FOOD AND AGRICULTURE ORGANIZATION

SURVEY OF LAND POTENTIALITY FOR IRRIGATION OF WESTERN OKAVANGO BY SATELLITE REMOTE SENSING TECHNIQUES

By

M.K. NOSSEIR

Remote Sensing Consultant

Technical Report No. 2

TCP/BOT/6653 (I)

NOVEMBER, 1987

联合国粮食及农业组织 FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE ORGANIZACION DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION منظمة الأغذية والزراعة للأمم المتحدة

技术合作计划 TECHNICAL COOPERATION PROGRAMME PROGRAMME DE COOPÉRATION TECHNIQUE PROGRAMA DE COOPERACIÓN TÉCNICA برنامج التعاون الفني

Country:	**BOTSWANA**
Project title:	Survey of Land Potential for Irrigated Agriculture by Satellite Remote Sensing Technique
Project number:	TCP/BOT/6653(I)
Starting date:	February 1987
Completion date:	January 1988
FAO contribution:	US$ 100 000

Signed:............................. Signed:.............................

Edouard Saouma
Director-General

(on behalf of the Government) (on behalf of FAO)

Date of signature:.................. Date of signature:..................

I. BACKGROUND AND JUSTIFICATION

For many years, agriculture has held the highest priority in the Government's objectives of improving the lives of all the people of Botswana. However, since the country is endowed with a semi-arid climate, for the most part with sparse and unpredictable rainfall, dependence on rainfed agriculture for food production is, at best, precarious. Even in the best of years, rainfed agriculture yields much less than one half of the annual food requirement for the one-million population. The situation becomes more dramatic when the inevitable periods of drought occur. For example the national production of foodgrains in 1984 was only 7 300 tons, less than 5 percent of annual requirements.

Given such conditions, the Government has made substantial efforts to develop the existing potential for irrigated agriculture in the country. The recent experience with the drought has given fresh impetus in this area, and the Government has increased its efforts to help develop irrigated agriculture in those areas of the country where this potential exists but has not as yet been tapped.

The new areas with the greatest potential for irrigated agriculture are in the north, particularly on the fringes of the Okavango Delta. The total area of the Delta comprises approximately 40 000 sq. km, of which about half are perennial swamps. Other areas with potential, further north, are those bordering on the Caprivi Strip.

Two areas of immediate concern include the Shorobe/Mayanga and the Gomare/Ethosha areas in the Okavango Delta, where it is hoped that large and small scale irrigation projects can be developed. Current Government programming calls for feasibility studies of these areas following the results of this TCP assistance. The feasibility studies will be conducted to determine the technical and economic suitability for irrigation development and the extent (hectares) to which these areas might be exploited.

II. OBJECTIVES OF THE ASSISTANCE

The immediate objective of the assistance is to strengthen the capability of the Ministry of Agriculture to identify and assess land suitable for irrigated agriculture.

III. WORK PLAN

- Select two sites in the Okavango Delta in consultation with government. Each site will be approximately 10 000sq.km	Feb/March 1987
- Order satellite imagery (Landsat MSS) for both sites. Images will be selectedto cover the annual and seasonal flooding fluctuations in each site since the mid-1970s;	Feb/March 1987
- Gather existing aerial photographs, maps (topography, geology, soils, etc.) and documentation from any other surveys and inventories covering the sites selected;	Feb/March 1987
- Obtain new aerial photographs from light aircraft flights along transects identified on satellite imagery;	August 1987
- Conduct field sampling surveys (soils, hydrology, land use) in locations identified on satellite imagery;	Aug/Nov 1987
- Assess suitability of each site for irrigated agriculture based on the analysis of multidate remote sensing imagery, existing maps and sample field surveys;	Aug/Nov 1987
- Prepare a Landsat-based photomap at 1:250 000 scale or larger with delineated classes showing potential for irrigated agriculture (high, medium, low) for each site;	Sept/Nov 1987
- Conduct on-the job training programme for counterpart national officers;	Sept/Oct 1987
- Select two officers for one-month study tour in USA;	October 1987

- Prepare a technical report and terminal statement. Oct/Nov 1987

IV. INPUTS TO BE PROVIDED BY FAO

Personnel

One consultant in remote sensing applications in agricultural land assessment (two missions of 3 months each) (TOR in Annex I).

Officiel travel up to US$ 4 000

General operating expenses up to US$ 3 000

Supplies and material (satellite imagery, 35 mm aerial photograph, drafting material etc. up to US$ 22 000

Equipment (one optical enlarger and one light table) up to US$ 13 000

Training

2 one month each study tours abroad and local training expenses up to US$ 10 000.

V. REPORTING

The consultant will prepare a report (field document) at the end of each of his missions. He will also draft a Terminal Statement in accordance with TCP procedures, at the end of his second mission.

VI. GOVERNMENT CONTRIBUTION AND SUPPORTING ARRANGEMENTS

The Government of Botswana will be responsible for the provision of the following:

- national project coordinator and two full-time counterpart officers (soils and water resources);
- cooperation with and support for the project by relevant Government services (soils, hydrology, mapping) as required;

- suitable office space for personnel and equipment, including office space for the consultant;
- in-country transport and other technical support as needed.

PROJECT BUDGET COVERING FAO INPUTS

(in US Dollars)

Country: BOTSWANA

Project title: Survey of Land Potential for Irrigated Agriculture by Satellite Remote Sensing Technique

Project number: TCP/BOT/6653(I)

		US$
10.	Personnel	48 000
20.	Internal travel	4 000
40.	General operating expenses	3 000
50.	Materials and supplies	22 000
60.	Equipment	13 000
80.	Training	10 000
	Total	100 000

TERMS OF REFERENCE

Consultant on assessment of land potential for irrigated agriculture using remote sensing

Under the overall supervision of the National Project Coordinator and in cooperation with the national counterpart officers, the consultant will be responsible for the Work Plan. Specifically, he will:

- carry out a study of three sites selected by the Government involving assessment of suitability of each site for irrigated agriculture based on multidate remotely-sensed imagery, existing information and sample field survey;
- purchase satellite imagery for all the sites for the study;
- review all documents,etc. available about the selected areas;
- obtain new aerial photographs from light aircraft;
- conduct field sampling surveys of soils, hydrology and land use in selected locations of the three sites;
- prepare a Landsat-based imagery map of the studied sites, delineating classes showing potential for irrigated agriculture;
- conduct on-the-job training for counterpart national officers;
- prepare a technical report and terminal statement for the project.

Qualifications:

The consultant should have a post-graduate university degree in earth science, agriculture, soil science, geography or related field, and remote sensing. He should have at least seven years working experience and be conversant with the use of remote sensing techniques in assessment of land resources for determining land suitability for irrigation.

Duty station: Gaborone, Botswana

Duration: Two missions totalling 6 months

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LIST OF MAPS

LIST OF ABBREVIATIONS

BOT	Botswana
CEC	Cation Exchange Capacity
CFDA	Communal First Development Area
C.V.	Coefficient of Variation
F.A.O.	Food and Agriculture Organization
Ha	Hectare (10 000m^2)
LANDSAT-MSS	Multispectral Scanner System of Landsat Satellite
LANDSAT-TM	Thematic Mapper of Landsat Satellite
NDP	National Development Plan
SPOT-MSS	Multispectral System of the French Satellite SPOT
UNDP	United Nation Development Programme
USBR	United States Bureau of Reclamation

1. INTRODUCTION

The developing of productive rural employment opportunities and food self sufficiency have been identified as an important part of the strategic considerations in the implementation of Botswana Sixth National Development Plan (1985-1991). Therefore, it became necessary to conduct prefeasibility studies for the evaluation of potential lands for irrigation. The emphasis on irrigation can be justified based on the possible increase of productivity and the possibility of increasing job opportunities on the irrigated lands. The recent experience with the drought demonstrated once more, the importance of searching for reliable water sources for food production.

Consequently, the Government started looking at the Okavango system as potential water and land resources. This was based on the large extension of 2 800 Km^2 of the delta and its 10 000 km^2 of permanent swamps system. Therefore, the Government requested the technical assistance of FAO in surveying land potential for irrigated agriculture, by Satellite Remote Sensing techniques in two sites of Okavango Delta: Shorobe/ Mayanga and Etsha/Gomare/Nokaneng. Results of this survey will lead to feasibility studies with the objective of determination of the technical and economic suitability for irrigation development. Meanwhile, a feasibility study of Southern Okavango Integrated Water Development - Phase I (SMEC, 1987), indicated the severe limitations of the land and water resources in the mentioned area which included Shrobe/ Mayanga but excluded Etsha/Gomare/Nokaneng. For this reason, the present FAO study, in this report, was restricted to the latter area, which covers approximately 580 000 Ha. This area is located on the western fringe of the Okavango plains with Kalahari desert. It is mainly influenced by the Thaoge river system and its associated swamps.

