Chapter 2

Biophysical characteristics

INTRODUCTION

The Limpopo River Basin is situated in the east of southern Africa between about 20 and 26 °S and 25 and 35 °E. It covers an area of 412 938 km^2. Figure 4 shows the basin in relation to major physical features of the subcontinent. The basin straddles four countries: Botswana, Mozambique, South Africa and Zimbabwe. Figure 5 shows the main overland transport routes, urban centres, rivers and nature conservation areas in the basin.

CLIMATE

Classification of the climate of the Limpopo River Basin

Climate conditions vary considerably in southern Africa, as the subcontinent lies at the transition of major climate zones. The climate in the Limpopo River Basin is influenced by air masses of different origins: the equatorial convergence zone, the subtropical eastern continental moist maritime (with regular occurrence of cyclones), and the dry continental tropical and marine west Mediterranean (winter rains) (Bhalotra, 1987b; GOB–MMRWA, 1991; Schulze, 1997; Unganai, 1998).

According to the Köppen Classification (Köppen, 1918; Rosenberg, 1999), the basin is predominantly semi-arid, dry and hot (BSh in Figure 6). The central river valley is arid, dry and hot (BWh). Here, the average rainfall is less than 400 mm with likely crop failure in 75–90 percent of years (Reddy, 1985; 1986). The South African highveldt part of the basin is temperate with summer rainfall and cool to hot summers (Cwc and Cwa). The Mozambique coastal plain is mainly warm-temperate with no dry season and hot summers.

Rainfall

The Limpopo River Basin is a region of summer rainfall, generally with low precipitation. The overall feature of the mean annual precipitation is that it decreases fairly uniformly westwards from the northern reaches of the Drakensberg Escarpment across the interior plateau. However, rainfall is highest on the Drakensberg Escarpment because of its orographic effect. There is also a north–south rainfall gradient towards the Limpopo River.

Rainfall varies from a low of 200 mm in the hot dry areas to 1 500 mm in the high rainfall areas. The majority of the catchment receives less than 500 mm of rainfall per year (Figure 7). The hot dry areas receiving about 200–400 mm of annual rainfall are located mostly within the main Limpopo River Valley itself.

Rainfall is highly seasonal with 95 percent occurring between October and April, often with a mid-season dry spell during critical periods of crop growth. It occurs on a few isolated rain days and isolated locations, seldom exceeding 50 rain days per year. Rainfall varies significantly between years, with maximum monthly rainfall being as high as 340 mm compared with mean monthly rainfalls of 50–100 mm for January, February and March.

FIGURE 4
The Limpopo River Basin in relation to country boundaries and physical features of the subcontinent

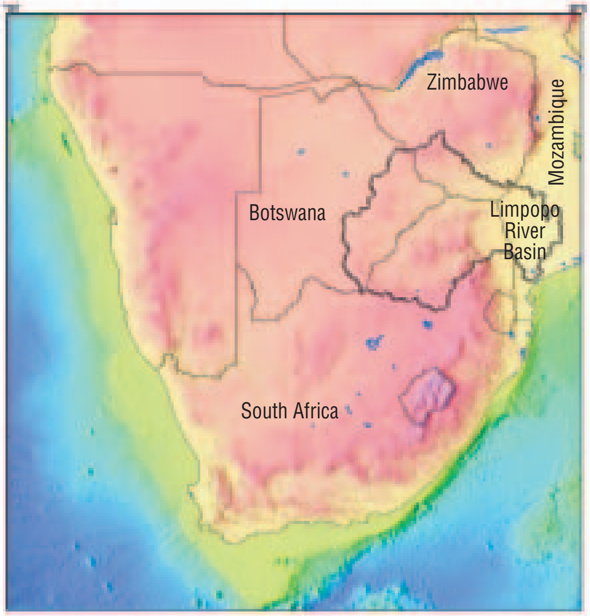
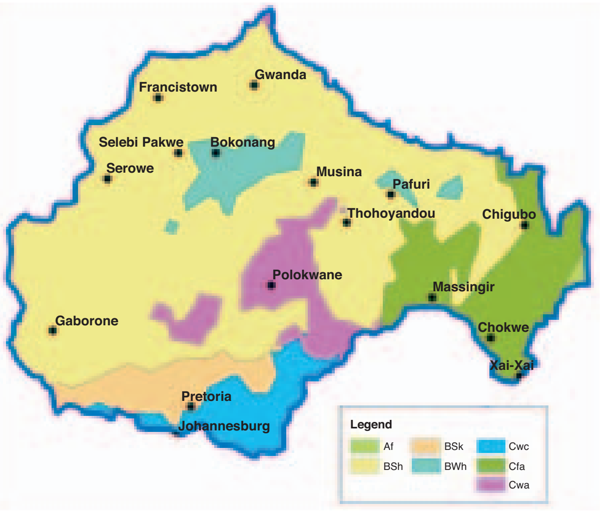


FIGURE 5
The Limpopo River Basin in relation to transport routes and urban centres

FIGURE 6
Köppen climate classes

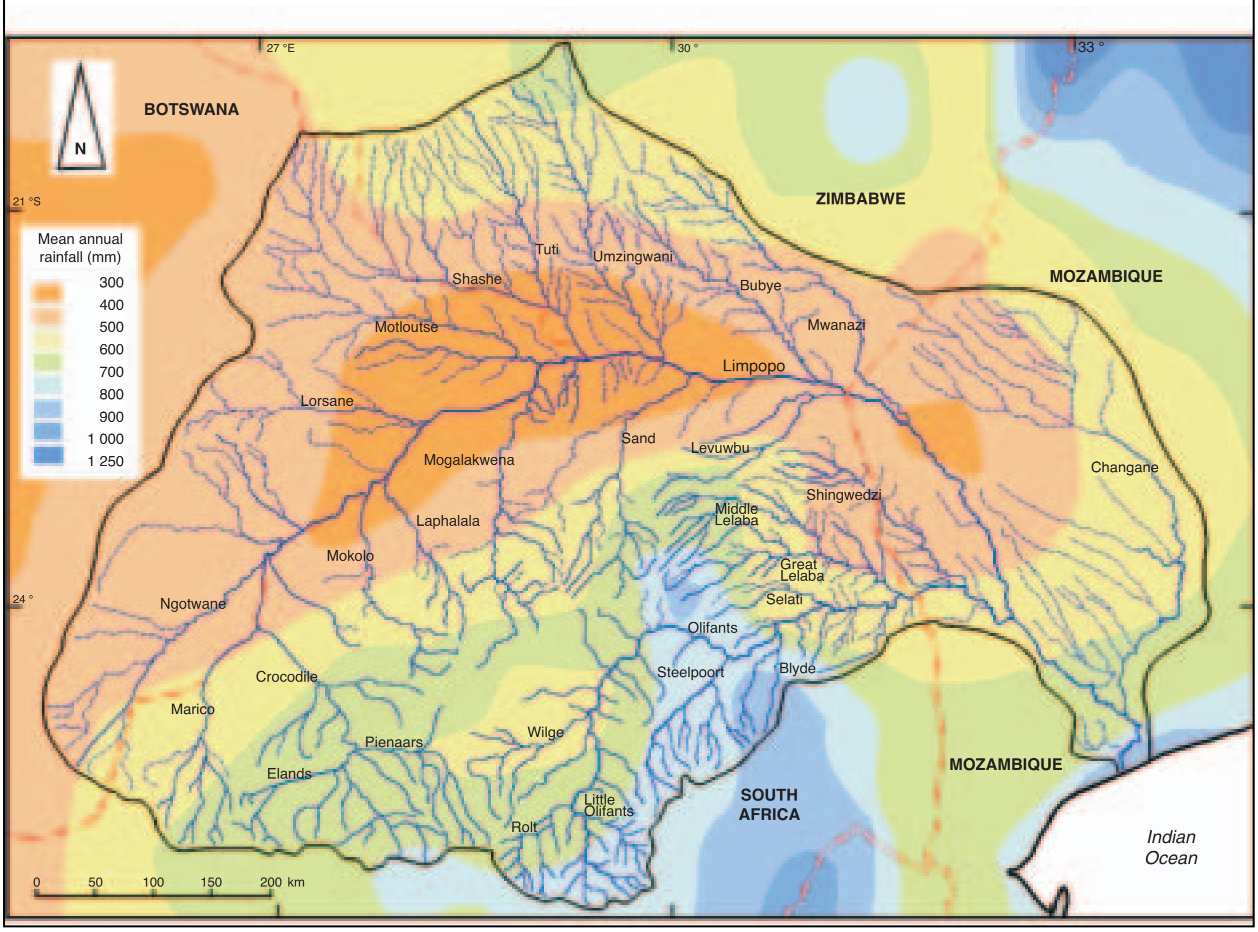


The Limpopo River Basin generally experiences short rainfall seasons, except for some of the outer limits of the basin that have higher rainfall and longer seasons. The rainfall concentration index is 60 percent and above, and this limits crop production because most of the annual rainfall is received in a short period of time.

A rainfall concentration index of 100 percent implies that a location receives all its rainfall in a single month. The rainfall season usually begins in early summer (late November to early December) for the southernmost parts of the basin and in mid-summer (mid-December to January) for the central parts of the basin around the Limpopo River itself. The rainfall season lasts an average of four months.

Rainfall in Botswana is caused mainly by convection thunderstorms, which typically occur

FIGURE 7
Average seasonal total rainfall in the Limpopo River Basin



Source: UNCTAD (2003).

as localized events with a high spatial and temporal variability. The annual rainfall in the Botswana part of the Limpopo River Basin varies from 350 mm in the northeast to about 550 mm in the southeast.

Zimbabwe experiences a single annual rainy season of five months (November–March), associated with the summer movement of the Inter-Tropical Convergence Zone over southern Africa. Within the Zimbabwe part of Limpopo River Basin, the mean annual rainfall varies from slightly more than 600 mm in the southern highveldt (Bulawayo) to less than 400 mm in the southeastern lowveldt (Tuli and Beitbridge). The annual variability is considerable, with a coefficient of variation (CV) of about 40 percent. The probability of receiving more than 500 mm of rainfall in any year is less than 60 percent in the southern highveldt and less than 30 percent in the southeastern lowveldt (with less than 10 percent in Beitbridge).

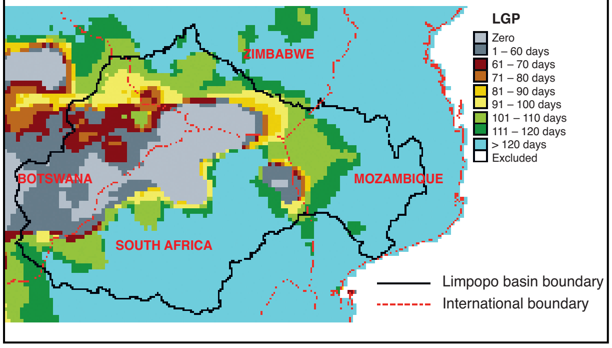
In Mozambique, the generalized rainfall pattern shows a sea-to-land gradient with a CV of about 40 percent in the Limpopo River Basin. Along the coastal strip, the mean annual rainfall is 800–1 000 mm, declining to less than 400 mm in the dry interior bordering Zimbabwe.

Rainfall generally has to exceed a minimum threshold of 20–30 mm before any runoff occurs, owing to high temperatures, low humidity and flat terrain. Many rainstorms are less than this and hence the flow regimes of rivers vary considerably. This results in high storage requirements for dams in order to deliver the yields that are required. Increased storage is costly and causes increased evaporation losses.

Evaporation

Evaporation within the Limpopo River Basin varies from 1 600 mm/year to more than 2 600 mm/year. The highest evaporation occurs in the hot Limpopo River Valley. High levels of evaporation mean that the soil dries up quickly and this reduces the

FIGURE 8
Estimated length of growing season derived from satellite imagery



amount of water available for plant uptake. This results in crops being more prone to drought.

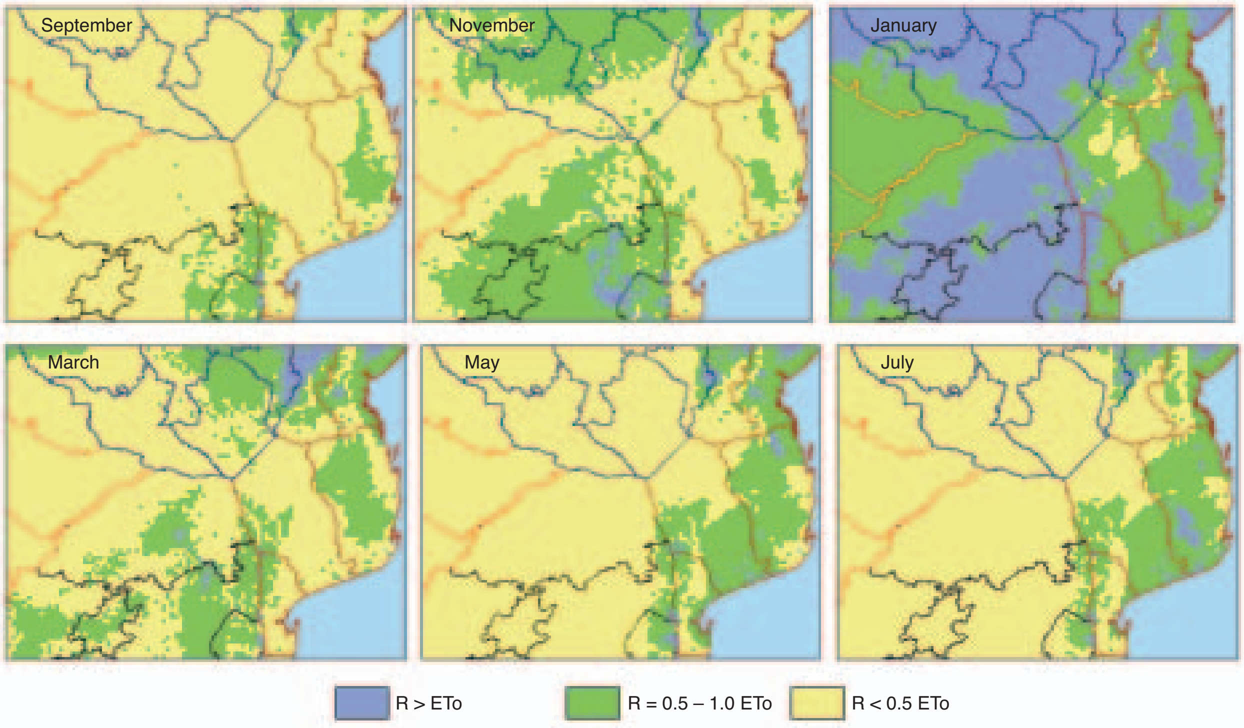
Evaporation from open water in Botswana varies from about 1 900 mm/year to 2 200 mm/year. Slightly lower annual figures of about 1 500 mm are derived from evapotranspiration calculations based on the Penman method. Daily figures range from about 2 mm to 5 mm. Evaporation is highest during the rainfall season, and it significantly reduces effective rainfall, runoff, soil infiltration and groundwater recharge. Evaporation loss from dams is significant owing to the high storage–yield relationship and flat dam basins.

Dryland subsistence farming is generally not viable given the variable rainfall, high evaporation and high evapotranspiration. Figure 8 shows the estimated length of growing period (LGP) derived from satellite imagery. Figure 9 shows the average crop water availability for selected months.

Temperature

Summers in the Limpopo River Basin are generally warm, and winters are mild. In summer, daily temperatures may exceed 40 °C, while in winter temperatures may fall to below 0 °C. The general figures for air temperature are related closely to altitude, and also to proximity to the ocean. The mean maximum daily temperature in most of the Limpopo River Basin, notably South Africa, Botswana and Zimbabwe, varies from about 30–34 °C in the summer to 22–26 °C in winter. The mean minimum daily temperature in most areas

FIGURE 9
Average crop water availability expressed as the relation between monthly rainfall, R, of selected months and the reference evapotranspiration, ET_o



Source: E. Mellaart, personal communication (2003).

lies between 18–22 °C in summer and 5–10 °C in winter.

The eastern and northern parts of the Limpopo River Basin are frost-free while the southern and western areas experience winter frosts. Frost does not occur in Mozambique and it occurs only occasionally in the southern highveldt of Zimbabwe, associated with an influx of cold dry air from the southeast. Frost-free areas also exist in the lowveldt of South Africa and along the Limpopo River in the Messina area.

Most of the higher-lying areas in South Africa and Botswana within the Limpopo River Basin experience frost, occurring most severely in the southwest of the basin. This may be very moderate in the areas of Tzaneen (Limpopo Province of South Africa) or Mahalapye (Central District of Botswana), but increases to 90–120 days of frost in Lobatse (southeast Botswana) or Mafeking (North West Province of South Africa). The average number of days with heavy frost in these areas is about 30 days. This does not imply that frost occurs over a short uninterrupted period. On the contrary, single or clusters of frost days may occur over a long period, usually between May and September. This may create a problem for late-planted crops.

Relative humidity

Relative humidity is generally higher on the eastern side of the Limpopo River Basin, and decreases inland. The relative humidity varies from less than 50 percent in September and October in the hot western parts of the basin in South Africa, to about 65 percent in January and February. Humidity in the lowveldt in South Africa varies only slightly (65–70 percent) in the same period.

Relative humidity in Botswana is comparatively low, with daytime averages of about 30 percent in winter and 40 percent in summer. However, much higher values are reached in the morning, nearing 60 percent in winter and more than 70 percent in summer. Humidity also increases before rainstorms, and is therefore highest between January and March. The dry western parts of Botswana record the lowest humidity.

Variation in rainfall and impact on growing season

There is considerable spatial and temporal variation in the rainfall regime in the Limpopo River Basin, as in most dryland areas, as much of the rainfall occurs in a limited number of rain events. A prerequisite to effective agriculture is a description of the rainfall regime in response to questions (Dennett, 1987) such as:

- When is rain likely to occur?
- What is the probability of a dry spell greater than a certain length?
- What is the probability of receiving a daily rainfall greater than a particular amount?

Probabilistic rainfall models to address these questions have been developed by Stern, Dennett and Dale (1982), and Stern and Coe (1982). These models have been applied to rainfall data from Gaborone and Tshane, two Botswana stations, 350 km apart. Model results calculated over a ten-year period indicate that as much as 50 percent of the total rainfall occurs in the 10 percent wettest days, and 80 percent in the 23 percent wettest days. The pattern is apparent in both dry and wet years. In addition, days with high rainfall are clustered. Understanding of such patterns is of prime interest because they determine the length of the growing season.

Reddy (1985, 1986) reported that the Limpopo River Basin in Mozambique presents a high risk of agricultural drought, depending on the type of dryland cropping systems in place. Here, there is high variation in terms of both commencement and cessation times of effective rains; that is, the risk associated with planting time. In terms of reliability, the erratic rainy season may begin any time from November to February. Therefore, average planting dates are only 50-percent reliable. Only 25 percent of the rainy seasons have 120 crop days. These begin on the average date for the rainy season, in December, whereas 25 percent of the years have 120 crop days starting later than this. Half of the remaining years have rainy seasons of more than 60 crop days.

Moreover, Reddy (1986) classified the upper Limpopo River Basin extending to the Zimbabwe border as a very high-risk area with probable crop failure in 75–90 percent of years. The dry semi-arid zone of the middle Limpopo River Basin extending to the lower Limpopo just off the coastline was assessed as a moderate to high-risk dryland agricultural zone where crop failure is expected in 45–75 percent of years. Kassam *et al.* (1982) determined the pattern of growing period zones in Mozambique. The interior of the Limpopo River Basin permits one growing period per year in 30 percent of the years, two growing periods per year in 45 percent of the years, and three growing periods per year in 25 percent of the years. The

FIGURE 10
Total rain for the summer season, October–March

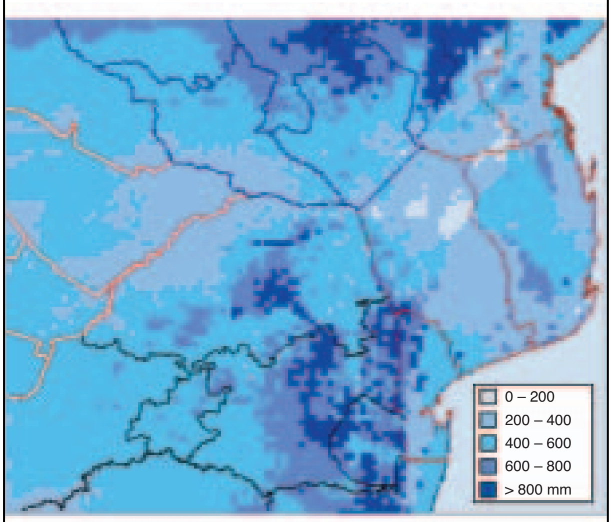
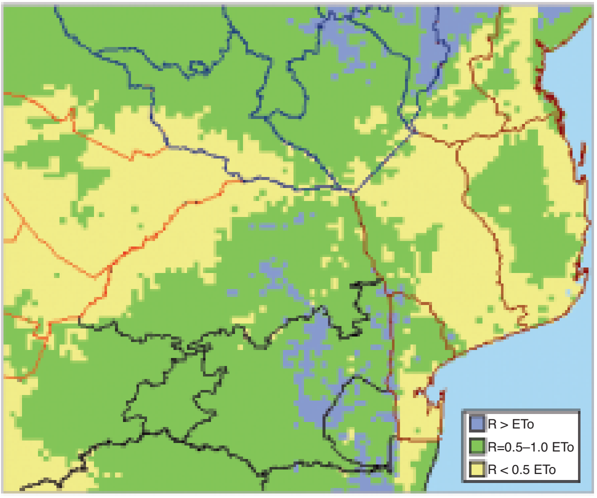


FIGURE 12
Total water balance for the summer season, October–March

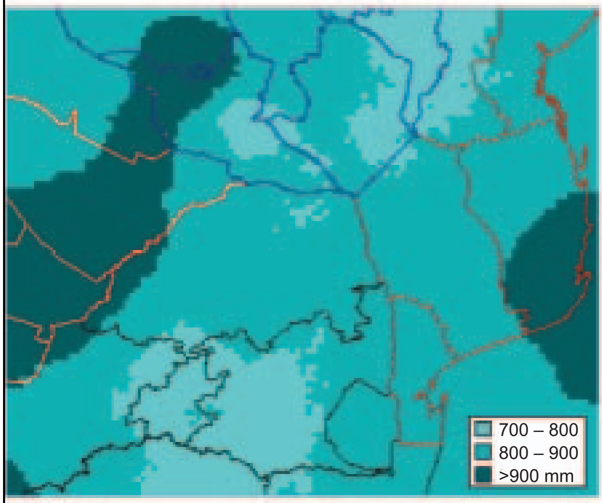


Source: E. Mellaart, personal communication (2003).

mean total dominant LGP for the middle and upper Limpopo River Basin was calculated at less than 120 days, compared with a gradient from 120 to 270 days at the coast (Figure 8).

Using gridded SADC–RRSU data, Mellaart (personal communication, 2003) illustrates the distribution of rainfall over ET_o in the basin area in Figures 9–12. The class $R < 0.5$ ET_o denotes non-arable conditions. The class $R = 0.5–1.0$ ET_o indicates marginally arable to arable conditions. The availability of good soils with favourable water-holding characteristics determines the agricultural potential of these areas. The class $R > ET_o$ is restricted to mountainous areas of the eastern escarpment receiving high orographic rainfall. These generally steep areas are generally under plantation forestry.

FIGURE 11
Total evapotranspiration for the summer season, October–March



Reliability of climate forecasts

Predicting drought is very complicated and has so far been unreliable, although there are strong indications for cyclic occurrence of drought, notably in southern Africa. In general, cycles of drier years are followed by successive seasons with opposite conditions. However, after two dry years in a recognized drought cycle, there is no guarantee that the third year will also be a drought year.

El Niño/La Niña phenomena and the Southern Oscillation

In a study on the impact of El Niño – Southern Oscillations (ENSOs) on the climate and crop production in Zimbabwe, Deane (1997) found that ENSO events (Box 4) do affect the subcontinent and that these provide instruments for assessing climate events at the natural region level. Deane concludes that research on the ENSO phenomena has the potential to result in improved management of the risk posed by weather through enabling potential drought years, as well as years with very good rainfall, to be better prepared for.

Recurrent droughts have put strong political pressure on meteorological services and early-warning systems to produce reliable forecasts.

