OKACOM

Soils of the Okavango River Basin

Specialist Report prepared by Sophie Simmonds for :

PERMANENT OKAVANGO RIVER BASIN COMMISSION

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1. INTRODUCTION

OKACOM is an initiative of the three Okavango River Basin states, Angola, Botswana and Namibia. The Commission has the functions of advising the governments on the sustainable development of the basin and of co-ordinating investigations and research activities.

The Okavango River plays a key role in the lives of the people of the region. It is also one of the few relatively undeveloped river basins in the world containing unique environmental and ecological features. Recognising this, there is a need to manage the mounting regional development pressures through the formulation of an Integrated Basin Management Plan. Such a plan would span national boundaries and interests and promote the sustainable development of the Okavango River Basin through a process of open consultation at all levels.

A Preparatory Assessment Programme was established to facilitate stakeholder participation in the Environmental Assessment and the development of the Integrated Basin Management Plan. Phase I of the programme concludes with a Diagnostic Assessment identifying key areas of concerns and gaps in knowledge of the physical and socio-economic systems of the Okavango River Basin. This will be based on review of the current state of information and knowledge.

Phase I will be followed by a Strategic Action Programme through which an Environmental Assessment will be undertaken to address issues, priorities and gaps in information and understanding. This will lead to the formulation of an Integrated Basin Management Plan.

1.1 DIAGNOSTIC ASSESSMENT - SOILS REVIEW

With respect to the review of soils of the Okavango River Basin, a summary of the ToR is given below:

- Provide a brief overview of the soils of the study area. This should not entail new work. Where an area has not been covered by previous studies, this should be stated, as well as an indication of whether there are data and mapping or imagery available that could be used for a study. Gaps in knowledge will therefore be identified at this stage.
- Provide an overview of what work has been done, which areas are covered, and how useful it may be for the environmental assessment. This can take the form of an annotated reference list.
- Provide an overview of mapping and imagery that is available, and an assessment of its potential. This is a major portion of the assignment and should include a description of what thematic maps are available. Some samples should be provided for illustration. The cost of obtaining/printing samples will be paid by the project over and above your fee. This part of the assignment should not exclude Angola, to the extent that if maps and information are known of, they should be sourced if possible.
- Provide a summary of work to be done in the Environmental Assessment Phase of the study. This should include ideas for Angola.

2. OVERVIEW OF SOILS OF THE OKAVANGO RIVER BASIN

2.1 SUMMARY

Section 3 documents previous and current studies, the areas covered and their potential use to an environmental assessment of the Okavango River basin. This section draws upon the results of these studies to provide a description of soils of the lower Okavango River basin located on Namibian and Botswanan territory. No attempt has been made to describe soils found in the upper segment of the basin on Angolan territory as no relevant study could be obtained within the time frame of this report.

Due to the scattered nature and paucity of published reports and data on the Namibian soils it was necessary to merge data collected in a variety of formats. Available reports lacked detailed soil survey results and were in some cases incomplete (maps without legends, reports without supporting data). Only one study provided comprehensive information on a regional scale (Loxton *et al*, 1971).

In contrast, comprehensive, recently produced and readily available Botswanan material (De Wit & Nachtergaele, 1990; Joshua, 1991; Radcliffe *et al*, 1991; 1992) provided this overview with considerably more information. For the Okavango Delta region, mapped soils and landform data were supported by detailed survey reports and soil profiles.

Available soils data were based on three systems of classification. Namibian soils data were based on the South African Binomial Soil Classification System (MacVicar et al, 1977) and on the earlier South African National Soil Series Classification System. The latter acted as an early approximation of the Binomial System. Botswanan soils data were correlated to the FAO/UNESCO/ISRIC Soil Classification Legend (1988).

Due to the lack of correlation between the systems, and because soils information was derived from surveys undertaken at different intensities and mapping scales, this overview of soil resources of the river basin inevitably lacks comparative depth. It would make sense, therefore, to develop a methodology for correlation of the RSA systems with the FAO Revised Legend (1991) to provide a systematic description of the river basin. This however, would not be a straightforward exercise on the following grounds (*pers.comm,* Nachtergaele, 1998):

- The systems were developed with different guidelines for soil profile description,
- Certain soil features receive a different emphasis on parallel definitions,
- Some of the laboratory procedures supporting the RSA systems used in the 1970s were different to current FAO procedures.

Further use of previous Namibian soils studies for environmental assessment and river basin management purposes will thus be limited, unless a method can be found to solve the difficulty of correlating the South African Binomial Soil Classification System/National Soil Series Classification System with that of the internationally accepted FAO Revised Legend employed in the other Okavango River basin states.

As with the soil data, landform data were based on two systems of classification. Both systems, however, were based on similar diagnostic features and hierarchies. The Botswanan data derived from De Wit & Bekker (FAO, 1990), presented a three-tiered sub-division into land systems, whereas the older Namibian data lacked land division boundaries (FAO / UNDP, 1984). For environmental assessment purposes the Namibian classification is adequate, although at the Namibia/Botswana border the two systems failed to match.

This overview presents an incomplete picture of soil resources of the Okavango River basin. It is therefore presented with the following caveats:

- The utility of available Namibian information is compromised by a serious classification incompatibility with Botswanan data sets.
- Angolan soils data are not included. Angolan soils data correlated to the FAO Legend will become available at an estimated scale of 1:1,000,000, although this scale will be inadequate for both environmental assessment and river basin management purposes.

- The lack of a coherent regional soils database in which information is based upon standard procedures, mapping scales and survey intensity, completely prevents a systematic river basin assessment based on comparative soil attributes.

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2.2 LANDFORMS AND SOILS OF FUNCTIONAL AND NON-FUNCTIONAL SUB-CATCHMENTS IN THE SOUTHWESTERN REACHES OF THE OKAVANGO RIVER BASIN

2.2.1 Summary

The southwestern portion of the Okavango River Basin can be divided into sub-catchments in terms of surface water inflow to the Okavango River and delta system. Sub-catchments can therefore be characterised on the basis of 'functionality', whether they actively channel surface water to the major thoroughfares of the system. Such a first-order division of the river basin is practical for environmental assessment and river basin management purposes, although the capacity of non-functioning sub-catchments to channel meteoric water directly into aquifers may also contribute to the functioning of the system. This contribution is not likely to be significant in areas characterised by deep surface sand deposits. However, at the western boundaries of the southewestern reaches the Kalahari sand deposits overlying calcrete thin out considerably, providing favourable conditions for aquifer recharge.

Sections 2.2 and 2.3 categorise the southwestern reaches of the river basin into functional and non-functional sub-catchments as defined above.

To summarise the southwestern reaches, land surfaces gradually descend from 1200 masl in the south (Grootfontein District) to 1150 masl west of Rundu, and to 1000 m at Andara on the Caprivi West boundary. The south-north regional gradient is thus of the order of 0.8 m/km (0.08%).

Gentle slope factors combined with high permeability of the sandy soils combine to allow very little surface drainage. With the exception of rare high intensity rainfall events following favourable antecedent soil moisture conditions, the absorption capacity of these soils is never exceeded. However, where long slopes, shallow sands, and inadequate grazing management systems are combined, extensive aeolian and sheet-wash erosion surfaces are evident.

Deep horizontal drainage does occur after heavy rains in the catchment areas of well-defined omuramba, although surface flow is ephemeral and generally truncated by sand drift and alluvial deposits. Surface waters present at the confluences of deep omuramba and the eastward draining perennial Okavango River are largely the result of lateral flooding by the Okavango River itself. The deepest Omatako Omuramba has not drained into the Okavango River in recorded time.

In the extreme south and southwest of the basin, no omuramba are developed. Drainage mainly occurs via shallow depressions into numerous pans where impeded drainage conditions are found in shallow to moderately deep vertisols (up to 50 cm) overlying and adjacent to calcrete outcrops.

2.2.2 Landforms and Soils of Non-Functional Sub-Catchments

2.2.2.1 Pedological Context

The largest non-functioning sub-catchment lies within the Kalahari Sandveld region on the extreme southern end of the basin. It is bounded to the east by the Okavango Delta, to the west by the Omatako omuramba, and crosses over the Namibia/Botswana border.

In geomorphological terms, this area represents a large aggradational land surface in which increasing differentiation of the aeolian sands is being made into two groups - the true Kalahari sands of Tertiary age, and younger red sands and later redistributed sands. The aeolian sands were mostly deposited on a calcrete erosion surface, the calcretes having been formed by quasi-pedogenic processes associated with receding water surfaces, probably under increasingly arid conditions. Most of the calcretes are of the hardpan, boulder or honeycomb types.

Skirting the Central Highlands, on the southwestern watershed boundary, is a broad apron-like flat zone where these calcrete and silcretes outcrop or lie near the surface (giving rise to the term Kalkveld). Red Kalkveld has been applied to those more undulating parts of the Central Highlands where dominantly red

soils overlie calcretes, having been formed mainly from the weathered products of other rocks. To the east and northeast, the calcretes gradually disappear under the aeolian sands.

In relatively recent times, subsequent to the aggradational phase, there were at least two further changes in climate that influenced landform and soil development. Extensive areas of massive seif dunes occur in the northeast and eastern parts, now partly stabilised by vegetation. The dunes were formed under arid conditions by easterly prevailing winds.

Subsequently, in a wetter period, and possibly under climatic conditions similar to the present, water obtained from the Central Highlands drained eastwards and north-eastwards to promote dissection of these dunes to form the main omuramba valleys of Otjosondjupa and Okavango. In the case of the omurambas draining towards Botswana, the depth of the incision into the underlying calcretes increases to the east, with the result that their valleys tend to narrow along their length. It is apparent that wind as well as water influenced the form of these valleys and their environs. Thus dunes of wind blown-blown sand commonly fringe omurambas, being more pronounced in southern and eastern banks, indicating the action of northwesterly winds.

The depth of the Kalahari Sandveld increases generally to the north and east, as does the extent to which those sands have been worked and reworked by wind.

The eastern plains of Kalahari sand, embracing Okavango and Otjosondjupa regions, slope gradually to the northeast and east, being drained by a number of well-defined non-meandering omurambas, the central and eastern sections of which have been incised into the underlying calcretes.

Over large tracts of the Kalahari Sandveld, surface drainage is imperceptible or non-existent. The largest of such areas is a broad belt to the immediate east of the Omatako omuramba in Otjosondjupa. Prominent in the eastern and northern parts of the Kalahari sand zone are extensive sub-regions of larger stable linear dunes - seif dunes - with an east-west orientation. A distinctive topographic feature of this physiographic region is the Aha Mountains on the Namibia/Botswana border. More in the nature of low hills, these outcrops give rise to soils of higher potential than the surrounding sands (Loxton *et al*, 1971).

2.2.3 Landforms and Soils of Functional Sub-Catchments

The Okavango River basin straddles two of the major Namibian physiographic regions encompassing the Plateau and the Kalahari regions, with the southwestern edges lying on the Plateau and the remainder lying in the Kalahari Basin to the north, east and northeast.

The major land region dominating the southwestern catchment boundary area (Landform Map 1, IIIG1) is described as karst on hard Damara limestones in the plateau country: north-central karst (FAO, 1984).

With the exception of a small area of karst hills and ridges to the northwest of Grootfontein (81BD), the predominant land system (82) encompasses gently undulating and nearly level lowland. Dominant soil series are shallow and stony greyish brown to black immaturely developed lithosols, classified as Muden (Macvicar *et al*, 1977,1991) on shallow buried calcretes, and associated with Okavango sub-dominant series on surface calcretes. Under these conditions, large areas are not physically arable.

At 19°10' S, elevation and slope change imperceptibly, belying the fact that the basin abruptly enters Kalahari Sandveld (IVA2) crossing through a marginal apron of surface calcrete outcrops. This interface is not illustrated by landform although soils observations reveal impediments to surface drainage, shallow clayey soils (including vertisols), and a strong susceptibility to compaction. Soils Map 1 indicates that this calcrete outcrop area dips under deep aeolian Kalahari sands at 19°28'S / 18°40'E.

