in order to be successful. The further development of fenced communal grazing under the auspices of the NPAD, which is part of the mainstream cattle management theory, is not relevant for the study area because of its variable rainfall (Table 3.1), among other factors. This study shows how communal cattle management strategies respond to change in rainfall and grazing land availability. Secondly, the rainfall cycle and amount are the major factors considered for local cattle management strategies. The various livestock water sources and grazing areas used, including moving out of the study area, are examples of how the rain affects the local management. Thirdly, areas with variable rangeland resources need a local strategy to implement a national cattle management policy. The local strategies for the different areas will be based on the local conditions. For example, in Tlokweng Sub District the NPAD should help to improve the efficiency and maintain the effectiveness of the present cattle management system. The Rain Land Cattle model is a first attempt to develop a methodology to determine the local strategy suitable for a communal area. Fourthly, the quantitative outputs of the model enable effective cattle management because they are objective. Although the model outputs are objective, the study included the people's views. The model optimises the use of data from different government departments. The data quality, reliability and cost effectiveness improves because it serves a practical purpose, and loopholes are quickly and easily noticed. Cattle data for a number of years were missing during the survey despite the annual data compilation exercise. Collecting data for the sake of data collecting is not cost effective. The Rain Land model will need to be validated hence a specific data need is created.

Summary

This chapter crystallised the various benefits of using the Rain Land Cattle model. The Rain Land Cattle model is used to describe and predict the behaviour of cattle management under various conditions. It identifies the most sensitive parameters for management control which are grazing capacity, grazing land loss, and offtake (Table 7.3). The Rain Land Cattle model is dynamic, pragmatic, simple, adaptable and compatible with current data sources. It integrates data on households' cattle management strategies and the physical attributes of the area. The study shows that new thinking in cattle management is applicable to Tlokweng Sub District. The study area has an effective cattle management strategy that needs to be efficiently operated. The grazing land and livestock water availability determines sustainable cattle production in the study area. The model will enable cost effective data collection. When a GIS database is included, the model will show spatial as well as temporal aspects.

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Appendix 1

Dairy Farms Allocated in Tlokweng Tribal Land 1982-1995

Serial No	Allocation Date	Locality	Area of Farm (Ha)
40	13/09/82	Lemonyaneng	6.0
45	30/10/85	Sefoke	0.52
6	16/10/87	Sefoke	0.5
39	16/05/88	Ramokobetwane	0.5
46	12/7/89	Maratadiba	0.68
38	14/03/90	Lenganeng	0.5
1	19/07/90	Lemonyaneng	1.5
44	13/11/90	Terateng	1.5
7	14/01/91	Maratadiba	0.25
8	14/01/91	Maratadiba	0.25
10	14/05/91	Sefoke	1.5
9	14/05/91	Terateng	1.5
11	08/07/91	Terateng	1.5
42	09/09/91	Ramokobetwane	Not available
41	09/9/91	Mmamogofu	Not available
43	11/11/91	Mmamogofu	Not available
12	19/11/91	Maratadiba	0.485
2	13/01/92	Ramokobetwane	0.53
3	13/01/92	Ramokobetwane	0.53
5	14/01/92	Maratadiba	0.5
4	14/01/92	Terateng	0.5
37	09/03/92	Maratadiba	0.25
13	09/03/92	Maratadiba	0.5
14	09/03/92	Maratadiba	0.5
15	11/03/92	Diphiring	0.25
16	12/05/92	Sefoke	0.5
17	12/05/92	Sefoke	0.5
18	13/05/92	Diphiring	0.5
19	14/07/92	Mosonngwa	0.5
22	23/03/93	Maratadiba	0.5
21	29/07/93	Maratadiba	0.5
20	30/07/93	Lemonyaneng	0.5
23	08/11/93	Lemonyaneng	0.5
24	10/01/94	Mmamogofu	0.5
25	11/1/94	Maratadiba	0.5
35	22/03/94	Ramokobetwane	0.5
26	09/5/94	Maratadiba	0.5
36	10/05/94	Mmamogofu	0.25
27	20/05/94	Lemonyaneng	0.5
28	15/07/94	Ramokobetwane	0.5
29	27/07/94	Selokwane	0.3
31	04/10/94	Radipotsanyane	0.5
30	05/10/94	Diphiring	0.5
32	06/03/95	Matlakaneng	0.5
33	14/03/95	Mmamogofu	0.12
34	14/03/95	Mmamogofu	0.5
			30.415

Source: Tlokweng Sub District Development Officer, Unpublished Mimeo.

Appendix 2

QUESTIONNAIRE FOR LIVESTOCK MANAGEMENT SURVEY

Respondents Identity

1. Relationship to the head of household

sibling	spouse	herder	head	other

2. Age of respondent /// years

3. Length of stay in the area /// years

4. Sex /M/F/

PPU's background information

5. Identity of livestock herd (to correspond with codes on maps)

Code number	Locality Name

6. Number and types of livestock held by PPU

Livestock type	Number
Cattle	
Goats	
Sheep	
Donkeys and horses	
Others (specify)	

7. Any other livestock owned at different location /Yes/No/

PPU's involvement in arable agriculture

8. Does your household have a field? /Yes/No/

9. Where is the field (locality name)

10. What is the size of the field(s) which you regularly plough?

11. Do you consider your agricultural field to be important for your pastoral activity?

/Yes/No/

12. Give reasons for answer on Q11

Grazing management strategies

13. What are the grazing area for the different livestock during drought (locality names)

Livestock	Grazing
Cattle	
Goats	
Sheep	
Donkeys and horses	
other	

14. Describe five most significant characteristics about your livestock grazing areas(s)

Livestock	Grazing
Cattle	
Goats	
Sheep	
Donkeys and horses	
other	

15. Management strategies used during periods of grazing shortage

Strategy	Cattle	Goats	Sheep	Don + horses	others
Move					
Supplement					
Sell					
Govt help					
Do nothing					
Other					

16. Detail of the most popular grazing strategy used during grazing shortage (identified in Q15)

Why is it adopted	
Frequency of use	
Cost to the PPU	
How convenient is it	
Labour demand	
Other reasons	

17. Explain your reasons in Q16

Livestock water management strategies (use place names where possible)

18. Type of livestock water point most frequently used during drought e.g. borehole, dam, well, etc.

Livestock	Drought water source
Cattle	
Goats	
Sheep	
Donkeys + horses	
Others (specify)	

19. What water sources are normally used at other times?

20. Ownership of water sources used per livestock type

Water point for	Drought
Cattle	
Goats	
Sheep	
Donkeys + horses	

21. What arrangements exist for the use of non communal water sources during drought

Rent (amount)	
Joint operation and maintenance (amount)	
Other (specify)	

22. Describe significant characteristics of the non communal water sources using the headings below (indicate yes/no)

Water source for	Reliable	Convenient	Costly	other
Cattle				
Goats				
Sheep				
Don + horses				

23. Strategies used during periods of livestock water shortage (tick and note detail)

Strategy	Cattle	Goats	Sheep	Don/horse	others
Less water					
Move					
Deepen					
Cart					
Others (specify)					

24. Detail of most popular livestock water strategy used during water shortage

(identified in Q23 above)

Why is it adopted	
Frequency of use	
Cost to the PPU	
How convenient is it	
Labour demand	
Other reasons	

Livestock movement as a management strategy

25. Straight line distances to the various places utilised as indicated in questionnaire

Places	Cattle	Goats	Sheep	Don+hrs
Hstgrz				
Hstwtg				
Grzwtg				

(*Hst is homestead; grz is grazing; wtg is watering point*)

26. What is the distance between winter and summer grazing

27. Is there any other area used for grazing by the PPU?

28. Has there been any change in the pattern of your livestock movements in the communal grazing area? /Yes/No/

29. If yes over what period has the change occurred?

30. Elaborate on your answer to Q29

31. What causes the change?

32. Do you regard livestock movement an important management strategy in your area? /Yes/No/

33. Why is it important?

34. If yes to Q32, is the present livestock movement in you area adequate for good livestock management /Yes/No/

35. Why

36. If no to Q34, how do you think it can be improved?

Livestock outputs and PPU's Utilisation

37. PPU's livestock utilisation in the last 12 months (indicate no of livestock)

Utilisation	Cattle	Goat	Sheep	Don/horses	Assessment of utilisation
Slaughter					
Milk (qty)					
Sale					
Gift					
Stray					
Predator					
Died					
Draft					
Other					

38. Explain why there is the highest number in any utilisation category

39. How often do you sell livestock?

40. Elaborate on Q39

41. How many young did your livestock give birth to in the last 12 months

Livestock	Male	Female	Assessment of reproduction rate

42. Give reasons for your assessment of the reproduction rate

Fencing aspect of the National Policy on Agricultural Production

43. What do you know about the fencing aspect of the NPAD? (if nothing the interviewer must describe the fencing aspect of the policy to the interviewee)

44. What are your views concerning the suggestion to fence off part of the grazing in your communal grazing area?

45. What you would be the three most important steps that you would take to improve the productivity of the livestock in your communal area?

i)

ii)

iii)

46. Do you agree that there is a shortage of land for communal livestock management in your area? /Yes/ No/

47. If yes, what suggestions do you have to alleviate the land shortage?

48. Do you think that there is too much livestock in your communal area? /Yes/No/

49. Explain your answer to Q48

Appendix 3

Tlokweng Database Questionnaires Code Book

Ques no.	Fieldno	Field code	Response codes
serial no	1	1-80	not applicable
1	2	respndt	1 sibling 2 spouse 3 herder 4 head 5 other
2	3	age	1-100
3	4	lngthstay	1-100
4	5	sex	1 male 2 female
5	6	locality	204 mmamogofu 205 terateng 208 radipotsane 209 mabowana 210 ramokobetwane
[1]6	7	cattle	1-100
6	8	goats	1-100
6	9	sheep	1-100
7	10	other loclty	1 yes 2 no
8	11	fld ownship	1 yes 2 no
9	12	localty2	204, 205, 208, 209, 210 and elsewhere
10	13	tshimo	1-50 hectares 0-not available
10	14	lesope	1-50 0-not available
10	15	segotlo	1-50 0-not available
11	16	pstorl sign	1 yes 2 no 9 n/a
12	17	reason	1 winter grazing 2 supplementary feeding 3 harvest + feed byproducts 4 sell harvest to buy cattle feed