Thus, the specific objective of this study is to identify and map potential lands for irrigated agriculture, based on the flooding pattern and soil restrictions. The multi-temporal and multi-spectral Satellite Remote Sensing techniques have been the main tools in monitoring the boundaries of the permanent swamps, annual overflow plains and the annual extension of the flood water into Thaoge, Karongana, Potae and Xinitshaa rivers. Landforms were mapped from the satellite imagery. Interpretation of aerial photographs and field work were conducted to correlate landforms with their soil characteristics and restrictions for irrigation. Based on this information each landform was evaluated for its potentiality for irrigation. A map was produced indicating the potentiality classes, restrictions for irrigation and the recommended irrigation system or land use. It should be mentioned that evaluation of the potentiality has been conducted taking into consideration the assumption that irrigation water will be available in the Thaoge, as a result of the on-going project for the restoration of flow of the Thaoge river. This project aims at securing 2.5-5 m^3/s flow in the mentioned river by June, 1988.

2. MATERIALS AND METHODS

2.1 Site Location

The site under evaluation covers approximately 577 000 Ha. It is located between latitudes S 19°00 and S 20°00 and longitude E 22°00 and E 22°30' , MAP (GO-1). This area covers the eastern part of Nokaneng topographic sheet No. 5, at scale 1:250 000. The western part of the same sheet is covered by Kalahari longitudinal sand dunes.

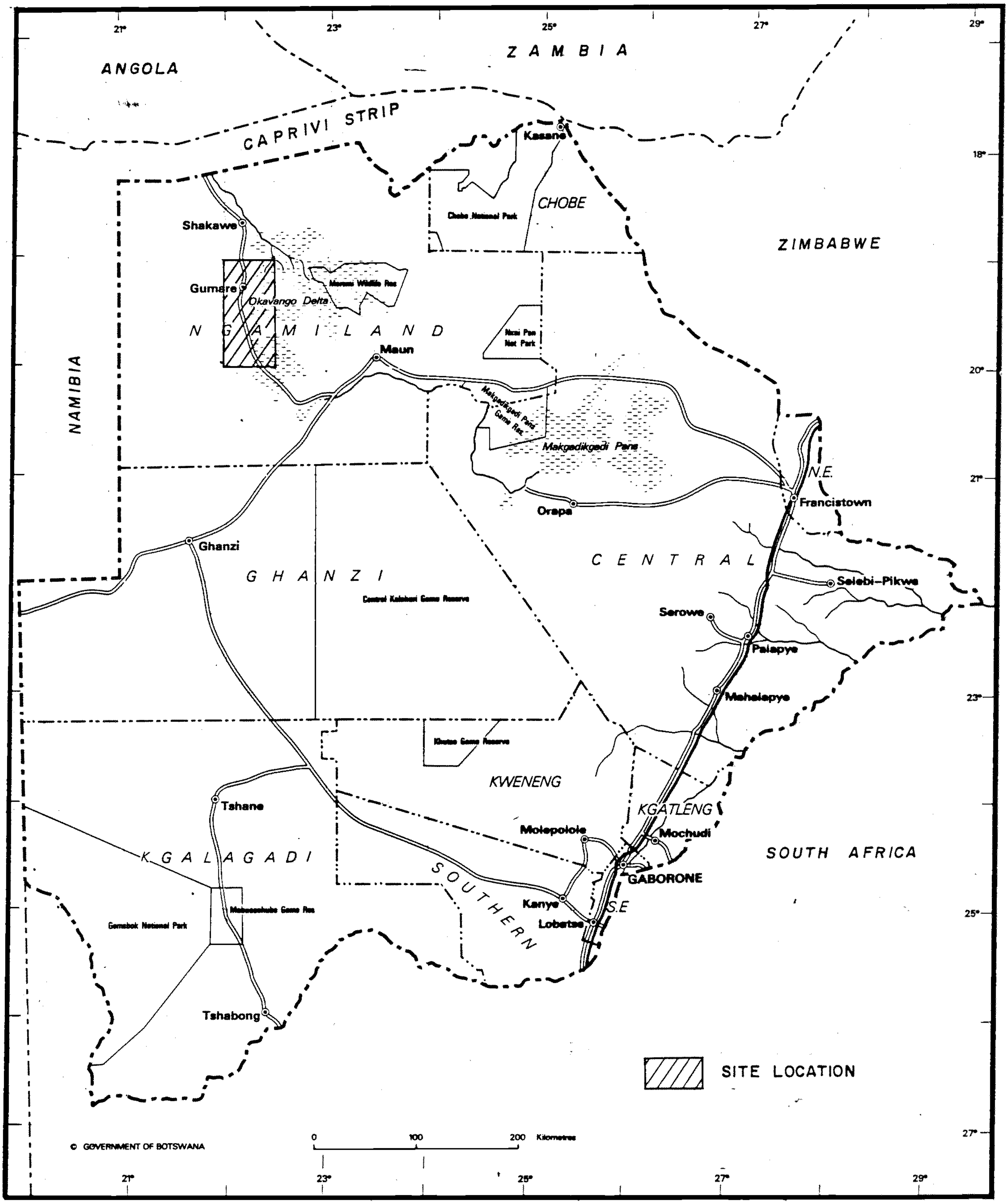
The track road connecting Sehithwa with Shakawe crosses the area in north-south direction. It represents the only ground communication route of the area. Etsha, Gomare and Nokaneng are the major villages in the area. They have been always the largest settlement centres in Ngamiland district. Due to their high development potential, they have been chosen as the Communal First Development Area (CFDA), Bendsen (1983).

2.2 Materials

2.2.1 Landsat imagery

Landsat imagery have been used as the main source of information for monitoring the flooding pattern and its extension in the Thaoge river system. Selection of the imagery was based on the analysis of the discharge flow at Mohembe which is the only site with long discharge records, since 1974.

Analysis of the monthly data indicated that the maximum flow reaches Mohembo during the months of March, April and May. This also indicates that the peak of the flow reaches the site during August and September. Moreover, the analysis of the annual discharge data at Mohembo showed that the maximum annual discharge took place during the season of 1976/1977 reaching 14641.1 x 10^3 m^3/y. The minimum during the period of 1974/75 to 1985/86, took place during the season of 1982/83, reaching only 6042.4 x 10^3 m^3/y. On the other hand, imagery of Landsat, MSS before 1981 were



MAP (GO - I) - SITE LOCATION

not available. Therefore imagery covering the period of 1981 to 1985 were used in monitoring flood extension in the site. Monthly discharge at Mohembo is given in Table (1). Black and white Imagery of Landsat-MSS bands 7 and 5 at scale 1:250 000 were used to map the boundaries of the flooded area. Actual water surface, waterlogged land and areas with defaulted meanders and oxbows when retaining water, have been considered inside the flooded area. Imagery of the following dates were analized:

16/06/81	16/09/82	01/07/83	29/09/84	12/06/85
07/11/81	02/10/82	18/08/83		15/08/85
		03/09/83		02/10/85

Landsat imagery was also used for the mapping of the Landform units. A recent image of 20/07/87 in colour composit, edge enhanced and systematically corrected was used to finalize the landform boundaries.

2.2.2 Aerial photographs

The site is covered by 1:50 000 aerial photographs. They were flown during May, 1983. These photographs were very useful in the establishment of the relationship between Landsat interpretation elements and the landform units and their boundaries. The aerial photographs were also used in correlating landforms with soil characteristics.

2.3 Methods

2.3.1 Cartographic base

The site under evaluation has very limited number of cultural features such as roads or cities which can be identified on both Landsat imagery and the

Table (1) - Monthly Flow of Okavango River,

at Mohembo (Station No. 7112)

Month	Flow in x 100 m^3/year				
	80-81	81-82	82-83 (Lowest)	83-84 (Highest)	84-85
October	358.4	321.3	268.6	275.0	469.6
November	267.3	294.3	278.3	331.3	473.7
December	289.5	331.1	406.0	605.7	619.9
January	451.7	349.1	529.3	629.9	850.5
February	588.8	565.9	606.0	1020.8	853.4
March	1042.9	1045.1	784.9	1449.5	916.1
April	1365.4	1144.5	937.0	1508.8	1169.3
May	1192.4	985.1	699.3	1332.9	1341.1
June	839.5	658.1	500.4	1028.3	894.2
July	565.4	492.3	411.6	771.5	699.3
August	462.9	383.1	342.5	626.8	571.2
September	371.1	324.7	278.5	499.1	451.0
TOTAL	7795.5	6894.6	6042.4	10079.7	9309.4

Source: Records of Department of Water Affairs
Gaborone, Botswana

topomaps at 1:250 000 scale. It was also noticed the presence of differences in the location or configuration of some parts of Thaoge, Karongana and some lakes as compared from Landsat imagery and the above mentioned topomap. Therefore, it was necessary to establish a cartographic base which can permit better registration of land features during the temporal monitoring of the boundaries of the overflow plains and the connection between the Thaoge river and its different feeder resources. Landsat imagery of 29/9/84, ID : 50212-08012 Path 175, Row 73 and 50212-08014 Path 175, Row 74, were used for the purpose of establishing the cartographic base. These imagery represent the maximum extension of the overflow area and the maximum extension of water into Thaoge river and also into Karongana, Potae and Xinitshaa rivers systems. Therefore, it was possible to draw the accurate course of the rivers, their active meanders, their inter connection, their connection with the overflow area and their blocked sections. Gomare air strips was also distinguishable on Landsat imagery Parts of the road connecting Shakawe in the north with Tsau in the south were also identifyable. All the six lakes, which have been used for flood monitoring were easy targets for mapping. From these natural and man-made features a cartographic base was prepared. Thaoge and Karongana rivers were used as transfer linear features in the overlapped area of image 175/74 and 175/73. MAP (GO-2) represents this cartographic base.