Throughout the calcrete deposition belt lie shallow, grey and darkly coloured sandy loams to sandy clay loams and black clays on the flat plains and frequent small depressions. These predominantly shallow Okavango and Limpopo soils (<25 cm deep) are characterised by impeded internal drainage, a patchy distribution of deeper soils, and pose management problems when associated with Arcadia sub-dominant forms in areas of heavier soils. Areas of potential salinity are associated with calcareous Muden sub-dominant series. Rainfed arable agricultural potential is thus marginal and limited to the patches of deeper soils too small to be of commercial value.

North of latitude 19° 10' S and east of Grootfontein, the river basin supports an extensive area of stabilised east-west aligned fossil dunes (Landform Map 2, IVA2). The two land systems of the southern

half of this area (51) are characterised by long slopes undulating between dune and dune-street, flat plains intersected by numerous omuramba, and sandy soil associations mainly of aeolian origins.

Sandspruit and Okavango represent the dominant soil series in a repetitive parallel pattern of brown and yellowish brown sands and dark grey sandy loams on rolling dunes, and on the flat plains loose grey and yellowish brown deep sands (Fernwood and Sandspruit series) encompass areas of sub-dominant dark grey sandy loams and sandy clay loams (Okavango and Limpopo series).

The stock disease control fence (the 'red line'), separating commercial land to the south from communal land to the north across the width of Namibia, follows the dune system in an east-west direction at latitude 18° 46' S. To the north of this fence it is evident that long slopes, shallow soils of low water holding capacity, and inadequate grazing management systems have combined to produce extensive aeolian and sheet-wash erosion surfaces exposing reddish subsoil/parent material (Landform Map 2, 51EB).

To the south of the fence, where physical conditions are similar and where grazing systems are interspersed by small-scale rainfed maize production, both grazing and water-induced erosion intensities were observed to be lower although moderate aeolian erosion surfaces were evident.

On the flat plains to the north of the dune field, sheet-wash erosion surfaces are generally slope-controlled although incipient gullies have been formed on slope-breaks feeding into small omurambas.

Land facets of dune and dune-streets, broken by isolated calcrete outcrops, provide the final land division between the sandy flat plains and the Okavango river terraces at the northerly end of the Kalahari Sandveld. This area is characterised by a mix of loose and stabilised sand drift (Landform Maps 2 & 3, IVB3) on a relatively deep aeolian sand mantle. Flat to undulating areas with little surface drainage support deep grey and greyish brown loose sands (Fernwood; Soils Map 2 & 3) with patches of yellowish brown sands (Sandspruit) located in better-drained positions.

Subsistence land use systems of a type similar to the mixed arable/pastoral practices of the adjacent flat plains to the south, significantly increase in intensity on these deeper soils and with proximity to Rundu (56BD). Areas of land cleared for housing and kraal construction, wood craft, fuelwood, fencing and mahangu production, no longer appear to be controlled by physical access from the trunk road as opportunistic village developments can be observed along a greater number of cutlines perpendicular to the road in both E - W directions. Soil fatigue appears to be widespread on numerous abandoned clearings in various stages of regeneration located within 30 km of the Grootfontein-Rundu road, although no clear indications of accelerated water erosion were observed. The increased number of new clearings and kraal constructions observed may reflect the combined effects of reduced soil fertility and the needs of a growing population - an issue which would warrant further study when considering the feasibility of offtakes from the proposed pipeline to serve the needs of the rural population.

Across the northern stretch of the Sandveld ochreous Kalahari sand layers tens of metres deep predominate on the inland sand plateau. Calcrete-like materials occur along the riverbanks and at shallow depths in the terraces associated with the Okavango River (Schneider, 1987; Landform Map 3, IVD5).

2.3 LANDFORMS AND SOILS OF THE OKAVANGO RIVER HINTERLAND, NAMIBIA

The Okavango river 'hinterland', situated immediately to the south of the river in Namibia, lies entirely inside the Kalahari landform (FAO, 1984), for which five land units are recognised. These are summarised below (Table 1) and illustrated on Landform Maps 3 and 4.

Table 1. Land Units Downstream of Rundu to Mahango Border Post

Land Unit	Land Unit Description
IVA 2	North-eastern stabilised E-W aligned Kalahari sand dunes
IVA 3	North-eastern (Caprivi) stabilised E-W aligned Kalahari sand dunes
IVB 3	North-eastern stabilised Kalahari sand drift
IVD 5	Northern river banks in Kalahari sand
IVD 6	North-eastern (Caprivi) river banks in Kalahari sand

Physiographically, two land units are dominant; the riverine borders of the perennial Okavango River, and the sand plateau of its 'hinterland'. The riverine unit (IVD5 and IVD6) comprises a floodplain 2-6 km wide showing evidence of a braided river system, and a terrace system differentially covered by alluvial deposits and situated 6-7 m above the river bed. The floodplain is partly inundated during the wet season, and as the water level drops, ponds and lakes remain.

On the sand-covered plateau (IVA2, IVA3, IVB3), relief is flat to gently undulating in regions where low, linear dunes and intervening troughs (omuramba) occur. The Omatako Omuramba crosses this area. Although the Omatako is the largest tributary of the Okavango in Namibia, surface water flow from this omuramba has not been recorded to reach its Okavango confluence. As with all other omuramba, the valley of the Omatako is steeply incised and free of terrace deposits.

2.3.1 Soil and Landform Associations

Fundamental to the distribution of the soils of the Kalahari Region is an understanding of the interactive effects of two factors: depth of aeolian sand mantle and degree of relief (Loxton *et al*, 1971). Subsequent to their deposition on the Tertiary calcretes and other sedimentary rocks, the Kalahari sands were eroded and partially re-worked by wind and water, the end result being landforms varying from flat plains to massive seif dunes, and sand depths varying from 50 m or more to zero. Ignoring intermediate conditions, the main factorial combinations of sand depth and relief are listed below with map references:-

Table 2. Relief / Sand Mantle Relationships

Relief/Sand Mantle Association	Map Reference
Deep sand mantle and no surface relief	Landform map 3 - IVB 3; Soils map 3 - D19
Deep sand mantle and marked relief	Landform maps 3 & 4 - IVA2, IVA3; Soils maps 3 & 4 - D16
Shallow or no sand mantle and no relief	Landform maps 3 & 4 -IVD5, IVD6; Soils maps 3 & 4 - D24, D33, A22

2.3.1.1 Soils associated with north-eastern stabilised Kalahari sand drift

Where the sand mantle is deep, but where there is no relief and where surface drainage is imperceptible (IVB3), the dominant soils are loose grey sands of the Fernwood Series. These are found in the southerly hinterland to the river terrace system (D19) and exhibit very low water holding capacity (< 4% clay). In this case, the soils and soil parent materials are both sands of aeolian origin. In places these sands are nearly white in colour under a surface layer stained by fire ash. Grey sands also commonly occur as recent infill in omuramba floors and interdune streets.

2.3.1.2 Soils associated with North-eastern stabilised E-W aligned Kalahari sand dunes and North-eastern (Caprivi) stabilised E-W aligned Kalahari sand dunes

In areas of deep sand where relief and drainage are more pronounced (IVA2, IVA3), pedogenic processes have typically given rise to a catenary sequence of red sands (Gaudam) on elevated situations, yellowish brown sands on mid-slope positions (Fernwood) and either grey sands (Sandspruit) or heavier dark coloured soils in the bottomlands, depending on the depth to which erosion of the sand mantle has there produced. The red sands occur mainly on the dunes that commonly fringe omuramba valleys, particularly on their eastern and southern banks (D16). They also occupy higher positions in undulating country formed by lateral tributaries to omurambas, on parallel sand ridges, and on dunes formed by sand blown out of pans.

2.3.1.3 Soils associated with Okavango river banks and omuramba floors in Kalahari sand and North-eastern (Caprivi) river banks in Kalahari sand

Where the river terrace system is discontinuous east of the Okavango/Quito confluence in Kavango Region, loose grey (Sandspruit) and yellowish brown (Fernwood) sands occur on flat areas having a shallow sand mantle (D33) Lacking such a mantle they are found on omuramba floors (IVD5), old flood plains (IVD6), pans and incipient pans, and interdune streets. In these bottomland sites, the parent materials include products of weathering of calcretes and silcretes which contribute darker colours and textures to the soils.

The floors of the omurambas confluencing with the Okavango river (A22) constitute flat low-lying localities hosting grey sandy loams (Okavango). These are commonly associated with sandy clay loams (Limpopo) and to a lesser extent claypan soils (Valsrivier). In the latter, impeded internal drainage and salinity hazards are evident where irrigation schemes have been established, as at Shadikongoro.

Red loamy sands (Zwartfontein) and sands with inclusions of dark grey coarse sandy loams (Gaudam) are found alongside riverbanks where the terrace system is discontinuous to the east of the Okavango/Quito confluence and south along Kavango/Caprivi border to Botswana. These soils also predominate on flat riverine terraces and relict omuramba floors with frequent small depressions (IVD6; D24).

2.4 LANDFORMS AND SOILS OF THE OKAVANGO RIVER FLOODPLAIN AND TERRACES

2.4.1 Summary: Soils of the Okavango river floodplain and terraces

Soils of the Namibian and Botswanan segments of the Okavango River floodplain and terraces are composed predominantly of infertile aeolian sands of the Kalahari Formation with a low organic matter content (Bethune, 1991; OCC, 1995). These sandy soils are variously coloured (red, orange, grey and white), can contain deposits of fine-grained water-worn gravels, and are several tens to several hundreds of metres in depth (Bethune, 1991; OCC, 1995).

Along the Okavango River channel in Namibia, the sandy soils of the floodplain and river terraces are enriched with interspersed clay and silt layers deposited by seasonal flood waters (FAO, 1984). Vegetated slacks between scroll bars on the floodplain trap deposits of clay and fine silt, whilst layers of calcrete are exposed on many river terraces. Away from the main river channel, the soils are predominantly grey to yellow-orange sands (Schneider, 1987). According to Bethune (1991) floods seldom deposit alluvial silt on the higher river terraces.

Both the floodplains (which regularly receive flood-borne deposits of silt), and the river terraces are intensively cultivated by subsistence farmers (Bethune, 1991). Formal (irrigation) agriculture is confined to the higher river terraces, and is restricted to a few locations with suitable soils, along the Okavango River between Rundu and Bagani (Cashman *et al.,* 1986).

Soil erosion is evident over much of the southern bank of the Okavango River between Rundu and Bagani. Extensive soil erosion is particularly evident for a distance of some 50 kilometres downstream of Rundu and between Andara and Popa Falls. Elsewhere along the Okavango River, soil erosion occurs in scattered areas, which mark the sites of existing and former mahangu gardens, livestock kraals and

villages. Most of this "scattered" erosion pattern is due to trampling by livestock, indiscriminate clearing of riparian vegetation for agriculture, and collection of construction materials and fuel-wood.

2.4.2 Soils of the Okavango River Terraces

Along the south and west banks of the Okavango River the terrace system constitutes a distinct but discontinuous physiographic unit, lying some 7 m above the river and separated from it by a floodplain which varies in width between 2-6 km. The terrace itself is flat to even and gently sloping, and incised by numerous minor drainage lines.

Clovelly, Oakleaf and Hutton soil forms pre-dominate on the terrace system exhibiting classic catenary associations with slope position (Schneider, 1987).

The three soils exhibit physical, chemical and mineralogical properties typical of semi-arid soils in which moderate to high base saturation due to slow leaching of the basic cations results in pH values between 6.8 and 7.6 (slightly acid to slightly alkaline). The cation exchange capacity is low to moderate and in all three soil forms kaolinite is the most abundant clay mineral.

Soil Series identified are mostly sandy and differ little in colour. Particle size analysis indicated that the sand fraction dominates in all series by more than 50%. The clay content of all identified series varies from 0-15%; locally more clay was recorded, as for example in the case of an Oakleaf Limpopo.

All three soils have a relatively thin surface layer of non-calcareous loamy sand, overlying thicker non-calcareous to loamy and clayey sand in B1 and B2 horizons. Calcareous subsoils are found in the lower parts, as in the C-horizon of the Hutton Zwartfontein. The calcic C-horizon (which has more carbonate than the parent material) appears to have formed by the upward movement of carbonate-rich capillary water from the shallow groundwater table.

