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Eastern Nile Irrigation and Drainage Studies

Field Investigations Wad Meskin

Final Report

VOLUME I: MAIN REPORT

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SHOURACONSULT Co.

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EASTERN NILE IRRIGATION AND DRAINAGE STUDY
WAD MESKIN PROJECT FIELD INVESTIGATIONS
FINAL REPORT

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ABBREVIATIONS AND ACRONYMS

Fiscal Year:

Egypt: 01 July – 30 June

Ethiopia: 08 July – 07 July

Sudan: calendar year

MEASURES

km	=	kilometre
km^2	=	square kilometre
m	=	metre
m^3	=	cubic metre
mm	=	millimetre
Mm^3	=	million cubic metres
BCM	=	billion cubic metres
1 ha	=	2.38 feddans
1 feddan	=	0.42 ha

ABBREVIATIONS

ADB/F	African Development Bank/Fund
AGS	Addis Geo Systems
ANRS	Amhara National Regional State
API	Aerial Photo Interpretation
ARBID/MPS	Abbay River Basin Integrated Development Master Plan
ASTM	American Society for Testing of Materials
BCM	Billion Cubic Meters = 1 km^3
B/C ratio	Benefit Cost ratio
BH	Borehole
BS	British Standards
CEC	Caution Exchange Capacity

SIS	Site Investigations Study
DC	Direct electrical current
DIU	Dams Implementation Unit (Sudan)
DOCS	Date of Commencement of Services
dS/m	deci-Siemens per meter
d/s	downstream
EC	Electrical conductivity
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EMA	Ethiopian Mapping Agency
ENCOM	Eastern Nile Council of Ministers
ENPV	Economic Net Present Value
ENTRO	Eastern Nile Technical Regional Office
ENSAP	Eastern Nile Subsidiary Action Program
ENSAPT	Eastern Nile Subsidiary Action Program Team
ENCOM	Eastern Nile Council of Ministers
EPMS	Environmental Protection Monitoring Strategy
ESP	Exchangeable Sodium percentage
ESCP	Ethiopian Standard Code of Practice
EWA	Ethiopian Water Authority
FAO	Food and Agriculture Organization
FNPV	Financial Net Present Value
FIRR	Financial Economic Rate of Return
G	Gravity
GOE	Government of Egypt
GFDRE	Government of the Federal Democratic Republic of Ethiopia
GOS	Government of Sudan
GPS	Geographical Positioning System

GRP	Glass reinforced polyester
GTZ	German Technical Cooperation Agency
Ha	hectare
HDPE	high density poly ethylene
HP	hydro power
HQ	High Quality (classification for drilling core)
ICCON	International Consortium for Co-operation on the Nile
ICT	International Consultants and Technocrats Pvt Ltd.
IEE	Initial Environmental Examination
ISL	Isambert Salembier Lino Consultants
LUT	Land Utilisation Type
LUR	Land Use Requirement
masl	Meters above sea level
MC	Main Conveyor
MCA	multi-criteria analysis
mcm	Million Cubic Meters
MoIWR	Ministry of Irrigation and Water Resources (Sudan)
MoWR	Ministry of Water Resources (Ethiopia)
mS	micro Siemens
N1, N2	Land suitability classes
NBI	Nile Basin Initiative
NEDECO	Netherlands Engineering Consultants (Consulting Firm)
NELSAP	Equatorial lakes subsidiary action programme
NELT	North East Lake Tana
NGO	Non-Governmental Organization
Nile-SEC	NBI Secretariat
Nile-COM	Nile Council of Ministers
NQ	Normal Quality (classification of drilling core)

OIDA	Oromiya Irrigation Development Authority
ONRS	Oromya National Regional State
O&M	Operation and Maintenance
P	Pumping
PA	Peasant Association
PF	Pre-feasibility
PFS	Pre-feasibility Study
PMO	Project Management Office
PS	Pump station
RfP	Request for Proposal
RQD	Rock Quality Designation
S1, S2, S3	Land suitability classes
SAP	Subsidiary Action Programmes
SAR	Sodium Adsorption Ration
SEIA	Social and Environmental Impact Assessment
SDS	Small Disturbed Sample
SPT	Standard Penetration Test
SPT-N	Standard Penetration Test-Normal
SVP	the Shared Vision Programme
TAMS	Tippets-Abbett-McCarthy-Stratton Engineers and Architects
tc	ton of cane
T_c	time of concentration (only used in hydrological calculations)
TCC	Technical Coordinating Committee
TDS	Total Dissolved Solids
TLU	Tropical Livestock Unit (metabolic weight equivalence)
TOR	Terms of Reference
TRBID/MPS	Abbay River Basin Integrated Development Master Plan
TTB2	a set of geological formations

UA	Unit of Account
u/s	upstream
USBR	United States Bureau of Reclamation
UTM	Universal Trans Mercator
VES	Vertical Electric Sounding
WAPCOS	Water and Power Consultancy Services (India) Ltd.
WB	World Bank
WRMP	Water Resources Management Policy
WUA	Water Users Association
WWD&SE	Water Works Design and Supervision Enterprise

CONVERSION FACTORS

0.42 ha = 1.00 feddan

Preface

This report, that comprises three volumes has been prepared in accordance with the requirements of the contract for the Site Investigations Study, concluded between the Eastern Nile Technical Regional Office (ENTRO), the Client and BRLi, the Consultant who has subcontracted the topographic surveys, soils studies and geotechnical investigations to Metaferia Consultants and Shoraconsult, respectively for the Dinger Bereha project site in Ethiopia and the Wad Meskin project site in Sudan.

The report presents the results of the fully completed soils and topographic investigations and the partly completes geotechnical investigations in the Wad Meskin Project area that were carried out before accessibility of the area became impossible by the end of June. Subsequently, all laboratory analyses for the full soils investigations and for the partially completed geotechnical investigations were finalised by the end of September 2009, whereas the Topomap for the command area and for the diversion site were completed by mid October. Reporting on the investigations was completed by the end of October.

In order to proceed with the Feasibility Study (FS) activities without delay the Client and the Consultant agreed to submit the in-complete report as draft by 31st October 2009 and to programme the submission of the final report for 31st December 2009, pending the completion of the outstanding toposurvey work and geotechnical investigations.

1. INTRODUCTION

1.1 Background

The Nile Basin Initiative (NBI) was established in 1999 by the ten Nile Riparian States[1] as a co-operative programme to address poverty, environmental degradation and instability in the Nile Basin while promoting socio-economic development. The African Development Bank was represented at the launching of the International Consortium for Co-operation on the Nile (ICCON) which took place in Geneva, 26-28 June 2001, and on that occasion, committed itself to support the Nile countries in their effort "to achieve sustainable socio-economic development through equitable utilization of, and benefit from, the common Nile Basin water resources"[2].

In order to transform their Vision to action, the Nile Riparian countries developed a Strategic Action Programme which is being implemented through two complementary programmes: (i) the Shared Vision Programme (SVP) and (ii) the Subsidiary Action Programme (SAP). The SVP seeks to build trust among the states, improve implementation capacity and lay the foundations for cooperative investment and development. The SAP is oriented towards investment projects at the sub-basin level, involving all potentially affected states.

Two sub-basins Subsidiary Action Programmes (SAP) have been initiated, covering respectively the Eastern Nile and the Nile Equatorial Lakes regions. Egypt, Ethiopia and Sudan form part of the Eastern Nile Subsidiary Action Programme (ENSAP) under the Eastern Nile Council of Ministers of Water Affairs (ENCOM) while Burundi, Democratic Republic of Congo, Egypt, Kenya, Rwanda, Sudan, Tanzania and Uganda form part of the Equatorial Lakes Subsidiary Action Programme (NELSAP). The goal of the ENSAP and the NELSAP are to develop the water resources of the Eastern Nile Basin and of the Equatorial lakes Basin respectively in a sustainable and equitable way to ensure prosperity, security, and peace for the whole Nile basin.

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1 The ten Nile countries are Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Eritrea, Kenya, Rwanda, Sudan, Tanzania and Uganda. Eritrea currently holds an observer position.

2 Vision of the NBI

The Eastern Nile Irrigation and Drainage Study Project (ENIDS) aims at contributing to the enhancement of food security, reduction of rural poverty, and reduction of population pressures in the region, with all associated beneficial effects on the environment. The study will contribute to attaining the agricultural sector goals of the participating countries (Egypt, Ethiopia and Sudan), towards an integrated approach to irrigation and drainage development in the Eastern Nile sub-basin as a means for enhancing food security, poverty reduction, improved welfare of the rural population and sustainable natural resource management.

The ongoing study has two components: Engineering Sub-component and the Cooperative Regional Assessment (CRA) sub-component. The engineering sub-component will identify a total of 15,000 ha (net) in Ethiopia and Sudan from among the proposed potential sites and undertake a feasibility study for irrigation development.

The CRA sub-component will prepare a guideline for the identification and selection of irrigation and drainage projects presenting regional benefits; undertake assessment of the need for institutional and legislative reforms; and propose a cooperative framework and a common agenda on irrigation development in the Eastern Nile Basin (Egypt, Ethiopia and Sudan) for the medium and long term.

The Inception Phase of the Study described above commenced in September 2007. The findings of this phase indicated that there was a need to undertake detailed field surveys related to soils, topography and geotechnical investigations that would be a critical input to the feasibility study under the Engineering sub-component.

Therefore, ENTRO made arrangements intended to prepare soil and topographic maps as well as to undertake geotechnical investigations of the sites selected for feasibility study. The terms of reference of the Site Investigations Study were prepared during the beginning of 2008, and after funding was committed by the AfDB a RFP was issued in March 2008. Proposals were submitted in July 2008 and after evaluation, selection and negotiations a contract was signed in January 2009 by ENTRO, the Client, and the Joint Venture BRLi, Shoraconsult and Metaferia Consulting Engineers (MCE), hereinafter named 'the Consultant'.

The identification of sites with a total area of 15,000 ha (net) for feasibility study among the proposed potential sites was finalized in September 2008, after the locations of the sites were determined. As per the Phase 1 Engineering Report, the Consultant's findings indicated that the sites proposed for feasibility study were the Dinger Bereha area, in Ethiopia and the Wad Miskeen project, in Rahad II area in Sudan. The precise boundaries would have to be determined during the Inception Phase of the SIS.

Inception Reports have been prepared for each project separately. A brief description of the Project Area is given in the following sections, whereas Appendix A of the Inception Report presents additional information on various subjects.

1.2 LOCATION AND DESCRIPTION OF THE PROJECT AREA

1.2.1 General

The proposed project is about 7,500 ha net and lies in the southern end of Rahad II (see Map 1.1). It lies between Hawata town and Wad Meskin on the eastern side of the seasonal Rahad river. The defunct railway line from Khartoum to Gadarif then Port Sudan crosses the Rahad river at Hawata which lies on the northern end of the project. The Wad Meskin Project site is close to the Rahad **Pr**oject Phase II which lays within latitudes 13º - 40´ and 15º - 10´ and longitude 33º - 40´ to 34º - 20´ E. The project area is located on the eastern bank of Rahad River and its land is shared between Gezira and Gadarif States.

1.2.2 REVIEW OF AND ANALYSIS OF PREVIOUS STUDIES AND DATA

At the time of preparation of the Inception Report there are no previous studies, apart from some soil studies.

1.2.3 PROJECT OUTLINE

Wad Meskin barrage across Rahad River has been planned to regulate the flood flows during rainy season, for Dinder and Rahad rivers so as to satisfy the needs of Rahad Project Phase I, through Abu Rakham barrage as a downstream regulator, and to divert water to Rahad Project Phase II for summer crops through a main canal.

This same barrage would regulate water transported from the Roseires Dam, after the heightening project completion, with the link canal through Dinder River barrage to the project.

Rahad Project Phase II Supplementary Irrigation Phase:

The site for the proposed barrage across Dinder river has been selected, originally a siphon is proposed to pass the link canal under Dinder river. Cross sections at the proposed site "Dinder River" continued up stream to the affected length "8.0 km" covering the backwater curves are available.