BOX 4

El Niño – La Niña events and the Southern Oscillation

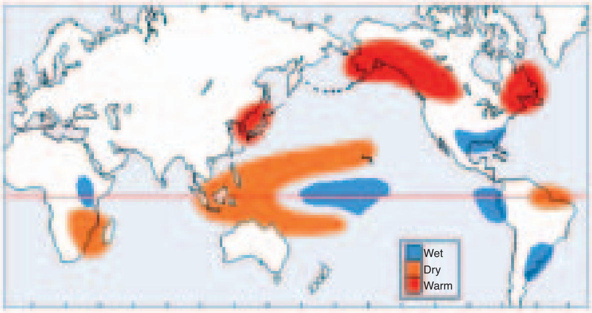
El Niño refers to the large-scale warming of the equatorial eastern and central Pacific Ocean due to a disruption of the ocean-atmosphere system (Figure 13). El Niño events occur irregularly at intervals of 2–7 years, although the average is about once every 3–4 years. They typically last 12–18 months. They have important consequences for weather and climate around the globe, including lower than normal rainfall for South Africa accompanied by higher than normal rainfall for central-east Africa. La Niña refers to unusually cold ocean temperatures in the equatorial Pacific. The impacts of La Niña tend to be opposite to those of El Niño. Various indices of sea surface temperature deviation are obtained by taking the average deviation over some specified region of the ocean. Figure 14 shows the Sea Surface Temperature Index for the NINO 3.4 area. (For assessing widespread global climate variability, NINO 3.4 is generally preferred, because the sea surface temperature variability in this region has the strongest effect on shifting rainfall). El Niño/La Niña events are accompanied by swings in the Southern Oscillation. The Southern Oscillation Index (SOI) is defined as the normalized difference in barometric pressure between Tahiti (French Polynesia) and Darwin (Australia). It is intimately related to the ocean temperature changes mentioned above and is a measure of the strength of the trade winds. SOI values (Figure 15) generally vary between +30 (La Niña) and -30 (El Niño). Together, these phenomena are referred to as ENSO (NOAA, 1994; University Corporation for Atmospheric Research, 2001; Pacific Marine Environmental Laboratory, 2003; Commonwealth Bureau of Meteorology, 2003).

Although substantial progress in the ENSO interpretation has been made, actual climate conditions in recent years have, to a large extent, not corresponded with the predicted outcomes. This raises concern about the reliability of the early-warning information used and applied, in particular in the southern African region. Until the mid-1990s, the general practice of declaring drought was based on the actual occurrence of drought. The severe drought of the 1991/92 season in southern Africa was only recognized officially as such as late as January 1992, well into the agricultural season.

The first time that drought was forecast in a very early stage – on the basis of global interpretations of the effects of El Niño – was in June 1997, when severe drought was predicted for the 1997–98 season (SADC, 1999). This led to actions by governments in the SADC region towards information dissemination and providing planting advice to farmers. Recommendations to farmers ranged from the planting of drought-tolerant and early-maturing varieties to destocking (Box 5). Even with improvements in the reliability of the climate forecasts, the occurrence of recurrent drought and related risks have to be accepted and integrated into land use systems sustainable under

FIGURE 13

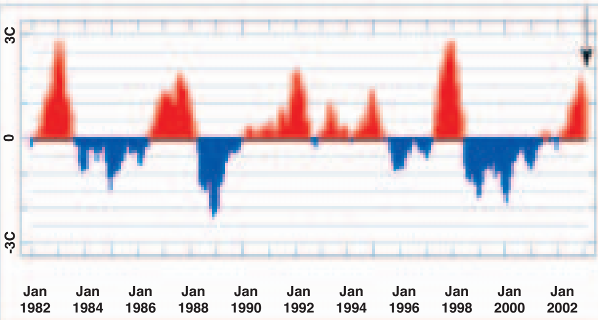
Precipitation anomalies during El Niño in the Southern Hemisphere summer



Source: NOAA (1994).

FIGURE 14

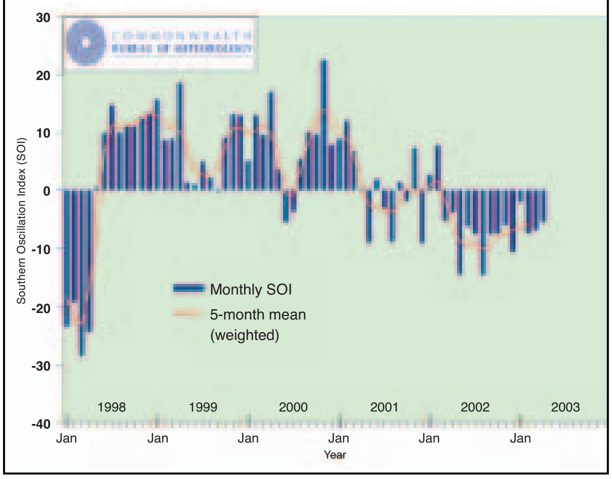
Sea Surface Temperature Index



Source: International Research Institute for Climate Prediction (2002).

FIGURE 15

Southern Oscillation Index, 1998–2003



Source: Commonwealth Bureau of Meteorology (2003).

the present climate conditions. The prospect of accelerated global warming, and associated regional changes in climate, reinforces the need for the consideration of the longer-term constraints that future climate may place on developments in the region. Recent studies conducted on climate variability and change in the region give strong indications of regional temperatures rising in coming decades (Hulme, 1996; Hulme and Sheard, 1999). Rising temperatures could change the rainfall regime in the coming decades, resulting in changes in natural vegetation, as well as agriculture and range conditions and water resources.

Long-term temperature trends

Africa is considered highly vulnerable to climate change. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) notes a warming of about 0.7 °C over most of the African continent during the twentieth century based on historical records (UNEP, 2002). It was found with respect to Zimbabwe that the diurnal temperature range is decreasing. There

BOX 5

Farmers and climate forecasts, Zimbabwe

In Zimbabwe, only 3 percent of farmers use climate information for planning purposes. Some of the reasons given are that the information is not received in time and that farmers do not trust the meteorological information. Although farmers listen to climate forecast from radios, the poor and marginalized farmers prefer to use their traditional knowledge systems as a control. When contemporary climate forecasting deviates from traditional forecasts, the farmers' inclination is towards indigenous information for reasons that it blends well with the culture, has been tried and tested over the years, and is in a language that the farmers understand.

There is often a striking similarity between indigenous and contemporary climate indicators. Some indicators are the same in both systems, such as wind direction, clouds and temperature. In addition, indigenous climate predictions are also based on plant and animal behaviour.

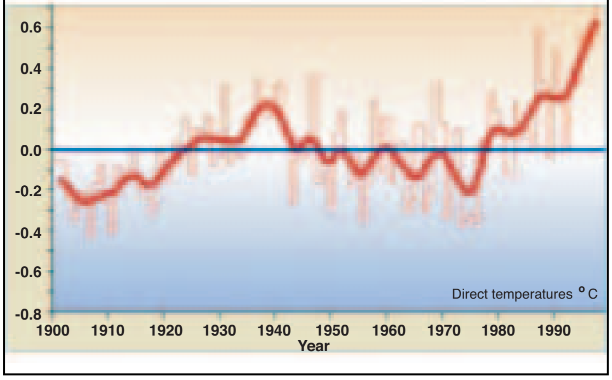
Farmers associate heavy production of tree leaves with a good season while high fruit production is a sign of a poor season. The reasoning behind this observation is that high fruit production implies that people will be living on fruits for lack of alternative foods. The production of white flowers by a local tree called *mukuu* is also a signal for a dry season, while flower production on top branches of a tree called *mukonde* indicates a good rainy season. Other indigenous signs of an imminent drought include: heavy infestation of most tree species by caterpillars during springtime; late bearing and lack of figs in July–September of a tree called *mukute*; late maturing of acacia trees along valleys; and drying off of *chigamngacha* fruit between September and early November.

One of the most important animal indicators is the behaviour of spiders. When spiders close their nests, an early onset of rain is expected because spiders do not like any moisture in their nests. When a lot of crickets are observed on the ground, a poor rainy season is expected. The movement of elephants is associated with occurrence of rainfall because they need a lot of water. A stork flying at very high altitude is associated with a good season. Observing a bird singing while facing downwards from the top a tree is a good indicator that it is about to rain, while a lot of birds is a sign of heavy rain.

The wind blowing from west to east, and from north to south, is assumed to bring a lot of moisture and a good rainy season. The prevalence of a strong wind from east to west during the day and at night between July and early November is an indicator of drought.

FIGURE 16

Anomalies in mean surface temperatures over Africa



Source: UNEP (2002).

are more hot days and fewer cold days over time. Night-time minimum temperatures increased at twice the rate of daytime maximum temperatures. Precipitation deviations from a long-term mean are stated to have increased during the last century. While the exact nature of the changes in temperature or precipitation and extreme events are not known, there is general agreement that extreme events will become worse, and trends in most variables will change in response to warming. The expected warming is greatest over the interior semi-arid margins of the Sahara and central-southern Africa. Figure 16 illustrates anomalies during the past 100 years in mean surface temperatures in Africa. A notable upward trend/cycle is shown for the past 25 years. This rate of warming is similar to that experienced globally (UNEP, 2002).

PHYSIOGRAPHY

Physiography relates to the physical features of the earth, and it is used here to describe the landscapes of the Limpopo River Basin. The physiographic features of a region commonly affect its climate patterns and tendencies (e.g. rainfall intensity and distribution) and water drainage patterns (surface and subsurface). An important application of physiographic classification is the provision of a physical framework for land use planning in general and catchment management in particular. In addition, the physiography, together with the climate, forms the basis of agro-ecological zoning (AEZ), which is discussed in a later section.

Geology

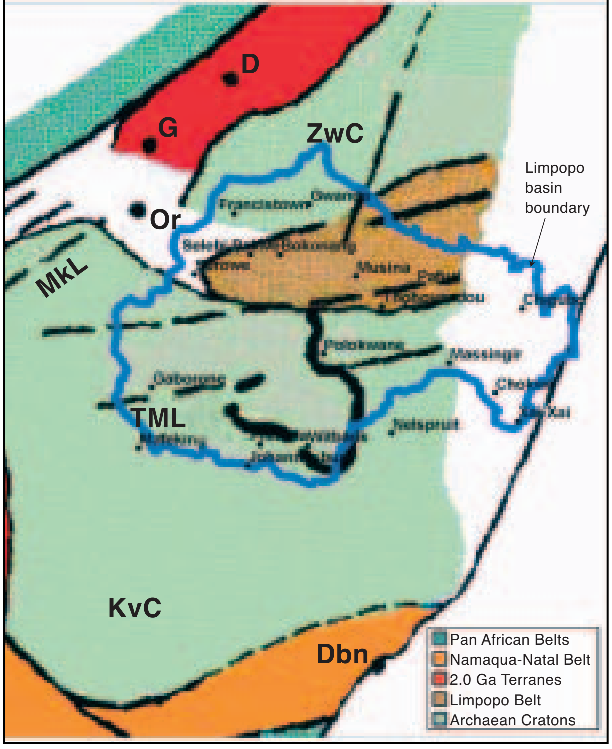
Landform and soil development are linked to geological and tectonic development at a subcontinental scale. Much of the present landscape of the Limpopo River Basin reflects recent geological events – in geological terms – following the break-up of Gondwanaland (Moon and Dardis, 1988). Tankard *et al.* (1982) and McCourt and Armstrong (2001) recognized the sequence of crustal evolutionary stages in southern Africa.

The Limpopo River Basin is located on the northeast edge of the Kaap-Vaal or Kalahari craton (KvC in Figure 17) and extends onto the southern part of the Zimbabwe craton (ZwC in Figure 17). The Limpopo mobile belt (granulite facies; shown in centre of the basin in Figure 17) and the Bushveld Igneous Complex (not shown in Figure 17) separate the two. The cratons constitute a stable shield, predominately of igneous and metamorphic rocks, at the base of the continental crust. The Kaap-Vaal craton is mostly covered sedimentary rocks. The genesis of the Basement Complex covers a period of 1 000 million years, falling within the Archaean period.

Granite and gneiss are the dominant rock types of the Basement Complex on the highveldt and escarpment of South Africa, with quartzites, granodiorites, and various slightly to moderately metamorphosed sedimentary rock occurring subordinately. The southern part of the Limpopo

FIGURE 17

Generalized tectonic framework of southern Africa



Source: McCourt and Armstrong (2001).

River Basin within the highveldt is characterized by the occurrence of Karoo sediments (Vryheid Formation), including sandstones, claystones, shales, and coal deposits. Karoo sediments and basalt also occur in a strip from northeast Botswana through southern Zimbabwe. Similar Cretaceous sediments (sandstones, grits and conglomerates) border Zimbabwe with Mozambique. The eastern strip of the lowveldt and the Lebombo Ridge are also dominated by similar Karoo formations, with subordinate occurrence of dolerite intrusions.

Cycles of geological erosion

Cycles of erosion have shaped the present landscapes of southern Africa. There is general agreement with respect to the major phases, but opinions differ regarding the more complex subdivisions (King, 1976; Partridge and Maud, 1987). Most of the Limpopo River Basin shows relatively advanced eroded conditions, and often shows younger and shallower soils as compared with less-eroded surrounding areas.

Erosion cycles during the early Tertiary period formed the African denudational surface at high or medium plateau level, such as the highveldt in South Africa. Its major occurrence is southwest of the southern divide of the Limpopo River Basin, the high-level plateau zone in Zimbabwe, the elevated areas near Polokwane (Pietersburg) in South Africa, and the flat-topped hills in eastern Botswana and Limpopo Province in South Africa.

Further erosion in the late Tertiary period formed the Post-African denudational surface. Various phases of this surface are dominant in the Limpopo River Basin. The most recent erosion was active during the Quaternary period, primarily downstream of the main rivers and tributaries in the basin area.

Most of the land within the Limpopo River Basin in Mozambique was formed by aggradational surfaces during the Quaternary and Tertiary periods, except for a band of Cretaceous rocks occurring north of the Save River to the border with Zimbabwe. Extensive, well-developed alluvial formations occur in the middle and lower reaches of the Limpopo River, and in the watercourses of the non-perennial rivers entering the Limpopo River. The oldest formations (Palaeocene and Eocene rocks) are of marine facies and correspond to the calcareous sandstones and conglomerates, which are disconformably overlain and border the effusive Karoo formations on the western border with South Africa.

The main unit of the Quaternary cover is a thick, homogenous mantle of yellowish-brown, saline, sodic, calcareous, sandy clay loam extending over the vast interior of Gaza Province west of the Limpopo River. It builds large, slightly sloping plateaus called *Mananga* developed over sedimentary, coarse and siliceous rocks. Near the incised valleys, the basal gravels have been exposed after erosion of the *Mananga* cover. Different cycles of weathering and landscape lowering reworked the resistant gravels into basal gravel floors. The highest gravels correlate to the red sandstones and conglomerates of the late Tertiary. The higher, lower and young gravels are associated with the respective *Mananga* platforms.

Physiographic description and mapping

The three major physiographic units of the interior are the South African Plateau (or Cape–Transvaal highveldt), the Zambia–Zimbabwe Plateau and the Kalahari Basin (Bridges, 1990). The Great Escarpment separates these units from the coastal ranges and coastal plains.

Figures 18 and 19, derived from digital elevation modelling, illustrate the basin structure with elevated remnants in places. The Limpopo River Valley separates the plateau areas of South Africa and Zimbabwe, and is bounded to the west by the Kalahari Basin. Towards the east, the Elephants River and several other smaller tributaries of the Limpopo River (see also Figure 7) traverse the Lebombo Ridge before joining the Limpopo River on the coastal plain in Mozambique.

At a generalized level, plains at various altitudes are the dominant landforms of the basin. These

FIGURE 18
Relief map of the Limpopo River Basin

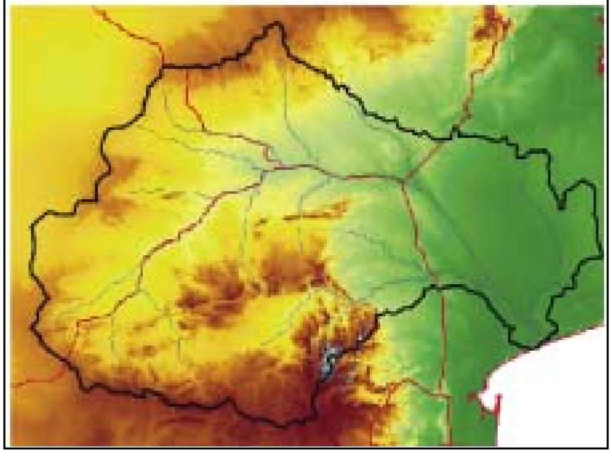
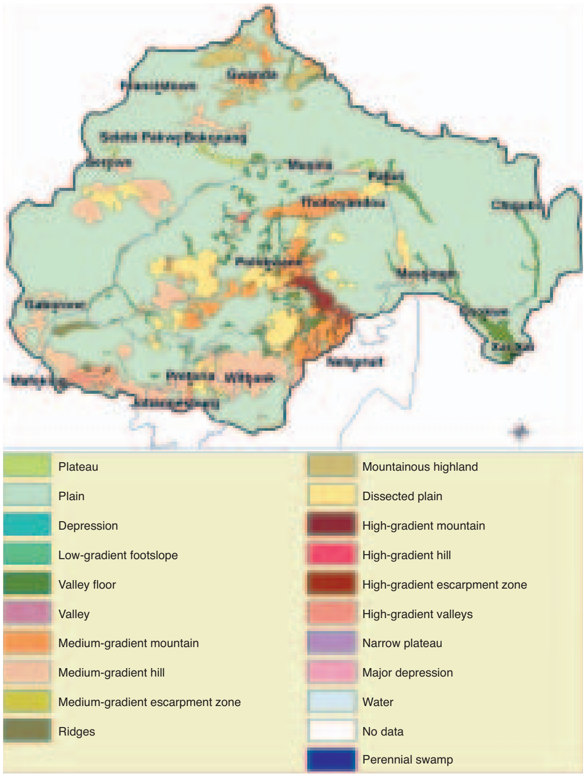


FIGURE 19
Dominant landforms in the Limpopo River Basin



Source: FAO–ISRIC (2003).

are interspersed with low-gradient hills, locally incised valleys and medium-gradient mountains (e.g. the South African Waterberg plateau and the Soutpansberg mountain range). The morphology of the basin, in particular the position of the mountain ranges, has a strong influence on the climate and rainfall pattern in the basin.

Botswana

The land systems of Botswana (De Wit and Bekker, 1990) follow the original land systems concept developed in Australia. This is a hierarchical system based on the subdivision of larger land units into smaller land units, using various criteria linked to major landforms, geomorphological forms, and geology (lithology). This approach is useful for exploratory and reconnaissance mapping, but is of limited use in regional correlation exercises given the use of local nomenclature and non-standard terminology. The Limpopo River Basin falls within the major land division of the hardveldt, a mainly flat to undulating surface with occasional hills and ridges that developed on the Basement Complex. The associated soils vary strongly, especially in depth and clay content, and hence in water-holding capacity and sensitivity to drought.

Mozambique

In Mozambique, the Limpopo River Basin is almost flat, with a gentle slope in a northwest–southeast direction. The Limpopo River crosses a fluvial plain with terraces 1–3 km wide before the confluence with the Elephants River, widening to 2–5 km after the confluence. All basins in Mozambique lie below 400 m above sea level. The Changane River Valley is unusual in that it is situated along an old beach line and flows intermittently.

The main physiographic features of the basin in Mozambique are captured on a generalized landscape map at scale 1:1 million whose units are derived from geology, geomorphology and soils. Landscape patterns are described based on landform, and topography and slope subdivisions, of which 12 classes are applicable to the Gaza Province in which the Limpopo River Basin is located (Figure 20).

South Africa

The terrain morphology map of southern Africa (Kruger, 1983) depicts six broad terrain divisions subdivided according to relief, topography, slopes, and drainage density. The map provides a useful

FIGURE 20
Landscape map of Gaza Province, Mozambique

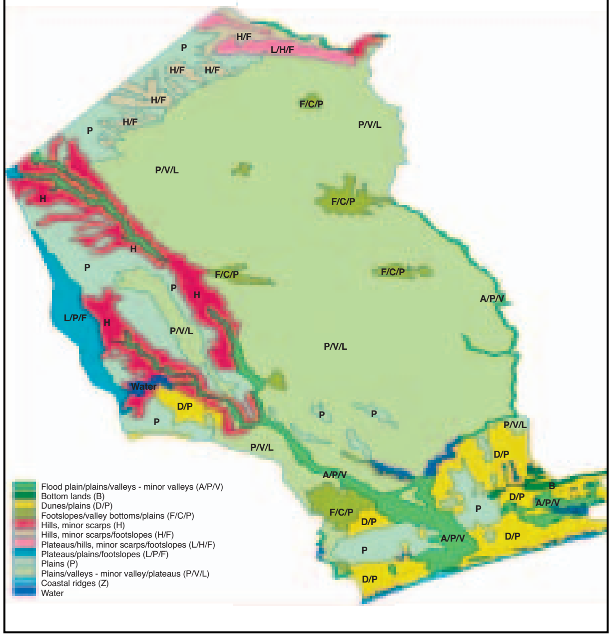
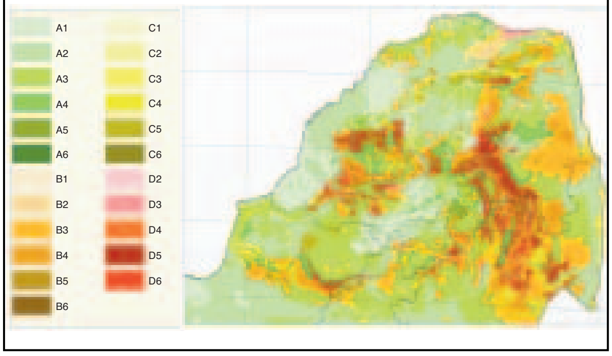


FIGURE 21
Terrain types of the northern parts of South Africa



Source: ARC-Institute for Soil Climate and Water (2004).

pattern of the landscapes of South Africa, but lacks systematic definitions of landforms and other terrain units, and is thus difficult to correlate with approaches used by other countries. At a more detailed level, the procedure for terrain description employed by the national land type survey (Turner and Rust, 1996) describes the terrain or relief of an area quantitatively by means of two parameters: percentage of level land and local relief (Table 3 and Figure 21).

Zimbabwe

Lister (1987) describes four geomorphic provinces within Zimbabwe: the Eastern Highlands, the Limpopo–Save Lowlands, the Zambezi Valley, and the Central Axis (including highveldt, middleveldt and Kalahari sandveldt). The Limpopo River Basin takes up parts of the Limpopo–Save Lowlands and parts of the highveldt and middleveldt subdivision of the Central Axis. Other than a relief map at a scale of 1:1 million (GOZ–Surveyor-General, 1984), no systematic physiographic inventory of Zimbabwe is available.

A description of the physical resources of the communal lands by Anderson *et al.* (1993) includes a generalized account of the landform of the mapped land units (1:500 000), e.g. "the landform is characteristically almost flat to gently undulating with slopes mainly less than 2 percent". The land units described in this study cover 42 percent of the country.

TABLE 3
Terrain parameters used in the South African Land Type Survey

Percentage level land [1]		Local relief (m) [2]		Terrain type description [3]
Symbol	Class	Symbol	Class	
A	> 80	1	0–30	Level plains
		2	30–90	Level plains with some relief
		3	90–150	Plains with open low hills or ridges
		4	150–300	Plains with open high hills or ridges
		5	300–900	Plains with open low mountains
		6	> 900	Plains with open high mountains
B	50–80	1	0–30	Rolling or irregular plains with low relief
		2	30–90	Rolling or irregular plains with some relief
		3	90–150	Rolling or irregular plains with low hills or ridges
		4	150–300	Rolling or irregular plains with high hills or ridges
		5	300–900	Rolling or irregular plains with low mountains
		6	> 900	Rolling or irregular plains with high mountains
C	20–50	1	0–30	Open low hills or ridges with low relief
		2	30–90	Open low hills or ridges
		3	90–150	Open hills or ridges
		4	150–300	Open high hills or ridges
		5	300–900	Open low mountains
		6	> 900	Open high mountains
D	< 20	2	30–90	Low hills or ridges
		3	90–150	Hills or ridges
		4	150–300	High hills or ridges
		5	300–900	Low mountains
		6	> 900	High mountains

[1] Land with slope of less than 8 percent.
[2] Average difference between the highest and lowest point in the landscape as measured per 7.5 by 7.5 minute sampling area.
[3] After Kruger (1973; 1983).
Source: ARC–Institute for Soil Climate and Water (2004).

Synthesis of the physiography of the Limpopo River Basin

The following main landforms occur: plateau, hills, escarpment and plains.

Plateau

The plateau (flat to undulating, 600–1 500 m above seal level) includes the highveldt area of Botswana, Zimbabwe and South Africa. Although the Limpopo drainage system has eroded deeply into the overall plateau, it has not formed a distinct valley and thus a separate landform unit. Slopes towards the rivers are generally gradual. The plateau includes subordinate occurrence of groups of hills and ridges, which can be distinguished at more detailed scales.

In Botswana, the Limpopo River Basin starts within the transition boundary with the Kalahari sands. At Serowe, a distinct escarpment is formed in Karoo sandstone. The majority of the plateau is flat to gently undulating, in places undulating to rolling with kopjes. The main rock type is granite or granitic gneiss. Sandstones occur south of Mahalapye, and basalt dominates the eastern tip of Botswana, with some subordinate occurrences at Serowe.