2.4.2.1 Landuse and soil quality on the Okavango river terraces

Soil formation processes on the river terrace system have ultimately been controlled by the exogenic factors of topography and semi-arid climate. These factors, together with sandy parent materials and the accumulation of carbonates, soluble salts and silica, combine to yield soils unfavourable for agricultural purposes. However, the terraces of the Okavango River and its tributaries are intensively cultivated by traditional subsistence farming, and, during the past 15 years, by the establishment of centre-pivot irrigation schemes.

Subsistence farming on the river terraces downstream from Rundu is dominated by dryland cropping systems where maize and mahango are cultivated along the silt-enriched river banks, and stock (primarily cattle) are grazed on the flood plains. Terrace slopes are extensively cleared for vegetable production.

In the vicinity of Rundu, subsistence arable farming activities are intense although restricted to areas adjacent to the Okavango River, where maize and mahangu are produced. Both small and large stock are grazed on the terraces and floodplain.

A marked degree of environmental degradation is evident along the entire length of the riparian environment. Landslip features, slope failures and moderate gully formations can be observed on the discontinuous terrace slopes east of Rundu. In the area 0-4 km east of Rundu, these appear to be associated with excavations and earth diggings. Both incipient and extensively developed gully systems, observed from Rundu to Mukwe, radiate from numerous footpaths and animal tracks linking villages situated on terrace ridges to the floodplain and river banks. Accelerated and extensive riverbank erosion was observed on the northern (Angolan) riverbanks and floodplain where land has recently been cleared for village and garden development.

Parastatal irrigation schemes have been developed on the river terrace soils to increase and stabilise food production in the area. No comment can be made on the environmental status of these areas without further research, although detailed soil studies (Schneider, 1987; Engels, *pers.comm*) indicate that the quality of the terrace soils would be expected to deteriorate rapidly under irrigation, given their high potential to allow upward movement of carbonate-rich capillary water.

Production levels of the schemes do appear to be lower than the development opportunity suggests as volumes abstracted from the Okavango River for irrigation purposes have recently been measured at levels substantially lower than the maximum permissible abstraction limit of 13.223 Mm^3 /annum, set by the Agreed Commitment for irrigation permits in Namibian territory (Crerar, 1997). It is possible that the reasons for under-utilisation of available abstraction water for irrigation purposes are rooted in decreased production levels under conditions of declining soil fertility and the inability to fund increased production costs.

2.5 SOILS AND LANDFORMS OF THE PANHANDLE AND OKAVANGO DELTA

2.5.1 Summary: Soils of the Panhandle

In Botswana, the sandy soils associated with the river channels of the upper Panhandle are overlain along the channel margins by deposits of alluvial clay and silt. Between Mohembo and Shakawe, areas of intensive small-scale agriculture along the riverbank have denuded much of the vegetation and have led to extensive areas of soil erosion.

Lower down the Okavango Panhandle, the sandy soils along the river channel margins are overlain with deep organic peat deposits which have been produced in the peripheral swamp areas. The depth of peat layers decreases with increasing distance from the permanent swamps, eventually grading into grey and orange coloured Kalahari sands, overlying deeper white sands, in the zone of terrestrial vegetation (OCC, 1995)

Excluding the swamp and marsh zones, three major divisions of soils (with 40 different soil units or sub-units) have been identified for the Okavango Panhandle and Okavango Delta regions of north-western Botswana (OCC, 1995); these are:

- soils developed from lacustrine deposits, located in deflated pans or inter-dune depressions;
- soils developed from alluvial deposits or alluvially re-worked materials;
- soils developed from unconsolidated sand deposits or coarse-grained sedimentary rocks.

2.5.2 Summary: Soils of the Okavango Delta

The Okavango Delta displays a succession of soil types and forms which are closely related to annual and long-term variations and arenaceous (sandy) sediment load of the inflowing rivers, and is modified by the precipitation of sodium, calcium and silica (McCarthy et al., 1991, 1993; OCC, 1995).

The topographic mosaic of perennial channels, seasonal channels, floodplains, riverine fringes and islands is dependent on minute changes in level and hydrology. Where finer-textured units accumulate in depressions, nutrient levels are appreciably higher (OCC, 1995).

Where sand cover is thin, as around pan margins and along drainage lines, prominent calcified horizons are usually present (OCC, 1995).

Extensive areas of rich organic peat deposits have been formed in present and past regions of permanent swamp within the Okavango Delta (McCarthy et al., 1993). Several areas of permanent swamp along the lower Thaoge channel have dried out over many years and peat fires are a common occurrence in this region. In addition, numerous areas of small-scale agriculture have been opened up in this region; these are particularly evident in the area southeast and east of Gumare.

2.5.3 Geological Setting

The Okavango River terminates in the semi-arid Kalahari, forming one of the largest inland deltas in the world. This setting can be explained by reference to the tectonic development of this drainage basin.

Du Toit (1933) states that the Okavango river once flowed across the Kalahari via what is now the Boteti River valley and the Makgadikgadi depression to link up with the Limpopo River. The link to the Limpopo was broken *circa* 2M years ago by upwarping of the Kalahari-Rhodesian axis, which resulted in the formation of a great lake covering the Makgadikgadi depression and possibly extending further north.

A subsequent major interruption of the drainage system occurred through the sinking of a tract of land north of a line joining the present Ngami Lake and Mabebe depression. This impounded the Okavango River, which then built a gigantic delta across the depression. Consequently, the flow of water to the Makgadikgadi Lake was severely reduced. More recent climatic aridity caused the lake to dry out, forming the Makgadikgadi pans.

Today, the Okavango Delta lies within a seismically active zone. These events are relatively weak, and the majority of foci lie along the Kunyere and Thamalakane Faults. Seismic activity may affect the future hydraulic gradient and roughness indices of the Delta.

2.5.4 Landforms of the Okavango Delta

A general description of the landforms of the Okavango Delta is given to provide a geomorphological context to the pedological environment.

Lying at an elevation of 850 -1000m, the Okavango Delta comprises two major geomorphological features, or landforms. These are the Kalahari-sand plain, and the Okavango-Linyanti depression which is bounded by the Gomare fault to the northwest and the Kunyere and Thamalakane faults to the southwest. The landforms are characterised by three land divisions within which five land regions can be recognised (De Wit & Bekker, 1990; Landform maps 5-8).

Table 4. Landforms of the Okavango Delta

Land Division	Land Region
Sandveld	Aeolian sand deposits Partly submerged aeolian sand deposits
Alluvial System	Recent alluvial deposits Fossil alluvial deposits
Lacustrine System	Major lake and depression deposits

Five land regions are distributed throughout the delta and the surrounding plains giving rise to fourteen land systems. These are summarised in Tables 5 - 7, where associated soil units are introduced by land system. Spatial variability and characterisation of soil properties are given.

2.5.5 Land Systems and Associated Soils

2.5.5.1 Sandveld Region

Kalahari sand occurs as a widespread blanket of predominantly brownish or greyish medium to fine grained sand, derived by aeolian reworking of underlying Kalahari beds comprising clay, marl, sand, gravel, calcrete and silcrete. This terrain unit features outcrops of Kalahari beds, particularly calcrete and silcrete.

Sand dunes of the area can be divided into longitudinal and transverse, both forming under a drier climate than present and now stabilised by vegetation cover. Longitudinal dunes are best developed to the west of the Okavango Delta. They lie roughly parallel to the present prevailing wind system, spaced approximately 1.5 km apart and extending for over 70 km. Relief from trough to crest is of the order of 7 m. Prominent vegetation banding accentuates the dune pattern, the crests carrying woodland and the troughs grassland.

Dunes at the western margins have been degraded by sheet erosion although it is thought that the longitudinal dunes north and south of the Okavango swamp have been further degraded by flooding. These dunes are described as aleb dune relicts of large sand ridges once standing over 90 m high flooding (Grove in Watson, 1990). A pattern of transverse hummocky dunes can be seen to the east of the

Okavango Delta. They lie roughly perpendicular to the prevailing wind direction and, like the longitudinal dunes, these dunes have been degraded by sheet erosion.

Outcrops of consolidated rock are scarce in this area where Kalahari sand predominates. The largest outcrop of bedrock, comprising quartzite, shale and limestone of the Pre-Cambrian Ghanzi formation occurs to the south of the area near Lake Ngami. The Tsodilo Hills in the northwest formed from metamorphic rock of the Pre-Cambrian supergroup, and the Gubatsaa Hills in the northeast of the area formed from porphyry of the pre-Cambrian Kgwebe formation, represent the few low-lying isolated hills of consolidated rock.

Table 5. Sandveld Land Systems and Associated Soils

Land Region	Land System	Soil Unit
Aeolian Sand Deposits	Undulating to rolling longitudinal dunes system	Haplic Arenosols Ferralic Arenosols
	Flat to almost flat plain with depressions	Haplic Arenosols Ferralic Arenosols
	Almost flat to gently undulating longitudinal dune system	Haplic Arenosols Ferralic Arenosols
	Almost flat plain with eroded longitudinal dunes	Haplic Arenosols Ferralic Arenosols
	Almost flat to gently undulating parabolic dune system	Haplic Arenosols Petric Calcisols Haplic Luvisols
Partly Submerged Aeolian Sand Deposits	Almost flat to gently undulating longitudinal dune system	Haplic Arenosols Ferralic Arenosols

2.5.5.2 Alluvial Region

Recent and fossil alluvial deposits are widespread on the Okavango River, the delta floodplains, and in areas where inundation formerly extended over a greater area than present. Abandoned drainage channels represent the latter areas. Relief is flat to gently undulating, and the predominantly grey colour of the sandy alluvium indicate waterlogged conditions resulting in the removal of any reddish or yellowish iron oxide coatings.

Table 6. Alluvial Land Systems and Associated Soils

Land Region	Land System	Soil Units
Recent Alluvial Deposits	Flat to almost flat river floodplain (panhandle)	Gleyic Arenosols
	Flat to almost flat delta floodplain	Haplic Arenosols Gleyic Arenosols Eutric Gleysols Gleyic Luvisols Eutric Fluvisols Gleyic Phaeozems Luvic Phaeozems Haplic Luvisols Calcic Luvisols
	Flat perennial swamps	Gleyic Arenosols
Fossil Alluvial Deposits	Almost flat to gently undulating delta floodplain	Haplic Arenosols Haplic Luvisols
	Flat to almost flat delta floodplain	Haplic Arenosols Ferralic Arenosols Haplic Luvisols Calcic Luvisols Gleyic Luvisols Gleyic Phaeozems
	Flat to almost flat river floodplain (panhandle)	Haplic Arenosols

2.5.5.3 Lacustrine Region

The main lacustrine deposits are found in the Ngami and Makgadikgadi basins. Boundaries of these deposits are indicated by strandlines to the northwest of Lake Ngami and by a gently curving strandline which marks the border of a lake once occupying the Makgadikgadi depression. The strandlines are of subdued relief but demarcated by vegetation banding.

Table 7. Lacustrine Land Systems and Associated Soils

Land Region	Land System	Soil Units
Major Lake and Depression Deposits	Flat to almost flat lake depressions with associated shorelines and pans (Lake Ngami)	Calcic Gleysols Haplic Calcisols
	Almost flat fossil lagoon	Haplic Arenosols

2.5.6 Soils of the Okavango Delta

Soil units of the Okavango Region are summarised in Table 8 below. Detailed maps are supplied.

2.5.6.1 The Role of Soils in the Functioning of the Okavango Delta

The main hydrological feature of the delta is the difference between water inflow and outflow (Manley, 1997). By far the greatest proportion of this difference (84%) can be accounted for by direct evaporation from open water surfaces, although a further 13% of the water losses can be attributed to the filling of

voids in soils riparian to the delta. The importance of each soil type to the water balance of the delta is related to spatial coverage coupled with the degree to which each soil influences water flow through the system. In other words, the role of soils in the functioning of the delta can be defined in terms of potential to transfer water from one point to another, together with position within the hydrological regime. It is therefore important to look at the characteristics of the major soil units and their spatial variability. These are discussed in relation to the hydrological regime as described by McCarthy (1997).

Soils are developed on five categories of land around the delta: on the banks of the permanent channels, on seasonally flooded swamps, on seasonally flooded grassland, on intermittently flooded land, and on dryland. Together, these categories cover almost 70% of the total delta region.