2.3.2 Flood monitoring

The boundary of the overflow plains was delineated from band 7 of each of Landsat imagery, covering the years of 1981, 1982, 1983, 1984 and 1985. The used imagery have been listed in Item 2.2 of this chapter. Lakes, waterlogged areas, defaulted meanders and ox-bows which were retaining water have been included within these boundaries. A separate overlay was prepared for each image. Acreage of the flooded areas were estimated by using a 2 mm x 2 mm grid. Acreage of the main lakes were estimated separately, by using the same procedure. These lakes were:

Xhamu
Weboro (Mapororo)
Wabe (Ranta)
Qurube
Qutshiga (Xusinxa)
Gwekatshum (Gwekatsumi)

It was noticed that some of the lakes have different names on the topo maps of 1:250 000 as compared with the topo maps of 1:50 000. The names used in this report are those of the 1:250 000 maps. Meanwhile names of lakes as shown in 1:50 000 maps are also given between brackets in the above list of lakes' names.

Acreage of lakes and their changes have been used as indicator of flood intensity and of the storage capacity of these lakes. The boundaries of the maximum flood (29/09/84) and the minimum flood (03/09/83) are presented in Map (GO-2). Additional linear indicators of flood changes are the extension of water in the main rivers: Thaoge, karongana, Potae and Xinitshaa. Their maximum extension have also been presented in Map (GO-2). Connections between the last three rivers and the Thaoge river are presented on the same map. Then finally the blocked sector of the Thaoge river, and the bypass channel in the flow restoration scheme are indicated on the map.

2.3.3 Assessment of land potentiality for irrigation

The major assumption in this assessment procedure is that water for irrigation will be available in the Thaoge river as a result of the on-going Flow Restoration Scheme as designed by Kraatz, (1976). Result of this restoration is expected to secure 2.5 - 5.0 m^3/second of flow in the Thaoge river by 1988. Without this restoration no source of irrigation water will be available except during the extremly high flood such as the one on 1984.

The potentiality assessment process was initiated by mapping the Landform units. For this purpose a legend was prepared which indicates the formation process of each unit and its terrain characteristics. This kind of legend is adequate for mapping landforms from Landsat - MSS, bands 5 and 7. Moreover, it becomes possible to relate the mapped units with their soil properties and natural vegetation. The legend, Map (GO-3), indicates the presence of 3 major terrain groups:

- Permanent and seasonal overflow plains
- Alluvial deposits terrains
- Kalahari sandy terrains

The first and the last groups of terrain have no potential for irrigation due to their many restrictions as will be discussed later. Thus, the potential land for irrigation is located within the second group of terrains. Therefore, the precise definition of the location of the boundaries between the groups and within each group was the main task. Consequently, the boundary of both permanent and seasonal overflow plains together was considered to be the boundary of the maximum overflow, which is that of 29/09/84. Within this area it was necessary to distinguish between the permanent swamp and the seasonal swampy area which is subject to flooding risk. The boundary between these two landform units was considered to be the boundary of the lowest flooded area before the arrival of the flood of the lowest season. This boundary should be the one of the overflow plains of 1/07/83. It was noticed that some small sand islands are located within the overflow plains. Due to their small acreage at the mapping scale of 1:250 000, these islands were not separated as different mapping units. Only the large sand islands were mapped separately. Other landform units were mapped from Landsat imagery bands 5 & 7. Then the composition of each unit was described by photo interpretation and field checking. Soil properties of each landform unit were obtained from Staring, (1978), unpublished soil description sheets by Rhebergen, photo interpretation and field checking. Summary of the soil characteristics which are relevant to the assessment of land potentiality for irrigation are presented in Table (3). The choice of these soil characteristics has been based on the recommendations of FAO and USBR which are published in FAO, Soil Bulletin No. 42, FAO, (1986). Consequently, definition of land restrictions for irrigation was based on the interpretation of soil characteristics of each landform The following restrictions were considered in this assessment:

- Flood damage as a consequence of the yearly overflow and the Flooding of the main rivers (f).

- Oxygen availability as a consequence of high water table in the lower positions of the flood plains or due to water logging of the soil at the margin of the overflor plains (o).

- Nutrient availability due to the low Cation Exchange Capacity (CEC) and low organic matter (n).

- Available moisture due to the sandy texture (m).

- Levelling requirements due to the irregural micro relief as a result of the fluvial process of the main rivers (ℓ).

- Wind erosion as a consequence of lack of vegetation cover due to overgrazing and firewood collection on the alluvial plains (e).

- Deposit of blown sand which has been removed from the sand ridges and dunes and then deposited on the surface of the alluvial plains (s).

- Distance from source of irrigation water, considering the possible sources to the Thaoge river or at lesser extent the Karongana river (d).

As a result of this analysis each landform was classified into one of the following three classes:

- Potential for irrigation (P)
- Marginally potential for irrigation (M)
- Not potential for irrigation (N)

Then finally a recommended irrigation method was indicated. In case of the lands with marginal or no potential for irrigation, an alternative land use was recommended. The spatial distribution of each potentiality class is presented in Map (GO-4). A mapping symbol was elaborated in a fraction form. Land potentiality class for irrigation is indicated by a capital letter on the denumerator position of the fraction. This is followed by lower case letters or more between brackets representing land restrictions for irrigation. The recommended irrigation system or land use is indicated by a capital letter on the numerator position of the symbol form.

The recommended irrigation systems are:

- Furrow irrigation (F) from Thaoge river after flow restoration.

- Drip (D) or Sprinkle (S) irrigation if additional irrigation water sources become available.

The recommended land use types are:

- Wildlife (W) on the permanent swamps and east of the buffalo fence.

- Molapo farming (M) in the areas subject to seasonal overflow.

- Improved molapo farming (Mi) on the flood plains, after the recession of the flood (September and October).

- Dry farming (D), depending only on the precipitation, starting plantation in December.

- Grazing (G), under improved management system by following rotation, in order to reduce the grazing pressure and avoid overgrazing.

3. RESULTS AND DISCUSSION

3.1 Climate

Climatological data records are only available from Shakawe (50 years) and Maun (65 years). The total annual precipitation in Shakawe is 561.6 mm/y and in Maun is 463.7 mm/y with coefficient of variation (C.V.) of 36% and 38% respectively, Vossen, (1987). The C.V. is higher during the beginning and the end of the rainy season as compared with its value during the peak, which takes place during January and February. Meanwhile, Potential Evapotranspiration is 1616 mm/y in Shakawe and 1909 mm/y in Maun, Vossen, (1987). Analysis of Agroclimatic zones of Botswana classifies the site into two ecological zones: 1b2 and 2c2, Rhebergen, (1987). Combination of data from the two zones indicates that the site can be characterized as:

- Length of growing season: 101-120 days in the northern part and 81-100 days in the southern.

- Number of dry days within the season are 11-20 days in the northern, and 21-30 days in the southern part.

- Duration of the humid period is 20-40 days all over the site.

The above mentioned agroclimatic characteristics of the site illustrate the drastic restriction of the dry farming in the area and justify the necessity for additional moisture sources for agriculture development, rather than depending only on precipitation. Moreover, the agroclimatic characteristics explains the reason why dry farming is more successful in Etsha, especially the northern part from Etsha 6 to 13 as compared with the dry farming southword.

3.2 Water resources

3.2.1 General description

The Thaoge river system is the most western distributary of the Okavango system. A Landsat imagery of the area indicates clearly that the Thaoge system receives the smallest part of the inflow which passes from Okavango river to Nqogha river at Ikoga area. On the contrary during the first half of the 19th century, the Thaoge system was the major out-let of the Okavango system, Wilson and Dincer, (1976). This statement can be confirmed from the presence of old dry channels and alluvial deposits west of the present Thaoga river flood plains and in higher position as compared with the present flood plains and terraces of the same river. There are several reasons which have been given, by different authors, Brind, (1954), Thompson, (1974), and Wilson and Dincer, (1976). These reasons are:

- Papyrus islands with root developing during the low flood season.

