Soils and Land Evaluation of the Lake Ngami Region in Northwestern Botswana

by

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INTRODUCTION

In April 1982 the soil surveyor began a 1 year posting to Maun, in Northwestern Botswana, to initiate the reconnaissance level soil mapping of the region under the FAO-UNDP project BOT/80/003 - Soil Mapping and Advisory Services. He formed part of a team working towards mapping the soils of the entire country at the scale of 1:250,000, and became a coopted member of the Regional Agricultural staff in Maun. His primary duties were to describe, classify and map the soils of the area, prepare short demonstration courses for resource officer trainees on the identification of important field characteristics of soils and their relevance to crop production, and to train counterpart staff in all aspects of field and office soil survey operations.

The lack of information concerning the soils of Botswana became especially apparent in the late 70's during the planning stage of the Arable Land Development Programme (ALDEP). Earlier soil survey reports have produced only generalized soils information. In Northwestern Botswana, some of the soils have been described by Siderius (1971) and Staring (1978), including land evaluation for defined land use activities. SWECO (1976), in a study of water development in the Okavango Delta, evaluated the potential (soil, water, availability and costs) of specific areas for irrigated agriculture. The Government of Botswana realized, however, that a systematic and comprehensive soils inventory and land evaluation were necessary for sound agricultural land planning and development.

This report does by no means represent the work that is needed to complete the survey of Northwestern Botswana, but covers only a fraction of the area. It is a preliminary document, pending the completion of the project. It is hoped that the progress achieved by the survey team as a whole will greatly facilitate the acquisition and evaluation of soils data by the soil surveyors to come.

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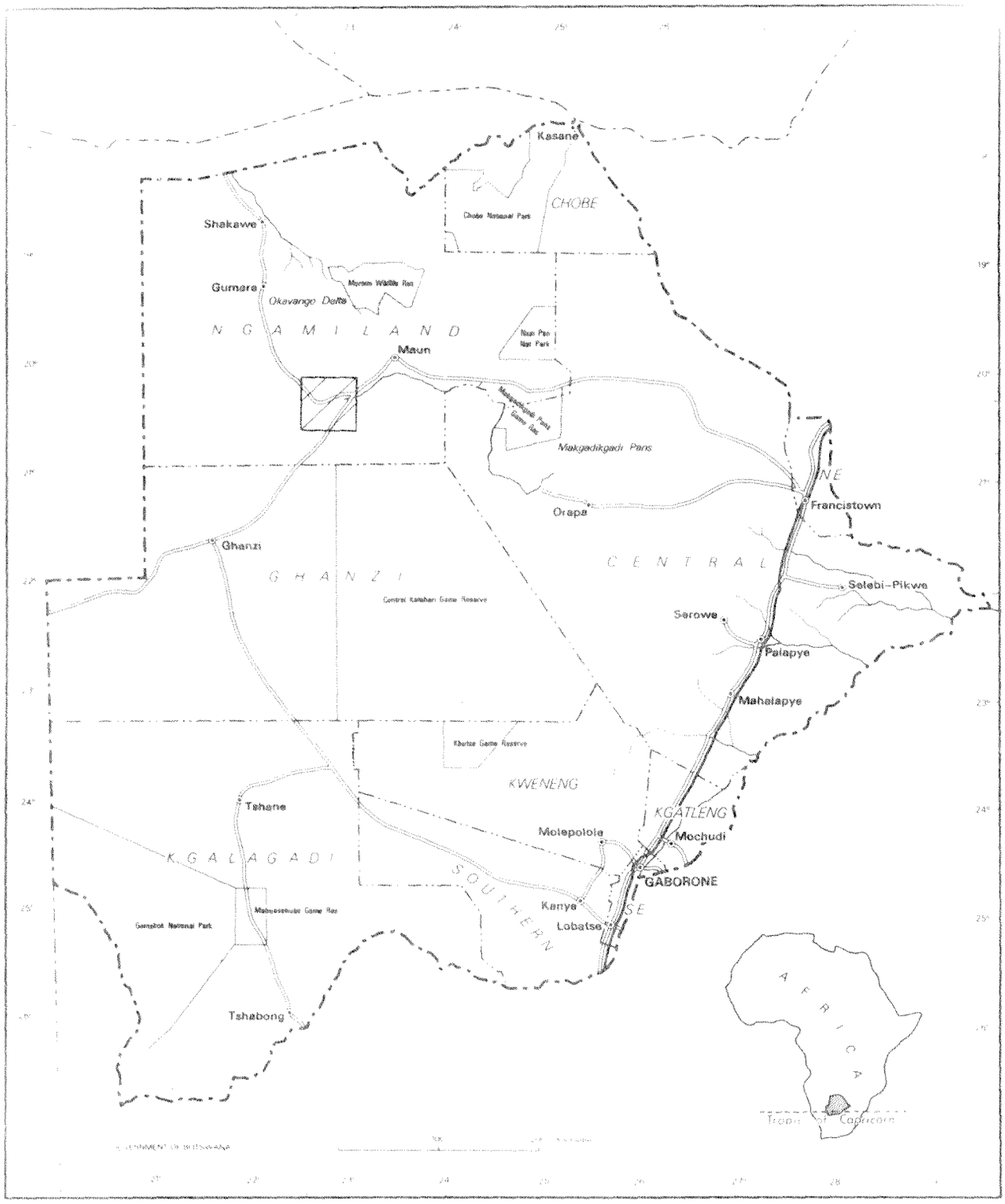
MAUN APRIL 1983

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to his supervisor Mr. J. Venema, for his patient guidance and assistance throughout the survey; and to his counterpart, Mr. C. Ketlogetswe, for his helpful assistance in carrying out the fieldwork and office duties.

LOCATION MAP



THE SURVEY AREA

1. The Survey Area

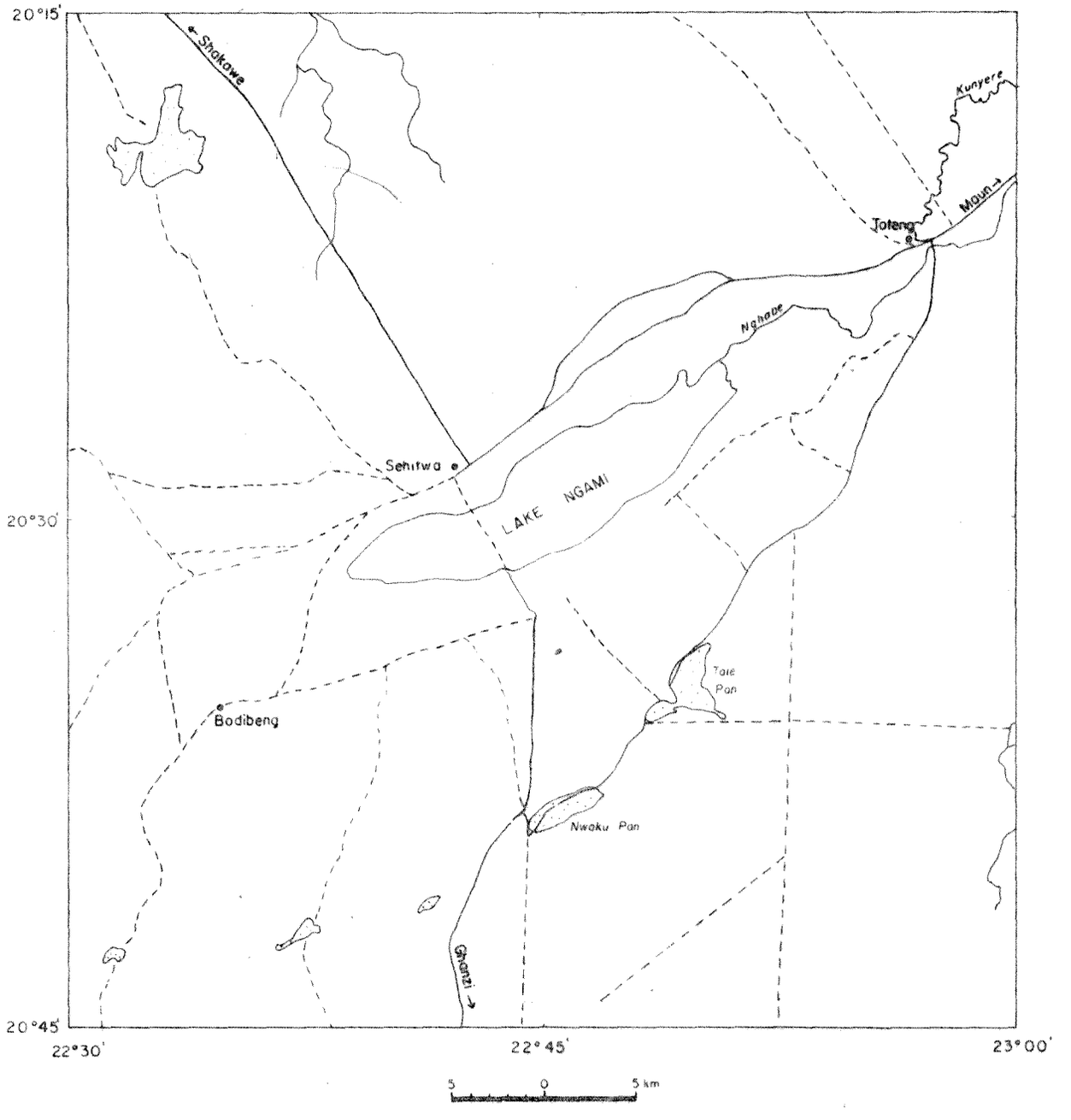
1.1 Location and History

The survey area is located in Northwestern Botswana between 22°30' and 23°00' East and 20°15' and 20°45' South, and has an area of 286,000 ha. It belongs to the Northwest District (known as Ngamiland) with Maun being the district's largest village and administrative center. (See map of survey area on following page).

Toteng and Sehitwa are the two main villages within the survey area. Sehitwa, the larger of the two, is a distance of 100 km southwest of Maun. Numerous smaller villages are scattered throughout the area. Accessibility is good, as the area is traversed by the main road (dirt) from Maun northwards via Sehitwa to Gomare and Shakawe, and southwards via Toteng to Ghanzi. From Sehitwa there is a 30 km stretch of paved road north. Many other roads, tracks and cutlines crisscross the survey area facilitating relatively easy travel and orientation.