Several groups of relatively small hills occur in the southern and central parts of the Botswana hardveldt, in particular near Gaborone and Palapye, often with flat tops at levels of about 1 200 m above seal level, corresponding with the African planation surface. These hills of medium relief (200–400 m above the base) consist mostly of sedimentary rock, but are also formed of dolerite (Shoshong) and other rock. The hills, e.g. the granite hills near Mahalapye, are often associated with pediments.

The plateau developed on the Basement Complex continues on the eastern side of the Limpopo River, in South Africa, also with a flat to gently undulating topography. The occurrence of Karoo sediments (sandstones and shales), including coal deposits near Middelburg and Witbank, characterizes a large area of the southern highveldt.

North of the Limpopo River, the plateau includes parts of the southern highveldt region of Zimbabwe (above 1 200 m above seal level, with Plumtree–Bulawayo as the main catchment) and the adjacent southeast middleveldt region (600–1 200 m, near Gwanda and surroundings). Tributaries of the Shashe and Limpopo Rivers, which run in a north–south direction, dissect the middleveldt. Rocks of the Basement Complex with greenstone belts dominate the geology.

Hills

In South Africa, quite large hilly areas (rolling, 400–600 m above sea level) and ridges occur in the southwest half of Limpopo Province. These hills of the Bushveldt Complex include the Waterberg Hills – which could also be described as a plateau – and also groups of hills towards the southern edge of the catchment (Pilanesberg and Magaliesberg). The lithology of these hills differs from the granite of the basement, and includes quartzite and resistant rock types.

Escarpments

The escarpment zone is a complex landscape consisting of steep hills and mountains (600–1 500 m), forming the transition from the highveldt or Transvaal Plateau to the coastal plains of the lowveldt. The escarpment at the southeast divide of the Limpopo River Basin forms the watershed with the Komati River. Some parts rise to more than 1 500 m above sea level (medium relief class).

The Drakensberg Mountains form the highest part of the escarpment, rising above 2 300 m. Low, east–west mountain ridges (e.g. Soutpansberg and Strydpoortberg) arise above the plateau and link up with the escarpment. The escarpment is characterized by a complex of steep slopes between low and high levels, dissected plateaus and plateau remnants, with associated hills, valleys and basins.

Plains

The plains (gently undulating to undulating, 0–600 m) are the lowveldt of South Africa and Zimbabwe, and the coastal plains of Mozambique. The higher western part (300–600 m) forms the piedmont zone of the escarpment, consisting of eroded foot slopes, developed in mainly granite. Dolerite intrusions occur throughout the lowveldt.

The South African and Mozambican plains are separated by the Lebombo Ridge, which is a cuesta, or a tilted plateau with a steep escarpment bordering the lowveldt and a gradual dipslope of about 5 percent descending east into the coastal plains of Mozambique. This ridge, consisting of rhyolite, is more prominently developed towards the south, outside the Limpopo River Basin.

West of the Lebombo Ridge, north–south zones can be distinguished by rock types. In the Kruger National Park, there is a distinct zone of Karoo basalts, followed by Karoo sediments of the Ecca series (shales and sandstones) lying west.

The southeast lowveldt of Zimbabwe is a broad pediplain with elevations of generally less than 600 m and an almost flat to gently undulating topography. The transition to the middleveldt is gradual. The pediplain of the southeast lowveldt is developed in paragneiss of the Limpopo and Zambezi mobile belts, Karoo volcanics, and for a small part in Karoo sedimentary rocks.

In Mozambique, landforms in most of the interior basin east of the Limpopo River comprise flat to gently undulating plains, valleys, minor valleys and plateaus, not exceeding 5–8 ° in slope and 100 m in elevation. This unit coincides with the dominant soil characteristics belonging to the *Mananga* group of soils. Coastal dune and plain formations, extending inland from the coast to border the Changane River, dominate the landscape in the lower Limpopo River Basin. Extensive areas of floodplains exist along the Limpopo and Changane Rivers, with hills and minor scarps enclosing the middle–upper reaches of the Limpopo River as well as the Elephants River, the latter above 1 200 m.

SOIL RESOURCES

Regional overview

The soil resources of an area are an important factor in managing the effects of drought and climate variability. Those soil properties that relate to water storage (texture, soil depth and internal drainage) are particularly critical in semi-arid environments experiencing drought conditions. Soils also reflect environmental changes, and monitoring such changes is important in assessing the impacts of land use.

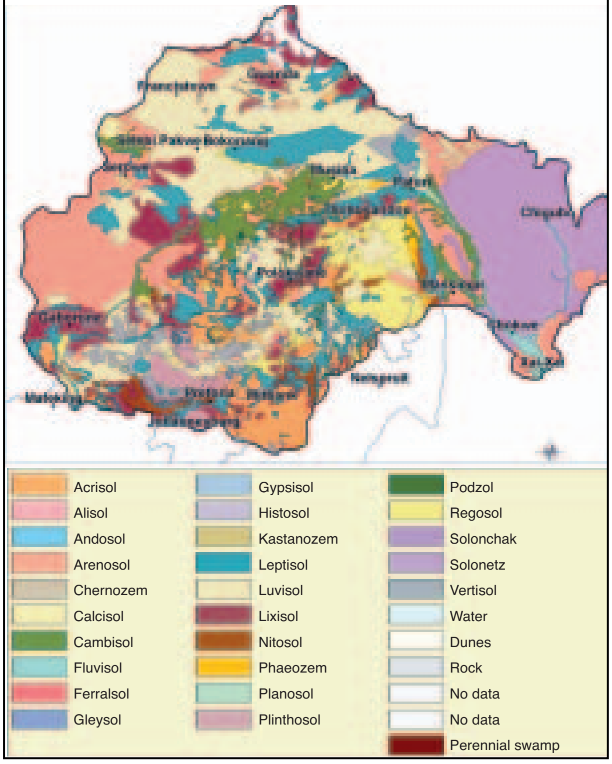
The soils in the Limpopo River Basin may be categorized broadly into two main groups: (i) old soils formed on deeply weathered parent materials, influenced by earlier erosional surfaces; and (ii) relatively young soils, formed on the more recent erosional surfaces, or on alluvial deposits. Deeply weathered ancient soils occur mainly on the plateaus (highveldt) of South Africa and Zimbabwe, and in some protected areas of the escarpment zone. These soils have formed over long periods on the weathering mantle or saprolite, and have developed under warm and humid climate conditions needed for intense chemical weathering. Younger and less weathered soils characterize the denuded hills and mountain ridges, the lowveldt, the coastal plains of Mozambique, and also large parts of the higher plains within the Limpopo River Basin where recent and subrecent erosion has removed any deeply weathered soils. Recent and subrecent climate conditions have not been conducive to strong weathering and new formation of saprolite in the eroded areas. This applies also to the highveldt; higher rainfall and higher temperatures than those occurring at present are required for progressive saprolite formation.

Extensive work on soil mapping has taken place in the last 20–30 years in the subregion, including the four countries of the Limpopo River Basin. A wealth of soil information is available, but it is not easily accessible. Different systems of mapping and classification are evident, and still in use.

FAO, in cooperation with the SADC countries and the International Soil Reference and Information Centre (ISRIC), has produced a seamless, generalized soils coverage (scale: 1: 2 million) of those countries with soil and terrain digital databases (SOTER) (Figure 22). The World Reference Base for Soil Resources (WRB) classification (FAO–ISRIC–ISSS, 1998) was used as a unifying medium of communication. However, the beta version of the CD-ROM released does not contain information on critical soil attributes such as soil depth and texture, apart from what may be inferred from a number of soil profiles for which data are given (not included here). Figure 22 shows the following:

- Arenosols (recent and preweathered sands) occur on the Mozambique coast, in a zone adjacent to the Lebombo range, and in the southern half of the Botswana part of the basin.
- Solonetz soils (sodium-affected soils) cover the bulk of the Mozambique coastal plain.
- In the Zimbabwean and northern Botswanan parts of the basin, Luvisols (soils with a clay increase, not highly leached) and Leptosols (shallow soils) dominate.
- In the South African part of the basin, Regosols (weakly developed soils) dominate the lowveldt between the eastern escarpment and the Lebombo range. Leptosols occur wherever the terrain is hilly.
- Vertisols (swelling clays) and associated Nitisols (red, fertile clays or clay loams) are found on mafic rocks.
- Acrisols, soils with a low cation exchange capacity (CEC) and low base status, dominate the highveldt of the southern basin.

FIGURE 22
Generalized soils map of the Limpopo River Basin in terms of the WRB classification



A message that might not be conveyed effectively by overview maps, presenting taxonomic information only, is that the soil cover is highly variable and mostly thin except for the areas covered by sandy blanket surface deposits in the southwest, the coastal plain in the east and the highveldt plateau in the south. This is due to the hard and variable geology, the dry climate and the process of basin incision.

Status of soil mapping in the four basin countries

Botswana

Extensive soil mapping in the 1980s covered most of the country at a reconnaissance scale of 1:250 000, including the Limpopo River Basin. Systematic soil description, classification and analytical methods were developed, as were computerized systems for storage and retrieval of soil information, in which 3 500 soil profiles were captured (Remmelzwaal, 1988). The soil database (SDB) developed in Botswana has become the FAO SDB standard (in terms of quantity and quality, it is one of the most comprehensive and reliable databases in Africa).

An ongoing soil survey (1:50 000) is taking place within the agricultural areas. The general soil map of Botswana (De Wit and Nachtergaele, 1990) provides information and spatial distribution on a national basis.

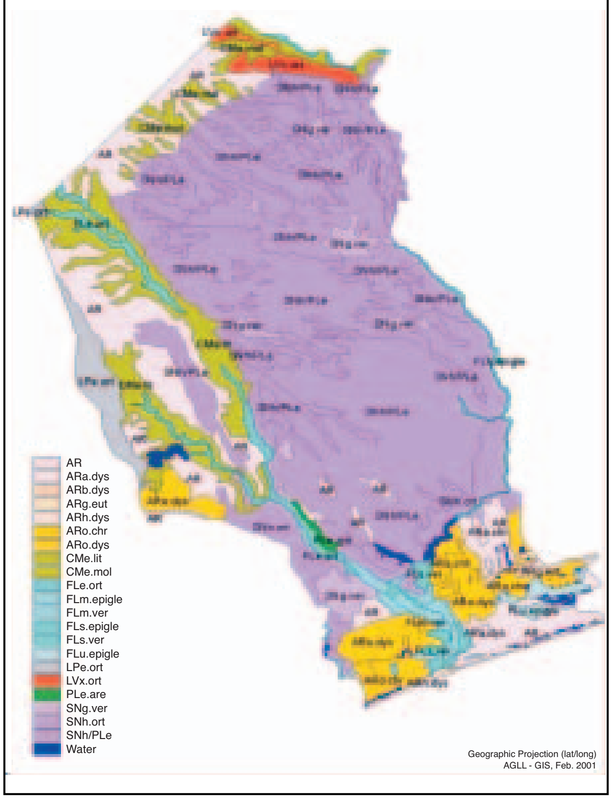
The Limpopo River Basin is covered by a series of soils and land suitability reports and maps which include the following areas: southeast central district (Remmelzwaal, 1989), northern central district (Moganane, 1990), Gaborone (Moganane, 1989), Lobatse (Mafoko, 1990), and northeast district (Radcliffe, Venema and De Wit, 1990).

Mozambique

Soil distribution in Mozambique generally follows the physiographic characteristics (Figure 23). The southern region and the coastal plains have sandy soils, except for the rich alluvial deposits along the major rivers and streams.

Soil survey activities in Mozambique started in the 1940s with the compilation of the first soil map of Mozambique (Schokalsky, 1943). In the same decade, exploratory studies covered large areas, done principally by the Centro de Investigacoes Cientifica Algodoeira, which compiled the second

Figure 23
Dominant Soil map of Gaza Province, Mozambique



soil map of the country at a scale of 1:6 million (CICA, 1948). Soil studies continued over the years, and in the early 1970s various foreign consulting firms (e.g. Loxton-Hunting, COBA and ETLAL) completed reconnaissance surveys of large areas. During this period, two published soil maps covered the whole country: (i) Carta dos Solos (scale: 1:4 million); and (ii) the Soil Map of the World (scale: 1:5 million) (FAO–UNESCO, 1974a; 1974b). In Mozambique, 34 different soil units of the FAO–UNESCO system occur, comprising 16 major soil units. However, for areas defined as belonging to the Limpopo River Basin (with the exception of a narrow coastal strip north of Maputo), the reliability of soil units is reported as poor for the upper reaches of the Limpopo River in Gaza Province to the Zimbabwe border, extending north to the Save River; and fair for the middle and lower zones of the Limpopo River to the coast. This map served as the inventory of soil resources, providing essential phase data until its revision in 1984 (Voortman and Spiers, 1984). In 1991, a revised national soil map based on descriptions of 800 soil profiles was produced at scale of 1:1 million (digitized), using the 1988 FAO–UNESCO–ISRIC legend (INIA, 1995). The National Institute for Agronomic Research (INIA) maintains computerized soil records using the FAO–ISRIC SDB. Specifically, the soils of the Limpopo River Basin were covered by a general reconnaissance survey as part of the Limpopo Master Plan studies by Selkhozpromexport (1983), covering an area of approximately 4.17 million ha.

South Africa

South Africa has a vast database on soil and terrain conditions, the national land type database, containing the data of a complete coverage of land type maps at a scale of 1:250 000. This database contains soil classification, soil attributes, terrain and climate data (Turner and Rust, 1996). A second database contains descriptive and analytical data of a vast number of representative soil profiles. These databases are archived at the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC). Eleven 1:250 000-scale land type map sheets cover the Limpopo River Basin. Detailed soils maps are also available for a 2-km-wide strip along the Limpopo River and for most irrigated areas in the South African part of the basin. The Generalized Soil Patterns of South Africa is the most recent national soil map compilation (GOSA–Land Type Survey Staff, 1997). The main soil groupings of the legend are subdivided according to properties such as base status, topsoil development and texture (in brackets, the number of subdivisions):

A red-yellow well-drained soils lacking a strong textural contrast (4);
B soils within a plinthic catena (2);
C soils with a strong textural contrast (2);
E soils with high clay contents (1);
F soils with limited pedological development (5);
G Podzolic soils (1);
H rocky areas (1).

The map is useful for an overview of the spatial distribution of the main soil types in the Limpopo River Basin and its relationship with the main landscape units. The dominant soil groups are A and B, with C, E and H subordinate or occurring in complex. The oldest and most-weathered soils (B with low base status) are found on remnants of the African erosion surface. This surface is of Tertiary to Cretaceous age (Partridge and Maud, 1987) and, within the Limpopo River Basin, constitutes the highveldt southeast of Pretoria. Soils from group A with high base status are dominant in the eroded areas nearer to the Limpopo River.

Zimbabwe

The most comprehensive map available is the Soil Map of Zimbabwe, at a scale of 1:1 million (GOZ–DRSS, 1979). Although there is large uncertainty with respect to the accuracy of the information for some areas, this map is widely used. The legend to the soil map reflects primarily the degree of weathering and leaching of the soils, and the influence of geology. Nyamaphene (1991) provides a relevant summary of the soils of Zimbabwe, with details on the properties and distribution of the major soil groups.

The soils of the communal lands of Zimbabwe, which cover 42 percent of the country, were mapped at a scale of 1:250 000 in a physical resource inventory (Anderson *et al.*, 1993). The information is presented as land units, which represent a combination of features such as geology, erosion, soils and land use. Typical soil profiles are classified according to the Zimbabwe soil classification system, and have been correlated with the legend of the Soil Map of the World (FAO–UNESCO–ISRIC, 1990) and soil taxonomy (Soil Survey Staff, 1975).

A project under the auspices of FAO, the ISRIC and the UNEP aims to update the 1979 soils map with information from the communal lands study. Information will be digitized and contribute to the revision of the 1:1 million Soil Map of the World.

Soil classification and correlation

The sustainable use of major soil groupings and specific soil types requires differential management. Soil classification is an important element of soil science, and allows transfer of information relevant to soil resources in comparable environments. Efficient transfer requires correlation of the different classification systems.

Botswana and Mozambique use the FAO soil classification system (FAO–UNESCO–ISRIC, 1990). The South African binomial system of soil classification (MacVicar *et al.,* 1977) is applied to all major mapping programmes in South Africa. The revised South African soil classification (GOSA–Soil Classification Working Group, 1991) introduced new soil forms for the arid and semi-arid regions, which were underrepresented in the first edition. Thompson and Purves (1978) developed the classification system used in Zimbabwe, based on the inter-African pedological system of the 1960s.

Soil correlation between the first version of the legend of the Soil Map of World (FAO–UNESCO, 1974a) and the South African, Zimbabwean and Botswana soil classification systems was undertaken in the 1980s (SARCCUS Standing Committee for Soil Science, 1984). Although the results of this first effort are still relevant, there have since been two revisions of the FAO system: (i) the revised legend of the Soil Map of the World (FAO–UNESCO–ISRIC, 1990); and (ii) development of the WRB (FAO–ISSS–ISRIC, 1994, 1998; ISSS–ISRIC–FAO, 1998; ISSS Working Group RB, 1998a, 1998b).

In preparation for developing the SOTER, Remmelzwaal (1998) correlated the South African soil forms with the soil units of the WRB (FAO–ISSS–ISRIC, 1998), and between the South African soil forms and the legend units of the generalized soil map of South Africa (GOSA–Land Type Survey Staff, 1997). These classification efforts contain several useful elements for the 1:1 million South African SOTER soils definition currently under preparation, but require further analysis, and probably a development towards a larger and more precisely defined set of soil groups. Remmelzwaal (1998) also proposed the transfer of soil series information from the South African land type maps to the new SOTER system. The FAO classification and description systems are the ones most commonly used in the SADC region. The SOTER system has close links with the FAO approach, and its wider introduction would promote the standardization of soil and terrain description in southern Africa. The SOTER should be organized in such a way that it readily provides the basic information needed for land evaluation and AEZ.

The Africa volume of the Soil Map of the World (FAO–UNESCO, 1974b) shows major deficiencies as its compilation took place when insufficient soil information was available from southern Africa. The new SOTER standardized soil map covering the Limpopo River Basin (Figure 22) would facilitate land evaluation and appraisal of land suitability for various uses, once the necessary soil attributes have been provided.

Major soil units of the Limpopo River Basin

This section contains an overview of the major soil units in the Limpopo River Basin, based on available soil maps and reports and using soil classification terminology defined in the World Reference Base for Soil Resources (FAO–ISSS–ISRIC, 1998). Their occurrence is linked to the physiographic units applied to the Limpopo River Basin (above).

Soils of the high plateaus and escarpment

Highveldt

Non-incised plateau areas in the southeastern part of the basin, the highveldt east of Pretoria in particular, are mainly covered by Acrisols and Ferralsols. These deeply weathered and highly leached red-yellow soils reflect long periods and cycles of soil formation. They are characterized by an acid soil reaction, high or moderate clay contents, low CEC of the clay, and low base saturation. Ferralsols and Acrisols also occur in watersheds adjacent to the Limpopo River Basin, in South Africa and in the northern highveldt and eastern highlands of Zimbabwe. Within the Limpopo River Basin, these soils also occur as relicts in southeast Botswana, in North West Province in South Africa and at the Northern Divide in Zimbabwe. Associated soils include Leptosols, Regosols and Histosols on incised topography.

In the western highveldt areas of the basin, Arenosols and Regosols are dominant on sandstone and sandy surface deposits. These occur extensively in Botswana, and also in the western parts of South Africa, and to some extent in Zimbabwe towards the Mozambican border. Occasionally, Fluvisols and Gleysols occur on alluvial deposits.

Incised highveldt

Parts of the highveldt within the basin consist of incised topography. Examples occur in relatively close proximity to the Limpopo River in Botswana, Zimbabwe and South Africa. The soils in these areas reflect the rejuvenating effects of stream incision on the landscape (mostly in the form of shallow profiles). They also reflect the current relatively dry climate. Dominant soils on the granite/gneiss Basement Complex are Lixisols and Luvisols, with slightly acid to neutral soil reaction extending to alkaline in poorer drained conditions. These yellowish-red soils are of sandy loam to sandy clay loam texture, with medium to relatively high CEC and medium to high base saturation. Associated soils are Regosols, Arenosols and Leptosols. Calcisols, Planosols and Solonetz may occur in the lower positions of soil catenas. Most Calcisols and Solonetz occur in the driest parts of the basin.

The soil sequences found on basalt and other basic rock include Vertisols, Regosols, Luvisols and Calcisols. These predominantly dark-coloured clayey soils generally have a high base status and CEC. Basalt occurs at the border near Gaborone, and eastwards in a strip from the extreme northeastern part of Botswana across Zimbabwe towards Mozambique. Soil patterns on basalt are variable, often dominated by shallow Regosols. Vertisols occur predominantly in lower and alluvial positions, such as on the Springbok Flats north of Pretoria. Luvisols, Lixisols and Nitisols are the main soils in Zimbabwe, particularly in areas with mafic rocks (greenstone belts) around Bulawayo (highveldt) and Gwanda (middleveldt).

Hills, mountains, and higher parts of the Escarpment

Hills and mountains exhibit a larger variety of rock and weathering materials than the relatively level plateaus and plains. On the lower and middle slopes, a variety of soils occur such as Regosols, Luvisols, Cambisols and Lixisols. Leptosols dominate the higher and most-eroded hills and mountain slopes.

Soils of the lowveldt and coastal plains

Lowveldt

Soils of the escarpment foot slopes and the lowveldt itself are at best moderately weathered and show a wide range of soil characteristics, depending on parent material, position, erosion, etc. They include Vertisols, Planosols, Solonetz, Lixisols, Luvisols, Phaeozems, Cambisols, Arenosols, Regosols and Leptosols. All these soils have a neutral or alkaline soil reaction, a high base status and medium or high CEC values. However, textures and some other properties such as soil depth, colour and structure show a wide variation.

The interior plains and low plateaus of the basin in Mozambique consist almost entirely of Solonetz, associated with Solonchaks and Arenosols in secondary occurrence across large areas to the east of the Limpopo River. These soils coincide with the *Mananga* landscape and exhibit characteristics of coarse texture, very low water retention capacity, and low inherent fertility (especially nitrogen and phosphorus). Coupled with a low rainfall environment, these areas impose severe limitations on rainfed agriculture.

There are two distinct belts of soils running north–south on the western side of the Lebombo Ridge. Soils formed on basalt occur immediately west of the ridge. These consist of dark brown Luvisols in high landscape positions and dark grey and black Cambisols and Vertisols in lower landscape positions. Further to the west is a belt of soils mainly developed on shales and sandstones, with Lixisols, Luvisols and Arenosols dominant.

Nitisols are found in some specific locations, such as on the Lebombo Plateau. This soil type shows more intensive weathering and soil formation than generally found in the low plains, and is characterized by intermediate CEC, relatively high base saturation and high clay contents. This belt extends towards the south outside the basin.

Coastal plains and alluvial areas

The dominant soils of the coastal dunes and coastal plains of Mozambique are Arenosols, with Gleysols found in secondary occurrence. Alluvial deposits upstream from Messina are found mainly in narrow strips along the Limpopo River and its main tributaries. The most common soils are Cambisols, Luvisols, and Arenosols on terraces and levees, with some Fluvisols on recent deposits.

Downstream from Messina and into Mozambique, Fluvisols dominate the extensive floodplains along the Limpopo, Changane and Elephant Rivers. Cambisols are characteristic soils of the hills and minor scarps bordering the Limpopo and Elephant Rivers, extending north from their confluence.

Problem soils and environmental aspects

Some of the soils of the Limpopo River Basin may be regarded as problem soils. The constraints may be inherently present or caused by unsustainable use (Barnard *et al.*, 2000; Van Der Merwe *et al.*, 2000; Nzuma, Mugwira and Mushambi, 2000). Depletion of soil resources may result from a range of interrelated natural and anthropogenic factors, whose processes and causes are elaborated more fully in the section on land degradation (below).

Restricted water-holding capacity

Although the rainfall of the basin is mostly low and erratic, large rain events occur periodically. The best soils have the ability not only to absorb and make available to plants small rainfall events of 5–10 mm, but also to absorb, store and make available the water from rain events of 50–70 mm. Three common restrictions are: inadequate soil depth (restricting the plant water reservoir); high clay content (causing runoff and low water availability); and excessively low clay content (causing excessive drainage and restricting the plant water reservoir). The presence of slowly draining material beneath a permeable rooting zone may add considerably to the profile water-holding capacity (Box 6). Figure 24 shows some examples of problem soils in the South African part of the basin.

BOX 6

Beneficial drainage-retarding layers beneath the rootzone

In the South African soil classification system (MacVicar *et al.*, 1977; GOSA–Soil Classification Working Group, 1991), the presence of drainage-retarding layers beneath the rootzone (soft plinthic B horizon, gleycutanic B horizon, signs of wetness) is recognized for its beneficial effect on rainfed land use under restricted rainfall conditions. The soil forms in which drainage-retarding layers occur at the bottom of the profile (Avalon, Bainsvlei and Pinedene) have become known for their favourable water-holding properties and good crops. The reason is that more plant-available water is held than the amount suggested by the matric potential alone, corresponding to soil depth and texture. This phenomenon is difficult to quantify because of lateral water movement above the drainage-restricting layer.