A report on the geological formation at Dinder site is available, stating that a sandy bed is dominant. The site for the proposed Wad Meskin barrage across Rahad River has been studied. Cross sections from the site up to the affected area, by the back water curve, are available. A report for the geological formation at Wad Meskin barrage site, is available "Mainly clay ". The profile of the proposed link canal from Dinder river barrage up to Rahad river barrage, at Wad Meskin, is available. The topographical survey map for the proposed land for irrigation (100,000 ha), between Rahad river up to Jebel Al Faw with a grid 200x200m is available. The proposed main canal profile, from Wad Meskin barrage (Rahad river) was set and surveyed.

Facts for consideration:

- The maximum discharge in the Dinder River during flood is about 430 m^3/s. Bed width and depth are 200 m and 4 m respectively;
- The link canal from Dinder River up to Rahad River crosses many Khors and Wadis, the major one is Khor Al Atshan with a maximum discharge of 70 m^3/s. Bed width and depth are 100 m and 4.0 m respectively;
- Rahad river bed width is about 150 meter and depth about 4.0 m;
- The main canal from Wad Meskin barrage crosses Khor Abu Farga, which is the main water course in the area.
- The main missing data that are essential for a Feasibility Study have been identified as follows :
  - The geophysical survey for Dinder River at the site of the proposed barrage; including bore holes for the foundation layers structure etc
  - The geophysical survey for Rahad River at the site of the proposed WM barrage; including bore holes for the foundation layers structure etc
  - The geological and geophysical survey for Khor Al Atshan and Khor Abu Farga, based on the crossing structure means needed for the link/main canal for these two main water courses

Access to the Study Area: using the Highway road from Khartoum to Al Faw town "the head quarter of Rahad Project Phase I" the travel distance is about 270 km. Then transferring to a paved road with asphalt cover and a gravel, from Al Faw town up to Hawata town about 160 km. Then using rough unpaved road from Al Hawata to Wad Meskin village "Rahad River Barrage site" about 70 km. Then from Wad Meskin village to Dinder barrage site very rough road about 60 km.

It is difficult to access the major structures area "Rahad and Dinder barrages" during rainy season, normally from June to October, due to a heavy clay soil makes it very rough roads between Al Hawata towards south to reach these villages near the structures sites.

It is essential to note that, these irrigation structures *"Rahad and Dinder barrages the link canal and the main canal"* to be built at this supplementary irrigation phase are part of the requirements of the irrigation system needed after heightening Roseires dam. That is to say when the whole potential area planned to be developed "185,000 ha" is implemented.

1.2.4 PRESENT SITUATION

Wad Meskin village lies some of 70 km south of Al Hawata village. The road between Al Hawata village to Wad Meskin village is unpaved which is difficult to use especially during the rainy season.

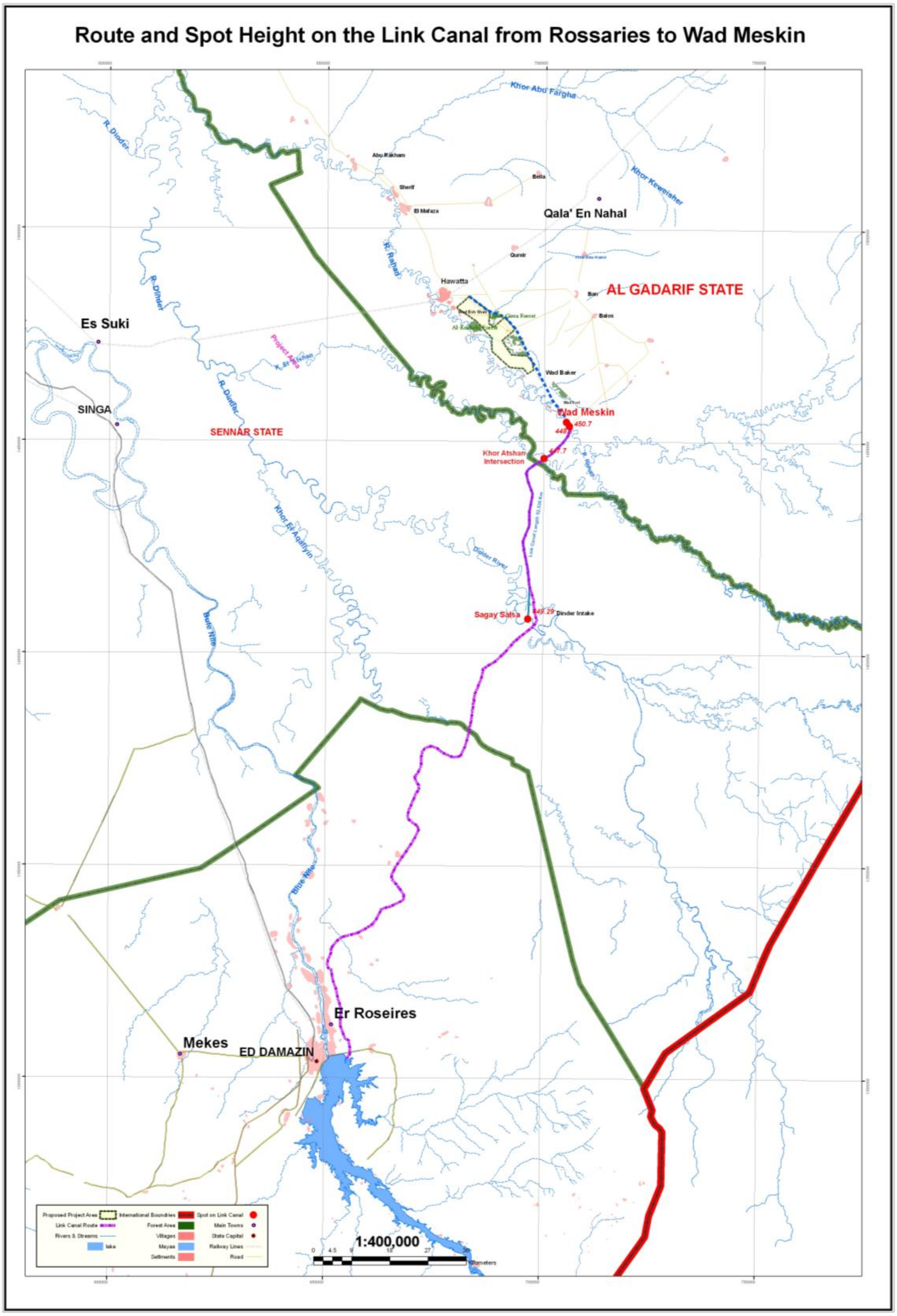
Wad Meskin barrage on the Dinder River are two major structures within the Rahad phase II scheme. They direct water from Rahad and Dinder rivers as well as from the Blue Nile after November.

The highest temperature is experienced during the months April – May when the mean daily temperature is around 33 ^{0}C. Average rainfall goes up to about 600 mm. Precipitation normally occurs during the period June – October with the heaviest falls during the period of late July to early September. The dry period normally extends from 7 to 8 months from November through to early June.

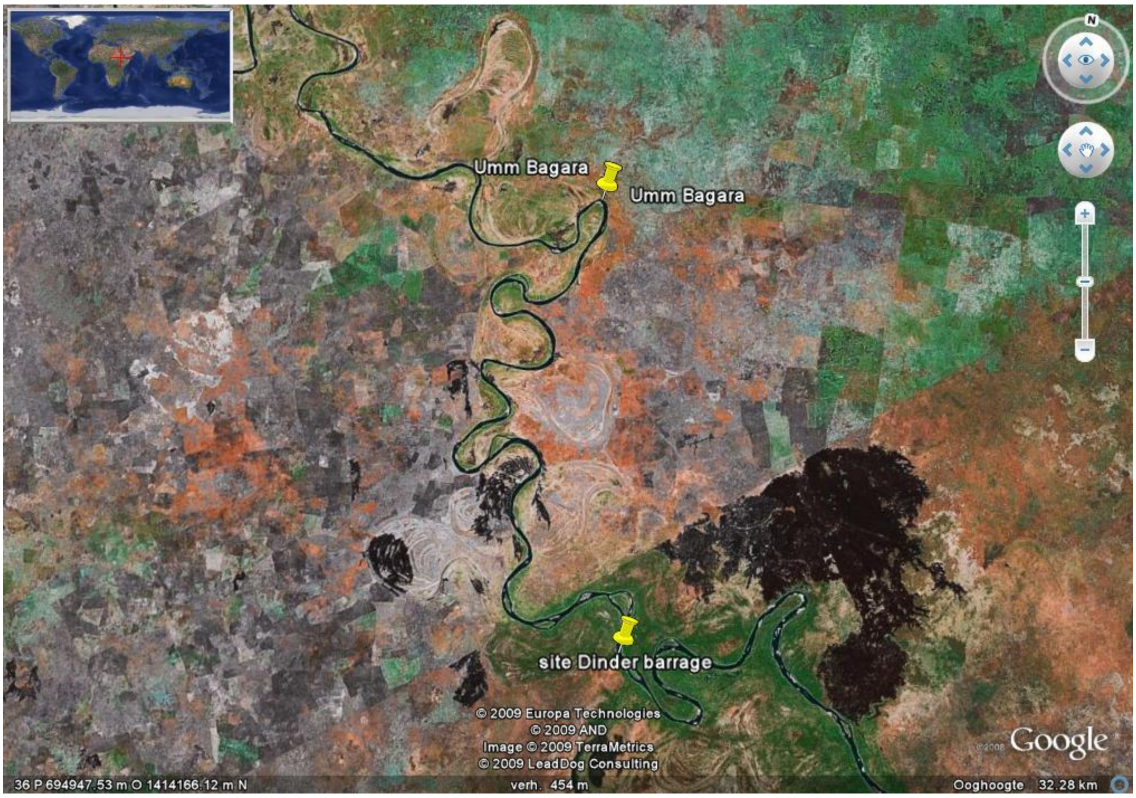
People in the project area are either farmers living in villages or nomads moving with their livestock from north to south and vice versa looking for good grazing areas and drinking water for themselves and their animals. Most of the farmers are involved in rainfed agriculture; however, some are involved in irrigated agriculture on the banks of Rahad and Dinder rivers. The main crops grown in the rainfed agriculture are sorghum, millet, and sesame. The irrigated agriculture mainly constitute small farms around the banks of the rivers where farms have small areas of orchard trees and some vegetables which are locally marketed .The seasonality of the two rivers flows makes it difficult to cultivate big areas without any storage facilities. Nomads in the area are of different tribes. The major tribes in the area are Rofaa, Gawasma, Halloween and Lahoween .The income for both farmers and nomads is law because of the limited production in agricultural crops and livestock products .Only big rainfed agricultural farms in uplands can have big production and therefore have large returns.

More details are presented in Annex A of the Inception Report.

Map 1.1: Location of barrage sites and Project Area



Map 1.2: Location of potential barrage sites on Dinder River



Map 1.3: Approximate location of Dinder barrage site inside park

Map 1.4: Approximate location of Wad Meskin Barrage site

2. OBJECTIVE AND SCOPE OF THE SITE INVESTIGATIONS STUDY

According to the RfP and the Inception Report, the main objective of the SIS study is to undertake detailed site investigations on 15,000 hectares (net) in the Dinger Bereha and Wad Meskin Project areas that would prepare information for feasibility studies of irrigation development. The site investigations were carried out on areas of minimum 7,500 hectares net of land in each country and would include the following:

- Undertaking detail soil survey and land suitability study on 15,000 hectares (net) of irrigable land selected for feasibility study in Sudan and Ethiopia (equally divided between them);
- Conducting detailed topographic surveys and map preparation on the 15,000 hectares of the same selected areas;
- Undertaking detailed geotechnical investigations on diversion sites, pump sites, major structures, and along main canal routes of the selected areas.