[1] 99 for unknown herdsize

			5 for human consumption only 6 don't plough regularly 7 limited crops due to drought 8 keep livestock from fields 9 not applicable/no livestock 10 keep livestock at Tlokweng 11 prevent livestock from feeding on crop residue 12 never feed livestock on crop residue 2+3=13 14 others 15 livetsock kept elsewhere 3+4=16
13	18	cattlemgt	1 supplementary feeding 2 move to another area 3 sell livestock 4 remain where they are 5 Egepeto 6 Diphiring 7 Kgatleng district 8 other areas 9 not applicable 10 grazing along the river 11 Tlokweng village 12 Modipe farm 13= 5+8 14 l'stock not managed by HH
13	19	goatmgt	(as in ctlmgt above)

14	20	chrcter grz	(prefix 1 cattle;2 goats; 3 sheep; 4 cattle and goats) 1 deteriorated/ overgrazed 2 good grazing 3 ngotwane river grazing 4 poor herding 5 grzg far from fields 6 serious stock theft 7 = 1+4 8 = 2+5 9 n\a 10 nearby convenient for herding 12=2+3 13=2+11 14=1+2 15 good but limited grazing area
15	21	shortage-grz	(prefix 1 cattle;2 goats; 3 sheep; 4 cattle+goats) 1 move 2 supplement 3 sell 4 do nothing 1+2=5 (or 8 to be deleted) 6 graze along Notwane river 7 other strategies 8 = 2+3 10= 1+2+3
16	22	why adopted	1 livestock survival 2 livestock improvement 3 due to poor grazing 4 better grazing elsewhere 5 use crop residue 6 help herding 7 no access to winter stalk grazing 2+6 =8 99 not applicable 10 too few l'stock/cant afford alternatives

16	23	usefrqcy	1 as frequently as necessary 2 once a month 3 every year 4 rarely 5 don't know 6 when possible 7 continuous 8 drought 99 not applicable
16	24	ppucost	1 bag *moroko* 2 other supplements 3 moroko + other supplements 4 crop residues 5 not known 6 nothing 7 sell to finance supp feeding 8 P1500 per year 99 n\a *(110.0 means moroko cost P10 per bag)*
16	25	con vinience	1 keep livestock healthy 2 keep livestock from straying 3 hh own source of supplements 4 =1+2 5 HH can not afford better 6 not convenient at all 7 reduces risk of livestock losses(join with 2) 8 a lot of transport needed due to distance *(11 means moroko keep livestock healthy)*
16	26	labour demand	1 family labour only 2 more labour needed 0 none
16	27	othrens	-------

18	28	cattle water	<u>code prefix</u> <u>code suffix</u> 1 borehole 1 Lephala 2 dam/waterhole 2 MMakgaila 3 river 3 Mabutswe/sef 4 cart water 4 Ngotwane 5 sewage pond 5 Petros 6 HH tap 6 Tlokweng 7 Elsewhere (21 is dam at Mmamogofu) 8 no other sources 50=21+13 51=23+25+34 52=46+12
18	29	gotwater	(as in field 28 above)
19	30	othrwtr	(as in field 28 above*)*
20	31 (refers to qstn 18 only)	ctlwtrown	1 communal 2 syndicate hh is member 3 syndicate hh is not member 4 local government 5 private 6=4+1 7=1+5 9 not applicable
20	32	gotwtrown	(as in field 31 above*)*
21	33	rentwater *(joining+ mmbership fee)*	1 P10 per 210 litres drum 2 P1 per beast per month 3 P2 per cow per month 4 refer to questionnaire 5 P10.00 per beast p.a. 6 P70 p.a. 7 don't know/ have forgotten 8 P200 per HH 9 not applicable 10 other figures 11 depends on HH water requirements 12 P100 per HH 13 bought borehole for P65000

21	34	opercost (m'tenncecost only)	1 P100 per year 2 P50 per month 3 P10 per day for hired labour to drive cattle to water point 4 depends on repairs cost 5 own vehicle (cost not known) 6 P10 per 210 litres 7 P210 per year 8 P30 per HH per year
22	35	how catwatr (dry season source*)*	1 reliable 2 convenient 3 costly 4 not reliable 5 not convenient 6 not costly 7= 1+2 8= 1+2+6 99 n/a 10=1+5+6 11= 1+2+3 12=1+5+3 13=4+5+6
22	36	how gotwatr	*(as in field 35 above)*
23	37	cat wterstr	1 less water 2 move 3 cart 4 other 5= 1+2 6= water as usual 7=1+3 8=1+4 9 n/a 10=2+4
23	38	got wterstr	*(as in field 37 above)*

24	39	whyadopt	1 avoid livestock deaths 2 shortage of labour 3 use available river water 4 financial problems 5 use various sources 6 long distance to water 7 no alternatives available 8 nearby free and always available 9 n/a 10 use source where we are accepted
24	40	usefrequency	1 daily watering 2 as frequently as possible 3 twice a week 4 only when necessary 5 every year 6 3x per week 7 2x in past 5 years 99 not known/not applicable
24	41	watercost *(xcheck* quest21)	1 not assessed/ don't know 2 none 3 P10 per drum 4 see field 33 and 34 5 varies according to HH meter reading 6 P20 per 210 litre drum 7 depends on livestock nos
24	42	con vinience	1 cumbersome 2 very near us 3 far from us 4 acceptable 5 inconvenient to hire vehicles 6 water is a health hazard 7 herding technique
24	43	labour	1 hh labour adequate 2 hired labour 3 other labour available
26	44	catdist (to be measured on maps later)	use xx until map measurements are done
26	45	goatdist	use xx until map measurements are done
27	46	other grazing	1 yes 2 no

28	47	grzchange	1 yes 2 no 3 don't know
29	48	chngtime	1 since road was built 2 very recently 3 over 5 yrs ago 9 n/a
30	49	elaborate	1 never changed movement 2 road prevents movement 3 deterioration due to drought 4 small grazing cant move 5 moved livestock from village 6 moved away from lands area 7 don't know about change 8 arable fields encroach grazing 99 n/a 10 no herding/ cattle not kraaled at night 11 small govt dams cause difference 12 l'stock moved into field before harvesting 13 fenced fields restrict access to l'stock 14 long distance to grazing
31	50	chnge cause	1 road changed movement 2 drought 3 problems in village 4 better grazing at Modipe 5 increasing demand for land 6 no herdboys 7 people moved out 8 reliable water 99 n/a 10 no land overseeers 11 selfishness
32	51	movesigf	1 yes 2 no 9 n/a

33	52	why signifc	1 arable area grazing recovers well before grazed 2 avoid road livestock hit by vehicles 3 move to better grazing 4 fence stops livestock from straying 5 better use of grazing in our area 6 keep them away from village 7 good feed from grain stalk 8 overgrazing evident 9 n/a 10 mobility along river grzg is important 11 access to water during drought 12=5+11
34	53	mov adquate	1 yes 2 no 3 don't know
35	54	why adequate	1 overgrazing visible 2 increasing grazing pressure 3 avoids road 4 go to better grazing 5 few cattle in the area 6 used to limited land 7 = 1+2 8 there is enough grazing 10 movement allows more grazing 11 livestock damages crops 12 limited land 13 enough room for livestock 14 other reasons 15 l'stock do not go far even with limited grazing
36	55	can improve	1 yes 2 no 3 don't know
37	56	catslter	insert no (99 for l'stock not kept by HH just like HH w'out livestock*)*
37	57	gotslater	"
37	58	catsale	"
37	59	goatsale	"
37	60	catstray	"
37	61	gotstray	"
37	62	catpredt	"
37	63	gotpredt	"
37	64	catdied	"
37	65	gotdied	"