Erodibility and crusting/surface sealing

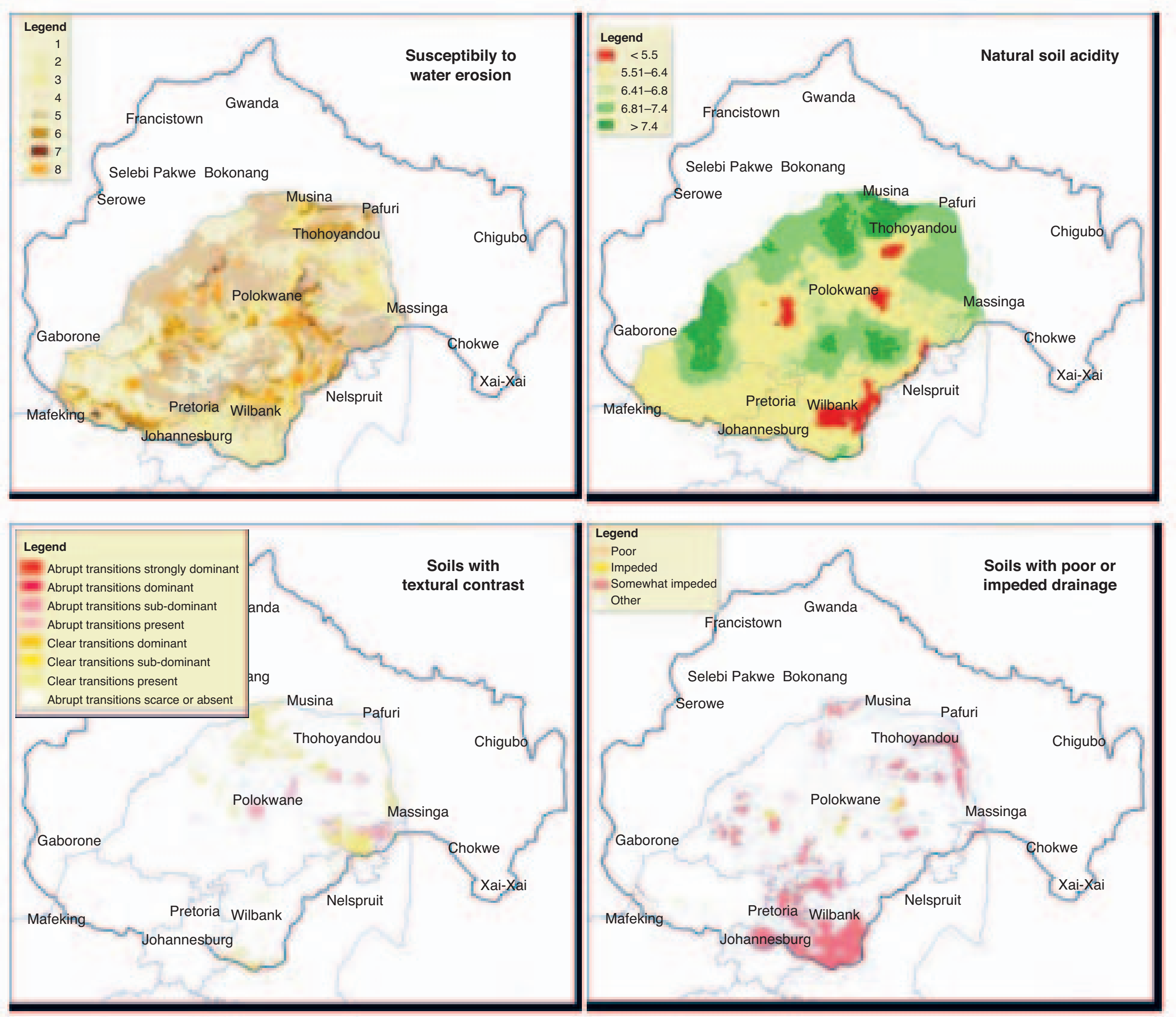
Four relatively permanent land characteristics determine the susceptibility of land to water erosion. These are slope gradient and length, rainfall erosivity and the susceptibility of the soil to water erosion. The latter is of concern here. Solonetz and Planosols generally have low structural stability, resulting in adverse macrostructure conditions in the subsoil and susceptibility to crusting of the surface horizon. These conditions stem from the presence of relatively easily dispersible clay minerals or clay-size quartz (Bühmann, Rapp and Laker, 1996; Bühmann, Van Der Merwe and Laker, 1998; and Bühmann, Beukes and Turner, 2001) and may be aggravated severely by sodicity. These soils are rendered susceptible to erosion and require adequate management. Southern African soils in general are susceptible to crusting/surface sealing owing to a low organic matter content, high rainfall energy and sparse vegetation cover in places.

In the western arable districts of the basin, wind erosion is an acknowledged problem. This is caused by the prevalence of sandy soils (Arenosols), cultivation practices and low rainfall resulting in low plant biomass production and soil organic material. Smit (1983) and Hallward (1988) have pointed out that the main danger of wind erosion is the loss of fine materials (fine silt and clay) from topsoils in the form of dust. By losing fine material, the soil loses much of its ability to provide plants with water and nutrients.

Textural contrast

The strong textural contrast displayed by Solonetz, Planosols and some Luvisols renders them problematic from a plant-extractable water viewpoint. Some members (mostly Solonetz or Planosols) display an abrupt transition between the topsoil (or sandy layer beneath the topsoil) and the subsoil with respect to texture, structure and consistence. The material above the transition is usually of light texture, permeable and can be penetrated readily by water and roots. The material below the transition is usually clayey, dense, very slowly permeable and can be exploited by roots to

FIGURE 24
Examples of soil attributes affecting resilience and sensitivity in the South Africa part of the Limpopo River Basin



a very limited extent. The subsoil is characterized by very low water stability and, thus, is highly susceptible to water erosion, particularly deep gullying, when exposed. In other members (certain Luvisols), the textural contrast is less prominent. A clear transition is found between the topsoil and the subsoil in respect of texture, structure and consistence. The topsoil is relatively sandy in relation to the subsoil, and the subsoil is clayey and dense, but commonly not to the extreme. Nevertheless, these soils are less water stable than the norm, and water infiltration is slower than the norm, rendering them prone to water erosion. Sodium is often present in the subsoils of both types, contributing to water instability and erodibility. Because of the severely limited effective depth and plant extractable water-holding capacity, textural contrast soils have become known as "droughty" agricultural soils.

Vertic properties

Vertisols and soils with vertic properties are common in South Africa and Botswana. They are reported to suffer from crusting, runoff, erosion and other forms of degradation (Van Der Merwe *et al.*, 2000). This rather negative picture is not generally applicable, but depends rather on specific occurrence, development, and management. For example, crusting is not typical of Vertisols. On the contrary, well-developed Vertisols have a surface mulch layer and cracks rather than crusts. Infiltration rates are impeded after the first rains close the cracks and, hence, are susceptible to waterlogging, especially after heavy rains. Although

Vertisols have a high water-holding capacity, they also have high water retention unavailable to plants. Nonetheless, vertic soils belong to the better and most fertile soils, but they require good management with low tillage and stubble cover.

Acidity

Acid problem soils are those most frequently reported, often without indicating their specific occurrence in the basin. Most acid soils are found in areas with relatively high rainfall, e.g. on the northern and southern fringes of the basin, in particular the South African highveldt areas occupied by Ferralsols and Acrisols. Acrisols and other inherently acid soils also occur locally in the more central parts of the basin, in southeast Botswana, in some of the central higher rainfall parts of Limpopo Province in South Africa, and in similar areas of Zimbabwe and Mozambique.

Salinization of irrigated soils

Inappropriate irrigation methods have led to saline soils, and in the worst cases result in the formation of Solonchaks, characterized by high salinity. Commercial irrigation normally applies improved management systems to control and monitor salinity levels, but under small-scale irrigation salinity is not always well managed. According to Barnard *et al.* (2000) about 10 percent of all irrigated soils in South Africa suffer from salinity or sodicity in one form or another, and this problem is likely to increase with the expected scarcity of water. Mashali (1997) discusses causes of salinization, its impact on production, and options to improve management.

Salinity is a major factor limiting the use of land developed for irrigation in this basin in Mozambique. Saline soils occupy 8 percent of the total productive area in the upper Limpopo River Valley, 30 percent in the middle Limpopo River Valley and as much as 70 percent in the lower Limpopo River Valley, where the Chokwé irrigation scheme is located.

The Chokwé irrigation scheme is the largest in Mozambique, and dates back to plans initially drawn up in the 1920s to irrigate the Limpopo River Valley. It was constructed in the early 1950s. It has supported intensive irrigated agriculture in the Limpopo River Valley, but has suffered badly from gross negligence in maintenance. By 1992, it was able to irrigate barely half of its design command area of about 33 000 ha (Tanner, Myers and Oad, 1993). In the past 40 years of irrigation, groundwater has risen to within about 30–50 cm of the soil surface, and the already significant land area out of production because of high soil salinity is increasing annually. The irrigation scheme suffered serious physical damage during the large-scale flooding in February–March 2000.

The problem of salinity is aggravated by the lack of adequate water management skills and by the poor drainage systems, resulting in soil fertility loss from waterlogging and salinization. Saltwater intrusion into deep-seated "soil" materials in the dry season exacerbates the risk of salinization, particularly during high tides. This is observed in the coastal areas of Xai-Xai District, from where the Limpopo River enters the sea, extending up to 50 km inland. The view is held that some Limpopo River Basin areas are too saline for complete reclamation to be economic.

Organic matter and nutrient depletion

Intensively cultivated soils in the basin generally undergo serious decline in organic matter. This results in structural and biological degradation and contributes to acidification. Organic matter contents are reported to have dropped to unacceptably low levels, leading to undesirable changes in soil structure and sharp yield declines. Folmer, Geurts and Francisco (1998) assessed the loss of soil fertility in Mozambique from agricultural land use, producing a map at scale 1:3 500 000. Negligible loss in soil fertility was reported for the middle and upper zones of the Limpopo River Basin, compared with moderate to high fertility loss south of Chokwé, particularly in Xai-Xai District and areas on both sides of the Limpopo River extending to the coast. Another study by Tique (2000) in the northern district of Chicualacuala links farmer observations to soil fertility declines associated with land pressure and reduced fallow periods in the district.

Soils with a serious decline in fertility as a result of cultivation are commonly reported from Zimbabwe and South Africa, but their extent is not known owing to the lack of monitoring on a wider scale (Van Der Merwe *et al.*, 2000). However, the negative impact on production is well documented from experimental plots and other observations. Their main occurrence is associated with soil types that are already of low inherent fertility (Box 7). Nabhan (1997) discusses general aspects of these soils and presents management options for addressing the problem. Low fertility soils, together with soils with a low organic matter

BOX 7

Nutrient deficiencies in the Maputaland sands linked to human health disorders

Pooley, Fey and Willis (1997) and Ceruti, Fey and Pooley (2002) have linked unusually high incidences of dwarfism and the endemic occurrence of Mseleni Joint Disease in a narrow north–south corridor of the Maputaland coastal plain to nutrient deficiencies in the recent Quaternary sands (Fernwood soil form). Soil samples were collected along transects through the high incidence area. Pooley, Fey and Willis (1997) found a suboptimal supply of calcium, phosphorus, zinc, copper and boron, and as all the deficient elements have been associated in medical literature with skeletal disorders, hypothesized that these might exert their influence synergistically. Ceruti, Fey and Pooley (2002) confirmed all soils to be deficient in Bray-1 extractable phosphorus and ammonium-EDTA extractable copper and zinc, with respect to critical levels for maize growth, having averages of 4.5, 0.5 and 0.4 mg/kg, respectively. There was a marked difference in ammonium-acetate extractable potassium and ammonium-EDTA extractable selenium between the low- and high-incidence areas, with average values of 209 and 27 mg K/kg, and 0.46 and 0.09 mg Se/kg, respectively. Other nutrients studied did not show anomalies between the two areas. In a subsequent study (Ceruti, Fey and Pooley, 2002), topsoil samples were collected at 1-km intervals along a roughly east–west transect (34 km) through the area with a high incidence of Mseleni Joint Disease. These were analysed for: phosphorus, potassium, manganese, iron, copper and zinc (Ambic-2 method); calcium and magnesium (KCl extraction); and boron (hot water extraction). In a subtractive maize growth pot trial, using a complete nutrient solution from which one element was withheld per treatment, yields for the minus phosphorus, potassium, calcium, sulphur and zinc treatments were all below 80 percent, relative to the complete treatment, indicating deficiencies of these elements. Plant tissue analysis showed deficiencies of phosphorus, potassium, calcium, magnesium, copper and zinc. Pockets within the landscape of multiple deficiencies were indicated, with copper and zinc deficiencies throughout the landscape.

content, are the main focus of a large number of soil fertility programmes, which have been implemented throughout the region. Chapter 4 discusses the results of these programmes.

Resilience and sensitivity of soils in relation to erosion and drought

Erosion-induced loss in soil productivity is a major threat to food security. There is sufficient evidence of a relationship between changes in productivity and cumulative water erosion, following a negative exponential curve. This means that initial yield decline is severe but that after prolonged erosion the yield decline lessens (Tengberg and Stocking, 1997).

Resilience and sensitivity of soils are important factors relating to changes in productivity (Table 4). Resilience describes the property of a soil to withstand an external force; it is site specific and relates to the erosion rate or the ease of restoring the land. Solonetz (sodic soils) are one of the least-resilient soil types, while Vertisols are one of the most resilient. Sensitivity describes the degree to which the soil changes when subjected to an external force, such as erosion; and relates to the relationship between soil loss and yield or how easy it is to degrade the land. Good, productive soils are more sensitive than eroded soils. The combination of the two factors is important. Tengberg and Stocking (1997) analysed a number of major soil units with respect to these factors. The sensitivity to yield decline from erosion was found to be highest in Phaeozems and lowest in Luvisols. Of the soils studied, resilience to erosion was highest in Phaeozems and lowest in Ferralsols and Acrisols. Of key importance are: soil organic carbon, erosion-induced acidity, and soil–water relationships.

Food security issues are related strongly to soil resilience and sensitivity as these factors determine critical production levels of a soil. The number of years required to reach this level varies considerably, and is dependent on management and soil type. The time taken for the major soil groups to reach their critical production level is, in increasing order: Ferralsols, Acrisols, Luvisols, Phaeozems, Cambisols and Nitosols.

It is concluded that Acrisols and Ferralsols are unsustainable under any continuous use without rest, and that Luvisols and Cambisols allow

TABLE 4

Factors affecting soil resilience and sensitivity

	Intensive rainfall	Low SOM	Steep slopes	Sodic soils	Poor management	Drought	Deforestation	Luvisol	Vertisol
Vertisol	Low S Low R	Low S Low R	N/A	Mod S Low R	Low S Mod R	High S Low R	High S Low R	N/A	
Luvisol	High S High R	High S High R	High S Low R	N/A	High S High R	High S High R	High S Mod R		
Deforestation	High S High R	High S Mod R	High S Low R	High S Low R	High S Mod R	High S Mod R			
Drought	N/A	High S Low R	High S Low R	High S Low R	High S Mod R				
Poor management	OF = S Low R	High S Mod R	High S Low R	High S Low R					
Sodic soils	High S Low R	High S Low R	N/A						
Steep slopes	High S Low R	High S Mod R							
Low SOM	High S High R								
Intensive rainfall									

S = sensitivity; R = resilience; OF = determined by combination of other factors; SOM = soil organic matter.

Source: Stocking and Murnaghan (2000).

continuous use only under good management. Management is related to soil cover. Bare or poor soil cover can result in productivity declines within 5 years, moderate cover indicates a period of 20–50 years, and a good cover 100–200 years (Tengberg and Stocking, 1997).

Although not always based on sufficiently long records of monitoring soil conditions, the importance of soils, their management and erosion risk in relation to food security is evident. This may also be extended to drought as a major factor in food security, and to drought as a factor in accelerating erosion. The results of soil resilience studies are very relevant to land use planning, in particular in drought sensitive areas.

TABLE 5

Rainfall and evaporation figures for major subcatchments (Figure 25)

Catchment	Area (km^2)	MAP (mm)	MAE (mm)
Mahalapswe	3 385	454	2 000
Lephalala	4 868	513	2 328
Lotsane	9 748	430	2 000
Mogalakwena	20 248	386	1 902
Motloutse	19 053	430	2 000
Shashe	18 991	485	2 154
Umzingwani	15 695	475	2 065
Sand River	15 630	384	1 690
Nzhelele	2 436	422	2 160
Bubi	8 140	315	2 427
Luvuvhu	4 826	715	1 635
Mwenezi	14 759	465	1 810
Elephants	70 000	500	1 700

WATER RESOURCES

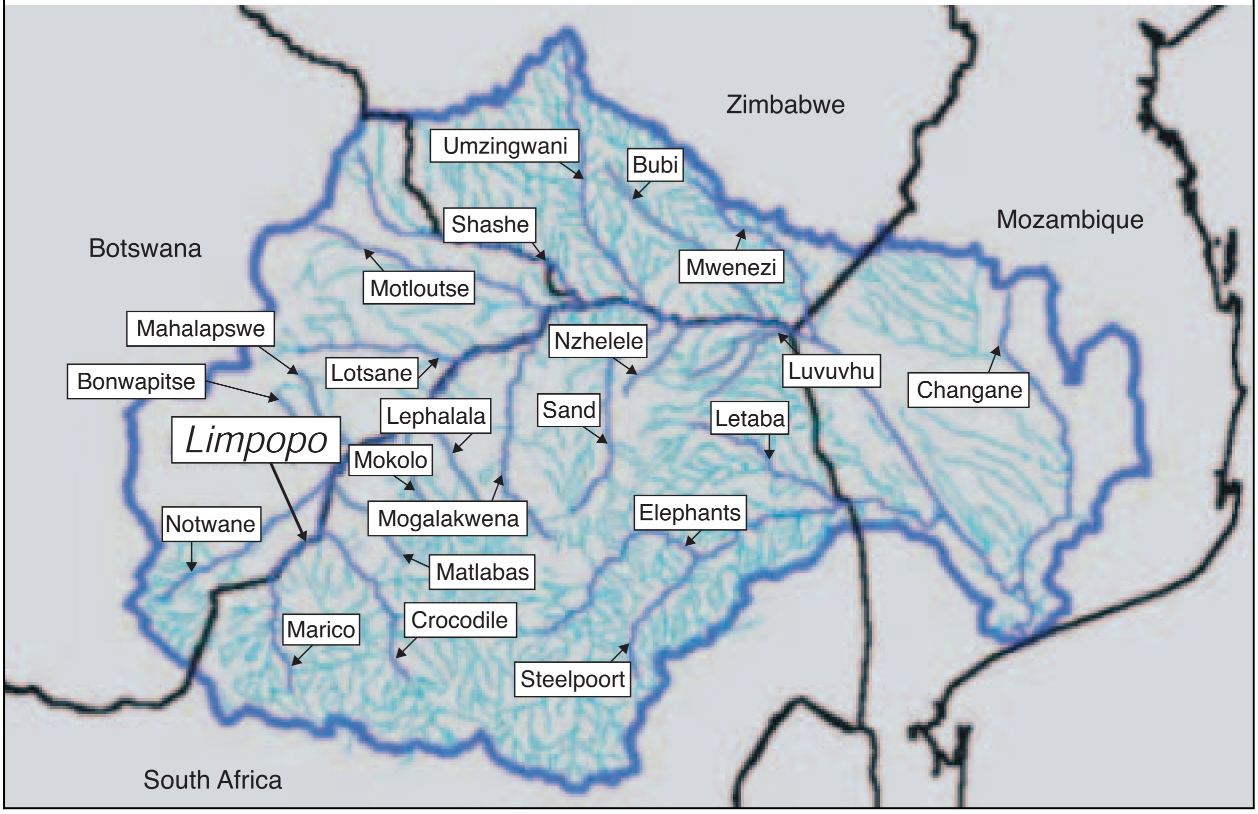
The section on rainfall (above) showed that the mean annual rainfall of the basin varies considerably (200–1 500 mm) and that the bulk of the basin receives less than 500 mm/year (Figure7). Rainfall is highly seasonal with 95 percent occurring between October and April. The rainy season is short with the annual number of rain days seldom exceeding 50.

Figure 25 shows the major rivers and streams within the Limpopo River Basin. Table 5 lists the main subcatchments constituting the basin and the area, mean annual precipitation (MAP) and mean annual evaporation (MAE) of each.

Table 5 shows that the Elephants (known as Olifants in South Africa) subcatchment (Figure 25) ranks first in terms of area, covering 17 percent of the basin. It receives the third-highest rainfall and has the third-lowest evaporation. Most of this sub-basin (84 percent) is located in South Africa, including the high-rainfall parts. To the north, in Zimbabwe, there is a short divide with the Zambezi River Basin near Bulawayo, and further east along the watershed, with the Save River.

The southeastern Limpopo River Basin borders the Incomati River (with the upstream Komati and Sabie tributaries), whose basin covers the southern half of the Kruger National Park and the adjacent Nelspruit area. To the south and southwest, the boundary is shared with the watershed of the Orange River, which flows into the Atlantic

FIGURE 25
Major rivers and streams within the Limpopo River Basin



Ocean, with the Vaal River as the nearest most-northern main tributary.

The western boundary of the Limpopo River Basin borders on the internal drainage system of the central Kalahari Desert and the Okavango Delta. After swinging eastward between Limpopo Province in South Africa and southern Zimbabwe, the Limpopo River receives the Shashe River and flows about 240 km to Mozambique, where it reaches the fall line. In this zone, the river drops about 250 m, with most of the drop concentrated in 43 km of rapids, especially those at Malala, Molukwe and Quiqueque. The Limpopo River is unnavigable until its confluence with the Elephants River, 209 km from the coast in the Indian Ocean. Though partially blocked by a sandbar at its outlet, coastal steamers can enter the river at high tide.

Other tributaries are the Changane River (left bank and downstream of Chokwé), with an area of 43 000 km^2, and the Lumane River (right bank), with an area of 1 030 km^2. Both the Changane and Lumane Rivers are entirely in Mozambique, but have very low runoff coefficients and long periods with no discharge at all.

Surface water resources

FAO (1997) has provided an overview of the hydrology of the Limpopo River Basin. The main river can be divided into the following logical reaches:

- Upper Limpopo River, down to the Shashe confluence at the South Africa–Botswana–Zimbabwe border; runoff from South Africa and Botswana.
- Middle Limpopo River, between the Shashe confluence and the Luvuvhu confluence at the South Africa–Zimbabwe–Mozambique border (at Pafuri); runoff from Botswana (Shashe), Zimbabwe and South Africa.
- Lower Limpopo River, downstream of Pafuri to the rivermouth in the Indian Ocean; runoff from Zimbabwe (Mwenezi), South Africa and Mozambique.

Several tributaries originate in Botswana, the most important being the Shashe River, which forms the border between Botswana and Zimbabwe before flowing into the Limpopo River. Other major tributaries, ranked according to decreasing mean annual runoff (MAR), are the Motloutse, Lotsane, Notwane, Bonwapitse and Mahalapswe Rivers. The main tributaries within Zimbabwe are the Shashe and Umzingwane Rivers, with the Mwenezi and Bubi Rivers as other major tributaries. The Mwenezi River originates in Zimbabwe, but joins the Limpopo River in Mozambique.

The most important tributary within South Africa is the Elephants River, which originates between Johannesburg and Witbank and flows into the Limpopo River in Mozambique. Important tributaries of the Elephants River are the Shingwedzi and Letaba Rivers. Major tributaries of the Crocodile–Limpopo part of the Limpopo River Basin, ranked according to decreasing MAR, are: Luvuvhu (which joins the Limpopo River at Pafuri), Mokolo, Mogalakwena, Marico, Lephalala, Nzhelele, Sand and Matlabas Rivers.

The part of the Limpopo River Basin in Mozambique is estimated to contribute 10 percent of the total MAR runoff of the river. The Limpopo River, which was initially a perennial river in Mozambique, can actually fall dry for up to a period of eight months per year, mainly as a consequence of abstractions in the upper catchment area (GOM–DNA, 1995). Downstream of Chokwé, the Changane River (an intermittent tributary) joins the Limpopo River. Although it drains 43 000 km^2, it has a very low runoff coefficient and periods with no discharge at all. The Lumane River, the last of the most important tributaries, originates in Lake Pave and receives water from the sandy hillsides and, therefore, flows permanently.