- Sedimentations, then aguatic vegetation blockage.

- Tectonic activities (Earthquake) which cause tilting toward east.

Independent on a single reason or a combination of reasons, the fact is that Landsat imagery indicates different blockage locations and aquatic vegetation areas associated with the river course. The first blockage, in the site, is located south of Xhamu lake, until the connection with the southern end of Weboro lake, Map (GO-2). Following that point there is a major spillway from the Thaoge river into the permanent swamp area. Another major and longer blockage is located from north of Wabe lake all the way southward until east of Gomare along the river course. Coincidentally, the end of the blockage agrees with the boundary of the maximum overflow of 1984 flood. Southward from this point the extension of the flow in the Thaoge river depends on the extension of the flood on the overflow plains and the feeder atributaries southward. There are three atributaries which feed the Thaoge river at different locations. These atributaries, from west to east, are:

- Karongana
- Potae
- Xinitshaa

It was observed that both topo maps at scale 1:250.000 and 1:50.000, indicate one location of contact between each one of the above mentioned three rivers and Thaoge river. The three contact points are located on the meanders between Xuruee and Hubu. But interpretation of Landsat imagery revealed connections in additional locations, Map (GO-2). There is an atributary cannal of Karongana river which starts from nearby Tubu island and drains into Thaoge river east of Danenga. Southward, east of Nokaneng, there are two additional connection locations where Karongana atributaries drain into the Thaoge river. Moreover, Xinitshaa river drains into Thaoge in two locations north of

Hubu as oposed to the single location indicated on the above mentioned topo maps. Further more, interpretation of Landsat imagery indicated several connections between the three rivers: Karongana, Potae and Xinitshaa. It should be noticed that the above mentioned information has special importance in proposing new schemes for the restoration of the flow in middle Thaoge river. Such restoration may become complementary to the ongoing restoration of the flow in the upper Thaoge river as was proposed by UNDP-FAO/BOT/71/506, Kraatz, (1976). This scheme is known as D2 which contains the enlargement of a bypass channel between Gomare and north of Qutshiga lake and the connection of the Thaoge river to the permanent swamp. It is expected that a flow of 2.5 - 5.0 m^3/second, can be available in the Thaoge as a result of this restoration. It will be possible to evaluate this result only after the conclusion of Stage D2, which is scheduled by middle of 1988.

Detailed topographic survey and field work will be required to evaluate the feasibility of further restoration of flow in the Thaoge by assuring a permenant or at least seasonal flow from Karongana river into Thaoge river. This feasibility study will be based on the fact that Karongana river receive its flow, during the flooding period from the overflow plain nearby Tubu Island Map (GO-2). Deepening of the existing channels and establishing adequate gradient will guarantee continuous flow from Karongana's atributaries into the Thaoge. Meanwhile, the feasibility study should consider that the establishment of this proposed flow will have its impact on draining a part of the overflow water. A similar scheme may be evaluated by establishing a flow from Potae and Xinitshaa rivers, into the Thaoge. More serious impact is expected as a result of these last schemes, because the mentioned two rivers will cause increase and deviation of the drainage from the permanent swamps east of the buffalo fence. These swamps are the habitat for large wildlife species in the region.

3.2.2 Monitoring of the flooding pattern

Analysis of landsat during the flooding periods of 1981-1985 indicated the following characteristics as presented in Table (2) and Map (GO-2):

- The highest flood took place in 1984, extending over an area of approximately 153 700 Ha.

- The lowest flood took place in 1983 extending over an area of approximately 90 125 Ha.

- The peak of the flood reaches the site during August and September. If this characteristic is compared with the peak of the flow discharge at Mohembo, Table (1), it can be concluded that while the flood peak reaches Mohembo during April and May, it reaches the site after about four months.

  Unfortunately, there are no flow measurement records in the area which cover the monitoring period. Measurements of flow in the area have been initiated only in March, 1985 at Guma lake. Therefore, it is recommended, for future monitoring of flooding pattern, to continue monitoring the overflow area before, during and after the flood, by using remote sensing techniques and establishing the correlation coefficient between these measured areas and the flow measurements at Guma lake. Further more a regression model can be developed as a flood

Table (2) - Acreage of Overflow Plains and Lakes,

as estimated from Landsat imagery

(Hectares)

Date	Overflow	Lakes					
		Xhamu	Weboro	Wabe	Qurube	Qutshiga	Gwekatshum
16/8/81	110 900	75	100	50	75	37.5	0
7/11/81	146 500	85	200	175	225	150	12.5
16/9/82	144 325	62.5	87.5	62.5	50	25	0
2/10/82	113 400	75	125	62.5	75	37.5	0
1/7/83	76 600	50	100	50	12.5	25	0
18/8/83	90 125	75	175	100	50	50	0
3/9/83	85 424	75	175	75	25	37.5	0
29/9/84	153 700	62.5	100	75	50	37.5	62.5
12/6/85	79 550	62.5	187.5	100	25	25	0
15/8/85	94 200	100	200	75	50	25	0
2/10/85	93 725	75	137.5	37.5	37.5	12.5	0

prediction model from the collected data over longer periods. Further monitoring of the flooding boundaries from Landsat, indicated that the major fluctuation of the flood takes place east of the blocked section of the Thaoge river north of Tsau Tsaa and north of Tubu Island. This indicates that the river flow which is spilled away flows into the permanent swamp area in a south eastern direction. Then further south a part of the flow runs through Karongana river starting from different locations east of Tubu Island, then running south and south east to reach the Thaoge river in different locations, as has been discussed above and presented on Map (GO-2). Potae and Xinitshaa rivers also receive their flow from the permanent swamps east of the Buffalo fence and run southward between Sand Islands to reach the Thaoge river. The seasonal flooding of the above mentioned rivers formed along the time, a region of alluvial deposits associated with sand formation in the north-southern direction. Consequently, this area, east of the Thaoge river in front of Danega and extended south, represents another area of overflow fluctuation during the different flood intensities. There is also a small area of flood fluctuation in east-west direction. This is in the northern part of the site east of Etsha villages, mainly 6-13.

Monitoring of the changes in water surface of the major lakes showed a problem in estimating the acreage at scale 1: 250 000 by using 2 x 2 mm^2 grid. This is due to the small size of the lakes at the mentioned scale and the gross size of the grid. It is expected that better results can be obtained by digital image analysis where the resolution is of 80 meters of Landsat-MSS. Even better results can be obtained from Landsat-TM and SPOT-MSS whose resolutions are

30 and 20 meters respectively. Inspite of this difficulty, monitoring of lakes acreage from Landsat indicated that lake Weboro has the highest storage capacity, (Table 2) and may be subject of evaluation the lake potential to supply complementary irrigation water to Etsha villages, 6-13. Moreover, this monitoring exercise by visual interpretation of Landsat indicates the possibility of using the acreage of water surface of these lakes as indicator of the flood intensity.

3.3 Geology

Different authors agree that the Okavango system has been recently built up, mainly from Pleistocene and Holocene, Hutchins et-al, (1976), Wilson and Dincer, (1976), Grey and Cook, (1977) and Mallick et-al, (1981). They have established that the Okavango delta occupy a graben between the Gomare-Chobe fault and Thamalakane - Kunyere falt zone. The recent sediment thickness in the swamp is in the order of 300 m, Grey and Cook, (1977). Hutchins et-al, (1976) summarize the geological events of the system as during the tertiary, longitudinal sand dunes formed under desert regime with prevailing eastern wind.

- The north-eastern Gomare fault disturbed the dune formation.

- Ridges formation, as a result of the fault, held back the flow and diverted water.

- Wetter climate caused the formation of the inter-dunal depressions.

- Drier climate caused flood recession and leaving the fossil river channels abandoned.

- Drying of vegetation cover and removal of clayey soil surface by wind erosion.

The last two events, as reported by Hutchins et-al, (1976), are still ongoing processes and their evidences have been observed during the interpretation of Landsat imagery and during the field work. Grey and Cook, (1977), therefore, concluded that the evolution of the present Okavango system is a far from a simple interaction of tectonic movement and climatic changes.

The Geological map which was prepared by Mallick et-al (1981), from Landsat and aerial photographs, indicates that the site under investigation is composed of reddened Kalahari sand in its north-western corner followed by old vallies and depressions mainly alluvium to the east and wind blown silty sands on calcrete. Further east there is the swampy formation interrupted by sand islands.