While the Engineering component of the ENIDS aims to undertake a feasibility study for irrigation development on 15,000 hectares (net) equally divided between Ethiopia and Sudan, the current task is to provide detailed information on soils and topography as well as on geotechnical conditions at foundations of diversion, pumping sites and in main canal alignments in the selected sites. The site investigation works may need to be conducted on larger areas in order to achieve a net irrigable/suitable area of 15,000 hectares. The Consultant retained for undertaking the feasibility study of the areas, has made a reconnaissance level assessment and delineated the gross areas that needed to be investigated.

3. Organisation and Management and overall approach

3.1 Responsibilities of ENTRO and National Coordinators

ENTRO is the recipient of the Grant from AfDB and the Executing Agency in charge of direct execution of the Study. ENTRO is located at Addis Ababa, Ethiopia, and is managed by an Executive Director who is Head of the office. The role of ENTRO coordinated the intervention of the Consultant for all matters related to the site investigation activities of Component 1 (Engineering sub-study). The line Ministries of the Ethiopian and Sudan Governments will supervise the work of the Consultant concerning the site investigation study, for all aspects related to their national projects. The mandate for provision of information was given to national line ministries; hence the information provision is channelled through national focal persons. The national focal persons of the two countries, Ethiopia and Sudan, will form a Technical Coordinating Committee (TCC) that will liaise, as needed, with ENTRO and ENCOM on all matters related to the site investigation studies.

The specific responsibilities and duties of the national focal persons are, as far as their national sub-component is concerned: to provide all technical information needed by the Consultant to fulfil its assignment at the national level; to follow-up and oversee the day-to-day implementation of the studies; to ensure achievement of study objectives; to manage and oversee, under ultimate responsibility of ENTRO, all activities pertaining to procurement of services; to ensure that reports at all stages of the study are prepared by the Consultant and that the views of the beneficiaries are duly incorporated; to verify the Consultant's claims for payment, to prepare bi-monthly progress reports and the Study Completion Report at the completion of the study for distribution to appropriate bodies.

3.2 Responsibilities of the Consultant

With regard to the implementation of the SIS the Consultant, who is also responsible for the feasibility study cooperated and liaised fully with the ENTRO, which is the executing agency and the Client. He also liaised with all relevant Government's and other agencies on matters pertaining to the proposed study.

The Consultant exercised all due skill, care and diligence in the performance of his services. In that regard the Client recommended strongly the inclusion in the team of local consultants knowledgeable in their field of expertise. The Consultant has taken into account relevant comments from the executing agency, all Government authorities and other agencies and has been responsible for the accuracy of all data collected, his work, conclusions and recommendations. The Consultant carried and is carrying out the study in a professional manner in keeping with internationally accepted standards, using qualified and appropriate staff. The staff implemented the assignment with diligence and within a timeframe agreed upon in the contract.

The Consultant was responsible for providing staff salaries, fees of the experts, benefits, welfare, freight and travel, including visas. The Consultant declared himself prepared to replace any staff member, unable to carry out the work or considered by the Coordinator as unsuitable.

3.3 Overall Approach

As the Consultant had already established its office in Addis Ababa in order to implement the ENID study, commencement of the assignment could be immediately, with a minimum time for mobilization. This mobilisation started not later than the Date of Commencement of Services (DoCS), which was one week after the date of receipt of the advance payment in the bank account of the Consultant. Because of the serious delay in transfer of the advance payment it was very much likely that the fieldwork could not be completed before the onset of the rain. Therefore, the Consultant decided, after consultation with the Client, to mobilise and start work before the DoCS, using his own financial resources.

Reconnaissance and preparation visits to the Project area, the proposed weir & intake sites and the link canal alignment were made between 2nd and 6th February and from 20-22 March. Review of some project relevant documents was made culminating in the preparation and submission of this Inception Report.

Mobilization of topographic survey and soil survey teams was commenced after receipt of the advance payment and before the submission of this Inception Report. The teams would require approximately 1.5-2 months to complete fieldwork, including data collection and sampling. Such fieldwork can only be undertaken during the dry season that ends by the third week of May. Ideally, the soil survey team should have a base topographical plan of the investigation area while they conduct their auger and profile pit surveys. However, in order to compress the field survey period the Consultant has run the two tasks concurrently, with the soils team using handheld GPS instruments to record auger and pit locations for plotting later onto base topographical maps when they are ready. At preliminary stage 1:50,000 maps, satellite images, and Google maps have been used.

4. TOPOGRAPHIC SURVEYS AND MAPPINGs

4.1 INTRODUCTION:

In January 2009 ENTRO has awarded the preparation of Wed Meskin project complementary surveys (CS) to BRLi, with Shoraconsult as subcontracted firm. Conducting the topographic survey of the project was among the principal components of the complementary survey assignments to provide the basic data and working documents for the feasibility study (FS) that would be carried out subsequently. Shoraconsult awarded the preparation of the project topographic surveys and mapping to Mierag Space Tech. Co. as a subcontracted firm. This chapter presents the approaches and methodologies used to produce topographic maps of the project command area, link canal alignment, barrage sites and the major crossing structures.

4.2 TOPOGRAPHIC SURVEY PROGRAM.

The topographic survey works were programmed to be carried out by four survey crews using two 4WD cars in forty eight days. The survey team was stationed in Al Hawata town and the survey activities were programmed to be carried out in the early mornings and the late afternoons to avoid problems which may be posed by hot temperatures in the project area during the execution of the assignment. All the required survey works were executed in 31 days plus two days during which one survey crew revisited Wed Meskin barrage site for resurveying. The survey was carried out in four subsequent phases, office preparation and delineation of the project area boundaries, mobilization, establishment of benchmarks, and levels collection and maps preparation.

4.3 WEATHER CONDITIONS.

The Wed Meskin project area, named after Wed Meskin village is found in Rahad II area, Gadarif state, eastern region of Sudan. It is located east of river Rahad and south of Rahad irrigation scheme. In general terms the climate of the area is very hot, particularly from April to June. The average daily temperature during the hot season around 33^{0}c. The average rainfall goes up 600 mm, and it concentrates during the periods of July to September. The dry period normally extends from November to early June. The topographic survey was carried out during the dry season, when the climate was characterized by very hot temperatures during the day. Generally, weather conditions in the project area did not affect the progress of work significantly until it was completed at the end of May. The weather conditions negative impacts on the survey activities were compensated for by increasing the working hours per day and working through the weekends. Map 1.1 above, shows the locations of the project area and specific sites.

4.4 SCOPE OF THE STUDY.

The topographic survey team was briefed about the objectives, methodologies and planning of the survey works before mobilization to site. The team includes highly qualified and well experienced staff in their fields in different levels. Senior surveyors were included in the team to ensure the quality of the topographic surveys. All the survey works were carried out conform to the requirements of the TOR and the Inception Report. The topographic survey of the command area was executed in order to prepare for the feasibility design of the irrigation scheme, including selection of irrigation methods, preparation of irrigation layouts, preparation of bill of quantities and cost estimates, design of irrigation infrastructure, etc.

The project area and the command area boundaries were delineated. Horizontal and vertical control points with known x, y, and z co-ordinates were established in the project area. These control points were tied to the National grids using existing National geodetic reference stations (Trig. Stations) in the area and static differential GPS of duel accuracy under long period observation. Traverse surveying using digital and automatic levels was used to tie these established control points to the M.S.L. These BMs were established by installing a 1.5 inch iron pipe of about 70 cm long into the ground, where the upper part of the pipe is prepared in a 25x25x25 cm cube of concrete. They were clearly marked with identification numbers and painted with visible colours. Figure 4.1, shows a sample of the BMs established in the project area.

A topographic survey covering a gross area of about 8,369 ha was carried out, following the topographic survey methods stipulated in the TOR and the Inception Report. Topographic maps at scale 1:25,000 and 0.25 meter interval were prepared for current use. These maps can be prepared latter at a larger scale, up to 1:2,500 as required. Also, a detailed topographic survey was carried out at the project diversion sites (Dinder and Rahad barrages) and one major canal structure site (Khor Al Atshan crossing). Topographic maps at scale of 1:500 and 1:750 according to the size of the area, and 0.25 meter contour interval were prepared for these sites. Finally, A topographic map at scale 1:50,000 covering the whole project area were prepared for general use. These prepared topographic maps show every major feature in the area, including rivers, roads, springs, hills, forests, water bodies, settlements, etc.

Figure 4.1, a sample of the BMs established in the project area.

4.5 STUDY METHODOLOGY.

4.5.1 Delineation of the Irrigable Area for Survey.

At the commencement of the study, a review of all the data and documents provided by the National Coordinator of the project was made in order to determine the project planned topographic survey area. As mentioned before, the project area lies in the eastern bank of the Rahad River.

The western extent of the area was delineated by the Rahad River and the eastern extent was delineated by contour + 447.5 meter above M.S.L, this is due to the water level at Wed Meskin barrage. The exact project area is located south of Al Hawata town and extended south to cover an approximate area of 32,000 ha north of Wed Meskin village. The delineation of the area was carried out using ArcGIS software and a digital Georeferenced map of the project area.

Considering the exclusion of areas for villages, roads, buffer zones along streams, water bonds, forests, and topographically unsuitable areas, the approximate net command area was assumed to be 30% of the gross delineated area between contour +447.5m and Al Rahad River. After the delineation of the command area, coordinates were delivered to the survey team to carry out the survey as planned. High resolution satellite images (Quick Bird 60 cm) were acquired, and loaded on the computers of the surveyors and used at field level for orientation and verification of the survey activities. The topographic survey was carried out for the planned study area, excluding the topographically unsuitable areas and covered a gross area of 8,369 ha. The network of BMs established in the project area was used to control the topographic survey. Ground levels were then collected at maximum grids of 200x100 meter depending on the topography of the land using automatic and digital levels. Topographic maps were prepared at different scales and contour intervals for the project area.

4.5.2 Mobilization.

A survey team consists of five surveyors, equipped with the appropriate survey equipments, including a set of differential GPS, with one base and two rovers, one automatic level, and two digital levels were stationed at site on 18 April 2009. Two 4WD cars were joining the team. Before mobilization the topographic survey team was briefed about the objectives, methodologies and planning of the survey works. The survey team rented a house in Al Hawata town that accommodated all the survey team including the drivers. In addition to the staff mobilized, rod men were recruited from the localities and trained for providing assistance for the survey works. The team stayed on site until all the survey works were completed. The list of the equipments used in the project is presented in table 4.1 and that of the personnel mobilized to the project area is presented in table 4.2. This chapter therefore, presents a brief description of the approaches and methodologies used to conduct these topographic surveys and mapping activities, more details are presented in the attached subcontractors report.

Table 4.1: List of Survey equipments used in the project

S. No.	Description	No. available on site
1	Digital Levels, LEICA, DNA03 with accuracy of 1 mm Double running 1 km, SD not exceeds 0.5 mm.	2
2	Automatic Levels,	1
3	Communication devices	7
4	Office Equipment, ArcGIS 9.2- ERDAS- AutoCAD Software, PC Workstations,	5
5	Lap top computers	3
6	Dual frequency Differential GPS Horizontal ±10 mm + 1 ppm RMS Vertical ±20 mm + 1 ppm RMS	1 set (2 GPS)
7	Normal GPS	2
8	4WD, vehicles,	2

Table 4.2: Personnel mobilized to the project site

Sr. No.	List of Manpower	No. on site	Remarks
1	Team leader	1	
2	Chief surveyors	4	
3	Technical Labours	3	
4	Level man	8	

4.5.3 Establishment of Benchmarks and Connection with the National Grids.

The project area was delineated by establishing concrete poles of 0.6 m long steel bar (40 cm inside ground and 20 cm above). A network of permanent benchmarks with X, Y, Z values was established in the project area. All BMs were clearly marked with identification numbers on the site and on the produced topographic maps with list of coordinates. Differential GPS dual accuracy under long observation was used to tie the project area to the National girds from existing National geodetic reference stations (Trig. Stations). Traverse surveying using digital and automatic levels was used to tie the project area with M.S.L height from the existing National reference BMs in the area. In addition, a group of site reference points were established at each of the project specific sites using differential GPS with the GPS site calibration model established for the project area. The benchmarks established in the project area are listed in table 4.3 and the GPS site reference points established at Wed Meskin barrage, Dinder (Salsal) barrage and Al Atshan stream crossing sites are presented in table 4.4.