Hydrological studies of the Limpopo River Basin

Görgens and Boroto (1999) mention the following hydrological studies of parts of the Limpopo River Basin (year and executing countries in brackets):

- Limpopo Water Utilization Study (1989, Botswana);
- Botswana National Water Master Plan Study (1990, Botswana);
- Joint Upper Limpopo Basin Study (JULBS) (1991, Botswana and South Africa);
- various studies on a number of tributaries (Botswana and South Africa);
- Surface Water Resources of South Africa (South Africa);
- Zimbabwe National Master Plan for Rural Water Supply and Sanitation (1986, Zimbabwe);
- Monografia hidrografica da bacia do rio Limpopo (1996, Mozambique);
- Hydrological Modelling of the Limpopo Main Stem (1999, South Africa).

According to Görgens and Boroto (1999), hydrologically, the JULBS study was particularly significant, as it revealed the existence of significant transmission losses, attributable to alluvial channel and floodplain recharge and channel evaporation, as well as riparian consumptive use by the well-established riparian bush.

Table 6 shows the catchment area of each tributary of the Limpopo River as well as the naturalized MAR and the denaturalized MAR for each tributary, as derived from the above sources. Different studies have employed different hydrological estimation techniques and covered various long-term periods and denaturalization horizons. Thus, the comparison of MARs is merely indicative.

Pallett (1997) has estimated the total natural runoff of the Limpopo River at more than 5 500 million m^3. Recent figures for South Africa (GOSA–DWAF, 2003a–d) indicate a figure of about 8 000 million m^3. Entering Mozambique, the main river has an average natural MAR of 4 800 million m^3 (FAO, 1997). According to Görgens and Boroto (1999), the current MAR at its mouth is about 4 000 million m^3, almost 2 000–4000 million m^3 less than the estimated natural MAR.

From Table 6, the following observations can be made:

- The Elephants River, which joins the Limpopo in Mozambique, has the largest catchment area and is also the largest contributor of flow to the Limpopo River. The Massingir Dam in Mozambique is located on the Elephants River.
- The Luvuvhu River is the tributary with by far the highest unit runoff and also has a high ratio of denaturalized to naturalized MAR (86 percent), indicating a relatively low level of development in the catchment. The water of the Luvuvhu River also flows directly into Mozambique at Pafuri.
- The Crocodile River, which is the tributary with the second-largest catchment area, has a low ratio of denaturalized to naturalized MAR (43 percent), indicating a high level of development in its catchment.

The naturalized MARs of the Shashe, Umzingwane, Bubi and Mwenezi Rivers are not known. However, the level of development in the Umzingwane is known to be high because a

TABLE 6

Characteristics of the Limpopo River Basin from upstream to downstream

Reach	Country	Tributary	Catchment area (km^2)	Naturalized MAR (million m^3)	Denaturalized MAR (million m^3)	Unit runoff (denat. MAR) (mm)
1	South Africa	Marico	13 208	172	50	3.8
1	South Africa	Crocodile	29 572	391	205	6.9
1	Botswana	Notwane	18 053	55	24	1.4
1	South Africa	Matlabas	3 448	382	21	6.0
1	South Africa	Mokolo	7 616		117	15.4
1	Botswana	Bonwapitse	9 904	15	15	1.5
1	Botswana	Mahalapswe	3 385	13	13	3.9
1	South Africa	Lephalala	4 868	150	99	20.3
1	Botswana	Lotsane	9 748	62	62	6.4
1	South Africa	Mogalakwena	20 248	269	79	3.9
1	Botswana*	Motloutse	19 053	111	111	5.8
Total for upper reach			139 103	1 620	796	5.7
2	Botswana	Shashe	12 070	250	250	20.7
2	Botswana	Other	7 905			
2	Zimbabwe**	Shashe	18 991	462	462	24.3
2	Zimbabwe**	Umzingwane	15 695	350	350	22.3
2	South Africa	Sand	15 630	72	38	2.4
2	South Africa	Nzhelele	3 436	113	89	26.0
2	Zimbabwe**	Bubi	8 140	53	53	6.5
Total for middle reach			81 867	1 300	1 242	15.2
3	South Africa	Luvuvhu	4 826	520	492	102.0
3	Zimbabwe**	Mwenezi	14 759	256	256	17.4
	Zimbabwe**	Other	4 956	36	36	7.3
3	South Africa	Elephants	68 450	1 644	1 233	18.0
	South Africa	Other	13 996	2 352		
3	Mozambique	Changane	43 000			
3	Mozambique	Elephants	1 550			
	Mozambique	Other (e.g. Lumane)	40 431	315		
Total for lower reach			151 537	5 123	2 017	21.7
Total			412 938	± 8 043	± 4 055	±9.8

Notes:

* Denaturalized MAR will change when utilization of the Letsibogo Dam increases.

** According to Görgens and Boroto (1999), the MAR for Zimbabwe is the denaturalized MAR; according to GOZ–MRRWD–DWD (1984), the given MAR is the naturalized MAR.

Sources: Görgens and Boroto (1999); GOSA–DWAF (1991); GOSA–DWAF (2003 a–d); GOB–MMRWA (1992); GOZ–MRRWD–DWD (1984); FAO (1997).

TABLE 7

Characteristics of the Botswana sub-basins of the Limpopo River Basin

Tributary	Catchment (km^2) (GOSA)	Naturalized MAR		Denatural. MAR (million m^3)	Unit runoff (mm)	MAP (mm)	MAE (mm)
		(million m^3) (GOSA)	MAR*** (GOB)*				
Notwane	18 053	54.7	85.0	24.3	1.35	450–500	1 950
Bonwapitse	9 904	14.8	55.0	14.8	1.49	400–450	2 000
Mahalapswe	3 385	13.2		13.2	3.90	400–450	2 000
Lotsane	9 748	62.3	195.0	62.3	6.39	300–400	2 100
Motloutse**	19 053	111.1		111.1	5.83	300–400	2 100
Shashe	12 070	250.0	270.0	250.0	20.71	400–450	2 100
Other	7 905						
Total	80 118	506.1	605.0	475.7	5.94		

Notes:

* 55 = Bonwapitse + Mahalapswe; 195 = Lotsane + Motloutse.

** Denaturalized MAR (111.1) will change when utilization of the Letsibogo Dam increases.

*** According to Görgens and Boroto (1999).

Sources: GOSA–DWAF (1991), GOB–MMRWA (1992), Görgens and Boroto (1999).

large number of small to large dams have been constructed in its catchment. Some dams have also been built in the Shashe catchment.

Botswana

The Botswana part of the basin feeds into the upper reach of the Limpopo River. It consists mainly of the following sub-basins:

- Notwane,
- Bonwapitse and Mahalapswe,
- Lotsane and Motloutse,
- Shashe (part also in Zimbabwe).

The catchments of some sub-basins are difficult to define, as the topography is very flat towards the Mkgadikgadi Pans and the Central Kalahari. The development of surface water resources is also complicated by the semi-arid environment where potential evapotranspiration is about four times higher than the rainfall and where streamflow records are relatively short and of poor quality. This explains why estimates of catchment areas and related runoff figures differ between one study and the other. Table 7 lists relevant water catchment information from various sources.

With the exception of the Shashe River, most of the available water resources are highly developed. The demand for water is increasing rapidly because of rapid urbanization and industrial development. The total water demand of Botswana was estimated at 193.4 million m^3 for 2000. Of this total, 24 percent goes to urban centres, 23 percent to livestock, 18 percent to mining and energy, 15 percent to irrigation and forestry, 11 percent to major villages, 5 percent to rural villages, 3 percent to wildlife and 1 percent to settlements (GOB–MFDP, 1997). Owing to high water demands, most of the subcatchments have a water deficit and rely on water importation and water saving techniques to meet demand. The potential storage capacity of dams in Botswana is estimated to be almost 300 million m^3, but this potential is not regularly realized.

The Notwane sub-basin

The Notwane River rises on the edge of the Kalahari sandveldt and flows northeast until it reaches the Limpopo River some 50 km downstream of the confluence of the Limpopo River with the Marico River. About one-third of Botswana's 1.6 million population reside in the Notwane Basin, which includes the urban centres of Gaborone, Molepolole, Mochudi, Kanye, Lobatse and Jwaneng.

Domestic water needs dominate water use in the Notwane sub-basin and demands are growing rapidly. The large urban centres account for more than 60 percent of the domestic water demands. Gaborone consumes 50 percent of all urban use (i.e. 30 percent of national domestic water use) and this is expected to increase significantly because of rapid urbanization (i.e. up to 40 percent of national domestic demand by 2020).

In order to address inequalities of water abstraction, the South African Department of Water Affairs and Forestry is planning the transfer of 124 million m^3 of water per year from the Crocodile West and Marico Water Management Area to Gaborone in Botswana (GOSA–DWAF, 2003c).

The Gaborone and Bakaa Dams are located on the Notwane River and are the main sources of domestic water supply to Gaborone and surroundings. The Nywane Dam serves Lobatse, which is also linked by a pipeline to the Gaborone Dam. The catchment contains about 200 small dams which result in an estimated 25-percent reduction in runoff, serving primarily livestock needs. In most years, the catchment has a water deficit, and water importation from South Africa from another part of the Limpopo catchment (i.e. from the Molatedi Dam on the Marico River) to Gaborone is one of the mitigating measures. The completion of the North–South Water Carrier, which is designed to transport water from the Shashe Dam near Francistown to Gaborone, will bring much needed relief to the stressed local surface water and groundwater resources, and secure water resources up to 2020 (Pallett, 1997).

The Bonwapitse and Mahalapswe sub-basins

The Bonwapitse River has its upper catchment in the Kalahari sandveldt and is seldom in flow. The Mahalapswe River also contributes very little to the flow of the Limpopo River and normally does not have surface runoff during the winter. However, water is stored in the sand bed and this is an important source of domestic water for small communities and their livestock along the river reaches. No large dams have been constructed and no potential exists. Small dams provide suitable water resources for stock watering, small-scale irrigation (horticulture) and in some cases also serve domestic uses of small villages.

The Lotsane and Motloutse sub-basins

Both rivers flow mainly during summer rainfall and have limited development potential owing to the relatively flat terrain and restricted options for the building of larger dams. Development potential is suited primarily for small communities, livestock and small-scale irrigation. Communities along the river reaches often access water stored in the sandy riverbed or small dams and depend on this for most of the winter months. However, investigations for the Botswana National Water Master Plan (BNWMP) have shown that the sand volume of riverbeds is generally limited in depth and, hence, does not support a major abstraction capability (GOB–MMRWA, 1992). A total of 366 small dams have been constructed in Central Region, mostly located in the Lotsane and Motloutse catchments.

The Motloutse River has an MAR of 111 million m^3/year. Construction of the Letsibogo Dam is probably the only significant development and will serve primarily the industrial town of Selebi-Pikwe and surrounding local needs, including potential irrigation (Box 8). Its potential contribution to the North–South Water Carrier is uncertain.

BOX 8

Irrigation with gypsiferous coal mine water

A simulation study in Botswana with gypsiferous coal mine water with an electrical conductivity (EC) of about 310 mS/m^3 (Jovanovic *et al.*, 2001) led to the conclusion that, under the particular climate and soil conditions of Selibe-Pikwe, large amounts of effluent mine water can be disposed successfully of through irrigation. Between 18 and 32 percent of the total amount of salts added through irrigation was predicted to leach after 11 years, the remainder being precipitated in the soil profile in the form of gypsum. A slow process of gypsum dissolution and leaching by rainfall was predicted after the cessation of irrigation with mine water. This means that large quantities of salt can be immobilized in the soil profile, removed temporarily from the water system, and released in small amounts into the groundwater over an extremely long time period.

The Shashe sub-basin

The Shashe sub-basin shows potential for development. To date, there are 146 small dams in the Francistown region, and the Ministry of Agriculture is investigating various small- to medium-sized irrigation schemes. The existing Shashe Dam serves Francistown and Selebe-Pikwe. During Phase-I of the North–South Water Carrier Project, the Shashe Dam will also transfer water via Selebe-Pikwe to Gaborone, supplementing local water resources of the main towns on-route including Palapye, Mahalapye, Palla Road and Mmamabula. Construction of the Letsibogo Dam on the Motloutse River will relieve the Shashe Dam, to serve primarily Francistown and growing urban and peri-urban areas in the region.

Further phases of this project will construct and link the Lower Shashe Dam and duplicate the pipeline from Selebe-Pikwe to Gaborone providing for all water demands until 2020, given current water use trends (IUCN, 1999). Thereafter, Botswana will have to resort to international water sources from the Limpopo, Ramokgwebana and Zambezi Rivers (GOB–MFDP, 1997). Three possible dam sites in the Limpopo River are being investigated, including the Pont Drift Dam, the Martin's Drift Dam and the Cumberland Dam. Several committees are responsible for joint planning and decision-making (see Chapter 3).

South Africa

The South African part of the Limpopo catchment feeds into all three river reaches mentioned in the beginning of this section, and can be grouped into two major components (Table 8):

- Crocodile/Limpopo River Basin up to the confluence with the Luvuvhu River (near Pafuri) at the border with Zimbabwe, South Africa and Mozambique;
- Elephants River Basin, which leaves South Africa through the Kruger National Park and joins the Limpopo River in Mozambique.

Storage capacity in the Limpopo River Basin

Effective storage and bulk distribution of water is located mainly in the upper part of the Crocodile River and the upper and middle parts of the Elephants River. Only a few additional development options exist within the Limpopo River, which are basically the Pont Drift, Martin's Drift and Cumberland dam sites. The present infrastructure is limited to run-of-river abstractions by irrigation farmers in a narrow band around the main stem of the Limpopo River, primarily along the South African side of the river.

Some 100 large dams exist of which about 40 are categorized as major dams with a capacity of more than 2 million m^3. The total capacity is almost

TABLE 8
Characteristics of major South African sub-basins of the Limpopo River Basin

Tributary	Catchment Area (km^2)	Naturalized MAR (million m^3)	Denaturalized MAR (million m^3)	Ecological reserve (million m^3)	Unit runoff (denatural. MAR) (mm)
Marico	13 208	172	50	29	3.77
Crocodile	29 572	391	205	82	6.93
Matlabas	3 448	382	21	76	6.03
Mokolo	7 616		117		15.35
Lephalala	4 868	150	99	17	20.28
Mogalakwena	20 248	269	79	41	3.92
Sand	15 630	72	38	10	2.41
Nzhelele	3 436	113	89	12	26.02
Luvuvhu	4 826	520	492	105	101.95
Elephants	68 450	1 644	1 233	366	18.02
Other	13 996	2 352		266	
Total	185 298	5 066	> 2 400	1 004	13.07

Source: Görgens and Boroto (1999); GOSA–DWAF (2003a–d).

2 500 million m^3. Of these, the following dams are key sources for domestic water (capacity in brackets):

- Roodeplaat (41.2 million m^3), Vaalkop (56.0 million m^3), Roodekoppies (103.0 million m^3) and Klipvoor (42.1 million m^3) in the Crocodile catchment;
- Molatedi (201.0 million m^3) on the Marico River (water supply to Gaborone, Botswana);
- Witbank (104.0 million m^3), Middelburg (48.1 million m^3), Loskop (362.0 million m^3) and Arabie (99.0 million m^3), and the Phalaborwa barrage on the Elephants River;
- Ebenezer (69.1 million m^3) and Tzaneen (157.0 million m^3) on the Letaba River (serving Polokwane, Tzaneen and surroundings);
- Vondo (30.5 million m^3) and Albasini (28.2 million m^3) on the Luvuvhu River.

Some other major dams, used mainly for irrigation, but with capability for domestic use include:

- Hartebeespoort (186.0 million m^3) on the Crocodile River (currently experiencing water quality problems);
- Marico (27.0 million m^3) on the Marico River;
- Mokolo (145.0 million m^3) on the Mokolo River (currently serving irrigation and the Matimba power station);
- Blyderivierpoort (55.2 million m^3) and Rooipoort (proposed) on the Elephants River;
- Glen Alpine (20.0 million m^3) and others on the Mogalakwena River;
- Nzhelele (55.3 million m^3) on the Nzhelele River.

The future construction of the Rooipoort Dam on the Elephants River and a proposed dam on the Steelpoort River will make the system highly regulated and it will probably exceed its full capacity by about 2020. However, if more emphasis is put on water demand rather than water supply management, the construction of the dams can be postponed for a number of years. Most of the water-needy population is located far from the existing dams and, thus, costly distribution networks will be required in order to include them in supply systems. The most suitably located dams and their future extended supply capacity include:

- increased height for the Arabie Dam and the future Rooipoort Dam until 2020 and possibly 2035;
- proposed new dam on the Steelpoort River until 2020 and possibly 2030;
- the Middle Letaba Dam until 2020 and possibly 2030;
- the Vondo Dam is already close to its limit and the Nzhelele Dam has only a limited capacity;
- the Glen Alpine Dam can also only serve the immediate surroundings until 2020.

Water is imported from the Vaal River catchment (Orange River Basin) to urban areas (Johannesburg and Pretoria) in Gauteng Province in order to augment local water resources (Box 9). A significant portion of the return flows from these water uses enters the Limpopo catchment and as such supplements the capacity.

However, recent surveys by the Department of Water Affairs and Forestry (DWAF) make it evident that most of the rural households in the Limpopo River Basin in South Africa cannot be

BOX 9

The Lesotho Highlands Water Transfer Scheme

The Lesotho Highlands Water Project is the largest civil engineering project in Africa and is the world's second largest water-transfer scheme.

The first phase (1A) of the proposed four-phase scheme, comprising a giant dam at Katse in the central Maluti mountains, an 82-km transfer and delivery tunnel system reaching to the Ash River across the border in South Africa, a hydropower station at Muela, and associated structures, has been completed. This phase was commissioned in 1998, and an average of 17 m^3/s of water is now being delivered to South Africa.

Phase 1B, comprising the Mohale Dam, a 145-metre-high dam on the Senqunyane River some 40 km southwest of Katse, a 32-km transfer tunnel between the Mohale and Katse reservoirs, a 19-metre-high concrete diversion weir on the Matsoku River and a 5.6-km tunnel, is in progress. The Mohale reservoir and Matsoku diversion will add 9.5 and 2.2 m^3/s to the yield of Katse. Completion of these components is scheduled for 2003/04.

Completion of all four phases could transfer 70 m^3/s to the Vaal River system for urban use in Gauteng Province (Anon., 2003). A portion will be released in the Limpopo watershed (mainly the Hartebeespoort Dam) as return flow.

served by surface water only. Present indications are that up to 52 percent will use only groundwater, and the majority of remaining communities will use a combination of groundwater and surface water (GOSA–DWAF, 1999a–c).

Water management areas

In preparation of a national water resource strategy, the country was subdivided into 19 water management areas. Of these, the following four constitute the Limpopo River Basin in South Africa (Table 9).

Crocodile (West) and Marico water management area

Particularly evident from Table 9 is the overriding importance of water transfers into this water management area. In total, nearly 45 percent of the current water available in the water management area is supplied by transfers from the Upper Vaal water management area and beyond. Almost 30 percent of the total water available for use is from effluent return flows, most of which results from water transferred to the large urban and industrial centres in the water management area. Also significant is the contribution of groundwater, representing about 40 percent of the yield available from the water resources naturally occurring in the water management area.

DWAF plans the transfer of 124 million m^3 of water per year from the Crocodile (West) and Marico water management area to Gaborone in Botswana.

Limpopo water management area

In the Sand subarea, groundwater is of overriding importance, while the contribution of groundwater to the total water available in the water management area is among the highest of all water management areas. However, well over half of the available water originates from surface resources, which require careful and efficient management. Water transfers into the water management area serve to augment supplies to the larger urban and industrial areas as well as some mining developments, and are vital to the economy of the water management area. Also noticeable is the volume of return flows estimated to be available for reuse, the quantification of which requires improvement.

Elephants water management area

Large quantities of water are also transferred into the Upper Elephants subarea. These constitute about 22 percent of the total water available in the water management area. Of note is the significant contribution of groundwater, which constitutes nearly 20 percent of the water naturally occurring in the water management area. Usable return flows also represent a substantial proportion of the water available for use in the water management area. However, there is particular uncertainty about the quantity of return flow from irrigation water use, which may have an important impact on the total water availability in the water management area.

Luvuvhu and Letaba management area

Surface water is the dominant source of supply in four of the five subareas. The only exception is the Shingwedzi subarea where more than half of the water available is abstracted from groundwater, while water is also transferred into the subarea

TABLE 9

South African water management areas and sub-basins of the Limpopo River Basin: available water in 2000

Subarea	Natural resource		Usable return flow			Total local yield	Water transfers	Grand total
	Surface water	Groundwater	Irrigation	Urban	Mining and bulk			
	(million m^3/year)							
Crocodile (West) and Marico water management area								
Apies/Pienaars	38	36	4	106	2	186	182	368
Upper Crocodile	111	31	21	158	15	336	279	615
Elands	30	29	3	10	14	86	71	157
Lower Crocodile	7	29	14	1	8	59	112	171
Marico	14	12	2	3	1	32	0	32
Upper Molopo	3	9	0	5	2	19	0	19
Subtotal	203	146	44	283	42	718	519	1 237
Limpopo water management area								
Matlabas/Mokolo	35	7	3	1	0	46	0	46
Lephalala	38	4	0	0	0	42	0	42
Mogalakwena	50	15	3	4	0	72	3	75
Sand	10	71	0	10	0	91	15	106
Nzhelele/Nwanedzi	27	1	2	0	0	30	0	30
Subtotal	160	98	8	15	0	281	18	299
Elephants water management area								
Upper Elephants	194	4	2	34	4	238	171	409
Middle Elephants	100	70	34	5	1	210	91	301
Steelpoort	42	14	3	1	1	61	0	61
Lower Elephants	74	11	5	2	8	100	1	101
Subtotal	410	99	44	42	14	609	172	781
Luvuvhu and Letaba management area								
Luvuvhu/Mutale	88	20	5	2	0	115	0	115
Shingwedzi	1	2	0	0	0	3	0	3
Groot Letaba	133	12	13	1	0	159	0	159
Klein Letaba	21	9	1	1	0	32	0	32
Lower Letaba	1	0	0	0	0	1	0	1
Subtotal	244	43	19	4	0	310	0	310
Total for Limpopo basin	**1 017**	**386**	**115**	**344**	**56**	**1 918**	**709**	**2 627**

Source: GOSA–DWAF (2003a–d).

from the Luvuvhu River catchment. Also noticeable is the volume of return flows estimated to be available for reuse, the quantifications of which require improvement.

The quality of the water from the Limpopo River poses serious problems during periods of low flow, in particular upstream of the confluence with the Shashe River (P. Nell, personal communication, 1999). Water pumped from the riverbed from deeper than 1–2 m is very costly and rapidly becoming of inferior quality owing to salinity, herbicides, toxic elements and heavy metals such as boron.

Zimbabwe

Zimbabwe is divided into six hydrological zones (A–F). The Limpopo catchment corresponds to Zone B, which has 30 hydrological subzones, covering a total area of 62 541 km^2 (16 percent of Zimbabwe's land area). The catchment has an MAR of 1 157 million m^3 or 19 mm, which is less than 6 percent of the total MAR of the country (GOZ–MRRWD–DWD, 1984). Table 10 summarizes the characteristics according to the main tributaries.

The Limpopo River Basin has a highly variable and unreliable flow, and consequently an unreliable water supply. The rivers are intermittent with peak flows in February followed by low flow from May to early November. The reliability of runoff can be indicated by the percent CV, which is the difference between the highest runoff and the lowest runoff of the catchment over time, expressed as a percentage of the MAR. The higher is the percent CV, the less reliable is the runoff. For the Limpopo catchment in Zimbabwe, the CV is 130 percent, which reflects a low reliability, hence the greater the risk of water shortage in the area, unless groundwater sources exist (GOZ–MRRWD–DWD, 1984).

The priority of water allocation in this catchment goes to domestic and industrial purposes, followed

TABLE 10
Characteristics of the Zimbabwe part of the Limpopo River Basin

Tributary	Catchment area	MAR	MAR	Storage	Flow right	Commitment	Potential remaining	MAP	MAE
	(km^2)	(mm)	(million m^3)					(mm)	(mm)
(1)	(2)	(4)	(3)*	(5)	(6)	(7) = (5) + (6)	(8)	(9)	(10)
Shashe	18 991	24.33	462.0	178.5	15.0	193.4	310.9		2 000–2 150
Umzingwane	15 695	22.30	350.0	592.1	25.1	617.1	131.0	475	2 065
Bubi	8 140	6.51	53.0	21.3	0.1	21.3	33.6	315	2 425
Mwenezi	14 759	17.35	256.0	341.7	7.8	349.5	103.3	465	1 800–1 810
Other	4 956	7.26	36.0	12.6	17.3	29.9	7.9		
Total**	62 541	18.50	1 157.0	1 146.1	65.2	1 211.3	586.7	465	1 800–2 425

* According to Görgens and Boroto (1999), the MAR given in column (3) is the denaturalized MAR, but according to GOZ–MRRWD–DWD (1984), the MAR given in (3) is the natural MAR (see also Table 7, where it is put as denaturalized MAR).