Table 8. Soil Units of the Okavango Delta Area

Soil Type*	Occurrence	Soil Unit	Soil Unit Description
Arenosols	Widespread	Haplic Arenosols	Deep to very deep, moderately well somewhat excessively drained, dark grey to white, sands to loamy sands
		Ferralic Arenosols	Deep to very deep, well to excessively drained, yellowish brown to dark red, coarse sands to loamy fine sands
		Gleyic Arenosols	Very deep, very poorly drained, white to dark greyish brown, sands to loamy sands
Luvisols	Floodplains of seasonal swamps and in Sandveld depressions	Gleyic Luvisols	Deep to very deep, poorly to imperfectly drained, dark grey to greyish brown sandy clay loams to clays
		Haplic Luvisols	Moderately deep, to very deep, imperfectly to well drained, very dark grey to yellowish red, sandy loams to clays
		Calcic Luvisols	Moderately deep to very deep, imperfectly to well drained, dark greyish brown to red, sandy clay loams to clays
Gleysols	Floodplains of seasonal swamps and fringing Lake Ngami	Eutric Gleysols	Deep to very deep, poorly to imperfectly drained, dark greyish brown to black, sandy loams to clays
		Calcic Gleysols	Partly sodic, deep to very deep, poorly to imperfectly drained, very dark grey to grey, loams to clays
Fluvisols	In the channels and on the floodplains bordering the seasonal swamps	Eutric Fluvisols	Very deep, poorly to imperfectly drained, black to dark greyish brown, silty loams to silty clays, often overlying sands to loamy sands
Calcisols	Flat to almost flat lake depressions with associated shorelines and pans (Lake Ngami); almost flat to gently undulating parabolic dune system	Petric Calcisols	Moderately deep, moderately well to well drained, greyish brown to pale brown, fine sandy loams to silt loams
		Haplic Calcisols	Moderately deep to very deep, imperfectly to well drained, grey to brown, sandy loams to clays
Phaeozems	Flat to almost flat delta floodplain in both recent and fossil alluvial deposits	Gleyic Phaeozems	Deep to very deep, poorly to imperfectly drained, black to greyish brown, clay loams to clays over sands to loamy sands
		Luvic Phaeozems	Moderately deep to very deep, imperfectly drained, very dark greyish brown, sandy loams to clays, overlying sands to loamy sands

* FAO (1988)

2.5.6.1.1 Arenosols and water transfer mechanisms

The three soil units classified as Arenosols are by far the most extensive group found in the Okavango delta area, covering all land systems with the exception of flat lake depressions and associated shorelines and pans. Properties of these soils would therefore be expected to control the extent and mechanisms by which both inflow and direct rainfall are transferred through the delta.

Fine sand is the dominant size fraction, indicating the aeolian nature of the parent material. The profiles are quite uniform throughout the depth. The total fine sand is generally more than 50% and very often it is greater than 75%. Clay and silt are less than 10%, often around 5%.

Bulk densities vary between 1.5 and 1.6gm/cc. The organic matter content is low (<2%) and as a result, the differences in bulk densities between surface and sub-surface horizons are not appreciable. Due to the high sand content infiltration rates are high to excessive and in the area of 25 - 30 cm/hr, with initial rates being much higher. Run-off would be expected to be minimal.

Soil pores are large and freely draining and consequently these soils are poor in moisture retention. These soils therefore have a very low amount of available moisture, contents varying between 5-10% by volume. Crop production will be very limited in these soils due to moisture stress.

These properties produce a high water transfer potential. Combining the high water transfer potential with the spatial variability of these soils it is evident that the Arenosols act as an important agent in the rapid transfer of water between channels and swamps of the Okavango Delta. The mechanism is described below.

Arenosols dominate the panhandle area located to the north of the alluvial fan. The Okavango River enters the swamp zone at Mohembo and meanders down the panhandle through a gradually widening and seasonally inundated floodplain before distributing into the alluvial fan. All soil units of the riverbanks and the floodplain in this area are classified as Arenosols. Differences in diagnostic properties can be related to their locations relative to bedload deposition processes, by which local concentrations of fine materials deposited on the sandy alluvial matrix produce units with hydromorphic properties (Gleyic Arenosols).

At the southern end of the panhandle, the surface water gradients steepen between the main channel and backwater swamps, and relative surface water elevations may differ by 60 cm. Within this region the major distributaries supplying the alluvial fan arise. The main channel of the upper pan is the Nqoga from which the Thaoge and Jao-Boro discharge. The Thaoge supplies water to the western margin of the fan, although since experiencing progressive failure from its distal end it has become a relatively minor distributary. The Jao-Boro removes 25% of the Nqoga discharge.

Arenosols dominate all delta shorelines, channel banks and islands of the upper fan with the exception of the Thaoge distributary where Fluvisols pre-dominate. It is estimated that 40% of the total discharge reaching the upper fan is lost by water transfer (leakage) through the soils of the channel banks and margins. These soils are all Arenosols. As the seasonal flood wave arrives, increased leakage from the Arenosols of the upper fan channel margins supplies the surrounding permanent swamps. The Nqoga carries water to the north of Chief's Island and leakage provides a steady supply of water to the Maunchira channel. Thus, seasonal water level fluctuations between the Nqoga and Maunchira are minor. The seasonal swamps of the Khwai river system are supplied by the Maunchira where water easily dissipates through the soils of the channel margins. From leakage in its middle reach the Mboroga-Santantadibe-Gomoti system to the east of Chief's Island is supplied.

The Jao-Boro channel appears to be taking the role of main distribuary from the Nqoga channel, due to the failure of primary supply channels at the apex of the fan (McCarthy, 1997). Channel failure in turn has been attributed to water loss from the channel margins and a consequent accumulation of bedload sediment in the channel. It is probable that the Arenosols of the channel margins are responsible for the distributory shift. As the medium through which leakage occurs, these soils are therefore able to act as catalysts of change in delta flow patterns.

2.5.6.1.2 Fluvisols and abandoned drainage lines

Water transfer properties appear to be low along the western margin of the upper Okavango Delta. This area is drained by the Thaoge channel, once the main distributary supporting an extensive swamp system. It is now largely dry and filled with accumulated peat (Eutric Fluvisols) soils. These soils are found in association with alluvial deposits (Gleyic Arenosols) along minor distributory lines at the southern margin of the permanent swamp, and with Calcic Luvisols lying along linear topographic depressions towards the extreme southwest end of the abandoned distributary. Fresh sediments regularly rejuvenate these soils producing stratified layers and an irregular distribution of organic matter with depth. Bulk densities thus vary. The soils are fertile and wet in all or part of the profile, depending on seasonality of floodwater inundation.

2.5.6.1.3 Gleysols, Phaeozems and seasonal swamps

The topography of the lower fan is gently undulating with local relief areas rarely higher than 1.5 m. This area is characterised by seasonal swamps surrounding higher dry land during flood periods.

The boundary between permanent and seasonal swamps is diffuse and constantly shifting in response to regional climatic factors that contract or expand the area of wetland. For the same reasons the distal extremities of the seasonal swamps are also poorly defined.

Seasonal swamps develop by expansion of permanent swamps, primarily by overland flow along local topographic depressions. Following the 'transpirational pump' theory of McCarthy (1997) the soils of seasonal swamp islands would be expected to store dissolved solutes (principally sodium bicarbonate) efficiently, and to confine saline brines by virtue of high water-holding capacities.

Gleysols and Gleyic Phaeozem soils are found in association with seasonally inundated swamps on flat to almost flat areas of the south-eastern delta floodplain. Their spatial extent is not limited to these areas as they also occur on the shorelines around Lake Ngami and pans in the southern reaches of the delta.

These soils present an accumulation of finer particles such as silt and clay deposited by seasonal floods and run-off. The coarse sand fraction is almost negligible and is seldom greater than 2%. The fine sand fraction, although dominant, is less, and the silt and clay are relatively high. Average silt content is 15% and clay content is over 40%.

The high amounts of organic matter and clay in these soils give rise to low bulk densities throughout the profile. The surface soils have very high organic matter and consequently bulk densities are of the order of 1.1gm/cc. The sub-surface bulk densities vary from 0.5 to 1.4gm/cc depending on organic matter content. Infiltration rates are very low, of the order of 1-2 cm/hr.

Although the total porosities of these soils are high, the dominant pore sizes are micro, which limits flow rates within the profile. The high clay content increases the microporosity, although the high organic matter content also causes an increase in the capillary porosity. Freely draining pores are therefore relatively low. Thus these soils can develop anaerobic conditions with only a slight excess of water, and remain waterlogged for prolonged periods after saturation, due to low infiltration rates.

Saturation moisture contents are 50-55% by volume and they can retain 40-45% moisture after free-drainage. The average available moisture of 20% by volume is the highest of all the soils in the Okavango. The high moisture content in relation to total porosity can cause poor aeration to inhibit plant growth. These soils must therefore dry (but not crack) sufficiently below field capacity to allow water to become available for plant growth.

Through the mid-southern reaches of the lower fan runs the perennial Boro channel which becomes seasonal to the south of Xo Flats. Whereas most distributary channels are poorly defined, this channel is incised in its upper reaches and carries water south even in years when the total area of inundation is relatively small. The small percentage of water to reach the Thamalakane River is conducted through the Boro channel. The soils of the margins of its lower reaches are Gleysols, which exhibit the lowest water transfer potential of all delta soils. Given these properties it is highly unlikely that the Boro could act as a conduit for the supply of water to seasonal swamps in this area. In terms of the role of soils in the functioning of the delta, Gleysols situated on seasonal channel margins in the south of the delta area effectively block potential leakage and therefore prevent water losses by this mechanism. This would account for a significant proportion of the 2% outflow from the delta to the Thamalakane River.

Although it would require much time for these soils to dry, the drying process itself can produce cracks radiating down the profile. In turn, soil cracking would allow excessive amounts of water to transfer through the profile and under these conditions rainfall as a contributor to outflow would be significantly reduced through channels lined by Gleysol margins.

2.5.6.1.4 Luvisols and Calcisols on intermittently flooded areas and on dryland

Heavy Luvisols are roughly equal to Gleysols in areal extent although unlike the Gleysols they are located on the terminal reaches of poorly defined channels and in back-swamp regions of the upper fan blocked from main distributory courses by bedload deposition. In the lower fan Luvisols are found in the flat lake depressions, shorelines and pans around Lake Ngami in association with Calcisols. On the western margin of the swamps where the Thaoge abandons its former main distributary course, and on the eastern reaches of the Nqoga channel, these soils support intermittently flooded back-swamps and exhibit gleyic properties.

The contribution of Luvisols to the water balance of the delta can be characterised by their ability to retard the further transfer of water reaching distal areas of the delta system. On the eastern margins of the delta floodplain, in particular the properties of heavy Luvisols produce environments favouring both the maintenance of seasonal swamps and high vegetation diversity.

These soils have a high organic matter content in the surface horizons and a high clay content in the entire profile. Both these factors tend to cause the soils to have low bulk densities. However, although the organic matter of the surface horizons are often greater than 5%, the immediately underlying horizons have relatively lower organic matter varying between 0.2 - 0.4%. Consequently, the surface horizons are well aggregated and have lower bulk densities. The bulk densities of surface horizons average at 1.45gm/cc and this gradually increases with profile depth to 1.55gm/cc.

The high clay content is reflected markedly in the low infiltration rates. The proportion of slow and non-conducting pores is high, thereby reducing the rate of water flow within the soil profile. Occasional high infiltration rates do occur when cracks develop in the drying surface clays, although the basal rate is 5 cm/hr seldom exceeding 10 cm/hr.

Heavy Luvisols have very good moisture retention properties, tending to retain the maximum amount of moisture against free drainage. At saturation point 45 - 50% of moisture by volume can be held, and only 10 -15% drains by gravity. Moisture availability is on average 18% by volume, although the time taken for moisture storage levels to reach the range available to plants would be markedly longer than for Arenosols by comparison.

Luvisols at the southern extremities of the lower fan are found in catenary association with Calcisols in the flat to gently undulating parabolic dune systems of the Sandveld. These associations thus contribute less to the functioning of the delta system than to the drainage system of the drier Sandveld. Nevertheless, in terms of outflow, the topographic relationship of Calcisols and Luvisols and the high water holding capacities of these soil associations combine to supply a slow, small but steady flow of groundwater during periods of minimum inundation and out of phase with peak rainfall.