3.4 Groundwater

Very few quantitative information is available about the groundwater storage and quality of the Kalahari beds. The Hydrogeological reconnaisance map (1:250 000) indicates that the aquifer potential of the Kalahari beds varies widely, depending on the recharge conditions. At the western fringe of the Okavango, the boreholes between Etsha and Nokaneng shows possible recharge from the Thaoge river system. The examination of the borehole testing charts indicate a discharge of 1-4 m^3/h increasing northward (1.4 m^3/h at Konde to 3 m^3/h at Etsha). The general lithology of most of the boreholes is sand and clay in the upper layers then followed by softer materials which are mostly sand. Few boreholes encountered with calcrete layers in the deeper layers.

In the Delta area groundwater levels are extremely shallow, varying from less than a meter to 4 meters in the inactive flooding areas. On the other hand the boreholes on the sand region indicate groundwater levels of 18-35 m below surface. The shallower groundwater level under the alluvial soils represents a risk of salinesation when these soils become irrigated. Meanwhile analysis of 13 groundwater samples in the Delta area east of Gomare, Leenaers, (1986) showed that the water properties are:

Total Disolved Solids to be 84-462 ppm;
Sodium Adsorbtion Ratio to be 0.15-2.71,
Electric Conductivity to be 108-676 μs/cm

These properties indicate that the subsurface water is acceptable for irrigation, but no conclusion on the available quantity of this kind of water can be reached. Possible seepage of water from the bypass canal has been raised by Leenaers, (1986), but further investigation after the completion of the bypass will be required before confirming the possibility of recharge of the groundwater.

3.5 Landforms (Map GO-3)

The site under investigation has been divided into three landform categories:

- Overflow plains
- Alluvial plains
- Kalahari sand deposits

3.5.1 Overflow plains

These are the flat terrain on the western edge of the Okavango alluvial fan. The spilled way water from the Ngokha and the Thaoge rivers is the responsible agent for the formation of the landform category. Lakes, spill-way channels and scattered islands are the most common terrain elements in this landform category. Furthermore, this category can be divided, based on the flooding duration, into two landform units:

3.5.1.1 Permanent Overflow Plains:

These plains are always covered by water. They consist of lakes, swamps and permanent waterlogged soils. These plains are at the lowest position in the investigated site. They extend as one unit from north of the site until latitude S19°12' where a narrow part continues in south-western direction following the Thaoge river toward Qutshiga lake. The other major part continues southward, interrupted by some long but narrow islands in north-south direction.

3.5.1.2 Seasonal Overflow Plains:

These plains are covered by water only during the flooding season. They are the extension of the previous landform unit. This unit is characterized by its intensive features of alternated islands, channels and plains. The boundary of this unit has been obtained from the boundary of the maximum flood as mapped from Landsat imagery of 29/9/84.

3.5.2 Alluvial plains

They are flat or nearly flat terrain formed at different periods, mostly if not all during the Quaternary. The Thaoge river system during different time and positions is the major responsible agent for the formation of these plains. Another river system which has been forming alluvial deposits is the Karongana/Potae/Xinitshaa rivers system on the south-eastern part of the site. The relative difference in the levels of these plains is a good indicator of the period of their formation. The older plains are in higher level than the present flood plains. Based on that property and the geographical location, this landform category has been divided, furthermore, into four landform units:

3.5.2.1 Floodplains:

They are flat with very little micro relief along the margins of the Thaoge river. Their common features are the defaulted meanders, ox-bows and point-bars. Deposition of blown sand with different thickness has been observed during the field work and from the aerial photographs. These flood plains are relatively wider east of Gomare and become narrower as going southward. The plains are subject to flooding in the years when water reaches the middle Thaoge river.

An additional narrow strip, between the overflow plains and the sand ridge east of Etsha 1-13, has been mapped as flood plain. This strip is not affected directly by the Thaoge river course but has the same features of the flood plains.

3.5.2.2 Terraces:

They are flat terrains on a relatively higher level than the flood plains. They are not subject to flooding and have more homogeneous topography and micro-relief. They had been formed from old flood plains or abandoned meanders. Therefore, these soils are deeper with higher clay contents and deeper water table. These terraces have been mapped on both sides of the Thaoge flood plains. On the eastern side of the river, the terraces are in intermediate position between the overflow plains and the flood plains.

3.5.2.3 Old Alluvial Deposits:

They have been formed from an old flood plains and terraces of the previous courses of either Thaoge or other rivers, which were running west from the present Thaoge courses. They are located in higher levels than the present terraces of the Thaoge river. In most of the cases their surface is covered by a thicker layer of blown sand and they are usually supporting a canopy cover of dense tall Acacia trees.

An additional area of old alluvial deposits has been mapped in the northern part of the site, west of the Etsha villages (1-13). It has been formed as a depression within the sand ridges. It could be formed independently or as a part from the other Alluvial deposits south of Gomare.

3.5.2.4 Alluvial Deposits of Karongana, Potae, Xinitshaa System:

These are alluvial materials which have been deposited by the mentioned system in alternation with sand deposits. They have been mapped east and west of the Buffalo fence surrounded by overflow plains and sand islands from the north, east and west. The southern boundary of this landform unit is the Thaoge river terraces.

3.5.3 Kalahari Sand Deposits

These are aeolictic deposits which are located on the eastern edge of the Kalahari plateau. This landform category has been divided into four units, based on their physiographic characteristics:

3.5.3.1 Sand Ridges:

These are sand ridges in north-south direction formed by calcareous sand. They are found on the eastern fringe of the sandveld. Encroachment of the sand from these ridges over the terraces and the flood plain is expected and has been observed as a consequence of the degradation of the vegetation cover of these ridges.

3.5.3.2 Sand Islands:

There are many of them associated with the permanent and seasonal overflow plains. Only those of reasonable size have been mapped. Some of the sand islands are subject to partially flooding. Otherwise, their characteristics are similar to the sand ridges, with the exception that their canopy cover is denser and more diversified than the sand ridges.

3.5.3.3 Undulating Plateau:

They are deep undulating plateau with compacted sand and silt depressions. They form the major part of the site east of the Alluvial plains. They are also found between the old Alluvial deposits in the south and between the overflow plains and the terraces in the south eastern part of the site.

3.5.3.4 Longitudinal Sand Dunes:

These are the typical east-west sand dunes of the Kalahari desert with some narrow depressions of compacted silty and clayey materials.

3.6 Natural Vegetation

The natural vegetation communities of the site are highly determined by the moisture regime which is related to the landform units. Patterson, (1976) and UNDP/FAO, (1977) have described the natural vegetation species based on their environmental characteristics.

Permanent swamps natural vegetation:

- Cyperus papyrus
- Phragmites mauritianus
- Phragmites australis
- Vossia cuspidata

Seasonal Overflow plains natural vegetation:

- Scirpus inclinatus
- Fimbristylis complanata
- Pennisetum glaucecladum
- Polygonum pulehrum
- Polygonum senegalense
- Mikania cordata
- Cynodon dactylon

Sand Island natural vegetation:

-	Ficus verruculosa	on the summit
-	Ficus cycamorus	
-	Nymphea caeruba	on the slopes
-	Phoenix reclinata	
-	Hyphaenea ventricosa	
-	Phragmites spp.	on the fringe
-	Cyperus papyrus	

Flood plains natural vegetation:

- Oryza longistaminata
- Cynodon dactylon
- Andropogon eucomus
- Panicum subalbidum
- Imperata cylindrica
- Eragrostis lappula
- Panicum repens
- Panicum subalbidum

Terraces natural vegetation:

- Eragrostis sp
- Urochlea mosambicensis
- Cenchrus ciliaris
- Cynodon dactylon
- Digitaria sp
- Blumea gartipina

Old Alluvial plains natural vegetation:

- Acacia tortilis
- Acacia hebeclada
- Acacia nigrescens
- Rhus quartiniana
- Syeygum guinease

3.7 Soils

Soil characteristics are presented as they related to the landform units, because these units are used as the mapping units for the assessment of the land potentiality for irrigation. The summary of soil characteristics are presented in Table (3).

3.7.1 Soils of the Seasonal Overflow Plains

Most of the soils of this unit have A horizon of dark organic clayey loan to silty loan over grey clay B horizon which is under lain by white sand within less than 1 m from the soil surface. Mollic epipedon is common and gleyic and luvic features are the main characteristics of these soils. They are high in nutrients due to the presence of organic matter and clayey texture but phosphorus fixation is expected. These soils are associated with the presence of scattered sandy islands.

3.7.2 Soils of the Flood Plains

They have dark silty to clayey loam A horizon, usually over calcic B horizon or fine to medium white sand within 90 cm from the soil surface. On the lower position of this landform unit, soils are shallower to the white sand horizon and to the water table, representing fluvic features. These soils are flat to nearly flat but their surface is occupied by defaulted meanders, ox-bow, point-bar and discontinuous terraces. A layer of blown sand over the A horizon is very usual. These soils are flooded during the high floods and usually used for molapo farming after the flood recession.