** There is a discrepancy between the area of the catchment given above (62 541 km^2) and the area according to FAO (1997) (51 467 km^2). An explanation may be that the FAO study had included part of the Limpopo River Basin in the adjacent Save or Zambezi basins, which should be corrected

Source: GOZ–MRRWD–DWD (1984).

by mining and finally agriculture. The city of Bulawayo is supplied by the Mzingwane, Inyankuni and Ncema dams; Gwanda by the Mtshabezi Dam, Kezi by the Shashani Dam, Mwenezi and Rutenga by the Manyuchi Dam. Beitbridge receives its water directly from the Limpopo River (GOZ–MRRWD, 1999). Most irrigation schemes also receive their water from dams. However, in the schemes developed along the major rivers, sand abstraction is practised. The river sand acts as the aquifer into which boreholes are sunk in order to abstract irrigation water. The water is normally found at 3–10 m below the riverbed.

Storage capacity in the Limpopo River Basin

There are 2 168 dams in the Zimbabwean part of the Limpopo River Basin. However, regardless of the potential available in dams and rivers, the water demand of the rural communities is rarely satisfied. This can be explained by a lack of the costly infrastructure needed to bring the water to these communities. In Zimbabwe, the total capacity of the dams has fallen by about 29 million m^3 in the last three years as a result of siltation (Pallett, 1997; GOZ–MRRWD–DWD, 2000).

Currently, of the total MAR, almost 99 percent of the water is already being harnessed/stored. The potential for development exists in places where the MAR is larger than the storage and/or flow rights. However, where the MAR is less than storage, it means that the subcatchment has been developed or already has more dams constructed than can be filled up with the MAR. These dams can still fill up during wet years with a higher runoff than that reflected by the MAR. This is significant when the total commitment is larger than the MAR. Total commitment includes both storage and flow rights. Where a subcatchment has no dams in it, the flow rights will exceed the storage rights.

Mozambique

To a large extent, Mozambique's water resources are conditioned by the fact that they form part of international river basins, where neighbouring countries upstream are increasingly exploiting available water resources. Such action is claimed to exacerbate downstream problems of water shortages and drought in Mozambique.

An extensive number of studies and reports have provided assessments of national water resources (GOM–DNA, 1986, 1998) and other hydrological assessments (MacDonald and Partners, 1990), including irrigation development in the Limpopo River Basin (Sogreah, 1993).

Using data cited in Sogreah (1987), the basin at the Chokwé station (Figure 5) covers 342 000 km^2 and the MAR is 5 280 million m^3, calculated over a period of 34 years (from October 1951 to September 1985). Figures given above reveal that about 4 800 million m^3 enters Mozambique, which means that less than 10 percent is generated within Mozambique. The area of the Limpopo River Basin within Mozambique is 84 981 km^2, which is about 11 percent of the total area of the country and 21 percent of the total area of the basin (Table 6).

The main tributary, the Elephants River, has a basin of 70 000 km^2, most of which is in South Africa (68 450 km^2). The Elephants River is regulated by the Massingir Dam, with a capacity of about 2 200 million m^3. At the Massingir Dam site, the MAR is 1 800 million m^3, calculated over the same period of 34 years. The Massingir Dam controls 34 percent of the total flows at Chokwé. Mihajlovich and Gomes (1986) estimated that the annual volume of water entering the station of Mapai on the Limpopo River (upstream of the confluence of the Limpopo and Elephants Rivers) is 3 510 million m^3, calculated over a period of 32 years, representing 65 percent of the total flows at Chokwé. However, the discharge is very irregular and may be practically zero in winter.

Downstream of Chokwé, the Changane River (an intermittent tributary without regulation structures), drains a basin covering 43 000 km^2, but it has a very low runoff coefficient and long periods with no discharge at all. The Lumane River, the last of the most important tributaries, originates in Lake Pave and receives regular inflows from the sandy hillsides. It has a discharge of about 10 m^3/s. Table 11 shows the flow regime of the Elephants and Limpopo Rivers in Mozambique.

Sogreah (1993) noted that more than 75 percent of the annual volume occurs during only three months (January–March), which is quite extreme even in comparison with other rivers in the south of Mozambique, and that the whole dry semester (May–October) represents less than 10 percent of the annual flow.

The annual inflow CV is 1.07 for the Limpopo River at Mapai and 0.61 for the Elephants River at Massingir (comparable with those of the Sabie, Incomati and Umbeluzi). In addition to the irregularity of natural inflows, which calls for the construction of dams in order to guarantee a regulated annual volume, another problem lies in the form of offtake in the neighbouring countries. Many dams have been built in Zimbabwe and South Africa and the effect of water storage in these countries may be seen in recent years in terms of change in the discharge recession curves during the dry season.

TABLE 11
Flows measured at the Massingir and Chokwé stations

Flow	Frequency	Elephants at Massingir	Limpopo at Chokwé
		(million m^3)	
MAR		1 800	5 280
Annual runoff surpassed	1 in 2 years	1 600	2 800
Annual runoff surpassed	8 in 10 years	700	850
Annual runoff surpassed	9 in 10 years	550	400
Minimum annual runoff	(1982–83)	253	63

Offtake in countries upstream of Mozambique may have a favourable effect in reducing floods, but it is detrimental in low-water periods, when water requirements are most acute. Citing Sogreah (1993), South Africa and, to an unknown extent, Botswana and Zimbabwe are extracting considerable quantities of water from the Limpopo River Basin, estimated at 1 173 million m^3 in 1980 (GOSA–DWA, 1985). This figure was projected to increase to 1 385 million m^3 in 1990 and 1 723 million m^3 in 2000. The corresponding figures for the Elephants River Basin were 1 038, 1 188 and 1 254 million m^3, but their origin is questionable as they were presented within a negotiation framework.

The effect of the increase in abstractions is already apparent in the dry season in the Limpopo River, where it has become normal to find it completely dry for some months each year. Sogreah (1993) used recession curves of different years to demonstrate an increase in their gradient in more recent years, and developed a number of scenarios for analysis of water abstractions and their impact in Mozambique.

Between October 1981 and September 1986, the mean inflow at Massingir was 792 million m^3, which is only 44 percent of the mean over a period of 34 years. The reason for this is not offtakes in South Africa, but rather climate conditions. The mean inflow of the five earliest years (1961–66) was 834 million m^3. Conversely, the mean inflow in 1973–1978 was 2 976 million m^3, which is 165 percent of the 34-year mean. The possibility of several successive dry years occurring means that large-capacity dams will have to be built and will enable a maximum of only 60 percent of the natural inflow to be regulated (Sogreah, 1987).

Groundwater resources

Groundwater is used extensively in the region, mainly for irrigation and rural supplies. Communities are often located at significant distances from river reaches and depend solely on groundwater resources for survival.

Botswana

Most of the rural population is located far from surface water resources and depends mainly on groundwater resources. Traditionally, most major villages have also used groundwater, which is now being augmented by local or regional surface water supplies, including the North–South Water Carrier. Most smaller rural villages can derive their domestic water needs from groundwater without depleting the available resource. However, in periods when rivers and local dams are dry, these groundwater resources are overexploited to also serve livestock watering needs. Groundwater resources at Jwaneng and Orapa are being overexploited resulting in so-called groundwater mining, which is depleting available groundwater reserves.

Botswana's groundwater is characterized by very low recharge rates, low probability for high-yielding boreholes and relatively high salinity. In the Limpopo catchment of Botswana, the mean recharge to groundwater ranges from 1 to 3 mm/year in the Kalahari and northwestern parts of Central Region to 5–9 mm/year for most of the eastern areas, except for the Tuli Block. Extended drought periods affect the reliability of these sources and require active monitoring and management. The low recharge precludes any large-scale development of groundwater because it would lead to unacceptably high rates of groundwater exploitation (mining) and subsequent damage to the resource.

The median yield from successful boreholes is moderate to low ranging from 3 to 6 m^3/h for most of the Limpopo catchments in Botswana. The best production areas are between Gaborone and Mahalapye and in smaller areas around Ramotswa and Palapye. They have been defined into 10 production areas, including well fields at Palla Road, Ramotswa, Lobatse, Ramonnedi, Molepolole, Mochudi, Palapye, Serowe, Paje and Shashe. The Palla Road and Ramotswa well fields have the highest capacity and will probably be linked as sources to the North–South Water Carrier Project. Dolomite aquifers in the Kanye, Sekoma, Molopo and Mashaneng areas have significant storage capacity and high yields.

Sandstone formations, which are linked to the central Kalahari, have the largest recharge areas and total storage, but often have high salinity and require large numbers of boreholes. Occasionally, sand rivers provide good recharge and storage capacity for local extraction, but generally they have inadequate capacity for regional uses. The main aquifers and their related storage and yield capacities are listed in the national water master plan (GOB–MMRWA, 1992). Subsequent national development plans (GOB–MFDP, 1997) provide upgraded information based on groundwater investigations and compliance monitoring.

Groundwater quality is often deficient with high salinity and excess concentrations of fluorides, nitrates, and other harmful elements in some regions. The total dissolved solids range from 1 000 to 1 500 mg/litre for most of the Limpopo catchments in Botswana, and increased levels of nitrates are occurring near irrigation and within settlement areas.

Conjunctive use of surface water and groundwater is essential for sustaining water quantity and quality requirements of users. Monitoring programmes are being implemented to protect and manage groundwater and surface water against pollution and overexploitation. Active management of water demand and water quality is critical to managing drought and the impact of drought in Botswana.

However, the management of groundwater is complicated by the "common pool" problem. While individual use or misuse may not result in a significant problem, the combined impact is often unacceptable. It is then difficult to determine who is responsible and how the situation is to be regulated.

South Africa

Rural communities and irrigation farming make extensive use of groundwater, extracting a total of about 850 million m^3/year. It is estimated that more than 55 percent of rural communities are supplied from groundwater as their only source. Most of the remaining communities use a combination of groundwater and surface water (GOSA–DWAF, 1999a–c).

Dolomite aquifers occur in the Crocodile River Basin and the Blyde River area, but are generally distant from the needy rural communities. Most rural communities are located on minor aquifer types with an average borehole yield of about two litres per second. Communities north of Soutpansberg are located on poor aquifer types yielding less than 1 litre/s. The water they provide often fails to meet domestic water quality standards because of high salinity. Only the southeastern parts of the former Bolobedu area of Lebowa have reasonable groundwater potential and quality.

On average, 5–10 boreholes need to be drilled for each community and they can generally serve only communities of fewer than 2 000 people. There are indications that up to 27 percent of boreholes have a water quality that is marginal or poor for

BOX 10

Overexploitation of groundwater in Limpopo Province, South Africa

The Dendron area is one of the prime examples in South Africa where uncontrolled extraction of groundwater on private farms for irrigation purposes greatly exceeded recharge, leading to unsustainable development. In the 1970s and 1980s, on a cluster of farms on which boreholes supplied copious volumes of groundwater, a flourishing potato production industry developed in this semi-arid area. The area receives 440 mm mean annual summer rainfall, and the seasonal recharge varies between 3 and 35 mm (1–8 percent of the MAP). After a number of years and great expenditure, the granite aquifer became depleted and potato production ground to a permanent halt.

There were two issues in this case. The first was a lack of recognition of the fossil nature of the groundwater body, and the second was the way safe delivery was estimated. Borehole yield information was based on the initial drilling-rig blow test of the borehole. This test was later shown to be overgenerous. In recent years, DWAF has been recommending 30–50 percent of the blow yield for long-term use (Bang and Stimie, 1999).

domestic use and causing it to have a number of limitations for crop irrigation. Key problem areas are: the Springbok Flats and surroundings, where high fluoride concentrations are common; the area north of Soutpansberg, where high solute concentrations are found; and areas around Dendron (Box 10) and along the main stem of the Limpopo River, where high evaporation influences the salinity level of the water.

Zimbabwe

The Limpopo River Basin area in Zimbabwe is not well endowed with groundwater. Most of the wells in the communal areas that are used for household purposes, caring for livestock, and watering of gardens, run dry long before the rainy season starts. However, in addition to a few groundwater aquifers, the basin also has subsurface water stored close to the surface in a few *dambo* (wetland) areas. True *dambos* no longer exist in most parts of Matabeleland South Province, primarily because of land degradation over the years from prolonged droughts and overstocking. However, vegetable production on seasonal wetlands does occur on communal lands near Matopo, Esigodini, Godlwayo and some other areas (DANIDA, 1990).

Data on the exact extent and quantity of groundwater are not available. Areas with reasonable groundwater reserves, both in terms of quantity and quality, are found in two areas (Figure 5). The first is around Esigodini, south of Bulawayo in the Umzingwane River Basin, where the water is used for the production of vegetables and fruit under irrigation. The second is in the Malipati area at Manjinji, near the southern reaches of the Mwenezi River, where there is potential to irrigate up to 1 000 ha, out of which only a very small portion is already irrigated.

The water at both Esigodini and Malipati occurs at shallow depth (20–30 m) and is of good agricultural quality. Groundwater also occurs along the Limpopo River and below the riverbed sand aquifer (3–10 m deep). The quality of water east of Beitbridge around Grootvlei is low owing to salinity, although the quantities are good (GOZ–AGRITEX, 1990). An irrigation scheme established before independence has been abandoned because of poor water quality.

Mozambique

Existing data on groundwater resources relate to information from wells (at time of construction) and to geological information. According to Sogreah (1993), the groundwater potential in the Limpopo River Basin area is limited, particularly because of the high mineralization of many of the aquifers. According to another synthesis report on water resources in Mozambique (GOM–DNA, 1999), groundwater in the vast interior area of Gaza Province is unfit for consumption because of high levels of salinity.

Six different zones are considered in characterizing the groundwater potential in the Limpopo River Basin in Mozambique:

- Dune area: a 40–60-km wide strip along the coast. Productivity is considered low to medium. Quality is good because of to the high recharge rate of 50–200 mm/year. Recent studies estimate the exploitable amount of groundwater to be about 5–10 m^3/h per km^2.
- Alluvial valleys: formed by the incised main valleys of the Limpopo and Elephants Rivers. Productivity is high, but water quality is a major problem because the rivers drain the

adjacent plains that have highly mineralized groundwater. Fresh groundwater occurs where the surface waters of the rivers replenish the aquifers directly, but care is needed to prevent overexploitation and avoid the risk of salinization of the aquifers.
- Old alluvial plains: bordering the dune area. This region does not provide any potential for groundwater exploitation as it is highly mineralized.
- Erosion plains and erosion valleys: a shallow eluvial cover of sandy clays over the entire inland area. Productivity is low in general but calcareous sandstones have higher specific yields. Water quality is usually poor, with exceptions found along water lines and local depressions that are recharged from the temporary rivulets.
- Deeper aquifer: found in the medium and lower Limpopo River Valley at depths ranging from 80 m at Mabalane to 200 m at Xai-Xai. The total exploitable groundwater in this aquifer, which seems to be enclosed by a saline cover and a brackish base, has been estimated at 300–600 m^3/h.
- Lebombo Range: the rhyolites of the Lebombo Range have very low productivity. Very few wells have been drilled in this region and the failure rate is high.

The aquifers related to the sedimentary post-Karoo formation deliver sufficient water of suitable quality for irrigation. This formation generally runs parallel to the course of the main rivers south of the Save River. The more recent deposits of the coastal dunes also provide water of good quality, but the yield is small.

Many reports conclude that large-scale groundwater abstractions in the Limpopo River Basin are very limited as a consequence of low productivity and poor water quality. There exists a deep aquifer between 250–350 m, which may be continuing to the south, but exploitation of this source is not economically feasible. Water quality becomes progressively worse downstream of Chokwé and the confluence with the Changane River. Only the dune unit can be used for small- and medium-scale abstractions without restrictions posed by water quality. For irrigation purposes, groundwater safe yields are too small and can be ignored.

Another source of water is that from the sandy hillsides in the lower Limpopo area, which is being partially used for the irrigation of the *Machongos*. *Machongo* is the local name for a type of hydromorphic soil (a kind of peat soil wetland) with very high organic matter content, part of which is in a very coarse form. While not directly under the irrigation subsector, subsurface irrigation on *machongos* is practised in Xai-Xai District. *Machongos* are found mostly along the sea coast, in the valleys of the main rivers (at the junction of the valley with the higher surrounding ground), or associated with smaller streams where the flow of water is seasonally impeded.

Interbasin and intrabasin water transfers

A number of water transfer schemes have been developed or proposed in order to address the relatively severe water shortage in the Limpopo River Basin while maintaining the current emphasis on water supply management rather than water demand management. Transfers of water may be made from one sub-basin of the Limpopo River Basin to another, within one country or between countries. This is termed intrabasin water transfer. Water can also be transferred between the Limpopo River Basin and other basins, within one country or between countries. This is termed interbasin water transfer. The Limpopo has four interbasin transfer schemes and two intrabasin schemes (Table 12).

In South Africa, water is imported from the Usutu, Vaal and Komati Rivers to serve the high water quantity and quality demands of the power stations in the Upper Elephants River Basin. In addition, continued importing of water from the Orange and Vaal River system (Box 9) and greater reuse of return flows in the Crocodile River could create surplus water in the Crocodile River, which could then be exported to supplement the Mogalakwena, Mokolo and Elephants basins. However, these return flows affect the quality of the water, and it becomes increasingly important to manage the resulting water quantity and quality in an integrated way in order to prevent environmental impacts and to ensure compliance with other water user requirements.

These transfer schemes are the subject of intense debate because of their high cost and potentially negative impacts on the environment and ecological balance. Transfer schemes affect river basin planning, water quantity, water quality, land, aquatic systems, terrestrial systems and socio-economic issues in the countries sharing the receiving or supplying basins. This requires all countries affected directly and indirectly to be involved from the outset in the planning and

TABLE 12

Interbasin and intrabasin water transfers related to the Limpopo River Basin

Name of water transfer scheme	Basins involved	Countries involved directly in scheme[1]	Countries involved/affected indirectly[2]
Interbasin water transfer schemes			
Komati Scheme	From Incomati to Limpopo	South Africa	Swaziland, Botswana, Mozambique, Zimbabwe
Usutu Scheme	From Usutu to Limpopo	South Africa	Swaziland, Botswana, Mozambique, Zimbabwe
Grootdraai Emergency Augmentation Scheme	From Orange to Limpopo	South Africa	Botswana, Mozambique, Zimbabwe, Lesotho, Namibia
Vaal-Crocodile	From Orange to Limpopo	South Africa	Botswana, Mozambique, Zimbabwe, Lesotho, Namibia
Intrabasin water transfer schemes			
North–South Water Carrier (within Limpopo basin)	From Shashe to Notwane	Botswana	Mozambique, Zimbabwe, South Africa
Molatedi Dam to Gaborone	From Marico to Notwane	Botswana, South Africa	Mozambique, Zimbabwe

[1] Countries initiating and implementing the transfer scheme.

[2] Countries sharing involved basin and which consequently are affected by the scheme.

decision-making. However, the existing treaties on the Limpopo River Basin are either bilateral or trilateral agreements and, as yet, no agreement has been established and signed by all four countries sharing the basin.

Issues such as interbasin water transfers are meant to be regulated by the protocol on shared watercourse systems in the SADC region, which came into force in 1998 after ratification by the required two-thirds majority of the SADC member states (SADC, 1998). The introduction of proper water management demand systems could postpone future transfer schemes and overabstraction from international rivers. However, the protocol fails to incorporate water demand management as an explicit strategy. Notwithstanding this, the agreement supports the requirement that national resources be used as efficiently as possible prior to international abstractions (IUCN, 1999).

Even though the Limpopo River Basin lacks a single comprehensive treaty, there is the firm commitment to cooperate through the Limpopo Basin Permanent Technical Committee, established in Harare in 1986, which includes all four countries. Negotiations are currently underway for this committee to become the Limpopo Basin Commission (LIMCOM). The draft agreement is under preparation at present and is discussed in more detail in Chapter 3.

LAND AND VEGETATION CLASSIFICATION AND ASSESSMENT

Agro-ecological zoning and land evaluation

FAO's AEZ has been developed to assist with land resources assessment for better planning management and monitoring of these resources (FAO, 1996). The AEZ system includes:

- inventory of land resources and land utilization systems;
- evaluation of land suitability and productivity;
- mapping of AEZ, land suitability, problem soils, etc.;
- land degradation and population-supporting capacity assessment.

The AEZ methodology was developed in the 1970s and is applied as a system to evaluate land for rainfed and irrigated agriculture, forestry and extensive grazing. The AEZ concept involves the combination of layers of spatial information, such as topography, physiography, soils, climate, catchments, land cover, production systems and population, combined and analysed using a geographical information system (GIS). AEZ is applied widely across the globe, including in countries in southern Africa. However, a regional AEZ map of southern Africa does not exist.

AEZ is an established reference system in Botswana, and is also used in multiple applications, including the production of land suitability maps. The general soil map of Botswana (De Wit and Nachtergaele, 1990), in combination with climate data, crop requirements and other information, has provided the basis for the national land suitability map for rainfed crop production (Radcliffe, Tersteeg and De Wit, 1992). In several areas of the northern part of the Limpopo River Basin, detailed land evaluation studies have determined land suitability for rainfed and irrigated crop production (De Wit and Cavaliere-Parzanese, 1990; De Wit and Moganane, 1990).

AEZ has been used in Mozambique since the 1970s, and a national AEZ map at a scale of 1: 2 000 000 is available (not digital). Following independence in 1975, a handful of foreign consulting firms, contracted by national directorates and secretariats, acted as the principal providers of ad hoc land resources information and their assessment for agricultural potential, applying their own methodologies and procedures. In the last 20 years, a series of multilateral and bilateral programmes (FAO, the Netherlands and the Soviet Union) have upgraded the capacity in soil surveying and land evaluation in the National Directorate for Geography and Cadastre (DINAGECA) and the INIA.

Voortman and Spiers (1981) produced a qualitative national assessment of land resources and their suitability for rainfed production in a series of five maps (mean annual rainfall; vegetation and potential utilization; agroclimate zones; terrain limitations for rainfed agriculture; and agricultural land suitability) at a scale of 1:4 million. Further systematic land resource inventories and associated studies were conducted by FAO in 1982, which compiled information nationally on land suitability for eight rainfed crops in a six volume report by Kassam *et al.* (1982). Based on the AEZ methodology of FAO (1978), this study determined the agroclimatic suitability of the major rainfed crops for each growing period zone, to arrive at the land suitability classification. It produced the National Land Resources Map at a scale of 1:2 million and determined climate suitability for maize, sorghum, millet, wheat, soybean, groundnut, cassava and cotton, each mapped at a scale of 1:5 million. The inventory was updated by Snijders (1986).

Another FAO project conducted land resource assessments at regional scale involving systematic soil surveys and land evaluation. This included an assessment of Gaza Province, in which soils, geomorphology and terrain were mapped at a scale of 1:250 000. The project also introduced the automated land evaluation system (ALES) to handle the 125 soil mapping units in Mozambique, resulting in individual land evaluations that are crop, area and land-user specific.

AEZ according to FAO standards has not yet been determined in South Africa. The closest related system currently in use is that of land type maps showing climate zones. The Institute for Soil, Climate and Water of the ARC uses statistics from weather stations to determine the climate zones and to develop ten-daily vegetation greenness maps using a normalized difference vegetation index (NDVI), which form part of the drought management system. The introduction of AEZ in South Africa is recommended, as it would also provide essential linkages with other global land resource approaches (Van Der Merwe *et al.,* 2000).

Venema (1999) used the AEZ concept to subdivide the five natural regions of Zimbabwe into 18 provisional agro-ecological zones. The zones reflect rainfall probability, LGP, and predominant soil type. The system is based on the long-established system of the five natural regions of Zimbabwe defined by the Agricultural, Technical and Extension Service (AGRITEX), based on mean annual rainfall, rainfall distribution and altitude (GOZ–Surveyor-General, 1998).

Bernardi and Madzudzo (1990) distinguished six agroclimatic zones, based on the ratio of mean annual rainfall at the 80 percent probability level and the calculated or extrapolated average annual ET_o. In the moist areas of Zimbabwe, the AGRITEX natural regions are similar to these agroclimatic zones. However, in the dry southeast lowveldt, Natural Region V has been split into two parts in order to create Agroclimatic Zone VI in the extreme south, representing the most arid climate of Zimbabwe.