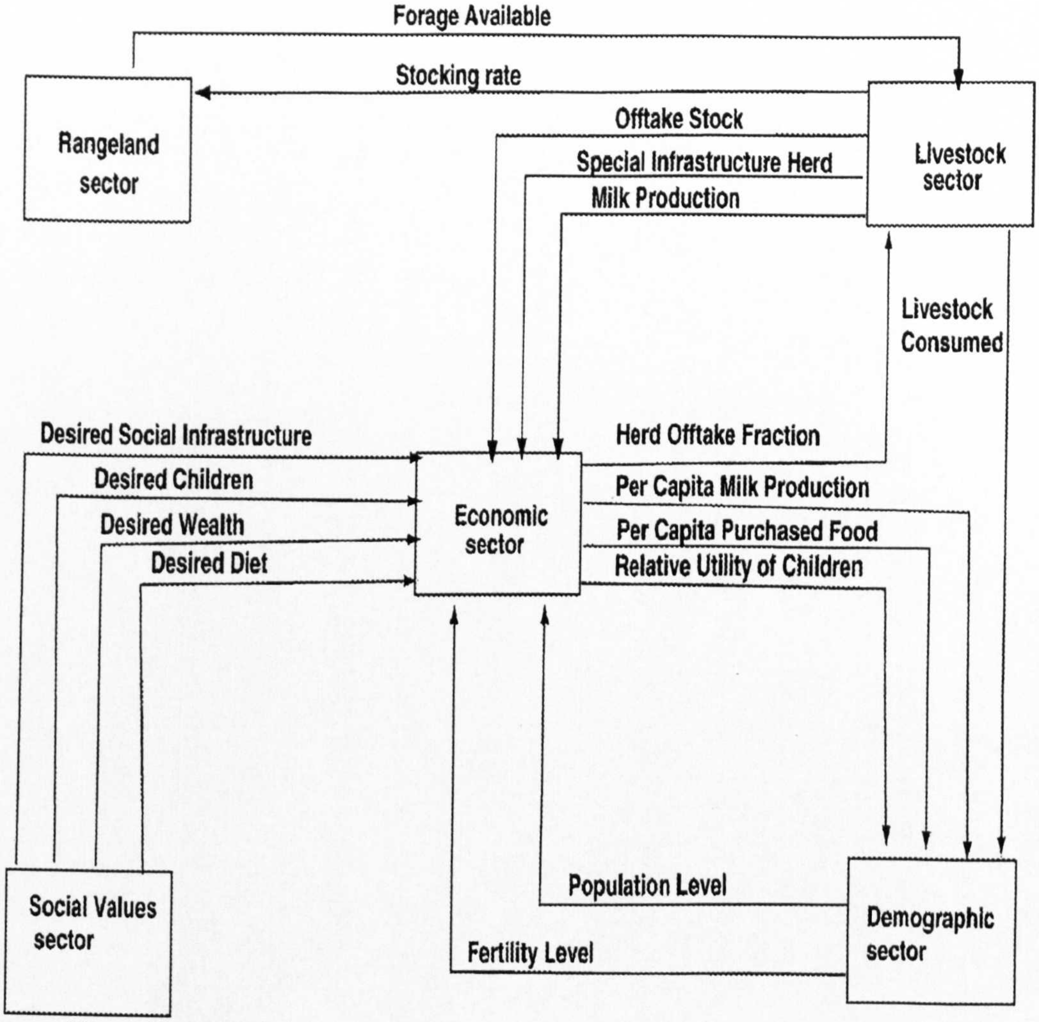
38	66	why utilise	1 no herdboy 2 disease outbreak 3 hit by vehicles on the road 4 fox is a nuisance 5 sell to buy supp feeding 6 stolen livestock 7 killed by people 8 cattle stray into Gaborone city 10 HH consunption 11 sell old cows 12 other reasons 13 too few 14=6+4 15 livestock go astray after rains
39	67	salefrqcy	1 none 2 when necessary 3 when nos accumulated 4 sell young as business 5 rarely 6 if there is a good buyer 7=2+6 8 2 per year
40	68	why salefrq	1 too few to sell 2 try to accumulate livestock 3 for hh consumption only 4 to buy supp feeding 5 prefer exchanging males for females 6 must sell profitably 7 have other sources of income 8 when ready to sell 9 n/a 10 for HH cash requirements
41	69	young cattle	1 don't know 2 *(give a number*) 99 not applicable
41	70	younggoat	(same as field 69 above)
42	71	reprod rate	prefix suffix 1 cattle 1 very good 2 goats 2 satisfactory 3 sheep 3 poor 1+2=4 *(13 means poor reproduction rate for cattle)*

43	72	knowNPAD	1 yes 2 no
44	73	view fencng	1 not feasible land limited 2 may be useful 3 may cause landlessness 4 we have fenced already 5 may cause land destruction 7=1+3 8=4+5 9n/a 10 don't know how it affects land 11=1+4
45	74	produc tivity	1 better breeds 2 supplements 3 reliable convenient water 4 improve herding practise 5 control predators 6 don't know 7 = 1+2 8 = 2+5 10 more land+castrate poor breeds 11 control movement from outside farm 12 other practices 13=1+3 14 kraal cattle at night 15= 14+3 16= 12+3 17= 3+4
46	75	land shrtge	1 yes 2 no
47	76	soln shrtge	1 move outside district 2 intensify supp feeding 3 limit Gaborone growth 4 don't know what to do 5 kraal livestock at night 6 limit livestock herds 7 claim back land lost to neighbouring districts 8 no solution 9 n/a 10 others
48	77	lvstk 2much	1 yes 2 no 3 don't know

49	78	explain ans	1 there is overgrazing 2 crowded by lvstck from elsewhere 3 now lvstck fewer than before 4 Batlokwa keep limited lvstck 5 problems only due to drought 6 area has small lvstck herd 7 need to separate grazing from homesteads 8 men know better 99 n/a 10 limited land 11 kraal cattle at night 12 communal farm is crowded 13 too much livestock 14 other reasons 15 grazing lost to other landuses

Appendix 4

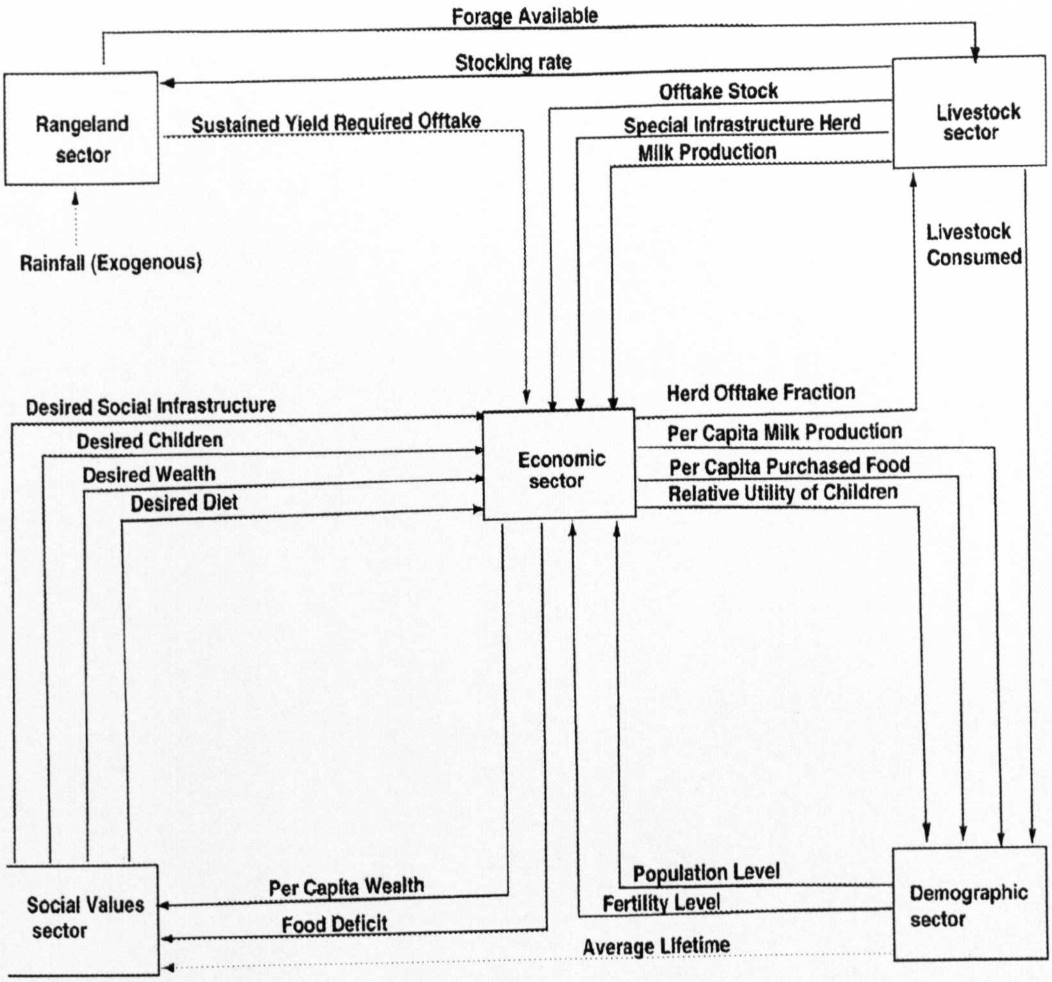
ECNOMAD3



Source: *Picardi*, 1975

Appendix 5

SOCIOMAD



Source: Picardi, 1975

Appendix 6

The Formulas Used in the Rain Land Cattle Model (in Alphabetical Order)

CATTLE(t) = CATTLE(t - dt) + (Births + Purchase - Offtake - NatDeath - Emigration) * dt
INIT CATTLE = 1000
INFLOWS:
Births = Birate*CATTLE
Purchase = 0.025*CATTLE
OUTFLOWS:
Offtake = CATTLE*Offtake_Rate
NatDeath = CATTLE*ND_rate
Emigration = 0*CATTLE

DELAYED_Rain1(t) = DELAYED_Rain1(t - dt) + (Del_Rf1 - DRAIN1) * dt
INIT DELAYED_Rain1 = Rainfall
INFLOWS:
Del_Rf1 = Rainfall
OUTFLOWS:
DRAIN1 = DELAYED_Rain1

DELAYED_Rain2(t) = DELAYED_Rain2(t - dt) + (Del_Rf2 - DRAIN2) * dt
INIT DELAYED_Rain2 = DELAYED_Rain1
INFLOWS:
Del_Rf2 = DELAYED_Rain1
OUTFLOWS:
DRAIN2 = DELAYED_Rain2

DEL_STrate(t) = DEL_STrate(t - dt) + (Inrate - Outrate) * dt
INIT DEL_STrate = ST_Rate
INFLOWS:
Inrate = ST_Rate
OUTFLOWS:
Outrate = DEL_Strate

Permanent_Grazing(t) = Permanent_Grazing(t - dt) + (- GrazeLandloss_fraction) * dt
INIT Permanent_Grazing = 100
OUTFLOWS:
GrazeLandloss_fraction = 0.005*Permanent_Grazing
Birate = 0.23*R1

Boreholes = (5*8)

BRCI = (8*Rainfall+4*DELAYED_Rain1+2*DELAYED_Rain2)/8

CarryCap = ((Rf_Factor*GrazeCap)+(ST_Factor*GrazeCap))/2

cat2
IF(RfMultiple=0.5)THEN(1*6*0.5)ELSE(IF(RfMultiple=1)THEN(1*6*1)ELSE(1*6*1.5))

cat3 =
IF(RfMultiple=0.5)THEN(4*4*0.5)ELSE(IF(RfMultiple=1.0)THEN(4*4*1)ELSE(4*4*1.5))

cat4 =
IF(RfMultiple=0.5)THEN(3*2*0.5)ELSE(IF(RfMultiple=1.0)THEN(3*2*1)ELSE(3*2*1.5))

catLSU = CATTLE*0.7

CCWA_Ratio = LW_Months_Density/CarryCap

GrazeCap = 12.5

LW_Months = (Boreholes+Notwane_P'rnial+cat2+cat3+cat4+Notwane_S'snal)

LW_Months_Density = (TotalGrazing/LW_Months)