Table (3) - Summary of Major Soil Characteristics relevant to Land Potentiality for Irrigation

Landform	Description	Depth (cm)	Texture	CEC (30 cm)	ESP (30 cm)	Distance from Water Source	Infiltration	Topography	Flooding Risk	Phosphorus Fixation
Seasonal overflow plains	Dark organic clayey loam to silty loam A horizon, black to grey clay B horizon over fine white sand	> 100	Clay loam	12 - 28	2.4	Very Close	Low	Flat	Yes	Yes
Food Plains	Dark silty loam to clayey loan A horizon over calcic B horizon or fine to medium white sand within 90 cm	> 100	Sandy loam to loamy sand	3.0 - 6.3	3.4	Very Close	Medium	Nearly Flat to Flat	Yes	Yes
Terraces	Dark silty loam to silty clay loam A horizon over well structured clay B horizon, mostly with presence of calcic features in B horizon	> 100	Sandy loam	11.8 - 12.6	2.5	Medium	Low	Nearly Flat to Flat	No	No
Old alluvial deposits	Light grey sandy clay loam to sandy clay with Orchric A horizon over fine sand	> 100	Loamy sand to sandy clay	3.8 - 11.0	0.5 - 1.1	Far	Medium	Nearly Flat	No	No
Alluvial deposit of Karongana Potae/Ximitshaa system	- Dark organic fine sand to silt over weakly structured clay or fine sand - Dark brown to grey fine to medium sand with calcic B horizon within 90 cm	> 100	Silty fine sand to loam	2.5 - 3.0	1.3	Close	High to Medium	Nearly Flat to Slightly undulating	Some Years	No
Sand Ridges	- Yellow brown sand to loamy sand over yellowish red loamy sand - Dark to brown sand to loamy sand	> 100	Fine to medium sand	3.0	1.0	Medium	High	Slight Slope to Flat	No	-
Undulating plateau	Dark to pale brown sand over sandy loam with calcic horizon within 1m	> 100	Fine sand	4.8 - 5.0	1.0	Far	High	Flat to gently undulating	No	-
Longitudinal dunes with interdunal depressions	- Dark to brown sand to loamy sand - Yellow to brown sand over loamy sand	> 100	Medium sand to fine sand	2.7 - 3.8	0.5 - 1.5	Very far	High	Undulating	No	-
	- Dark brown to grey loam with calcic horizon		Sandy loam	11.8 - 12.6	2.5		Medium	Flat		
Sand islands	Dark to brown sand to loamy sand with calcic horizon within 1 m	> 100	Fine sand to loamy sand	4.8 - 10.6	3.5 - 5.0	Close	High	Undulating	No to partialy	-

3.7.3. Soils of the Terraces

They have dark silty loam to silty clay loam A horizon over strong well structured clay B horizon, mostly with the presence of calcic features in B horizon over fine sand. These soils are usually deeper than the soils of the flood plains. Their nutrition status is higher than those of the flood plains and Phosphorus fixation is not expected to be a problem.

3.7.4 Soils of the Old Alluvial Deposits

They are located in a relatively higher level than the alluvial deposits of the recent Thaoge river. They have light grey sandy clay loam to sandy clay with Ochric A horizon over fine sand. These soils have wide varieties of soil characteristics due to the presence of sand deposits and calcic features in the B horizon. Therefore, the nutrition value is widely variable, as the CEC varies from 3.8-11.0 meg/100g in the upper 30 cm of the soil profile. These soils are located far from the present available water sources and their topography is nearly flat although there is difference in the micro relief due to the presence of the old meanders. Consequently the infiltration rate is medium due to the presence of clayey soils and sandy soils.

3.7.5 Soils of the Alluvial Deposits of the Karongana/Potae/ Xinitshaa rivers system

These are the soils which are deposited, by the mentioned rivers system, in association with the sandy formations in the south eastern corner of the site. These soils have dark organic fine sand to silt A horizon over weakly structured clay or fine sand. Some of the soils in this landform unit have dark brown to grey fine to medium sand with calcic B horizon within 90 cm from the soil surface. Nutrition status and infiltration rate are variable due to the variations in the soil properties. The topography is nearly flat to slightly undulating with sand deposits. These soils may be subject to flooding by the Karongana/Potae/Xinitshaa rivers system.

3.7.6 Soils of the Sand Ridges

These soils are yellow brown to dark brown sand over yellowish red loamy sand with some depressions of calcarous loamy soils. The soil texture is predominately fine to medium sand. Therefore, its infiltration rate is high and the CEC is low.

3.7.7 Soils of Undulating Plateau

These soils are dark to pale brown sand over sandy loam with calcic horizon within 1 m from the surface. Their texture is predominately fine sand and their CEC is low. The topography is flat to gently undulating.

3.7.8 Soils of the Longitudinal Dunes

These soils are dark to brown and yellow sand over loamy sand. In the interdunal depression the soils are sandy loam with higher CEC than those soils of the sand dunes. Topography is undulating but flat in the depressions.

3.7.9 Soils of the Sand Islands

These are dark to brown sand to loamy sand with calcic horizon within 1 m from the soil surface. Their texture is fine sand to loamy sand. Some of these islands are partially flooded during the high floods. Their CEC is generally low and their infiltration rate is usually high. Low nutrition status is expected.

3.8 Population and Land Use

These two aspects are closely related as the ethnic origin of the population groups defines the dominant land use type in each sector of the investigated site, Bendsen and Gelmroth (1983). While farming is the main activitiy of the Bahambukushu in Etsha, cattle raising is the main dominant activity of the Baherero and the Batswana in Nokaneng-Hubu area. Table (4), summarizes the Agriculture land use patterns in the Communal First Development Area (CFDA). More than 80% of the population are located in Etsha and Gomare areas in almost equal proportion. But the indicators Arable land/person and Cattle/person demonstrate that Farming absorbs most of the manpower in Etsha while Cattle raising is the dominant activity in Gomare. In Nokaneng and Hubu, there is no doubt about the domination of grazing as the major land use type.

The site under investigation can be divided based on ethnical origin and land use type into 3 areas:

1- ETSHA area:
As a result of the eradication of the Tsetse fly in 1969/1970 settlement of 3 800 Angolan refugees started along 20 km strip on the western fringe of the Thaoge overflow plains. These refugees are mainly Bahambukushu who are traditionally dry farmers. Thirteen villages (Etsha 1-13) were established through this settlement programme. Fast agricultural development was the result of this settlement. By the end of 1970, a year and a half from the beginning of the arrival of the Bahambukushu, an area of 1 340 Ha was cleared and cultivated. In 1980 this area reached 3 560 Ha. Millet is the staple crop, while sorghum, maize, beans, pumpkins and melons are intercropped. It is important to note that the Bahambukushu do not broadcast the

Table (4) – Agricultural Land Use Pattern in CFDA

Aspects / Area	Etsha	Gomare	Nokaneng	Habu	Total
– Population (1981 Census)	4 686	4 094	1 570	632	10 980
– Present, Arable Land (Ha):					
Dry	3 560	304	52	36	3 952
Molapo	120	1 900	822	369	3 211
Total	3 680	2 204	874	405	7 163
– Arable Land/Person	0.8	0.5	0.6	0.6	0.6
– Cattle (1981)	5 619	10 504	16 297	10 534	42 954
– Cattle/Person	0.9	1.5	12.0	14.9	3.9

Source:

Compiled from Bendsen and Gelmorth, (1983) seeds before the rainy season, but they plant each seed by hand in rows. Moreover, when they clear the land for the first cultivation, they do not remove the tree stumps and the main roots, in order to avoid soil erosion. The main problems to agriculture development are:

- Crop damage by birds
- Post harvest losses
- Poor road condition

2- GOMARE area:

The population are predominately Bayei, who came originally from Chobe-Zambezi rivers area. Other typical groups of the area are Batswana, Baherero, Bahambukushu, Basarwa and Basubia. The major agricultural activity of the Bayei is the cultivation of the flood plains (Molapo farming). Maize is the major molapo crop in addition to small amounts of beans, pumpkins, squash and melon which are intercropped. Sorghum and millet are planted on the western part of the area, under dry farming system in areas which are not flooded. Cattle are grazing within the cultivation areas. As a result of the drying up process of the Thaoge river system, people are moving eastward into the overflow plains. Eradication of the Tsetse fly helps this trend but the Buffalo fence acts as a restriction to this same trend. As crop production is in a decline trend, livestock became more important, Table (4).

The main problems to agricultural development are:

- Crop damage by livestock
- Drying up of the Thaoge river system
- Overgrazing of the flood plains as livestock move eastward searching for water
- Buffalo fence as a limiting boundary in the communal grazing areas.