The salient physical feature of the survey area is the Lake Ngami Depression, situated at the southern end of the Okavango Delta. The catchment of the Delta is in the Angolan Highlands, and the water enters Botswana above Shakawe in the north via the Okavango River. The water then spills into an inland delta through channels, overflow plains and floodplains. Due to the low gradient and blockages of channels by aquatic weeds, 95% of the inflow is lost due to evapotranspiration from open water, bare soil, and aquatic plants (Staring, 1978). However, a portion of the outflow of the Delta has traditionally found its way into Lake Ngami. Historically, a very large and continuous body of water may have been formed by the Okavango - Ngami Depression (Grey and Cooke, 1977).

THE SURVEY AREA



Aerial photographs do reveal older beach ridges which suggest that the area of the Lake Ngami Depression most recently flooded in only a fraction of what it once was, when the explorer David Livingstone referred to the Lake as "a magnificent sheet of water" (after Potten, 1975).

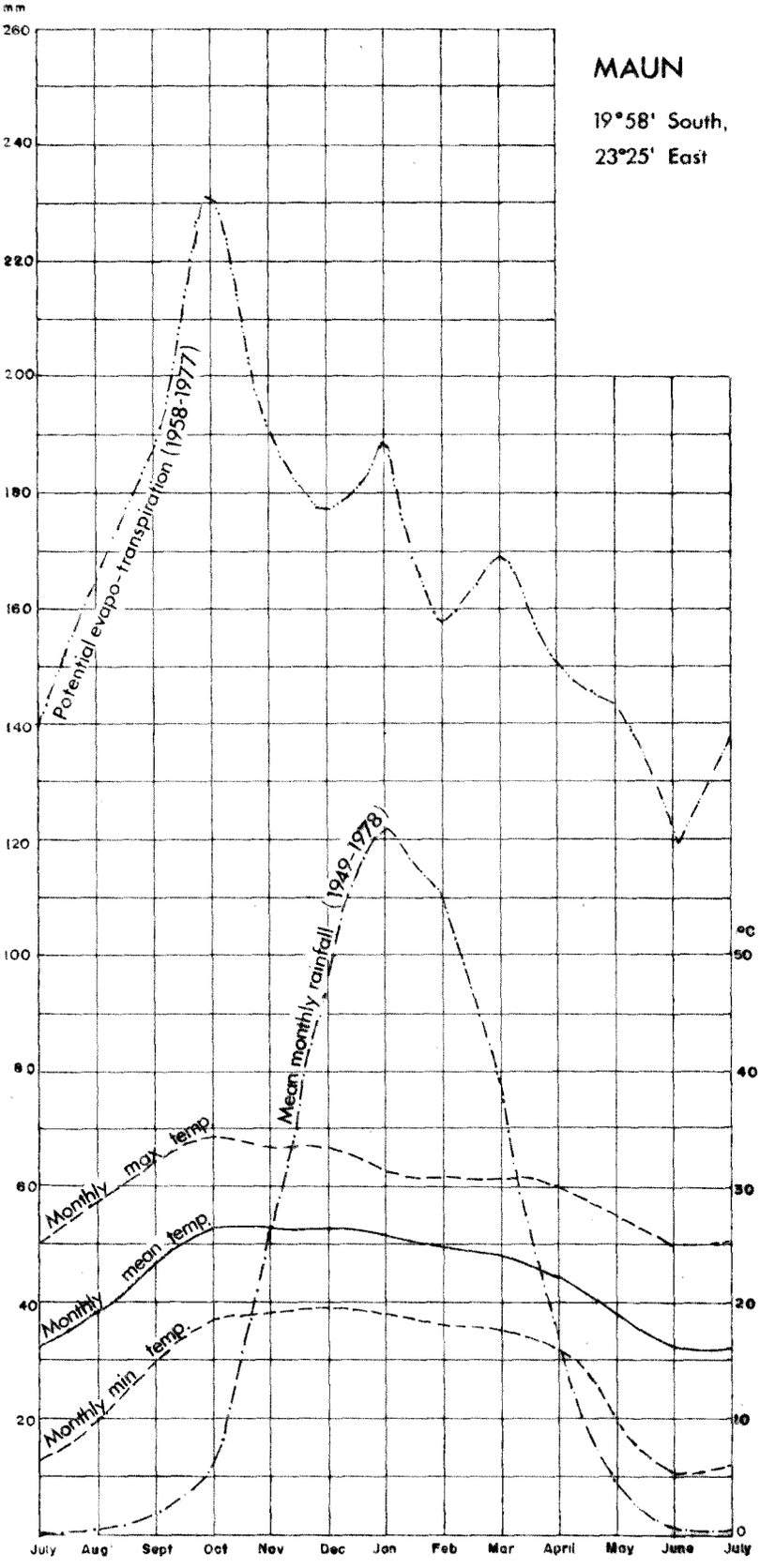
While numerous schemes have been prepared for the development of the Okavango - Ngami water system since Livingstone's visit to the lake area in 1849, only few have come to fruition (Potten, 1975). The Delta area remains the subject of much interest, facing an influx of people and development projects all geared to taking advantage of the Delta's vast potential, and sure to bring change in the coming years.

1.2 Climate

The climate of the Sehitwa area is not markedly different from that of Maun, being characteristically hot and semi-arid. The summer day temperature may rise above 37°C with night temperatures seldom below 21°C. The winter is dry, with day temperatures rising above 21°C and night temperatures sometimes below 0°C, with the chance of frost occurring in low lying areas between June and August (Cole and Brown, 1976).

The average annual rainfall in Maun is 457 mm (Department of Meteorological Services). The monthly rainfall distribution is illustrated in fig. 1, and is highly variable from one year to the next. The rain occurs between October and April with up to 60% falling between January and March. The potential evapotranspiration is higher than rainfall throughout the year.

Temperature, Rainfall and Potential Evapotranspiration



Soil temperatures for the Maun area are shown in table 1. The general trends indicate the lowest temperature at any depth and time of day to be in July, increasing to the highest temperatures during the period from November to January. The soil temperature appears to increase with depth at 0800, but decreases with depth at 1400 and 2000 due to the incoming solar radiation and retention of heat at the surface. The soil temperature regime is 'hyperthermic' with the mean annual soil temperature being higher than 22°C and the difference between mean summer and winter soil temperature at 50cm depth being more than 5°C (USDA, 1975). The winds are predominantly easterly and northeasterly.

1.3 Geology and Geomorphology

The survey area is made up predominantly of deposits of the Kalahari Beds. Of Tertiary to Recent age, they include sands, calcretes, alluvial - fluvial and lacustrine (pans) deposits, usually covered with loose, undisturbed sand and characteristic longitudinal dunes (Geological Map of Botswana, 1973).

Prominent relief occurs where resistant bedrock forms hills and undulating to rolling upland, such as the quartz and feldspar porphyries of the late Precambrian Kwebe formation comprising the Kwebe and Ngwanalekau hills southwest of Lake Ngami.

TABLE 1 MEAN MONTHLY SOIL TEMPERATURES ** (MAUN) °C 1965 - 1980

time	0800					1400					2000					
depth (cm)	10	20	30	60	120	10	20	30	60	120	10	20	30	60	120	mean monthly
January	25.4	27.3	28.0	28.7	28.7	34.6	31.1	29.5	29.3	29.2	30.6	31.5	30.7	29.7	29.2	29.6
February	24.7	26.2	27.1	28.2	28.5	32.9	29.7	28.3	28.3	28.3	29.4	30.1	29.2	28.5	28.2	28.5
March	23.8	25.8	26.5	28.0	27.8	32.5	29.3	28.0	28.2	28.0	29.7	30.4	29.1	28.1	27.7	28.2
April	21.7	23.5	24.3	26.2	26.6	30.6	27.2	26.2	26.6	27.1	27.5	27.9	27.4	26.8	26.9	26.4
May	17.3	19.7	21.2	23.1	24.2	26.1	22.9	23.2	24.0	24.9	23.9	24.4	24.0	23.8	25.2	23.2
June	14.1	17.6	18.6	20.5	21.5	22.3	19.2	19.2	20.2	22.0	20.2	20.3	20.4	20.1	21.8	19.9
July	13.4	17.4	18.2	19.6	20.8	22.7	19.0	19.0	19.7	21.1	20.7	19.9	19.7	19.5	20.8	19.4
August	16.7	19.8	20.6	21.7	21.7	25.9	21.7	21.3	21.3	21.9	23.7	23.0	22.1	21.4	21.7	21.6
September	20.9	23.7	23.0	24.7	23.9	30.9	25.7	25.2	24.7	24.1	28.4	27.3	26.1	24.7	24.3	25.2
October	25.0	27.4	27.9	27.7	26.5	34.6	29.9	28.8	28.3	26.7	31.5	30.9	29.8	28.3	27.4	28.7
November	25.4	27.7	28.7	28.6	28.4	36.0	30.9	29.3	29.1	29.0	33.3	31.7	30.5	29.2	28.7	29.8
December	25.7	26.5	28.5	28.8	29.0	34.1	30.5	29.3	28.9	28.7	31.2	30.8	30.6	29.2	28.8	29.4
mean annual	21.2	23.6	24.4	25.5	25.6	30.3	26.4	25.6	25.7	25.9	27.5	27.4	26.6	25.8	25.9	

** measurements taken in loamy sand

source: Dept. of Meteorological Services

Minor relief occurs along old drainage courses where former streams have incised valleys into the bedrock, and where aeolian sands have been reworked by lacustrine and alluvial processes. The sandy beach ridges of Lake Ngami are an example of the aeolian sands reworked by lacustrine processes, while the densely dissected Thaoge overflow plain moving southwards towards the Lake Ngami Depression (northwest section of the survey area) illustrates the aeolian sands reworked by the action of the fluvial deposits.

The alluvial plain of Lake Ngami is a prominent physiographic feature of the survey area. Traditionally receiving fresh deposits from the inflow of the Kunyere and Nghabe rivers, it has in recent years been drying out due to the low floods descending from the Angolan highlands through the Okavango Delta. There is presently only very little surface water in the area, found at Toteng village.

Cyclical climatic changes have been cited as possible factors influencing the formation of the Okavango Delta. Garner (after Grey and Cooke, 1977) has suggested that a succession of drier and wetter climates will affect the flow volume of the channels, and thus the sediment load capacity, resulting in the Delta's complex and unstable drainage pattern.

Calcrete, believed to cement the Kalahari Beds at depth (Cole and Brown, 1976) is commonly found in pans, interdunal depressions and low lying areas at depth, but often at or near the surface due to evaporation from high groundwater levels (Staring, 1978).

