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REPORT ON A RECONNAISSANCE SURVEY OF THE SOILS OF NORTHERN SOUTH WEST AFRICA IN TERMS OF THEIR POTENTIAL FOR IRRIGATION

Undertaken for the

DEPARTMENT OF WATER AFFAIRS
WINDHOEK

NOVEMBER, 1970

R. F. Loxton, Hunting & Associates,
P. O. Box 39265,
BRAMLEY. Tvl.

TS/1/70

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OPSOMMING EN AANBEVELINGS

Hierdie verslag handel oor die uitslag van 'n verkenningsopname van die gronde in die noorde van S. W. A. met spesiale verwysing na hulle potensiaal vir ontwikkeling onder besproeiing. Die gebied sluit in meeste van die blanke gebiede noord van Otjiwarango, en 'n groep plase suid van Waterberg, insluitende ook Hereroland, Boesmanland, suidelike Okavangoland, westelike Ovamboland, die Kaokoveld, gedeeltes van Damaraland en die Etosha Natuurreservaat. Verslag is gedoen oor verkenningsopnames van sentraal en oostelike Ovamboland en noordelike Okavangoland in 1966 en 1967, onderskeidelik. Hierdie verslag behoort gelees te word tesame met die grondkaarte en die verklaring wat al die betrokke inligting bevat van die besproeiingspotensiaal van die grond. Die grondkaart en die verklaring klassifiseer die gronde beide ten opsigte van besproeiingspotensiaal en aanbevelings vir ontwikkeling. Met verwysing na laasgenoemde word die kriteria vir onderskeid in die kaartverklaring uiteengesit. Die benaderde omvang, in hektaar, van aanbevole en marginale grondassosiasies binne administratiewe en etniese gebiedseenhede word ook op die kaart aangedui.

Die geskiktheid van die grond vir besproeiing is bepaal volgens die eienskappe van die grond en die terrein alleen, en neem nie in aanmerking die hoogte of die afstand verbonde aan watervoorsiening nie. Die opnamegebied is groot en dit is daarvoor nie verbasend dat die gebiede geskik vir besproeiing 'n klein gedeelte van die geheel uitmaak nie. Laasgenoemde is nietemin van aansienlike totale grootte en dit moet in gedagte gehou word dat een vierkant duim op die 1 : 250,000 kaart byna 5,000 hektaar verteenwoordig en die besproeiing daarvan sal min meer ongeveer $2\frac{1}{2}$ tot 3 kumek water vereis. Met ander woorde, dit kan ook gese word dat die besproeiing van 'n gebied wat deur 3 vierkant duim op die kaart aangedui word, óf 'n groot suikermeul of katoenfabriek kon onderhou, óf driekwart miljoen sakke graan per jaar sou kon produseer.

Die omvang van aanbevole en marginale grondassosiasies in terme van administratiewe en etniese eenhede binne die opnamegebied word in Tabel 1 uiteengesit. By die samestelling van die tabel het ons die grense van die verskillende Bantoetuislande, sowel as die natuurreservate aangeneem soos deur die Department van Bantoe-administrasie en ontwikkeling aangedui. In die geval van die noord-westelike gedeelte van die Etosha Natuurreservaat neem ons berekeninge nie die wegneming en byvoegings, wat tans voorgestel word, in aanmerking nie.

TABEL 1 : TOTALE OMVANG EN VERSPREIDING VAN GRONDASSOSIASIES MET BESPROEIINGSONTWIKKELING POTENSIAAL, VOLGENS DIE OPNAME GEBIEDE (HEKTAAR)

EENHEID	HOOGS AANBEVEEL	AANBEVEEL	MARGINAAL
KAOKOVELD	11,390	5,141	84,685
DAMARALAND	3,428	10,182	104,485
WESTELIKE OVAMBOLAND	2,319	155,749	484,081
SUIDELIKE OKAVANGOLAND	-	17,752	533,386
BOESMANLAND	-	42,540	346,082
HEREROLAND	302	479,083	3,339,833
ETOSHA NATUURRESERVAAT	-	279,950	167,953
DISTRIK OUTJO	44,664	142,646	491,954
DISTRIK TSUMEB	806	13,509	247,392
DISTRIK GROOTFONTEIN	41,756	23,689	1,295,811
DISTRIK OTJIWARONGO	46,774	110,696	114,928
TOTAAL:	151,439	1,280,937	7,210,590

Die hoof komponent gronde en geografiese verspreiding van Hoog Aanbevole en Aanbevole grondassosiasies word in Tabel 3 saamgevat.

Verwysing na die kaart, verklaring en Tabel 3 sal toon dat, behalwe vir twee klein geïsoleerde gebiede in die Kaokoveld, gebiede van groot besproeiingspotensiaal almal ver geleë is van noordelike water-bronne en kom voor in hooggeleë gebiede. Dit is daarom duidelik dat 'n baie noukeurige studie gemaak sal moet word om die praktiese moontlikhede van besproeiingsskemas ten opsigte van (a) die kwaliteit van die grond en (b) ligging ten opsigte van watervoorraad, vas te stel.

Dit word verstaan dat politieke, ekonomiese, vakkundige en ander oorwegings, sowel as pedologiese kriteria, in aanmerking geneem sal word by die bepaling van 'n besproeiingsbeleid, en besproeiingsbeplanning. Eersgenoemde oorwegingsword nie in die verslag in aanmerking geneem nie, maar, in die geval van pedologiese faktore moet ons daarop wys dat ons verslag en kaarte die hele opname op verkenningsvlak dek. Die hooffunksie daarvan was om die ligging van besproeibare gebiede vas te stel en hul besproeiingspotensiaal te bepaal. Hierdie inligting behoort van aansienlike waarde te wees in sovere dit die veld heelwat vernou met die fokus op sekere spesifieke gebiede, maar dit behoort nie die basis te vorm vir die beplanning van 'n besproeiingsontwikkelingsprojek in enige gebied nie. 'n Voorvereiste vir projekbeplanning van enige gebied van besondere belang is 'n semi-gedetaileerde bodemopname. Ons stel voor dat sodanige opnames uitgevor moet word.

Ons beskik nie oor al die feite wat by berekening gebring behoort te word by die prioriteitsbepaling van moontlike ontwikkelingsgebiede nie en die nie-pedologiese oorwegings mag wel daartoe lei dat sekere marginale gebiede verkies word bo ander gebiede met 'n hoër intrinsieke produksie potensiaal. Nieteenstaande, beskoudende alleenlik (a) gronde van 'redelik' tot 'baie hoë' potensiaal, (b) hoogte, en (c) bereikbaarheid van noordelike waterbronne, is dit moontlik om 'n kort lys op te stel van gebiede wat 'n meer gedetaileerde ondersoek verdien. Daar behoort op gelet te word dat die sentrale en oostelike Ovamboland en die noordelike Okavangoland, wat buite die opname gebied val, nie in ag geneem is nie. Die nommers verwys na die in Tabel 3.

1.1 Die Okambele - gebied in die noordelike Kaokoveld,

3.2 Die Ovamboland plato suid-oos van die Ruacana waterval,

5.1 Die noordelike Omatako vallei,

7.1 Die Otjivalunda gebied in die omgewing noord-wes van die Etosha pan,

11.3 Die Okosongomingo - Okakarara gebied van die suidelike Omatako vlaktes

Die insluiting van Nr. 11.3 - die Okosongomingo- Okakarara gebied - is onderhewig aan die moontlikheid om die vloedwaters van die Groot en Klein Omatako omurambas op te vang.

Met verwysing na die moontlikhede om water op te gaar, is ons nie in 'n posisie om enige nuttige voorstelle te maak nie. Toe ons egter deur die gebied gery het, was ons beindruk deur die geweldige brûe en stormwaterslote, die groottee waarvan miskien kan dui op periodieke, maar substansiële, vloedwater. Sodanige strukture in die Tsumeb - Grootfontein gebied waar daar gronde van hoë kwaliteit is, het veral die aandag getrek.

Ons wil veral die aandag vestig op die gebied op die kaart, eenheid A5, noord-wes van die Etosha pan. Verwysing na die kaart (Vel 3) en daarmeegaande verklaring, sal dui dat, terwyl ons kan aanbeveel dat besproeiingsontwikkeling in verskeie gebiede in die Etosha natuurreservaat en westelike Ovamboland onderneem kan word, die gebiede kan varieer van "redelik" tot "redelik hoog" ten opsigte van kwaliteit van die grond. Kaarteenheid A5 val in laasgenoemde kategorie. Die owerhede mag dalk die teenwoordigheid van hierdie groot gebied grond van redelik hoë besproeiingspotensiaal in aanmerking neem in die daarstel van toekomstige grense vir die Etosha natuurreservaat. Dit is die enigste groot stuk grond in die gebied wat vir die "redelik hoë" kategorie kwalifiseer.

Ons moet egter ook aandag vestig op die gebied wes van die Oshana - Etaka in Ovamboland. Tydens 'n vorige verkenningstog (Verslag TS/45/66 van November 1966) is 'n omvangryke eenheid geidentifiseer, wat bestaan uit 'n assosiasie van plaaslik afkomstige non-solonetz materiale - (kaarteenheid L : Locally Derived Aeolian and Related Materials). Hierdie landvorm, wat effens hoër gelee is as die solonetz-vlakte, skyn potensiaal te besit vir besproeiing. Gedurende die huidige opname, tydens die veldwerk, is 'n poging aangewend om verdere differensiasie aan te bring in die kartering van hierdie groot landeenheid. Ongelukkig egter, is die kwaliteit en skaal van die fotos (1/75,000) volkome ontoereikend vir meer differensiasie en ons is nie instaat om op vorige werk te verbeter nie. Die gebied is op die oomblik ingesluit in kaarteenheid E1 wat nie aanbeveel is vir besproeiingsontwikkeling nie. Ons stel 'n meer gedetaileerde opname voor om beter gronddifferensiasie aan te dui.

Vanweë die grootte van die opnamegebied en die skaal van die kaart, mag 'n kaarteenheid met 'n laer graad, wel gebiede insluit wat 'n hoë besproeiings-potensiaal besit. Met die oog hierop, en aangesien fisiese faktore 'n invloed mag hê op die uitlê van kanale, is ons aanmerking hierbo met betrekking tot die belang-rikehid vir beter opnames, ook van toepassing sover dit die onmiddelike omgewing van voorgestelde kanaalroetes aangaan. Ons beveel dit as sodanig aan.

Hierdie opname is uitgevoer tesame met 'n opname van die natuurlike hulpbronne van Boesmanland en Hereroland. Vir die gebiede is 'n baie meer omvattende ondersoek aangevra. Laasgenoemde studie sal die onderwerp wees van 'n afsonderlike verslag maar dit is paslik om hier te noem dat, uitsluitende water vir huis en industriële gebruik; die mees ekonomiese gebruik van die water van die Okavangorivier in hierdie tuislande mag die langafstand pomp van water na weigebiede van redelike hoë potensiaal waarop grootskaalse veeboerdery, moontlik ook ondersteun deur groot vleisverpakkingsfasiliteite ontwikkel deur paslike owerhede op 'n trustbasis, bv. die Bantoebeleggingskorporasie, wees. Dieselfde moontlikheid geld ook in die geval van suidelike Ovamboland en Okavangoland.

Hierdie studie het nie die ekonomiese en akkerbou-kundige faktore verbonde aan besproeiingsverbouing behels nie. In teenstelling met baie ander besproeiingsopnames wat ons uitgevoer het, is geen aandag geskenk aan moontlike gewasse en produksiesisteme, besproeiingstegnieke, bemarkingsprobleme en vooruitsigte, alternatiewe gebruik van water, ekonomiese bedryfstudies, ens. nie. Hierdie faktore sal wel deeglik in aanmerking geneem moet word in die geval van besproeiingsbeplanning. Die betrokke owerhede is seker bewus van die nodigheid

van sodanige studies. Ons beveel aan dat hulle aangepak word.

Met die stigting van die Mahenene Navorsingstasie in Ovamboland, is die tot-nou-toe onbevredigende toestand met betrekking tot akkerboukundige besproeiingsnavorsing in Suidwes Afrika gedeeltelik verlig. Die nuwe stasie kan op die oomblik alleenlik 'n geringe reeks studies onderneem met die klem op grondverbetering en besproeiingstegnieke. Die besproeiingspotensiaal van noordelike Suidwes Afrika is aansienlik, en alle grootskaalse ontwikkeling behoort voorafgegaan,en gepaard te gaan, met plaaslikgeorienteerde navorsing in verskeie velde, soos die geval was in noord-Natal, Rhodesië en Swasiland. Ons verwag dat voorkeur gegee sal word aan(a)proewe met verskillende kultivaars en (b) grondvrugbaarheidsproewe. Voorgenoemde werk behoort alreeds in 1972 aangepak te word.

SUMMARY AND RECOMMENDATIONS

This is a report on the results of a reconnaissance survey of the soils of northern South West Africa with particular reference to their potential for development under irrigation. The survey area includes most of the European areas north of Otjiwarongo and a block of farms south of Waterberg, together with Hereroland, Bushmanland, southern Okavangoland, western Ovamboland, the Kaokoveld, parts of Damaraland and the Etosha Game Reserve. Reconnaissance surveys of central and eastern Ovamboland and northern Okavangoland were reported on in 1966 and 1967 respectively. This report should be read in conjunction with the soil maps and expanded legend, which contain all information relevant to the irrigation potential of the soils. The soil map and expanded legend classify the soils both in terms of irrigation potential and recommendation for development. In respect of the latter, the criteria for differentiation are set out in the map legend. The approximate extent in hectares of Recommended and Marginal soil associations within administrative and ethnic land units is also indicated on the map.

The capability of soils for irrigation is assessed according to soil and terrain features alone and does not take into account elevation or distance with respect to water supply.

The survey area is large and, not surprisingly, the areas suitable for irrigation constitute a small proportion to the whole. The latter are nevertheless of considerable extent in the aggregate and it is to be borne in mind that one square inch on the 1 : 250,000 map represents nearly 5,000 hectares, the irrigation of which requires about $2\frac{1}{2}$ to 3 cumecs of water. Framed differently, it could be said, for example, that the irrigation of an area covered by three square inches on the map could support a large sugar mill or cotton ginnery, or produce three quarters of a million bags of grain per annum.

The extent of Recommended and Marginal soil associations in terms of administrative and ethnic units within the survey area is set out in Table 1. In compiling this table we have adopted boundaries for the various Bantu Homelands and Game Parks as advised by the Department of Bantu Administration and Development. In the case of the north western part of Etosha Game Park our calculations do not take account of excisions and additions currently proposed.

TABLE 1 : AGGREGATE EXTENT AND DISTRIBUTION OF SOIL ASSOCIATIONS WITH POTENTIAL FOR IRRIGATION DEVELOPMENT ACCORDING TO SURVEY REGIONS (HECTARES)

UNIT	HIGHLY RECOMMENDED	RECOMMENDED	MARGINAL
KAOKOVELD	11,390	5,141	84,681
DAMARALAND	3,428	10,182	116,403
WESTERN OVAMBOLAND	2,319	155,749	963,836
SOUTHERN OKAVANGOLAND	-	17,752	53,631
BUSHMANLAND	-	42,540	396,588
HEREROLAND	302	479,083	3,289,327
ETOSHA GAME PARK	-	279,950	173,407
OUTJO DISTRICT	44,664	142,646	506,700
TSUMEB DISTRICT	806	13,509	247,392
GROOTFONTEIN DISTRICT	41,756	23,689	1,349,139
OTJIWARONGO DISTRICT	46,774	110,696	114,928
TOTAL:	151,439	1,280,937	7,296,032

The main component soils and geographical distribution of Highly Recommended and Recommended soil associations are summarised in Table 3.

Reference to the map and legend and to Table 3 will reveal that apart from two small and isolated areas in the Kaokoveld, areas having high and very high irrigation potential are all distant from northern water sources and occur at relatively high elevations. It is apparent that very careful study will be necessary to establish the feasibility of irrigation schemes in terms of (a) soil quality and (b) accessability to water supply.

It is appreciated that political, economic, engineering and other considerations, in addition to pedological criteria, are taken into account in the determination of irrigation policy and in the planning of irrigation development. The former do not concern us in this report, but, in respect of pedological factors, we must point out that our report and maps cover a survey at the reconnaissance level. Its main function has been to locate, broadly assess and categorise areas of irrigation potential. It should prove of considerable value in narrowing the field and focusing attention to specific areas, but it should not form the basis for a

commitment to an irrigation development project in any area. A pre-requisite to project planning is the soil survey at semi detailed intensity of any area of particular interest. We recommend that such surveys be carried out.

We are not in possessionof all the facts that will enter into the short listing of areas for possible development, and non pedological considerations may well lead to certain marginally suitable areas being preferred to others of higher intrinsic productive potential. However, having regard solely to (a) soils of moderate to very high potential, (b) elevation and (c) proximity to northern water sources, we short list the areas set out below for more detailed examination, pointing out that no account has been taken of central and eastern Ovamboland and northern Okavangoland which fall outside the area embraced by this survey. The numbers refer to those in Table 3.

1.1	The OKAMBELE area in the northern Kaokoveld
3.2	The OVAMBOLAND PLATEAU south east of Ruacana Falls
5.1	The northern OMATAKO Valley
7.1	The OTJIVALUNDA area and environs north west of Etosha Pan
11.3	The OKOSONGOMINGO-OKAKARARA area of the southern Omatako Plain.

The inclusion of No. 11.3 - the Okosongomingo - Okakarara area - is subject to the feasibility of the local storage of flood waters of the Groot and Klein Omatako omurambas.

With regard to local water storage possibilities we are not in a position to make helpful suggestions. In passing, however, we have noted the presence of massive bridges and culverts in the survey area, the size of which may be indicative of periodic but substantial runoff. Structures in areas of high quality soil in the Tsumeb-Grootfontein area attracted attention in this regard.

We draw particular attention to the area of map unit A5, north west of Etosha Pan. Reference to the map (Sheet 3) and to the expanded map legend will reveal that, while we can recommend irrigation development in several areas in the Etosha Game Reserve and western Ovamboland, these areas range in terms of soil quality from "moderate" to "moderately high". Map unit A5 falls into the latter category. The authorities concerned may wish to take into account the presence of this large block of land of moderately high irrigation potential in the determination of future boundaries of the Etosha Game Reserve. It is the only large block of land in the area which qualifies for the "moderately high" rating.

In passing we must draw attention to the area West of the Oshana - Etake in Ovamboland. In a previous reconnaissance (Report TS/45/66 of November 1966), a major land unit was identified, comprising an association of locally derived non solonetz materials; (Map unit L : Locally Derived Aeolian and Related Materials). This landform, which is slightly elevated above the solonetz plain, appears to have irrigation potential. Now during this current survey, an attempt was made during field work to accomplish further differentiation as regards mapping of this somewhat gross landform. Unfortunately, the quality and scale of the photographs (1/75,000) proved entirely unsuitable for more detailed differentiation and we have not been able to improve in any way on earlier work. For the time being, therefore, this area has been accommodated in mapping unit E1 which is not recommended for irrigation development. We recommend a more detailed investigation to accomplish more satisfactory soil differentiation.

Because of the size of the survey area and the scale of the mapping, a map unit with a low quality class may well contain areas of soil having high irrigation potential. In view of this, and because physical factors may dictate the routes of canals, our remarks above regarding the need for more detailed soil surveys must also apply to the environs of any proposed canal route. We recommend accordingly.

This survey has been executed concurrently with a survey of the natural resources of Bushmanland and Hereroland for which our terms of reference are more comprehensive. The latter study will be the subject of a separate report but it is appropriate to mention here that, excluding water for domestic and industrial purposes, the most economically beneficial use of Okavango river water in these Homelands may prove to be long distance pumping to moderately high potential grazing areas on which massive livestock ranching schemes, possibly complemented by meat packing works, could be mounted by an appropriate agency on a trust basis, e.g. the Bantu Investment Corporation. The same possibility exists in the case of southern Ovamboland and Okavangoland.

This study has not embraced economic and agronomic factors relating to irrigated crop production. By contrast with many other irrigation surveys we have carried out, in this exercise no attention has been paid to possible crops and production systems, irrigation techniques, marketing problems and prospects, alternative uses of water, economic input-output studies, etc., all of which will figure in irrigation development planning. The authorities concerned will be aware of the need for such feasibility studies, which we recommend be put in hand.

With the establishment of Mahanene Research Station in Ovamboland, the hitherto unsatisfactory situation in respect of agronomic irrigation research in South West Africa has been partially remedied. However, the new station can at present handle only a limited range of studies, the emphasis being on soil amelioration and irrigation techniques. The irrigation potential of northern South West Africa is considerable and any large scale development should be preceded and accompanied by multi discipline, local applied research, as was the case in northern Natal, Rhodesia and Swaziland. We anticipate that the priority fields for reinforcement will be (a) cultivar introduction and performance testing and (b) soil fertility investigations. It would not be premature to put the former in hand in 1972.

INTRODUCTION

THE COMMISSION:

More so than in many other areas of southern Africa, water in South West Africa is a major limiting factor to economic development. Having regard to the undeveloped water resources along the northern boundaries and conscious of the need to ensure that maximum benefit will be derived from such water supplies as will be available from these sources, the authorities concerned prudently concluded that a pre-requisite to rational long-term development planning in northern South West Africa is an assessment of the soils of the region in terms of their suitability for irrigation.