ND_rate = .10*R2

NormalisedCCWA = (1/CCWA_Ratio)*100

Notwane_P'rnial = 1*8

Notwane_S'snal =
IF(RfMultiple=0.5)THEN(2*2*0.5)ELSE(IF(RfMultiple=1.0)THEN(2*2*1)ELSE(2*2*1.5))

Offtake_Rate = .08

Rainfall = 520+AutoRegress+MA3+Stochastic

RfMultiple =
IF(RF_Weighted>975)THEN(1.5)ELSE(IF(RF_Weighted<675)THEN(0.5)ELSE(1))

RF_Weighted = (Rainfall+0.5*DELAYED_Rain1)

Seasonal_Grazing = STEP(50,1945.5)-STEP(50,1945.83)+STEP(50,1946.5)-STEP(50,1946.83)+STEP(50,1947.5)-STEP(50,1947.83)+STEP(50,1948.5)-STEP(50,1948.83)+STEP(50,1949.5)-STEP(50,1949.83)+STEP(50,1950.5)-STEP(50,1950.83)+STEP(50,1951.5)-STEP(50,1951.83)+STEP(50,1952.5)-STEP(50,1952.83)+STEP(50,1953.5)-STEP(50,1953.83)+STEP(50,1954.5)-STEP(50,1954.83)+STEP(50,1955.5)-STEP(50,1955.83)+STEP(50,1956.5)-STEP(50,1956.83)+STEP(50,1957.5)-STEP(50,1957.83)+STEP(50,1958.5)-STEP(50,1958.83)+STEP(50,1959.5)-STEP(50,1959.83)+STEP(50,1960.5)-STEP(50,1960.83)+STEP(50,1961.5)-STEP(50,1961.83)+STEP(50,1962.5)-

STEP(50,1962.83)+STEP(50,1963.5)-STEP(50,1963.83)+STEP(50,1964.5)-
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STEP(50,1990.83)+STEP(50,1991.5)-STEP(50,1991.83)+STEP(50,1992.5)-
STEP(50,1992.83)+STEP(50,1993.5)-STEP(50,1993.83)+STEP(50,1994.5)-
STEP(50,1994.83)+STEP(50,1995.5)-STEP(50,1995.83)

Stochastic = NORMAL(0,117.2,1000)

Stocking Ratio = (ST_Rate/CarryCap)*100

ST_Rate = TotalGrazing/catLSU

St_Weighted = (ST_Rate+0.5*DEL_STrate)

TotalGrazing = Seasonal_Grazing+Permanent_Grazing*100

AutoRegress = GRAPH(TIME)
(1945, 0.00), (1946, 0.00), (1947, 0.00), (1948, -21.0), (1949, -65.7), (1950, -0.307), (1951, 4.73), (1952, -3.72), (1953, -39.9), (1954, -54.9), (1955, -75.3), (1956, 61.3), (1957, 109), (1958, 40.7), (1959, 68.1), (1960, 10.1), (1961, -58.3), (1962, -19.9), (1963, -49.6), (1964, -93.7), (1965, -111), (1966, -106), (1967, -74.2), (1968, 114), (1969, 170), (1970, -18.2), (1972, -60.3), (1973, -52.1), (1974, 31.5), (1975, -18.4), (1976, 49.3), (1977, 164), (1978, 192), (1979, 202), (1980, 121), (1981, 80.3), (1982, -0.209), (1983, 67.0), (1984, 82.8), (1985, -52.8), (1986, -148), (1987, -180), (1988, -151), (1989, -55.0), (1990, -7.31), (1991, 125), (1992, 51.6), (1993, -23.3), (1994, 33.8), (1995, -106), (1996, -96.4), (1997, 0.00)

MA3 = GRAPH(TIME)
(1945, 0.00), (1946, 0.00), (1947, -56.9), (1948, -27.7), (1949, -21.5), (1950, 42.6), (1951, 4.95), (1952, -18.6), (1953, -81.9), (1954, -28.4), (1955, 77.8), (1956, 112), (1957, 86.3), (1958, -0.428), (1959, -50.0), (1960, -56.9), (1961, -67.3), (1962, -30.7), (1963, -64.9), (1964, -77.4), (1965, -80.5), (1966, 13.2), (1967, 180), (1968, 163), (1969, 37.2), (1970, -174), (1972, -65.9), (1973, 6.85), (1974, 39.8), (1975, 67.4), (1976, 122), (1977, 204), (1978, 103), (1979, 45.3), (1980, -75.0), (1981, -70.6), (1982, -0.633), (1983, 28.0), (1984, -51.8), (1985, -179), (1986, -201), (1987, -62.2), (1988, 2.72), (1989, 138), (1990, 154), (1991, 53.6), (1992, 12.6), (1993, -97.4), (1994, -64.5), (1995, -109), (1996, -8.08), (1997, 56.2)
R1 = GRAPH(CarryCap)

(5.00, 2.50), (7.50, 1.67), (10.0, 1.25), (12.5, 1.00), (15.0, 0.833), (17.5, 0.714), (20.0, 0.625), (22.5, 0.555), (25.0, 0.5), (27.5, 0.454), (30.0, 0.417)

R2 = GRAPH(CarryCap)
(5.00, 0.821), (7.50, 0.853), (10.0, 0.918), (12.5, 1.00), (15.0, 1.13), (17.5, 1.32), (20.0, 1.66), (22.5, 2.13), (25.0, 2.77), (27.5, 3.41), (30.0, 4.00)

Range_Factor = GRAPH(BRCI)
(100, 5.20), (185, 2.81), (270, 1.93), (355, 1.46), (440, 1.18), (525, 0.99), (610, 0.85), (695, 0.75), (780, 0.67), (865, 0.6), (950, 0.55)

ST_Factor = GRAPH(St_Weighted)
(10.0, 1.88), (11.5, 1.63), (13.0, 1.44), (14.5, 1.29), (16.0, 1.17), (17.5, 1.07), (19.0, 0.99), (20.5, 0.92), (22.0, 0.85), (23.5, 0.8), (25.0, 0.75)

Appendix 7

Calculating a Level Equation

In system dynamics, a level represents an accumulation of items (Section 5.4.1). The items could be rainfall, cattle. Because it is an accumulation, a level takes into account the numbers in the past in order to calculate those in the future. A level equation determines the amount of stock at the present time (t), based on the stock accumulated during the previous time (t – dt) and the rates of inflow and outflow during the time interval. "*In short what we have equals what we had plus what we have received less what we sent away*" Forrester (1961:76). The calculation will be demonstrated using three examples.

<u>Example 1 DELAYED RAIN1</u>

Rainfall Equation 6.3 shows:

DELAYED RAIN1(t) = DELAYED Rain1 (t-dt) + (Del RF1 - DRAIN1) x dt where:

DELAYED Rain1 (t) is the delayed rain at the present time

DELAYED Rain1(t - dt) is the delayed computed a time moment ago

(Del RF1 - DRAIN1) * dt is the difference between the inflow rate and out flow rate multiplied by the time over which the rates occur. Inflow (Del RF1) is last year's rainfall and outflow (DRAIN1) which is rainfall two years ago. dt is 1 year.

Tables 1, 2 and 3 show how a level equation works using data from the Rain Land Cattle model.

Table 1 Calculating the Delayed Rain1

Year	Delayed Rain1	Del RF 1	DRAIN1	Rainfall
1948	335.91	478.59	335.91	478.59
1949	478.59	492.48	478.59	492.48
1950	492.48	508.07	492.48	508.07

The 1950 DELAYED Rain1 is the product of:

i) DELAYED Rain1(t - dt) or Delayed rain in 1949 = 478.59

ii) Del RF1 or last year's (1949) rainfall, as inflow = 492.48

iii) DRAIN1, or rainfall two years ago, as outflow = 492. 48

DELAYED RAIN1 (t) is 478.59 + (492.48 – 478.59) = **492.48.**

Example 2 The DELAYED RAIN2

Rainfall Equation 6.4 shows:

DELAYED Rain2(t) = DELAYED Rain2 (t-dt) + (Del Rf2 – DRAIN2) * dt where:

DELAYED Rain2(t) is the DELAYED Rain2 at the present time

DELAYED Rain2 (t-dt) is the *DELAYED* Rain2 computed a time moment ago

(Del Rf2 – DRAIN2) * dt is the difference between the inflow rate and out flow rate multiplied by the time over which the rates occur. Inflow (Del Rf2) is rainfall three years ago and outflow (DRAIN2) which is rainfall four years ago.

Table 2 Calculating the Delayed Rain2

Year	Delayed Rain2	Del RF 2	DRAIN2	Rainfall
1948	654.82	335.91	654.82	478.59
1949	335.91	478.59	335.91	492.48
1950	478.59	492.48	478.59	508.07

The 1950 DELAYED Rain2 is the product of:

iv) DELAYED Rain 2(t - dt) or Delayed rain2 in 1949 = 335.91

v) Del RF2 or rainfall three years ago (1948) , as inflow = 478.59

vi) DRAIN2, or rainfall four years ago, as outflow = 335.91

DELAYED RAIN2 (t) is 335.91 + (478.59 – 335.91) = **478.59**.

Because the DELAYED Rain2 is delayed from DELAYED Rain1, it takes into account more years of rainfall than DELAYED Rain1 does.

Example 3 CATTLE

Cattle Equation 6.2 shows how the number of cattle at a given time is calculated. It states:

CATTLE (t) = CATTLE(t – dt) + (Births + Purchase – Offtake – NatDeath – Emigration) * dt

where:

CATTLE is the number of cattle at the present time

CATTLE (t – dt) is the number of cattle a moment ago, last year

Births, Purchase is the inflow, which represent cattle born and those bought

Offtake, NatDeath, Emigration is the outflow, which represents cattle sold, dead, or driven out of the study area

dt is one year

Table 3 Calculating the Number of Cattle

Year	Cattle	Births	Emigration	NatDeath	Offtake	Purchase
1945	1000	268.16	0	97.61	80	25
1946	1115.55	289.69	0	110.13	89.24	27.89
1947	1233.76	300.88	0	125.68	98.7	30.84
1948	1341.1	309.8	0	141.86	107.29	33.53
1949	1435.27	308.9	0	158.71	114.82	35.88
1950	1506.53	315.33	0	169.3	120.52	37.66

The number of Cattle in 1950 is the product of:

vii) CATTLE(t - dt), the number of cattle in 1949 = 1435.27

viii) Births and Purchases in 1949, as inflow, is 308.9 + 35.88 = 344.78

ix) Offtake, NatDeath and Emigration in 1949, as outflow, is 114.82 + 158.71 + 0 = 273.53

CATTLE (t) is 1435.27 + (344.78 – 273.53) = **1506.52**.