1.4 Vegetation and Land Use

The vegetation found within the survey area is primarily savanna woodland. Acacia tree species are abundant with A. tortilis (setswana name - moshu), A. mellifera (mongana), A. erioloba (mogotlho), A. erubescens (moloto), and such Terminalia species as T. prunoides (motsiara), and T. sericea (mogonono) found on both the savanna and low savanna woodland areas.

Associated with the above species are shrub communities which include Dichrostachys cinerea (moselesele), Boscia foetida (mopipi), B. albitrunca (motopi), Grewia flava (moretlwa), G. bicolor (mogwana), Combretum apiculatum (mohudiri), and Zizyphus mucronata (mokgalo). Generally speaking, tall trees are found on the upper slopes and ridges, while low growing shrubs dominate on the lower slopes. Soil and microclimatological factors are most likely related to this variability, with certain species being better adapted to the deeper, better drained soils of the upper slopes, and others preferring the low lying areas where the colder air settles and drainage may be somewhat poorer.

The lowest lying basin of the Lake Ngami Depression is characterized (seasonally) by a dense cover of the weed Sesbania, with grasses such as Digitaria spp., Cynodon dactylon and Echinochloa also found on the floodplain and channels of the Lake. Eragrostis, Stipagrostis, and Aristida grass species are found on higher, sandy areas, with Setaria verticiliata and Acacia tortilis (shrub) found mainly on disturbed land (overgrazed). The midslope of the Depression (towards the high water line) is covered with C. dactylon and some scattered shrubs of Acacia spp. and Z. mucronata.

Other indicators are Cataphractes alexandrii shrubs for areas where there is calcrete development, and T. sericea and Croton gratissimus shrubs for areas with a deep sand cover. C. apiculatum is dominant on red sandy soils. (Cole and Leroux, 1978; Weare and Yalala, 1971).

Cattle grazing is the dominant land use activity within the survey area. This has led to severe overgrazing and competition for the diminishing water supply. Arable farming, mainly sorghum and maize cultivation, is practised by some farmers at a subsistence level, but only on a very limited scale due to tribal preferences for cattle rearing.

At present, the water shortage is critical. With the low rainfall and the drying up of Lake Ngami, the existing boreholes are being heavily drawn from to meet the needs of the large numbers of cattle.

The Okavango Delta is being increasingly exploited by hunters and safari tour operators because of the beauty of the natural area and the abundant wildlife. Wildlife can still be found in the survey area, with numerous bird species gathering at Lake Ngami and small numbers of Kudu and other small antelope seen on the eastern and southern sides.

2. Methods of Investigation

2.1 Airphoto Interpretation and Fieldwork

The soil survey was carried out utilizing airphoto interpretation in conjunction with field observations. Both aerial photography and satellite imagery of the survey area were readily available.

Aerial photography: scale 1:70,000

13 June 1975	series	151-BT	12	photo no.	067-074
14 June 1975	"	151-BT	13	" "	039-048
3 June 1978	"	1/78 C.K.1A		" "	001-008
1 June 1978	"	"	1	" "	034-067
1 June 1978	"	"	2	" "	023-033

Satellite imagery: scale 1:250,000
26 November 1972 bands 4, 5, 7 scene ID: 10126-07580
- false colour composite, edge enhanced.

A preliminary interpretation of the airphotographs was carried out prior to commencing the fieldwork, the aim being to identify the main physiographic units (land forms) and the nature of the surficial deposits and to delineate the soil boundaries. Lacustrine, alluvial and aeolian deposits, were generally discernible on the photographs.

The ground survey was then carried out at a 'detailed' reconnaissance level, using a 4 x 4 vehicle to facilitate travel on difficult terrain. Photomaps at the scale of 1:50,000 were used for accurate orientation and site recording. The 'free survey' method was employed, with observations being sited in relation to landform. Field observation consisted mainly of augerings to a depth of 100-120 cm, or shallower if an inpenetrable layer was encountered. The soil characteristics recorded were in keeping with the standard FAO 'Guidelines for Soil Profile Descriptions' (FAO, 1977) including the use of the Munsell Soil Colour Chart.

With the information acquired from the photointerpretation and fieldwork, the initial list of soil units was constructed. Subsequent photointerpretation and field work allowed for the checking of soil boundaries, the redefinition of soil units, the delineation of additional units and associations of units, and the sampling of representative soils. The number of augerings was 132, with 13 pits being dug and 40 samples taken. The soil map was then produced using the cumulative field data and revised photointerpretation. The physiographic features and soil boundaries as seen on the aerial photographs were for the most part, distinguishable on the satellite image, thus facilitating the transfer of soil boundaries directly onto the image. The soil units of the survey area were correlated with those of the other team surveyors, and a comprehensive legend of the soils of Botswana was produced.

All field data from the survey area will be kept by the FAO Soil Surveyor at the Regional Agricultural office in Francistown.

2.2 Laboratory Analysis

All samples were sent for analysis to the FAO soil chemist at the Sebele Agricultural Research Station, near Gaborone. A standard series of determinations was carried out including:

- pH : H_2O and $CaCl_2$
- electrical conductivity
- available phosphorous (Bray and Kurtz method)
- organic carbon (Walkley and Black method)
- Cation exchange capacity
- exchangeable Cations (Ca, K, Mg, Na) exchanged by ammoniumacetate
- particle size distribution (USDA system); sand fraction by sieving; clay and silt by hydrometer method.

3. Soils of the Survey Area

3.1 Soil Classification

The soil classification system employed for the soil survey of Botswana is the one set out by the Food and Agriculture Organization of the United Nations (FAO). Soil units are identified by the recognition of diagonostic horizons and properties, and are described in the legend to the Soil Map of the World (FAO-UNESCO, 1974). With respect to the survey area, only the mollic and ochric A, cambic and argillic B, and calcic C horizons are recognized as being diagnostic. The petrocalcic C, not usually recognized as diagnostic, was considered as such after communication with FAO owing to its significant occurrence in Botswana.

For the soils of the survey area, the following definitions have been drawn from the above mentioned legend. They are given here for the benefit of the reader who is familiar with soil classification terminology. Definitions of terms used are to be found in the FAO-UNESCO legend. A discussion of the occurrence and distribution of the soil units will follow in the section entitled 'Description of the Soil Units'.

Fluvisols (J)

Soils developed from recent alluvial deposits (fluviatile, marine, lacustrine, or colluvial), having no diagnostic horizons other than (unless buried by 50 cm or more new material) an ochric or an umbric A horizon, a histic H horizon, or a sulfuric horizon.

Eutric Fluvisols (Je)

Fluvisols having a base saturation on 50% or more at least between 20 and 50 cm from the surface but which are not calcareous at the same depth; lacking a sulfuric horizon and sulfidic material within 125 cm of the surface.

Regosols (R)

Soils from unconsolidated material, exclusive of recent alluvial deposits, having no diagnostic horizons (unless buried by 50 cm or more new material) other than an ochric A horizon, lacking hydromorphic properties within 50 cm of the surface, lacking the characteristics which are diagnostic for Vertisols and Andosols, lacking high salinity; when coarse textured, lacking lamellae of clay accumulation, features of cambic or oxic B horizons or albic material which are characteristic of Arenosols.

Calcaric Regosols (Rc)

Regosols which are calcareous at least between 20 and 50 cm from the surface.

Arenosols (Q)

Note: The modified definition of Arenosols, and the inclusion of Arenosol units not found in the FAO-UNESCO legend comes as a result of personal communication between the project's soil corrolator and senior FAO Land Resource Officers, and is felt to better express the representative sandy soils found in Botswana.

Soils from coarse textured (loamy fine sand or coarser) unconsolidated material, and less than 35% of rock fragments

or other coarse fragments in all subhorizons to a depth of 100cm or to a lithic, petroferric, or petrocalcic contact, exclusive of recent alluvial deposits, consisting of albic material occurring over a depth of at least 50 cm from the surface or showing characteristics of argillic, cambic or oxic B horizons which, however, do not qualify as diagnostic horizons because of textural requirements; having no diagnostic horizons (unless buried by 50 cm or more new material) other than an ochric A horizon, an albic E, or a calcic or petrocalcic horizon; lacking hydromorphic properties within 50 cm of the surface; lacking high salinity.) (includes Eutric Arenosols - Qe).

Cambic Arenosol (Qc)

Arenosols showing colouring or alteration characteristics of a cambic B horizon immediately below the A horizon; lacking lamellae of clay accumulation; lacking ferralic properties.

Ferralic Arenosol (Qf)

Arenosols showing ferralic properties and evidence of alteration (B horizon characteristics); lacking lamellae of clay accumulation within 125 cm of the surface.

Calcaric Arenosol (Qc)

Other Arenosols showing soft powdery lime within 125 cm from the surface, or which are calcareous at least between 20 and 50 cm from the surface.

Calcic Arenosol (Qk)

Other Arenosols having a calcic horizon within 125 cm from the surface.

Petrocalcic Arenosol (Qp)

Other Arenosols having a petrocalcic horizon within 125 cm from the surface.

Luvic Arenosol (Ql)

Other Arenosols showing lamellae of clay accumulation.

Cambisol (B)

Soils having a cambic B horizon and (unless buried by 50cm or more new material) no diagnostic horizons other than an ochric or an umbric A horizon, a calcic or a gypsic horizon; the cambic B horizon may be lacking when an umbric A horizon is present which is thicker than 25 cm; lacking high salinity, lacking the characteristics diagnostic for Vertisols or Andosols; lacking an aridic moisture regime; lacking hydromorphic properties within 50cm of the surface.

Calcic Cambisol (Bk)

Cambisols having an ochric A horizon and showing one or more of the following: a calcic horizon, a gypsic horizon or concentration of soft powdery lime within 125 cm of the surface; calcareous at least between 20 and 50 cm from the surface; lacking hydromorphic properties within 100 cm of the surface, lacking permafrost within 200 cm of the surface.

3.2 Description of the Soil Units

For the soil map of the survey area, 7 parameters are used to describe the individual soils. These are: the parent material, depth, drainage, colour, texture, topography and calcium carbonate content. The limits of these parameters are as set out by FAO (FAO, 1977).

The soils are first grouped according to the parent material. Four main units have been distinguished in the survey area:

C unit - soils on highly calcareous material (calcrete)
L unit - soils on lacustrine deposits
A unit - soils on alluvial deposits (exclusive of lacustrine)
S unit - soils on coarse-grained sedimentary rocks (sandstones, aeolian sands, etc.)

The units will be discussed individually. The sequence of soils listed under each unit is indicative of a general increase in soil development. The symbols used are those of the general soil map legend of Botswana. Chemical properties are given here for the most commonly found soils. Descriptions of representative profiles can be found in Appendix 1.