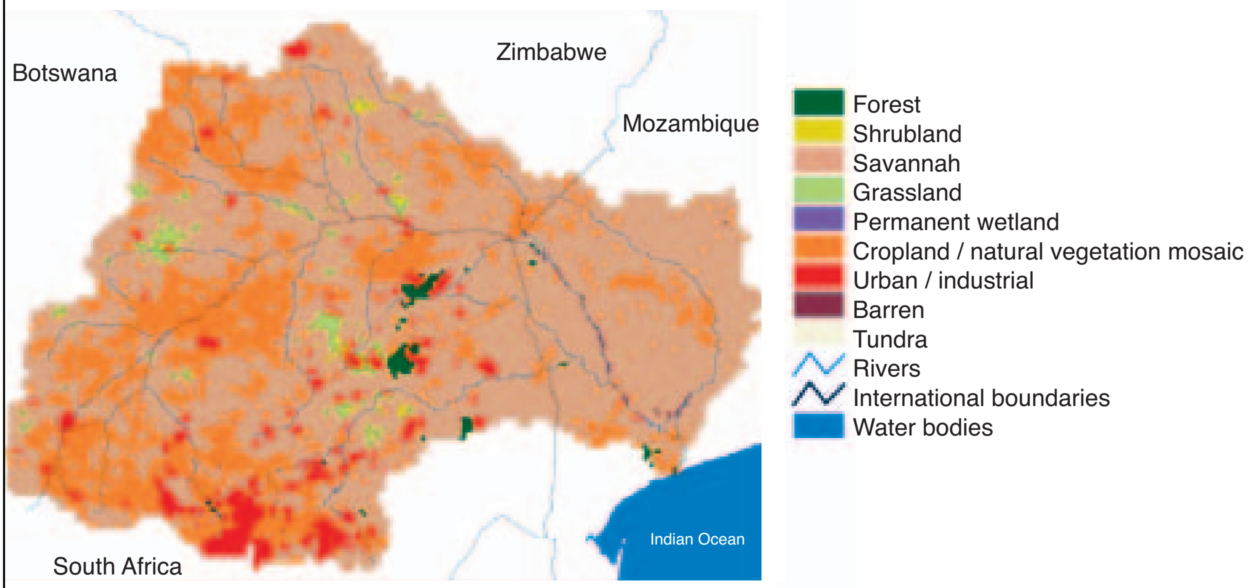
Land cover and vegetation classification

Currently, individual land cover exercises are difficult to compare as countries use different categories and legends, based on a variety of definitions. Descriptions of land cover are usually dominated by forest types, such as woodland, bushland, savannah, and wooded and open grassland. There are also differences between the database structures and descriptions, and as these have been defined without coordination, the exchange and comparison of data from different countries is difficult.

At a generalized scale, the World Resources Institute, has published generalized land cover data (GLCCD, 1998; Loveland *et al.*, 2000) and other information derived from the *Water Resources eAtlas* (World Resources Institute, 2003) for a number of Basins, including the Limpopo River Basin (Box 11). This information shows the Limpopo River Basin to be occupied mainly by savannah, cropland/natural vegetation mosaic, some grassland and urban/industrial areas (Figure 26).

Apart from the coverage of the Eastern Africa Region by UNESCO's International Classification

FIGURE 26
Generalized land cover classes of the Limpopo River Basin



Source: World Resources Institute (2003).

and Mapping of Vegetation in 1973, no regional vegetation coverage using a standardized classification and a larger scale is presently available. Using Landsat images and aerial photos, the Southern Africa Regional Office of the World Wildlife Fund (WWF) has done some mapping of land cover and land use change in southern Africa. The USGS–EROS Global Land Cover Project is also developing more standardized datasets on land cover using satellite imagery.

BOX 11
Land cover and use variables in several basins in southern Africa

- ➢ Percent forest cover: 0.7
- ➢ Percent grassland, savannah and shrubland: 67.7
- ➢ Percent wetlands: 2.8
- ➢ Percent cropland: 26.3
- ➢ Percent irrigated cropland: 0.9
- ➢ Percent dryland area: 82.5
- ➢ Percent urban and industrial area: 4.5
- ➢ Percent loss of original forest cover: 99.0

Source: World Resources Institute (2003).

Botswana

Information on forest cover in Botswana is often conflicting, depending on the definition applied to forest, woodland, etc. The land systems map of Botswana gives detailed information on the occurrence of woodlands, savannahs and grassland, including subdivision into density classes (GOB–MOA, 1990). The provisional vegetation map of Botswana by Weare and Yalala (1971) is the first detailed national vegetation map of Botswana. The most important units distinguished from northeast to southwest along the Limpopo River are:

- arid sweet bushveldt;
- mopane bushveldt;
- tree savannah (*Acacia nigrescens/Combretum apiculatum*);
- arid sweet bushveldt;
- semi-sweet mixed bushveldt.

Timberlake (1980) described and mapped the vegetation of southeast Botswana, distinguishing five main types:

- sandveldt tree and shrub savannah;
- hardveldt woodland and tree savannah;
- woodland on hills;
- shrub savannah on clay and calcrete;
- riverine woodland.

Timberlake's mapping approach was used during the soil mapping of the hardveldt (e.g. Remmelzwaal, 1989; Moganane, 1990), providing a better relationship with soil patterns as compared with the Weare and Yalala mapping. All soils reports of the standard 1:250 000 Botswana map series contain detailed descriptions of the vegetation. The overall descriptions were then combined in a national vegetation map of Botswana at a scale of 1:2 million, showing a strong relationship with underlying soil patterns (Bekker and De Wit, 1991). The four dominant vegetation associations along the Limpopo catchment from north to south are:

- *Colophospermum mopane* with *Acacia nigrescens*;
- *Combretum apiculatum* with *Acacia nigrescens*;
- *Terminalia sericea* with *Acacia tortilis* and *A. erubescence* (in sandy areas);
- *Pelthophorum africanum* with *Acacia tortilis*.

Currently, the Botswana Range Inventory and Monitoring Project (BRIMP) is re-mapping and sampling the vegetation of Botswana. About 20 percent of the task is complete. Ground data on species composition and cover is captured in GIS format.

Mozambique

Baseline information on the country's natural forest and woodland resources was first provided by a 1980 reconnaissance forest inventory, carried out in 1979–80 under an FAO–UNDP forestry sector project. At this time, the forest area of Gaza Province was inventoried at 1.3 million ha (Macucule and Mangue, 1980).

The 1980 inventory was updated in the early 1990s using visual interpretation of 1990–91 colour composite images (1:250 000) and Landsat TM (1:1 million), together with field truthing in all provinces. It produced a national land cover and land use map at a scale of 1:1 million, with quantitative data on the extent of the forest resource base by major forest type and land use classes (using the AFRICOVER legend), the extent of agricultural encroachment within the natural woody vegetation, as well as an estimate of deforestation rates. Table 13 provides data on land cover in Gaza Province according to the updated national forest inventory.

TABLE 13
Forest type and land use class in Gaza Province, Mozambique

Forest types and land use classes	Total (ha)
High forest (high–low density)	25 338
Low forest (high–low density)	635 923
Thicket (low–high density)	4 014 494
Grassland (open & wooded)	1 868 244
Mangrove communities	387
Dune vegetation	20 833
Agriculture	1 067 568
Irrigated agriculture	27 590
Total productive forest	1 437 162

Source: Saket (1994).

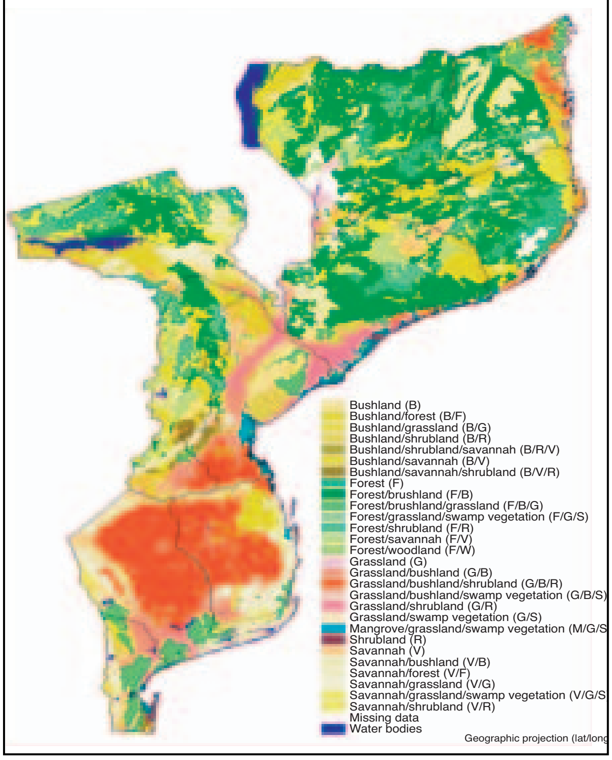
Overall, Gaza Province showed a low rate of deforestation (0.92 percent over 18 years), even though clearings of natural vegetation occurred widely along the Limpopo Corridor where many villages were created after 1972, and around the districts of Chicualacuala and Massangena. In contrast to other provinces, woody vegetation had recovered over wide areas in Chigubo, Dindiza, Nalazi and Changane districts and along the western border with Inhambane Province. Deforestation is most severe in Xai-Xai District, caused essentially by inappropriate agricultural practices, the collection of woodfuels and building materials from woodlands, and the high frequency of extensive forest fires. The forest inventory determined the allowable cut at 13 141 m^3 from an area of productive forest of 1 437 162 ha.

Current initiatives involve the mapping of land use and land cover for the whole of Mozambique at a scale of 1:250 000 and eight selected districts at a scale of 1:50 000 scale (Desanker and Santos, 2000), using the FAO AFRICOVER legend.

The National Remote Sensing Centre (CENACARTA), created in 1989 under a French aid programme, is the supplier of satellite images in Mozambique (SPOT, Landsat, Radarsat, ERS and SPIN). Mozambique does not have a receiving station, but the CENACARTA has agreements with image suppliers in South Africa, such as the Satellite Applications Centre (SAC) of the Council for Scientific and Industrial Research (CSIR) in South Africa. The CENACARTA has technical capacities to process images and supply them in analogue and digital format.

The main biome in Gaza Province is the dry/eutrophic savannah (Figure 27), which lies between the 400-and 600-mm rainfall isohyets. It is characterized by the dominance of *Acacia* spp. and *Colophospermum mopane* on heavier-textured, base-saturated soils, and *Caesalpinoideae* and *Combretaceae* on leached, sandy and lighter-textured soils. The Miombo savannah woodlands, which typify the moist/dystrophic savannah, reach their southern limit as a whole system north of the Limpopo River estuary. Three main ecoclimate

FIGURE 27
Vegetation map of Mozambique



zones can be distinguished from upstream to downstream:

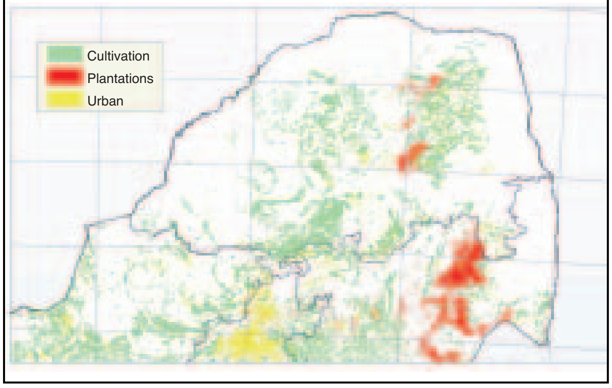
- From the border to 100 km downstream of the confluence with the Elephants River, the sand plateau is dominated by a vegetation of very dense arid sand thicket communities or by woodlands dominated by multistemmed short trees. On the slopes of the plateaus, *Colophospermum mopane* and *Acacia exuvialis* dominate an open woodland community, with woodlands of *Acacia, Commiphora* and *Terminalia* at lower elevations. Floodplains support woodland and open woodlands of *Acacia* (*xanthophloea, tortilis* and *nilotica*) with shrub-thickets of *Salvadora persica*. *Acacia xanthophloea*, a flat-topped tree with yellow bark, grows where its roots can find water easily. It is, as is *Salvadora persica*, an indicator of saline-alkaline soils on flat seasonally waterlogged soils close to the riverbanks. *Acacia tortilis* is a salt-tolerant tree found on the more permeable soils.
- In the more subhumid zone downstream to about 100 km inland from the sea, there are very open woodlands with short dense thorn thickets in the bottomlands; a result of the continued removal of woody elements for fuelwood in this region. The floodplain supports woodlands of *Acacia*. It is within this region that the transition from a xeric to moist sand thicket and woodland takes place. On the levee deposits along the Limpopo River, there are dense thickets of *Ficus, Diospyros* and *Zanthocercis*. The near floodplain supports *Acacia* or open woodlands. Around the Chokwé scheme, there are considerable reductions in the woody biomass, except in the western part where very dense thickets and woodlands of *Acacia* remain. A survey by Timberlake, Jordáo and Serno (1986) showed a close association of vegetation with soil type and drainage, determined primarily by soil texture, and by period of water inundation. Poorly drained soils support open grassland vegetation with few shrubs or trees, while the grass species present on the plains appear to depend on length of inundation by water. Sandy loam soils support an *Acacia* woodland, often associated with reasonably high soil-calcium levels. Deep sandy soils (Arenosols) support woodlands of broad-leaved deciduous tree species.
- In the coastal area characterized by a humid tropical climate, the present composition and the physiognomy of the vegetation patterns reflect anthroprogenic changes to the original mixed forest-woodland-grassland physiognomy of many species and facies.

Tique (2000) characterized the vegetation in Chicualacuala District as being dry deciduous tree savannah dominated by *Androstachys johnsonii* and deciduous tree savannah at medium and low altitudes, which is a secondary formation of *Colophospermum mopane* and other low-altitude tree savannah, occasionally mixed with smaller trees such as *Sclerocarya caffra, Kirkia acuminata* and *Combretum* spp. There is also a strong relationship between soil types and vegetation patterns on the sandy plains. *Terminalia sericea* and *Rhigozum* sp. are the dominant species on the very deep yellowish-brown sands (Ferralic Arenosols), along with *Androstachys johnsonii* and some *Commiphora, Grewia* and *Combretum*. In soils with a high clay content, *Colophospermum mopane* is dominant.

South Africa

The South African National Land Cover Database Project (NLC) was completed in 1999 (Thompson, 1999; Fairbanks *et al.*, 2000), producing a

FIGURE 28
Transformed land cover types in the South African part of the Limpopo River Basin



standardized land cover database for all of South Africa, Swaziland and Lesotho (see Figure 28 for transformed land cover types in the South African part of the Limpopo River Basin). The project utilized Landsat TM satellite imagery captured in 1994–95. The product is designed for 1:250 000-scale mapping applications, intended to provide national baseline information on land cover. Georeferenced land use types at a national scale are inferred from the land cover map, to be read in conjunction with information from Statistics South Africa and the Department of Agriculture. Data sources are available, at best, at magisterial district level.

The classification scheme is based on clear and unambiguous terminology and class definitions, designed to ensure data standardization and to conform to internationally accepted standards and conventions, such as in use for the Vegetation Resource Information System (VEGRIS) of Zimbabwe, and the FAO AFRICOVER project.

One advantage of the NLC classification is that it shows simultaneously the major land cover, based primarily on broad structural vegetation, but also incorporating land use components. There are three levels of classification and the second level includes useful subclasses based on degradation and different crops.

On the South African side, the Limpopo River Basin falls largely within the savannah biome (commonly known as bushveldt), which is the largest biome in southern Africa, occupying 46 percent of the southern African area. The vegetation is well summarized in Low and Rebelo (1996), from which extracts have been included below.

A grassy ground layer and a distinct upper layer of woody plants characterize the vegetation. A major factor delimiting the biome is the lack of sufficient rainfall, which prevents the upper layer from dominating, coupled with fires and grazing, which keep the grass layer dominant. Several variations in vegetation occur within the basin.

The mopane bushveldt dominates the undulating landscapes from Kruger National Park to Soutpansberg in Limpopo Province. The vegetation is characterized by a fairly dense growth of mopane (*Colophospermum mopane*) and a mixture of other tree species. The shrub and grass layers are moderately well developed.

The Soutpansberg arid mountain bushveldt is restricted to the dry, hot, rocky, northern slopes and summits of the Soutpansberg Mountains (Low and Rebelo, 1996). There is a distinct tree layer, which is characterized by *Kirkia acuminata*, *Englerophytum magalismontanum* and other tree species. The shrub layer is moderately developed and the grass layer is poorly to moderately developed. The Waterberg moist mountain bushveldt, although related to the Soutpansberg arid mountain bushveldt, occurs on the sandstone and quartzite soils on the rugged and rocky Waterberg Mountains. The tree layer is well developed with a moderately developed shrub layer and a moderately- to well-developed grass layer.

The clay thorn bushveldt is distributed widely on the flat plains that have black or red vertic soils southeast of Potgietersrus and Nylstroom in Limpopo Province and similar habitats in North West Province. Vegetation is dominated by *Acacia* species and turf grasses (*Ischaemum afrum*).

Sweet bushveldt occurs on deep greyish sand overlying granite, quartzite or sandstone in the dry and hot Limpopo River Valley and the associated valleys of tributary rivers in northwest Limpopo Province. The vegetation structure is mostly short and shrubby. Trees such as *Terminalia sericea, Rhigozum obovatum* and *Acacia tortilis* dominate sandy areas. Grasses dominate the herbaceous layer. The mixed bushveldt vegetation type found on undulating to flat plains varies from a dense, short bushveldt to a rather open tree savannah covering most of Limpopo Province and northern North West Province. On shallow soils, *Combretum apiculatum* dominates the vegetation. Grazing is generally sweet and the herbaceous layer is dominated by grasses such as *Digitaria eriantha* on shallow soils and *Terminalia sericea* on deeper soils.

The mixed lowveldt bushveldt is found on the sandy soils of the undulating landscapes of Limpopo Province and Mpumalanga Province on the eastern boundary of the country. Vegetation is usually dense bush on the uplands, open tree savannah in the bottomlands, and dense riverine woodland on riverbanks. This bushveldt is confined to frost-free areas. In general, vegetation has been damaged severely in vast areas and has in some cases been destroyed almost completely by overgrazing and injudicious utilization.

Zimbabwe

In Zimbabwe, the VEGRIS supports a land use database for the whole country, derived from SPOT imagery of 1992 and ground truthing. This database also contains topographic information, but no detailed species data are captured. Recently, the Zimbabwe land reform programme has stimulated the digitization of commercial farm boundaries at a scale of 1:250 000 in order to produce a national land inventory.

Land cover information is available from the woody cover map of Zimbabwe (GOZ–FC, 1998), which distinguishes the following main categories of vegetation structure:

- cultivation (27.5 percent);
- woodland (53.2 percent);
- bushland (12.7 percent);
- wooded grassland/grassland (4.8 percent);
- plantation forestry (0.4 percent).

The remaining 1.4 percent consists of water bodies, settlements, rock outcrops and natural moist forests.

Two woodland types predominate in the Limpopo River Basin: mopane woodlands and *Acacia–Combretum–Terminalia* woodlands. Mopane woodlands are quite widespread in Zimbabwe and are associated with low-altitude, hot areas with sodic or alluvial soils. *Colophospermum mopane* is the dominant species and constitutes 18.5 percent of the 101 500 ha under mopane woodland. It is used for craftwork, fuelwood, poles, railway sleepers and parquet floors.

Acacia–Combretum–Terminalia woodland type is found in the vleis in the drier parts of the country. Acacias tend to form the dominant component of these woodlands. In terms of population pressures, these woodlands are second to the miombo woodlands. Acacias provide nutritious fodder, improve soil fertility and rehabilitate degraded sites and fix sand dunes. On the other hand, *Terminalia* tends to dominate burnt sites and is important for fuelwood, poles, tools and wagon draught shafts.

The southeast middleveldt is an area of transition with low mopane woodland in the drier areas (less than 500 mm mean annual rainfall) and *Terminalia sericea* open woodland in the slightly wetter areas. *Julbernardia globiflora* is found locally on high ground, and *Brachystegia glaucescens* on outcrops of granite and gneiss. An association of *Colophospermum–Combretum–Acacia* is common in lower slope positions. *Acacia* spp. are dominant on the few areas of red clay soils derived from schist.

Colophospermum mopane is the dominant species in the southeast lowveldt, where it forms an open tree savannah. *Commiphora* tree savannah is the typical vegetation type on shallow soils over basalt, which includes *Combretum apiculatum, Boscia albitrunca, Adansonia digitata* and *Colophospermum mopane.* Mopane shrub savannah dominates moderately deep vertic soils on basalt. The Karoo sandstone areas near the border with Mozambique are characterized by *Guibourtia conjugata* tree savannah and *Guibourtia conjugata/Baphia massaiensis* woodland thicket, with *Androstachys johnsonii* thicket occurring locally.

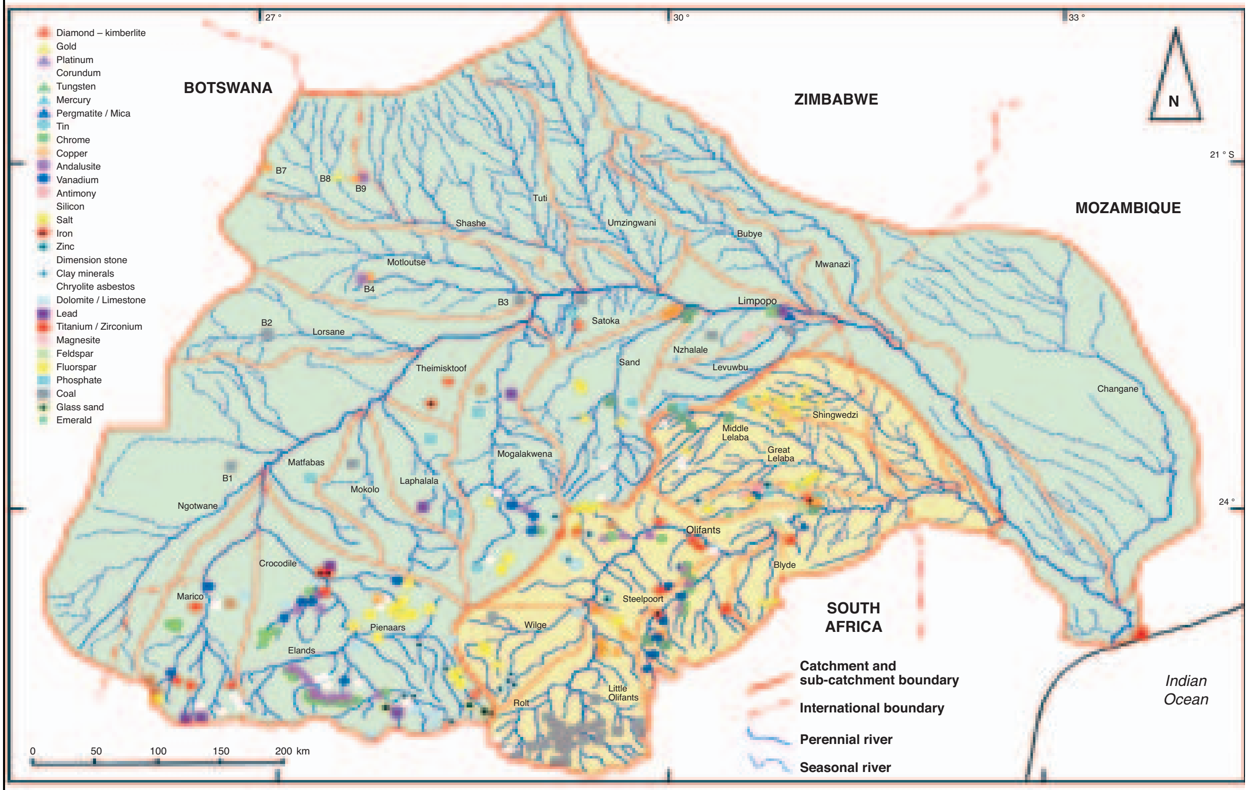
OTHER RESOURCES

Economic geology and minerals

Southern Africa is very rich in mineral and mining products, including (in order of importance): gold, diamonds, coal, platinum, iron, copper, limestone, nickel and chromium (Figure 29). In addition, quarried stone is processed for road and other construction, and sand and gravel are extracted from riverbeds and other sources. The richest concentration of minerals, in particular extensive gold fields, in South Africa is found along the Witwatersrand around Johannesburg in Gauteng Province, which is at the southern divide of the Limpopo River Basin. Botswana is especially rich in diamonds, and also has coal, copper and nickel. The main mineral reserves of Zimbabwe in the Limpopo River Basin include gold (southeast of Bulawayo), coal, asbestos, limestone, iron and emeralds. These resources are of great economic importance to local and national economies, especially in Botswana and South Africa.

The mining of minerals has significant ecological consequences. Until recently, there was a general lack of rehabilitation and ecological protective measures at mining sites. Although substantial environmental improvements have been made

FIGURE 29
Location and type of all mining operations located in the Limpopo and Elephants River Basins



Source: MMSD Southern Africa Working Group (2001).

in the last few years, many land and water areas remain heavily polluted. Some of the most common environmental effects of mining are:

- destruction of landscapes and ecosystems by open-cast mining;
- waste accumulation and groundwater contamination by leachates;
- lowering of the groundwater level;
- toxic concentrations of elements such as copper, nickel, zinc, chromium and boron;
- environmental health threats through unsafe mining operations, or specific minerals (e.g. asbestos).

Fish resources

The Limpopo River has few fish species compared with other rivers in Africa. This is primarily because of the harsh environment with its wide variations in temperature, prolonged dry periods, and highly variable river levels. There are greater fish populations in the more permanent tributaries and in the many dams built within the catchment, especially in South Africa.