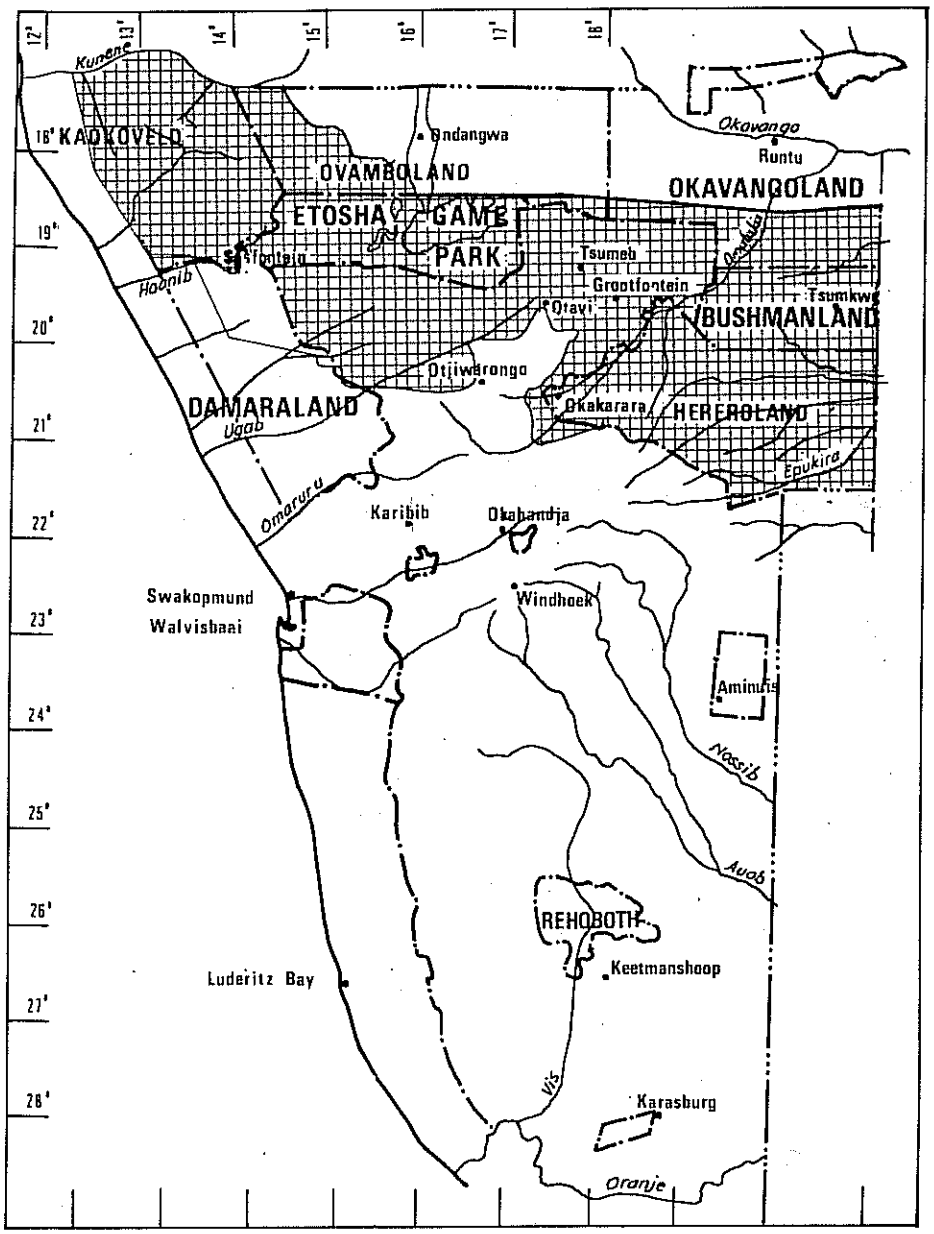
We were commissioned by the Department of Water Affairs to undertake a broad reconnaissance survey of the soils of those areas of northern South West Africa which have not previously been surveyed. Our terms of reference are to survey, assess and classify the soils of the region and to present the collated information on maps at scales of 1 : 250,000 and 1: 500,000. We were also requested to give more detailed study to areas of apparent high potential for irrigation. While this was done to a certain extent, the sheer size of the survey area precluded its comprehensive classification into areas of low, moderate and high potential at the time of the field work. It was only when the map compilations of the field teams were studied on a co-ordinated basis in the office, in the light of laboratory analytical results, that a satisfactory overall appreciation of the soils of the area could be obtained. We refer below to the need for more detailed surveys of higher potential.

This report is to be read in conjunction with the soil maps and their expanded legend. The map at 1 : 250,000 scale consists of 14 sheets and that at 1 : 500,000 of 5 sheets.

THE SURVEY AREA :

The soil maps show the boundaries of the survey area in detail. The small scale map in Fig. 1 depicts the location of the survey area in relation to South West Africa as a whole. The survey area covers some 90,000 square miles and includes Hereroland, Bushmanland, southern Okavangoland, western and southern Ovamboland, the eastern Kaokoveld, northern Damaraland, the Etosha Game Park and large portions of the European areas in the Grootfontein, Tsumeb,

LOCATION OF SURVEY AREA
NORTHERN SOUTH WEST AFRICA



SCALE 1:8,000,000

0 100 200 300 400 500 Kilometres

Survey Area

TS 1/70
August 1970

R. F. Loxton, Hunting and Associates
Johannesburg

Outjo and Otjiwarongo districts. An upper elevation limit of 1,400 metres above sea level was established as a survey boundary, this limit being extended to the 1,500 metre contour in the vicinity of Grootfontein and Tsumeb. Absence of aerial photographic mosaics at the time of field work prevented the mapping of an area to the south west of Otjiwarongo,(Sheet 12 of the 1 : 250,000 map.) This omission, occasioned by the necessity to proceed with the field work at the earliest possible date, can be made good only by means of further field surveys. Fortunately, the area not mapped is that most distant from major sources of irrigation water.

A number of other soil and resource surveys have been undertaken in South West Africa, most of them with reference to irrigation potential. For ease of reference we list the Reports concerned :-

Nov. 1965	Report on the Reconnaissance Soil Survey of the Ovamboland Irrigation Scheme, S. W. A. Ref: TS/30/65 : S. W. A. Admin., Water Affairs Branch.
Apr. 1966	Report on the Reconnaissance Soil Survey of the Omaruru State Water Scheme, South West Africa. Ref. TS/14/66 : S. W. A. Admin., Water Affairs Branch
Nov. 1966	Reconnaissance Survey of Riparian Soils on South Bank of Lower Cunene River. Ref: TS/15/66 : S. W. A. Admin., Water Affairs Branch
Sep. 1966	Report on the Reconnaissance Soil Survey of the Naute State Water Scheme, S. W. A. Ref. TS/30/66 : S. W. A. Admin., Water Affairs Branch
Nov. 1966	Report on the Preliminary Soil Survey of the Ovamboland Irrigation Project, S. W. A. Ref. TS/45/66 : S. W. A. Admin., Water Affairs Branch
Feb. 1967	Report on a Reconnaissance Soil Survey of Okavangoland with Particular Reference to the Riparian Lands Ref: TS/34/66 : S. W. A. Admin., Water Affairs Branch
Jun. 1967	Report on the Reconnaissance Soil Survey of the Calueque Dam Basin, Lower Kuenen River Ref: TS/44/66 : S. W. A. Admin., Water Affairs Branch
Apr. 1967	Report on a Preliminary Survey of the Natural Environment of the Agricultural Resources of Ovamboland. Ref: TS/1/67 : Department of Bantu Admin. & Development
Mar. 1967	An Economic Assessment of the Proposed 4,000 Hectares Irrigation Project. Supplement to the Report on a Reconnaissance Soil Survey of Ovamboland (TS/4/67) Ref: TS/8/67: S. W. A. Admin., Water Affairs Branch
May, 1967	Report on an Agronomic and Management Study of the Proposed First Phase Irrigation Areas in Ovamboland - Supplement

Ref. TS/4/67 : S. W. A. Admin., Water Affairs Branch.

Jun. 1967 Report on a Land Valuation Inspection of the Calueque Dam Basin.
Ref: TS/16/67 : S. W. A. Admin., Water Affairs Branch

METHOD OF SURVEY :

Essentially, the survey was a broad reconnaissance exercise to acquire results in a short space of time. Our techniques were determined accordingly, account also being taken of the great extent of the area, the poor road coverage over much of it and the absence of topo-cadastral maps for a large block of country in the centre.

In the first instance aerial reconnaissance of five days duration was undertaken over the whole area to obtain both a broad appreciation of the terrain and soils and to determine suitable ground traverses. Using photo interpretation techniques, base maps were produced for those portions of the survey area for which no topographic maps in the 1 : 250,000 series are available. Aerial photo mosaics for the survey area were then prepared in our laboratories and annotated for orientation in the field. Subsequently, four teams spent over a month on continuous soil survey on the ground, in the process collecting some 1,200 soil samples for laboratory study. Contact by radio telephone enabled the field parties to discuss technical problems encountered each day and to accomplish the necessary correlations of mapping units in the field.

The soil samples collected in the field were analysed in our laboratories and the final mapping was completed by photo interpretative extrapolation of field observations and analytical results.

CLIMATE

The climate of the survey area ranges from arid to sub-arid, with features characteristic of southern hemisphere, west coast, continental areas. Thus there is a dry coastal belt and a somewhat more humid interior; there are distinct moist and dry seasons with rains occurring in summer; the diurnal temperature range is high and ratios of evaporation to precipitation are wide.

RAINFALL:

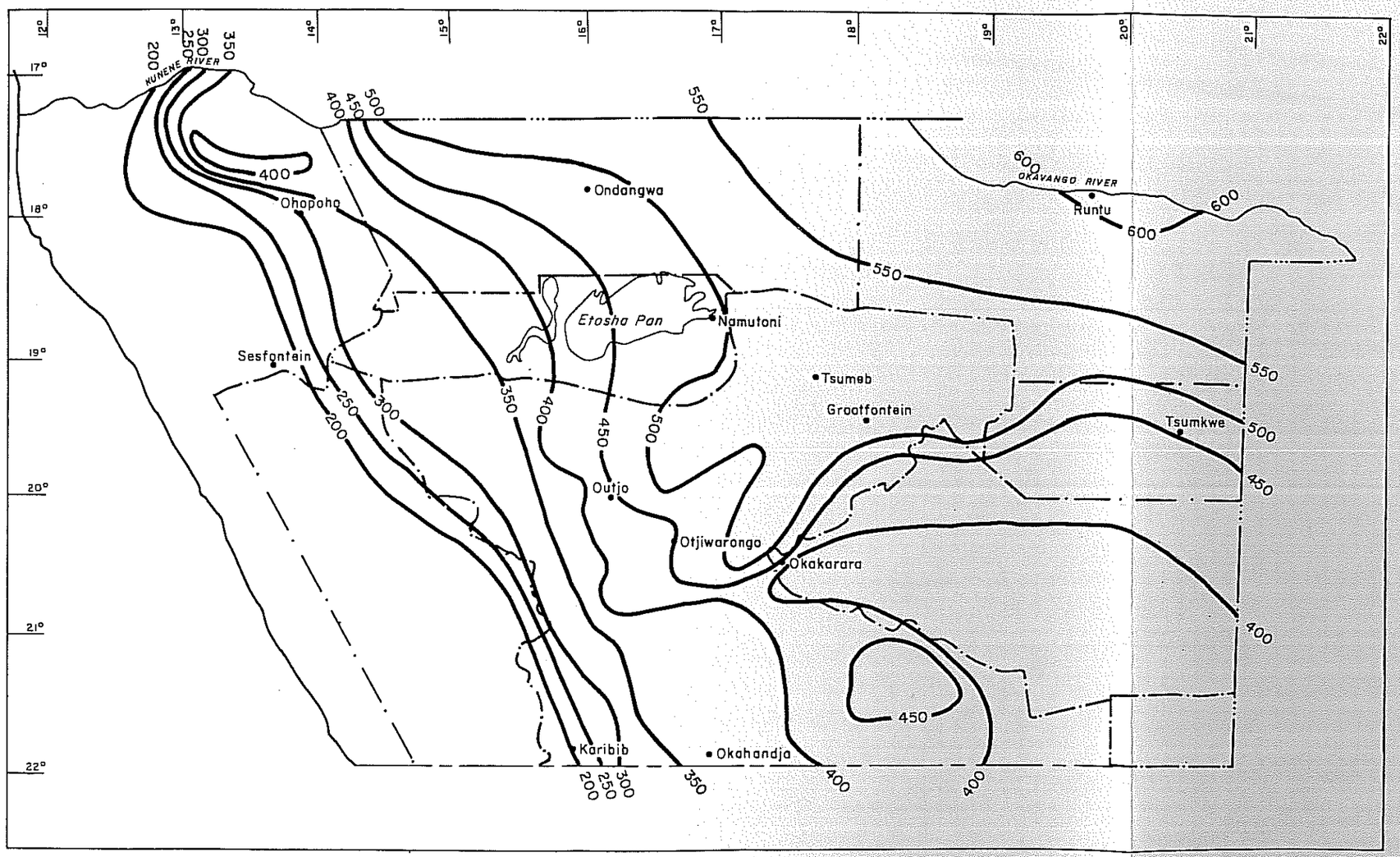
Rainfall increases generally from south west to north east, the curves of the isohyets bulging south westwards where the central highlands attract increased precipitation. Mean annual rainfall varies from less than 200 mm in the Kaokoveld to a little more than 600 mm in north eastern Okavango-land in the vicinity of Runtu. Most of the survey area receives between 300 and 550 mm per annum on average, the moisture concerned deriving almost entirely from trans-continental winds from the Indian Ocean. The contribution of the Atlantic Ocean to the rainfall of the area is negligible and the rainy season is accordingly limited to the summer months from November to April. Character-istic of the rainfall is its variability and incalculable nature, droughts and floods occurring regularly, with no cyclical pattern being apparent according to the available statistics.

A small scale rainfall map is presented in Fig. 2. The isohyets on this map have been drawn on the basis of official rainfall statistics for those areas for which statistics are available in Angola, Botswana and South West Africa; for the remaining areas the isohyet lines constitute estimates based on the nature of the soils, vegetation and topography.

TEMPERATURE :

Temperatures in the survey area are conditioned by elevation, and mean temperatures are generally lower than the latitude would suggest. Summer day temperatures are, however, high, with temperatures in excess of 100°F being often recorded. Summer nights are warm but in winter frost occurs regularly in most parts of the survey area except in the north where it is experienced occasionally in some years. The large diurnal temperature range increases generally from south to north.

NORTHERN SOUTH WEST AFRICA
MEAN ANNUAL RAINFALL IN MILLIMETRES



SCALE 1:4000000

0 100 200 300 400 KILOMETRES

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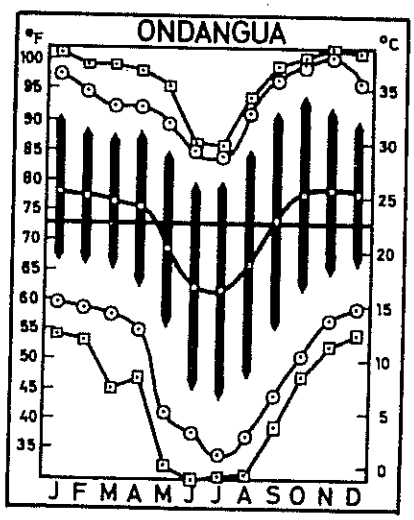
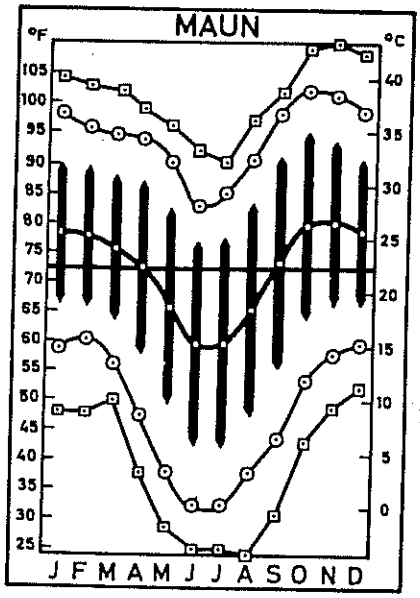
TEMPERATURE REGIMES





Temperature

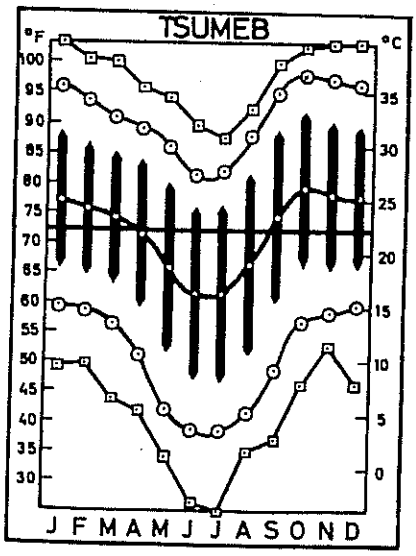
Absolute highest and lowest

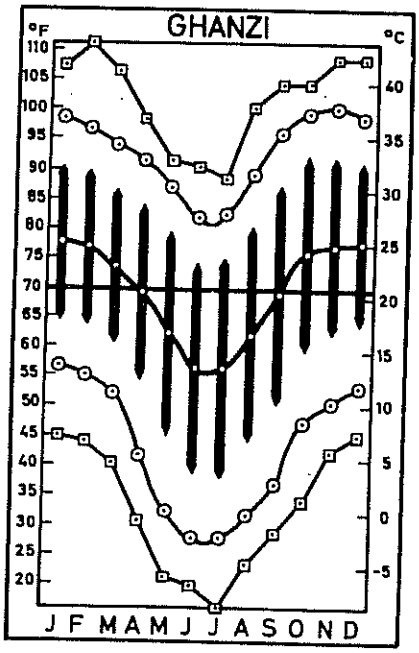
Mean daily max. and min.

Mean annual

Daily mean

Mean diurnal range





The graphs in Fig. 3, extracted from a Weather Bureau Report, depict the main features of the temperature regime at two stations in the area. There being no temperature figures for the south eastern zone, data for two Botswana stations to the east of the survey area have been included.

EVAPORATION

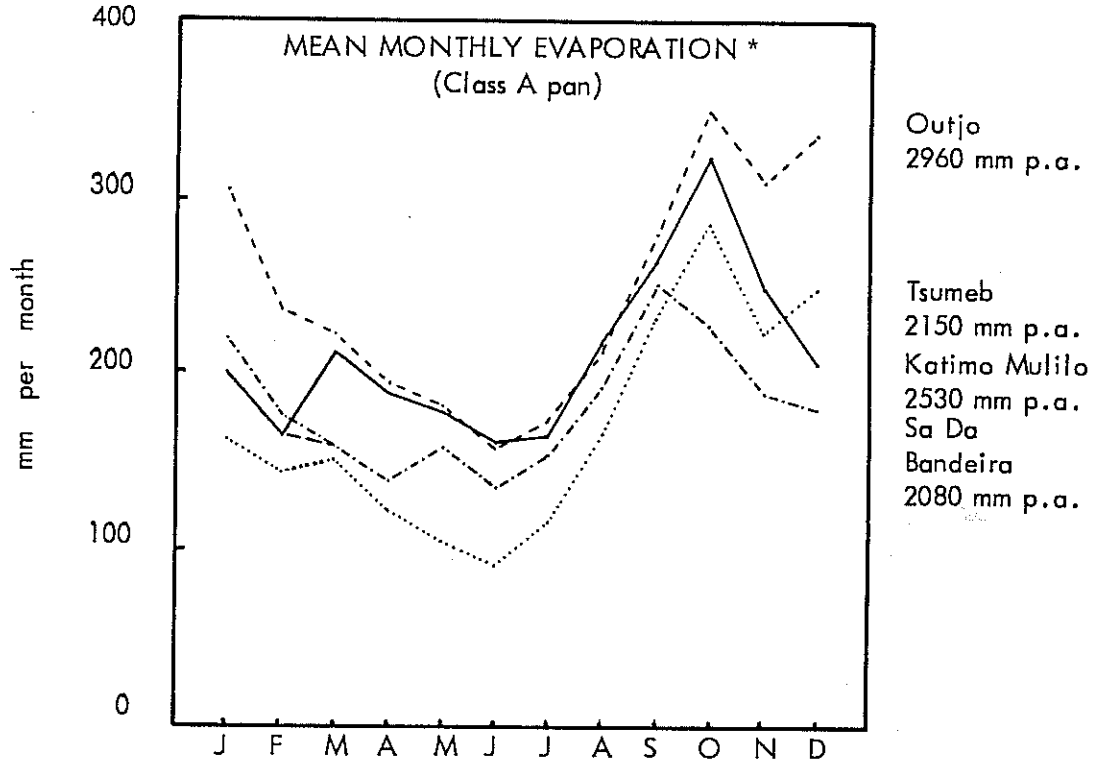
Data for evaporation and evapo-transpiration are vital to the planning of irrigation schemes, including cropping and irrigation practices; such data also constitute useful aids to an understanding of the soils and their seasonal moisture status. Unfortunately, there is a dearth of recorded information on evaporation in the survey area. The need for more local research and environmental assessment is apparent. Data from the only evaporation pans in the area for which several years records are available (8 years) are set out graphically in Fig. 4; included are records from Sa Da Bandeira in Angola and Katimo Mulilo in the Caprivi. Having regard to other climatic factors, such as wind and temperature, and in the light of evaporation rates elsewhere, we consider that the typicality of the Tsumeb figures is questionable. It could be that evaporation at that station has been reduced by hills, trees or other obstacles.

Evaporation in the survey area increases generally from north to south. Maximum water losses occur in October while evaporation is at its lowest in mid winter.

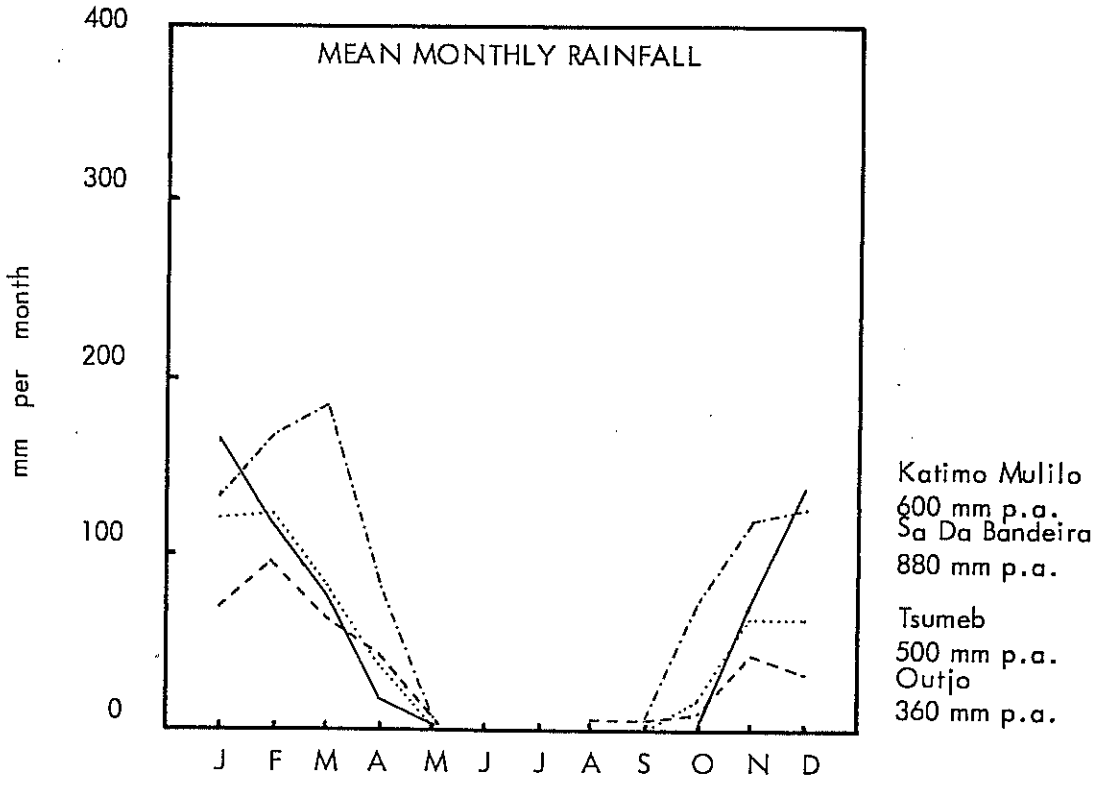
It is of interest to compare moisture accruals as rainfall with losses by evaporation and we have accordingly included in Fig. 4 rainfall data for the same four stations.