C Unit - soils on highly calcareous material

The soils of the C unit are shallow, calcareous, and are found exclusively in areas surrounding pans.

1. Shallow, moderately well to well drained, very dark to dark greyish brown, loamy fine sand to fine sandy loam; flat to gently undulating;
   classification: Calcaric Regosol (Rc); SU: C2
   partly petrocalcic.

L Unit - soils on lacustrine deposits

This unit encompasses the soils found on the alluvial plain of Lake Ngami, or the Lake Ngami Depression. They are generally fine textured (silt loams to silty clays) non-calcareous soils with a weak platy structure within angular and subangular peds. Towards the high water line these soils are underlain by fine sand to loamy fine sands. Both the platy structure and sharp textural difference seem due to sedimentation (Siderius, 1971).

Also observed are the sandy to loamy soils (calcareous, calcic) of the alluvial plain edge and the sandy clay loam to clay loam soils of smaller pans.

The following soil units have been distinguished:

1. very deep, imperfectly drained, black to very dark greyish brown, silt loam to silty clay abruptly over dark brown to brown (fine) sand to loamy fine sand; flat to gently undulating; non-calcareous.
   classification: Eutric Fluvisol (Je)
   soil unit (SU): L9 ; profile no. To 180
   - found in the lake bed of Lake Ngami towards the high water line. The variation within the unit includes the increasing proportion of the silty layer to the sandy layer as you move towards the deepest basin of the floodplain.

2. very deep, poorly, drained, black to very dark grey, silt loam to silty clay; flat; non-calcareous.
   classification: Eutric Fluvisol (Je); SU: L9a ; profile no. To183
   - found in the deepest basin of the lake bed

The soil reaction for units L9 and L9a are commonly strongly acid to slightly acid (to slightly alkaline for L9, with pH ($CaCl_2$) values of 2.88-7.65, with the topsoil being generally moderately acid to slightly alkaline (pH $CaCl_2$ 4.04-6.57). The organic carbon content of the topsoil is very high with values ranging from 2.25-4.64%, decreasing substantially to values of .01-.8% in the sandy subsoil of unit L9. The CEC of the topsoil is high (29.08-44.85 me per 100 g soil) decreasing to low in the subsoil of L9 (2.16-6.65 me). Base saturation is greater than 60%. Available phosphorous is very low to moderate with topsoil values of 2.5-26.6 ppm (subsoil 1.2-28.4 ppm). Exchangeable cations (Ca, Mg, K) are all high.

3. moderately deep, imperfectly drained, dark greyish brown sandy clay loam to clay loam; calcareous; calcic within 125cm.
   classification: Calcic Cambisol (Bk); SU: L14
   - found in pans.

4. deep, imperfectly drained, very dark grey to dark greyish brown clay over very fine sandy loam; flat; calcareous; calcic.
   classification: Calcic Cambisol (Bk); SU: L20

A unit - soils on alluvial deposits (including colluvium)

This unit includes the soils formed on embankments, in river valleys, old stream beds and interdunal depressions.

1. very deep, imperfectly to poorly drained, brown to dark greyish brown, silt and silty clay; valley bottom; non-calcareous.
   classification: Eutric Fluvisol (Je); SU: A24
   -found in river valleys of Kunyere River near Toteng.

2. deep to very deep, moderately well to well drained, black to dark greyish brown loamy fine sand over silt loam to silty clay over loamy fine sand; flat; non-calcareous.

classification: Arenic Eutric Fluvisol (Jea); SU: A24a
-colluvium, found at base of beach ridge on north side of Lake Ngami, transitional to (L)S unit. Also found in river valley of Nghabe River at Toteng (alluvium).

3. moderately deep, well drained, dark greyish brown to brown, fine sand to loamy fine sand over gravel; gently undulating; non-calcareous.
classification: Eutric Arenosol (Qe); SU: A22a
-colluvium, found on embankment on south side of Lake Ngami.

4. deep to very deep, moderately well to well drained, dark greyish brown, fine sand to loamy fine sand; flat; non-calcareous.
classification: Eutric Arenosol (Qe); SU: A22
-found in old stream beds.

5. moderately to very deep, moderately well to well drained, dark greyish brown to yellowish brown, loamy (fine) sands; flat to gently undulating; calcareous.
classification: Calcaric Arenosol (Qc); SU: A20
-found in old stream beds and interdunal depressions, often in association with Eutric Arenosols.

6. deep to very deep, imperfectly to moderately well drained, dark greyish brown to brown, sandy loam to sandy clay loam over loamy fine sand; flat to gently undulating; calcareous (calcic).
classification: Calcic Cambisol (Bk); SU: A4C ; profile no. To 176
-found in old stream beds, usually in association with Eutric and Calcaric Arenosols. The soil reaction for soil unit A4C is moderately acid in the topsoil (pH $CaCl_2$ 3.81-4.52) increasing to very strongly alkaline in the subsoil (pH $CaCl_2$ 7.92). The organic carbon content of the topsoil is high with 3.63%, but drops to 0.05% in the subsoil. The CEC is high in the topsoil at 36.24 me, decreasing to 2.82 me in the subsoil. Available phosphorous is moderate (6.2-22.3 ppm). The exchangeable cations (Ca, Mg, K) are generally very high in the topsoil, and low to moderate in the subsoil (except for the high calcium of the calcic horizon). The high topsoil values are suggestive of a recent alluvial deposit.

S Unit - soils on coarse-grained sedimentary rock (including sandstones, aeolian sands, etc.)

The soils of the S unit are by far the most predominant in the survey area, and in the district as a whole. They are, generally speaking, deep, fine, windblown Kalahari sands to loamy fine sands, and can either be calcareous, (if they have been subjected to high water table resulting in the accumulation of carbonates) non-calcareous, or recently deposited non-calcareous sands covering calcareous profiles. They show little evidence of structural development, and horizonation is only weakly evident. Staring (1978) has distinguished 3 non-calcareous and 5 calcareous Kalahari sands. Corrolation with Staring's series is generally good, differing mainly in the depth criteria of the carbonates, and in the distinction of a calcic and petrocalcic horizon.

These soils are generally of low inherent fertility. The soil reaction is moderately acid to very strongly alkaline (pH $CaCl_2$ 5.58-7.94). The organic carbon content is typically low with values of less than 0.4%. The CEC is low, with values generally less than 3 me, and the base saturation is over 80%. Available phosphorous is very low to low (2.4-11.8 ppm). Exchangeable cations (Ca, Mg, K) are generally low, except for high calcium values in calcaric soils, or soils with a calcic or petrocalcic horizon. Sandy soils of the A unit have comparable chemical properties.

1. shallow to moderately deep, well to somewhat excessively drained, dark yellowish brown to reddish brown, loamy fine sand; flat to gently undulating; non-calcareous.
   classification: Arenic Eutric Regosol (Rea); SU: S1b
   -upland soils.

2. very deep, moderately well to well drained, dark greyish brown to dark brown, fine sand to loamy fine sand; flat; non-calcareous.
   classification: Eutric Arenosol (Qe); SU: S17 profile no. To 143 and To 175
   -includes soils of the Lake Ngami beach ridges.

3. deep to very deep, well to somewhat excessively drained, strong brown to yellowish red, fine sand; flat to gently undulating; non-calcareous.
   classification: Ferralic Arenosol (Qf); SU: S3 ; profile no. To 227
   -includes dunes.

4. deep to very deep, well drained, very dark grey to brown, fine sand to loamy find sand; flat; calcareous.
   classification: Calcaric Arenosol (Qc); SU: S15
   -found in sandy section of the (west) Lake Ngami Depression.

5. moderately to very deep, moderately well to well drained, dark greyish brown to brown, fine sand to loamy fine sand; flat; calcareous; calcic.
   classification: Calcic Arenosol (Qk); SU: S13 ; profile no. To 160 and To231
   -found primarily in lower lying areas in association with Eutric Arenosols.

6. moderately deep to deep, well drained, dark brown, loamy fine sand (non-calcareous) over very calcareous material; flat.
   classification: Petrocalcic Arenosol (Qp); SU: S13a
   -generally found around soils of the C unit.

7. very deep, well drained, dark greyish brown to dark brown; loamy fine sand; flat; non-calcareous.

classification: Luvic Arenosol (Q1); SU: S5b ; profile no. To196 -found near Toteng Village, in lower lying areas on approach to the Nghabe River floodplain.

3.3 Soil Mapping Units and the Soil Map

Because of the complexity of the landforms and the low level intensity of the survey, it was often not possible to separate out the individual soil units as described in the previous section. In such cases, the mapping unit will be made up of an 'association' of soil units, with the proportion of the individual soil units being shown on the map in parentheses. Where the mapping unit was considered homogeneous, the soil unit and mapping unit are identical.

In the case of the S unit, the letters 'K' and 'L' have been used as descriptors. When the soil unit has been derived from Kalahari (aeolian) sands, as opposed to having developed in situ from sedimentary rock (sandstone), the mapping unit is expressed as KS. When lacustrine deposits are found reworked by aeolian action, and the results of the deposition occur within the former lake environment (such as the Lake Ngami beach ridges) an 'L' is added and the mapping unit is expressed as LS (main unit sand).

The soil map itself has been produced at the scale of 1:250,000. This scale should facilitate the identification of the forms of development that are physically possible within a region of a given country (FAO, 1979). The level of detail within the survey area is sufficient to identify a number of factors which could limit potential development. This will be discussed in more detail in the section on 'land evaluation'. It must be realized, however, that the soil map presents only a general picture of the occurences and distribution of the soil units and does not give specific information about individual fields.

Table 2 lists the mapping units and associations, and the proportions in which they occur in the survey area.