All level equations have the same format. For further detail on calculating level equations see Forrester, 1961; Coyle, 1977; Roberts *et al.*, 1983; Moffatt, 1991.

ID	question	respndtq	ageq2	lngthsta	sexq4	locality	cattleq6	goatsq6
1	48	4	65	36	2	205	0	4
3	49	3	60	40	2	205	0	10
4	50	1	23	23	1	205	20	6
5	51	4	87	30	1	205	0	7
7	52	4	75	75	1	205	20	12
8	53	4	78	51	2	205	0	20
9	54	4	63	17	2	205	2	10
10	55	4	71	71	1	205	0	92
11	56	4	63	63	1	205	17	46
12	57	1	54	55	2	205	0	0
13	58	4	72	5	1	205	0	6
14	59	5	55	6	2	210	0	0
15	60	4	49	10	1	210	0	18
16	61	4	70	70	2	210	6	23
17	62	4	42	42	1	210	0	0
18	63	4	63	63	1	210	125	150
19	64	1	58	58	2	210	0	14
20	65	4	82	44	1	210	30	31
21	66	4	68	68	2	210	14	0
22	67	4	93	33	1	210	26	48
23	68	4	68	68	2	210	30	50
24	69	1	31	31	1	210	0	31
25	70	3	46	15	1	210	60	50
26	71	4	70	70	1	210	0	0
27	72	5	73	73	2	210	0	0
28	73	4	63	63	1	210	0	0
29	74	4	89	60	1	210	46	10
30	75	4	71	71	1	210	5	6
31	76	4	76	76	1	210	21	5
32	77	4	71	71	1	210	8	0
33	78	4	57	57	1	210	0	0
34	79	4	71	37	1	210	6	20
35	80	4	80	80	2	210	0	0
36	81	4	64	24	1	210	30	40
37	82	1	47	57	1	209	60	12
38	83	4	78	78	1	209	42	33
39	84	4	57	36	1	209	19	26
40	85	4	69	69	1	209	15	15
41	86	4	54	54	1	209	20	50
42	87	4	66	13	1	209	0	0
43	88	4	62	25	1	209	0	0
44	89	4	69	22	2	209	40	12
45	90	4	61	61	1	209	30	50
46	1	4	70	70	1	208	5	5
47	2	4	70	70	1	208	18	16
48	3	2	62	62	2	208	30	0
49	4	4	63	19	1	208	0	7
50	5	4	70	70	2	208	3	0
51	6	4	63	44	2	208	5	0
52	7	5	48	1	1	208	15	10
53	8	4	64	64	1	208	6	17
54	9	4	94	94	2	208	0	0

ID	question	respndtq	ageq2	lngthsta	sexq4	locality	cattleq6	goatsq6
55	10	4	71	71	2	204	0	0
56	11	5	39	18	1	204	6	0
57	12	4	84	84	2	204	3	6
58	13	4	75	46	2	204	6	19
59	14	5	69	5	1	204	1	13
60	15	4	60	60	2	204	4	9
61	16	4	70	70	2	204	0	23
62	17	2	54	30	2	204	0	10
63	18	4	70	70	2	204	60	6
64	19	4	46	20	2	204	0	2
65	20	4	56	20	1	204	0	5
66	21	4	62	13	1	204	0	0
67	22	4	66	66	1	204	6	40
68	23	4	80	58	1	204	0	7
69	24	4	50	9	2	204	2	10
70	25	2	61	61	2	204	8	0
71	26	2	66	5	2	204	10	14
72	27	4	60	60	2	204	8	30
73	28	4	71	37	1	204	35	10
74	29	4	80	80	2	204	0	0
75	30	4	56	23	2	204	0	0
76	31	4	64	17	2	204	0	0
77	32	1	47	47	1	204	98	150
78	33	4	106	72	1	204	0	0
79	34	4	73	66	2	204	0	12
80	35	1	35	35	1	204	6	2
81	36	3	65	20	1	204	6	25
82	37	4	65	65	1	204	9	42
83	38	4	82	82	1	204	10	15
84	39	4	57	57	2	204	0	3
85	40	4	64	31	1	204	4	13
86	41	4	80	40	2	204	58	15
87	42	2	65	40	2	204	3	7
88	43	4	60	10	2	204	0	0
89	44	4	74	36	1	204	4	20
90	45	2	62	33	2	204	21	18

ID	sheepq6	otherloc	fldownsh	localty2	tshimoq1	lesopeq1	segotloq	pstorlsi
1	0	1	1	205	10	0	0	2
3	0	2	2	205	7	0	0	2
4	20	1	1	205	12	0	0	1
5	0	2	1	205	8	2	0	2
7	0	2	1	205	2	0	0	1
8	0	1	1	205	5	0	1	1
9	0	1	1	205	1	0	0	2
10	0	2		205	5	0	0	1
11	0	1	1	205	7	0	0	1
12	0	1	1	205	15	9	0	9
13	0	2	1	204	4	0	0	2
14	0	2	1	210	6	0	0	2
15	0	2	1	210	5	0	0	1
16	26	2	1	210	3	0	0	1
17	0	2	1	210	4	0	0	2
18	0	1	1	210	11	1	0	2
19	0	2	1	210	3	0	0	1
20	0	2	1	210	3	0	0	1
21	0	1	1	210	6	0	0	2
22	11	2	1	210	4	1	0	1
23	0	2	1	210	6	5	0	1
24	0	2	1	210	6	1	0	2
25	0	1	1	210	99	99	99	1
26	0	2	1	210	10	0	0	2
27	0	2	1	210	10	4	0	2
28	0	1	1	210	12	0	0	2
29	0	2	1	210	6	0	0	2
30	0	2	1	210	4	2	0	1
31	0	1	1	210	4	0	0	1
32	0	2	1	210	2	0	0	1
33	0	2	1	210	18	2	0	99
34	0	2	1	210	3	0	0	1
35	0	1	1	210	10	0	0	2
36	0	1	1	210	3	0	0	1
37	2	0	1	209	5	0	0	1
38	18	1	1	209	23	0	2	2
39	0	1	1	209	7	0	0	2
40	0	2	1	209	5	0	0	1
41	20	2	1	209	6	0	0	1
42	0	99	1	209	4	0	0	2
43	0	1	1	209	7	0	0	2
44	0	2	1	209	5	0	0	1
45	0	2	1	209	5	2	0	2
46	0	2	1	208	5	2	0	2
47	0	2	1	208	3	0	0	2
48	0	1	1	208	4	0	0	1
49	0	2	1	208	2	0	0	1
50	0	2	1	208	5	0	0	1
51	0	2	1	208	4	0	0	2
52	0	1	1	208	5	0	0	2
53	0	2	1	208	2	0	0	1
54	0	2	1	208	5	0	0	2

ID	sheepq6	otherloc	fldownsh	localty2	tshimoq1	lesopeq1	segotloq	pstorlsi
55	0	2	1	204	5	0	0	2
56	0	2	1	204	7	0	0	1
57	0	1	1	204	5	0	0	1
58	0	2	1	204	15	0	0	1
59	2	1	1	204	4	0	0	2
60	0	2	1	204	4	0	0	1
61	0	2	1	204	5	0	0	1
62	0	1	1	204	3	0	0	2
63	0	1	1	204	14	5	0	1
64	0	2	1	204	4	0	0	2
65	0	2	1	204	2	0	0	2
66	0	1	2	204	1	0	0	2
67	0	1	1	204	5	0	0	1
68	0	2	1	204	4	0	0	2
69	0	2	1	204	4	0	0	1
70	0	1	1	204	5	0	0	2
71	0	1	1	204	3	0	0	2
72	0	2	1	204	4	0	0	1
73	0	2	1	204	10	2	0	1
74	0	2	1	204	4	0	0	2
75	0	2	1	204	2	0	0	2
76	0	2	1	204	5	0	0	2
77	8	1	1	204	12	0	0	2
78	0	2	1	204	14	0	0	2
79	0	1	1	204	4	0	0	2
80	6	1	1	204	3	0	0	1
81	5	1	1	204	99	99	99	1
82	0	1	1	204	5	1	0	1
83	0	2	1	204	7	0	0	2
84	0	2	1	204	2	2	0	2
85	0	2	1	204	3	0	0	2
86	0	2	1	204	8	0	0	1
87	0	2	1	204	3	2	0	1
88	0	2	1	204	2	0	0	2
89	0	2	1	204	3	0	0	1
90	0	1	1	204	4	0	0	1