FIGURE 4

EVAPORATION AND RAINFALL



* Outjo, Tsumeb, Katimo Mulilo 8 yrs to 1968
Sa Da Bandeira 4 years to 1969



RELIEF AND DRAINAGE

The small scale map in Fig. 5 gives an indication of the general configuration of the survey area and the main directions of surface drainage. The scale precludes accuracy for the more broken country.

Essentially the survey area consists of a belt of escarpment mountains in the west and two vast elevated plains, separated by a central highland area. Altitude ranges from 700 metres a. s. l. in the deeper valleys of the Kaoko-veld to peaks approaching 1,800 m. in height in the mountain ranges of the north west. Water can be abstracted by gravity from the main peripheral sources in the north (the Kunene and Okavango rivers and the Cuvelai drainage system) at altitudes of approximately 1,050 to 1,100 metres. Most of the utilizable soils of the region lie below the 1,400 metre contour line.

The western mountain belt is strongly dissected and broken, being incised by numerous juvenile river systems falling rapidly and draining westwards through the Namib desert to the Atlantic Ocean. Much of this mountain country is too high, rocky, steep or fragmented for irrigation development, the only areas presenting opportunity for arable cultivation being the broader valleys, but in many of these, the dendritic drainage pattern would present problems in irrigation. Most of the deeper valleys on the western side of the mountain belt have been filled with loose aeolian sand originating from the Namib.

The highly saline Etosha Pan forms a central sump of the inland drainage system in the western plains. The main water inflow to this one-time inland lake is occasional floodwaters from the Cuvelai drainage system, rising in Angola. Concensus of opinion is that river capture by the Kunene has made Etosha a relict feature.

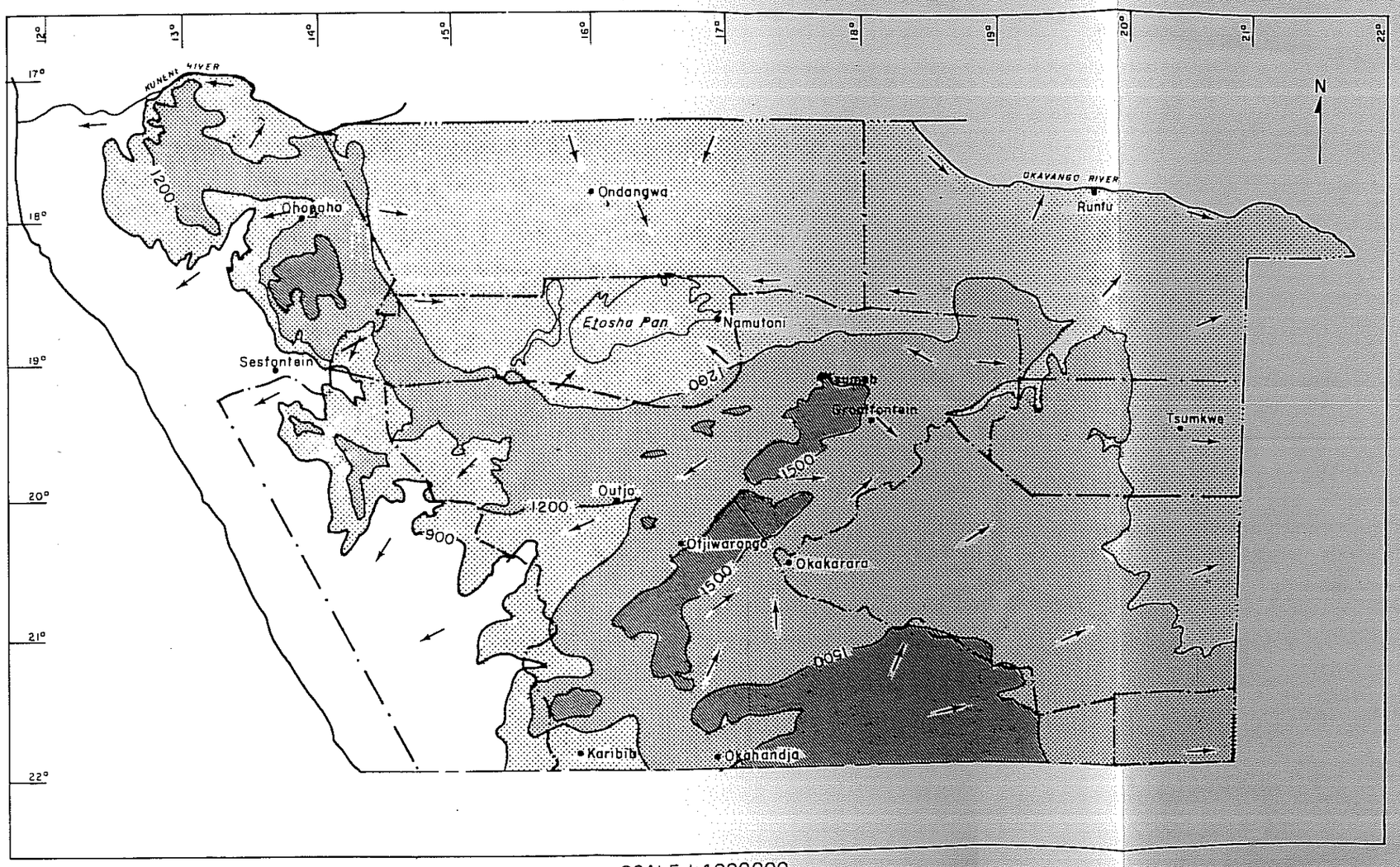
The central highlands, which constitute a water divide between the western and eastern plains, have a south west - north east axis, terminating in outlier hills north of Grootfontein. The region is drained mainly to the east but also to the west by well defined omurambas, chief of which is the Omatako Omuramba "flowing" north east with a very gradual fall to the Okavango river.

The eastern plains of Kalahari sand embracing Okavangoland, Bushmanland and Hereroland, slope gradually to the north east 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

FIGURE 5

NORTHERN SOUTH WEST AFRICA
RELIEF AND DRAINAGE

(FORM LINES AT 300 METRE VERTICAL INTERVALS)



SCALE 1:4000000

0 100 200 300 400 KILOMETRES

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large tracts of the Kalahari Sandveld, surface drainage is imperceptable or non existent. The largest of such area is a broad belt of country to the immediate east of the Omatako omuramba in Hereroland and Bushmanland. Prominent in the eastern and northern parts of the Kalahari sand zone are extensive sub-regions of large,stable linear dunes - seif dunes - with an east-west orientation. Another distinctive topographical feature of this physiographic region is the Aha Mountains on the eastern border. More in the nature of low hills, these outcrops give rise to soils of higher potential than the surrounding sands.

Major topographical features of possible relevance to the planning of water reticulation include :-

a) the almost straight north-south direction of the 1,150 metre contour running southwards from the Ruacana area on the Kunene river;

b) the flatness of central Ovamboland and the contour line circumscribing Etosha Pan at about 1,100 metres;

c) the proximity of the uppermost reaches of some Kaokoveld river systems to the 1,200 metre north-south contour line, and

d) the well-developed, gently sloping valley of the Omatako, connecting the central zone with the Okavango river in the north.

GEOLOGY AND GEOMORPHOLOGY

A simplified geological map of South West Africa is shown in Fig. 6.

The oldest rocks occurring within the northern and central areas are those belonging to the Epupa, Huab and Abbabis formations. These formations consist predominantly of metasediments and metavolcanics with associated crystalline gneisses and granites. Occurring in southern Angola and extending just south of the Kunene River into South West Africa is a roughly layered anorthositic mass, the Kunene Basic Complex, which may have resulted from the differentiation of an igneous intrusion.

Unconformably overlying the basement formation (Huab) in the Kamanjab area of the Outjo District are metaquartzites, phyllitic slates and porphyries and tuffs, collectively labelled the Khoabendus formation.

The greater portion of the northern and central areas is underlain by sediments belonging to the Damara System which were deposited under geosynclinal conditions and orogenically deformed and intruded by syn - to post-tectonic granites in later Pre-cambrian to early Cambrian times.

In the Otavi Mountainland area, where the sediments are comparatively unmetamorphosed, the Damara System is represented by coarse clastic sediments of the Nosib formation followed by dolomites, limestones with subordinate shales, quartzites and arkoses and a tillite horizon (Chuos) of the Otavi Series. Succeeding felspathic quartzites and dolomites have been grouped in the Mulden Series.

In the Kaokoveld and central areas, the Nosib formation is intermittently developed and is overlain by a great thickness of crystalline limestones, dolomites, para-amphibolites and graphitic schists of the Hakos Series. Overlying biotite schists, quartz-mica schists and micaceous quartzites belong to the Khomas Series.

The Damara System exhibits two dominant structural trends : a north-northwesterly trend in the Kaokoveld area and a northeasterly trending direction in the central area.

Remnants of the Karroo System, represented by tillite (Dwyka), shales, mudstones, sandstones and basaltic lavas are found discordantly overlying the Damara System along the northwestern coast and in the central areas.

FIGURE 6

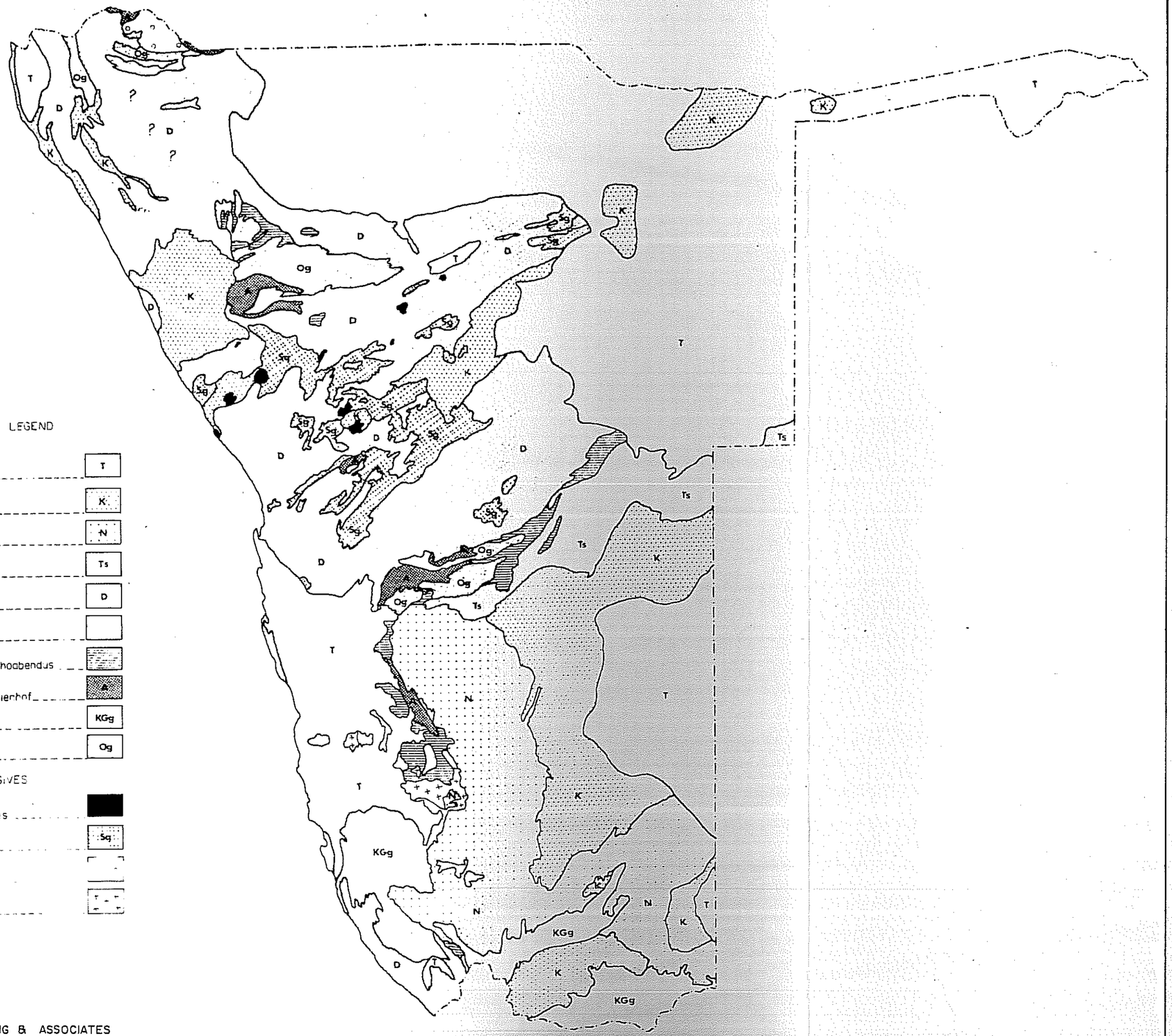
GEOLOGICAL MAP OF SOUTH WEST AFRICA

GEOLOGICAL LEGEND

Tertiary	T
Karroo	K
Nama, Numees, Kaigas	N
Tsumis, Bushmannsklippe	Ts
Damara, Nosib, Gariep	D
Auborus	
Kapok, Dordabis, Konkip, Khoabendus	
Abbabis, Haub, Epupa, Marienhof	A
Kheis & Grey Gneiss	KGg
Older Granite-Gneiss	Og

INTRUSIVES

Post Karroo Intrusives	
Salem Granite	Sg
Kunene Basic Complex	
Post Nagatis Granite	



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The northern to eastern portions of northern South West Africa are overlain by younger sedimentary formations (Kalahari) of Tertiary to Recent ages.

The juxtaposition of the younger geological formations and the landscapes and soils developed on them reflect changes in past climate, from pluvial periods to desert conditions, when water and wind were the dominant erosive agents respectively. Also reflected are periods of aggradation and periods characterised by the large scale removal of material from the survey area.

Four erosion surfaces have been recognised, occurring at distinct elevations: relicts of an ancient Gondwana surface occur atop the hills in the Tsumeb-Grootfontein area and in the northern Kaokoveld, while much of the central highlands and the kalkveld reflect a late Cretaceous - Tertiary surface - African surface. At a lower elevation, the Etosha pan area and the Etaka and Cuvelai drainage basin represent a post African (Quaternary) erosion surface. At still lower levels the deep valleys of the Kaokoveld have been identified as a Plio-Pleistocene surface.

The largest aggradational land surface in the survey area is the Kalahari Sandveld, (including outliers in Ovamboland), in which authorities are increasingly differentiating the aeolian sands into two groups - the true Kalahari sands of Tertiary age, and younger red sands and later redistributed sands. A minor area of accumulation of material occurs to the west and north west of Etosha Pan, where recent wind blown sand has accumulated.

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 in the survey area are of the hardpan, boulder or honeycomb types. No gypsum calcretes were encountered. Skirting the Central Highlands, except to their south, is a broad apronlike zone where these calcretes and silcretes outcrop or lie near the surface, giving rise to the name "Kalkveld". To the west the calcretes give way to the hard rock formations of the Kaokoveld while to the north west, north east and east they gradually disappear under the aeolian sands.

In relatively recent times, subsequent to the aggradational phase, there were at least two further changes in climate which influenced landform and soil development. In the north eastern and eastern parts of the survey area occur extensive areas of massive seif dunes, now stabilised by vegetation, which were

formed under arid conditions by easterly winds. Subsequently, in a wetter period, possibly under climatic conditions similar to those presently obtaining, water from the Central Highlands draining westwards and north-westwards promoted dissection of these dunes to form the main omuramba valleys of Hereroland, Bushmanland and Oakvangoland. In the case of the omurambas draining towards Botswana the depth of 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 sand commonly fringe omurambas, being more pronounced on southern and eastern banks, indicating the action of north westerly winds. The depth of the sand mantle in 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.

Three broad geomorphological regions are thus recognised in the survey area - the "hard" country of the western mountains and central highlands, the Kalkveld where calcretes are exposed or lie near the surface, and the Sandveld of the Kalahari. Major extraneous elements in these regions of significance in relation to soils are :-

a) deposits of Namib sand which carpet the valleys of the western margin of the Kaokoveld,

b) exposures of Ghanzi group rocks in the Rietfontein block,

c) outcrops of constituents of the Damara System that form the Aha Mountains in the eastern Kalahari, and

d) recent accumulations of wind blown material in the north western portion of the Etosha Game Park and south western Ovamboland, containing both aeolian sand and weathered products of calcrete.

VEGETATION AND SOME SOIL-VEGETATION RELATIONSHIPS

For the purpose of this Report, concerned as it is with a reconnaissance soil survey, we do not deal with the vegetation of the area in depth. The many vegetation types of the survey area are accordingly aggregated in eight broad groups which are depicted on the small scale map in Fig. 7.

1) MOPANE SAVANNA

The mopane (Colophospermum mopane) dominates the vegetation of of this region except on mountain slopes, on recent alluvia, and in low-lying areas where frost has restricted the growth of the species. Other locally important substituents include Terminalia prunioides, Commiphora spp., Combretum spp. and Dichrostachys cinerea, the latter being especially common in disturbed sites. On the recent alluvia, Acacia spp., especially A. albida commonly form an Open Woodland. Mopane is ubiquitous in relation to the soils on which it is found, occurring on a wide range of soil types. Almost dense stands of Mopane Woodland to Open Woodland occur on the saline solonetz soils and on the black clays and calcareous soils it occurs most often in the coppice or shrub form, (as distinct from the Short Woodland in the dry western Kaokoveld where growth is stunted but still takes the tree form).

2) MOUNTAIN SAVANNA

Occurring extensively in the mountains within the Mopane Savanna region and in and around the mountains of the Tsumeb - Grootfontein - Otavi triangle, is a Mixed Open Woodland vegetation dominated by Kirkia acuminata, Gyrocarpus americana, Sterculia africana, Pachypodium lealii, Cyphostemma juttae and Croton and Commiphora species.

The flats skirting the hills, which are of greater significance from the point of view of irrigation potential, carry Open Woodland in which common species are Sclerocarya caffra, Spirostachys africana, Peltophorum africanum, Dichrostachys cinerea, Combretum apiculatum and Acacia and Heeria species. Where the "huilboom" (Peltophorum africanum) is a major constituent, the soils are commonly shallow.

3) PALMVELD

Lying between the aeolian sands to the east and the hills near Grootfontein is a boomerang shaped strip of "palmveld" occurring on shallow soils on calcrete and silcrete. Other small outliers of palmveld were found in Bushmanland. This vegetation type is characterised by the presence of the tall and prominent palm Hyphaene ventricosa in Medium to Short Open Woodland. The presence of palms is normally indicative of shallow dark coloured soils, occasionally saline, and normally of low potential for irrigation. In the northern part of the Palmveld - the Ondangua - Oshakati area - the palms are confined to the sandier phases of the solonetz soils.

4) ETOSHA PAN WITH DWARF SHRUB FRINGE

This vegetation type embraces Etosha Pan and its environs. The pan itself is largely bare of vegetation. It is fringed by a belt of Dwarf Open Woodland in which common species are Acacia nebrownii, Monechma tonsum, Lecosphaera bainesii, Petalidium englerí and Salsola tuberculata.

5) THORNVELD

This extensive vegetation type, which includes many variants, is dominated by Acacia species of which the most common are Acacia mellifera ssp. detinens, A. hebeclada, A. reficiens, A. tortilis ssp. heteracantha, A. erubescens and A. fleckii. It replaces the Mopane Savanna south of Etosha Pan where, no doubt due to the incidence of frost, the latter cannot survive.

6) NORTHERN KALAHARI WOODLAND AND OPEN WOODLAND

In the survey area this vegetation type occurs on aeolian sands in southern Okavangoland, Bushmanland and, to a lesser extent, in the north-western corner of Ovamboland. Physiognomically the type ranges from Medium to Tall Open Woodland and Woodland. Important constituents of economic value are Pterocarpus angolensis and Baikiaea plurijuga. The dominant tree is Burkea africana, with which is usually associated Terminalia, Combretum and Grewia species. Other common species are Lonchocarpus capassa, Guibourtia coleosperma and Ricinodendron rautanenii.

In this region the better stands of tall trees usually occur on those phases of Fernwood sands that have the lowest agricultural potential. It would appear that because of the poor water-holding capacity and nutrient status of these nearly white loose sands, a less luxuriant grass cover develops which is less subject to hot burns than the denser sward on more fertile soil types. Fire damage to trees is accordingly a less frequent occurrence and the fires that do occur are less damaging - better tree growth results. This inverse relationship between inherent soil potential and tree development in the sandveld also obtains in the central Kalahari area (Hereroland), but is less pronounced there.

The rare areas of Grassland and Wooded Grassland in this vegetation region occur only on heavier bottomland soils, some of which are saline.

7) CENTRAL KALAHARI OPEN WOODLAND

The sandveld vegetation of most of Hereroland and Ovamboland is typified by a Mixed Open Woodland ranging from Short Shrub Open Woodland only a few feet tall to Tall Open Woodland attaining a height of 35 feet. Fire has played a dominant role in the determination of the current physiognomy and successional stage of the vegetation in any one locality. Dominant species are Terminalia sericea and Combretum spp. with which are commonly associated Grewia spp., Ziziphus mucronata, Bauhinia mucrantha, Ochna pulchra and Acacia spp. Burkea africana is common in the northern part of the region but is rare to the south.