TABLE 2 SOIL MAPPING UNITS

mapping unit (soil unit)	classification	unit area (ha)	% of survey area
C2	Rc	9,000	3.1
L9	Je	21,100	7.4
L9a	Je	6,500	2.3
L14	Bk	900	0.3
L20	Bk	7,500	2.6
A24	Je	1,000	0.3
A24a	Jea	3,200	1.1
A22a	Qe	3,100	1.1
A22	Qe	2,000	0.7
A20	Qc	8,200	2.9
A4C	Bk	7,100	2.5
S1b	Rea	24,800	8.7
KS17 (S17)	Qe	5,800	2.0
LS17 (S17)	Qe	17,700	6.2
KS3 (S3)	Qf	12,200	4.3
LS15 (S15)	Qc	18,200	6.4
KS13 (S13)	Qk	-	-
KS13a (S13a)	Qp	19,200	6.7
KS5b (S5b)	Q1	600	0.2
associations:*			
A22(50) + A20(50)		32,500	11.4
A22(40) + A20(30) + A40(30)		26,800	9.4
S1b(60) + C2(40)		7,200	2.5
KS17(60) + KS13(40)		11,500	4.0
KS17(60) + S1b(40)		7,600	2.7
KS17(60) + KS3(40)		8,300	2.9
KS17(40) + KS3(30) + A20(30)		21,300	7.4
LS17(50) + A22(50)		2,700	0.9
		286,000	100 %

* proportions given in parentheses (%)

4. Land Evaluation

4.1 Land Suitability Classes and Land Qualities

The method of land evaluation that is used for Botswana is that developed by Venema and Rhebergen (1983), based on the FAO Framework for Land Evaluation (FAO, 1976).

Land evaluation is concerned with the assessment of land performance when used for specified purposes. For this report, the survey area will be evaluated for sorghum and maize production under dryland agriculture utilizing improved traditional management, as this is representative of the arable agriculture presently being practiced (or aspired to) in the district, and in many parts of the country. Dryland farming under rainfed conditions, utilizing improved traditional management implies a good knowledge of modern, non-mechanical farming practices. These may include timely (row) planting, improved seeds, crop rotation, weeding, modest fertilizer use, insecticides, the use of a planter or inter-row cultivator, contour plowing, and proper storage of the harvest.

In the system of land evaluation there are two orders, suitable (S) and non-suitable (N). Within order S, there are four classes:

S1- highly suitable

Land which is expected to be highly productive for the defined use. High returns amply justify required inputs. No significant limitations.

S2- moderately suitable

Land which is expected to be moderately productive for the defined use. Moderate returns justify required inputs. Limitations reduce crop yields by 10-25% and/or increase recurrent costs for production and conservation.

S3- marginally suitable

Land which is expected to have a low productivity for the defined use. Yield benefits are just high enough to justify required inputs. Limitations reduce yields by 25-50% and/or considerably increase costs for production and conservation.

S4 - very marginally suitable

Land which is expected to have a very low productivity for the defined use. It is doubtful whether yield benefits alone justify required inputs. Severe limitations reduce crop yields by more than 50% and/or substantially increase costs for production and conservation.

(Land classed S4 may still be cultivated for traditional farming where capital inputs are extremely low, and some produce can be obtained, or where severe limitations occur seasonally such as in years of poor or unreliable rainfall).

Within order N, there are two classes:

N1- currently unsuitable land.

Land with severe limitations which at present cannot be corrected economically.

N2- permanently unsuitable land.

Land Qualities- Twelve land qualities have been distinguished which could be considered as factors limiting maize or sorghum cultivation depending on the extent to which they are expressed in the soil (e.g. nutrient, moisture availability) or in the environment (e.g. climatic factors).

a. accessibility
c. correct temperature regime
e. resistance to soil erosion
f. absence of damaging floods
g. adequacy of conditions for germination
m. moisture availability
n. nutrient availability
o. oxygen availability
p. absence of pests and diseases
r. adequacy of foothold for roots
t. absence of toxic substances
w. workability

When any of the land qualities appear to limit cultivation it will be indicated by subclasses, with the corresponding lower case letter being placed after the suitablility class. This will be discussed in the section entitled 'Limits to Cultivation'.

4.2 Crop Requirements

To evaluate the land for its suitability for crop production, the crop requirements must be known. A partial list of requirements for maize and sorghum follows (after Venema and Rhebergen, 1983; Sims, 1981):

	maize	sorghum
mean temperature-^{o}C optimum (range)	20-30 (18-35)	20-30 (18-35)
moisture (mm)	500-800	450-650
pH (H_2O) optimum(range)	5.5-7.5 (5.2-8.2)	5.5-7.0 (5.2-8.2)
drainage: optimum	mod.well-well	same
range	(imp-s.exc)	
ponding tolerance	few hours	few days
nutrient status	moderately-high for good yields	moderate for good yields, but does reasonably well on poor soils.
Salinity: EC(mmhos)		
optimum (prohibitive)	0-2(10+)	0-4(18+)
CaCO3 %		
optimum (prohibitive)	0-15(50+)	0-25(80+)

4.3 Limitations to Cultivation

In the land evaluation system each land quality mentioned in section 4.1 has been rated, using numbers through 1-6, with 1 being the best, decreasing in suitability for all land use types. However, these ratings are not specific for sorghum and maize. Each land quality is then weighted according to the requirements for sorghum and maize grown under improved traditional dryland farming. To illustrate this, consider land quality 'o' - oxygen availability in the root zone, which is mainly a function of drainage. Five ratings have been established:

			Ponding Frequency during Growing Season		
rating		drainage class	every 1-2 yrs	every 3-5 yrs	every 6-10 yrs
1	3-6	moderate-somewhat excessively	none	none	1 day
2	2-3	imperfect-moderate	none	1 day	1-7 days
3	2	imperfect	1 day	1-7 days	7-30 days
4	1	poor	1-7 days	7-30 days	30-60 days
5	0	very poor	7-30 days	30-60 days	60 days

For sorghum, which is more tolerant to ponding than maize, the characteristics of both ratings 1 and 2 would be highly suitable, with no significant limiting affect (suitability class S1). An imperfectly drained soil (rating 3) would then be moderately suitable (suitability class S2). For maize, the rating for land quality 'o' would correspond to the suitability class (rating 1 to suitability class 1) as it is more sensitive to ponding. For most land qualities, given the defined land use activity, the rating corresponds to the suitability class. The lowest suitability class among all of the land qualities will establish the final evaluation, with each soil mapping unit being considered individually. The land quality(ies) bringing it to that class will be expressed as subclasses.

To use the previous example, a poorly drained soil (rating 4) would have a suitability class S3 - marginally suitable. If this was the most severe limitation to sorghum production, the final evaluation would be S3o. If other land qualities also merited suitability class S3, they would be expressed as additional subclasses, up to a maximum of three.

While it is not practical in this report to reproduce the complete land evaluation system, it is hoped that this introduction will serve to illustrate the workings of the system. The rating of each land quality is often dependent on a number of interrelating factors and while the criteria for each will be discussed here, the derivations and the practical limits of each rating will not. Where possible the suitability class for the defined land use activity (sorghum and maize under improved traditional agriculture) will be indicated in parentheses. Where the suitability class for maize differs from that of sorghum, it will be listed second (applies only to land quality 'o'). While the moisture and nutrient requirements also differ from sorghum to maize, these differences were not considered significant for the evaluation within the survey area.

a - accessibility

The following elements are of importance:

1. access of the farmer and implements to the land: distance, quality of roads and possibilities for improvement.
2. distance and quality of roads between the farm and a suitable market for sale of produce.
3. distance and quality of roads between the farm and a source of supplies and services.

Four ratings have been established:

1. good access(S1)
2. somewhat limited access (S1)
3. limited access (S2)
4. poor access (S3)

For the survey area as a whole, access is considered as somewhat limited to good - suitability class S1.

c - correct temperature regime

The following factors are considered:

-mean daily temperature
-mean maximum and mean minimum temperature.
-occurrence of frost in the growing season.
-daylength.

Four ratings have been established:

1. correct temperature regime and daylength (S1)
2. low possibility of extreme temperatures resulting in crop failure or reduced yield. (S2)
3. high possibility (S3-4)
4. temperature or daylength not correct. (S4-N1)

For the entire survey area, the temperature regime is considered as correct -suitability class S1.

e - resistance to soil erosion

Resistance to soil erosion by water and by wind are assessed separately-the lowest rating being the final one. Five ratings are distinguished. Erosion by water depends on many factors such as rainfall erosivity, soil erodibility, vegetative cover, slope, infiltration rate and conservation measures. The rating for erosion by water is determined taking the following factors into account:

soil characteristics-relates to the resistance of soil.

-soil texture
-soil structure
-% organic matter

land characteristics-relates to quantity and velocity of runoff.

-slope %
-slope length
-infiltration rate

climatic-mean annual rainfall, relates to rainfall erosivity

The rating for erosion by wind is dependent on climatic factors, (windspeed, rainfall in relation to evaporation), topographic factors, and soil erodibility (soil structure, consistence, texture).

f - absence of damaging floods.

This refers to the occurence of damaging floods during the growing season which may damage crops or infrastructure.

Five ratings have been established:

1. frequency of floods less than once in 10 years. (S1)
2. once every 5-10 years. (S2)
3. once every 3-4 years (S3)
4. once every 2 years. (S4)
5. every year. (N1)

g - adequacy of conditions for germination

The main soil characteristics which determine the conditions for germination in a moist soil are surface crusting, surface stones and gravel, and the structure and consistence of the topsoil. Three ratings have been established.

m - moisture availability

The rating for moisture availability takes into consideration the climate (rainfall, potential evapotranspiration), modified by topography (upslope or downslope), and the soil characteristics infiltration, permeability, and available water holding capacity (texture, depth, and stoniness). Six ratings have been established.

n - nutrient availability.

The nutrients considered for land quality 'n' are calcium, magnesium, potassium. Insufficient data are available to consider nitrogen, but organic carbon will be used as an indicator. Cation exchange capacity and pH are also taken into account. Four ratings are used.

o - oxygen availability in the root zone

Discussed in introductory paragraph to this section.

rating 1	S1	S1
2	S1	S2
3	S2	S3
4	S3-4	S4
5	N1	N1

p - absence of pests and diseases

While difficult to quantify such a land quality due to the variability in type and intensity, four ratings are established.

1. potential damage by pests and diseases is limited and/or easy to control by individual farmers. (S1).
2. potential damage considerable: moderate input needed in the form of labour (weeding, bird deterence). (S2)
3. potential damage high: moderate input in the form of materials (fencing, insecticides) or very high labour input needed. (S3-4)
4. potential damage very high: very high input in the form of materials and/or paid labour needed. (N1).

For the entire survey area, the potential damage is considerable, mainly from birds and small animals - suitability class S2.

r - adequacy of foothold for roots.

Adequacy of foothold is a function of effective soil depth, i.e. the part of the soil in which root growth is possible.

Five ratings have been established.

	effective soil depth (cm)	
1.	100	(S1)
2.	50-100	(S1)
3.	25-50	(S2)
4.	10-25	(S3)
5.	10	(N2)

t - absence of toxic substances.