ID	reasonq1	cattlemg	goatmgtq	chrcterg	shortcat	shortgoa	whyadopt	C23usefr
1	11	99	10	15	99	4	99	99
3	5	99	4	2	99	4	10	3
4	3	5	4	2	2	2	3	1
5	8	99	4	2	99	2	10	3
7	1	4	1	15	2	2	1	1
8	3	99	4	15	99	2	6	8
9	8	6	11	15	99	99	10	3
10	1	99	4	22	99	2	1	3
11	1	6	4	22	8	2	1	1
12	9	99	99	99	99	99	99	99
13	12	99	4	2	99	2	2	4
14	9	99	99	99	99	99	99	99
15	16	99	4	1	99	8	1	4
16	16	4	4	2	2	2	1	4
17	9	99	99	99	99	99	99	99
18	15	8	8	2	1	2	2	7
19	2	99	4	2	99	2	11	3
20	16	4	4	2	8	2	2	3
21	15	4	99	99	8	99	99	99
22	3	4	4	16	8	2	1	8
23	13	4	4	15	2	2	1	10
24	12	99	4	17	99	2	4	1
25	17	4	4	42	2	2	1	1
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	15	99	99	99	99	99	99	99
29	12	4	4	2	4	4	12	3
30	16	4	4	2	4	4	1	3
31	2	7	4	12	5	2	4	4
32	4	12	99	42	2	99	6	7
33	99	99	99	99	99	99	99	99
34	1	4	1	2	2	2	13	1
35	15	99	99	99	99	99	99	99
36	17	4	4	2	8	2	13	8
37	13	12	12	2	8	2	14	1
38	15	8	4	99	1	2	99	99
39	10	11	16	3	2	2	2	1
40	3	4	4	2	4	4	12	99
41	3	4	4	1	2	2	2	7
42	99	99	99	99	99	99	9	99
43	15	99	99	99	99	99	99	99
44	3	12	4	2	10	10	2	7
45	14	4	4	41	2	2	1	1
46	5	4	4	17	2	2	1	2
47	5	4	4	1	2	2	3	3
48	3	6	99	8	10	99	15	5
49	12	99	4	26	99	2	5	3
50	3	4	99	2	2	99	1	1
51	5	5	0	3	6	99	10	1
52	14	7	6	8	1	6	13	7
53	1	4	4	41	2	2	3	1
54	9	99	99	99	99	99	99	99

ID	reasonq1	cattlemg	goatmgtq	chrcterg	shortcat	shortgoa	whyadopt	C23usefr
55	99	99	99	99	99	99	99	99
56	3	4	99	2	2	99	6	7
57	4	4	11	10	4	6	4	3
58	1	4	4	2	2	2	1	4
59	7	4	4	2	4	4	10	1
60	2	2	4	2	2	2	1	2
61	1	99	10	2	99	2	3	3
62	14	99	4	2	99	2	5	4
63	1	12	4	18	6	2	13	3
64	15	99	99	99	99	4	99	99
65	14	99	4	22	99	2	8	1
66	99	99	99	99	99	99	99	99
67	4	5	4	42	2	2	1	7
68	12	99	4	22	99	4	10	3
69	4	4	4	42	2	2	1	2
70	15	5	99	13	6	99	7	3
71	15	11	11	2	6	2	1	3
72	4	4	4	42	2	2	6	4
73	3	4	4	42	2	2	8	3
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	15	2	17	42	1	2	1	8
78	99	99	99	99	99	99	99	99
79	5	99	11	210	99	4	6	7
80	3	5	11	42	2	2	8	2
81	2	4	4	16	2	2	3	7
82	1	11	4	42	6	2	12	6
83	5	7	4	41	1	2	2	7
84	5	99	4	215	99	2	6	6
85	12	2	4	41	5	2	2	7
86	3	4	1	42	8	8	1	3
87	1	4	4	42	2	2	13	8
88	99	99	99	99	99	99	99	99
89	2	4	4	42	2	2	2	7
90	14	7	7	42	1	1	6	3

ID	ppucostq	convingr	labourde	othrensq	cattlewa	gotwater	catothrw	ctlwtrow
1	99	99	99	99	99	67	99	99
3	6	6	1	99	99	46	99	99
4	110	7	1	99	13	46	27	3
5	6	6	9	99	99	27	99	99
7	7	31	1	99	13	46	21	3
8	110	5	1	99	99	66	99	99
9	5	6	99	99	34	66	34	1
10	5	4	1	99	99	46	99	99
11	5	31	1	99	46	46	21	4
12	99	99	99	99	99	99	99	99
13	5	21	1	99	99	46	99	99
14	99	99	99	99	99	99	99	99
15	108	2	1	99	99	12	99	99
16	5	4	1	99	12	52	21	2
17	99	99	99	99	99	99	99	99
18	10	8	2	99	17	17	8	5
19	5	110	1	99	99	46	99	99
20	5	41	1	99	12	12	21	2
21	5	99	99	99	12	12	21	2
22	110	31	1	99	12	12	21	2
23	108	7	1	99	12	66	21	3
24	6	6	2	99	99	76	99	99
25	5	32	2	99	12	46	21	2
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	99	99	99	99	99	99	99	99
29	6	6	1	99	12	17	21	2
30	6	12	1	99	12	46	21	2
31	5	7	2	99	12	46	27	2
32	5	31	1	99	12	99	21	2
33	99	99	99	99	99	99	99	99
34	10	8	1	99	46	46	21	4
35	99	99	99	99	99	99	99	99
36	7	7	1	99	12	46	21	2
37	7	7	1	99	12	46	27	2
38	5	99	99	99	17	46	8	3
39	110	12	1	99	54	66	36	1
40	99	5	99	99	12	66	21	3
41	110	12	1	99	12	46	21	2
42	99	9	99	99	99	99	99	99
43	99	99	99	99	99	99	99	99
44	5	1	1	99	12	46	21	2
45	5	13	1	99	34	46	21	1
46	110	1	1	99	21	21	34	1
47	5	7	2	99	46	46	21	4
48	5	8	1	99	12	99	27	3
49	6	12	1	99	99	46	99	99
50	5	1	1	99	13	99	21	3
51	6	12	1	99	22	99	21	1
52	6	12	1	99	17	53	27	3
53	10	1	1	99	13	34	21	3
54	99	99	99	99	99	99	99	99

ID	ppucostq	convingr	labourde	othrensq	cattlewa	gotwater	catothrw	ctlwtrow
55	99	99	99	99	99	99	99	99
56	10	4	1	99	12	99	21	3
57	6	12	1	99	13	66	34	3
58	110	4	1	99	13	46	21	4
59	99	6	6	99	13	46	21	4
60	5	2	1	99	10	21	21	1
61	5	2	1	99	99	46	99	99
62	6	12	1	99	99	66	99	99
63	6	12	1	99	12	21	21	2
64	99	99	99	99	99	66	99	99
65	108	10	1	99	99	46	99	99
66	99	99	99	99	99	99	99	99
67	108	4	1	99	34	46	21	1
68	99	6	99	99	99	21	99	99
69	110	2	1	99	12	17	21	2
70	6	6	1	99	54	99	34	1
71	10	4	1	99	13	66	27	4
72	108	4	1	99	10	71	21	2
73	10	1	1	99	46	46	21	4
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	7	12	2	99	17	54	21	5
78	99	99	99	99	99	99	99	99
79	6	7	1	99	99	66	99	99
80	5	1	1	99	54	66	21	1
81	5	2	2	99	46	46	21	4
82	110	2	1	99	56	46	21	1
83	5	12	1	99	17	46	21	5
84	5	7	1	99	99	46	99	99
85	108	2	1	99	13	46	21	3
86	5	2	2	99	13	66	21	4
87	108	14	1	99	21	46	21	1
88	99	99	99	99	99	99	99	99
89	5	2	1	99	10	71	21	5
90	110	2	1	99	17	17	27	2

ID	gotwtrow	rentwate	opercost	howcatwa	howgotwa	catwters	gotwters	whyadopt
1	5	99	4	99	11	99	6	7
3	1	99	4	99	11	99	1	4
4	4	10	5	10	10	2	8	10
5	1	99	9	99	13	99	3	1
7	5	7	6	7	7	10	3	1
8	5	11	99	99	12	99	2	4
9	5	11	99	14	11	99	4	7
10	4	1	99	99	12	99	2	1
11	4	99	99	8	8	99	4	1
12	99	99	99	99	99	99	99	99
13	4	99	99	99	8	99	4	1
14	99	99	99	99	99	99	9	99
15	2	99	7	99	7	99	1	6
16	7	12	8	7	7	6	1	1
17	99	99	99	99	99	99	99	99
18	5	13	5	8	8	6	6	99
19	4	99	6	99	8	99	4	11
20	2	12	10	8	8	1	1	7
21	99	7	11	8	99	11	11	99
22	2	12	10	10	10	6	1	6
23	5	7	11	10	7	6	3	6
24	4	14	99	99	8	99	2	8
25	4	7	11	7	7	6	3	10
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	99	99	99	99	99	99	99	99
29	2	2	4	8	8	2	4	1
30	4	15	6	8	12	6	3	1
31	4	12	6	8	12	6	12	1
32	99	8	10	7	99	5	99	7
33	99	99	99	99	99	99	99	99
34	4	99	5	8	8	3	3	12
35	99	99	99	99	99	99	99	99
36	4	12	12	7	7	6	4	1
37	4	12	4	12	12	1	4	13
38	99	99	99	8	99	99	99	99
39	5	99	99	10	11	13	13	14
40	5	4	13	8	14	2	2	99
41	4	12	10	10	12	1	7	13
42	99	99	99	99	99	99	99	99
43	99	99	99	99	99	99	99	99
44	4	12	10	7	7	1	4	6
45	4	14	5	10	11	2	3	6
46	1	99	99	13	99	14	14	99
47	4	7	99	10	12	3	3	1
48	99	7	11	14	99	2	99	15
49	4	99	6	99	8	99	8	1
50	99	7	11	7	99	1	99	2
51	99	99	99	7	99	2	99	3
52	99	99	99	8	99	99	99	99
53	3	6	11	11	11	5	5	1
54	99	99	99	99	99	99	99	99

ID	gotwtrow	rentwate	opercost	howcatwa	howgotwa	catwters	gotwters	whyadopt
55	99	99	99	99	99	99	99	99
56	99	3	99	7	99	1	99	6
57	5	2	99	11	11	2	13	6
58	5	1	11	7	12	1	3	6
59	4	1	99	10	12	7	3	5
60	1	99	99	8	8	1	1	6
61	4	1	99	99	8	99	3	7
62	1	99	99	99	11	99	13	14
63	1	10	2	8	8	6	6	13
64	99	99	99	99	99	99	99	99
65	4	99	6	99	7	99	3	1
66	99	99	99	99	99	99	99	99
67	4	99	5	7	7	5	3	3
68	4	99	99	99	7	99	14	4
69	2	12	11	7	7	1	1	6
70	4	99	99	10	99	4	99	8
71	5	5	99	8	11	2	13	14
72	2	12	13	13	15	1	1	16
73	4	14	5	8	8	3	3	11
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	1	6	14	8	8	6	6	16
78	99	99	99	99	99	99	99	99
79	5	10	14	99	8	99	6	14
80	5	99	13	10	11	1	6	4
81	4	4	5	7	7	3	3	16
82	4	99	99	10	8	2	3	3
83	5	1	13	8	8	3	3	16
84	4	99	6	99	11	99	3	7
85	4	7	99	12	8	2	3	6
86	5	3	3	8	8	2	3	1
87	1	99	99	13	11	6	3	1
88	99	99	99	99	99	99	99	99
89	5	99	99	8	8	4	4	16
90	2	8	4	8	8	6	6	16