Table 4.3: List of Benchmarks established in the project area.

Name	Northing	Easting	Elevation	Code
BM01	1484263.026	678395.181	444.0063	BM
BM010	1467674.774	696013.532	446.306	BM
BM011	1465306.078	698057.236	448.7971	BM
BM012	1463644.528	700128.925	450.0173	BM
BM013	1461633.768	700889.212	449.8844	BM
BM014	1459073.246	702552.767	450.0949	BM
BM015	1457324.831	703421.41	450.8768	BM
BM016	1454645.45	705916.576	451.9612	BM
BM017	1477974.375	685385.88	443.0736	BM
BM018	1475517.651	683434.306	442.4705	BM
BM019	1474982.74	686842.298	442.7095	BM
BM02	1485437.885	681032.729	447.0615	BM
BM020	1473466.389	690019.45	442.639	BM
BM021	1471013.426	688301.041	443.981	BM
BM022	1469031.449	690879.811	445.2179	BM
BM023	1465686.693	693701.283	444.9433	BM
BM03	1481022.328	679644.028	442.5353	BM
BM04	1482314.71	682338.449	445.4862	BM
BM05	1479684.803	682713.412	443.2001	BM
BM06	1479604.805	686822.859	445.9784	BM
BM07	1477807.419	689225.14	444.4763	BM
BM08	1475870.774	691925.459	445.0128	BM
BM09	1470627.921	693466.282	445.3675	BM
BM32837	1485691.445	683718.848	449.616	Ref. BM
BM32838	1481698.463	679715.015	443.072	Ref. BM
BM32839	1481693.427	683714.423	445.979	Ref. BM
BM32851	1465688.817	695702.811	447.844	Ref. BM
BM32852	1465690.64	699699.752	451.57	Ref. BM
BM32955	1455729.157	704371.735	452.186	Ref. BM

Table 4.4
GPS Points established at the project specific sites.

Description	Easting (m)	Northing (m)	Elevation (m)	Site of installation
wmkn1	704663.423	1455153.135	449.954	Wed Meskin Barrage
wmkn2	704686.711	1454998.101	451.264	
wmkn3	705014.545	1455018.995	451.748	
wmkn4	704973.706	1455195.848	451.697	
Atshan1	700215.423	1446350.793	451.312	Khor Al Atshan Crossing
Atshan2	700353.017	1446071.563	451.524	
Atshan3	699910.359	1445818.427	450.120	
Atshan4	699701.001	1446105.546	449.564	
Salsal1	696482.798	1408185.373	454.253	Salsal Barrage (Dinder)
Salsal2	696636.447	1408273.294	454.500	
Salsal3	696774.000	1408004.000	453.824	
Salsal4	696620.351	1407916.079	453.935	

4.5.4 Establishing the network of benchmarks.

In order to facilitate the detailed design and the construction of the project works during the implementation phase an adequate number of benchmarks were established for horizontal and vertical control. These benchmarks were based on the existing National geodetic reference stations (Trig. Stations) and reference benchmarks in the area. Six reference stations were used to traverse these BMs within the project area as dense as possible. These reference stations are attached at the bottom of table 4.3. Overall 23 BMs were evenly distributed and installed at locations determined according to the shape of the area. These BMs were established by installing a 1.5 inch iron pipe about 70 cm long, supported by an iron base into the ground at selected locations, with the top 200 mm protruding above the ground. After the construction and curing of each BM an identification number was clearly marked on it. In addition a number of site reference points were established at each of the project specific sites, using differential GPS with duel accuracy under long observations. Overall, 12 GPS reference points were established in the project area, four points at each of Wed Meskin, Dinder barrages and Khor Al Atshan crossing site.

4.6 FIELD LEVEL TOPOGRAPHIC SURVEY.

4.6.1 General.

The network of BMs was connected to the Sudan National grids using the static differential GPS duel accuracy under long observation and the National geodetic reference stations (Trig. Stations) available in the area. The network was connected to M.S.L height, using digital and automatic levels traversing and the existing National reference BMs in the area. Thus all BMs in the area were given x, y, z values and used to control the topographic survey in the project area.

4.6.2 Command area survey.

A detailed topographic survey of the project area was carried out using a grid network of spot heights 200x100 meters. The spacing between the grid points was decreased to show features when required. The spot heights were collected using digital or automatic levels and were based on the network of benchmarks established in the project area. Significant features in the project area were located using Real Time Kinematic (RTK) with the GPS site calibration model. A digital topographic map with a high resolution satellite images (as back ground) was produced at scale of 1:25,000 and contour interval of 0.25 m and can be latter produced at a larger scale, up to 1:2,500 as required, using ArcGIS and Surfer application programs (VOLUME 3, Maps and Drawings). These maps include all the significant features in the project area, such as, rivers, water bodies, forests, roads, villages, tracks, gullies, hills and footpaths etc. The main features in the project area were extracted from the rectified satellite images. A general use map at scale 1:50,000 were produced for the whole project area (VOLUME 3, Map and Drawings). This topographic survey covered a gross irrigable area of 8,369 ha out of the 32,000 ha planned area, demarcated using land characteristics observed from satellite images and digitized topographic maps of the area.

4.6.3 Traversing of benchmarks.

The new benchmarks established in the project area were traversed using digital and automatic levels and connected to the M.S.L height using the existing National benchmarks in the area. A total of 23 BMs evenly distributed in the project area were established and used to control the topographic survey of the command area and will be used later to control the design and implementation of the project.

4.6.4 Diversion Sites Survey.

In line with the topographic survey of the command area, two barrage sites (Dinder and Wed Meskin barrages) were surveyed. This survey was carried out using GPS, Real Time Kinematic (RTK), based on the site reference points established at these locations. A grid network of spot heights 10x10 meters was collected for each site. A digital topographic map at scale 1:500 and 1:750 according to site and contour interval 0.25m, supported by a digital terrain model and profiles for two cross section lines was produced for each site (VOLUME 3. Maps and Drawings).

4.6.5 The Link Canal Survey.

The link canal survey was based on the data and documents provided by the National Coordinator of the project (maps, profiles, and cross sections, SIRM. MCDONALD & PARTNERS CONSULTING ENGINEERING, 1965) (VOLUME 3, MAPS and Drawings).

4.6.6 Detail Survey of Major Canal Structure.

In line with the topographic survey of the command area a detailed topographic survey of the major canal crossing at Khor Al Atshan along the route of the proposed canal between Dinder and Wed Meskin barrages was carried out. This detailed survey was made using GPS Real Time Kinematic (RTK), based on the site reference points established at this location. A grid network of spot heights 10x10 meters was collected for the site and a digital topographic map at scale 1:750 and contour interval 0.25m was produced, supported by a digital terrain model and profiles for two cross section lines. (VOLUME, 3, Maps and Drawings).

4.7 GENERATION OF TOPOGRAPHIC MAPS.

The daily collected survey data were down loaded after working hours and checked for consistency and errors. The terrain model was then prepared to compare the land features generated with the actual features of the land. Powerful computers with the latest versions of the survey application programs (ArcGIS, Erdas Imagine, Surfer, AutoCAD, etc) were used for data processing and the production of topographic maps. The contour maps with contour intervals of 0.25 meter and 1 meter were prepared at office level from the collected field survey data. Digital topographic map with high resolution satellite images (as background) were prepared and printed at a scale of 1:25,000 for current use and can be latter produced at larger scales, up 1:2,500 as required. These maps show all the significant features in the area, such as, rivers, forests, waters bodies, villages, tracks, hills, roads, etc. A general use map at a scale of 1:50,000 were also prepared. All these maps are presented in VOLUME 3, Maps and Drawings.

4.8 PROBLEMS ENCOUNTERED.

The first problem encountered by the survey team was the inaccessibility of most of the project area with motorized vehicles, particularly in Dinder and Rahad barrage sites, which are densely forested and can only be crossed on foot. Also, there were no access roads evenly distributed in the project area. This forced the team to travel on foot to cover the whole project area to conduct the survey and install the benchmarks.

The rough nature of the terrain coupled with the very hot temperatures in the project area during the conduction of the topographic survey works were also some of the constraints that hindered the team activities to some extent. However, though these faced problems created a negative impact on the survey activities in general, all the survey works were completed in a period of 31 days plus two days during which one survey crew revisited Wed Meskin site for resurveying. The farmer's communities residing within the project area were so cooperative and no problems were encountered by the survey team in this regard. Most of the people in the project area were aware of the planned development program and this created a positive impact on the team activities in the area.

4.9 CONCLUSIONS.

This topographic survey was performed according to the TOR and the Inception Report. It was carried out by highly qualified and well experienced personnel in the specializations required for topographic survey digital data, collection, management, presentation and documentation. All the services required were made in accordance with the industries accepted standards and practices for survey works in support of topographic survey for proposed irrigation schemes.

The field survey data was collected using modern digital survey equipments. Data processing and mapping were carried out by well experienced personnel in the fields of computer graphics, data processing and presentation using powerful computers. Specialized software programs were used for data plotting and presentation.

The topographic surveys and mapping assignment of the project area was completed within the planned period. The topographic survey has covered a gross area of 8,369 ha or 26% out of the planned 32,000 ha area demarcated using land characteristics observed from satellite images and digitized topographic maps of the project area. As the area surveyed from the project demarcated area is more than the amount to be surveyed and agreed with the client (7,500 ha), it is assumed that the command area topographic survey is completed.

The digital topographic maps produced for the project command area, barrage sites, the major crossing at Al Atshan stream and the canal alignment form an excellent basis for the preparation of the detail design of the proposed irrigation development scheme. These maps provide the required data and documents for the selection of irrigation methods, preparation of irrigation layouts, estimation of land levelling requirements and design of irrigation infrastructure etc.

The horizontal and vertical control network established in the project area and the site reference points at the project specific sites form a very good reference frame for the future setting out activities in the project area, the expansion of the project area and an excellent addition to the National horizontal and vertical control networks in the area.

The problems faced during the execution of the assignment were insignificant and mainly related to hot temperature and the inaccessibility of most of the project area with motorized vehicles. The hot temperature did not pose major problems as the works were programmed to be carried out in the early mornings and late afternoons. The inaccessibility problem forced the survey team to travel all the time on foot to cover the whole project area. The communities residing within the project area were cooperative and aware of the planned development program and no major problems were encountered by the survey crews from them. However, the negative impacts on the survey activities posed by the inaccessibility of the project area and hot temperature problems were compensated for by increasing the working hours during the day and working through the weekends.

5. SOIL SURVEY AND LAND EVALUATION

5.1 Soil Survey: Executive Summary & Report Structure

5.1.1 Summary

This report covers the soil study of 10,000 ha (7,500 ha net) area selected for Wad Misken irrigation project. The objective of the study is to identify and classify the soils of the selected area and evaluate their potential for irrigated agriculture.

It is located between latitudes 1472500-1478000 m and longitudes 678000-695000 m in zone 36P- WGS-84.

The works of soil survey included grid and free survey, as well as traverse survey techniques to characterize the geomorphology and soils of the study area. Field survey was located by GPS and adhered to a basic 1.0 km × 1.0 km grid. The survey comprised soil auger observations to 1.0 m and soil profile pit description to at least 2.0 m at selected sites representative of all major soil types.

In addition to previous auger and profile sites that can be located from previous soil surveys (HTS, 1966, and SSA, 1993), a total of 96 augers and 6 profile pits were made. Field recording of soil auger sites and profiles was standardized performs and soils were described according to the "Guidelines for Soil Description", FAO (2006).

Soil classification for the project area has been undertaken according to the U.S Soil Taxonomy (1999) and the keys to soil Taxonomy (USDA, 2006), the recognized soil mapping units in the area belong mainly to the Vertisols usterts suborder i.e. Vertisols with an ustic soil moisture, on the level of great group they are belong to chromic Haplusterts and Typic Haplusterts. Vertisols are classified as "chromic" if they are brownish or greyish coloured and "Typic if they are very dark coloured. Summarized area coverage of these soil types is presented below.