Within the many variants of the sandveld vegetation, associations dominanted by "vaalbos" (Terminalia) tend to occur on the lighter more pallid sands of low irrigation potential. Conversely, Combretum spp. are usually co-dominant with Terminalia on yellow-brown and red sands of the Sandspruit and Gaudam series, containing a little more clay and sesquioxides than the grey sands. "Rooibosveld", in which Combretum species are distinctly dominant, is usually indicative of shallow and somewhat heavier soils, with rock outcrops common.

The Terminalia - Combretum associations of the Kalahari sandveld tend to give way to associations dominated by Acacia species on heavier more fertile soils in bottomland sites and slight depressions, such as Omuramba

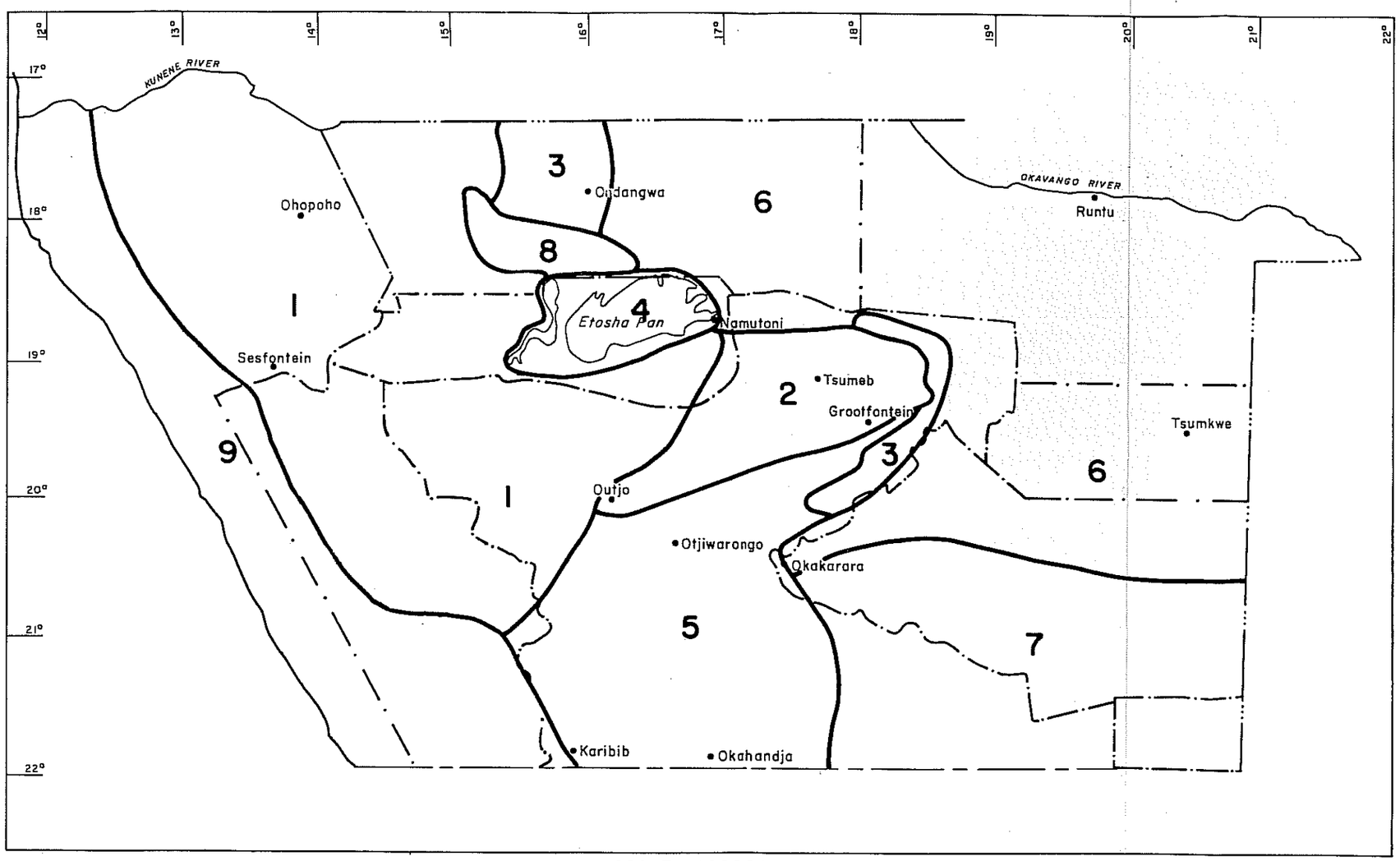
floors, interdune "straate", pans and incipient pans. Acacia patches on dune crests are usually indicative of red sands in Hereroland, while in western Ovamboland Acacia spp. are most common where the aeolian sand mantle overlies calcrete within about 3 to 10 feet.

Another soil-plant relationship of relevance to irrigation potential in this region is the tendency for shallow, markedly calcareous soils to carry stands of Tarchonanthus camphoratus and/or Catopharactes spp. often in association with Grewia flava.

8) EKUMA GRASSLAND

This vegetation type replaces the Cuvelai Palmveld of Geiss west of the Etaka - Oponono drainage system in southern Ovamboland surrounding the "lakes". Dominantly an Aristida spp. Grassland, it does contain a few woody elements in shrub form such as Peltophorum africanum and Commiphora spp. It occurs exclusively on duplex soils.

NORTHERN SOUTH WEST AFRICA
VEGETATION REGIONS



SCALE 1:4000000

0 100 200 300 400 KILOMETRES

1 Mopane Savanna

2 Mountain Savanna

3 Palmveld

4 Etosha Pan with Dwarf Shrub Fringe

5 Thornveld

6 Northern Kalahari Woodland and Open Woodland

7 Central Kalahari Open Woodland

8 Ekuma Grassland

9 Namib

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THE SOILS AND THEIR POTENTIAL FOR IRRIGATION DEVELOPMENT

SOIL CLASSIFICATION :

The National Soil Series Classification System has been used in this survey. This classification has been developed as a result of collaboration among the Soils Research Institute, University Departments, certain firms and individuals and our own Soils Division. It is based on the pedological definition of 31 Soil Forms which are broad groups of soils having the same defined sequence of diagnostic soil horizons down the profile. The Soil Forms are in turn divided into individual identifiable Soil Series, which are the building blocks of the classification. A Soil Series is a defined range of soil individuals having horizons similar as to differentiating criteria and arrangement in the soil profile. In the case of the Lindley Form soil series are aggregated into an intermediate grouping called the Soil Family. At the present time 243 Soil Series have been recognised and defined in Southern Africa and included in the national classification. At the more detailed level Series may be sub-divided into Phases but breakdown into Phases does not figure in this survey.

The Soil Forms, Families and Series in the National Classification have been given names, mostly place names, and non-pedologists concerned with agriculture, and particularly those associated with irrigation, will find it of assistance, irrespective of their particular discipline, to learn and use these names and to understand the main characteristics of the various soils. The degree of involvement in detail will depend on one' s function but the value of the designated list of names to inter- and intra-disciplinary functions is indisputable. For example, the name "Arcadia" will have various connotations to the botanist, the roads engineer, the economist, the pedologist and the administrator, but to all of them, "Arcadia" should denote a heavy black clay.

MAPPING UNITS :

The type of soil mapping unit used in soil surveys depends mainly on the detail of the survey and the map scale at which the data are presented. A highly detailed survey of an individual field or land might allow of mapping at the phase level, whereas a soil map of Africa would differentiate no more than the so-called great World Groups of soils, each containing many soil Forms and Series. This matter frequently leads to misunderstanding on the part of the non-pedologist,

who may expect to find all soils within a given map unit having the same characteristics.

In the case of this survey, which is a broad reconnaissance study with mapping at a scale of a : 250,000, the mapping units are necessarily associations of soils. Soil associations may and often do contain components of highly differing characteristics, but the composition of each association in terms of soil Forms and Series is defined in the map legend, and all like-numbered associations can be expected to have the same composition of discrete soils.

In this chapter is given a general review of the more important soils encountered, including comments on their irrigation potential: in Chapter 8 there is a discussion on soils and parent materials in relation to physiographic regions. In Table 2 are summarised the characteristics and properties of the more important soil series in the survey area. A summary of Recommended soil associations in relation to ethnic and administrative districts in the survey area is presented in Table 3; approximate location of areas of interest is shown in Fig. 11.

GENERAL REVIEW OF THE SOILS :

For the purpose of discussion the soils are grouped under the following headings :-

1) Black clays
2) Duplex soils
3) Clay pan soils
4) Gradational dark coloured soils
5) Aeolian sands
6) Red pediment soils
7) Lithosols and other soils.

Morphological descriptions and analytical data of representative soil series are given in the Appendix.

1) Black Clays

Only two soils eries, viz. ARCADIA and PAFURI, falling within the limits of this group were mapped. They differ from each other largely in the properties of the clay present. ARCADIA is a strongly expanding soil while PAFURI is only weakly expansive. Both occur exclusively in association with

calcrete in flat or depressed sites.

ARCADIA, normally a jet black soil, (black turf), has a self-mulching surface which is spongy underfoot. Although these soils are often too shallow to develop slickensides, their highly expansive properties are manifested by wide cracks in the dry state and in the "spewing out" of calcrete stones. Often the soil surface is quite stony with calcrete lumps which have been forced to the surface. In places soils mapped as ARCADIA exhibit only weakly self-mulching surface properties but since no crusting was evident such soils were not mapped separately (GELYKVLAKTE is the crusting analogue). Most of the ARCADIA soils are saline or nearly saline. The new National Classification no longer distinguishes soils on the basis of salinity at the series level, and the old ETAKA series thus became incorporated in ARCADIA. Soils of Arcadia series are difficult to work and the range of moisture content during which they can be ploughed is rather narrow. However, under certain circumstances, their self mulching characteristics can constitute an aid to cultivation. Infiltration rates on moist soils are very slow and it is not until the soils have cracked and crops are suffering from moisture deficiency that a reasonable rate of water infiltration can be achieved. Soils of Arcadia series tend to have a rather inefficient moisture regime because not only are relatively large quantities of water required to bring them to field capacity but also the availability of water in the drier range of moisture content is relatively low. Where a high standard of management can be ensured and the leaching requirement fulfilled (to control drainage and potential salinisation), the ARCADIA soils of the survey area could be irrigated to advantage.

PAFURI series is a very dark greyish brown to black sandy clay. The surface eight inches or so consists of a loose mass of "crumbs". This self-mulching surface overlies a weak blocky, fairly permeable subsoil on calcrete. Since these soils occur exclusively in arid areas, little is known concerning the stability of their self-mulching properties under cultivation. If they react like ARCADIA, cultivation will not destroy this agriculturally important property. Every care must be taken in working PAFURI not to puddle the soil since, should the self-mulching characteristics be destroyed, these soils could develop into very poor clay pan soils (c.f. LINDLEY series). PAFURI has a more efficient water regime than ARCADIA and in its natural state is easier to work. It is nevertheless a difficult soil to manage under irrigation and standards of management, leaching and drainage, similar to those necessary for ARCADIA, are required for its successful utilization.

2) Duplex Soils

An important feature of Duplex soils is the abrupt transition between a coarse textured surface horizon and a dense, slowly permeable B horizon, frequently with prismatic to columnar structure, occurring at variable depth below the surface.

The important series which have been identified and mapped are MOZI, ELIM, MECANHELAS and MKAMBATI. The three former series are solonetz soils (ESTCOURT Form) whereas MKAMBATI is a moist duplex soil of the Kroonstad Form. MAHANENE is a wet analogue of ELIM and occupies very gentle depressions which are subject to flooding during the rainy season.

Due to high salinity at depth, drainage impedence in the profile and low relief, these soils are not recommended for irrigation. However, a major research programme is currently being conducted at the Mahanene Research Station where attempts will be made to accomplish reclamation of the less severe forms of the solonetz soils, in particular the ELIM series. Rice will also be attempted on the Mahenene series.

3) Clay Pan Soils

Two very similar soils, VALSRIVIER and LINDLEY, fall in this group. These soils have a clear transition from a dark coloured surface horizon to an equally dark coloured, dense, extremely hard B horizon. VALSRIVIER has a sandy clay loam B while LINDLEY has a sandy clay B; both are calcareous at depth. They occur in fairly flat landscapes associated with black clays or in well developed drainage lines.

These soils have a high salinity hazard and in many places they are naturally saline. The immediate subsoil is dense and impermeable while the deeper subsoil, especially in the calcareous zone, is less so. Clay pan soils react like solonetz soils under irrigation and should not be irrigated.

4) Gradational Dark Coloured Soils

Of the soils of the LINDLEY Form those of the OAKLEAF FAMILY, have the best irrigation potential. The B horizons are not well developed and are consequently fairly permeable considering the texture and nature of the clay minerals present. The calcareous examples OKAVANGO, CALLEQUE and LIMPOPO are commoner than the non-calcareous LEVUBU and JOZINI.

OKAVANGO, CALLEQUE and LEVUBU have a loamy sand to sandy loam (6-15% clay) subsoil; OKAVANGO and LEVUBU have medium sand dominant, while CALLEQUE has coarse sand dominant. LIMPOPO and JOZINI have sandy loam to sandy clay loam subsoils (15- 35% clay).

As Oakleaf family soils often occur in low-lying sites or on flat plains of poor drainage, they rate a moderate salinity hazard. However, with the provision of drainage works, development of salinity can be avoided. Available water-holding capacities are good, the best for this type of soil probably occurring in the 10 - 20% clay range (which straddles the series boundaries). Infiltration rates are rapid for the lighter textured members and moderate for the heavier ones.

In places these soils overlie calcrete at fairly shallow depths and the individual associations have accordingly been downgraded. With adequate drainage even these shallower phases can be irrigated since they are seldom shallower than 18 inches and the underlying calcrete is usually not continuous, and not limiting to penetration by roots' and water.

Under irrigation ploughsole may develop and should be guarded against by varying the depth of ploughing and avoiding the puddling of the topsoil.

5) Aeolian Sands

These soils fall into three Forms, the grey FERNWOOD Form, the yellow CLOVELLY Form and the red HUTTON Form. All have less than 15% clay.

For soils having the same clay content, the irrigation potential of these Forms conventionally decreases in the order HUTTON - CLOVELLY - FERNWOOD since this order conforms with decreasing subsoil drainage; but in the survey area, such hydromorphic manifestations appear to be relicts of previous wetter conditions no longer operative. Therefore, series of these Forms can be rated more in terms of equal clay content than in terms of morphology. However, in the Sandveld areas the clay content of the red sands is normally slightly higher than that of the yellow and grey sands, making the red sands somewhat superior in irrigation potential.

The soil series comprising the group of aeolian sands encountered in the survey area are listed below :-

SOIL TYPE	SOUTHERN OVAMBOLAND		BUSHMANLAND, HERERQLAND AND NORTHERN OVAMBOLAND	
	0-6% clay	6 - 15% clay	0 - 6% clay	6-15% clay
Red	ROODEPOORT	MANGANO	GAUDAM	ZWARTFONTEIN
Yellow	OVAMBO	ANNANDALE	SANDSPRUIT	MAKUYA
Grey acid	-	-	FERNWOOD	FERNWOOD
Grey alkaline	MOTOPI	MOTOPI	LANGEBAAN	LANGEBAAN

In general the sands of Southern Ovamboland and the Etosha Game Reserve are better than those of the north and west since they contain more clay in addition to being finer in grade of sands. There are also medium sands in Ovamboland andin the Etosha Game Reserve, especially where local admixture of other materials has taken place. Sandy soils with 6 - 15% clay are recommended for irrigation development. Some of these may be compared with the sands of the Vaal - Hartz Irrigation Scheme. Soils with less than 6% clay have been historically regarded as too sandy for irrigation, having low water-holding capacities though excessively rapid infiltration. International experience shows that these soils are now coming into common use. At present research is being undertaken in Zululand and at Mahanene in Ovamboland to develop techniques of economic irrigation of sandy soils. If, as a result of such research, techniques are evolved that will allow of efficient production under irrigation of sands containing 6% or less clay, a more favourable assessment will be possible of the irrigation potential of vast areas in South West Africa.

6) Red Pediment Soils

This group includes soils of the highest irrigation potential. Generally these are freely drained, easily managed soils. The optimum clay percentage is in the 15 - 25% range (represented by SHORROCKS (-)). The table below shows the range of clay present within each series of phase of the apedal, red pediment soils encountered :

SERIES/PHASE	CLAY PERCENTAGE
CHESTER	0 - 6 (coarse sand dominant)
PORTSMOUTH	6 - 15 (coarse sand dominant)
ZWARTFONTEIN	6 - 15 (medium sand dominant)
SHORROCKS (-)	15 - 25
SHORROCKS (+)	25 - 35
MAKATINI	35 - 55

CHESTER has a very low water-holding capacity (lower even than GAUDAM) and it is usually fairly shallow. It is not recommended for irrigation.

Depending on soil depth, PORTSMOUTH and ZWARTFONTEIN are recommended, the latter being the better of the two. SHORROCKS (-) and SHORROCKS (+) and MAKATINI are also recommended, the rating for deep soils decreasing slightly in that order. All these red soils have been down-graded where they overlie any material which impedes root or water penetration. It is the experience with ZWARTFONTEIN and SHORROCKS that a ploughsole which impedes root development forms gradually under irrigation where they are mismanaged. Ploughing depths should be changed periodically, and the soil ploughed deeply if a ploughsole developes. Soil puddling is to be avoided.

7) Lithosols and Other Soils

Two lithosols, MUDEN and MISPAH, were mapped. Both these are shallow soils overlying hard rock. MUDEN generally overlies calcrete while MISPAH overlies any other rock. These soils are seldom physically arable to any extent, MUDEN being perhaps the better of the two in this respect. Neither are recommended for irrigation due to their shallow depth, low total available moisture and impeded internal drainage.

The soils mapped as DUNDEE are generally coarse, sandy, stratified alluvia. These soils have a very low water-holding capacity and are not recommended for irrigation.

Strictly speaking the DUDFIELD of the survey area is an intergrade between DUDFIELD and LIMPOPO. It is often too dark to be classified as

DUDFIELD but is lighter coloured than the normal LIMPOPO. It occurs on flat plains, often devoid of tree growth, with a succulent shrub vegetation. These soils are often so saline that a salt crust forms on the surface. Under normal conditions such soils would not be used for irrigation. With special irrigation techniques and salt tolerant crops such soils have been made productive in the Middle East, but under the circumstances obtaining in South West Africa, they are not recommended for irrigation.

TABLE 2 : SCHEDULE OF MORE IMPORTANT SOIL SERIES

SOIL SERIES	GENERAL DESCRIPTION	ASSOCIATED LANDFORM AND PARENT MATERIALS	IRRIGATION CHARACTERISTICS AND SPECIAL PROBLEMS	IRRIGATION RECOMMENDATIONS
ANNANDALE	A CLOVELLY Form soil; yellowish brown loamy fine sands to fine sandy loams (6-15% clay) with slight darkening of the surface by organic matter; generally deep, rarely saline	Gently undulating Ovamboland Sandveld; derived from aeolian sand; a fairly common soil	Low salinity hazard; generally 6 - 10% clay and a somewhat low water-holding capacity; very rapid infiltration rates; the Vaalhartz Irrigation Scheme is based on soils of similar physical characteristics	Recommended
ARCADIA	An ARCADIA Form soil; highly expansive black clays; weakly to moderate self-mulching; prominent heaving characteristics; frequently saline or nearly saline. Some non self-mulching soils - GELYKVLAKTE series - were mapped as ARCADIA	Most common on flat calcrete plains, especially where site is slightly depressed; also found in local depressions, pans and drainage lines throughout the area	Moderately high salinity hazard; slow infiltration rates once soil is moist; difficult to manage; in Mocambique and the Rhodesian Lowveld similar soils are irrigated	Marginal
CALLEQUE	A LINDLEY Form soil of the Oakleaf family; generally fairly deep; very dark brown loamy coarse sands to coarse sandy loams with a weakly differentiated B horizon; calcareous at depth	Found only in depressed sites, often overlying calcrete, in the Kalahari Sandveld. Formed by a process of wind "blowhole" development combined with lateral movement and accumulation of clay	Moderate salinity hazard due to site; moderate to moderately low water-holding capacity; rapid to moderately rapid infiltration rates; in places underlying calcrete impedes drainage. Physiographic drainage is often poor.	Marginal to Recommended
CHESTER	A HUTTON Form soil; generally shallow red sands (less than 6% clay) overlying weathering granite or conglomerate boulders	A rare soil of the western regions on gently sloping plains characterised by strongly developing juvenile streams; dissected but of low relief	Very low salinity hazard; low water-holding capacity; very rapid infiltration rate; variable impedance. Large areas are not physically arable	Not Recommended

DUDFIELD	A CLOVELLY Form soil; the soils mapped as Dudfield are not always Clovelly Form - they grade into the Oakleaf family; a grey brown sandy loam to sandy clay loam overlies a weak blocky, brown to dark yellowish brown sandy clay loam which overlies calcrete, at times at fairly shallow depths; often very saline	A fairly common soil in the Kaokoveld on broad, flat alluvial plains	High salinity hazard; infiltration somewhat slow, generally impeded at depth. Using saline water, salt tolerant crops could be grown on these soils	Not Recommended
DUNDEE	A DUNDEE Form soil; undifferentiated sandy stratified alluvia	Only encountered to any extent on levees of the larger rivers in the Kaokoveld	Low salinity hazard; very low water-holding capacity; very rapid infiltration rate	Not Recommended
ELIM	An ESTCOURT Form soil; solonetz soils; a grey sand abruptly overlies a dense, grey, loamy sand to sandy loam usually within 12 inches of the soil surface	Extensive in Ovamboland in the vicinity of the central Oshana Etaka	High salinity hazard; severely impeded drainage	Not Recommended
FERNWOOD	A FERNWOOD Form soil; generally deep, grey sands with less than 6% clay; at times a brown phase with up to 12% clay was encountered; differs from Langebaan only in its acid reaction	Occurs mainly in the Kalahari Sandveld on flat topography or in lower slope positions in the dune country	Commonly non saline; generally very low water-holding capacity; excessive infiltration rate	Marginal pending further research
FERRY	A SHORTLANDS Form soil; red, moderate coarse blocky, sandy clay to clay; calcareous at depth	A rare soil found in low-lying positions in alluvial or colluvial plains in the Kaokoveld	Moderate salinity hazard; slow infiltration rates; fairly difficult soils to manage	Marginal
GAUDAM	A HUTTON Form soil; generally deep red sands with less than 6% clay; some examples of Joubertina which differ from Gaudam only by having a lower base status, were mapped as Gaudam	Common in the Kalahari Sandveld regions in freely drained sites such as dune crests and steeper sloping margins of Omurambas. Joubertina possibly could be related to older weathering cycles	No salinity hazard; very low water-holding capacity; excessive infiltration rate	Marginal pending further research