Certain salts (chlorides, sulphates and carbonates causing salinity), sodium, and calcium carbonate can be considered toxic if they occur in high concentrations, and cause significant decreases in yield. In the land evaluation system, land quality 't' is rated separately for salinity, alkalinity, and calcium carbonate/gypsum. Five ratings have been established for each. Chemical data indicates that salinity

and alkalinity are at optimally low levels within the entire survey area-suitability class S1. Soils with a calcic horizon have been downgraded one class, while the petrocalcic horizon in not considered within the rooting zone.

w - workability

Workability, the ease with which a soil can be cultivated, is mainly a function of soil consistence, stoniness and rockiness. Four ratings have been established.

In the following section, each of the soil mapping units will be evaluated for the defined land use activity.

4.4 Evaluation of the Soil Mapping Units

In this section, each of the soil mapping units have been evaluated as to their suitability for the defined land use activity-sorghum and maize production under rainfed conditions utilizing improved traditional management. Soil mapping units with similar suitability classes and subclasses will be considered together, with a summary of all evaluations presented in tabular form (table 3). The final evaluation will be the one used on the land suitability map. Where two ratings are given, the first is for sorghum, and the second for maize. Where one rating is given it is the same for both crops.

C Unit - soils on highly calcareous material

C2 - currently unsuitable-class N1

Main limitations are very low moisture holding capacity due to sandy texture and shallow depth, and very poor topsoil workability due to surface or near surface stoniness.

L Unit - lacustrine soils

L9 and L 20 - marginally suitable-class S3 mwg/S3 mow

The main limitations are poor moisture availability, poor oxygen availability and poor topsoil workability. Moisture availability is commonly low throughout the entire survey area because of the climatic zone in which it falls, where the potential evapotranspiration exceeds mean annual rainfall throughout the year. Workability is poor due to the hard to very hard topsoil consistence. These soils could be productive under non-traditional management.

L9a - currently unsuitable-class N1

The Lake Ngami basin is currently unsuitable because of the high frequency of ponding due to annual flooding (flooding 7 out of 10 years).

L14 - marginally suitable-class S3mfo/S3mfw

The main limitations to these pan soils are a low moisture availability due to texture and only moderate depth, and the potential for seasonal flooding.

A Unit Alluvial, colluvial soils

A24 - marginally suitable-class S3me/S3moe

Main limitations are low moisture availability, low oxygen availability and the potential of erosion by water.

A24a - marginally suitable-class S3mne

Main limitations are a low moisture availability, low fertility, and the potential of erosion by water.

A22a - very marginally suitable-class S4m

Main limitation is very low moisture availability.

A22 - marginally suitable-class S3mne

Main limitations are a low moisture availability, low fertility, and the potential of erosion by wind.

A20 - marginally suitable-class S3mne

same limitations as A22.

A4C - moderately suitable-class S2mne/mno

Main limitations are a moderate moisture availability, moderate fertility, and the potential of erosion by both water and wind. These are the highest rated soils in the survey area.

S Unit - soils on coarse grained sedimentary rock (including aeolian sands)

S1b - very marginally suitable-class S4m

Main limitation is very low moisture availability.

KS17 - marginally suitable-class S3mne

Main limitations are a low moisture availability, low fertility, and the potential of erosion by wind. The following soil mapping units are given the same rating: LS17, KS3, LS15, KS13, KS5b

KS13a - very marginally suitable-S4m

same limitations as S1b

associations

The suitability (sub)class for the individual soil units may be different, resulting in an association of suitability (sub)classes.

When the final evaluation of the association differs from that of the individual soil units, the suitability (sub)class of the dominant soil unit will be used on the map, followed by a number in parentheses which will refer the reader to table 3, where the associations are given in full. The proportions of the individual soil units and suitability (sub)classes within the associations are in parentheses immediately following their listing.

Table 3 Land Suitability - Evaluation of the Soil Mapping Units

land qualities

soil mapping unit	a	c	e_1	e_2	f	g	m	n	o sorgh.	o maize	p	r	t**	w	final evaluation sorghum	final evaluation maize
L9	S1	S1	S2	S1	S1	S3	S3	S2	S2	S3	S2	S1	S1	S3-4	S3mwg	S3mow
L9a	S1	S1	S2	S1	S4	S3	S3	S2	N1	N1	S2	S1	S1	S3-4	N1	N1
L14	S1	S1	S1	S2	S3	S2	S3	*	S2	S3	S2	S1	S2	S3	S3mfo	S3mfw
L20	S1	S1	S2	S2	S1	S2	S3	*	S2	S3	S2	S1	*	S3	S3mw	S3mow
A24	S1	S1	S3	S3	S1	S1	S3	*	S2	S3	S2	S1	*	S1	S3me	S3moe
A24a	S1	S1	S3	S2	S1	S1	S3	S3	S1	S2	S2	S1	S1	S1	S3mne	S3mne
A22a	S1	S1	S2	S3	S1	S2	S4	S3	S1	S1	S2	S1	S2	S2	S4m	S4m
A22	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne
A20	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne
A4c	S1	S1	S2	S2	S1	S2	S2	S2	S1	S2	S2	S1	S1	S2	S2mne	S2mno
C2	S1	S1	S1	S3	S1	S2	N1	*	S1	S1	S2	S3	*	N1	N1	N1
S1b	S1	S1	S1	S3	S1	S1	S4	S3	S1	S1	S2	S1	S1	S2	S4m	S4m
KS17	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne
KS17	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne
KS3	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne
LS15	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne
KS13	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S2	S1	S3mne	S3mne
KS13a	S1	S1	S1	S3	S1	S1	S4	S3	S1	S1	S2	S1	S1	S1	S4m	S4m
KS5b	S1	S1	S1	S3	S1	S1	S3	S3	S1	S1	S2	S1	S1	S1	S3mne	S3mne

e_1 - erosion by water; e_2 - erosion by wind

* - data unavailable

** - evaluation for $CaCo_3$ only. Evaluation for salinity and alkalinity is S1.

Table 3 (continued)

association*	suitability (sub)class*	mapping symbol
A22(50) + A20(50)	S3mne(50) + S3mne(50)	S3mne
A22(40) + A20(30) + A4c(30)	S3mne(40) + S3mne(30) + S2mno(30)	S3mne(1)
S1b(60) + C2(40)	S4m(60) + N1(40)	S4m (2)
KS17(60) + KS13(40)	S3mne(60) + S3mne(40)	S3mne
KS17(60) + S1b(40)	S3mne(60) + S4m(40)	S3mne (3)
KS17(60) + KS3(40)	S3mne(60) + S3mne(40)	S3mne
KS17(40) + KS3(30) + A20(30)	S3mne(40) + S3mne(30) + S3mne(30)	S3mne
LS17(50) + A22(50)	S3mne(50) + S3mne(50)	S3mne

* proportions (%) given in parentheses

5. Conclusions and Recommendations

The land suitability map represents an evaluation of the soil mapping units found within the survey area for the defined land use activity. Like the soil map, it must be noted that the boundaries, while appearing to be sharp separations between mapping units, may represent transitional zones where the units merge into each other. Both maps are based on a limited number of observations, and the soil mapping units and land suitability classification may be amended with additional field and laboratory data. The table below illustrates the distribution of the suitability (sub) classes as shown on the land suitability map.

suitability subclass	area (ha)	% of survey area	
S2mne/S2mno	7,100	2.5	
S3mw/mow	7,500	2.6	
S3mwg/mow	21,100	7.4	
S3mfo/mfw	900	0.3	
S3me/S3moe	1,000	0.3	73.1
S3mne	144,200	50.4	
S3mne(1)	26,800	9.4	
S3mne(3)	7,600	2.7	
S4m	47,000	16.5	
S4m(2)	7,200	2.5	19.0
N1	15,500	5.4	
	286,000	100.0	

There was no land in the survey area which was classed as highly suitable (S1) for the defined land use activity. A small proportion (2.5%) of the survey area was found to be moderately suitable (S2). This unit occurs in old stream beds and depressions in the northwest of the survey area (soil mapping unit A4c). While there are some limitations to cultivation in the form of moderate fertility, slight potential of erosion, and a fair topsoil workability, it is the most suitable land in the survey area. Even though these areas can be small and discontinuous, they should be considered for small scale cultivation as only moderate inputs are required to maintain productivity.

Land classified as marginally suitable (S3) occupies the greatest proportion of the survey area (73.1). The main limitations to cultivation are a low moisture availability, low fertility (mainly the sandy soils), the potential for erosion, and the low oxygen availability due to somewhat impeded drainage in lower lying areas, which may contribute to significant reductions in crop yields. The land classified as S3mow for maize, encompassing soil units L9 and L20 , should be considered separately as they occur within the Lake Ngami depression. These areas outside the lowest basin, should be looked upon favourably due to their higher inherent fertility, and their close proximity to the water source of Lake Ngami which traditionally floods seven out of ten years. While only marginally suitable for dryland farming, they may be upgraded for irrigated agriculture. Potten (1975) speaks of proposals for irrigated agriculture on the Eastern part of the floor of Lake Ngami as early as 1926. Siderius (1971) has identified an area on the northern fringe of Lake Ngami as being recommended for irrigated farming. SWECO (1976), the Swedish consulting group, has identified 2 areas on the northern and northeastern fringe of the Lake Ngami floodplain as being moderately to marginally suitable for irrigated land use. While the tribal preference for cattle rearing in the area should not be overlooked, the development potential of the Lake Ngami depression should be looked at in more detail with the laying down of trials to assess productivity quantitatively.

Land classified as S4 and N1 is not recommended for the defined land use activity, as limitations in the form of very low moisture availability will severely hamper cultivation even though these areas may presently be cultivated on a subsistence level. Soil mapping unit L9a , in the Lake Ngami basin is classified N1 due to the occurence of flooding and hazard of ponding. However, the flooding is variable, and this area should be looked at on a seasonal basis to assess its suitability for cultivation. Upon recession of seasonal floods, areas may become more suitable for molapo cultivation.