Vertisols have deep soil depth, moderately well drained, and hard workability when moisture content is too high or too low, non-salinic and non-sodic.

The soils fertility status is poor in nitrogen and organic carbon. However, the soil samples major cations like calcium, magnesium and potassium values are found to be moderate to high. Table 5.1 shows the identification of Soil Types and area coverage.

Table 5.1

Soils types and area coverage

Soil Type (+)	Area ha
Chromic Haplusterts	288
Typic Haplusterts	9312

(+) at the great group level (USDA, Soil Taxonomy, 1999)

The land evaluation has shown that at current conditions 72% of the area (6,912 ha) are rated as class S2 (moderately suitable land for irrigated agriculture), 27.1 % of the area

(2,688 ha) are rated as S3 (marginally suitable land for irrigated agriculture), 0.9 % (86.4 ha) of the total area are rated permanently unsuitable land N2. The main current soil constraints to agriculture production in project area consist of:

a- Vertisolic (V) or high clay content which, retards water movement through the soil and also creates poor soil aeration conditions.

b- Topography (t) at the low lying and digressional sites.

c- Moderate chemical fertility (F).

d- Wetness (W, limitation due to water logging caused by slow permeability of slow surface drainage or combination of these.

e- Inundation (i), limitation caused by inundation (flooding) of the land from rivers.

If certain measures are adopted including, proper levelling, good drainage system, use for farm machinery at optimum soil moisture, addition of nitrogen fertilizer the expected potential land suitability class of the bulk of the project area will be upgraded to the moderately suitable land class S2 with only one inherent constraint i.e. Vertisolic limitation (V) due to high content of swelling clay.

Table 5.2 below summarizes the area current and potential land suitability classes and subclasses. The table also gives the recommendations for each soil unit for agricultural development based on the land suitability classification and suggested remedies for land management.

Table 5.2

Summary Table for current and potential suitability classes and subclasses

Map Unit	Current Land Suitability Subclasses	Potential Land Suitability Subclasses	Area		Recommendations for development based on land suit. Classification
			ha	%	
10	S2 vf	S2 v	6,624	69	Recommended
20	S2 vf	S2 v	288	3	Recommended
30	S3 wvf	S3 v	2,315	24.1	Recommended for paddy rice production
40	S3 tvf	S3 v	288	3	Recommended
50	N2	-	86.4	0.9	Not recommended

5.1.2 Report Structure

The first chapter of the report discusses largely on background and objectives of the study for the project area. In chapter (2) location and accessibility, climate and topography, present land use and land cover, geology and geomorphology of the area have been explained briefly. Survey methodology, steps used to accomplish the task was explained under chapter (3). The chemical and physical characteristics of soils of the area, interpretations of analytical data on relevant parameters have been illustrated in chapter (4). The soil classification was made according to the USDA Soil Taxonomy (chapter 5). Characterization of each mapping unit is presented under chapter (6). For each mapping unit the site information, soil chemical, physical properties, area extent are illustrated. Soil survey conclusions and recommendations of the study area are illustrated in chapter (7).

Land evaluation background, objectives and scope of work illustrated in chapter (8). Methodology and approach for land suitability assessment, land suitability classes and subclasses and current and potential land suitability for irrigated agriculture are explained in chapter (9). In chapter (10) soils and land management are discussed. Conclusions and recommendations of the soil and management of the study area also forwarded at the end, chapter (11). It is deemed that this study presents detail assessment of the soil resource of the project area in a comprehensive way.

5.2 BACKGROUND

The technological options for putting irrigated agriculture on to a more ecologically sound, pathway while at the same time, not only achieving the projected output, but also laying the foundation for sustainable agriculture development in long term, should be based on physical resources assessment and sustainable resources management. Soil, among others, is an important land resource that influences crop suitability and choice of land utilization types. Therefore, every irrigation project should be pro-accompanied by an intensive soil study to ensure selection of land for irrigation development and other agricultural practices.

Soil survey of selected irrigation project area has been conducted by HTS in 1966 by Rahad Project, and Soil Survey Administration in 1993. However, taking into account the objective of the present study, the study has been conducted at semi-detailed level, to achieve a density of auger and pit observations is overall about 100 ha.

5.3 STUDY OBJECTIVES

The overall objective of the soil survey is to provide detailed information on the soils of the project area and prepare soil map of the project area at feasibility level for selection of appropriate crops and irrigation design. The specific objectives are;-

- To identify soil Types of the project area and describe their physical and chemical properties of the soils; and
- Map distribution of the soil/land units at scale 1: 10,000.

5.4 SCOPE OF THE SURVEY

A semi-detailed soil survey was carried out as per FAQ/UNESCO procedures and Guideline for feasibility study, to provide the variety; characteristics and geographic distribution in relation to the geomorphological units, a detailed classification and delineation of arable and irrigable land including maps were prepared.

The works of soil survey included grid and free survey, as well as traverse survey techniques to characterize the geomorphology and soils of the study area. An auger observation to depth 1.0 m was conducted along the grid to delineate soil boundaries.

Depending on the heterogeneity of the soils a total of 96 augers and 6 soil profile pits (2m depth) were opened for description and sampling.

The soil survey covered a total area of approximately 10,000 ha (7,500 ha net) and included the following activities:

- Review of the previous studies for the project area;
- Field level soil Investigation and observations;

- Laboratory, physical and chemical analysis;
- Preparation of soils map;
- Land suitability evaluation for Irrigation;
- Formulation of proper soil and land management practices including soil fertility management; and
- Establish land and soil management units.

5.5 General Features of the Area

5.5.1 Location and Accessibility

The proposed Wad Meskin irrigation project lies south of the railway line, east of Hawata town, between latitudes 1472500 – 147800 m and longitudes 678000 – 695000 m in zone 36 P–WGS–84. It extends southeast from the railway to Ingamaina village, on the eastern side of the seasonal Rahad River (Figure. 5.1). The proposed project is about 7500 ha net.

Access to the study area: using the Highway road from Khartoum to Al Faw town "the head quarter of Rahad Project Phase I", the travel distance is about 275 km. Then transferring to a paved road with asphalt cover and gravel, from Al Faw town up to Hawata town about 160 km. Then using rough unpaved road from Al Hawata to Wad Meskin village, which is difficult to use especially during the rainy season.

5.5.2 Climate and Topography

5.5.2.1 Topography

The dominant topographic feature is the flat cracking clay plain which covers the whole area. The landscape is gently sloping from southeast to northwest draining towards the Rahad River. The western part is mainly low lying area (depressions) making water pools (Mayas) and cut off meanders and Ox-bow lakes are the main features of the west boundary.

5.5.2.2 Climate

The climate of the study area is tropical sub-humid with annual rainfall between 500 – 800 mm, average rainfall goes up to about 600 m, and 2 – 3 humid months (Walsh, 1991). This climatic zone is more reliable for dry land farming system, and it is the major zone for mechanized agriculture in the country. According to Kevie (1976) the area lies within the semi-arid climate zone. Figure. 5.3 and 5.4 shows the rainfall and the potential evapo-transpiration in two stations on to the east (Gadarif) and one to the west (Abu Naama) of the project area. The moisture calendar for the two stations is calculated using Newhall Simulation Model program for moisture and temperature regimes and the tentative subdivision for the moist6ure regime is given (Table 5.3 and 5.4).

5.6 Land use / Land cover

The land use, land cover study was undertaken based on satellite imagery in conjunction with other available maps and ground verifications. The maps were used for the interpretation of the land unit which was supported by the ground checking, sampling and reinterpretation. The land use/cover mapping boundaries delineation were carried out by identifying the variable characteristics of the image elements such as colour, tone, pattern and texture.

Accordingly, for the project area five major land use/cover mapping units were identified and mapped. These units were cultivated land, grass land, natural forest, wooded shrub land and wet land (Mayas) lands.

People in the project area are either farmers living in villages or nomads moving with their livestock from north to south and vice versa looking for good grazing areas and drinking water for themselves and their animals. Most of the farmers are involved in rainfed agriculture; however, some are involved in irrigated agriculture on the banks of Rahad and Dinder rivers. The main crops grown in the rainfed agriculture are sorghum, millet and sesame. The irrigated agriculture mainly constitute small farms have small areas of orchard trees and some vegetables which are locally marked.

The seasonality of the two rivers flows makes it difficult to cultivate big areas without any storage facilities. Nomads in the area are of different tribes. The major tribes in the area are Rofaa, Gawasma, Halloween and Lahoween.

5.7 GEOLOGY AND GEO-MORPHOLOGY

The geology of the project area is well documented and comparatively straightforward. The main geological formations occurring in the study area are, from oldest to youngest:-

1. Basement Complex igneous and metamorphic rocks (Pre-Cambrian).
2. Um Ruwaba (Locally El Atshan) Formation gravels, sands and clays (late – Tertiary to Pleistocene).
3. Dark-coloured cracking clays (Vertisols; Pleistocene).

The project area is gently sloping with the only high ground being isolated remnants (Jebels) of mainly Basement Complex rocks, and basaltic lavas along the Gadarif - Gallabat axis and along the Ethiopian border. The predominant flatness of the area reflects its geologic history, where the Basement Complex rocks were eroded to a gently undulating peneplain with scattered Jebels. Onto parts of this plain were later deposited the fluviatile (water-laid i.e. flat) sediments of the Um Ruwaba Formation and irregularly the dark clays which now blanket most of the area.

Table 5.3

Moisture Calendar for Gadarif Station

	1************15**************30
January	111111111111111111111111111111
February	111111111111111111111111111111
March	111111111111111111111111111111
April	111111111111111111111111111111
May	111111111111111111111111111111
June	111111111111111222222222222211
July	111111111111111333333333333333
Aug	333333333333333333333333333333
September	333333333333333333333333333333
October	333333333333322222222222222221
November	111111111111111111111111111111
December	111111111111111111111111111111

1=dry;2= dry/moist; 3= moist
Temperature Regime: Isohyperthermic Moisture Regime: Ustic
Tentative subdivision: Aridic Tropustic
Calculated by: Basic Program NSM, Nov.1986
Source: Van Wambeke *et al*, 1986.

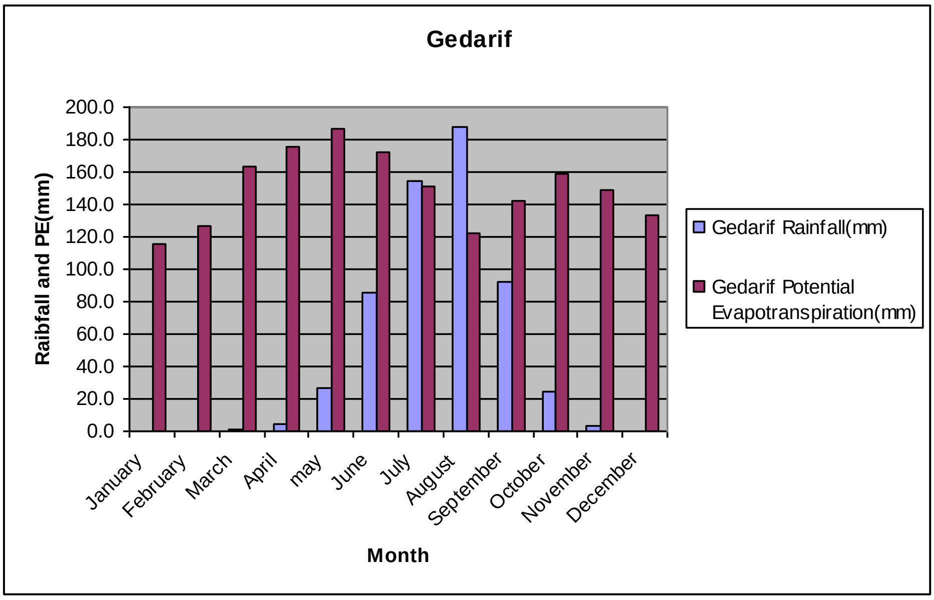
Table 5.4

Moisture Calendar for Abu Niaama

	1************15**************30
January	111111111111111111111111111111
February	111111111111111111111111111111
March	111111111111111111111111111111
April	111111111111111111111111111111
May	111111111111111111111111111111
June	111111111111111222222222222211
July	111111111111111222222222222222
Aug	222222222222222333333333333333
September	333333333333333333333333333333
October	333333333333332222222222222222
November	211111111111111111111111111111
December	111111111111111111111111111111