HARDAP	A HUTTON Form soil; apedal, red sandy clays; often shallow on calcrete; calcareous in the solum; occasionally saline	A rare soil of the Kalkveld	Moderate salinity hazard; high water-holding capacity; moderate infiltration rate	Marginal
JOZINI	A LINDLEY Form soil of the Oakleaf family; generally deep, dark, grey brown sandy clay loams with a weakly differentiated B horizon. Differs from Limpopo by being non calcareous at depth	A rare soil of low-lying areas and drainage lines in the Kalahari Sandveld	Moderate to moderately low salinity hazard; high water-holding capacity; moderate infiltration rate	Recommended
LANGEBAAN	A FERNWOOD Form soil; alkaline grey sands to loamy sands usually overlying calcrete below 30 ins; often calcareous in the solum	Rare soils formed in recent aeolian materials derived from the larger pans and Omurambas in the vicinity of which they occur	Moderate to moderately low salinity hazard; low water-holding capacity; very rapid infiltration rate; shallow soil depth at times	Marginal pending further research
LEVUBU	A LINDLEY Form soil of the Oakleaf family; generally deep, dark grey brown sandy loams with a weakly differentiated B horizon. Differs from Okavango by being non calcareous at depth	A rare soil of low-lying areas and drainage lines in the Kalahari Sandveld	Moderately low salinity hazard; moderate water-holding capacity; rapid infiltration rate	Recommended
LIMPOPO	A LINDLEY Form soil of the Oakleaf family; variable depth, dark grey brown calcareous sandy clay loams usually overlying calcrete; the B horizon is slightly better developed than in Jozini; a deep, apedal grey sandy clay loam, formed by termites in their mound construction, was mapped as Limpopo (termitaria var.)	Fairly common soils in the Kalkveld, normally occur in the weakly developed drainage lines	Moderate salinity hazard; moderate water-holding capacity; moderate infiltration rates	Recommended

LINDLEY	A LINDLEY Form soil of the Valsrivier family; clay pan soils; a dark greyish brown sandy clay loam overlies a dense blocky to prismatic sandy clay subsoil which becomes less dense and calcareous at depth	Fairly rare soils of the Kalkveld where some admixture of aeolian or colluvial material from the calcrete weathering products has taken place	High salinity hazard; impeded drainage; under irrigation the clay pan will develop into a solonetz B	Not Recommended
MAKATINI	A HUTTON Form soil; generally deep, apedal, red sandy clays; at times may overlie calcrete at shallow depths	Only encountered to any extent in the Kaokoveld on pediplains/ river terraces overlying calcrete	Low to moderately low salinity hazard; high water-holding capacity; moderate infiltration rate	Recommended
MAKUYA	A CLOVELLY Form soil; generally deep, yellow loamy sands to sandy loams (6-15% clay) with the surface horizon slightly darkened by organic matter; occasionally overlies calcrete within 48 inches	Restricted to fairly broad flat plains in the Kalahari Sandveld	Very low salinity hazard; somewhat low water-holding capacity; rapid infiltration rate	Recommended
MANGANO	A HUTTON Form soil; generally deep, red, fine sandy loams to loamy fine sands (6-15% clay) occasionally overlying calcrete within 30 inches of the soil surface	Fairly common but not extensive in the Ovamboland Sandveld on gently undulating plains and higher lying dunes	Very low to no salinity hazard; moderate water-holding capacity; rapid infiltration rate	Recommended
MECANHELAS	An ESTCOURT Form soil; a solonetz soil; differs from Elim only in that it has a dominant coarse sand fraction instead of medium sand; a coarse sand abruptly overlies a coarse sandy loam; usually within 12 ins. of the soil surface; the wet analogue is Mahanene Series	Extensive on the alluvial plain of Ovamboland in the Etaka - Cuvelai drai nage basin	Severely impeded internal drainage; high salinity	Not Recommended
MISPAH	A MISPAH Form soil; lithosols; shallow stony soils overlying rock within 12 ins.; non - calcareous	Common in the mountainous regions and dissected areas	Largely non arable; impeded drainage, shallow rooting depth	Not Recommended

MKAMBATI	A KROONSTAD Form soil; duplex soils; a grey sand abruptly overlies a mottled grey and yellow sandy loam normally at between 18 and 30 inches	Limited to a flat plain in the Kalahari Sandveld	Moderate salinity hazard; impeded drainage; very difficult to control irrigation to avoid water-table development	Not Recommended
MOTOPI	A FERNWOOD Form soil; generally deep, grey, fine sands often overlying calcrete below 30 inches; occasionally calcareous in the profile. Neutral to alkaline reaction, rarely saline	A rare soil in slightly lower-lying areas in the Ovamboland sandveld	Moderately low salinity hazard; low water-holding capacity; very rapid infiltration rate	Not Recommended
MOZI	An ESTCOURT Form soil; solonetz soils; a grey fine sand abruptly overlies a dense grey loamy sand to sandy loam usually within 12 inches of the soil surface; differs from Elim only in being a fine sand grade	Very extensive in Ovamboland on the flat Ekuma Grassland and in the vicinity of the lower Oshana Etaka	High salinity hazard, severely impeded drainage	Not Recommended
MUDEN	A MISPAH Form soil; lithosols, shallow stony soils overlying calcrete within 12 inches	Very extensive in the Kalkveld	Largely non arable; impeded drainage; shallow rooting depth; very low total available moisture	Not Recommended
OKAVANGO	A LINDLEY Form soil of the Oakleaf family; generally fairly deep, dark greyish brown sandy loams (6-15% clay) overlying calcrete	Fairly extensive soils in the Kalkveld especially where an admixture of calcrete weathering products and aeolian sand has occurred on flat plains; elsewhere limited to low-lying positions	Moderate to moderately low salinity hazard; moderate water-holding capacity; rapid infiltration rate	Recommended
OVAMBO	A CLOVELLY Form soil; deep yellow fine sands with less than 6% clay; mapped as Annandale series since it was of very minor occurrence	Rare soils in the gently undulating Ovamboland Sandveld	Very low to no salinity hazard; low water-holding capacity; very rapid infiltration rate	Marginal pending further research

PAFURI	A STANGER Form soil; a weakly self-mulching, very dark greyish brown sandy clay overlies a weak blocky sandy clay B on calcrete	Not very extensive, found on flat plains in the northern Etosha area, usually in minor depressions	Moderate salinity hazard; high water-holding capacity; moderate infiltration rate; in places drainage through the calcrete may be impeded; fairly difficult soils to work	Marginal
PORTSMOUTH	A HUTTON Form soil; variable depth; red coarse sandy loams to loamy coarse sands, often overlying granite or conglomerates	Encountered mainly in the Kaokoveld and western areas on gently sloping pediments and hilly regions where it is fairly common	Very low to no salinity hazard; moderate water-holding capacity; rapid infiltration rate, at times soil depth may be a limiting factor	Recommended (Marginal where shallow)
ROODEPOORT	A HUTTON Form soil; generally deep, fine sands (less than 6% clay); the surface horizon is slightly darkened by organic matter	Limited to the undulating Ovamboland Sandveld; a fairly rare soil	Very low to no salinity hazard; low water-holding capacity; very rapid infiltration	Marginal pending further research
SANDSPRUIT	A CLOVELLY Form soil; deep, yellow sands with less than 6% clay	Common soils in the Kalahari Sandveld region	Very low to no salinity hazard; low water-holding capacity; very rapid infiltration rate	Marginal pending further research
SHORROCKS SHORROCKS (-) SHORROCKS (+)	A HUTTON Form soil; variable depth; apedal, red sandy loams to sandy clay loams SHORROCKS series with 15-25% clay SHORROCKS series with 25-35% clay	Fairly extensive on gently sloping pediments and on plains in the Kaokoveld and Central Highlands	Low to no salinity hazard; soil depth may be limiting; moderate water-holding capacity. Although both are highly recommended, Shorrocks (-) is considered the better of the two phases	Highly Recommende where deep; margin where shallow
SILOA	A SHORTLANDS Form soil; expansive, moderately structured, red sandy clays to clays; overlying calcrete	Rare soils of low-lying positions on gently sloping colluvial plains in the Kaokoveld	Moderate salinity hazard; moderate water-holding capacity; slow infiltration rate; rather difficult soils to work when wet	Marginal

VALSRIVIER	A LINDLEY Form soil of the Valsrivier family; clay pan soils; dark greyish brown sandy clay loams with a prominent dense, hardsetting B horizon. With depth, sub.-soil becomes calcareous and less dense	Not very extensive, occur mainly in low-lying areas, often as an unmentioned minor constituent of associations containing Lindley series	High salinity hazard; impeded internal drainage	Not Recommended
ZWARTFONTEIN	A HUTTON Form soil; variable depth; red sandy loams to loamy sands (6-15% clay)	Fairly extensive in areas where the aeolian sand has received an admixture of weatherable minerals. Common on pediments in the dolomite areas	Very low to no salinity hazard; moderate water-holding capacity; rapid infiltration rate; soil depth may be limiting at times	Recommended (Marginal where shallow)

PHYSIOGRAPHIC REGIONS AND ASSOCIATED SOILS AND TERRAIN CONDITIONS :

The survey area embraces more than one type of country. For the purposes of this report it has been divided into eight gross physiographic regions, as follows :-

1) The Kaokoveld Valleys
2) The Ovamboland Sandveld
3) The Ekuma Grassland
4) The Kalkveld
5) The Central Highlands
6) The Southern Omatako Plain
7) The Kalahari - Sandveld
8) The Etaka - Cuvelai Drainage Basin

These regions are depicted on a small scale map (Fig. 10)

The Kaokoveld Valleys:

The great diversity of rock formations within the Kaokoveld has not given rise to comparable diversity in soils, because, under the arid climate, weathering is largely physical. The landscape at present is undergoing severe dissection and the soil materials are consequently very young. Except for the gently sloping valleys where deposition of erosion products from the hills has occurred, there is very little soil. It is remarkable how actively the current erosion processes remove soil materials from slopes as flat as 6 per cent.

A few relicts of the Tertiary calcrete surface occur; as at Ohopoho and Kaoko Otavi, as do some aeolian sand outliers north of Ohopoho. For the rest, the soils of agricultural significance are either alluvial or colluvial.

The greater part of the Kaokoveld is rugged and hilly. Although there are a number of large dry rivers, the majority of the area is drained by juvenile streams actively eroding the landscape; the extent of soils suitable for irrigation development is therefore limited.

Red colluvial soils predominate on the more freely drained landscapes while greyish brown, often saline, soils occur on the flatter landscapes associated with the Tertiary calcrete.

The colluvial red soils vary texturally from loamy sands to sandy clay loams, depending largely on climate and age of parent materials. Given similar parent materials, the resultant soil is coarser textured the further west, and therfore the drier the climate. Under similar climatic conditions the granitic colluvia give rise to coarse sandy soils, the dolomites to medium sandy soils, while the colluvia influenced by basic rocks give rise to the heavier sandy clay loams. None of the soils is highly weathered and each is therefore inherently fertile for its particular textural class. The sandy soils of the more western valleys are composed largely of chemically unweathered sand sized rock particles.

Most of the deep soils which occur have a reasonably high irrigation potential. Deep soils are, however, very limited in occurrence, and as a region the Kaokoveld has a very low potential for irrigation. Those areas that are suitable are in the main rather isolated and distant from major sources of water. In most cases the delivery of water to the suitable sites would entail major engineering works.

The Ovamboland Sandveld :

This region comprises a discontinuous mantle of Kalahari sand varying in depth from a few inches at the outer margins to many feet - possibly hundreds - in the centre. In general, the sand of this region is markedly finer -in the south especially - than in the vast eastern Kalahari sandveld. Well sorted, the sand contains little of the coarse grades,being concentrated mainly around the 0.2 mm size. By pedological definition, most of the sand qualifies as fine sand although some medium sands do occur, especially in northern Ovamboland. Within the region only rare rock outcrops occur, these usually being covered by a veneer of Tertiary calcrete.

Landcapes are generally gently undulating and catenary sequences commonly occur. The red -yellow - grey - dark grey sequence, so typical of the Kalahari Sandveld is fairly well represented, except that the red sand component is more often confined to the steeper and high lying dunes or to the more undulating areas transitional to the Kalkveld.

As well as having a finer grade than the sands of the Kalahari Sandveld, the soils of the Ovamboland Sandveld have slightly more clay and can be regarded as a better proposition for irrigation development. However, further research into their management is needed.

As a region, the potential for irrigation is for the greater part, uniformly marginal. The sandy soils have rather low water-holding capacities and very rapid infiltration rates. Unless suitable soil compaction techniques are developed as a result of research it must be assumed that these soils can be irrigated only by sprinkler systems. Since the water-holding capacities are somewhat low, frequent water applications will be necessary, entailing increased management costs as well as larger capital outlays on sprinkler equipment. It is essential that any assessment of the suitability of these soils for development under irrigation include an economic feasibility study.

A large portion of the Ovamboland Sandveld lies below the 1150 m. contour and at its furthest point it is only some 95 Km. from the Kunene River. Not only is it accessible to water, but it is also bisected by a direct line between Ruacana and the large block of land in the Etosha Game Reserve which has moderate to high irrigation potential (Map unit A5 in the Otjivalundu area), and which is highly recommended.

The Ekuma Grassland:

This small region is covered by a uniform textured, terrace, sandy loam overlain by a mantle of aeolian and/or fluviatile sand. Calcrete or other rock outcrops were not encountered. The subsoil materials are generally mildly to strongly saline.

The landscape of the Ekuma Grassland is extremely flat, the monotony being broken only by the occasional pan. Towards the outskirts, in a zone transitional to the Ovamboland sandveld it becomes gently undulating.

The uniformity of soil pattern over so large an area is remarkable. Except for the pans and in the peripheral transitional zones, the area is demarcated by shallow duplex soils. The general salinity of the landscape is reflected in the salt accumulation in the pans. Towards the outer edge of the area the sand mantle becomes thicker and the duplex transition deeper, until fairly abruptly the deep sands, with no impeding layers, are encountered.

Salinity, and severe impedence to root and water penetration in the subsoil, render these very poor irrigation soils. Should experimentation at the Mahenene Research Station evolve techniques allowing of the utilisation of the solonetz soils there, then more detailed surveys of the Ekuma Grassland could indicate areas suitable for irrigation. In the meantime, this area cannot be recommended for irrigation.

The Kalkveld :

Most of the soils in this region are derived from the Tertiary calcrete or its erosion products. Around the isolated inselbergs are minor areas of colluvia on the pediments.

The terrain varies from flat with suppressed drainage to gently undulating with diffuse drainage. Minor pans, low lying areas and "blind" drainage lines or omurambas are a prominent feature.

Where slopes are steep or where physiographic drainage is good, red soils have developed; by far the greater part of the region, however, is covered by dark grey geogenic soils and calcareous lithosols, with heavier soils, often black clays, in depressions. Due to the diffuse and often blind nature of the surface drainage, there is often a mildly saline or nearly saline soil component somewhere in the landscape.

Should soils within this region be developed for irrigation, it is essential that drainage works be constructed at the outset.

The major part of this region is covered by unsuitable shallow lithosols but it does contain some large blocks of soil suitable for irrigation, notably associations A5 and A4 north west of the Etosha Pan, which have the merit of being situated below the 1150 metre contour. These areas differ from the normal Kalkveld in that there has been an admixture of aeolian materials with the calcrete weathering products, resulting in the development of deeper soils.

The Central Highlands:

This region includes areas which are similar to the Kalkveld and others having affinities with the Kaokoveld valleys. As with the Kaokoveld, the

soils are almost exclusively formed in transported materials. Unlike the Kaokoveld, however, most of the valleys are not being actively eroded, so that fairly large areas of deep red colluvial soils and pediplain soils occur, especially towards the southern limit of the survey area. As in the Kaokoveld, the country rocks in this region have contributed to soil character largely in soil texture. The granites and conglomerates generally give rise to coarse sandy soils, the dolomites to medium sandy soils and the basic rocks to medium textured soils.

The general landscape of this physiographic region is composed of pediments or pediplains (coalesced pediments) with isolated inselbergs and mountain ranges. The steep areas, hills and mountains are devoid of arable soils, while the pediments and valleys generally have medium textured red soils, with grey geogenic soils in low lying positions. The pediplains, often underlain by the tertiary calcrete, have a somewhat deeper and more variable soil pattern than the Kalkveld, although the composition in terms of soil series often may be similar. Other pediplains have red sandy soils more closely related to the parent rock. The major part of the region is covered by rock and lithosols. However, most of the physically arable soils have high irrigation potential and these are more extensive than in the Kaokoveld.

Soil associations of high irrigation potential dominated by light to medium textured red and dark grey soils occur extensively in the Outjo-Otjiwarango area and in a more dispersed pattern in the broader valleys and small plains between hills in the Otavi - Tsumeb - Grootfontein triangle. These are mapped as units C1, C5, C8, C13 and B6, B7 and B13.

To the north-east of Fransfontein is a large area of lower but nevertheless moderate irrigation potential, (Map unit C11). The soils of this area have been formed on granite and are downgraded in terms of irrigation potential on account of their patchy distribution and moderately low water-holding capacity.

The region as a whole contains the largest areas of soil of high irrigation potential in the survey area and the highly rated soils are amongst the best available. Regrettably such areas occur at relatively high elevations and far from the large rivers in the north.

The Kalahari Sandveld :

This vast physiographic region includes a number of distinct sub-regions but consideration of the soils in terms of these variants would have more relevance to dryland agriculture than to irrigation potential. For the specialised purposes of this survey the Kalahari Sandveld is considered as a single gross landscape.

Fundamental to an understanding of the distribution of the soils in the Kalahari Sandveld is an appreciation of the interactive effects of two factors : depth of aeolian sand mantle and degree of relief, or landform. 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 metres or more to zero. Ignoring intermediate conditions, the main factorial combinations of sand depth and relief are accordingly :-

Deep sand mantle and no surface relief,
Deep sand mantle and marked relief,
Shallow or no sand mantle and no relief,
Shallow or no sand mantle and marked relief.

Patently, many variants occur, with gradations of sand depth and relief as other factors intrude.

Generally, where the sand mantle is deep, but where there is no relief and where surface drainage is imperceptable, the dominant soils are loose grey sands of Fernwood Series. In this case the soils and soil parent materials are both sands of aeolian origin. In places, particularly in Bushmanland, these sands are nearly white in colour under a surface layer stained by ash from veld fires. They cover many thousands of hectares in the Kalahari, the largest single block being the water divide area of map unit D19. Grey sands also commonly occur as recent infill in omuramba floors and interdune "straate".

In areas of deep sand where relief and drainage are more pronounced the pedogenic processes have typically given rise to a catenary sequence of red sands on elevated situations, yellowish brown sands on mid-slope positions and either grey sands or heavier dark coloured soils in the bottomlands, depending on the depth to which erosion of the sand mantle has there proceeded. The red sands occur mainly on the dunes that commonly fringe omuramba valleys, particularly on eastern and southern banks, as well as on the higher positions in

undulating country formed by lateral tributaries to omurambas, on the extensive seif dunes and parallel sand ridges, and on lunettes and other dunes formed from sand blown out of pans. Examples of extensive soil associations in which red sands are dominant are mapping units D16 (areas where relief is associated with omurambas and D27 (relief arising out of dune development).

Red sands have also developed under a different set of conditions along the western margin of the aeolian sand area, south of Waterberg. (Mapping unit D15). In this area the red soils of Gaudam series occur not only on well drained localities but also on extensive somewhat elevated flats at an altitude around 1,400 metres. It would appear that in this area soil parent materials are not exclusively aeolian sand but include products of the weathering of Stormberg rocks. Alternatively, the elevated red sands of this area may consitute a more recent (possibly pleistocine) deposition.

Intermediate between the two contrasting conditions of sand depth and relief referred to above, i. e. where relief on deep sand areas is subdued and where the sand mantle on flat plains is of moderate depth, yellow, brown, and yellowish brown sands of Sandspruit series are typically dominant. Mapping units D17, D18 and D36, embracing the plains of much of Hereroland, are examples.

Examples of flat areas having a shallow sand mantle, or lacking such a mantle, are omurambas floors, old flood plains, pans and incipient pans, and interdune "straate". In these bottomland sites the parent materials include products of the weathering of calcretes and silcretes, which contribute darker colours and heavier textures to the soils. The more important soil series of bottomland associations are dark grey sandy loams to sandy clay loams of Okavango and Limpopo series, and the "claypan" soils of Valsrivier series.

The pans and incipient pans of the Kalahari are mostly too small to map individually. They are most numerous in south-western, western and northern Hereroland and in a broad north-south belt traversing central Bushmanland, the number of pans in any area varying with the depth of the aeolian sand mantle.

The floors of omurambas are generally widest in the western and central zones of the Kalahari Sandveld. In eastern Hereroland the omurambas have been incised into the underlying calcretes, resulting in the development of narrower valleys providing little scope for irrigation. The bottomland associations of pans and omurambas are mapped as unit A22.

In dune country where erosion in the interdune "straate" has approached the level of the underlying calcrete, broad tracts of the bottomland association occur. It is not feasible to map these "straate" individually but in the northern and eastern areas, mapped as units D27 and D30, they constitute in the aggregate large areas of soil suitable for irrigation.

Areas of marked relief which lack a sand mantle or have a very shallow mantle are mostly too rocky for cultivation. The narrower omuramba valleys in eastern Hereroland fall into this category. Also unsuitable for cultivation are those flat areas where rock outcrops are frequent, such as areas mapped as D32 (Rietfontein block) and E3 (near Tsumkwe).