Texturally the Calcisols resemble the heavy textured Luvisols. The coarse sand and silt fractions vary between 0.5% to about 30%, although the fine sand fraction is relatively high - between 30% to 60%, and the clay fraction averages at 25%.

The high calcium carbonate content in the sub-surface horizons tends to increase the porosities of these soils. Consequently, the calcic horizons have low bulk densities ranging from 1.00 to 1.45gm/cc. The surface horizons are generally non-calcareous and have higher bulk densities varying from 1.55gm/cc to 1.7gm/cc.

Infiltration rates are similar to those of the heavy textured Luvisols, although average values tend to be slightly higher due to higher soil porosities (7- 18 cm/hr). The increase in pore size is due to the presence of calcium carbonate in the profile. Consequently there is an increase in the proportion of freely draining macro-pores and a decrease in the micro-pores, which retain the adsorbed moisture.

At saturation, 45-50% volumetric moisture is held, and 15-20% drains freely under gravity. Moisture-holding capacities of Calcisols are comparable to that of heavy Luvisols although field capacity and wilting point are lower. However, the increase in pore sizes in the available range is such that the available moisture in both these soils are similar.

2.5.6.1.5 Summary of the role of soils in the functioning of the Okavango Delta system

The water transfer potential of predominantly Arenosol soils in the panhandle and upper reaches of the fan is high. This encourages rapid water flux through poorly defined channels of the upper fan, and thereby discourages the concentration of salts. It also contributes to an estimated 40% loss of discharge.

This potential also causes soils to act as catalysts of change in delta flow patterns. Water loss from the channel margins and consequent accumulation of bedload sediment in the channel can cause channel failure and the re-routing of distributaries. On the western margin of the delta in abandoned channels such as the former Thaoge channel, peaty Fluvisols develop under seasonally inundated swamps.

Water transfer potential of the lower fan is considerably lower. The amount of water reaching the seasonal swamps to the east and southeast of the delta is therefore a function of flow from the upper fan and direct

rainfall, rather than flow from within the lower fan area. The low water transfer potential of Luvisols in the lower fan retard the further transfer of water reaching distal areas of the delta system. On the eastern margins of the delta floodplain the properties of heavy Luvisols produce environments favouring both the maintenance of seasonal swamps and high vegetation diversity.

Whereas most distributary channels are poorly defined, the Boro channel is incised in its upper reaches and carries water south even in years when the total area of inundation is relatively small. This channel becomes seasonal in the lower reaches of the delta. Gleysols situated on Boro channel margins in the south of the delta area exhibit the lowest water transfer potential of all delta soils. These soils effectively block potential leakage and therefore prevent water losses by this mechanism. This would account for a significant proportion of the 2% outflow from the delta to the Thamalakane River.

The catenary relationship of Calcisols and Luvisols situated at the southern end of the delta and the high water holding capacities of these soil associations combine to supply a slow, small but steady outflow of groundwater during periods of minimum inundation and out of phase with periods of peak rainfall.

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• Document supplied

3. OVERVIEW OF PREVIOUS STUDIES AND THE AREAS COVERED

This section covers previous and current studies which have contributed to the soils overview, and the services and end products of known studies which could be employed in a future soils assessment of the river basin.

A complete list of references has been given at the end of the previous section. Notes have been attached to each reference indicating whether it has been obtained for Okacom, and if not, where it can be found.

Where possible, the results and documents of completed studies were obtained. These are supplied with this report, in either original or copied format, with accompanying maps. Map details associated with the studies are referenced in section 4, together with a summary of known maps and satellite imagery that would have potential use in the environmental assessment phase.

Projects whose services and end products have potential use to a soils assessment of the Okavango River Basin are presented first (section 3.1). For ease of reference, summaries in terms of objectives, services provided, end products and potential use of each project are given in tabular format. Further details are provided with three of the summaries.

3.1 PROJECT SERVICES AND END-PRODUCTS OF POTENTIAL USE TO A SOILS ASSESSMENT OF THE OKAVANGO RIVER BASIN

Project Name: Caprivi Environmental Profile Project	**Name of Client/Funding Agency:** Kingdom of the Netherlands
Country: Namibia	**Project Location within Country:** Caprivi Region
Start Date: March 1996	**Completion Date:** November 1997
Contact Name: John Mendelsohn	**Contact Details:** Tel: +264 61 249015 Fax: +264 61 240339 e-mail: mendelso@windhoek.alt.na
Name of Associated Institution(s), if any: Directorate of Environmental Affairs, Ministry of Environment & Tourism	
Project Objective: Establishment of an environmental database and production of a publication on Caprivi Region.	
Actual Services/End-Products: 1. Database of environmental parameters of Caprivi Region 2. An environmental profile and atlas of Caprivi Region (publication)	
Project services/end-products of potential use to a soils assessment of the Okavango River Basin: One mid dry season LANDSAT TM scene 176-072 (28/06/94; processed to enhance bands 4-5-3 using IHS-decorrelations) spans a segment of the Okavango River Basin covering the border territories of Southern Angola, Northeast Okavango, West Caprivi and Northwest Ngamiland. Copies of processed image data available from project; raw data stored at NRSC (viewing only on premises). Six environmental database files including soils.xls, erosion.xls and terrain.xls, and nine thematic map coverages including soil texture and pH (ArcView 3.0) are available. See over page for details of database features and methods used for the classification of individual features.	

Project Name:	**Name of Client/Funding Agency:**
A Geographical Information System For Okavango Region	Government of The Republic of Namibia Government of Luxembourg
Country:	**Project Location within Country:**
Namibia	Okavango
Start Date:	**Completion Date:**
1995	Estimated completion late 1998
Contact Name:	**Contact Details:**
Mr U. Okafor	Tel: +264 61 245056/7
Name of Associated Institution(s), if any: Directorate of Survey and Mapping, Ministry of Lands, Resettlement & Rehabilitation Implementing agency: Lux Development	
Project Objective: To digitize and update the topographic maps of Okavango Region	
Actual Services/End-Products: Updated topographic data in digital format and hard copy. See over page for details of database features and methods used for the classification of individual features into the 1: 50,000 geographical database.	
Project services/end-products of potential use to a soils assessment of the Okavango River Basin Paper copy topographic maps will become available at 1: 50,000 and 1: 250,000 scales. Data digitized using Auto-World GIS. Digital data, including databases and map coverages, will be available on CD. In digital format relevant data layers can be extracted to provide basemap information as a backdrop to a new set of digitized soils maps, although the compatibility of Auto-World with other mapping software should first be investigated.	

Project Name:	**Name of Client/Funding Agency:**
Reconnaissance Surveys of the North and Central South West Africa in terms of Irrigation Potential	Department of Water Affairs (Windhoek) Ministry of Agriculture & Water, SWA Administration
Country:	**Project Location within Country:**
Namibia	North and Central Areas
Start Date:	**Completion Date:**
1966	1971
Contact Name:	**Contact Details:**
Mr R. Davies	Namibia Resource Consultants P.O. Box 11607, Windhoek Tel: +264 61 230679 Fax: +264 61 227406

Name of Associated Institution(s), if any:

Department of Water Affairs, Ministry of Agriculture & Water, SWA Administration
Loxton, Hunting & Associates (now Loxton, Venn & Associates)

Project Objective:

To locate, broadly assess and to categorise main areas of irrigation potential in northern and central areas of Namibia

Actual Services/End-Products:

Reconnaissance level survey, assessment and classification of soils. Soils classified according to South African 'National Soil Series Classification' system. Maps of soil associations compiled at 1: 250,000 and 1: 500,000; paper copy. Major topographic and pedological features included on legend.

Project services/end-products of potential use to a soils assessment of the Okavango River Basin

Six soil association maps cover the Okavango River Basin within Namibia:- Sheet 5-11687/20; Sheet 6-11687/21; Sheet 10-11687/11; Sheet 11-11687/26; Sheet 14-11687/29; Sheet 15-11687/30. A limited number of copies are in circulation and all show evidence of photocopy stretch (see samples).

The soil classification employed was an early approximation of the Binomial System for South Africa (1977). Correlation of this system with the FAO classification of soils of the Okavango River Basin in Botswana would not be straightforward due to differences in guidelines for profile description and diagnostic criteria.

Soil surveys have subsequently been carried out over small areas of the Okavango Region although the reports and maps are, with one or two exceptions, unpublished and exceedingly difficult to source. This survey remains the only available complete representation of soils of the region, albeit on a broad scale and difficult to merge with soils information from other parts of the river basin. Nevertheless, to digitize the mapped information as a preliminary boundary definition exercise would speed up the process and reduce the costs of a re-survey undertaken to standardise soils data for the Okavango River Basin.

Project Name:	**Name of Client/Funding Agency:**
Feasibility Study on the Okavango to Grootfontein Link of the Eastern National Water Carrier - Initial Environmental Evaluation	Department of Water Affairs, Ministry of Agriculture, Water & Rural Development
Country:	**Project Location within Country:**
Namibia Botswana	Namibia: Grootfontein-Rundu corridor; riverine environment downstream from intake (Rundu). Botswana: border post to distal end of Okavango Delta at outflow of Thamalakane river.
Start Date:	**Completion Date:**
August 1996	August 1997
Contact Name:	**Contact Details:**
Ms S. Bethune	Water Environment Division, Department of Water Affairs Tel: +264 61 296 9111

Name of Associated Institution(s), if any:

Water Transfer Consultants, Windhoek
CSIR, Pretoria, RSA

Project Objective:

Emergency water supply to the central areas of Namibia.

To identify key environmental issues and potential fatal flaws, provide information for engineering study, and detail the nature of further investigations required with respect to an abstracted volume of 17Mm^3/a from the Okavango river in the vicinity of Rundu, and the construction of a buried pipeline 200m to the western side of the main Grootfontein-Rundu tar road.

Actual Services/End-Products:

Four-volume Initial Environmental Evaluation report containing 25 specialist reports. Soils and geomorphology report includes 16 digitized landform and soils overlays compiled from published data. Namibian basemaps (used in several specialist reports) digitized from 1: 250,000 topographic sheets (refs: 1718 Rundu, 1820 Mukwe, 1818 Karakuwisa, 1918 Grootfontein). Botswanan maps digitized from 1: 350,000 Okavango Delta reproduced basemap (Dept. of Surveys and Lands, Jan 1987).

Project services/end-products of potential use to a soils assessment of the Okavango River Basin

All report contents available in digital and hardcopy format. The digitized base, soils and landform maps on Namibian territory extend beyond the project areas to the boundaries of the 1: 250,000 topographic sheets, covering a significant portion of the 'functional' segment of the river basin.

Project Name:	**Name of Client/Funding Agency:**
Vegetation Mapping Project	Government of the Republic of Namibia Swedish Agency for International Technical & Economic Co-operation (BITS)
Country:	**Project Location within Country:**
Namibia	Northern and north-eastern Namibia
Start Date:	**Completion Date:**
January 1993	July 1994
Contact Name:	**Contact Details:**
Mr M. Chakanga	National Remote Sensing Centre Tel:+264 61 239047

Name of Associated Institution(s), if any:

Directorate of Forestry, (ex-) Ministry of Agriculture, Water and Rural Development
SSC Satellitbild, Sweden

Project Objective:

1. To supply up-to-date multi-spectral satellite image maps
2. To obtain rapid and up-to-date mapping and assessment of vegetation
3. To achieve on-the-job training of Namibian participants in satellite mapping technology

Actual Services/End-Products:

Forty (40) LANDSAT TM and 160 SPOT XS satellite image scenes supplied as photographic paper copies and transparencies, and as geo-referenced digital data on CD. Dates of data capture range from 29/4/92 to 27/6/92. Data processed to enhance bands 3-2-1 for vegetation boundary definition and false colour composites produced on hard copy at 1:100,000 from LANDSAT and 1:50,000 from SPOT data. Information was subjected to unsupervised vegetation classification, amended after low-intensity ground-truthing, and digitized. Vegetation association maps produced in B/W at 1:100,000 and 1:50,000 (available from NRSC).