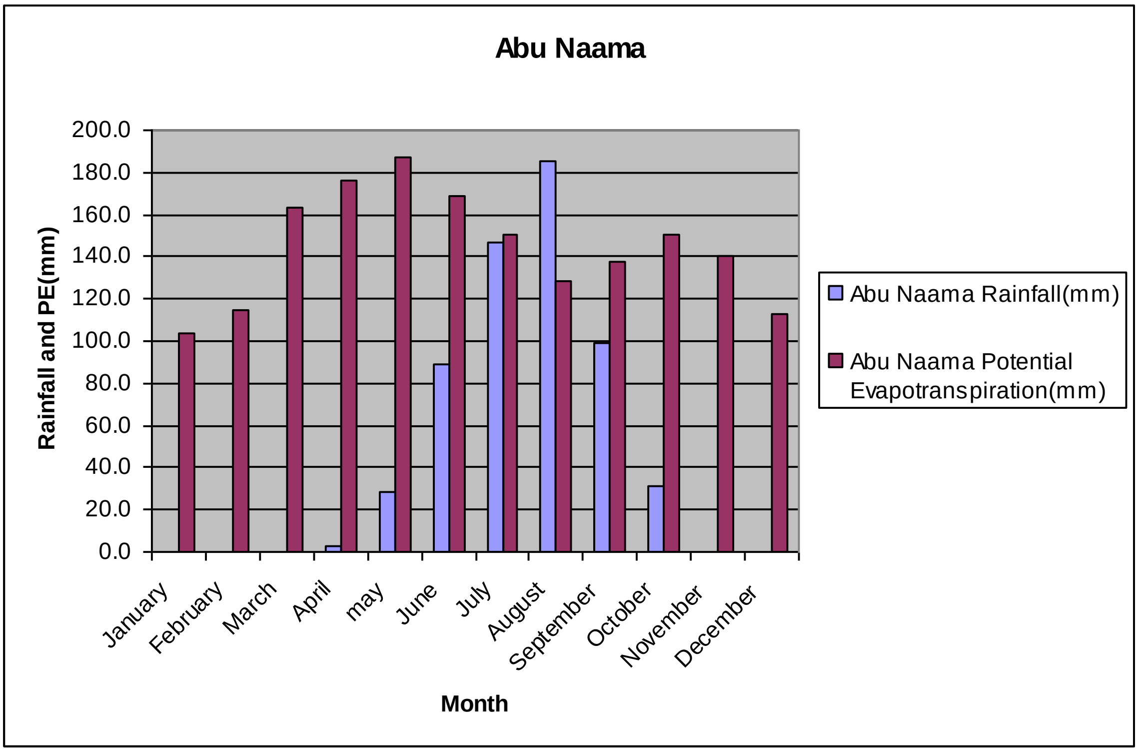
1=dry;2= dry/moist; 3= moist
Temperature Regime: Isohyperthermic Moisture Regime: Ustic
Tentative subdivision: Aridic Tropustic
Calculated by: Basic Program NSM, Nov.1986
Source: Van Wambeke *et al,* 1986.

Figure.5.1 Rainfall and Potential Evapotranspiration of Gadarif Station



Source: Sudan Meteorology Department

Figure.5.2 Rainfall and Potential Evapotranspiration of Abu Naama Station



Source: Sudan Meteorology Department

The origin of the Vertisols remains uncertain. The literature is divided between two schools of thought. One maintains that the clays have derived from weathering in situ of the underlying rocks, with sheet wash and wadi flows responsible for redistributing the clays. This view seems implausible given the vast extent of the clays, their considerable

thickness, the range of the underlying rocks, the semi-arid climate unlikely to produce deep weathering mantles and the gentle slopes restricting any widespread overland flows.
The alternative theory holds that only on the outcropping basalt ridges and hills are Vertisols forming in situ. Elsewhere the smectitic clay has developed under the current semi-arid climate from fine-textured sediments deposited as large fans and alluvial plains of rivers (Rahad, Dinder, etc) carrying base - rich erosion debris down from the Ethiopian highlands during wetter and more erosive climates throughout the Pleistocene period. Such alluviation may represent the upper and last member of the Um Ruwaba Formation.

5.8 METHODOLOGY

5.8.1 General

To provide detailed information on the soil and land data for irrigation development semi-detailed soil survey at feasibility level has been conducted. The survey implemented on grid system where, one observation represents 100 ha. It is proposed to follow the procedure indicated by FAO guidelines, for soil mapping unit and description of different soil types of the irrigation project area at a scale 1: 10,000. Accordingly, in order to properly accomplish the soil study task the survey has been performed in three steps. These steps are:

* Pre-field work;
* Filed work; and
* Post field work

5.8.2 Pre-field work:

Prior to the start of field work all available land resources reports on the region were gathered and reviewed. Existing maps were digitalized and their datasets were incorporated into the study. Recent satellite imagery scenes were used to prepare a thematic map series for field work to locate sites for mapping land use and soils.
Preliminary reconnaissance visits were made to the area in June 2008 and later in February 2009 by specialist from Shouraconsult and BRLi Ingenierie which enabled an assessment to be made of the survey area and relate it to the previous soil surveys (HTS, 1996); Coure et Belier/ HTS et. al. 1977, LWRC, 1993).
Field soil guidelines, description sheets for auger boring, profile pits, hydraulic conductivity and infiltration tests have been prepared during this phase. Besides that the base map, which shows location and numbers of auger boring, profile pits, infiltration and hydraulic conductivity tests also, has been planed during pre-field work time in the office.

5.8.3 Review of Previous Studies

Soil survey investigation for the study area has been conducted previously. However, some general studies at different levels, such as reconnaissance or semi-detailed level have been undertaken at different times by different agencies. A review of these major studies is presented in the following sections.

5.8.3.1 Studies by Hunting Technical Services (HTS) 1966,

The HTS surveys were mostly carried out in the period 1963 - 67 as part of the feasibility studies to identify irrigation projects following the construction of Roseires Dam. The survey of the Rahad II area, which lies on the right bank of the Rahad River, covered the entire project area relevance to the present study is significant. As the result of the study the land is general very even, and the soil is very uniform. Almost everywhere the soil is vertisols, with about 70 percent clay. The chief soil limitations are the heavy texture and the alkalinity. From 98.5 to 100 percent of the land was classified as class 2. The remaining one percent or so is nearly all class 3.

5.8.3.2 Studies by UNDP/FAO, 1970

In 1970 the UNDP/FAO had studied parts of the Central Clay plain, including the Dinder area, the land on both banks of the River Dinder, stretching from near Roseires in the south to the confluence with the Khor Atshan in the north.

According to this study, the soils of the plain are almost everywhere dark grey - brown or dark grey clays. The dark grey soils occupy the lower lands. Some patches of sandy clay loam 2 to 3 km across appear in the south.

The UNDP/FAO Land Classification Map puts nearly all the land in class 2. The limitation is the physical one of the high content of expanding lattice clay; very few class 2 soils are shown to be affected by salt or alkali. Certain areas are classed as class 3 on the grounds of high alkalinity (ESP). The assessment of salt and alkali is based on the analysis of very small number of samples.

5.8.3.3 Studies by Southern Kassala Agricultural Development Project (SKAP), 1993.

A broad soil survey was carried out by SKAP for the whole Southern Kassala (Gadarif State, now) as part of land use survey and use planning studies.

The study provided mapping of soils and their suitability and utilization at 1: 250,000 scales. The study was based on interpretation of satellite images for the entire state and subsequent field checking. The study provides general background information on the study area, but due to its scale limitation the study has limited importance to the currently envisage study.

5.8.3.4 Studies by Soil Survey Administration (SSA):

In 1993 the Soil Survey Administration (SSA), now Land and Water Research Centre (LWRC), had studied the entire project area. As the result of the study, the soils are believed to be developed on parent material derived from the weathering products of Ethiopian basaltic high lands, deep and moderately well drained to poorly drained.

The dark cracking fine textural clays, with the clay content exceeding 60%. The soil also have high available water holding capacity (18 - 24%), thus they can be irrigated at a longer intervals like in the other parts of the irrigated clay plain. According to the U.S. Soil Taxonomy, the recognized soil mapping units belong to the Vertisols order. The land evaluation has shown at current conditions 78% of the area surveyed (about 7297 ha) are rated s moderately suitable land for irrigated agriculture.

5.8.4 Imagery Interpretation and Base Map Production

5.8.4.1 Satellite imagery interpretation

Satellite imagery was interpreted and used to establish the location of soil traverse. The imagery was also used to provide an up – to date view of the present land use and other aspects of land cover.

5.8.4.2 Base map production

The interpreted preliminary mapping unit along with its legend was transferred to the satellite image, which was used as base map in the field. On the base map, features, like land use/cover system and drainage patterns of the area are shown. In addition, location and numbers of auger holes, profile pits, infiltration and hydraulic conductivity test sites were marked on the base map.

Based on landform, slope breaks and denudation interpretation (with help of contour map) on the image land units were constructed and preliminary legend was given for each land units. MS Excel spreadsheets compatible with Arc GIS version 9.X are used for data management and mapping.

All field and laboratory data were recorded initially in MS Excel spreadsheet so that all data can be displayed in GIS. All soil auger sites and all soil profile pits have been classified into their appropriate soil unit and land suitability class by interrogating the database against defined criteria for the soil units and land suitability classes.

Final land class boundaries were interpreted and manually placed and then digitized. Soil mapping unit legends were constructed at these levels of generalization, namely, geomorphic units (level 1) and slope class (level 2). Two major land units and two sub land units (phases) were identified and mapped for the project (see annex B).

5.8.5 Field work

A systematic free survey to confirm the location of soil types and boundaries was carried out. Field survey was located by GPS and adhered to a basic 1.0 km × 1.0 km grid. The survey comprised soil auger observations to 1.0 m and soil profile pit description to at least 2.0 m at selected sites representative of all major soil types.

In addition to previous auger total 99 and profile sites (6) that can be located from previous soil surveys, a total of 96 augers and 6 profile pits were made. The location of all pit and auger sites is shown on the accompanying Soil and Land Suitability Maps. Field recording of soil auger sites and soil profiles was on standardized performs and soils were described according to the "Guidelines for Soil Description" (FAO, 2006).

A total of 2-3 profile pits were dug in every soil unit to a depth and thickness of different soil layers, soil colour, texture, structure, concretions, pores, mottles, consistence, and layer boundaries. Other site specific observation including land use and land cover, topography, drainage, erosion and parent material was duly recorded, with the help of GPS for both auger holes and profile pits.

5.8.6 Post field work

5.8.6.1 General

After accomplishment of field data collection, final data compilations and soil survey report writing were undertaken. Improvements of soil/land units were conducted on the basis of field observation and topographic information. As soon as laboratory results were obtained, final soil legend was developed and the report along with the soil map was prepared.

5.8.6.2 Laboratory analysis

Soil samples were broken down to clods at the field base and made ready for the laboratory. The samples were dried and crushed for a fine earth, and sub-samples for the different analysis are prepared.

The laboratory methods outlined on the Richards (1954) were followed. They are briefly described below:-

Soil samples, which were collected from representative horizons, were sent to the LWRC laboratory centres for the analysis. All analysis were performed on air-dried fine earth fraction (<2 mm) according to the procedures outlined by Black (1965).