For the purposes of assessment of irrigation potential, the utilizable soils of the Kalahari sandveld can therefore be considered as two broad groups - the sands and the bottomland soils.

The red sands intrinsically have a somewhat higher potential for irrigation than the grey and brown sands, but, as they usually occur in the more broken and undulating country and on high ground, e. g. dune crests, they normally present greater problems with regard to water reticulation. The main disability of all the sands from the point of view of irrigation is their low water-holding capacity, which necessitates shorter irrigation cycles involving increased costs of water application. Research into appropriate and improved irrigation techniques for the sands is currently in hand in Ovamboland.

From the map legend it is seen that most components of the bottomland soil associations are suitable per se for irrigation. Physiographic and other considerations, however, may affect the potential of any such area or the feasibility of implementing irrigation. In the case of the pans, their limited size and scattered occurrence, together with the physical problem of providing adequate drainage, generally precludes their development under irrigation.

The broad omuramba floors and interdune "straate" (Unit A22) present the best propsects for irrigation in the Sandveld, notwithstanding localised problems arising out of rock outcrops and sand infill. Within this unit areas of "claypan" soil, which are unsuitable for irrigation, would not in practice constitute a serious problem as they usually occur in the lowest lying positions, which in any event would be used as main drainage lines. The main disability of the true omurambas from the point of view of irrigation is the danger of damage from flash floods in the lower slope areas.

The so-called Aha Mountains (which in reality are low hills) constitute an extraneous element in the Kalahari Sandveld. On the pediment slopes of these hills, colluviation has provided scree and drift materials that give rise to red soils of light to medium texture, having a moderately high potential for irrigation: map unit D14 refers. As the lower slopes merge into the sandy plains so the texture of the soils becomes lighter, with the result that the best irrigable soils in this area occur in relatively elevated situations. Other features that tend to downgrade Map Unit D14 are the hilly configuration of the area, which makes for somewhat discontinuous blocks of land, and the moderately low water-holding capacity of the soils, of which red sandy loams of Zwartfontein series are dominant.

Having regard to elevation above the Okavango river, land configuration, extent of suitable soils and proximity to urban services and existing communications, the northern valley or the Omuramba Omataka and the interdune "straate" of Okavangoland present the best prospects for irrigation development in the Kalahari Sandveld.

The Southern Omatako Plain :

The Omuramba Omatako is the largest of the rivers to the east of the Central Highland drainage divide. Physiographically its drainage basin may be divided into two zones, separated by a small transitional area. These are the upper basin in the Highlands, and that portion traversing the Kalahari Sandveld. The transitional area we refer to as the Southern Omatako Plain.

Near the south-western corner of Hereroland is a district debouchment area of considerable significance from the point of view of the irrigation potential of the soils. Here, near and to the south and the east of Okakarara, the Groot and Klein Omatako omurambas break through the Waterberg Range and debouch on to the Kalahari Sandveld, losing momentum as gradients are reduced and on impact with the sands. In the Southern Omtatko Plain soil parent materials include weathering products transported from the Central Highlands, which have had the dual effects of increasing the proportion of coarse sand in the soils and increasing clay contents. The aeolian sand mantle in the area is shallow and there is evidence that the south-eastern parts are an old floodplain, discontinuous lines of pans constituting relicts of one-time water courses. In this section the proximity of the calcrete, - here and there exposed in pans - has given rise to areas of heavier dark grey soils of which Okavango series is the most important

in mapping unit D23. The pattern of component soils in this unit is complex but both the red loamy sands and sandy loams and the dark grey soils have moderately high irrigation potential.

In the western corner of the Southern Omatako Plains, immediately outside the Hereroland border, are extensive gently sloping areas of deep red sandy loams and loamy sands, Zwartfontein being the dominant series. The uniform soil pattern in this area together with the soil type and the gentle slopes, make for moderately high irrigation potential. The only reason why the soils of map unit D12 are not given the highest rating for irrigation potential is because their water-holding capacity is sub-optimum.

Proceeding southwards towards Osire the red sandy loams give way to coarse yellow to yellowish brown sandy loams and loamy sands (Makuya and Denhere series) in which water-holding capacity is further reduced. On this account the areas embraced by map unit D25 have a lower potential for irrigation than D12 and D23, but higher than that of the sands of the Kalahari.

Pedologically, therefore, the Southern Omatako Plains constitute an area of fairly high irrigation potential. The distance of the region from northern water sources is patently a major limiting factor to development, but it may be that the large size of the Omatako catchment in the Highlands, taken in conjunction with dam site possiblities presented by kloofs in the Waterberg and the presence of "hard rock" formations, could offer prospects of irrigation development based on the local storage of flood waters in the Groot and Klein Omatako Omurambas.

The Etaka - Cuvelai Drainage Basin:

Only a minor part of this physiographic region falls within the area embraced by the present survey : most of it having been covered by previous reconnaissance soil survey (Report TS/45/66 of November, 1966)

The relief is monotonous and flat and the only dissection of any significance is occupied by the drainage of the Oshana Etaka flowing south-east into the Etosha Pan and its north-west extension, the Oshana Olushandja, which flows into the Kunene River.

The landform is a vast alluvial fan or low level terrace deposited by the Kunene River in Quaternary times when the Kunene flowed into the Etosha Pan; an internal drainage system which was eventually captured via the Ruacana Falls.

The alluvia are medium textured and strongly saline and soil genesis has resulted in the formation of classic solonetz soils with an abrupt transition between the coarse to medium sand surface soils and the dense, very slowly permeable solonetz B horizon which tends to be columnar or prismatic. The less severe solonetz forms are currently being investigated at the Mahanene Research Station to establish the feasibility of reclamation.

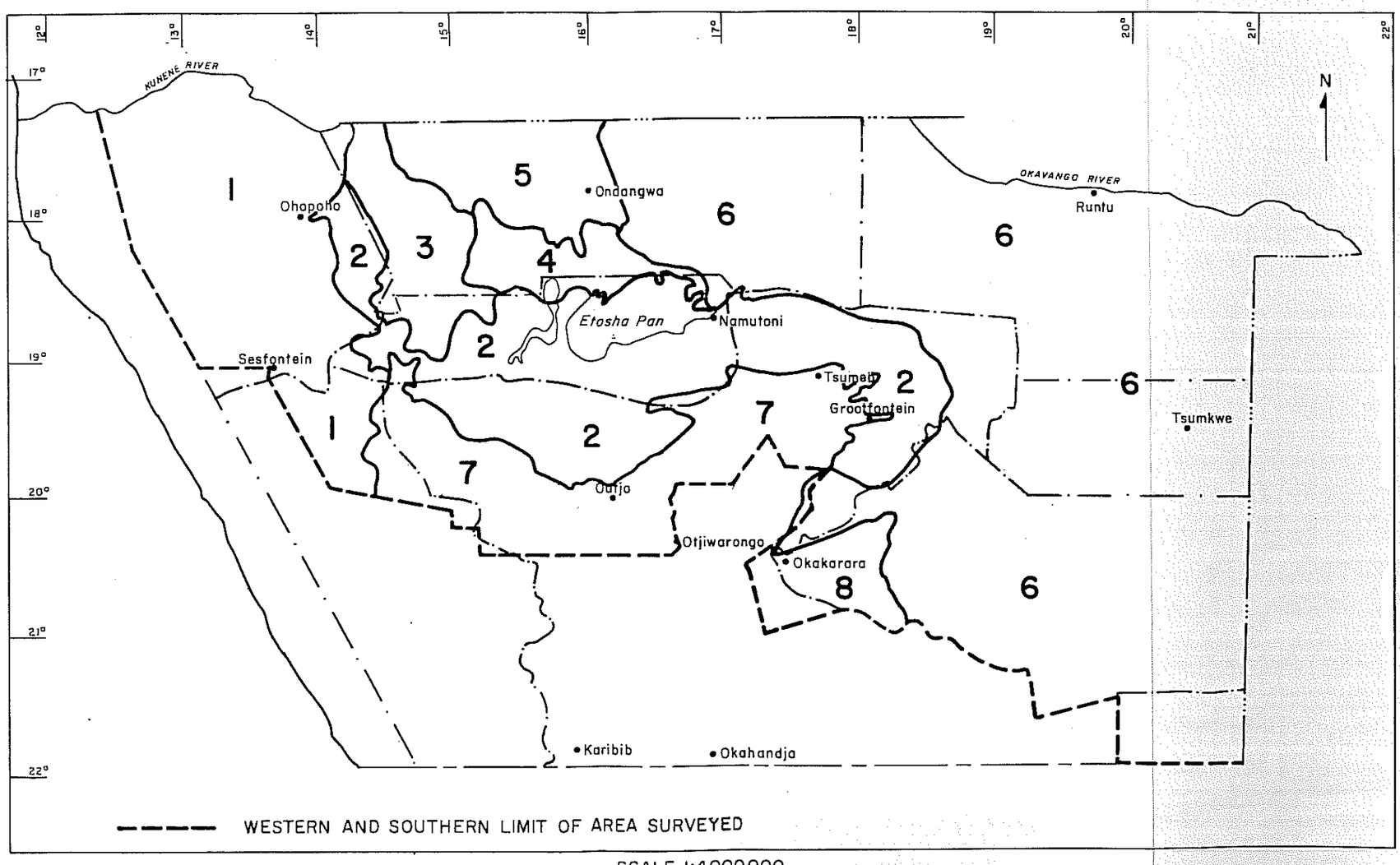
A regional analysis of particle size distribution has revealed that there is a recognizable grading of the sand fraction from a coarse sand in the North to a medium and later fine sand in the South. This gradation is obviously due to fluviatile sorting of transported material, apparently of granitic provenance.

In the previous reconnaissance, slightly elevated landforms of sandy material were identified: these were the well drained sandy soils of map unit L (locally derived aeolian and related materials). Further field study during this current survey suggests that these higher lying materials appear to be fluviatile levees, deposited by the Kunene river and although there is good reason to believe that aeolian action has also been a contributor of soil material, the major agent of transport is probably water. Due to limitations of photo scale (1/75,000) and complexity of soil pattern, these higher lying levees which have moderate to high irrigation potential, cannot be differentiated on the soil map. A more detailed study and a larger scale is therefore recommended to accomplish the necessary differentiation of soil types.

For the time being, the area as a whole has not been recommended for irrigation development but cognisance should be taken of the relatively high potential of these isolated levees.

FIGURE 10

NORTHERN SOUTH WEST AFRICA
GROSS PHYSIOGRAPHIC REGIONS



SCALE 1:4000000

0 100 200 300 400 KILOMETRES

1. KAOKOVELD
2. KALKVELD
3. OVAMBOLAND SANDVELD
4. EKUMA GRASSLAND
5. ETAKA–CUVELAI DRAINAGE BASIN
6. KALAHARI SANDVELD
7. CENTRAL HIGHLANDS
8. SOUTHERN OMATAKO PLAIN

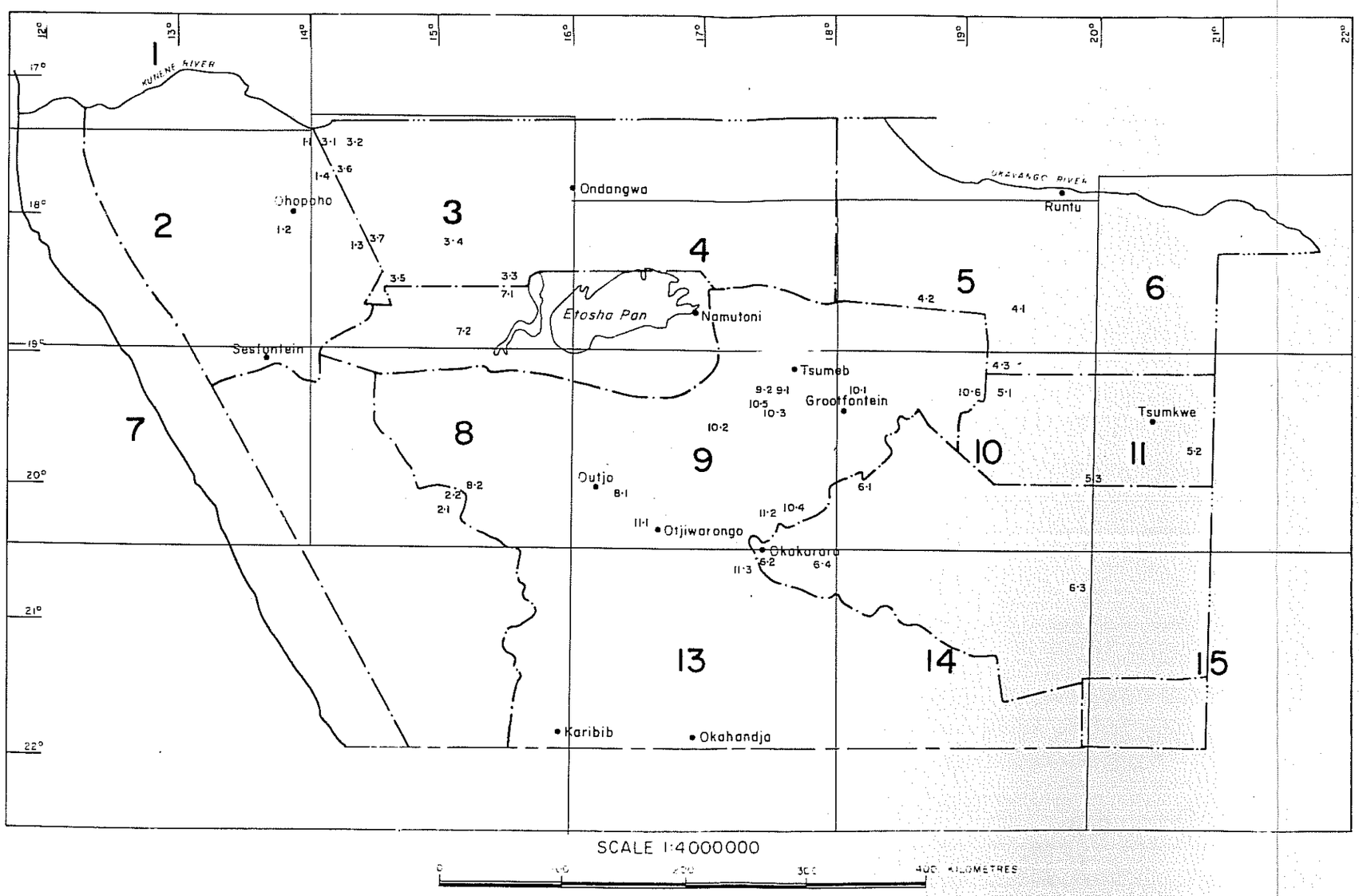
SUMMARY OF HIGHLY RECOMMENDED AND RECOMMENDED SOILS

In Table 2 we summarise the results of the survey in terms of areas of Highly Recommended and Recommended soil associations. The information is presented in terms of ethnic and administrative districts - Magisterial Districts, Bantu Homelands and Etosha Game Park - with cross reference to the relevant physiographic region and map sheet.

Figure 11 indicates the approximate location of areas of Highly Recommended and Recommended soils, with reference to the 1:250,000 soil map.

NORTHERN SOUTH WEST AFRICA

LOCATION OF AREAS OF HIGHLY RECOMMENDED AND RECOMMENDED SOILS



SCALE 1:4000000

0 100 200 300 400 KILOMETRES

1·2 AREA REFERENCE NUMBER IN TABLE 3

2 MAP SHEET NUMBER (1:250,000)

TS 1/70
SEPTEMBER 1970

R.F. LOXTON, HUNTING AND ASSOCIATES
JOHANNESBURG

TABLE 3 : SUMMARY OF MAIN AREAS OF HIGHLY RECOMMENDED AND RECOMMENDED SOILS : (See Fig. 11)

Area No.	RECOMMENDATION	PHYSIOGRAPHIC REGION: AREA: LOCATION : 1/250,000 SHEET	MAIN SOILS AND LANDSCAPES	Mapping Units	Total Extent (Hectares)	GENERAL COMMENTS
1. KAOKOVELD						
1.1	Highly Recommended	Kaokoveld region; Okambele area; ± 30 Km S. W. of Ruacana Falls; Sheet 3	Deep, red sandy loams to sandy clay loams in broad valleys, pediplains and terraces	C1 C5	4,133	Extent limited; relatively elevated; close to Kunene river
1.2	Highly Recommended	Kaokoveld region; Kaoko Otavi-Orumana area; Central Kaokoveld; Sheet 2	Red sandy loams to sandy clays in deep broad valleys, pediplains and terraces	C1 C5	7,056	Extent limited; scattered distribution; large lift involved in reticulating water to the area
1.3	Recommended	Kalkveld; Ookaoro Pan area; 20-50 Km N. W. of Omutambo Maowe Quarantine Camp; Sheet 3	Dark greyish brown sandy loams with black, weakly self mulching sandy clay loams in slight depressions (A5) and red and yellowish brown sands, red loamy sands and dark grey sandy loams; calcrete exposures common (D23); flat and gently undulating plains	A5 D23	4,133	Extent limited; drainage and potential salinity problems on dark soils; water-holding capacity of sands low; relatively elevated
1.4	Recommended	Kaokoveld region; Unnamed area in N. E. Kaokoveld; Sheet 3	Red loamy sands, red and yellowish brown sands and dark grey sandy loams; calcrete exposures common; flat and gently undulating plains	D23	1,008	Extent limited; water-holding capacity of sandy soils is low

TABLE 3 : SUMMARY OF MAIN AREAS OF HIGHLY RECOMMENDED AND RECOMMENDED SOILS : (See Fig. 11)

Area No.	RECOMMENDATION	PHYSIOGRAPHIC REGION: AREA: LOCATION : 1/250,000 SHEET	MAIN SOILS AND LANDSCAPES	Mapping Units	Total Extent (Hectares)	GENERAL COMMENTS
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1.1	Highly Recommended	Kaokoveld region; Okambele area; ± 30 Km S. W. of Ruacana Falls; Sheet 3	Deep, red sandy loams to sandy clay loams in broad valleys, pediplains and terraces	C1 C5	4,133	Extent limited; relatively elevated; close to Kunene river
1.2	Highly Recommended	Kaokoveld region; Kaoko Otavi-Orumana area; Central Kaokoveld; Sheet 2	Red sandy loams to sandy clays in deep broad valleys, pediplains and terraces	C1 C5	7,056	Extent limited; scattered distribution; large lift involved in reticulating water to the area
1.3	Recommended	Kalkveld; Ookaoro Pan area; 20-50 Km N. W. of Omutambo Maowe Quarantine Camp; Sheet 3	Dark greyish brown sandy loams with black, weakly self mulching sandy clay loams in slight depressions (A5) and red and yellowish brown sands, red loamy sands and dark grey sandy loams; calcrete exposures common (D23); flat and gently undulating plains	A5 D23	4,133	Extent limited; drainage and potential salinity problems on dark soils; water-holding capacity of sands low; relatively elevated
1.4	Recommended	Kaokoveld region; Unnamed area in N. E. Kaokoveld; Sheet 3	Red loamy sands, red and yellowish brown sands and dark grey sandy loams; calcrete exposures common; flat and gently undulating plains	D23	1,008	Extent limited; water-holding capacity of sandy soils is low

2. DAMARALAND					
2.1	Highly Recommended	Kaokoveld region; Fransfontein area; S. W. of Fransfontein; Sheet 8	Deep, red sandy loams to sandy clay loams in broad valleys and pediments	C1	3,428	Only part of area surveyed; extent limited; distant from major water sources
2.2	Recommended	Kaokoveld; Fransfontein area; N. E. of Fransfontein; Sheet 8	Shallow red sandy loams and rock outcrops on gently sloping granite pediments; about 30% deep, red sandy loams	C11	10,182	Irrigable areas somewhat scattered; distant from major water sources
3. WESTERN OVAMBOLAND					
3.1	Highly Recommended	Kaokoveld region; Etaka area; ± 35 Km to S. W. of Ruacana Falls; Sheet 3	Deep, red sandy loams to sandy clays in broad valleys and terraces	C1 C5	2,319	Extent limited; eroded and uneven in parts; close to Kunene river
3.2	Recommended	Ovamboland Sandveld; Western margin of Etaka-Cuvelai drainage; Ovamboland plateau; S. E. of Ruacana; Sheet 3	Dark greyish brown sandy loams and black, weakly self mulching sandy clay loams in slight depressions; flat plains; sandy levee remnants in Kunene Quaternary alluvial terrace	A5	10,986	Close to Kunene river and commanded by 1150 metre contour line; distribution somewhat patchy; physical drainage and potential salinity problems exist; sandy levees in environs of Eunda have irrigation potential but not included pro tem due to limitations of map scale
3.3	Recommended	Kalkveld; Otjivalunda Salt Pan area; N. W. of Etosha Pan; Sheet 3	Dark greyish brown sandy loams and black, weakly self mulching sandy clay loams in slight depressions; flat plains	A5	24,094	Large area; commanded by 1150 metre contour line; 180 Km from Ruacana; physical drainage and potential salinity problems
3.4	Recommended	Ovamboland Sandveld; ± 120 Km South of Ombalantu; Sheet 3	Red and yellowish brown fine and medium sands and loamy fine and medium sands and dark grey sandy loams; flat plain	D3	67,442	Two extensive areas below an elevation of 1150 metres; moderately low water-holding capacity