ID	usefrqcy	watercos	convinie	labourq2	catdistq	goatdist	othergra	grzchang
1	4	5	7	1	99	99	2	2
3	6	1	1	1	99	99	2	2
4	4	4	3	3	99	99	1	2
5	2	3	5	2	99	99	2	2
7	4	3	4	1	99	99	2	1
8	7	5	3	1	99	99	1	1
9	5	5	2	1	99	99	2	3
10	5	3	5	1	99	99	2	1
11	4	1	4	1	99	99	2	1
12	99	99	99	99	99	99	99	99
13	2	3	4	1	99	99	2	2
14	99	99	99	99	99	99	99	99
15	4	4	3	1	99	99	2	1
16	2	4	4	1	99	99	2	3
17	99	99	99	99	99	99	99	99
18	99	99	99	2	99	99	2	99
19	7	3	4	1	99	99	2	2
20	4	2	4	2	99	99	2	1
21	99	1	8	3	99	99	2	3
22	8	4	3	1	99	99	1	2
23	2	8	4	2	99	99	2	1
24	1	2	3	1	99	99	1	1
25	1	1	4	2	99	99	2	2
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	99	99	99	99	99	99	99	99
29	4	1	4	1	99	99	2	1
30	2	4	5	1	99	99	2	2
31	4	3	5	2	99	99	1	1
32	2	4	7	1	99	99	2	2
33	99	99	99	99	99	99	99	99
34	10	10	4	1	99	99	2	2
35	99	99	99	99	99	99	1	99
36	1	4	4	1	99	99	2	2
37	11	4	3	2	99	99	2	1
38	99	99	99	99	99	99	99	1
39	1	5	4	1	99	99	1	1
40	99	1	99	1	99	99	2	1
41	8	4	3	1	99	99	2	2
42	99	99	99	99	99	99	99	99
43	99	99	99	99	99	99	99	99
44	2	1	4	99	99	99	2	1
45	2	11	6	1	99	99	2	1
46	99	99	99	99	99	99	2	2
47	1	11	1	1	99	99	2	2
48	99	1	8	1	99	99	2	3
49	4	3	5	1	99	99	2	2
50	3	1	10	1	99	99	2	1
51	8	2	6	1	99	99	2	2
52	99	99	99	99	99	99	99	99
53	12	4	3	1	99	99	2	1
54	99	99	99	99	99	99	99	99

ID	usefrqcy	watercos	convinie	labourq2	catdistq	goatdist	othergra	grzchang
55	99	99	99	99	99	99	99	99
56	2	4	3	99	99	99	2	2
57	4	4	3	1	99	99	2	2
58	12	12	5	1	99	99	2	2
59	4	13	3	1	99	99	2	2
60	2	2	4	1	99	99	1	2
61	4	3	5	1	99	99	2	2
62	1	5	7	1	99	99	1	1
63	5	4	2	1	99	99	1	1
64	99	99	99	99	99	99	1	99
65	4	3	5	1	99	99	2	2
66	99	99	99	99	99	99	99	99
67	4	11	4	1	99	99	1	1
68	5	99	99	99	99	99	2	2
69	6	12	4	1	99	99	2	3
70	5	2	6	1	99	99	2	1
71	5	4	4	3	99	99	2	99
72	2	4	4	1	99	99	2	2
73	1	11	4	1	99	99	2	1
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	2	4	4	2	99	99	1	2
78	99	99	99	99	99	99	99	99
79	1	5	7	1	99	99	2	2
80	2	5	6	1	99	99	1	2
81	4	1	1	1	99	99	1	2
82	8	11	4	1	99	99	1	1
83	4	14	4	4	99	99	1	1
84	4	3	1	2	99	99	2	3
85	4	4	4	1	99	99	2	1
86	8	4	4	2	99	99	2	2
87	4	3	5	2	99	99	2	1
88	99	99	99	99	99	99	99	99
89	4	1	4	1	99	99	2	1
90	8	4	4	2	99	99	2	2

ID	chngtime	elaborat	chngecau	movesigf	whysigni	movadequ	whyadequ	canimpro
1	9	4	99	1	10	1	13	99
3	9	9	99	1	5	2	12	2
4	9	7	99	1	7	1	8	99
5	9	9	99	1	4	1	14	99
7	3	8	5	1	5	1	10	99
8	3	11	8	1	5	2	12	3
9	9	9	3	9	9	3	9	9
10	3	12	12	1	5	1	6	99
11	2	13	11	1	1	1	8	99
12	99	99	99	99	99	99	99	99
13	99	10	99	1	5	1	6	99
14	99	99	99	99	99	99	99	99
15	2	14	5	1	5	1	5	99
16	99	99	99	1	12	2	15	1
17	99	99	99	99	99	99	99	99
18	99	99	99	99	99	99	99	99
19	99	1	99	1	5	1	13	99
20	3	15	12	1	5	2	16	1
21	99	99	99	3	99	3	99	3
22	99	1	99	1	5	2	17	99
23	3	16	13	1	5	2	12	2
24	3	17	14	1	5	2	18	1
25	99	1	99	1	5	1	13	99
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	99	99	99	99	99	99	99	99
29	3	10	6	2	8	99	99	99
30	99	99	99	1	5	1	6	99
31	2	10	6	1	5	1	5	99
32	99	99	99	1	4	1	8	99
33	99	99	99	99	99	99	99	99
34	99	99	99	1	5	2	14	1
35	99	99	99	99	99	99	99	99
36	99	99	99	2	5	1	14	99
37	3	18	4	1	5	2	14	1
38	3	19	15	99	99	99	99	99
39	3	20	6	1	10	2	19	2
40	3	10	2	1	5	1	5	99
41	99	99	99	1	5	1	8	99
42	99	99	99	99	99	99	99	99
43	99	99	99	99	99	99	99	99
44	3	21	2	1	5	1	14	99
45	3	18	16	1	5	2	11	1
46	99	99	99	1	5	2	1	3
47	99	1	99	1	2	1	10	99
48	99	99	99	3	99	3	99	3
49	99	99	99	1	5	1	5	99
50	3	2	1	1	14	1	6	99
51	99	99	99	1	5	2	1	2
52	99	99	99	99	99	99	99	99
53	3	1	5	1	5	1	8	99
54	99	99	99	99	99	99	99	99

ID	chngtime	elaborat	chngecau	movesigf	whysigni	movadequ	whyadequ	canimpro
55	99	99	99	99	99	99	99	99
56	99	99	99	1	5	2	12	99
57	99	99	99	1	13	1	6	99
58	99	99	99	1	5	1	8	99
59	99	99	99	1	13	1	10	99
60	99	99	99	1	5	2	12	3
61	99	1	99	1	10	2	11	3
62	2	5	3	1	6	1	8	99
63	3	6	4	1	3	1	14	99
64	99	99	99	99	99	99	99	99
65	99	21	99	1	10	1	13	99
66	99	99	99	99	99	99	99	99
67	1	2	1	1	5	2	1	3
68	99	1	99	1	5	2	12	3
69	99	99	99	1	5	3	99	3
70	3	8	5	1	10	1	6	99
71	99	99	99	1	5	1	14	99
72	99	99	99	1	5	2	12	2
73	1	21	17	1	15	2	12	2
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	99	21	99	1	5	1	10	99
78	99	99	99	99	99	99	99	99
79	99	6	99	1	10	2	14	1
80	99	1	99	1	5	2	12	2
81	99	99	99	1	1	1	8	99
82	3	8	5	1	5	1	10	99
83	3	10	6	1	5	1	13	99
84	99	99	99	1	5	2	11	1
85	2	21	2	1	5	1	5	99
86	99	1	99	1	5	1	8	99
87	3	2	1	1	5	1	14	99
88	99	99	99	99	99	99	99	99
89	3	21	7	1	5	1	14	99
90	99	6	99	1	3	1	8	99

ID	catslter	gotslter	cattlesa	goatsale	cattlest	goatstra	cattlepr	goatpred
1	99	0	99	0	99	0	99	0
3	99	99	99	99	99	99	99	3
4	0	3	4	0	3	0	0	0
5	99	0	99	0	99	0	99	0
7	0	0	0	0	4	0	0	0
8	99	1	99	1	99	0	99	1
9	99	99	99	99	99	99	0	100
10	99	99	99	99	99	99	99	100
11	99	2	99	0	99	0	0	0
12	99	99	99	99	99	99	99	99
13	99	0	99	0	99	0	99	0
14	99	99	99	99	99	99	99	99
15	99	0	99	0	99	0	99	3
16	0	0	0	2	0	0	0	5
17	99	99	99	99	99	99	99	99
18	1	0	10	5	20	0	0	0
19	99	0	99	0	99	0	99	1
20	0	3	0	0	0	5	0	20
21	99	0	0	0	99	0	0	99
22	0	1	0	3	0	0	0	25
23	0	5	2	0	0	0	0	4
24	99	1	99	1	99	0	99	15
25	0	0	12	0	13	0	6	0
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	99	99	99	99	99	99	99	99
29	99	99	99	99	99	99	100	100
30	0	0	0	0	0	0	0	4
31	1	0	1	0	0	0	0	6
32	0	99	1	99	7	99	0	99
33	99	99	99	99	99	99	99	99
34	0	1	3	6	16	2	0	10
35	99	99	99	99	99	99	99	99
36	0	0	0	0	3	0	0	1
37	0	1	7	0	4	0	0	1
38	0	2	0	0	0	0	0	1
39	0	1	0	0	2	0	0	1
40	0	0	0	0	2	0	0	3
41	0	5	12	70	0	0	0	0
42	99	99	99	99	99	99	99	99
43	99	99	99	99	99	99	99	99
44	0	0	0	3	0	0	0	5
45	0	2	2	3	2	0	0	5
46	1	1	0	0	0	0	0	11
47	0	0	0	0	0	0	0	20
48	99	99	99	99	99	99	0	99
49	99	1	99	1	99	4	99	0
50	1	99	0	99	3	99	0	99
51	0	99	0	99	2	99	0	99
52	99	99	99	99	99	99	100	100
53	0	3	0	0	0	0	0	3
54	99	99	99	99	99	99	99	99