The lower zone of the Limpopo River system is important to Mozambique as its flows contribute to the productivity of the coastal brackish water area, where fish and shrimp production is significant. The fisheries of the Limpopo River make very little contribution to the economy and nutrition of the people of Botswana and Zimbabwe at present. Some *Tilapia* species have been introduced in Zimbabwe from the Zambezi River system.

There are at least 30 fish species inhabiting the Limpopo River (Box 12). Fish species, such as cyprinids (*Schilbe* spp.), catfish (*Clarias* spp.), substrate-brooding tilapias (*Tilapia* spp.), mouth-brooding tilapias (*Oreochromis* spp.), the introduced trout (*Salmo trutta*) and several brackish-water species in the lower reaches of the river in Mozambique, can be a source of food and income for the people living near the rivers and dams. These same species are suitable for aquaculture wherever soil conditions permit and where water is available for a substantial part of the year. The same indigenous and introduced species can be stocked in dams and reservoirs in order to enhance fish production. However, the abundance

BOX 12

Fish species of the Limpopo River

- *Ambassis* spp., possibly three species in lower reaches;
- *Amphlius natalensis*, in coastal areas;
- *Amphlius uranoscopus,* in the lower reaches of the river;
- *Aplocheilichthys johnstoni; A. katangae;* a variety of exotic poeciliids;
- *Austroglanis sclateri,* translocated through the Orange–Vaal water transfer schemes;
- *Chetia flaviventris*;
- *Chiloglanis pretoriae, C. paratus, C. swierstrai*;
- *Clarias gariepinus*, *C. ngamensis*, *C. theodorae*;
- *Gambusia,* an exotic species;
- *Glossogobius callidus, G. giurus* in the lower reaches;
- *Lepomis macrochirus,* an exotic species;
- *Micropterus* spp., an introduced bass;
- *Mugilidae* spp. (mullet), numerous species in coastal areas;
- *Nothobranchius orthonotus*, *N. rachovii, N. furzeri* in coastal areas;
- *Oncorhynchus mykiss*, introduced exotic;
- *Oreochromis macrochir*, translocated into parts of Zimbabwe from the Zambezi River system;
- *Oreochromis mossambicus*;
- *Oreochromis niloticus,* an exotic species with a barred tail;
- *Oreochromis placidus,* probably in lower river area;
- *Perca fluviatilis,* an exotic species;
- *Psedocrenilabrus philander,* a small cichlid;
- *Salmo trutta*, brown trout;
- *Schilbe intermedius*;
- *Serranochromis meridianus,* possible in lower reaches of the river;
- *Serranochromis thumbergi,* introduced in parts of Zimbabwe from the Zambezi River system;
- *Synodontis zambezensis*; an introduced exotic species;
- *Tilapia sparrmanii, T. rendalli,* substrate-spawning tilapias.

Source: Bell-Cross and Minshull (1988); Lévêque, Bruton and Ssentongo (1988).

and catch magnitudes have yet to be determined although some estimates have been made of fish populations in some dams. Possibilities exist for fish farming in all four countries, and increasing fish production and supply should be studied and ascertained. The major problem of managing fish in available dams will always be one of re-stocking when water is plentiful after a long period of drought.

LAND DEGRADATION AND DESERTIFICATION

Land degradation and desertification are related terms or processes. The accepted UNCED definition is that desertification is land degradation in arid, semi-arid and dry subhumid areas resulting from climatic variation and human activities.

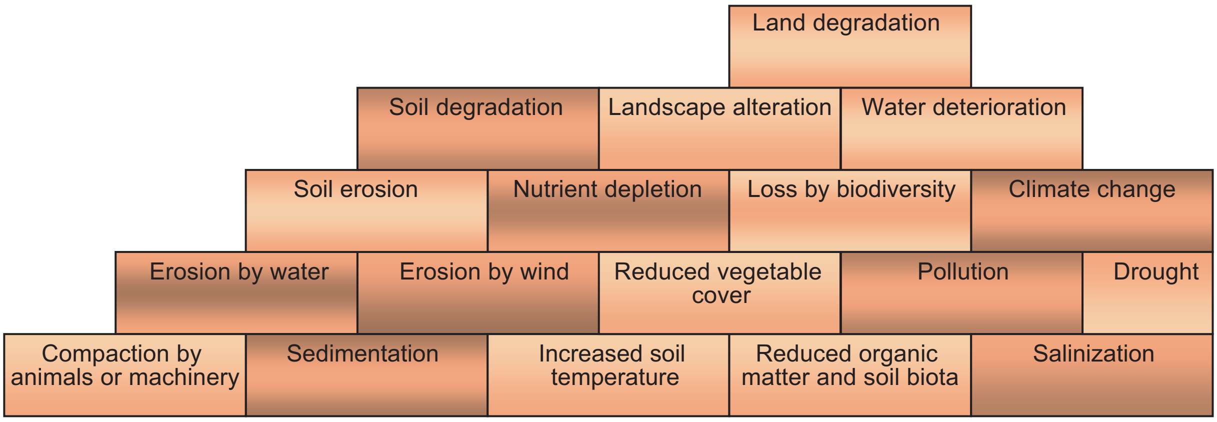
Land degradation threatens economic and physical survival (UNEP, 1999), and could lead to household and national food insecurity in many countries, including the southern African region. Crop yields could be reduced by 50 percent within 40 years if degradation continued at present rates. In South Africa, it is estimated that about 400 million m^3 of soil is lost annually. Key issues to be addressed throughout the region include declining soil fertility, escalating soil erosion, agrochemical pollution and desertification.

Main types of erosion and land degradation

Land degradation is a composite term, loosely defined as a sustained loss in the quality and the productive capacity of the land. As land degradation progresses, efforts by land users to secure a living become increasingly precarious and uneconomic. The most common indication of land degradation is soil erosion. Subtler but equally important factors include reduction in vegetation cover and changes in vegetation species composition. Stocking and Murnaghan (2000) provide sound practical guidelines on land degradation and its assessment in the field, viewing degradation from the perspective of the land user. Figure 30 illustrates how components of land degradation interlink with many other components that influence the quality and productivity of land, including how it is used or misused.

Identification of the direct and indirect causes of land degradation is essential, as any remedial measures designed to rehabilitate land must tackle the root causes of the problem in order for the reversal of land degradation processes to be successful.

FIGURE 30
The land degradation wall



Source: Stocking and Murnaghan (2000).

A clear distinction between causes, mechanisms and impacts of land degradation is often lacking in degradation studies (Mainguet, 1991), and it is difficult to distinguish between human and natural influences as both may occur simultaneously. Drought is often quoted as a direct cause of degradation, but it is also seen as the catalyst for other processes that lead to degradation.

Physical factors

Physical factors always play a role in degradation processes, but their role is less crucial than assumed in erosion hazard mapping. Nevertheless, the topography (slope in particular), the properties of the soil and underlying rock, the vegetation, and climate characteristics (rainfall in particular) are important factors in the acceleration of human-induced erosion.

Increased runoff and accelerated erosion relate strongly to poor surface conditions, including surface crusts, lack of vegetation, and compaction (decreased infiltration). In addition, the properties of soil horizons and other underlying materials play a major role, especially with respect to gully erosion. Porous materials such as weathered rock (saprolite) and soils with high hydrologic conductivity are conducive to gully erosion as relatively large and rapid subsurface flows may occur, causing collapse of the gully head or sides. Soils with weak structure and friable consistency are vulnerable to erosion, e.g. soils high in illitic or mixed-layer clays. The same applies to soils with high sodicity, inducing a high clay dispersion rate (Solonetz and Planosols).

Climate variability has a profound accelerating effect on erosion and land degradation. Extreme rainfall events aggravate the condition of already degraded land through increased runoff and flooding. Lack of rainfall and resulting drought accelerate desertification processes. Drought acts as a strong catalyst in the initial and progressive degradation of land.

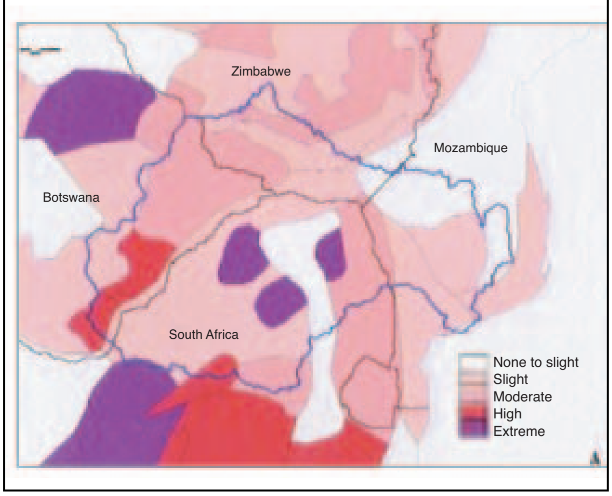
The cause of accelerated erosion is mostly a complex of several factors, as the two main spheres of influence – physical and human – are interrelated and interactive. There is always an element of human influence involved, related to the management of the resources, which may be aggravated by the conditions and characteristics of the environment (climate, soils, geology and landscape). Stable landscapes resistant to erosion normally show less erosion compared with vulnerable environments. Similarly, areas with reliable rainfall in general show less degradation than areas with frequent drought.

Most surveys and studies of land degradation conclude that the primary causes are related to land use, management and socio-economic attitudes. Increase in population is cited as the single most important cause of degradation. However, with land becoming scarce, communities may become more aware of the necessity to improve land management and conservation.

Assessment of erosion and land degradation in the Limpopo River Basin

The Global Assessment of Soil Degradation (GLASOD) by the UNEP is considered the first global assessment of the geographical distribution

FIGURE 31
Erosion severity in the Limpopo River Basin



of human-induced soil degradation (Oldeman, Hakkeling and Sombroek, 1990). Soil degradation is described in terms of: type of erosion and deterioration; cause; degree; rate; and relative extent. The overall status or severity of soil degradation is indicated by a combination of its degree and extent, represented on maps by five classes of severity: none, slight, moderate, high and extreme.

The main result of the GLASOD project is a map of the world (scale: 1:5 million) showing the occurrence of human-induced actual soil and land degradation. The occurrence of the several general areas of degradation in the Limpopo River Basin can be distinguished on the map as follows (Figure 31):

- No degradation, or stable terrain, along the lower northeast part of the Limpopo River Basin in Zimbabwe and Mozambique and in a north–south zone roughly following the Escarpment and associated mountains.
- Slight degradation along the upper Limpopo River Valley, in most of the adjacent southwest catchment in South Africa, and in southeast Zimbabwe. Most of these areas coincide with private farms. Most of the remainder of Mozambique also falls into this class.
- Moderate degradation in northeast Botswana and adjacent Zimbabwe, a north–south zone covering northeast South Africa (including Kruger National Park) and the southern tip of the catchment.
- High degradation in the southwest upper catchment in Botswana and in an area southwest from Pretoria.
- Extreme degradation in three areas in Limpopo Province in South Africa, corresponding with densely populated communal areas (former homelands of Venda and Lebowa).

Apart from the generalized pattern showing several unnaturally shaped units, the validity of the information may be questioned in a number of areas. The strong contrast between the southern part of the Limpopo River Basin and the adjacent Vaal River Basin does not seem realistic. The differences within Botswana do not appear to reflect original information or present status adequately. A substantial part of the South African lowveldt strip has no apparent erosion, notably the area covering Kruger National Park. This same unit should not include Swaziland, where some of the most degraded areas in southern Africa occur.

Hakkeling (1989) described the GLASOD results in more detail for the southern and eastern African regions covering Botswana, Mozambique and Zimbabwe, but not South Africa. This regional map shows a pattern of erosion and degradation in places quite different from that on the integrated global map. In general, the regional map provides a more accurate overview and the country descriptions below draw heavily on this information.

Botswana

The information from the GLASOD regional map (Hakkeling, 1989) indicates that almost all units fall into the overall class of high degradation, except for one area with slight degradation, because of dominant sandy soils. The units most affected by water erosion – both sheet and gully erosion – are found in the northern and southern parts of the Limpopo River Basin, caused mainly by overexploitation of vegetation and intensive cropping. Wind erosion is the dominant type of degradation in the middle units, caused primarily by overgrazing. Up to 50 percent of all units are considered to have recovered by natural stabilization from earlier degradation.

Reports from the first half of the twentieth century already expressed concern about the state of the land resources. Studies from the second half of the twentieth century indicated that the problem was severe, and that numerous examples of extreme overgrazing could be found. However, it is also claimed that such conclusions are based on flawed data, that the perception of range condition and management is biased in favour of western models, and that most of the examples of degradation are temporary conditions that are natural to a variable savannah ecosystem.

Evidence is based mainly on examples of: bush encroachment; decrease in general grass density and in numbers of the more nutritious and palatable species; and of an increase in patches of bare soil. The consensus is that rangeland degradation is occurring, but there is disagreement as to its extent, severity and reversibility. Abel and Blaikie (1989) argue that degradation should not be measured by using indicators such as short-term vegetation changes. Instead, changes in the environment should be judged according to their degree of irreversibility over longer periods. The assessment of detrimental changes must also take into account estimates of secondary production interest of the users, for which reason the productivity of communal grazing land may be higher than that of commercial ranches (De Ridder and Wagenaar, 1984).

The description of erosion and land degradation within the Limpopo River Basin (hardveldt) of Botswana is confined mostly to local observations, and although overviews have been produced (Arntzen and Veenendaal, 1986; Dahlberg, 1994), a comprehensive inventory is lacking. Ringrose and Matheson (1986) reported an increase in desertification manifested as decreased vegetation, increased erosion and reduction of soil water retention as a result of loss of soil organic matter induced by overgrazing and fuelwood collection. In this regard, the BRIMP also generates various degradation maps and datasets, based on ground monitoring and the interpretation of Landsat images specifically aimed at addressing desertification questions.

Occurrence of severe sheet and gully erosion is reported from several sites in east Botswana near Serowe and Kalamare, but erosion is generally estimated to be slight or moderate. Most of the erosion is associated with sloping land, including the footslopes of hills. The flat and slightly undulating parts of the plains show less evidence. Wind erosion is reported from areas with a bare surface, especially from fallow arable land, but the severity is difficult to estimate. This effect is most pronounced after periods of drought and reduction of the protective vegetation cover.

Mozambique

The information from the GLASOD regional map indicates that the northernmost units of the Limpopo River Basin have no livestock because of tsetse fly, hence, no erosion is described. Most other units have the overall class of slight degradation, except for two units with moderate degradation. High degradation is reported in the Changane Valley owing to crusting and sealing. Most of the degradation is caused by wind erosion – with some nutrient losses – but a variety of causes have been observed: overgrazing in the Lebombo Hills, intensive cropping along the coast, and salinization in the irrigated areas near Xai-Xai in the Limpopo River floodplain. Moreover, natural stabilization seems a common process in Mozambique.

Assessment of erosion risk in Mozambique was first undertaken on a national scale by FAO (1985) when Reddy and Mussage compiled a first approximation of an erosive capacity index. The low rainfall areas of Gaza Province were classified as a low erosion-hazard zone. High erosion-risk zones included the coastal areas of Gaza Province. Population density in the coastal belt has raised concern about dune vegetation, mangroves and coral reefs. While none of these ecotypes could yet be considered critically threatened in Mozambique, local areas of degradation have been identified and the government is anxious to take remedial action before the problems become more severe.

The various studies and surveys reviewed indicate that major problems in the development of the Limpopo Valley soils are related to salinity and alkalinity. These problems arise from the geological structure, which has very saline marine sediments under the recent alluvial sediments (primary salinization). Furthermore, mismanagement of the irrigation water supplies and of the drainage systems has raised groundwater tables and led to the efflorescence of salts at the ground surface (secondary salinization).

South Africa

The GLASOD map of Africa (Oldeman, Hakkeling and Sombroek, 1990) generally indicates less soil degradation in the Limpopo River Basin as compared with the rest of South Africa. Most of Limpopo Province shows none to slight degradation, with moderate degradation in the eastern parts, all caused by water erosion, and primarily caused by overgrazing. Moderate to high degradation resulting from pollution and acidification occurs in the south of the catchment (Pretoria–Johannesburg–Witbank area). The most severe soil degradation caused by overgrazing occurs in the former homeland areas in the central Limpopo Province.

Hoffman and Todd (1999) have provided an overview of erosion and land degradation in South Africa, in a first-phase review for the development of South Africa's national action programme to combat desertification. A number of general conclusions from this report were presented, which are also relevant to the Limpopo River Basin. The focus of land degradation has historically been on the degradation of vegetation, in particular of the rangelands. The study suggests that equal attention should be paid to degradation of vegetation, soil and water resources.

Earlier inventories of soil and land degradation have concentrated on erosion hazard with relatively little attention given to the influence of land use practices. The present view is that both land use and land tenure exercises have a significant influence on land degradation.

Hoffman and Todd (1999) state that soil and vegetation degradation is perceived as being significantly greater in communal areas as compared with commercial areas, by at least a factor of two. However, specific forms of vegetation degradation are more of a problem in commercial areas, such as change in species composition, alien plant invasion, and encroachment of indigenous woody species. It is suggested that areas with steep slopes, low rainfall and higher temperatures are significantly more eroded. Climate change in the last century may have had an impact on the intensity of erosion, but this needs to be further studied, in particular in order to define the relationship between drought and erosion.

The government policy of land allocation has had a major effect on land use and land degradation. In the commercial farming areas, this has been partially conducive to sustainable land use, but not so in the communal areas, where practices of crop production, communal grazing and use of the vegetation have led to accelerated erosion and degradation. The understanding in South Africa of communal land use and production systems is poorly developed, as is its relationship with land degradation (Hoffman and Todd, 1999).

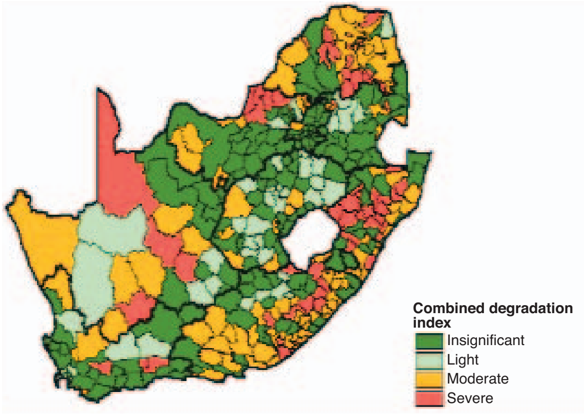
In an overview on soil degradation in South Africa, a report by FAO (1998a) states that data on degradation are incomplete and fragmented, with little information on spatial distribution and distinction between natural and human-induced erosion. Relevant land degradation information is available from a number of other sources (Newby and Wessels, 1997; Van Zyl, 1997; Scotney, 1995; Laker, 1994).

Nationally, it is estimated that water erosion affects 6.1 million ha, or more than 40 percent of the total of 14.6 million ha of cultivated soil in South Africa. Of this, 15 percent is seriously affected, 37 percent moderately affected and the remaining 48 percent slightly affected. Laker (1994) estimates that about 20 percent of all topsoil has been lost since the beginning of the twentieth century. Average annual soil loss is estimated at 2.5 tonnes/ha, equal to about 300 million tons. Wind erosion affects even more cultivated land, an estimated 10.9 million ha, or more than 70 percent. Of the affected cultivated land, 7 percent is seriously eroded, 29 percent moderately and 64 percent slightly. Compaction affects about 2 million ha, or about 15 percent of all cultivated land. Surface sealing is also a widespread and a serious problem. It is estimated that a total of 15 percent or more of the 1.2 million ha of irrigated land is moderately to severely affected by salinization and/or waterlogging. In addition, large areas are affected by pollution, acidification and fertility losses. Of the national grazing land about 3 million ha are rendered worthless for grazing as a result of encroachment by undesirable species.

Figure 32 shows the occurrence of soil and vegetation degradation combined in a single index per magisterial district. The provinces within the Limpopo River Basin are described as belonging to

FIGURE 32

Land degradation in South Africa



Source: Hoffman and Todd (1999).

BOX 13

Status of soil health in Mpumalanga Province

In a study on land quality indicators, Mpumalanga Province was stratified according to vegetation biome, maize, other crops and minesoils. Within each stratification, data were collected for the indicators set out in the table below (median topsoil values are shown):

Indicator	Grassland	Savannah	Maize	Other crops	Mine cover soil
Organic C (%)	2.51	1.28	1.16	1.19	0.53
Total N (%)	0.13	0.11	0.08	0.09	-
C/N ratio	20	13	16	15	-
pH_{water}	5.65	6.47	5.89	6.00	6.10
EC (mS/m)	33	30	40	41	36
SAR	-	-	0.20	0.39	-
P (mg/kg)	-	-	17.7	19.7	-

Median values did not reflect any serious soil ill health, the climate context being taken into account. However, lower quartile pH values tended to fall below 5.5, the threshold for acid saturation problems. Atmospheric deposition of acidifying agents from coal-fired power stations might have played a role in low topsoil pH values under grassland.

Source: Nell *et al.* (2000).

the most eroded and degraded parts of the country (which contradicts the GLASOD result). However, these estimates are based on perceptions from agricultural extension and resource conservation officers, and not on actual observations.

According to Newby and Wessels (1997), the estimated extent of degradation of vegetative cover is 25 percent for North West Province (poor to very poor condition), 87 percent for Limpopo Province (poor to critical condition) and 50 percent for Mpumalanga Province (poor to critical condition). Serious wind and water erosion is reported from North West Province, respectively 53 and 36 percent of all area affected. The mining industry – predominantly coal mining – has occupied and severely polluted 50 percent of all high potential arable land in Mpumalanga. However, this statement is contrary to the experience and results of other researchers (e.g. Box 13).

Wessels *et al.* (2001) mapped the conservation status of natural vegetation and soils in Mpumalanga Province, including the present land cover, rangeland condition, alien vegetation and bush encroachment. Table 14 summarizes some of their main findings. One-third or more of both the grassland and savannah biomes in the province is stated to be in poor to very poor condition. Visible soil erosion damage is stated to occur over less than one-third of the province.

TABLE 14
Soil and vegetation degradation in Mpumalanga

Attribute	Class	Percentage of biome in Mpumalanga
Grasslands		
Condition	Good to very good	53–75
Condition	Poor to very poor	35–42
Soil erosion	Light to considerable	14–28
Soil erosion damage	None visible	71–84
Savannah		
Condition	Poor to very poor	35–42
Bush encroachment	Severe	5
Bush encroachment	Extreme	4
Soil erosion damage	None visible	70–76

Source: Wessels *et al.* (2001).

Zimbabwe

Information from the GLASOD regional map indicates overall strong degradation in the communal areas in the northern and western part of the Limpopo River Basin adjacent to Botswana, with severe sheet and gully erosion caused by deforestation and intensive cropping. No erosion is described for the areas with commercial ranching as the dominant land use, and for national parks. The communal grazing area in the east has moderate soil degradation. As in Botswana, most units are considered to have stabilized in a natural way from earlier degradation.

The history of land degradation in Zimbabwe and the different views about it are quite similar to Botswana. Official interventions based on reports citing the occurrence of severe soil erosion have largely failed (Scoones, 1989a). The increase in crop and animal production in the 1980s is considered sufficient evidence that there is no substantial decline in the natural resource base (Scoones, 1992a). However, this may be a preliminary conclusion as the 1990s have shown a general decline.

Campbell *et al.* (1990) claim that there is sufficient evidence to indicate that cattle are linked to major environmental changes, but they also conclude that the issue of whether communal grazing practices cause degradation cannot be answered without additional data, in particular a spatial analysis.

Scoones (1989b, 1992b, 1993) finds that disregard of the heterogeneity of the environment is one of the main reasons for conflicting perceptions of environmental change. Areas will differ on the extent of degradation and the effects of the changes on secondary production. Scoones found that in most years the farmers are avoiding irreversible damage, in terms of productivity, by using strategies of herd mobility and local ecological knowledge. In drought years, migration between different savannah types is employed on a regional scale. Certain elements of the landscape or ecosystem, such as riverine strips, vleis (wet bottomlands) and drainage lines, are vital in providing fodder in critical periods.

The extent of soil erosion in Zimbabwe was mapped nationally using air photography (Whitlow, 1988). Only 5 percent of the country was badly eroded, in comparison with communal areas where badly eroded land comprised about 10 percent of the land area. Little difference was observed between cropland and grazing land. This is somewhat surprising as most arable land in Zimbabwe seems adequately protected by contour ridges. In other countries in southern Africa, erosion is always reported to be excessively higher on communal grazing land, e.g. in Swaziland (Remmelzwaal and McDermott, 1997).

Elwell (1980) calculated annual soil losses on cropland caused by sheet erosion followed by national surveys. Grohs (1994) re-interpreted Elwell's results according to administrative areas. The highest soil losses of more than 100 tonnes/ha were recorded in the north and east of the country. The lowest values of less than 5 tonnes/ha were found in the semi-arid south, within the Limpopo River Basin. On the basis of these findings, an average annual soil loss of about 55 million tonnes was calculated.