3.5	Recommended	Ovamboland Sandveld; S. W. corner of Ovamboland; Omutambo Maowe Quarantine Camp; Sheet 3	Red and yellowish brown fine and medium sands and loamy fine and medium sands and dark grey sandy loams; flat plain	D3	14,920	Single, large area; below an elevation of 1150 metres; ± 150 Km from Kunene river; moderately low water-holding capacity
3.6	Recommended	Ovamboland Sandveld; ± 60 Km S. E. of Ruacana Falls; Sheet 3	Red and yellowish brown fine and medium sands and loamy fine and medium sands and dark grey sandy loams; calcrete exposures common; flat plain	D23	30,041	Two large areas; between an elevation of 1200 and 1150 metres; moderately low water holding capacity
3.7	Recommended	Ovamboland Sandveld; ± 110 Km from Ruacana Falls on Kaokoveld boundary; Sheet 3	Dark, greyish brown sandy loams with black, weakly self mulching sandy clay loams in slight depressions (A5) and red and yellowish brown sands, red loamy sands and dark grey sandy loams; calcrete exposures common; flat and gently undulating plains	D3 D23 A5	8,266	Comprised of three areas; one major area ± 15 Km east of Ovamboland/Kaokoveld boundary and two minor areas on the boundar below an elevation of 1150 metres; moderately low water-holding capacity
4. SOUTHERN OKAVANGOLAND						
4.1	Recommended	Kalahari Sandveld; Omatako valley; Sheet 5	Dark greyish brown sandy loams to sandy clay loams with some clay-pan soils; omuramba valleys	A22	6,754	Configuration enlongated and narrow, possible flood hazard
4.2	Partially recommended	Kalahari Sandveld; Mangetti area; Sheet 5	Dark grey sandy loams in inter-dune "straate"	D30	"Straate" estimated at 64,000	Broader "straate" have moderately high potential
4.3	Recommended	Kalahari Sandveld; Omataka valley; East of Grootfontein district; Sheet 10	Dark greyish brown sandy loams to sandy clay loams with some clay pan soils; omarumba valley	A22	10,998	Valley is broad in this area and slopes are favourable. Recent sand infill a problem locally

5.	BUSHMANLAND					
5.1	Recommended	Kalahari Sandveld; Omatako valley; Sheet 10	Dark greyish brown sandy loams to sandy clay loams with some clay-pan soils; omuramba valleys	A22	23,488	The valley attains its broadest configuratic in N. E. Bushmanland providing extensive areas suitable for irrigation. Recent sand infill is a problem in places
5.2	Recommended	Kalahari Sandveld; Aha Mountains near eastern border; Sheet 11	Red sandy loams and red and yellowish brown sands; pediment slopes to low hills	D14	13,710	Better soils are relatively elevated and occur in a somewhat patchy pattern. Moderately high potential
5.3	Recommended	Kalahari Sandveld; Other omuramba valleys; Sheets 10 and 11	Dark greyish brown sandy loams to sandy clay loams with some clay-pan soils; omuramba valleys	A22	5,342	Configuration elongated; distant from Okavango river
6.	HERERO LAND					
6.1	Recommended	Kalahari Sandveld; Omatako valley Eastern Hereroland; Sheets 9 and 10	Dark greyish brown sandy loams to sandy clay loams with some clay pan soils; omuramba valleys	A22	12,601	Valley is narrow and contains much sand in places. Distant from northern water sources; possible flood hazard
6.2	Recommended	Southern Omatako Valley and adjoining plain; S. E. of Okakarara; Sheets 9 and 13	Dark greyish brown sandy loams to sandy clay loams and red sandy loams to loamy sands; occasional calcrete exposures; flat plain	A22 D12 D22	45,106	Extensive area; far from northern water sources; local storage of flood waters may be feasible; water holding capacity of sandy soils moderately low
6.3	Recommended	Kalahari Sandveld; Various omurambas in Hereroland; Sheets 10,11,14,15	Dark greyish brown sandy loams to sandy clay loams with some clay-pan soils; omuramba valleys	A22	166,024	Configuration of valleys elongated; distant from water sources and relatively elevate

Test Pit No: K 44 SOIL SERIES : FERNWOOD

Site and Landform: Flat plain on eastern margin ofRietfontein block

Parent Material: Aeolian sand

Vegetation: Short Open Woodland; Acacia mellifera dominant

Sample No.	Horizon	Depth (in.)	Description
K360	A1	0 - 11	(10YR 4/3) brown to dark brown, (10YR 7/3) very pale brown (dry); fine sand; apedal; loose; very rapid permeability; gradual transition
K359	C1	11 - 33	(10YR 4/3) brown to dark brown, (10YR 6/4) light yellowish brown (dry); sand; apedal; slightly hard; very rapid permeability; gradual transition
K423	C2	33 - 60	(10YR 4/3) brown to dark brown, (10YR 6/4) light yellowish brown (dry); fine sand; apedal; slightly hard; frequent dark yellowish brown (10YR 4/4) sand infillings in termite channels becoming more abundant in lower part of horizon; very rapid permeability

ANALYTICAL DATA

Sample No.	K360	K359	K423
Depth in.	0 - 11	11 - 33	33 - 60
Horizon	A1	C1	C2
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	0	1	1
m. sand	26	30	21
f. sand	69	64	74
silt	1	0	1
Net extractable cations (me/100 gm.)			
Na	0.05	0.05	0.10
K	0.20	0.15	0.20
Ca	0.60	0.40	1.00
Mg	0.45	0.20	0.25
S. value	1.30	0.80	1.55
T. value/C. E. C.	2.00	1.30	2.00
C. E. C. clay	50	26	67
pH. H_2O	5.0	4.4	5.4
Ohms R 60°F	7500	7500	2250

Test Pit No: K 124 SOIL SERIES : FERNWOOD

Site and Landform: Flat plain on main road to Tsumkwe in Bushmanland

Parent Material: Aeolian sand

Vegetation: Medium Burkea - Pterocarpus Open Woodland

Sample No.	Horizon	Depth (in.)	Description
K124a	A1	0 - 10	(10YR 4/2) dark greyish brown, (10YR 6/2) light brownish grey, dry; sand; apedal; loose; very rapid permeability; gradual transition
K124b	C1	10 - 31	(10YR 4.5/2) greyish brown to dark greyish brown, (10YR 7/3) very pale brown, dry; sand; apedal; loose; very rapid permeability; gradual transition
K124c	C2	31 +	(10YR 5/3) brown, (10YR 7/3) very pale brown, dry; sand; apedal; loose; very rapid permeability

ANALYTICAL DATA

Sample No.	K124a	K124b	K124c
Depth in.	0 - 10	10-31	31 +
Horizon	A1	B21	B22
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	0	1	1
m. sand	52	46	43
f. sand	44	50	53
silt	2	0	1
clay	2	3	3
Net extractable cations (me/100 gm.)			
Na	0.05	0.05	0.05
K	0.15	0.05	0.20
Ca	0.50	0.25	0.15
Mg	0.40	0.25	0.20
S. value	1.10	0.60	0.60
T. value/C. E. C.	1.30	2.05	1.90
C. E. C. clay	65	68	63
pH. H_2O	4.9	4.6	4.3
Ohms R 60°F	2250	>10,000	>10,000

Test Pit No: A 95 SOIL SERIES : FERRY

Site and Landform: 3% slope, gently undulating; Northern Kaokoveld

Parent Material: Colluvial drift Vegetation: Medium Mopane Woodland

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 6	(2.5YR 3/6) dark red; sandy clay loam; apedal; slightly hard; rapid permeability; gradual transition
C28	B21	6 - 20	(2.5YR 3/6) dark red; sandy clay loam; apedal to blocky; hard; rapid permeability; gradual transition
-	B22	20 +	(2.5YR 3/6) dark red; sandy clay loam; blocky; hard to very hard; rapid permeability

ANALYTICAL DATA

Sample No.	C28
Depth in.	6 - 20
Horizon	B21

Particle size distribution (%)

% fine earth	100
c. sand	2
m. sand	5
f. sand	23
silt	34
clay	36

Net extractable cations (me/100 gm.)

Na	0.20
K	0.70
Ca	10.80
Mg	10.95
S. value	22.65
T. value/C. E. C.	24.10
C. E. C. clay	67
pH. H_2O	7.4
Ohms R 60°F	350

Test Pit No: K 197 SOIL SERIES : GAUDAM

Site and Landform: Waterberg area west of Hereroland; mid (2%) slope in gently undulating plain

Vegetation: Terminalia sericea Short Open Woodland to Woodland

Parent Material: Aeolian sand

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 9	(5YR 4.5/5) reddish brown to yellowish red; sand; apedal; soft; rapidly permeable; gradual transition
K197	B21	9 - 30	(2.5YR - 5YR 4/6) red to yellowish red; sand; apedal; slightly hard; rapidly permeable; gradual transition
-	B22		(2.5YR - 5YR 4/6) red to yellowish red; sand; apedal; slightly hard; rapidly permeable

ANALYTICAL DATA

Sample No.	K197
Depth in.	9 - 30
Horizon	B21

Particle size distribution

% fine earth	100
c. sand	1
m. sand	40
f. sand	53
silt	1
clay	6

Net extractable cations (me/100 gm.)

Na	0.00
K	0.10
Ca	0.75
Mg	0.45
S. value	1.30
T. value/C. E. C.	2.30
C. E. C. clay	38
pH. H_2O	5.0
Ohms R 60°F	>10,000

Test Pit No: K 111 SOIL SERIES : JOZINI

Site and Landform: Flat plain ("Palmveld") on main road between Otjituo and Grootfontein

Parent Material: Calcrete with some aeolian sand

Vegetation: Short Open Woodland with scattered tall palms (Hyphaene ventricosa)

Sample No.	Horizon	Depth (in.)	Description
	A1	0 - 8	(10YR 3/1) very dark grey; loamy sand; apedal; soft to slightly hard; rapid permeability; gradual transition
K111a	B2	8 - 25	(10YR 3/2) very dark greyish brown; sandy loam; apedal to weak blocky; friable; rapid permability; gradual transition
K111b	C	25 +	(10YR 4/2) dark greyish brown; sandy loam; apedal to weak blocky; friable; rapid permeability

ANALYTICAL DATA

Sample No.	K111a	K111b
Depth in.	8 - 25	25 +
Horizon	B2	C
Particle size distribution		
% fine earth	100	100
c. sand	8	5
m. sand	30	31
f. sand	44	45
silt	1	2
clay	16	17
Net extractable cations (me/100 gm.)		
Na	0.10	0.10
K	0.20	0.10
Ca	7.50	7.90
Mg	2.05	2.20
S. value	9.85	10.30
T. value/C. E. C.	9.95	13.00
C. E. C. clay	62	76
pH. H_2O	5.3	5.5
Ohms R 601F	2500	2400

Test Pit No: ST 211 SOIL SERIES : LANGEBAAN

Site and Landform: Upper slope on gently undulating plain in the Etosha Kalkveld

Vegetation: Scrub Mopane, moderately good grass cover

Parent Material : Aeolian sand

Sample No.	Horizon	Depth (in.)	Description
L381	A1	0 - 8	(10YR 3/1) very dark grey; sand; apedal; soft; rapid permeability; frequent roots; gradual transition
L382	C1	8 - 24	(10YR 5/2) greyish brown; sand; apedal; soft; rapid permeability; rare roots; gradual transition
L383	C2	24 - 48 +	(10YR 5/3) brown; sand; apedal; soft; rapid permeability; rare roots

ANALYTICAL DATA

Sample No.	L381	L382	L383
Depth in	0 -8	8 - 24	24 - 48 +
Horizon	A1	C1	C2
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	0	0	0
m. sand	33	35	39
f. sand	58	55	53
silt	1	2	1
clay	9	8	7
Net extractable cations (me/100 gm.)			
Na	0.00	0.05	0.15
K	0.30	0.25	0.55
Ca	1.00	0.75	1.45
Mg	1.00	0.95	2.10
S. value	2.30	2.00	4.25
T. value/C. E. C.	4.40	3.40	4.60
C. E. C. clay	49	42	66
pH. H_2O	6.6	6.7	6.7
Ohms R 60°F	3200	3500	1900

Test Pit No: ST 125 SOIL SERIES: LINDLEY

Site and Landform: Level plain on the Southern Kalkveld

Vegetation: Medium and short Acacia spp. and Mopane Open Woodland; moderate poor Aristida spp. cover

Parent Material: Mixed drift and Tertiary calcrete

Sample No.	Horizon	Depth (in.)	Description
T64	A1	0 - 5	(10YR 3.5/1) dark grey to very dark grey; sandy clay loam; weak coarse prismatic; hard; moderate permeability; frequent fine subangular quartz gravels; gradual transition
T82	B2	5 - 19	(10YR 4/1.5) dark grey to dark greyish brown; sandy clay; moderate coarse prismatic breaking to weak coarse blocky; extremely hard; slow permeability; frequent fine subangular quartz gravel; frequent weak (10YR 3/1) very dark grey cutans; frequent roots; clear transition
-	C/Rca	19 - 30 +	Layer of medium and large calcrete fragments, in places cemented into massive calcrete layer; abundant thin tongues of B2 material in upper 4 ins., abundant fine and medium subangular quartz gravel in upper 3 ins.

ANALYTICAL DATA

Sample No.	T64	T82
Depth in.	0 - 5	5 - 19
Horizon	A1	B2
Particle size distribution (%)		
% fine earth	95	90
c. sand	15	19
m. sand	19	14
f. sand	32	21
silt	9	9
clay	25	36
Net extractable cations (me/100 gm.)		
Na	0.20	0.20
K	0.15	0.10
Ca	2.20	3.35
Mg	2.80	4.15
S. value	5.35	7.80
T. value/C. E. C.	6.10	8.40
C. E. C. clay	24	23
pH. H_2O	6.1	6.8
Ohms R 601F	1000	600

Test Pit No: ST 10 SOIL SERIES : LIMPOPO

Site and Landform: Level plain on the Central Highlands

Vegetation: Medium and short Acacia spp. Woodland

Parent Material: Mixed drift over Tertiary calcrete

Sample No.	Horizon	Depth (in.)	Description
T54	A1	0 - 9	(7.5YR 3/2) dark brown; sandy loam; apedal; soft; rapid permeability; gradual transition
T53	B2ca	9 - 22	(7.5YR 3/2) dark brown; sandy loam; apedal; hard; rapid permeability; rare weak (10YR 3/2) very dark greyish brown cutans; rare worm casts; soil material calcareous; gradual transition
T287	Cca	22 - 46	(7.5YR 4/2) brown to dark brown; sandy loam; apedal; soft; rapid permeability; frequent soft fine $CaC0_3$ deposits; gradual transition
-	C/R	46 +	Calcrete hard and massive

ANALYTICAL DATA

Sample No.	T54	T53	T287
Depth in.	0 - 9	9-22	22-46
Horizon	A1	B2ca	Cca
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	6	6	5
m. sand	31	28	27
f. sand	45	46	42
silt	10	12	11
clay	9	8	16
Net extractable cations (me/100 gm.)			
Na	0.20	0.10	0.15
K	1.00	0.50	0.50
Ca	4.10	4.10	6.15
Mg	4.45	3.90	6.30
S. value	9.75	8.60	13.10
T. value/C. E. C.	10.20	10.00	12.15
C. E. C. clay	113	125	76
pH. $H_2 0$	7.1	7.1	7.4
Ohms R 60°F	1200	1000	900

Test Pit No: A 62 SOIL SERIES : LIMPOPO (saline)

Site and Landform: Slight slope in basin (dry river bed) Central Kaokoveld

Vegetation: Coppice Mopane Open Woodland

Parent Material: Alluvium

Sample No.	Horizon	Depth (in.)	Description
	A1	0 - 2	(10YR 2/1) black; sandy loam; apedal; friable; rapid permeability; gradual transition
J288	B21	2 - 10	(10YR 5.5/1) light grey to grey; coarse sandy loam; apedal; friable to very friable; moderate permeability
	C	10 +	Rock, probably quartz

ANALYTICAL DATA

Sample No.	J288
Depth in	2 - 10
Horizon	B21

Particle size distribution (%)

% fine earth	100
c. sand	25
m. sand	24
f. sand	24
silt	12
clay	16

Net extractable cations (me/100 gm.)

Na	5.40
K	1.80
T. value/C. E. C.	15.60
C. E. C. clay	98
pH. H_2O	8.2
Ohms R 60°F	150

Saturation extract : soluble cations (me/100 gm.)

Na	2.10
$EC10^3$ cm25°C-mmhos	4.1

Test Pit No: A 142

SOIL SERIES : LIMPOPO (shallow phase)

Site and Landform: Undulating ; Etosha Kalkveld

Vegetation: Mopane - Terminalia prunioides Woodland

Parent Material: Calcrete

Sample No.	Horizon	Depth (in.)	Description
	A1	0 - 8	(10YR 4/2) dark greyish brown; sandy loam; apedal; slightly hard; moderate permeability; gradual transition
J186	B21	8 - 20	(10YR 3/1) very dark grey; sandy clay loam; apedal; soft to slightly hard; moderate permeability
	Rca	20 +	Calcrete

ANALYTICAL DATA

Sample No.	J186
Depth in.	8 - 20
Horizon	B21

Particle size distribution (%)

% fine earth	100
c. sand	2
m. sand	3
f. sand	51
silt	16
clay	28

Net extractable cations (me/100 gm.)

Na	0.80
K	0.60
T. value/C. E. C.	16.70
C. E. C. clay	59
pH. H_2O	7.3
Ohms R 60°F	220

Saturation extract : soluble cations (me/100 gm.)

Na	0.50
$EC10^3$ cm25°C-mmhos	1.78

Test Pit No: A 150 SOIL SERIES : LIMPOPO (saline phase)

Site and Landform: Flat to gently undulating ; Kaokoveld Kalkveld

Vegetation: Coppice Mopane

Parent Material: Calcrete

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 6	(N4/-) dark grey; sandy loam; apedal; slightly hard; rapid permeability; gradual transition
-	B21	6 - 12	(5YR 4/1) dark grey; sandy loam; apedal; soft to slightly hard; rapid permeability; gradual transition
C66	C1ca	12 - 24	(10YR 5/2) greyish brown; clay loam to sandy clay loam; apedal; slightly hard; rapid permeability; frequent $CaCO_3$ concretions
-	Rca	24 +	Calcrete

ANALYTICAL DATA

Sample No.	C66
Depth in.	12 - 24
Horizon	C1ca

Particle size distribution (%)

% fine earth	100
c. sand	1
m. sand	5
f. sand	46
silt	13
clay	34

Net extractable cations (me/100 gm.)

Na	1.00
K	1.30
T. value/C. E. C.	16.70
C. E. C. clay	49
pH. H_2O	7.3
Ohms R 60°F	150

Saturation extract : soluble cations (me/100 gm.)

Na	1.10
$EC10^3$ cm25°C - mmhos	3.3

Test Pit No: ST 26 SOIL SERIES: LIMPOPO

Site and Landform: Lower mid; 1 - 2% slope; gently undulating ; Central Highlands

Vegetation: Short Acacia spp. Woodland; moderate Eragrostis and Enneapogon spp. cover.

Parent Material: Tertiary drift and calcrete

Sample No.	Horizon	Depth (in.)	Description
T129	A1ca	0 - 8	(7.5YR 3/2) dark brown; sandy clay loam; apedal; soft; rapid permeability; rare $CaCO_3$ concretions; soil material not calcareous; gradual transition
T232	B2ca	8 - 26	(7.5YR 3/2) dark brown; sandy clay loam; apedal; soft; rapid permeability; frequent fine $CaCO_3$ deposits and concretions; frequent weak (10YR 3/4) dark brown cutans; clear transition
-	Cca	26 +	Layer of medium and large $CaCO_3$ concretions becoming massive calcrete from ± 27 ins. down

ANALYTICAL DATA

Sample No.	T129	T232
Depth in.	0 -8	8 - 26
Horizon	A1ca	B2ca
Particle size distribution (%)		
% fine earth	100	100
c. sand	8	10
m. sand	20	22
f. sand	53	52
silt	10	10
clay	10	6
Net extractable cations (me/100 gm.)		
Na	0.20	0.10
K	0.40	1.20
T. value/C. E. C.	7.80	8.90
C. E. C. clay	78	148
pH. H_2O	7.3	7.3
Ohms R 60°F	1100	450

Test Pit No. F 5 SOIL SERIES : MANGANO

Site and Landform: Gently undulating plain; Ovamboland Sandveld

Vegetation: Combretum spp., Acacia spp., Medium Open Woodland

Parent Material: Aeolian sand

Sample No.	Horizon	Depth (in.)	Description
C172	A1	0 - 8	(5YR 3/4) dark reddish brown; sand; apedal; soft; rapid permeability; frequent fine roots; gradual transition
J45	B21	8 - 18	(5YR 4/4.5) reddish brown to yellowish brown; loamy sand; apedal; soft; rapid permeability; frequent fine roots; abrupt tonguing transition
-	C/R + B	18+	Calcrete boulders plus dark reddish brown B21 material

ANALYTICAL DATA

Sample No.	C172	J45
Depth in.	0 - 8	8 - 18
Horizon	A	B21
Particle size distribution (%)		
% fine earth	100	100
c. sand	0	0
m. sand	16	14
f. sand	78	74
silt	3	4
clay	4	8
Net extractable cations (me/100 gm.)		
Na	0.05	0.60
K	0.30	0.40
Ca	1.70	1.20
Mg	1.55	1.25
S. value	3.60	3.45
T. value/C. E. C.	4.05	3.65
C. E. C. clay	101	46
pH. H_2O	7.0	6.9
Ohms R 60°F	3000	600

Test Pit No: ST 36 SOIL SERIES: MANGANO

Site and Landform : Level red plain; < 1% slope ; Central Highlands

Vegetation: Acacia tortilis and short Acacia spp. , Medium Open Woodland; poor Eragrostis spp. cover

Sample No.	Horizon	Depth (in.)	Description
T112	A1	0 - 8	(5YR 3/2) dark reddish brown; sandy loam; apedal; very hard; rapid permeability; gradual transition
T239	B21	8 - 16	(5YR 3/2) dark brown; sandy loam; apedal; very hard; moderate permeability; frequent weak (5YR 3/2) cutans; gradual transition
T110	B22	16 - 36 +	(5YR 3/3) dark reddish brown; sandy loam; apedal; very hard; rapid permeability; rare weak (5YR 3/2) dark reddish brown cutans

ANALYTICAL DATA

Sample No.	T112	T239	T110
Depth in.	0 - 8	8 - 16	16 - 36 +
Horizon	A1	B21	B22
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	3	2	1
m. sand	25	22	21
f. sand	47	48	46
silt	12	13	15
clay	14	14	16
Net extractable cations (me/100 gm.)			
Na	0.05	0.30	0.50
K	0.20	0.30	0.80
Ca	0.75	1.50	2.90
Mg	1.10	2.60	5.80
S. value	2.10	4.70	10.00
T. value/C. E. C.	2.30	4.40	10.80
C. E. C. clay	16	31	68
pH. H_2O	6.1	6.3	6.8
Ohms R 60°F	800	370	700

Test Pit No: A 193 SOIL SERIES : MOZI

Site and Landform: Flat to gently undulating ; Ekuma Grassland

Vegetation: Coppice Mopane Open Woodland

Sample No.	Horizon	Depth (in.)	Description
J273	A1	0 - 15	(10YR 4/2) dark greyish brown; fine sand; apedal; slightly hard; rapid permeability; abrupt transition
J48	B21	15 - 20 +	(10YR 4/2) dark greyish brown; loamy fine sand; apedal tending to prismatic; very hard to extremely hard; moderate permeability

ANALYTICAL DATA

Sample No.	J273	J48
Depth in.	0 - 15	15 - 20
Horizon	A1	B21
Particle size distribution (%)		
% fine earth	100	100
c. sand	6	4
m. sand	29	26
f. sand	59	61
silt	3	5
clay	2	4
Net extractable cations (me/100 gm.)		
Na	0.10	1.10
K	0.15	0.50
Ca	0.25	0.50
Mg	0.60	0.65
S. value	1.10	2.75
T. value/ C. E. C.	2.00	3.00
pH. H_2O	6.2	7.6
Ohms R 60°F	6000	400
E. S. P.		37

Test Pit No: ST 24 SOIL SERIES: MUDEN

Site and Landform: Gently rolling calcrete hills; upper slope; top of low ridge; Central Highlands

Vegetation: Acacia spp., Terminalia prunioides Short Woodland some Mopane and Boscia spp. Aristida and Eragrostis spp. cover

Parent Material: Tertiary calcrete

Sample No.	Horizon	Depth (in.)	Description
T151	A1ca	0 - 3	(10YR 3/2) very dark greyish brown; fine sandy loam; apedal; soft; rapid permeability; soil material calcareous; abundant calcrete fragments small to large; frequent roots; clear transition
-	C1ca	3 - 8	Layer of broken up calcrete (large calcrete lumps with (10YR 3/2) very dark greyish brown; sandy clay loam material between lumps
-	C/R	8 +	Massive white hard calcrete with thin infillings of A1 material

ANALYTICAL DATA

Sample No.	T151
Depth in.	0 - 3
Horizon	A1ca

Particle size distribution (%)

% fine earth	90
c. sand	4
m. sand	9
f. sand	71
silt	19
clay	8

Net extractable cations (me/100 gm.)