Project services/end-products of potential use to a soils assessment of the Okavango River Basin

The Okavango Region is covered by 23 SPOT scenes, which can be viewed at the NRSC. Scene references are given in appendix.
It is noted that the utility of these satellite images for vegetation mapping has been questioned for two reasons:- (1) data were captured during an early to mid dry-season within a particularly dry period documented from 1991; (2) the compiled vegetation polygons failed to match with field-checks and vegetation mapping results of other projects.
Over the Okavango region, a preliminary comparison of the composite satellite maps and polygon boundaries with selected areas of mapped soils information revealed a high level of correlation (to the author). In view of the data capture period, it is possible that bare earth signals feature strongly on the satellite composites and some polygons have been identified according to soil type. In other cases, strong relationships between vegetation association, landform and soil type may have been identified. The potential use of these satellite composites and polygons to a soil classification and mapping exercise based on FAO guidelines should be investigated prior to the planning of any future soil survey, whether undertaken to compile a coherent, standardised regional soils database or for the management of soils within the Okavango River Basin.

Project Name:	**Name of Client/Funding Agency:**
Initiation of National Agroecological Zoning Procedures (TCP/NAM/6611)	FAO
Country:	**Project Location within Country:**
Namibia	National
Start Date:	**Completion Date:**
1996	1998
Contact Name:	**Contact Details:**
E. De Pauw/M Coetzee	Tel: +264 61 202 2080

Name of Associated Institution(s), if any:

Land Evaluation Unit
Ministry of Agriculture, Water and Rural Development

Project Objective:

To build up a comprehensive inventory of agricultural resources, to manage these data through geographical information systems (GIS), to define agroecological zones as a basis for land use planning, and to conduct land evaluation studies for specific agricultural uses.

Actual Services/End-Products:

- An exploratory agroecological zones (AEZ) map at scale 1:1,000,000 of the whole country
- A reconnaissance soil survey and land evaluation for the Grootfontein area at scale 1:250,000
- An inception of data management, processing and software product creation through GIS technology

Project services/end-products of potential use to a soils assessment of the Okavango River Basin

The scale of the national AEZ map would only be appropriate for initial environmental evaluation of a segment of the Okavango River Basin. Nevertheless, the data are compatible with the existing Botswanan AEZ map in which similar procedural guidelines were used. The reconnaissance soil survey/land evaluation map of the Grootfontein area falls within the Okavango River Basin and the mapping scale would be adequate for environmental assessment watershed management and purposes. This, however, is the only map produced at 1:250,000.

It is noted that, whereas the project used the Loxton *et al* (1971) soil survey to identify main soil types and distributions, an attempt to use the South African Binomial System for classification purposes failed because it could not be applied in a consistent manner. No attempt was made to correlate the SA system with the FAO Revised Legend. Namibian soils data at scale 1:1,000,000 were accessed from the FAO soil and terrain database for Southern Africa. This database also contains soils data for Angola and Botswana.

Project Name:	**Name of Client/Funding Agency:**
Soil and Terrain Database of Southern Africa	FAO
Country:	**Project Location within Country:**
Includes Angola, Namibia & Botswana	International/Regional
Start Date:	**Completion Date:**
Unknown	To be announced
Contact Name:	**Contact Details:**
Dr F. Nachtergaele FAO Headquarter Backstopping Officer	E-mail: <freddy.nachtergaele@fao.org>

Name of Associated Institution(s), if any:

Namibia: Land Evaluation Unit, Ministry of Agriculture, Water & Rural Development
Angola: FAO, Mr. F. Beerneart, fax/Tel: +32 50 277683

Project Objective:

Production of Soil and Terrain Database of Southern Africa. Scale 1:1,000,000; FAO guidelines and classification.

Actual Services/End-Products:

Regional database to be available in digital format on CD-ROM.

Project services/end-products of potential use to a soils assessment of the Okavango River Basin

Angolan soils data were recently (1997) correlated to the FAO Revised Legend. This will be included in the Regional database. A hardcopy of the correlated Angolan soils map (unknown scale) with legend and report has been completed and has been made available to Okacom from FAO, Rome.

Namibian soils data from the regional database were used in the Initiation of National Agroecological Zoning Procedures project (see project details). Technical Report (1) of this project contains a soils listing although no separate hardcopy soils map has been prepared. Until the regional database is finalised, it will not be possible to obtain an advance copy of the full Namibian database.

Project Name:	**Name of Client/Funding Agency:**
Okavango Environmental Profile Project	Not secured
Country:	**Project Location within Country:**
Namibia	Okavango Region
Start Date:	**Completion Date:**
To be planned	Unknown
Contact Name:	**Contact Details:**
John Mendelsohn	Tel: +264 61 249015 Fax: +264 61 240339 e-mail: mendelso@windhoek.alt.na
Name of Associated Institution(s), if any:	
Directorate of Environmental Affairs, Ministry of Environment & Tourism	
Project Objective:	
Establishment of an environmental database and production of a publication on Okavango Region.	
Actual Services/End-Products:	
1. Database of environmental parameters of Okavango Region 2. An environmental profile and atlas of Okavango (publication)	
Project services/end-products of potential use to a soils assessment of the Okavango River Basin:	
Six early dry season LANDSAT TM scenes:- 176-072, 176-073, 177-072, 177-073, 178-072, 178-073 captured April -May 1997, were bought for this project. Digital data will be processed by NRSC when project funds are secured. As with the Caprivi Region Environmental Profile, copies of processed image data, environmental databases and thematic map coverages (ArcView) will be available from project contact. Data in original format will be stored at NRSC (viewing on premises).	

Project Name:	**Name of Client/Funding Agency:**
Botswana Rangeland Inventory and Monitoring Project (BRIMP)	Government of Botswana DIFD (UK)
Country:	**Project Location within Country:**
Botswana	National
Start Date:	**Completion Date:**
February 1996	December 1998
Contact Name:	**Contact Details:**
Dr G. Stuart-Hill	Tel: +267 350440 Fax: +267 356027 E-mail: <brimp@wn.apc.org>
Name of Associated Institution(s), if any:	
Ministry of Agriculture	
Project Objective:	
To strengthen the land use planning process and the development of land management policy - by establishing a national range monitoring programme that will provide reliable technical and sociological information on the use and condition of the rangelands.	
Actual Services/End-Products:	
Information in the form of user-friendly gender-sensitive reports and maps in paper form and on CD-ROM using GIS and remote sensing. Production of a Rangeland Information System to include data on long-term vegetation change, seasonal vegetation change, a vegetation inventory, and socio-economic concerns. See over page for details.	
Project services/end-products of potential use to a soils assessment of the Okavango River Basin	
Quantitative drought status reports and maps produced monthly. Extent of rangeland fires identified by classification of NOAA/AVHRR imagery and mapped regularly as overlays on NDVI basemaps. Project has capacity and mandate to produce new thematic end products on needs-driven basis.	

Project Name:	**Name of Client/Funding Agency:**
Remote Sensing for Crop Area Estimates in Northern Namibia	DFID (UK)
Country:	**Project Location within Country:**
Namibia	Okavango, Caprivi
Start Date:	**Completion Date:**
February 1998	April 1998
Contact Name:	**Contact Details:**
Chris Daffin	Central Statistics Bureau National Planning Commission Tel: +264 61 239360
Justin Saunders	GISL E-mail: <justin@gisl.co.uk> Web-site: www.gisl.co.uk

Name of Associated Institution(s), if any:

Ministry of Agriculture, Water & Rural Development
GISL Limited

Project Objective:

- Pilot study to measure crop areas in northern Namibia using videography and low-level digital survey integrated into a GIS.
- Agricultural survey of Okavango and Caprivi regions

Actual Services/End-Products:

State-of-the-art data capture using video images geo-referenced with GPS. Digital colour images (selective) of sample points to measure field boundaries, crop area and crop type.

Project services/end-products of potential use to a soils assessment of the Okavango River Basin

If pilot project provides sufficient accuracy from the videogaphy linked to GPS co-ordinates, then the need for ground survey is reduced dramatically. Thus the methodology would provide low cost and timely data capture, ideally suited to environmental monitoring and natural resource assessment.

The pilot project will sample segments of the Okavango River Basin, concentrating on areas of intensive agriculture. Sample video and digital camera imagery will be captured of agricultural corridors encroaching upon terraces, floodplain and the riparian environment within Okavango and Caprivi regions. The processed digital imagery and details of the final methodology will be available on request.

Project Name: Maun Groundwater Development Project Phase 1 - Environmental Assessment	**Name of Client/Funding Agency:** Department of Water Affairs Ministry of Mineral Resources and Water Govt. of Botswana
Country: Botswana	**Project Location within Country:** Ngamiland
Start Date: To be announced Tender closing date: 15/5/98	**Completion Date:** Unknown
Contact Name: Unknown	**Contact Details:** Department of Water Affairs Quote: Contract No. 4, Ref: TB 10/3/26/94-95
Name of Associated Institution(s), if any: To be announced	
Project Objective: • Determination of an environmentally acceptable way of using the Okavango Delta and its surroundings • Development of environmental guidelines based on the draft from the EIA on Palla Road Groundwater Resources Investigation • Assessment of the environmental sustainability of the proposed water development project • Review of project design and advice on its suitability • Develop an effective method of public consultation • Identification of resources that could be lost or altered by the proposed works	
Actual Services/End-Products: Environmental Assessment Report	
Project services/end-products of potential use to an environmental assessment of the Okavango River Basin On award of this contract, liaison with the EA team to confirm compatibility of first two project objectives as listed above with the aims of Okacom.	

3.2 REFERENCE LIST: DOCUMENTS OBTAINED FOR OKACOM

Doc. No.	Country	Title	Date & Reference No.	Author	Source	Associated Material
1	Botswana	Physical Properties of the Soils of Botswana	1991 AG: BOT/85/011 Field Document 33	Joshua, W.D.	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Soil Map of the Republic of Botswana
2	Botswana	Soils and Land Suitability of the Boro-Shorobe Area	1989 AG: BOT/85/011 Field Document 1	Rhebergen, G.J.	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Boro-Shorobe area soils map Boro-Shorobe area soil pit locations
3	Botswana	Soils and Land Suitability of North West Ngamiland	July, 1990 AG: BOT/85/011 Field Document 26	Jamagne, P.	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Gumare area soils map Tsau area soils map Shakawe area land suitability map for improved traditional dryland farming -main crop: sorghum
4	Botswana	The Soils of Southeast Ngamiland	1988 AG: BOT/85/011 Field Document 14 Annex 1	Verbeek, K.	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Maun area soils map Toteng area soils map (no legend) Nxai Pan area soils map
5	Botswana	Soils of the Linyanti Area	1990 AG: BOT/85/011 Field Document 29	Bekker, R.P.	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Linyanti area soils map
6	Botswana	Explanatory Note on the Land Systems Map of Botswana	1990 AG: BOT/85/011 Field Document 31	De Wit, P.V. Bekker, R.P.	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Land Systems Map of Botswana (partial coverage)
7	Botswana	Explanatory Note on the Soil Map of the Republic of Botswana	December 1990 AG: BOT/85/011 Field Document 30	De Wit, P.V. Nachtergaele, F.O	Soil Mapping and Advisory Services, Botswana FAO/UNDP/Govt. of Botswana	Soil Map of the Republic of Botswana
8	Namibia	Notes on the Terrace Soils of the Kavango River, Northern SWA/ Namibia	1987	Schneider, M.B.	Journal XL/XLI, SWA Scientific Society, Windhoek, SWA/Namibia 1986/86, 1986/87	Soils maps 2-4; Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier (1997).
9	Angola	Agricultural Recovery and Development Options Review. Confidential Draft Report	December 1996 Report No: 96/116 TCP-ANG	Ministry of Agriculture and Rural Development	MINADER/FAO/IFAD/UNDP/ WB/WFP	-

Doc. No.	Country	Title	Date & Reference No.	Author	Source	Associated Material
10	Botswana	Use of High Resolution Satellite Data for Soil Mapping - Pilot Study in Botswana	1990 M/U0480E/1/8.90/600	Guillobez, S., & Lantieri, D.	FAORSC Series No. 53 High Resolution Data Series No. 1	-
11	Botswana	Use of image processing and GIS techniques to determine the extent and possible causes of land management/fenceline induced degradation problems in the Okavango Area, Northern Botswana	1997	Ringrose, S., Vanderpost, C., & Matheson, W.	Int. J. Remote Sensing, Vol. 18, No 11, 2337-2364	-
12	Angola	Climatic Data, Southern Angola	1993	FAO Database - Agro-Ecological Zones Project	Weather Bureau, Ministry of Works, Transport & Communication, Windhoek Contact: Dr P. Hutchinson Tel: +264-61-2208-2169	-
13	Botswana	A Visual Interpretation of a LANDSAT Mosaic of the Okavango Delta and Surrounding Area	1991	Watson, J.P.	Remote Sens. Environ. 35, 1-9	-
14	Namibia	The Occurrence and Utilisation of Groundwater in Kavango, SWA/Namibia	1987	Simmonds, A.L.E. & Schumann, F.W.	Journal XL/XLI, SWA Scientific Society, Windhoek, SWA/Namibia 1986/86, 1986/87	Groundwater Investigation in Kavango and Bushmanland - Final Report. Prepared for the Department of Fisheries and Water, Windhoek (1991).
15	Namibia	Soil Map of Namibia: Legend	1997	FAO	Land Evaluation Unit Ministry of Agriculture, Water & Rural Development	A4 copy of Soil Map of Namibia (1: 8,000,000)

4. OVERVIEW OF MAPS & SATELLITE IMAGERY AVAILABLE AND AN ASSESSMENT OF ITS POTENTIAL

This section provides an annotated reference list of maps obtained for Okacom (4.1). The list is cross-referenced to projects and documentation employed for the soils overview, or which would be of use in the environmental assessment phase. A separate list of maps available, but not obtained, is given with cross-references in section 4.2.