Accordingly, standard soil analyses have been undertaken for the following parameters:

- Particle size distribution was determined by hydrometer method following pre-treatment with H_2O_2 to remove organic matter, and dispersion, aided by sodium hexametaphosphate
- Bulk density was determined on oven-dry weight basis using core samples.
- Water content at field capacity and permanent wilting point (0.33 and 1.5 MPa, respectively) were determined by pressure plate extractor.
- Electrical conductivity was determined at a soil/water saturation extract.
- Soil pH was measured in H_2O and 1 M KCI at a soil water suspension.
- Organic carbon was determined by the wet combustion procedure of Walkley and Black.
- Exchangeable Ca, Mg, K and Na were extracted by leaching with 1 M NH4OAc at pH 7, and the cations in the leachate were measured by atomic absorption spectrophotometer (AAS).
- The cation exchange capacity (CEC) was determined by saturation with NH4OAc at pH 7 and subsequent replacement of NH4 by NaCI extraction.
- The available phosphorus content of the soils was determined by 0.5 M sodium bicarbonate extraction solution (pH 8.5) method of Olsen.
- The free Caco3 content of the soils was determined by acid neutralization method.
- For Available Micronutrients determinations the most commonly used methods is that of Lindsay and Norvell.

5.9 Interpretation of Analytical Data of the Study Area

5.9.1 General

This section presents the approaches and details of the chemical and physical properties of the soil used that were employed in the soil classification. It also presents the overall picture of the soil characteristics of the surveyed area.

5.9.2 Chemical Characteristics of Soils

The following summary chemical characteristics of the soil should be regarded as a general one based on literature in compliance with applied laboratory methods and procedures. Its main use to evaluate the natural fertility of soils and to indicate its potentials abundance or otherwise deficiency in the project area. This will help in the planning of agronomic development activities that are best suited to the proposed irrigation project.

5.9.2.1 Soil Reaction (pH)

Soil reaction expresses the environment in terms of acidity and alkalinity in which plants exist within the soil solution. The reaction is expressed in terms of hydrogen ion concentration expressed as PH. The low plant nutrient status that occurs under acidic conditions arises when there is deficiency of absorbed base cations relative to hydrogen and aluminium ions. This condition is harmful to plants and impairs the absorption of nutrients especially of phosphorous. Some plants may tolerate relatively high concentration of H^{+} ions (low pH) as long as toxic elements such as AL^{3+}, Fe^{2+} are found in lower concentrations. The pH tolerance limits to the growth of different plants, but for most commercial crops a neutral range is most suitable i.e. pH values between 5.5 and 7.5. The average pH value of the surveyed area is 7.7 and the maximum and minimum pH values as measured in soil paste ranges from 7.2 to 8.3 which indicate that the soil reaction ranges from slightly alkaline to alkaline.

5.9.2.2 Organic Carbon (OC)

Organic matter influences physical and chemical properties of soils far out of proportion to the small quantities present. It commonly accounts for at least half the cation – exchange capacity of soils and is responsible perhaps more than any other single factor for the stability of soil aggregates. Furthermore, it supplies energy –and body– building constituents for micro organisms.

Organic carbon is often used as a measure of the quantity of organic matter in the soil, which in turn is taken as a crude measure of fertility status. It has been determined by using Walkly and Black method in the laboratory and expressed in percentage. The minimum and maximum values of organic carbon content of the overage upper 25 cm layer of the soils of the investigation area ranges from 0.62 to 0.88, which is very low. In soil fertility evaluation values less than 2% of organic carbon is deemed to be very low.

5.9.2.3 Total Nitrogen Percentage (TN %)

Of the various plant nutrients, nitrogen probably has been subjected to the greatest amount of study and even yet is receiving much attention, and there are very good reasons. The amount in the soil is small, while the quantity with drawn annually by crops is comparatively large. With all plants, nitrogen is a regulator in that it governs to a considerable degree the utilization of potassium, phosphorus and other constituents. Moreover, it increases the plumpness of the grain and their percentage of protein. The maximum and minimum values of the total nitrogen percentage of the soils of the survey area ranges from 0.036% to 0.072%, which is considered very low and the average content for the upper 25 cm top soil, is 0.050%.

5.9.2.4 Carbon: Nitrogen (C: N) Ratio

The C: N ratios are commonly quoted as indications of organic matter present and in particular the degree of humidification. C: N ratio is an indicator of the process of transformation of organic nitrogen to available nitrogen such as ammonium nitrite and nitrate. A minimum acceptable C: N ratio value is 1: 10. The average carbon nitrogen ratio value of the soils under study is within the range of 1:11. Thus, the organic matter of the soils is found within the range of medium.

5.9.2.5 Cation Exchange capacity (CEC)

Most soil colloids, both organic and inorganic have a net negative charge to which cations are attracted. The strength of cation attraction varies with the colloid and the particular cation. The total negative charge on the surface is the cation exchange capacity, and the exchangeable cations are those that are attracted to the negatively charged surface.

Cation Exchange Capacity measurements and the derived base saturation percentage are usually used as one of the criteria used for the overall assessment of the potentials fertility status of the soil and possible response to fertilizer application. The FAO (1979) quote CEC values of 8 – 10 meq/100gm of soil as indicative minimum values in the top 30 cm of soil for satisfactory production under irrigation, provided that other factors are favourable.

In general, any CEC values of less than 4 meq/100 gm of soil indicate a degree of infertility or unsuitability of the soils for agricultural development.

Accordingly, the average cation exchange capacity of soils of the project area is 70 meg/100 gm soils, which is found in high range. The analytical result indicates soils with fine textural classes have higher value of CEC and base saturation for all profile pits.

5.9.2.6 Exchangeable cations (Ca, Mg, K & Na)

It is generally assumed that adsorbed nutrients are rather readily available both to higher plants and to microorganisms. Several factors operate to expedite or retard the release of nutrients to plants. First, there is the proportion of the cation exchange capacity of the soil occupied by the nutrient cation in question. A second important factor influencing the plant uptake of a given cation is the effects of the ions held in association with it. Third, the several types of colloidal micelles differ in the tenacity with which they exchange. The balances of exchangeable cations are of great importance because many effects, for example on soil structure and on nutrient uptake by crops. Their balances vary in the soil. The ideal cation balance in the soil is calcium occupies 76%, Magnesium 18%, Potassium 6% and sodium 0%.

5.9.2.7 Exchangeable Sodium (N_a^+)

The overall content of exchangeable sodium of the study area arises from 1.35 to 8.20 with an average of 4.0 mg/100 grams of soil. In general the content of N_a^+ is low, thus it will not imply any adverse effect on soil profile such as increasing dispersion.

5.9.2.8 Exchangeable Potassium (K^+)

The overall potassium status of the soils varies from 0.09 to 0.53 with average of 0.31 mg/100 grams of soil, indicating the low content of K. The content of K may be as a result of the nature of the parent material.

5.9.2.9 Exchangeable Calcium (C_a^{2+})

Deficiency of calcium as a plant nutrient occurs only in soils of low CEC at pH values of 5.5 or less. Calcium may also e effectively deficient at high pH levels when there is excessive sodium content. Although it is known that Ca ions have an affinity for phosphate, the effect of the interaction on availability to plants is not well understood. It should be noted, however, that in calcareous soils and soils with high exchangeable Ca phosphate may be less available to plants. The content of exchangeable calcium in the soils in study area is medium to very high, ranging from 36% to 56.5 with an average value of 46.0 mg/100 grams of soil.

5.9.2.10 Exchangeable Magnesium (M_g^{+2})

Magnesium deficiency in a crop may not only be associated with low Mg content in the soil, but also with the presence of large amount of the cations, particularly Ca and K. With increasing Ca: Mg ratios above about 5:1, the Mg may become progressively less available to plants. Although soils can remain fertile over a very wide range of Ca: Mg ratios. When Mg is present in very much larger amount than Ca, the letter may become weaker due to increased deflocculating of the clay. From the laboratory results (appendix B), the average value of exchangeable magnesium is 22.0 meg/100 of soils, which is high to very high, however, it is less than Ca content (see 5.9.2.9)

5.9.2.11 Exchangeable Sodium Percentage (ESP)

Sodium is not an essentially plant nutrient. However, when sodium is present in significant quantities in soil, particularly in proportion to other cations, it can have an adverse effect, not only on many crops but also on the physical conditions of the soil.

A widely used measure of the effects of high sodium level is the exchangeable sodium percentage (ESP). The exchangeable complex of the soils of the study area is largely occupied by calcium and magnesium followed by potassium. The average value of the exchangeable sodium percentage within 100 cm depth is 3.7%, which is low.

5.9.2.12 Base Saturation Percentage (BS %)

The imbalance in the relative proportion of cations can cause severe plant nutrition problems. BS percentage values are mostly used as indicators in the process of soil classification. In line with that, BS percentage > 50% is considered as fertile soil and BS% < 50% is taken as less fertile soil. The calculated value of base saturation of soil mapping units were found between 25% and 98%, with an average 45%, indicating that the inherent fertility status of soils of study area is low.

5.9.2.13 Electrical Conductivity (EC)

When a soil is shaken with water and filtered, the filtrate will contain some dissolved salts but they only occur in significant proportions in the soils of arid and semi-arid areas. The electrical conductivity measurements are used as an indicator of total soluble salts in the soil. The EC of the project are varied from 0.2 to 2.2 with average of 1.4 ds/m. In general, the EC values indicate that the soil in the project area is free from salinity. Hence, salinity should not be a constraint for any crop production.

5.9.2.14 Available phosphorous (AV. P)

With the possible exception of nitrogen, no other element has been as critical in the growth of plants in the field as has phosphorus. A lack of this element is doubly serious, since it may prevent other nutrients from being acquired by plants. The available phosphorus content of the project area ranges from 3.9 to 8.2 mg/kg with an average value of 6.0 mg/kg. In the alkaline soil phosphorus combines with calcium and farms tri-calcium phosphate. Though, it is not readily available to crops. In the case of study area phosphorous deficiencies would be expected, as the soil is slightly alkaline to alkaline, therefore, application of phosphorous fertilizer is required.

5.9.2.15 Calcium Carbonate ($Ca\ C_{O3}$)

Carbonates of calcium and magnesium, particularly the former, are widely distributed in soils, occurring separately or they may be associated with other salts. The most important properties of carbonates are:

1) They are relatively easily soluble in water containing dissolved carbon dioxide, and therefore can be quickly lost or redistributed within the soil;
2) When present in an amount as small as I percent of the soil they can dominate the course of soil development because this amount is sufficient to raise the pH value over neutrality and sustain a high level of biological activity;
3) Both calcium and magnesium are essential plant nutrients. The content of carbonates has been determined at the field level using a 10% Hcl solution, and quantitative analyses have been done in the laboratory.

The soils of the project area are non to slightly calcareous; $Ca\ Co_3$ ranges from 4.0% to 9.0% with an average 5.0%.

5.9.3 Physical Characteristics

5.9.3.1 General

The physical characteristics of soil in the project area are discussed in following sections in brief.

5.9.3.2 Texture

Soil texture refers specifically to the relative proportion of particles of various sizes in a given soil. Many soil properties such as organic matter holding capacity are closely related to soil texture.

The outstanding characteristic of soils of the study area is the very high proportion of clay in all profiles described. The result of laboratory analysis showed that the content of clay varied from 70% to 80%, Laboratory results of soil texture of each land units are presented in Appendix B.

5.9.3.3 Drainage Class

Draining the land promotes many conditions favourable to higher plants and soil organisms. By giving a free rein to the forces of aggregation, granulation is definitely encouraged. The soils of the project are moderately drained. At has been investigated by deep boring that the survey area have deep water table.

Depth of ground water table is not a key constraint, which is greater than 5 meters.

5.9.3.4 Soil Colour

A very high proportion of the names of soils are based upon colour, since this is the most conspicuous property and sometime the only one that is easily remembered. Further, many inferences made about soils are based upon colour. It has relates to specific chemical, physical and biological properties of the soil. It was measured under dry and moist conditions by determining the Hue, value and chroma of the soils using Munsell soil colour chart. Soil colour of the survey area is mainly related humus content drainage and parent material. Soil colour on the surface olive brown (2.5 y $^{4}/_{3}$) to very dark greyish brown (10 YR $^{3}/_{2}$), and dark greyish brown (2.5 y $^{4}/_{2}$) in subsurface.