Na	0.30
K	0.70
T. value/C. E. C.	6.95
C. E. C. clay	87
pH. H_2O	7.2
Ohms R 60°F	700

Test Pit No: K 143 SOIL SERIES : OKAVANGO

Site and Landform: Eastern border track in Bushmanland, 36 miles south of junction with main Tsumkwe road; slight depression in flat plain

Parent Material: Aeolian sand influenced by weathered products of calcrete

Vegetation: Short Acacia Open Woodland

Sample No.	Horizon	Depth (in.)	Description
	A1	0 - 8	(10YR 3/2) very dark greyish brown; sandy loam; weak coarse prismatic; hard to very hard; rare termite channels; rapid permeability; gradual transition
K143b	B2	8 - 20	(10YR 3/1) very dark grey; sandy loam; weak coarse prismatic; slightly hard; rare termite channels; soil mass calcareous; rapid permeability; gradual transition
K143c	C1ca	20 - 40	(10YR 3.5/1) very dark grey to dark grey; loamy sand; apedal; slightly hard; frequent powdery $CaC0_3$ in termite channels; rapid permeability; gradual transition
	C2ca	40 - 54	(10YR 4.5/1) dark grey to grey; sandy loam; apedal; slightly hard; soil mass strongly calcareous; rapid permeability

ANALYTICAL DATA

Sample No.	K143b	K143c
Depth in.	8 - 20	20 - 40
Horizon	B2	C1ca
Particle size distribution (%)		
% fine earth	100	100
c. sand	2	1
m. sand	29	26
f. sand	51	61
silt	3	3
clay	14	10
Net extractable cations (me/100 gm.)		
Na	0.15	0.05
K	0.10	0.15
Ca	3.00	2.85
Mg	2.10	1.95
S. value	5.35	5.00
T. value/C. E. C.	6.10	7.15
C. E. C. clay	44	71
pH. H_2O	6.7	5.4
Ohms R 60°F	750	1700

Test Pit No: ST 166 SOIL SERIES: OKAVANGO

Site and Landform: Level Etosha plain; Etosha Kalkveld

Vegetation: Scrub Mopane; Shrub Open Woodland; moderate Aristida spp. and Enneapogon cover

Sample No.	Horizon	Depth (in.)	Description
T171	A1	0 - 7	(10YR 6/1) dark grey; loamy fine sand; apedal; soft; rapid permeability. frequent roots; gradual transition
T172	B2	7- 19	(10YR 4/2) dark greyish brown; loamy fine sand; apedal; soft; rapid permeability; frequent fine roots; gradual transition
T173	C1ca	19 - 30	(10YR 6/3) pale brown; loamy fine sand; apedal; soft; rapid permeability; gradual transition
	C2ca	30 +	Weakly cemented pale brown calcareous sandy material; becoming strongly cemented with depth

ANALYTICAL DATA

Sample No.	T171	T172	T173
Depth in.	0 - 7	7 - 19	19 - 30
Horizon	A1	B2	C1ca
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	0	2	0
m. sand	30	31	29
f. sand	57	54	50
silt	6	1	3
clay	8	12	18
Net extractable cations (me/100 gm.)			
Na	0.05	0.10	0.40
K	0.10	0.40	0.50
Ca	2.30	1.25	
Mg	3.45	0.80	
S. value	5.90	2.60	
T. value/C. E. C.	6.30	5.70	8.65
C. E. C. clay	79	48	48
pH. H_2O	7.0	7.3	7.5
Ohms R 60°F	1600	1300	700

Test Pit No: A 210 SOIL SERIES : OVAMBO

Site and Landform: Flat gently undulating; Ovamboland Sandveld

Vegetation: Acacia-Terminalia veld

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 8	(7.5YR 4/4) brown to dark brown; fine sand; apedal; loose; rapid permeability; gradual transition
-	B1	8 - 24	(5YR 4/4 - 7.5YR 4/4) reddish brown to dark brown; fine sand; apedal; soft to loose; rapid permeability; gradual transition
J293	B21	24 - 44 +	(7.5YR to 5YR 4/6) yellowish red to strong brown; fine sand; apedal; loose; rapid permeability

ANALYTICAL DATA

Sample No.	J293
Depth in.	24 - 44
Horizon	B21

Particle size distribution (%)

% fine earth	100
c. sand	5
m. sand	21
f.sand	71
silt	3
clay	5

Net extractable cations (me/100 gm.)

Na	0.05
K	0.10
Ca	0.50
Mg	0.55
S. value	1.20
T. value/C. E. C.	1.75
C. E. C clay	35
pH. H_2O	6.8
Ohms R 60°F	3600

Test Pit No: A 139 SOIL SERIES : PAFURI

Site and Landform: Gently sloping ; Etosha Kalkveld

Parent Material : Calcrete

Vegetation: Mopane and scattered Combretum spp. scrub

Parent Material: Calcrete

Sample No.	Horizon	Depth (in.)	Description
J92	A1	0 – 6	(10YR 2/1) black; sandy clay loam; apedal; friable; rapid permeability; weakly self mulching; clear transition
J252	B21	6 - 14	(10YR 2/1) black; sandy clay; moderate coarse blocky; firm; slow permeability; abrupt transition
-	Cca	14+	Calcrete

ANALYTICAL DATA

Sample No.	J92	J252
Depth in.	0 - 6	6 - 14
Horizon	A1	B21
Particle size distribution (%)		
% fine earth	100	100
c. sand	1	1
m. sand	14	16
f. sand	53	54
silt	11	10
clay	21	19
Net extractable cations (me/100 gm.)		
Na	0.20	0.30
K	0.70	0.70
Ca	17.00	22.70
Mg	5.00	4.00
S. value	22.90	27.70
T. value/C. E. C.	23.40	30.20
C. E. C. clay	111	159
pH. H_2O	6.5	6.4
Ohms R 60°F	500	450

Test Pit No: ST 57 SOIL SERIES: PORTSMOUTH

Site and Landform: Level red sandy plain; <1% slope; Central Highlands

Vegetation: Scattered short Acacia tortilis and other Acacia spp. with rare Boscia spp. Short Open Woodland

Parent Material: Granitic drift

Sample No.	Horizon	Depth (in.)	Description
T59	A1	0 - 10	(5YR 4/6) yellowish red, coarse sand; apedal; loose; rapid permeability; frequent fine sub-angular quartz gravel; gradual transition
T58	B21	10 - 24	(2.5YR 3/6) dark red; loamy coarse sand; apedal; loose; very hard; frequent fine sub-angular quartz gravel; gradual transition
T57	B22	24 - 48 +	(2.5YR 3/6) dark red; loamy coarse sand; apedal; loose; very rapid; frequent very fine quartz gravel

ANALYTICAL DATA

Sample No.	T59	T58	T57
Depth in.	0 - 10	10 - 24	24 - 42
Horizon	A1	B21	B22
Particle size distribution (%)			
% fine earth	98	98	98
c. sand	32	33	37
m. sand	31	27	21
f. sand	30	28	30
silt	2	4	3
clay	4	7	8
Net extractable cations (me/100 gm.)			
Na	0.05	0.10	0.05
K	0.90	0.25	0.30
Ca	0.50	0.40	0.25
Mg	0.50	0.10	0.80
S. value	1.95	0.85	1.40
T. value/C. E. C.	3.80	4.00	3.90
C. E. C. clay	95	57	49
pH. H_2O	6.1	6.7	6.8
Ohms R 60°F	3600	2700	2700

Test Pit No: K 202 SOIL SERIES: PORTSMOUTH

Site and Landform: Gentle (2%) upper slope area in Southern Omatako Plain south west of Okakarara

Parent Material: Aeolian and colluvial sand

Vegetation: Acacia mellifera Open Woodland

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 9	(5YR 3/4) dark reddish brown; coarse sand; apedal; soft; rapid permeability; gradual transition
K202	B21	9 - 26	(2.5YR 3/6) dark red; loamy coarse sand; apedal; slightly hard; rapid permeability; gradual transition
-	B22	26 +	(2.5YR 3/4) dark red; loamy coarse sand; apedal; slightly hard; rapid permeability

ANALYTICAL DATA

Sample No.	K202
Depth in.	9 - 26
Horizon	B21

Particle size distribution (%)

% fine earth	100
c. sand	16
m. sand	22
f. sand	47
silt	2
clay	13

Net extractable cations (me/100 gm.)

Na	0.05
K	0.30
Ca	0.60
Mg	1.35
S. value	2.30
T. value/C. E. C.	3.30
C. E. C. clay	25
pH. H_2O	4.4
Ohms R 60°F	5000

Test Pit No. A 215 SOIL SERIES : ROODEPOORT

Site and Landform: Flat to gently undulating ; Ovamboland Sandveld

Vegetation: Acacia spp. Terminalia sericea

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 10	(5YR 4/6) yellowish red; fine sand; apedal; loose; rapid permeability; gradual transition
-	B21	10 - 30	(5YR 4/7) yellowish red; fine sand; apedal; soft; rapid permeability; frequent yellow sand infillings; gradual transition
J268	B22	30 +	(5YR 4/6) yellowish red; fine sand; apedal; soft; rapid permeability

ANALYTICAL DATA

Sample No.	J268
Depth in.	30 - 36
Horizon	B22

Particle size distribution (%)

% fine earth	100
c. sand	0
m. sand	16
f. sand	77
silt	3
clay	5

Net extractable cations (me/100 gm.)

Na	0.10
K	0.10
Ca	0.25
Mg	0.60
S. value	1.05
T. value/C. E. C.	1.45
C. E. C. clay	29
pH. H_2O	6.5
Ohms R 60°F	1200

Test Pit No: K 31 SOIL SERIES : SANDSPRUIT

Site and Landform: Flat plain near eastern border of Hereroland on southern bank of Rooiboklaagte Omuramba

Parent Material: Aeolian sand

Vegetation: Short Combretum - Terminalia - Acacia Open Woodland

Sample No.	Horizon	Depth (in.)	Description
P314	A1	0 - 8	(10YR 3/2) very dark greyish brown; sand; apedal; slightly hard; rapid permeability; gradual transition
P320	B21	8 - 30	(10YR 3/4) dark yellowish brown (7.5YR 4/6) dry; sand; apedal; slightly hard; rare white sand infillings in termite channels; rare roots; rapid permeability; gradual transition
P316	B22	30 - 52	(10YR 3/4) dark yellowish brown (7.5YR 4/6) dry; sand; apedal; slightly hard; rare fine fossil $CaCO_3$ nodules and white sand infillings in termite channels; rapid permeability; gradual transition
P321	B23	52 - 75	By auger; (10YR 3/4) dark yellowish brown (7.5YR 4/6) dry; sand; apedal; slightly hard; rare fine fossil $CaCO_3$ nodules and white sand infillings in termite channels; rapid permeability;

ANALYTICAL DATA

Sample No.	P314	P320	P316	P321
Depth in.	0 - 8	8 - 30	30 - 52	52 - 75
Horizon	A1	B21	B22	B23
Particle size distribution (%)				
% fine earth	100	100	100	100
c. sand	2	3	5	3
m. sand	43	36	36	32
f. sand	50	54	51	56
silt	1	1	1	1
clay	4	5	6	7
Net extractable cations (me/100 gm.)				
Na	0.05	0.05	0.10	0.15
K	0.25	0.20	0.15	0.20
Ca	1.20	1.70	1.80	2.30
Mg	0.90	0.55	1.05	1.10
S. value	2.40	2.50	3.10	3.75
T. value/C. E. C.	3.40	4.10	3.55	3.80
C. E. C. clay	85	82	59	54
pH. H_2O	5.7	5.4	5.3	6.0
Ohms R 60°F	3800	4000	3300	1200

Test Pit No: K 186

SOIL SERIES : SANDSPRUIT

Site and Landform : Farms to north east of Hereroland, south of Tsumkwe road; flat plain

Parent Material: Aeolian sand

Vegetation: Medium Combretum - Acacia Open Woodland

Sample No.	Horizon	Depth (in.)	Description
K186a	A1	0 - 9	(10YR 4/4) dark yellowish brown, (10YR 5/4) yellowish brown (dry); sand; apedal; soft; rapid permeability; gradual transition
K186b	B2	9 - 28	(10YR 5/6) yellowish brown, (10YR 6/6) brownish yellow (dry); sand; apedal; soft; rapid permeability; gradual transition
	C	28 - 44	(10YR 5/6) yellowish brown, (10YR 6/6) brownish yellow (dry); sand; apedal; soft; rapid permeability

ANALYTICAL DATA

Sample No.	K186a	K186b
Depth in.	0 - 9	9 - 28
Horizon	A1	B2
Particle size distribution (%)		
% fine earth	100	100
c. sand	13	12
m. sand	36	35
f. sand	44	47
silt	1	1
clay	6	6
Net extractable cations (me/100 gm.)		
Na	0.05	0.05
K	0.15	0.15
Ca	0.80	0.70
Mg	0.65	0.45
S. value	1.65	1.35
T. value/C. E. C.	1.80	2.35
C. E. C. clay	29	30
Ohms R 601F	5,200	>10,000

Test Pit No: ST 196 SOIL SERIES : SHORROCKS (+)

Site and Landform: Upper slope ; 1% slope; undulating plain ; Central Highlands

Vegetation: Short Mopane and Terminalia prunioides Open Woodland, shrub Mopane

Parent Material: Drift overlying calcrete

Sample No.	Horizon	Depth (in.)	Description
L306	A1	0 - 6	(5YR 3/4) dark reddish brown; sandy clay loam; apedal; hard; rapid permeability; gradual transition
L307	B21	6 - 16	(2.5YR 3/4) dark reddish brown; clay loam; apedal; hard; moderate permeability; gradual transition
L308	B23	16 - 24	(2.5YR 3/4) dark reddish brown; clay loam; weak fine blocky; very hard; moderate permeability; abrupt transition
	C/R	24 +	Hard massive calcrete

ANALYTICAL DATA

Sample No.	L306	L307	L308
Depth in.	0 - 6	6 - 16	16 - 24
Horizon	A1	B21	B22
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	6	4	4
m. sand	20	16	14
f. sand	40	35	31
silt	14	17	15
clay	21	28	35
Net extractable cations (me/100 gm.)			
Na	0.05	0.05	0.05
K	0.85	0.80	0.75
Ca	6.35	9.85	11.10
Mg	7.20	11.20	12.40
S. value	14.45	21.90	24.30
T. value/C.E.C.	13.20	20.10	23.40
C.E.C. clay	63	72	67
pH. H_2O	6.8	6.8	7.1
Ohms R 60°F	1100	600	600

Test Pit No: ST 106 SOIL SERIES : SHORROCKS (-)

Site and Landform: Mid pediment; 2% slope; undulating; Central Highlands

Vegetation: Short Acacia spp. Open Woodland and scrub Boscia spp. moderately poor Eragrostis spp. Aristida spp and Enneapogon spp. cover

Parent Material: Mixed drift

Sample No.	Horizon	Depth (in.)	Description
T252	A1	0 - 7	(5YR 3/4) dark reddish brown; loamy coarse sand; apedal; soft; rapid permeability; gradual transition
T148	B21	7 - 20	(2.5YR 3/6) dark red; sandy clay loam; apedal; hard; rapid permeability; gradual transition
T21	B22	20 - 40 +	(2.5YR 3/6) dark red; coarse sandy loam; apedal; hard; rapid permeability

ANALYTICAL DATA

Sample No.	T252	T148	T21
Depth in.	0 - 7	7 - 20	20 - 40
Horizon	A1	B21	B22
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	21	19	22
m. sand	22	22	20
f. sand	40	35	32
silt	5	5	10
clay	12	20	15
Net extractable cations (me/100 gm.)			
Na	0.10	0.10	0.10
K	0.20	0.15	0.20
Ca	1.45	0.75	1.15
Mg	1.55	0.75	1.10
S. value	3.30	1.75	2.55
T. value/C. E. C.	3.75	4.55	3.50
C. E. C. clay	31	23	23
pH. H_2O	6.3	5.8	5.4
Ohms R 60°F	2000	2000	1700

Test Pit No: A 292 SOIL SERIES : VALSRIVIER

Site and Landform: Flat ; Etosha Kalkveld

Vegetation: Combretum - Acacia Open Woodland

Parent Material: Mixed drift

Sample No.	Horizon	Depth (in.)	Description
-	A1	0 - 8	(10YR 3/1 - 2/1) very dark grey to black; sandy loam to sandy clay loam; apedal; hard to very hard; moderate permeability; gradual transition
C128	B21	8 - 26	(10YR 3/1) very dark grey; sandy loam; coarse blocky; hard to very hard; moderate permeability
-	Cca	26 - 44	(10YR 4/1) dark grey; sandy clay loam; apedal; hard; moderate permeability; frequent small $CaCO_3$ concretions

ANALYTICAL DATA

Sample No.	C128
Depth in.	8-26
Horizon	B21

Particle size distribution (%)

% fine earth	100
c. sand	34
m. sand	12
f. sand	33
silt	3
clay	18

Net extractable cations (me/100 gm.)

Na	0.10
K	0.70
Ca	3.15
Mg	4.30
S. value	8.25
T. value/C. E. C.	9.90
C. E. C. clay	55
pH. H_2O	7.4
Ohms R 60°F	700

Test Pit No: F2

SOIL SERIES: ZWARTFONTEIN - PORTSMOUTH intergrade

Site and Landform: Gently sloping pediment; Kaokoveld

Vegetation: Mopane, Terminalia pruniodes, Combretum spp. Woodland

Parent Material: Mixed drift

Sample No.	Horizon	Depth (in.)	Description
C470	A1	0 - 8	(2.5YR 3/4) dark reddish brown; sandy loam; apedal; slightly hard; rapid permeability; gradual transition
C420	B21	8 - 21	(2.5YR 3/6) dark red; sandy loam; apedal; slightly hard to hard; rapid permeability; gradual transition
C120	B22	21 - 34	(2.5YR 3/6) dark red; sandy loam; apedal; slightly hard to hard; rapid permeability; two large calcrete boulders extending to within 12 inches of the soil surface; the calcrete is not present as a continuous mass, rather as discrete colluvial boulders

ANALYTICAL DATA

Sample No.	C470	C420	C120
Depth in.	0 - 8	8 - 21	21 - 34 +
Horizon	A1	B21	B22
Particle size distribution (%)			
% fine earth	100	100	100
c. sand	15	14	15
m. sand	24	26	23
f. sand	42	43	41
silt	8	10	7
clay	11	8	14
Net extractable cations (me/100 gm.)			
Na	0.20	0.10	0.30
K	0.40	0.35	0.40
Ca	1.95	2.20	2.90
Mg	2.20	2.10	4.60
S. value	4.75	4.75	8.20
T. value/C. E. C.	5.65	5.70	8.70
C. E. C. clay	51	71	62
pH. H_2O	6.1	6.2	6.4
Ohms R 60°F	1200	2600	600

Test Pit No: ST 107 SOIL SERIES: ZWARTFONTEIN

Site and Landform: Mid slope; 3% slope; gently undulating; Central Highlands

Vegetation: Short Acacia spp. Open Woodland; Boscia spp. shrubs; Aristida spp. and Enneapogon poor cover

Parent Material: Mixed calcareous drift

Sample No.	Horizon	Depth (in.)	Description
T282	A1	0 - 10	(5YR 3/4) dark reddish brown; sandy loam; apedal; friable; rapid permeability; gradual transition
T94	B21	10 - 20	(5YR 4/3) reddish brown; sandy loam; apedal; loose; rapid permeability; gradual transition
	B22ca	20 - 40	(5YR 5/4) reddish brown; sandy loam; apedal; loose; very rapid permeability; rare fine calcrete fragments; abrupt trandition
-	C/R	40 +	Massive hard calcrete

ANALYTICAL DATA

Sample No.	T282	T94
Depth in.	0 - 10	10 - 20
Horizon	A1	B21
Particle size distribution (%)		
% fine earth	100	100
c. sand	1	1
m. sand	37	42
f. sand	53	48
silt	3	2
clay	6	7
Net extractable cations (me/100 gm.)		
Na	0.10	0.10
K	0.30	0.45
Ca	1.30	
Mg	1.25	
S. value	2.95	
T. value/C. E. C.	4.25	3.45
C. E. C. clay	71	49
pH. H_2O	7.2	7.2
Ohms R 60°F	1400	2000