3- NOKANENG - HUBU area:
Baherero and Batswana are the predominate ethnic groups of this area. The population of the former group are originally from Namibia. Their traditional activity as cattle raisers is the main reason of the domination of grazing as the major activity in the area rather than land potentiality, Table (4). Farming is practised under molapo farming system in old trenches, feeder channels, ox bows, old Thaoge meanders or even in the proper Thaoge river course.

The main problems to agricultural development are:

. Crop damage by livestock
. Drying up of the Thaoge river system
. Overgrazing of the flood plains and under-utilization of the dry land pastures
. Buffalo fence as a limiting boundary for the communal grazing areas.

The above mentioned land use types and population characteristics indicate that in order to elaborate any irrigated cultivation plan, the following aspects must be considered:

- Ethnical and traditional characteristics of the population in the area.

- The existing conflict between farming and grazing.

- Overgrazing and consequently wind erosion and blown sand deposition.

- Road condition as a limiting factor for the marketing of the expected production.

- Adequate storage facilities.

- Water sources for irrigation and the expected conflicts with the use of water for animal and domestic use.

3.9 Assessment of Land Potentiality for Irrigation

3.9.1 Assessment

The major assumption which has been considered in this assessment is the future availability of water for irrigation in the Thaoge river as a result of the successful conclusion of the Flow Restoration Scheme by 1988. The assessment procedure has been based on the identification of the soils restrictions for irrigation for each landform unit which is the mapping unit of this investigation. Based on these restrictions one of three classes was assigned to each landform unit. The classification was done on a relative base, by designating "Potential" for the most adequate soil, in the site, for irrigation, followed by "Marginally Potential" class and then "Not Potential" class for the soils which should not be irrigated, (Table (5). Recommended irrigation system and recommended land use type have been indicated, as well. Finally the results of this assessment have been presented spatially in Map (GO-4).

3.9.1.1 Permanent Overflow Plains

This unit has no potential for irrigation because it is permanently flooded. Therefore wildlife is the only recommended use for this unit.

3.9.1.2 Seasonal Overflow Plains

This unit is subject to seasonal flooding during the period of June to October, depending on the flood intensity. Therefore, the soil of this unit is subject to waterlogging which causes lack of oxygen to the root system. Consequently this unit has no potential for irrigated cultivation and is recommended for molapo farming after the recession of the flood water.

Table (5) - Land Potentiality for Irrigation

LANDFORM	Restrictions	Potentiality Class for irrigation	Recommendation
Permanent Overflow Plains	Permanent Flooding	Not Potential N (f) $\frac{N}{W}$	Wildlife (W)
Seasonal Overflow Plains	- Flooding damage - Oxygen availability	Not Potential N (f,o) $\frac{N\ (f,\ o)}{M}$	Molapo farming
Flood Plains	- Flooding damage (f) - Nutrients availability (n) - Levelling requirement on micro relief scale (ℓ) - Wind erosion (e) - Blown sand deposits (s)	Not Potential $\frac{N\ (f,n,\ell,e,s)}{Mi\ ,\ G}$	Improved Molapo farming (Mi) and range management (G)
Terraces	- Wind erosion (e) - Blown sand deposition (s)	Potential $\frac{(P\ (e,s)}{F}$	Furrow irrigation lifted from Thaoge river after restoration of its flow
Old Alluvial	- Distance from irrigation source (d) - Nutrients availability (n)	Marginally Potential $\frac{M\ (d,n)}{D,\ S,\ P}$	Improved - Dry farming - Drip off Sprinkle irrigation when water becomes available
Alluvial deposits of Karongana, Potae and Xinitshaa system	- Flooding damage (f) - Wind erosion (e) - Topography (ℓ) - Blow sand deposits (s) - Nutrients availability (n)	Marginally Potential $\frac{M\ (f,e,\ell,s,n)}{Mi}$	Improved Molapo farming Mi
Sand Ridges	- Available moisture (m) - Topography (ℓ) - Nutrients availability (n) - Distance from irrigation source (d)	Marginally Potential $\frac{M\ (m,\ell,n,d)}{D,\ P,\ S}$	- Improved dry farming - Drip irrigation and sprinkle irrigation if water becomes available
• Undulating sand plateau	- Available moisture (m) - Nutrients availability (n) - Topography (ℓ) - Wind erosion (e) - Distance from irrigation source (d)	Not Potential $\frac{N\ (m,n,\ell,e,d)}{G}$	- Grazing G
Sand Islands	- Moisture availability (m) - Nutrients availability (n) - Topography (ℓ)	Not Potential $\frac{N\ (m,\ell,n)}{D}$	Dry Farming

3.9.1.3 Flood Plains

This unit is found along the Thaoge river and in a small area of the western fringe of the overflow plains east of Etsha villages. These areas have no potential for irrigation due to the following reasons:

- Flooding damage, which is destructive to the irrigation network and the crops.

- Low nutrient level due to low CEC and the capacity for phosphorus fixation.

- Levelling requirement on the micro-relief scale. Due to the annual flooding this landform unit is always associated with the presence of defaulted meanders, oxbows, levees and other fluvial features. Levelling of the surface will be damaging because it will remove the top soil which is the most fertile horizon of the soil profile.

- Susceptibility to wind erosion as a result of overgrazing.

- Deposition of the blown sand carried by wind from the overgrazed sandy formation.

Therefore this landform unit is not recommended for irrigated cultivation but it is recommended for improved molapo farming and grazing under improved range management system. Improved molapo farming can be based on the improvement of both water control practices, by bunding and inlet-outlet structure, and agronomic practices, by following crop rotation, use of manure and fertilizers and following row cultivation at adequate spacing.

In the case of practicing grazing system, a rotation system should be followed to avoid expected conflict between grazing and farming. Livestock should be kept away during the cropping season and can be introduced into the area only after harvesting.

3.9.1.4 Terraces

This unit has the highest potential level in the site, for irrigated cultivation. Its restrictions for irrigation are:

- Susceptibility for wind erosion as a result of over-grazing. Therefore, the establishment of windbreaks around the farms will be necessary.

- Deposition of blown sands over the soil surface.

Furrow irrigation will be adequate for this landform providing water is available from the Thaoge river.

It should be mentioned that although this landform unit has a flat or nearly flat topography, features of abandoned channels, oxbows and sand deposits cause discontinuity of the land surface. Detailed soil survey and topographic survey at scale 1:25 000 or 1:10 000 will be required to determine the acreage of each homogeneous area and the necessary levelling for the construction of furrow irrigation network.

3.9.1.5 Old Alluvial Deposits

This landform unit is marginally potential for irrigation because of the following restrictions:

- Distance from irrigation sources, as they are not related to any presently active river system.

- Low nutrients level as the CEC is low and variable due to the presence of sandy soil and calcareous soils associated with the loamy soils of this landform unit.

Therefore, these areas are recommended for improved dry farming in principle. But in case of available irrigation source then drip irrigation or sprinkle irrigation can be recommended. Capital investment in implementing irrigation system on this landform should be evaluated in detail as there will be a need to lift water and transport it to the farming sites.

3.9.1.6 Alluvial Deposits of Karaongana/Potae/Xinitshaa Rivers System

This landform unit has marginal potential for irrigated cultivation due to the following restrictions:

- Flooding damage from the three rivers systems.
- Low nutrients level due to the low CEC.
- Undulating topography as a result of the presence of sand deposits.
- Susceptibility to wind erosion as a result of overgrazing.
- Deposition of blown sand on the soil surface.

Therefore, this unit is recommended only for improved molapo farming.

3.9.1.7 Sand Ridges

This landform unit is usually associated or close by the old alluvial unit, but more restrictions are present in this unit. These additional restrictions are:

- Low moisture availability due to the predominant sandy texture which has high water infiltration rate.
- Undulating topography.

Therefore, this unit is marginally potential for irrigation. The recommended land use is improved dry farming. But in case water becomes available, then drip or sprinkle irrigation can be recommended.

3.9.1.8 Undulating Sand Plateau and Longitudinal Sand Dunes

These two landform units have the same restrictions for irrigation and consequently have the same potentiality class. Their restrictions are:

- Low moisture availability.
- Low nutrients level.
- Undulating topography.
- Susceptibility to wind erosion.
- Distance from any possible source of water for irrigation.

Therefore these landform units have no potential for irrigation and the recommended land use is grazing.

3.9.1.9 Sand Islands

This landform unit has similar characteristics as the sand ridges unit, with the exception that these islands are located within the seasonally flooded areas. But due to the limited extension of these islands their irrigation becomes unfeasible. Moreover, they have the following restrictions:

- Low moisture availability
- Low nutrients level.
- Undulating topography.

Therefore, this landform unit has no potential for irrigation. Consequently the only recommended land use is dry farming.