ID	catslter	gotslter	cattlesa	goatsale	cattlest	goatstra	cattlepr	goatpred
55	99	99	99	99	99	99	99	99
56	0	0	3	0	0	0	0	99
57	0	0	0	2	0	2	0	0
58	0	0	0	0	0	0	0	8
59	0	1	1	0	7	0	0	0
60	0	0	0	0	0	0	0	10
61	99	1	99	0	99	0	99	3
62	99	1	99	1	99	0	99	0
63	2	0	10	0	0	0	1	0
64	99	99	99	99	99	99	99	0
65	99	0	99	0	99	0	99	1
66	99	99	99	99	99	99	99	99
67	0	0	0	2	0	0	0	10
68	99	0	99	0	99	0	99	5
69	0	0	0	2	0	0	0	2
70	0	99	0	99	1	99	0	99
71	0	5	0	0	0	2	0	0
72	99	99	99	99	99	99	100	100
73	0	0	4	0	0	0	0	0
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	0	2	99	99	3	0	0	0
78	99	99	99	99	99	99	99	99
79	99	99	99	99	99	6	99	0
80	1	0	0	0	0	12	0	0
81	0	6	2	0	0	0	0	15
82	1	0	0	0	0	2	0	0
83	2	1	0	1	6	1	0	3
84	99	0	99	0	99	0	99	0
85	0	3	0	0	3	0	0	5
86	0	1	1	1	1	2	0	2
87	0	0	0	0	0	0	0	0
88	99	99	99	99	99	99	99	99
89	0	1	0	0	0	4	0	2
90	0	2	0	0	0	0	0	0

ID	cattledi	goatdied	whyutili	salefrqc	whysalef	youngcat	younggoa	reprodra
1	99	0	13	2	1	99	2	22
3	99	99	1	1	1	99	1	99
4	0	0	10	2	3	4	5	42
5	99	0	99	1	1	99	5	21
7	0	4	14	2	2	12	12	41
8	99	3	3	5	10	99	4	22
9	99	99	99	99	99	100	99	99
10	99	99	99	99	0	99	1	99
11	99	10	2	8	10	100	22	21
12	99	99	99	99	99	99	99	99
13	99	1	12	1	2	99	3	23
14	99	99	99	99	99	99	99	99
15	99	3	4	1	1	99	11	22
16	0	3	4	2	4	1	13	21
17	99	99	99	99	99	99	99	99
18	0	0	15	2	10	50	99	41
19	99	5	1	5	1	99	6	22
20	0	0	4	5	10	1	10	22
21	99	0	99	2	10	100	0	99
22	0	0	4	2	4	7	15	43
23	0	3	10	5	2	5	40	21
24	99	0	4	2	11	99	15	22
25	6	0	15	2	12	20	20	41
26	99	99	99	99	99	99	99	99
27	99	99	99	99	99	99	99	99
28	99	99	99	99	99	99	99	99
29	99	99	99	5	10	100	1	49
30	0	0	4	1	1	2	3	43
31	0	0	4	5	10	15	6	42
32	0	99	6	5	10	2	99	12
33	15	99	16	99	99	99	99	99
34	0	5	15	2	10	2	17	42
35	99	99	99	99	99	99	99	99
36	0	2	6	5	10	10	19	42
37	0	0	5	3	11	7	7	43
38	0	1	10	5	7	100	1	41
39	0	10	12	5	2	4	9	42
40	0	0	12	5	10	5	5	42
41	0	5	12	4	13	1	12	21
42	99	99	99	99	99	99	99	99
43	99	99	99	99	99	99	99	99
44	0	0	4	5	10	100	5	22
45	0	0	4	2	10	8	2	23
46	0	0	4	1	1	5	0	12
47	0	0	4	2	10	2	4	43
48	99	99	99	99	99	100	99	99
49	99	11	2	5	1	99	2	23
50	0	99	1	1	1	3	99	13
51	0	99	1	1	1	1	99	99
52	99	99	99	99	99	1	1	99
53	0	8	3	2	3	0	2	42
54	99	99	99	99	99	99	99	99

ID	cattledi	goatdied	whyutili	salefrqc	whysalef	youngcat	younggoa	reprodra
55	99	99	99	99	99	99	99	99
56	0	0	12	1	2	2	99	12
57	0	0	5	5	4	100	8	22
58	0	0	14	1	1	9	0	12
59	0	0	6	1	2	1	6	22
60	0	0	4	1	2	100	0	43
61	99	1	4	5	1	99	9	22
62	99	5	7	5	5	99	5	21
63	0	0	11	3	10	8	2	13
64	99	99	99	99	99	99	99	99
65	99	0	4	5	1	99	1	23
66	99	99	99	99	99	99	99	99
67	0	0	4	6	6	2	20	42
68	99	0	4	2	10	99	3	22
69	0	0	4	5	10	100	5	22
70	1	99	3	1	12	1	99	12
71	3	0	10	1	3	3	6	21
72	99	99	9	2	9	1	1	49
73	3	0	11	2	11	8	6	42
74	99	99	99	99	99	99	99	99
75	99	99	99	99	99	99	99	99
76	99	99	99	99	99	99	99	99
77	0	0	15	10	14	100	99	99
78	99	99	99	99	99	99	99	99
79	99	99	6	1	1	99	2	22
80	0	0	6	1	1	2	99	43
81	3	3	4	2	3	5	15	42
82	0	0	6	2	1	2	19	13
83	4	0	12	5	8	3	10	42
84	99	0	13	1	1	99	0	23
85	0	1	4	1	2	2	5	42
86	1	0	4	6	6	15	15	23
87	0	1	2	1	1	1	2	43
88	99	99	99	99	99	99	99	99
89	3	0	4	11	11	1	8	43
90	3	4	12	2	7	1	18	21

ID	knowNPA	viewfenc	producti	landshor	solution	livestoc	explaina
1	2	10	12	1	4	1	10
3	2	1	7	1	4	1	1
4	1	10	12	2	9	2	6
5	1	1	16	1	6	1	2
7	1	1	1	2	9	2	3
8	2	1	17	1	8	2	4
9	99	99	99	99	99	99	99
10	1	4	6	1	10	2	14
11	1	4	1	2	99	2	2
12	2	1	99	1	8	2	10
13	2	4	3	2	99	2	10
14	2	10	3	2	4	2	4
15	2	1	7	1	6	2	10
16	2	2	7	1	4	1	2
17	2	1	1	1	8	2	3
18	1	1	12	1	3	1	0
19	2	12	1	2	99	2	6
20	2	11	7	1	11	1	2
21	2	10	99	3	99	3	99
22	1	1	6	1	4	1	10
23	2	4	18	1	6	1	16
24	2	12	12	1	1	2	4
25	2	2	12	1	1	2	10
26	2	11	6	2	99	2	4
27	2	15	6	1	12	1	17
28	2	1	6	1	1	1	10
29	1	16	14	2	99	2	3
30	2	5	6	2	99	2	5
31	1	2	12	1	10	2	4
32	2	1	19	1	4	2	4
33	2	4	6	2	99	2	3
34	1	17	12	1	13	1	18
35	2	10	6	3	99	3	99
36	2	4	7	1	1	1	1
37	2	1	3	1	1	1	19
38	2	18	99	1	10	1	11
39	1	1	6	1	14	2	3
40	2	1	3	1	1	2	2
41	1	2	1	1	8	2	4
42	2	11	6	2	99	2	4
43	2	14	4	2	99	2	4
44	2	10	6	1	8	3	99
45	1	1	16	1	8	2	14
46	2	1	7	1	4	1	1
47	2	1	14	2	99	2	5
48	2	10	6	3	99	3	99
49	2	11	20	2	99	2	6
50	2	4	7	1	8	3	14
51	2	1	21	1	4	1	1
52	2	10	6	2	99	1	19
53	1	1	6	1	7	2	3
54	2	10	6	2	99	2	6

ID	knowNPA	viewfenc	producti	landshor	solution	livestoc	explaina
55	2	14	12	2	99	2	3
56	2	2	10	1	8	2	5
57	2	4	6	1	8	1	2
58	2	4	7	1	8	2	6
59	1	5	22	2	99	2	6
60	2	14	7	1	4	2	18
61	2	4	5	1	8	2	14
62	2	1	3	1	4	2	7
63	1	14	11	2	99	1	2
64	2	1	6	2	99	2	6
65	2	4	12	2	99	2	3
66	2	11	99	1	6	1	2
67	1	14	7	1	7	1	14
68	2	17	7	1	7	1	10
69	2	10	1	1	8	3	8
70	1	1	10	1	4	2	4
71	2	2	12	1	10	3	14
72	1	4	1	1	3	1	10
73	1	18	13	2	99	2	11
74	2	1	6	1	8	3	99
75	2	2	6	1	4	1	10
76	2	4	6	2	99	2	4
77	2	7	12	1	1	1	12
78	2	11	12	2	99	2	5
79	2	14	14	1	5	2	6
80	1	1	7	1	4	1	10
81	1	5	12	2	99	2	2
82	1	1	3	2	99	2	14
83	1	15	1	2	99	2	3
84	1	2	12	1	1	1	13
85	1	1	1	1	4	2	3
86	1	11	3	1	4	2	14
87	2	1	3	1	8	2	10
88	2	4	6	2	99	2	14
89	1	1	3	2	99	2	14
90	1	19	14	1	10	1	13