Similarly, satellite image material covering the river basin area over Namibia and which was considered to have potential use, was sourced. Scene references/IDs and dates of data capture are given in sections 4.3 and 4.4, and outlines of potential use are cross-referenced by scene to projects and associated maps in their respective sections.

4.1 REFERENCE LIST OF MAPS OBTAINED FOR OKACOM

Country	Title	Date and Map Reference No.	Author	Scale	Copy Status	Description
Namibia	'N Raamwerk vir Ontwikkeling van Kavango	December 1979	Page, D.	1: 1,000,000 (regional) 1: 100,000 (river terraces)	Photocopied from copies	One regional physiographic map. Okavango River terraces: 10 soil maps (RSA classification, 1977); 10 land potential maps (dryland farming and irrigation)
Namibia	Soil Survey of Northern South West Africa - Irrigation Potential	July 1970 Sheet 5-11687/20 Sheet 6-11687/21 Sheet 10-11687/11 Sheet 11-11687/26 Sheet 14-11687/29 Sheet 15-11687/30	Loxton, Hunting & Associates	Original scale 1: 250,000; presentation copies appear to have been re-scaled to 1: 500,000	Photocopied from presentation copies. Legend magnified x 200%	Six maps covering functional & non-functional areas of Okavango River basin, describing dominant soil series (early approximation of final RSA classification, 1977) and irrigation potential. Two-page legend includes associated soil series and landforms
Namibia	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Soils: maps 1-4.	January 1997 Soils: Map 1 Soils: Map 2 Soils: Map 3 Soils: Map 4	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four soil series maps (RSA soil classification) covering part of Okavango River Basin - Grootfontein district to Okavango River and Rundu to Mahango border post. Maps merge information from Page, D., Loxton, Hunting & Associates, and Schneider, M.B. Current borehole locations included (1997).
Namibia	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Landforms: maps 1-4.	January 1997 Landforms: Map 1 Landforms: Map 2 Landforms: Map 3 Landforms: Map 4	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four landforms maps covering part of Okavango River Basin - Grootfontein district to Okavango River and Rundu to Mahango border post. Maps derived from Land Types: Namibia map, Sheet 1 (FAO/UNDP, 1984)
Namibia	An Environmental Profile and Atlas of Caprivi	1997 Kavango.zip Releve.zip	Mendelsohn, J., & Roberts, C.	Tailored	Originals in digital format (ArcView 3.0); copied to diskette. Sample theme (soils) photocopied from presentation document.	Nine thematic maps and six database files in two zip directories, covering the Okavango River basin within Caprivi Region. Kavango.zip contains thematic map files: kavango.shp; soil-pH; soil-text; veg-struc; arable; livestock; com-res; diversity; cons-val; area; legend. Releve.zip contains database files: plantdata.xls; erosion.xls; coverdat.xls; sample.xls; soildat.xls; terrain2.xls.

Country	Title	Date and Map Reference No.	Author	Scale	Copy Status	Description
Botswana	Soil Map of the Republic of Botswana	1990 FAO/BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:1,000,000	Original	National soils map on 2 pages. FAO soil unit classification; phases indicated.
Botswana	General Soil Legend	1985 BOT/80/003	FAO/UNDP/Govt. of Botswana	N/A	Original	Provides correlation between Botswanan soil mapping symbols and FAO soil classification system to unit level; phases indicated.
Botswana	Soil Map of Boro-Shorobe Area. Location Map of Boro-Shorobe Area.	1986 BOT/80/003	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:50,000	Original	Map 1: Soils of Boro-Shorobe area, covering the middle and southern reaches of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Map 2: Location of soil pits. Description given in document (2)
Botswana	Gumare - Soils	1989 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (3).	Soils of Gumare area south of the panhandle, covering the western boundary of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (3)
Botswana	Tsau - Soils	July 1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (3).	Soils of Tsau area south of Gumare, southwest of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (3)
Botswana	Shakawe - Land Suitability for Improved Traditional Dryland Farming - main crop: Sorghum	1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (3).	FAO land suitability classification of panhandle area. Description given in document (3)

Country	Title	Date and Map Reference No.	Author	Scale	Copy Status	Description
Botswana	Maun - Soils	1986 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (4).	Soils north of Maun covering the eastern and southern reaches of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (4)
Botswana	Toteng - Soils	1988 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (4).	Soils of Toteng area south of Maun, covering Okavango Swamps outflow to the Thamalakane River. Botswanan map symbols, no legend. Refer to General Soil Legend. Description given in document (4).
Botswana	Nxai Pan - Soils	March 1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (4).	Soils of Nxai Pan area west of Maun, covering southeastern boundary of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification.
Botswana	Linyanti - Soils	September 1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1:250,000	Photocopied from original. B/W. Folded in back sleeve of document (5).	Soils of Linyanti area, covering northeastern boundary of Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (5).
Botswana	Land Systems Map of Botswana (partial coverage)	1991 BOT/85/011	Soil Survey Section, Land Utilization Division, Ministry of Agriculture FAO/UNDP/Govt. of Botswana	1: 2,000,000	Portion of original map colour photocopied x 200%. Scale approx. 1:1,000,000. Legend colour photocopied.	Land systems of Okavango Swamps area. FAO classification (1990). Explanatory notes given in document (6).
Botswana	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Soils: maps 5-8.	January 1997 Soils: Map 5 Soils: Map 6 Soils: Map 7 Soils: Map 8	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four soil maps describing soil units (FAO classification) covering lower Okavango River Basin on Botswanan territory. Information derived from Soil Map of Botswana + explanatory notes (documents 1 & 7)

Country	Title	Date and Map Reference No.	Author	Scale	Copy Status	Description
Botswana	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. Landforms: maps 5-8.	January 1997 Landforms: Map 5 Landforms: Map 6 Landforms: Map 7 Landforms: Map 8	Water Transfer Consultants	1: 250,000	Photocopied from original hand-drawn maps. For digitized copies (ArcInfo) refer to Peter Ashton, CSIR, Pretoria.	Four landforms maps covering lower Okavango River Basin on Botswanan territory. Maps derived from Land Systems of Botswana, Sheet 1 (FAO, 1991) + explanatory notes (document 6).
Botswana	Soils Distribution in the Okavango Delta Region	January 1997	Water Transfer Consultants	1: 1,000,000	Photocopy of hand-drawn map.	Sketch map describing soil groups (FAO, 1990) of the Okavango Delta area.
Angola	Ocorrências Minerais	1966	Direccâo Provincial dos Serviços de Geologia e Minas	1: 2,000,000	Photocopied from original.	National map describing mineral resources, overlaying feint surface drainage features.
Angola	Atlas Geográphico Volume 1	1982	Ministério da Educaçâo	1: 6,000,000	Available in digital format from Dr Carlos Amaral (Tel: +264-61-232432). Paper samples photocopied from Atlas. B/W & hand coloured.	National atlas featuring 21 themes including soils (Portuguese system).
Namibia	Soil Map of Namibia	1997	FAO/Land Evaluation Unit, Ministry of Agriculture, Water and Rural Development.	1: 8,000,000	Copy of printout. Original digitized from FAO Soil Map of the World. Contact: M. Coetzee, Land Evaluation Unit Tel: +264 61 202 2080	FAO classification to soil unit level; climatic regions, vegetation associations, pedogenetic environment provided in legend.

4.2 REFERENCE LIST OF AVAILABLE MAPS

Country	Title/Format	Date & Map Reference No.	Author	Scale	Source	Description
Botswana	Tsodilo - Soils *Hard copy*	1990 BOT/85/011	Soil Mapping and Advisory Services Project FAO/UNDP/Govt. of Botswana	1: 250,000	Josephine Magmbolwa (soils database) Tel: +267-350522 Fax: +267-307057 (Request form supplied, appendix *xx*)	Soils of Tsodilo area covering the panhandle & northwestern boundary of the Okavango Swamps. Botswanan map symbols, correlation to FAO classification. Description given in document (3)
Angola	Unknown *Possibly in digital format*	1997 FAO	Beernaert, F.	Unknown	Frank Beernaert Tel: +0032-9-282-2703 Fax: +0032-5-027-7683 Dr F Nachtergaele, FAO, Rome e-mail: freddy.nachtergaele@fao.org	Soils of Angola classified under Portuguese system, correlated to FAO (1990). Level of FAO classification unknown.
Angola	Atlas Geográphico Volume 1 *Digital format*	1982	Ministério da Educaçâo	1: 6,000,000	All maps digitized (ArcInfo). Dr Carlos Amaral (Tel: +264-61-232432).	National atlas featuring 21 themes including soils (Portuguese system).
Namibia Botswana	Feasibility Study on the Okavango River to Grootfontein Link of the Eastern National Water Carrier. *Digital format*	January 1997 Base maps: sheets 1-8 Soils maps: sheets 1-8 Landforms maps: sheets 1-8	Water Transfer Consultants	1: 250,000	Digitized maps (ArcInfo) held by CSIR, Division of Water, Environment and Forestry Technology, P.O. Box 395, Pretoria, 0001. Contact: Peter Ashton/Paul Donald. Tel:+0027-12-841-2022 Fax: +0027-12-841-2506 E-mail: pashton@csir.co.za	Eight base maps, soil maps and landform maps (total 24) covering Okavango River Basin on Namibian and Botswanan territory.
Namibia	Soil Map of Namibia *Digital format*	1997	Land Evaluation Unit, Ministry of Agriculture, Water and Rural Development	1: 8,000,000	Digitized from the FAO Soil Map of the World. Original scale 1: 5,000,000. Contact: Ms M. Coetzee Tel: +264-202-2080	FAO soil units; generalised.
Namibia	Okavango Region (Titles unknown) *Database, hard copy and digital format*	1998	Lux Development/ Ministry of Lands, Resettlement & Rehabilitation	1: 50,000	Lux Development, contact: Walter De Frieze (mapping trainer) Tel:+00264-61-285-2111 Surveyor General's Office, contact: Tel: +264-61-245056/7	Database contains 35 main features subdivided into 80+ display definitions (see appendix). Soils are not included. Maps due to be completed in 1998.

4.3 SATELLITE IMAGERY OF POTENTIAL USE TO A SOILS ASSESSMENT OF THE OKAVANGO RIVER BASIN

The table below cross-references to the Vegetation Mapping Project end products summarised in section 3.1. Archived at the National Remote Sensing Centre, the satellite scenes listed cover the Okavango River Basin over Namibian, Botswanan and Southern Angolan (border) territories. Dates of data capture are given in section 4.4 and the levels of image processing are outlined in section 3.1.