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ANNEX 1

Soil Profile Descriptions

Laboratory Analyses

Profile No.	Soil classification	Mapping unit
To 180	Je	L9
To 183	Je	L9a
To 176	Qe	A4c
To 175	Qe	LS17
To 227	Qf	KS3
To 231	Qk	KS13
To 196	Ql	KS5b

Laboratory Analyses

profile no.	depth(cm)	pH H_2O	pH $CaCl_2$	EC(mmho)	P(ppm)	org.C%	CEC(meq/100g)	exch. cations Ca	Mg	K	Na	BS%	class./ mapping unit
To 180a	15-35	5.35	4.56	-	2.8	2.76	30.08	13.03	4.81	2.91	0.52	71	Je/ L9
b	40-60	5.66	4.79	-	2.7	0.01	2.16	0.97	0.35	0.06	0.03	65	
c	80-100	7.50	7.25	0.110	1.8	0.03	5.18	6.43	1.04	0.26	0.10	100+	
To 183a	0-15	5.98	5.82		26.6	3.48	42.84	23.03	3.83	7.20	0.16	80	Je/ L9a
b	50-70	3.35	3.09		11.9	3.05	36.74	13.89	4.16	1.06	0.34	53	
c	90-110	3.22	2.88		28.4	3.34	37.30	8.23	2.19	0.68	0.32	31	
d	115-130	4.50	4.10		20.5	4.64	29.08	10.45	2.13	2.54	0.26	53	
To 176a	0-10	4.84	4.52	-	6.2	3.63	36.24	14.31	5.70	3.23	0.41	65	Bk/A4
b	10-30	4.61	3.81	-	22.3	0.27	2.82	0.58	0.38	0.08	0.04	38	
c	80-100	9.25	7.92	0.263	4.8	0.05	4.86	6.69	0.49	0.36	2.95	100+	
To 143a	0-20	6.79	6.37	-	2.4	0.15	2.56	1.56	0.31	0.22	0.04	83	Qe/KS17
b	50-70	6.40	5.58	-	6.0	0.10	2.84	1.46	0.55	0.22	0.03	80	
To 227a	0-10	6.54	6.05	-	1.1	1.08	5.34	2.57	0.97	0.18	0.12	72	Qf/KS3
b	20-40	6.41	5.46	-	0.8	2.00	4.70	1.96	0.97	0.19	0.15	70	
c	50-70	5.24	4.47	-	1.4	2.17	5.18	1.84	1.36	0.14	0.11	67	
To 160a	0-20	8.46	7.62	0.086	6.0	0.39	3.38	7.72	2.17	0.23	0.01	100+	Qk/KS13
b	30-50	8.52	7.30	0.092	1.9	0.15	2.42	15.96	2.32	0.23	0.02	100+	
c	70-85	8.65	7.94	0.098	0.5	0.10	2.10	19.49	2.18	0.14	0.04	100+	
To 196a	0-25	6.74	6.15	-	2.3	0.83	3.65	2.20	0.49	0.31	0.03	83	Q1/KS5b
b	40-60	6.65	5.77	-	0.7	1.42	3.94	1.79	0.61	0.42	0.00	72	
c	90-110	6.53	5.76	-	0.5	0.46	3.36	1.64	0.91	0.15	0.01	81	

* - To 143 is outside the survey area. The soil is similar to To 175 (within the survey area). Both profile descriptions are given.

** - To 160 is outside the survey area. The soil is similar to To 231 (within the survey area). Both profile descriptions are given.

photo series 1/78 C.K. no. 1A-004

SOIL PROFILE DESCRIPTION SHEET	SOIL SURVEY OF BOTSWANA	FAO BOT/80/003	
PROFILE NO. To 180	SHEET NO. 2022B4	GRID REF. FN 900435	UNIT L9
LOCATION, COORDINATES	Lake Ngami alluvial plain; 'seasonal road' along highwater line		
DATE 15/12/82	AUTHOR Paul and Ketlogetswe		
SOIL CLASSIFICATION (FAO)	Eutric Fluvisol Je		
SOIL CLASSIFICATION (ST)			
ELEVATION m.	PHYSIOGRAPHIC POSITION	(flood)plain	
TOPOGRAPHY flat		MICROTOP.	
SLOPE -		SURFACE COND.	
LAND-USE / VEGETATION	open shrub savanna		
SPECIES	shrubs: Z. mucronata, A. tortilis, A.leuderitzii		
	grasses: C.dactylon		
PARENT MATERIAL lacustrine		DRAINAGE imperfect	
MOISTURE COND. dry		SURFACE STONES -	
ROCK OUTCROPS -		SALINITY -	
EROSION / DEPOSITION			
HUMAN INFLUENCE			
REMARKS	area heavily grazed		

HORIZON DESCRIPTION

hor. symbol	Ah	2Ah	3C1	3C2		
depth	0-10	10-35	35-70	70-110+		
colour moist dry	10YR2.5/1 3.5/2	10YR2/1 3/2	10YR5/4 7/3	2.5Y4/2 5/4		
mottling	few, fine+med prominent 7.5YR5.5/8	few coarse prominent 7.5YR5/8	few fine distinct 7.5YR/8	few fine distinct 7.5YR5/8		
texture	sandy loam	silty clay	loamy sand	sandy loam		
structure	weak, med subang blocky	weak, med subang blocky	structureless massive	structureless massive		
consistence	sl.hard	v.hard	soft	sl.hard-hard		
cutans	-	-	-	-		
cementation	-	-	-	-		
pores	common fine	common fine	common fine	common fine		
rock fragm.	-	-	-	-		
mineral nod.	-	-	-	-		
carbonates	-	-	-	-		
biol. feat.	-	-	common borrowing			
roots	common fine-med	common fine	few fine	few fine-coarse		
boundary	grad smooth	abrupt smooth	wavy smooth			
samples		a 15-35	b 40-60	c 80-100		

photo series 1/78 C.K. no. 2-030

SOIL PROFILE DESCRIPTION SHEET	SOIL SURVEY OF BOTSWANA	FAO BOT/80/003	
PROFILE NO. To 183	SHEET NO. 2022D1	GRID REF. FN817276	UNIT L9a
LOCATION, COORDINATES	south side of Lake Ngami, at base of escarpment (across Sehitwa)		
DATE 16/12/82	AUTHOR Paul and Ketlogetswe		
SOIL CLASSIFICATION (FAO)	Eutric Fluvisol Je		
SOIL CLASSIFICATION (ST)			
ELEVATION m.	PHYSIOGRAPHIC POSITION	slight convex slope	
TOPOGRAPHY	gently undulating	MICROTOP.	
SLOPE 1%		SURFACE COND.	
LAND-USE / VEGETATION	open savanna woodland		
SPECIES	A.tortilis, Z.mucronata		
	dorminant grass: setaria verticiliata		
PARENT MATERIAL	lacustrine	DRAINAGE poor	
MOISTURE COND.	sl. moist at 90 cm	SURFACE STONES –	
ROCK OUTCROPS –		SALINITY –	
EROSION / DEPOSITION			
HUMAN INFLUENCE			
REMARKS			

HORIZON DESCRIPTION

hor. symbol	Ah1	Ah2	C1	C2		
depth	0-15	15-90	90-115	115-130+		
colour moist dry	10YR2/1 3.5/2	10YR2.5/1 3/1	10YR3/2	10YR3.5/1		
mottling	few, fine prominent 7.5YR5/8	many, coarse prominent 7.5YR5/7	–	–		
texture	humic silt loam	silty clay	silty clay	silt		
structure	weak, fine subang blocky	weak, med-coarse, subang blocky	structureless massive	structureless massive		
consistence	soft	ext.hard	friable-firm	soft		
cutans	–	–	–	–		
cementation	–	–	–	–		
pores	common, fine	common, fine	common, fine	common, fine		
rock fragm.	–	–	–	–		
mineral nod.	–	–	–	–		
carbonates	–	–	–	–		
biol. feat.	–	–	–	–		
roots	common, fine	v.few, v.few	–	–		
boundary	wavy, smooth	gradual, smooth	–	–		
samples	a 0-15	b 50-70	c 90-110	d 115-130		

photo series 1/78 C.K. no. 1A-001,002

SOIL PROFILE DESCRIPTION SHEET — SOIL SURVEY OF BOTSWANA — FAO BOT/80/003

PROFILE NO. To 176	SHEET NO. 2022B3	GRID REF. FN707495	UNIT A4c

LOCATION, COORDINATES 15.4 km from Sehitwa junction, on road to Tsau

DATE 14/12/82	AUTHOR Paul and Ketlogetswe

SOIL CLASSIFICATION (FAO) Calcic Cambisol Bk

SOIL CLASSIFICATION (ST)

ELEVATION m.	PHYSIOGRAPHIC POSITION slight convex slope
TOPOGRAPHY gently undulating	MICROTOP.
SLOPE 1%	SURFACE COND.

LAND-USE / VEGETATION woodland savanna

SPECIES T.prunoides, D.cinerea, A.erubescens, A.mellifera

PARENT MATERIAL alluvium	DRAINAGE imperfect-moderate
MOISTURE COND. dry	SURFACE STONES -
ROCK OUTCROPS -	SALINITY -

EROSION / DEPOSITION

HUMAN INFLUENCE

REMARKS

HORIZON DESCRIPTION

hor. symbol	Ah	Bt	Ck			
depth	0-25	25-60	60-100+			
colour moist dry	10YR2.5/1 4/1.5	10YR2.5/1 4/1.5	10YR4/3 5.5/3			
mottling	-	-	-			
texture	sandy loam	sandy clay loam	loamy fine sand			
structure	v.weak, med subang blocky to crumb	mod, fine-med ang blocky	structureless massive			
consistence	sl. hard - hard	hard-v.hard	soft			
cutans	-	-	-			
cementation	-	-	-			
pores	common, fine	common, fine	v.few, fine			
rock fragm.	-	-	-			
mineral nod.	-	-	-			
carbonates	+	+	++ in patches			
biol. feat.	-	-	common burrowing			
roots	rare fine	rare fine	-			
boundary	clear, smooth	clear, smooth				

photo no. 37-2123

SOIL PROFILE DESCRIPTION SHEET | SOIL SURVEY OF BOTSWANA | FAO BOT/80/003

PROFILE NO. To 143	SHEET NO. 2023 A1	GRID REF. FN289804	UNIT KS17

LOCATION, COORDINATES island across Moshu experimental station

DATE 16/9/82 | AUTHOR Paul and Ketlogetswe

SOIL CLASSIFICATION (FAO) Eutric Arenosol Qe

SOIL CLASSIFICATION (ST)

ELEVATION m. | PHYSIOGRAPHIC POSITION plain

TOPOGRAPHY flat | MICROTOP.

SLOPE 0-2% | SURFACE COND.