3.9.2 Land Potentiality Classes

As a result of the assessment of the 577 800 Ha, the following results can be obtained, Table (6):

3.9.2.1 There is an area of approximately 56 650 Ha which has some potential for furrow irrigation by lifting water from the Thaoge river, after the restoration of its flow. This area is located on the terraces position on both sides of the Thaoge river. Further restoration of flow south of Nokaneng may be feasible by activating the feeder channels which link the Karongana/Potae/Xinitshaa rivers system with the middle Thaoge river system. As mentioned in item 3.9.1.4 detailed soil survey and topographic survey will be required for this class. Based on the results of these surveys and the availability of water for irrigation a precise estimation of irrigable area can be done. Moreover, the optimum size of the farm unit can be determined from these data.

3.9.2.2 The acreage of the marginally potential land for irrigated cultivation is approximately 64 450 Ha. This area includes the old alluvial deposits of the old Thaoge (44 550 Ha) in addition to the portion of Karongana/Potae/Xinitshaa rivers system, west of the Buffalo fence (11 150 Ha). Drip or sprinkle irrigation in the first area can be recommended as supplementary to the dry farming. In the second area sprinkle irrigation can be recommended in addition to the improved molapo farming. In both cases, irrigation may be feasible only if irrigation water source at economic distance and level can be identified.

3.9.2.3 The remaining acreage of approximately 465 450 Ha has no potential for irrigation as indicated on Map (GO-4). The composition of this area is as follows:

LIST OF TABLES

Table (6) - Acreage of Land Potentiality Classes

Potentiality Class	Acreage (Ha)	
Areas which have some potential for Furrow irrigation		56 650
Areas which have marginal potential for irrigation		64 450
- Dry farming with suplementary sprinkle or drip irrigation	44 550	
- Improved Molapo farming or sprinkle irrigation	11 150	
Areas which have no potential for irrigation		465 450
- Wildlife	143 350	
- Grazing	266 350	
- Molapo farming	27 000	
- Improved molapo farming	19 000	
- Dry farming	9 750	
Total		577 800

- An area of 143 350 Ha is recommended for wildlife. This is the area of the permanent swamps and lakes in addition to the other landform units located east of the Buffalo fence.

- An area of approximately 266 350 Ha is suitable only for grazing. This is the area of the sandy soils. Adequate range management practices are urgently needed in this area in order to reverse the ongoing land degradation process which results from overgrazing and drought. As reduction of the herds will not be an easily acceptable proposal, then grazing rotation can be the alternative solution. In order to design a successful rotation system, both vegetation association and tribal composition aspects should be the basic considerations in the design of such rotation. Adequate water points distribution is another important aspect which needs to be considered in the design of the grazing rotation. Group fencing of the cultivated areas and Tribal grazing land approaches, as suggested by Bendsen and Gelmorth (1983) can be the successful approach in the implementation of adequate land use policy in the grazing areas.

- Molapo farming can be practiced in an area of approximately 27 000 ha. This area is located between the boundaries of the permanent overflow plains and the terraces. The annual acreage of this area depends on the extension of the flood.

- Improved molapo farming can be practiced in an area of approximately 19 000 Ha. This area is located on the flood plains of the Thaoge river. Restoration of the flow in the river is the determinant factor for the acreage of this area. There is a potential of yield increase of 200% by improving practices in molapo farming, UNDP/FAO (1981). Improvement can include improvement of water control methods by flood bunding and inlet/outlet constructions. Additional improvement can be in the agronomic aspects by following crop rotation, use of manure, intercropping, following adequate crops calendar, row cultivation and the use of certified seeds.

- Finally an area of approximately 9 750 Ha of the main sand islands is suitable for dry farming depending on the rainy season which begins around November or December.

3.9.3. Constraints for the Development of Irrigated Cultivation in the Site

1. Lack of reliable water source for irrigation under the relatively high evapotranspiration rate and infiltration rate.

2. Poor road condition for transporting additional production.

3. Poor storage and marketing facilities.

4. High cost of transportation of excess production to any major population centre such as Maun.

5. High Capital investment required for implementing and maintaining irrigation system.

6. Lack of experience of the ethnic groups of the population in irrigated cultivation.

7. The existing conflict between farming and grazing.

3.9.4 Recommended Crops

Based on the above mentioned constraints and the potentiality assessment, selection of crops should have the objective of reaching self sufficiency in grain production for the local population. Additional production will not be feasible unless storage, marketing and transportation constraints are resolved. Therefore, maize, sorghum and millet are the most adequate crops for the site as the agroclimatic requirements, Simis (1981), can be met in the site.

Quantitative data about water requirements of the three recommended crops, under irrigation in the site, will be necessary in order to estimate the necessary area for each crop. Meanwhile water available for irrigation after the conclusion of the flow restoration scheme will be the major determinant factor for the acreage of the irrigable area by each crop.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

1. As a result of the conclusion of the ongoing flow restoration scheme of the Thaoge river an area of approximately 56 650 Ha will be potential for furrow irrigation. This area is located within the terraces landform of the present Thaoge river.

2. The acreage of the marginally potential land for irrigated cultivation is approximately 64 450 Ha. This area includes the old alluvial deposits of the old Thaoge river (44 550 Ha) in addition to 11 150 Ha of the deposits of the Karongana/Potae/Xinitshaa rivers system west of the Buffalo fence. Drip or sprinkle irrigation can be recommended if water becomes available at a reasonable distance.

3. The remaining acreage of approximately 456 450 Ha has no potential for irrigated cultivation. They are recommended for: Wildlife (143 350 Ha), Grazing (266 350 Ha), Molapo farming (27 000 Ha), Improved molapo farming (19 000 Ha) and Dry farming (9 750 Ha).

4. Further restoration of the middle Thaoge river, south of Nokaneng may become feasible by activating the links between the Karongana/Potae/Xinitshaa rivers system and the Thaoge river course. Further topographic survey and field data will be necessary for the evaluation of this possibility.

5. Monitoring water surface of the lakes from Landsat imagery, indicated that Weboro lake has the highest water storage capacity and may be considered as a potential source of supplementary irrigation water to the Etsha villages (6-13).

6. Monitoring the flooding pattern from Landsat imagery indicated that the major source of water to the Thaoge, Karongana, Potae and Xinitshaa is the spillway water from the permanent swamps.

7. There are two major blockage areas in the upper Thaoge system: one is south of Xhamu lake until the connection with the southern end of Weboro lake, the other longer blockage is south of Wabe lake until east of Gomare.

8. The site in general is going through land degradation process due to the drought and the overgrazing. Conflict between farming and grazing is an existing problem.

9. Ethnic groups and their traditional characteristics are the determinant land use factors, rather than land potentiality.

10. Maize, sorghum and millet are the most adequate crops for the site as they meet the population needs and they match the local conditions including the availability of water during the flooding season (90-120 days). Land preparation can be started in June, then planting can start in July as soon as the flood water reaches the site.

11. The quality of the ground water is adequate for irrigation, but quantitative evaluation requires additional intensive hydrogeological investigation and drilling of test wells.

4.2 Recommendations

1. Monitoring flood patterns from satellite imagery needs to continue at monthly intervals during the period of May to November. Data from this monitoring should be correlated statistically with the ground flow measurement in order to establish a flood prediction model. This model can be a useful tool for land use planning.

2. Additional flow recorders will be needed at Weboro lake, Tubu, Qutshiga lake and the confluence at the bypass channel, for the construction of the above mentioned model. At present the flow measurements are available at Mohembo (station 7112 since 1975) and Guma lake (since March 1985).

3. The land use unit at the district level is adequate infrastructure to conduct the recommended monitoring procedure as the flow data can be rapidly and easily obtained from the Water Affairs staff on the same level. Adequate training and interpretation equipment will be needed.

4. Detailed topographic survey and field work are needed to evaluate the possible activation of the links between Karongana/Potae/Xinitshaa rivers and Thaoge, south of Nokaneng, as additional scheme for restoration of flow in the Thaoge.

5. Detailed soil survey and topographic survey of the area with potential for furrow irrigation (terrace of Thaoge river) are recommended at scale 1:25 000 or 1:10 000. Results of these surveys will permit precise estimation of the potential acreage for irrigation and the optimum farm size.

6. Field experiments to determine water requirement of the main crops on the different terraces soils will be needed as soon as water will be available after the conclusion of the Thaoge flow restoration scheme.

7. Updating of the topographic maps at scale 1:250 000 and 1:50 000 is recommended. Compatability of names and configuration of natural and cultural features is required. Landsat-TM and SPOT imagery are recommended tools. For scale 1:250 000 Landsat-TM is adequate and SPOT is adequate for 1:50 000.

ACKNOWLEDGEMENTS

The assistance and support offered by the international and national staff of the Soil Mapping and Advisory Service Project (BOT/85/011) is highly appreciated.

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