Territory	Scene Reference/ID		
LANDSAT TM			
Angola/Namibia	179-072 178-072 177-072		
Angola/Namibia/Botswana	176-072 176-073 175-072		
Namibia/Botswana	175-073 176-074		
Namibia	177-073 177-074 178-073 178-074		
Botswana	175-074 174-074		
Angola	Not Known		
SPOT XS			
Angola/Namibia	108-385 109-385 110-386		111-386 112-386 113-386
Angola/Namibia/Botswana	115-386		114-386
Namibia/Botswana	114-387 114-388		114-389 115-398
Namibia	108-390 109-386 109-390 110-387 110-388 110-389	110-390 111-387 111-388 111-389 111-390 112-387	112-388 112-389 113-387 113-388 113-389

The National Remote Sensing Centre holds the largest single archive of satellite image material in Namibia. Copies of satellite data are acquired from projects generated within the Ministry of Environment and from collaborating Ministries. These are stored in digital format and geo-referenced on demand. It is noted that, with respect to the use of satellite data, the policy of the NRSC is difficult to pin down. A considerable amount of negotiation is required and may involve the use of in-house staff for processing services in exchange for the release of data.

The NRSC archive however, represents only a portion of satellite data acquired in-country. Details of data held by the private sector are unknown. Within the public sector, under a recently contracted Government bulk order discounting scheme offered by CSIR/SAC, a number of Ministries have acquired satellite data captured from 1995-1997. With the exception of 10 scenes bought by the Ministry of Environment (April/May 1997), the NRSC holds no record of this data. Geological Survey holds a considerable amount of satellite data, although none of this covers Okavango or Caprivi regions.

4.4 SATELLITE IMAGE DATA ARCHIVED AT THE NRSC

LANDSAT TM				
Source	**Path/ID**	**Bands**	**Date**	**Medium and ID**
National Remote Sensing Centre[1]	179-073		1982	Unknown
"	179-076	1-7	1984/5	Tape
"	179-076	1-7	1984/5	Tape
"	180-073	1-7	1984/5	Tape
"	180-074	1-7	1984/5	Tape
"	181-073	1-7	1984/5	Tape
"	179-073		1988	Unknown
"	180-073		1988	Unknown
"	175-079	1-7	1989	Tape
"	176-075	1-7	1989	Tape
"	176-076	1-7	1989	Tape
"	176-077	1-7	1989	Tape
"	176-078	1-7	1989	Tape
"	176-079	1-7	1989	Tape
"	176-080	1-7	1989	Tape
"	177-073*	1-7	1989	Tape
"	177-074*	1-7	1989	Tape
"	177-075	1-7	1989	Tape
"	177-076	1-7	1989	Tape
"	177-077	1-7	1989	Tape
"	177-078	1-7	1989	Tape
"	177-079	1-7	1989	Tape
"	178-073*	1-7	1989	Tape
"	178-074*	1-7	1989	Tape
"	178-075	1-7	1989	Tape
"	178-076	1-7	1989	Tape
"	178-077	1-7	1989	Tape
"	178-079	1-7	1989	Tape
"	179-073	1-7	1989	Tape
"	179-074	1-7	1989	Tape
"	179-075	1-7	1989	Tape
"	179-076	1-7	1989	Tape
"	180-073	1-7	1989	Tape
"	180-074	1-7	1989	Tape
"	178-075		1991/2	Tape
"	178-076		1991/2	Tape
"	178-077		1991/2	Tape
"	178-078		1991/2	Tape
"	179-074		1991/2	Tape
"	179-075		1991/2	Tape
"	179-077		1991/2	Tape
"	180-074		1991/2	Tape
"	180-075		1991/2	Tape
"	178-075		1991/3	Tape

[1] NRSC listing updated 2/12/97

* Scene covers Okavango River Basin

LANDSAT TM				
Source	**Path/ID**	**Bands**	**Date**	**Medium and ID**
National Remote Sensing Centre[1]	178-076		1991/3	Tape
"	178-078		1991/3	Tape
"	179-074		1991/3	Tape
"	179-075		1991/3	Tape
"	179-077		1991/3	Tape
"	180-074		1991/3	Tape
"	180-075		1991/3	Tape
"	177-073*	1-7	1992	CD
"	178-073*	1-7	1992	CD
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"	178-074*	1-7	1992	CD
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"	179-072*	1-7	1992	CD
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"	179-074	1-7	1992	CD
"	180-072	1-7	1992	CD
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"	180-074	1-7	1992	CD
"	181-072	1-7	1992	CD
"	174-072	1-7	1994	CD
"	175-072*	1-7	1994	CD
"	176-072*	1-7	1994	CD
"	181-074	1-7	1995	CD
"	181-074	1-7	1995	CD
"	LS-177-072*	1-7	10/4/92	CD-101
"	177-073*	1-7	19/5/92	CD-102
"	LSQ4-178-072*	1-7	19/5/92	CD-103
"	178-073*	1-7	19/5/92	CD-104
"	178-074 *	1-7	19/5/92	CD-105
"	179-072 *	1-7	10/5/92	CD-106
"	179-073	1-7	10/5/92	CD-107
"	179-074	1-7	10/5/92	CD-108
"	180-072	1-7	15/4/92	CD-109
"	180-073	1-7	15/4/92	CD-110
"	180-074	1-7	24/4/92	CD-111
"	181-072	1-7	25/4/93	CD-112
"	181-073	1-7	25/4/93	CD-113
"	181-074	1-7	30/3/95	CD-114
"	182-072	1-7	02/5/93	CD-115
"	182-073	1-7	22/4/95	CD-116

[1] NRSC listing updated 2/12/97
* Scene covers Okavango River Basin

SPOT XS				
Source	**Path/ID**	**Bands**	**Date**	**Medium and ID**
National Remote Sensing Centre[1]	101-385		1989	Unknown
"	103-386-2		1989	CD
"	103-386-2		1989	CD
"	180-389		1989	Unknown
"	106-385	1-3	1992	CD
"	106-386	1-3	1992	CD
"	106-387	1-3	1992	CD
"	107-385	1-3	1992	CD
"	107-386	1-3	1992	CD
"	107-387	1-3	1992	CD
"	108-385 *	1-3	1992	CD
"	108-386	1-3	1992	CD
"	108-387	1-3	1992	CD
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"	119-385	1-3	1992	CD
"	114-389	1-3	1992	CD
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"	111-387 *	1-3	1992	CD
"	111-388 *	1-3	1992	CD
"	111-389 *	1-3	1992	CD
"	111-390 *	1-3	1992	CD
"	112-386 *	1-3	1992	CD
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"	112-388 *	1-3	1992	CD
"	112-388 *	1-3	1992	CD
"	112-389 *	1-3	1992	CD
"	112-390	1-3	1992	CD
"	113-386 *	1-3	1992	CD
"	113-387 *	1-3	1992	CD
"	113-388 *	1-3	1992	CD
"	113-389	1-3	1992	CD
"	113-390	1-3	1992	CD
"	114-386 *	1-3	1992	CD
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"	116-386	1-3	1992	CD
"	116-386	1-3	1992	CD

[1] NRSC listing updated 2/12/97

* Scene covers Okavango River Basin

SPOT XS				
Source	**Path/ID**	**Bands**	**Date**	**Medium and ID**
National Remote Sensing Centre[1]	117-385	1-3	1992	CD
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"	118-386	1-3	1992	CD
"	119-385	1-3	1992	CD
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"	120-387	1-3	1992	CD
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"	120-387	1-3	1992	CD
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"	106-385	1-3	29/4/92	CD-117
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"	106-387	1-3	29/4/92	CD-117
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"	108-390 *	1-3	22/7/94	CD-117
"	108-391	1-3	22/7/94	CD-117
"	108-392	1-3	22/7/94	CD-117
"	109-385 *	1-3	20/5/92	CD-118
"	109-386 *	1-3	20/5/92	CD-118
"	109-387	1-3	20/5/92	CD-118
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"	109-390 *	1-3	20/5/92	CD-118
"	109-391	1-3	20/5/92	CD-118
"	109-392	1-3	20/5/92	CD-118
"	110-386 *	1-3	6/9/91	CD-118
"	110-387 *	1-3	6/9/91	CD-118
"	110-388 *	1-3	6/9/91	CD-118
"	110-390	1-3	20/5/92	CD-118
"	110-391	1-3	20/5/92	CD-118
"	110-392	1-3	20/5/92	CD-118
"	111-386	1-3	21/5/92	CD-119
"	111-387	1-3	21/5/92	CD-119
"	111-388	1-3	21/5/92	CD-119
"	111-389	1-3	21/5/92	CD-119
"	111-390	1-3	7/3/94	CD-119

SPOT XS

[1] NRSC listing updated 2/12/97

* Scene covers Okavango River Basin

Source	Path/ID	Bands	Date	Medium and ID
NRSC[1]	111-391	1-3	7/3/94	CD-119
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"	122-3856	1-3	22/5/92	CD-124

[1] NRSC listing updated 2/12/97
* Scene covers Okavango River Basin

5. ENVIRONMENTAL ASSESSMENT PHASE: SCOPE OF WORK

5.1 INTRODUCTION

The diagnostic assessment reveals an incomplete picture of soil resources of the Okavango River basin. The lack of a coherent regional soils database in which information is based upon standard procedures, mapping scales and survey intensity frustrates any attempt to provide a systematic assessment based on comparable soil attributes and parallel definitions.

A wealth of applicable information can be obtained for Botswana. Information has been correlated and standardised using FAO guidelines, and has been reproduced at several scales of resolution for national, regional and local planning purposes.

In contrast, directly applicable material cannot be easily obtained for Namibia and Angola.

In the case of Angola, material is old and archives are scattered from Lisbon to Lubango. Angolan soils data correlated to the FAO Legend will become available at an estimated scale of 1:1,000,000, although this scale will be inadequate for both environmental assessment and river basin management purposes.

The utility of available Namibian information is compromised by a serious soil classification incompatibility with data from Botswana, which cannot easily be resolved.

For both environmental assessment and river basin management purposes, the production of a regional standardised soils database is imperative. The Soil and Terrain Database for Southern Africa (to be released by FAO) contains a preliminary correlation of Angolan soils to the FAO Revised Legend in addition to a full dataset of Botswanan soils. The scale of 1:1,000,000 is, however, of little value for river basin management.

The initial scope of work to be undertaken in the environmental assessment phase should focus on the development of a regional soils database in which information is based upon the FAO Revised Legend and from which thematic maps may be derived at a scale of 1:250,000.

5.2 SUMMARY OF WORK TO BE CARRIED OUT

1. Assess the level of difficulty and scope of work involved in the development of a methodology to correlate Namibian soils information with the FAO Revised Legend.
2. If a methodology can be developed, assess the level and intensity of ground-truthing necessary to provide representative and compatible soil profile information for entry to the regional soils database.
3. Develop the methodology, apply it to Okavango region, produce maps at an appropriate scale (minimum 1: 250,000) for environmental assessment and river basin management. Support maps with documented information on soil characteristics and representative profiles and chemical analyses.
4. Produce correlated Namibian soils data in a format appropriate for entry into the regional database.
5. If it is not feasible to develop a methodology, assess the cost, time and funding implications of a complete re-survey of the Okavango river basin in Namibia.
6. In the case of a re-survey, the use of other project services and end products referenced in this report could significantly reduce time and costs. In particular, an investigation of the utility of the 'vegetation' polygons derived from SPOT XS images (ref.: Vegetation Mapping Project, see explanatory note) is recommended. Thematic layers compiling the new 1: 50,000 and 1: 250,000 scale topographic maps for Okavango have been digitized (ref.: A Geographical Information System for Okavango Region) and may be re-used for base map production. Digital SPOT XS data held at the NRSC could be tailored for boundary compatibility with the topographic map reference system.
7. Follow steps 2-4, applying FAO guidelines for soil profile description, chemical analysis procedures, classification criteria and mapping protocols.

8. If the procedures developed for either the correlation of, or re-survey of the soils of Okavango included satellite data interpretation, apply these procedures and image processing levels to a supervised classification of Angolan soils within the river basin at a scale of 1:250,000. In this respect, the FAO soil and terrain database of Southern Africa would serve as a guideline to the initial determination of soil boundaries as would the knowledge gathered from the interpretation of Namibian satellite data. Follow step 7.

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