LAND-USE / VEGETATION woodland savanna

SPECIES A.erioloba, Grewia flava, G.bicolor, C.hereroensis

PARENT MATERIAL aeolian | DRAINAGE well-somewhat excessive

MOISTURE COND. dry | SURFACE STONES -

ROCK OUTCROPS - | SALINITY -

EROSION / DEPOSITION

HUMAN INFLUENCE

REMARKS

HORIZON DESCRIPTION

hor. symbol	Ah	C				
depth	0-30	30-120+				
colour moist dry	10YR3/1.5 5/2	10YR4/2 5/2.5				
mottling	-	-				
texture	fine sand	fine sand				
structure	structureless	structureless				
consistence	soft	soft-sl.hard				
cutans	-	-				
cementation	-	-				
pores	common fine	common fine				
rock fragm.	-	-				
mineral nod.	-	-				
carbonates	-	-				
biol. feat.	-	-				
roots	few fine	few, v.fine				
boundary	clear, smooth					
samples						

phot series 1/78 C.K. no. 1A-001,002

SOIL PROFILE DESCRIPTION SHEET — SOIL SURVEY OF BOTSWANA — FAO BOT/80/003

PROFILE NO. To 175	SHEET NO. 2022B3	GRID REF. FN714481	UNIT LS17

LOCATION, COORDINATES Sehitwa-Tsau road, 14.1 km from Sehitwa junction

DATE 14/12/82 | AUTHOR Paul and Ketlogetswe

SOIL CLASSIFICATION (FAO) Eutric Arenosol Qe

SOIL CLASSIFICATION (ST)

ELEVATION m. | PHYSIOGRAPHIC POSITION plain

TOPOGRAPHY flat | MICROTOP. 6

SLOPE 0-1% | SURFACE COND.

LAND-USE / VEGETATION shrub savanna

SPECIES A.mellifera, A.tortilis, Grewia flava

PARENT MATERIAL aeolian | DRAINAGE well

MOISTURE COND. moist at 40 cm | SURFACE STONES -

ROCK OUTCROPS - | SALINITY -

EROSION / DEPOSITION

HUMAN INFLUENCE

REMARKS not sampled, but profile similar to To 143

HORIZON DESCRIPTION

hor. symbol	Ah	C1	C2			
depth	0-30	30-50	50-110+			
colour moist / dry	10YR2.5/2 / 4/2	10YR3/3 / 5/2	10YR2.5/3 / 6/3			
mottling	-	-	-			
texture	loamy fine sand	loamy fine sand	loamy fine sand			
structure	structureless massive	structureless massive	structureless massive			
consistence	sl.hard	soft	soft			
cutans	-	-	-			
cementation	-	-	-			
pores	few fine-med	few fine-med	few fine-med			
rock fragm.	-	-	-			
mineral nod.	-	-	-			
carbonates	-	-	-			
biol. feat.	-	-	-			
roots	few, fine-med	few fine	v.few, fine			
boundary	gradual smooth	gradual smooth				

photo 151 BT 12 - 071

SOIL PROFILE DESCRIPTION SHEET | SOIL SURVEY OF BOTSWANA | FAO BOT/80/003

PROFILE NO. To 227	SHEET NO. 2022D2	GRID REF. FN935109	UNIT KS3

LOCATION, COORDINATES cutline southeast of Pelobothoko

DATE 23/2/83 | AUTHOR Paul and Ketlogetswe

SOIL CLASSIFICATION (FAO) Ferralic Arenosol Qf

SOIL CLASSIFICATION (ST)

ELEVATION m. | PHYSIOGRAPHIC POSITION plain

TOPOGRAPHY flat - gently undulating | MICROTOP.

SLOPE 0-1% | SURFACE COND.

LAND-USE / VEGETATION shrub savanna

SPECIES T.prunoides, A.erubescens, C.apiculatum, G.bicolor, D.cinerea

PARENT MATERIAL aeolian | DRAINAGE well

MOISTURE COND. dry | SURFACE STONES -

ROCK OUTCROPS - | SALINITY -

EROSION / DEPOSITION

HUMAN INFLUENCE

REMARKS

HORIZON DESCRIPTION

hor. symbol	Ah1	Ah2	B			
depth	0-10	10-45	45-100+			
colour moist dry	7.5YR3/4 4/4	7.5YR3/4 4/4	7.5YR4/6 5/6			
mottling	-	-	-			
texture	fine sand	fine sand	fine sand			
structure	weak, fine-med subang blocky	weak, med-coarse subang blocky	weak, med-coarse subang blocky			
consistence	soft-sl.hard	soft-sl.hard	soft-sl.hard			
cutans	-	-	-			
cementation	-	-	-			
pores	common find	common fine	common fine			
rock fragm.	-	-	-			
mineral nod.	-	-	-			
carbonates	-	-	-			
biol. feat.	-	-	-			
roots	common fine	common fine	few fine			
boundary	grad smooth	grad smooth				

no photo

SOIL PROFILE DESCRIPTION SHEET	SOIL SURVEY OF BOTSWANA	FAO BOT/80/003	
PROFILE NO. To 160	SHEET NO. 2023B4	GRID REF. GN973437	UNIT KS 13
LOCATION, COORDINATES	1 km after Samedupe bridge on road to Makalamabedi		
DATE 17/11/82	AUTHOR Paul and Ketlogetswe		
SOIL CLASSIFICATION (FAO)	Calcic Arenosol Qk		
SOIL CLASSIFICATION (ST)			
ELEVATION m.	PHYSIOGRAPHIC POSITION plain		
TOPOGRAPHY flat		MICROTOP.	
SLOPE -		SURFACE COND.	
LAND-USE / VEGETATION	shrub and tree savanna		
SPECIES	T.prunoides, A. mellifera, A.tortilis, A.leuderitzii		
PARENT MATERIAL	aeolian	DRAINAGE well	
MOISTURE COND. dry		SURFACE STONES -	
ROCK OUTCROPS -		SALINITY -	
EROSION / DEPOSITION			
HUMAN INFLUENCE			
REMARKS			

HORIZON DESCRIPTION

hor. symbol	Ah1	Ah2	Ck1	Ck2		
depth	0-20	20-70	70-88	88-100+		
colour moist dry	10YR3.5/3	10YR3.5/3	10YR5/3.5			
mottling	-	-	-			
texture	loamy sand	loamy sand	loamy sand	soft calcrete rock		
structure	v.weak subang blocky	structureless	structureless			
consistence	-	-	-	-		
cutans	-	-	-	-		
cementation	-	-	-	-		
pores	few fine	v.few, fine	v.few, v.fine			
rock fragm.	-	-	-	-		
mineral nod.	-	-	-	-		
carbonates	+	++	+++			
biol. feat.	-	-	-	-		
roots	common fine,med	few fine	rare fine			
boundary	clear smooth	clear smooth	clear smooth			
samples	0-20					

photo 151 BT 13 - 046

SOIL PROFILE DESCRIPTION SHEET — SOIL SURVEY OF BOTSWANA — FAO BOT/80/003

PROFILE NO. To 231	SHEET NO. 2022D1	GRID REF. FN951171	UNIT KS 13

LOCATION, COORDINATES campsite at Matamanyane

DATE 24/2/83 | AUTHOR Paul and Ketlogetswe

SOIL CLASSIFICATION (FAO) Calcic Arenosol Qk

SOIL CLASSIFICATION (ST)

ELEVATION m. | PHYSIOGRAPHIC POSITION plain

TOPOGRAPHY flat | MICROTOP.

SLOPE | SURFACE COND.

LAND-USE / VEGETATION woodland savanna

SPECIES T.prunoides, A.erubescens, G.bicolor, D.cinerea

PARENT MATERIAL aeolian | DRAINAGE well

MOISTURE COND. dry | SURFACE STONES -

ROCK OUTCROPS - | SALINITY -

EROSION / DEPOSITION

HUMAN INFLUENCE

REMARKS not sampled, but profile similar to To 160

HORIZON DESCRIPTION

hor. symbol	Ah1	Ah2	Bt1	Bt2	Ck	
depth	0–10	10–45	45–70	70–120	120+	
colour moist dry	10YR3/2 4.5/3	10YR3/3 4.5/3	10YR4.5/3 6/3	10YR4.5/3 6/3		
mottling	-	-	-	-		
texture	loamy sand	loamy sand	sandy loam	sandy loam	soft calcrete rock	
structure	mod,med subang blocky	weak,fine-med subang blocky	weak,coarse, subang blocky	weak,coarse subang blocky		
consistence	soft-sl.hard	soft-sl.hard	soft.sl.hard	soft-sl.hard		
cutans	-	-	-	-		
cementation	-	-	-	-		
pores	common fine,med	common fine,med	common fine, med	common fine,med		
rock fragm.	-	-	-	-		
mineral nod.	-	-	-	-		
carbonates	-	-	+	++		
biol. feat.	-	-	-	-		
roots	common fine and v. fine		few fine	few fine		
boundary	grad smooth	grad smooth	grad smooth	clear smooth		
samples	-					

photo series 1/78 C.K. no. 1A-007

SOIL PROFILE DESCRIPTION SHEET — SOIL SURVEY OF BOTSWANA — FAO BOT/80/003

PROFILE NO. To 196	SHEET NO. 2022B4	GRID REF. GN483055	UNIT KS5b

LOCATION, COORDINATES 2.1 km from Toteng bridge on Toteng Maun Road

DATE 2/2/83 | AUTHOR Paul and Ketlogetswe

SOIL CLASSIFICATION (FAO) Luvic Arenosol Q1

SOIL CLASSIFICATION (ST)

ELEVATION m. | PHYSIOGRAPHIC POSITION plain

TOPOGRAPHY flat-gently undulating | MICROTOP.

SLOPE 1% | SURFACE COND.

LAND-USE / VEGETATION open savanna woodland

SPECIES T.prunoides, T.sericea, C.apiculatum, B.albitrunca

grasses: Digitaria spp.

PARENT MATERIAL aeolian | DRAINAGE well

MOISTURE COND. dry | SURFACE STONES –

ROCK OUTCROPS – | SALINITY –

EROSION / DEPOSITION

HUMAN INFLUENCE

REMARKS

HORIZON DESCRIPTION

hor. symbol	Ah	B1	B2t			
depth	0-27	27-70	70-120+			
colour moist / dry	10YR3/2	10YR3/3	10YR5/3			
mottling	–	–	–			
texture	loamy fine sand	loamy fine sand	loamy fine sand			
structure	weak, med subang blocky	v.weak-weak med-coarse subangblocky	weak-mod med-coarse subang blocky			
consistence	soft-sl.hard	sl.hard	sl.hard			
cutans	–	–	thin, patchy			
cementation	–	–	–			
pores	common fine	common fine	common fine			
rock fragm.	–	–	–			
mineral nod.	–	–	–			
carbonates	–	–	–			
biol. feat.	–	–	–			
roots	few fine, v.fine	same	same			
boundary	grad smooth	grad smooth				
samples						