5.9.3.5 Soil Structure

Soil structure involves the binding together into aggregates of individual soil particles that result from pedogenic processes. The aggregates are separated from each other by pores or voids. To describe soil structure of the project area grade, size and type of structure elements are recognized. The vertisols of the project area is characterized by strong grade, coarse to medium size on the surface and subsurface and massive structure below 1 meter.

5.9.3.6 Effective Soil Depth

As it has been investigated in field the project area soils have very deep soil depth. Thus effective soil depth is not a major limitation for irrigation development in the area.

5.9.3.7 Hydraulic Conductivity Measurements of Study Area

An important soil property involved in the behaviour of soil water flow systems is the conductivity of the soil to water. The hydraulic conductivity of the soil is a volume of water, which passes through a unit cross sectional area of the soil unit in a given time. It is expressed in cm/hr or m/day. Its measurements provide information on permeability and drainage characteristics of different soils. It was determined by the constant method on disturbed soil samples. The hydraulic conductivity measurements of model profile pits are shown below in table (5.5).

Table 5.5

Hydraulic Conductivity (Cm/hr) of model profile pits

Model Profile	Mapping Unit	Depth Cm.	H.C Rate Cm/hr	Soil Taxonomy (USDA, 1999)
WMP01	VT	0 – 15 15 – 55 55 – 90 90 – 135 135 – 180 180 – 200	1.90 1.19 0.53 0.45 0.14 0.32	Typic Haplusterts
WMP02	VTd	0 – 25 25 – 50 50 – 75 75 – 120 120 – 155 155 – 200	2.04 0.89 0.82 067 0.43 0.35	Typic Haplusterts
WMPo5	Vc	0 – 20 20 – 45 45 – 85 85 – 130 130 – 170 170 – 200	3.83 0.97 0.46 0.31 0.24 0.22	Chromic Haplusterts
WMPo6	VTg	0 – 10 10 – 60 60 – 95 95 – 135 135 – 180 180 – 200	1.80 1.10 0.52 0.45 0.21 0.25	Typic Haplusterts

5.9.4 Soil Moisture Characteristics

5.9.4.1 General

An adequate and balanced supply of moisture is essential for plant growth. The moisture in soils can be considered in terms of input, retention and losses.

Fine textured soils have high water holding capacity because of their large surface areas. Water retention capacity of a soil in the rooting zone has direct bearing on the required depth and frequency of irrigation. Bulk density, field capacity, permanent wilting point and available water are presented below in table 5.6.

Table 5.6

Bulk Density (BD), field capacity (FC), wilting point (WP), and available water (AW ^{C})

Profile No.	Depth Cm.	Texture	F. C. %	W P %	AWC %	B D Gm/Cm^3
WMP01	0 – 15	Clay	40.0	19.5	20.5	1.82
	15 – 55	Clay	51.0	26.0	25.0	1.72
	55 – 90	Clay	51.8	25.5	26.3	1.82
	90 – 135	Clay	51.2	24.4	26.8	1.88
	135 – 180	Clay	-	-	-	1.68
	180 – 200	Clay	-	-	-	1.58
WMP 2	0 – 25	Clay	46.6	23.0	23.6	1.93
	25 - 50	Clay	50.2	26.0	23.8	1.90
	50 - 75	Clay	50.5	24.5	26.0	1.89
	75 - 120	Clay	51.0	26.0	25.0	1.87
	120 – 155	Clay	-	-	-	1.82
	155 - 200	Clay	-	-	-	1.81
WMP 5	0 – 20	Clay	50.0	24.0	26.0	1.88
	20 – 45	Clay	55.0	26.5	23.5	1.72
	45 – 85	Clay	50.0	24.5	26.0	1.82
	85 – 130	Clay	44.9	22.0	22.9	1.79
	130 – 170	Clay	-	-	-	1.73
	170 – 200	Clay	-	-	-	1.82
WMP 6	0 – 10	Clay	38.0	20.0	18.0	1.80
	10 – 60	Clay	41.7	21.3	20.4	1.81
	60 – 95	Clay	45.9	25.1	20.8	1.87
	95 – 135	Clay	48.0	23.0	25.0	1.83
	135 – 180	Clay	-	-	-	1.81
	180 – 200	Clay	-	-	-	1.83

5.9.4.2 Bulk Density (BD)

Bulk density is a widely used value. It is needed for converting water percentage by weight to content by volume, for calculating porosity when the particle density is known, and for estimating the weight of a volume of soil too large to weigh conveniently, such as the weight of a furrow slice, or a hectare-foot. The bulk density result is used as indicators of problems of root penetration and soil aeration in different soil horizons. To determined BD of soils of the study area, 36 undisturbed soil samples were collected and examined in laboratory. The result shows that the value ranges from 1.72 to 1.93. Therefore, the overall BD values indicate that the soils in the study area are not compact and thus do not restrict root crops development and water movement.

5.9.4.3 Field Capacity (FC)

Direct or indirect measures of soil water content are needed in practically every type of soil study. In the field, knowledge of the water available for plant growth requires a direct measure of water content or a measure of some index of water content. In the field, if soil is saturated and left to drain, the soil moisture stored in the pore space (after drainage) is known as field capacity. The field capacity of soil mostly depends on the soil texture and structure. Fine textured soils retain more water than coarse textured soils. The field capacity value of soils of study area varies from 38.0 to 55.0%, with the average value equal to 46.0%. The FC, laboratory results of the study project are shown in table (5.6).

5.9.4.4 Permanent Wilting Point (PWP)

The moisture retained in the soil is lost mainly by Evapotranspiration. Therefore, the rate of loss will depend upon temperature and plant cover, so that as temperature and plant cover increase, moisture will also increase. However, only part of the capillary water retained in the soil is available to be taken up by plants which will wilt and die after the available moisture has been exhausted. This is known as the wilting point. The permanent wilting point for study area ranges from 19.5 to 26.6% and have an average value of 23.0%.

5.9.4.5 Available Water Holding Capacity (AWC)

Available water holding capacity (AWC) is the volume of water retained between field capacity and permanent wilting point. Theoretically, all available moisture is not accessible to plants due to imperfect drainage, hydraulic conductivity of the soil and stage of plant growth. Soils with coarse texture classes have low AWC and those with fine texture classes have relatively high AWC. The average available water holding capacity value ranges from 18.0 to 26.8% and have an average value 22.4%. Table (5.4).

5.10 Soil Classification

5.10.1 General

After field survey and all laboratory results have been collected data based, all work from survey area was reviewed. The objectives of this review were to ensure that all data are correct before they are input to the GIS.

MS Excel spreadsheets compatible with Arc GIS version 9.x were used for data management and mapping. All field and laboratory data were recorded initially in MS Excel spreadsheets so that all data can be displayed in GIS.

All soil auger sites and all soil profile pits have been classified into their appropriate "soil units" and 'land suitability class' by interrogating the databases against defined criteria for the soil units and land suitability classes.

For the Soil Map, 'the soil unit' classification of every auger and pit site was plotted onto a 1: 10,000 scale contour maps (for final map compilation). The map datum is WGS 84 and the auger and profile sites have the same datum.

The Land Suitability Map was derived from plotting the "land suitability" classification of every auger and pit site onto the final Soil Map (at 1: 10,000 scales). Final land class boundaries were interpreted manually, placed and then digitized.

Vertisols cover the whole survey area. They are deep (> 2.0 m) cracking clays with a smectitic mineralogy formed under a semi-arid climate. Two soil units has been identified according to the soil Taxonomy (USDA, 1999) and Keys to Soil Taxonomy (USDA, 2006), Chromic Haplusterts and Typic Haplusterts. The recorded slope measurement and topography classification of every auger site is used for mapping the undulating, gently undulating or depression phases of the soil units along with the contour map (Table 5.7). The soil properties considered during the soil survey to classify the soil units and their phases are:

- Soil climate;
- Degree of soil profile development;
- Presence and absence of cracks, cracking pattern and pressure faces;
- Clay percent;
- Levels and distribution of ESP;
- Levels and distribution of EC;
- Presence, nature and distribution of gypsum content;
- Soil depth to hard rock;
- Thickness of sand or loamy sand; and
- Evidence of recent alluvial deposition.

The two vertisols (table 5.7); typic and chromic vertisols have clay contents between 72-80%, and are thus very fine textured. This implies that care should be taken for the management of these soils, especially if heavy machinery is used under moist conditions. The two units are non-saline and non-sodic (their Ece and ESP values being less than 4 ds/m and 15% respectively).

Table 5.7

Identified Soil Types of Study area as classified based on Soil Taxonomy, USDA (1999).

Soil Type	Area ha	%
- Typic Haplusterts	9312	97
- Chromic Haplusterts	288	3

5.10.2 Description of identified Soil Types

5.10.2.1 General

Based on field investigations and laboratory results two major vertisols types have been identified and mapped (Table 5.7). Detailed description of physical, chemical and morphological properties of these soil types are given below.

5.10.2.2 Typic Haplusterts (VT)

They are soils developed on alluvial parent material and cover around 9,312 ha which is 97% of the study area. They are characterized by clay texture throughout the profile pits, very deep soil depth, very dark greyish brown colour. They have wide and medium surface cracks in dry seasons and swelling nature during wet season. They have strong and coarse sub-angular blocky structure on top and moderate medium and fine sub angular blocky structure in subsurface.

Their consistencies are hard to very hard, friable moist and very sticky, very plastic wet, few fine concretions of calcium carbonate, and few-magnesium nodules in the surface. The average content of organic carbons and nitrogen percentage are 0.56% very (low) and 0.040% (very low) respectively. They are none saline and non sodic soils. Vertisols have relatively high CEC which is greater than 60 meg/100g soil, and relatively high available water holding capacity (AWC) and medium base saturation. The soil is slightly alkaline to alkaline. The average available phosphorous content is found to be at low level and average C/N ratio is within the optimal range 12: 1 summarized laboratory results of the model profile pit are presented in Table 5.8.

5.10.2.3 Chromic Haplusterts (VC)

Chromic Haplusterts occupy an area of 288 ha, which is about 3% of the surveyed area. They are developed on colluvial alluvial parent material olive brown to greyish brown. The soils texture class is clay; deep; moderately well drained; very hard dry; firm moist; very sticky and very plastic wet; common fine and medium pores; 60 mm wide cracks. The soils have slightly alkaline to alkaline reaction with an average value 7.5. The CEC and B.S% of the soils are found high throughout the soil depth. The total nitrogen and organic carbon of the soils are 0.06 % and 0.5% respectively. In general fertility status of the soils is also low, Table (5.8).

Table 5.8

Summary of Laboratory results of the Soil Types in the Project Area.

Soil Type	pH	Ec ds/m	CEC	ESP	B.d	Ca Co_3	O.C	TN	C: N	P_2O_5	AWC	H. C Cm/ hr	Dept Cm	Drain Class	Area	
															Ha	%
Typic Haplusterts	7.6	0.41	60	4.3	1.87	5.9	0.56	0.04	11	1.74	25.0	0.86	>200	M D	9,312	97
Chromic Haplusterts	7.8	0.40	72	6	1.75	5.9	0.50	0.06	10	1.10	24.6	0.75	>200	M D	288	3

5.11 Description of Soil Mapping Units of the Area

5.11.1 General

The formations of the soils in the study area are largely influenced by topography, climate and parent material. Topography influences the formation of any site through slope inclination and position. Accordingly, the gently undulating plain of the survey area are characterized by relatively well drained, and dark brown soils. The seasonally flooded (receiving sites; shallow depressions) area is described by poorly to moderately drained, dark grey to very dark, cracking and swelling fine textured Soils.

Full description, chemical analyses and photographs of the soil profile pits representing the major soil types and their phases are given in appendix B. Summary of physical and chemical and properties of the soil types are shown in Table (5.8). Soil auger and profile pit sites, with their phases has been plotted on a contour map, lines drawn include as much as possible the same soil type or phase. The contour base map highly influenced the positioning of soil boundary. The recorded slope measurement and topography classification of each auger site is used for mapping the undulating, gently undulating and depression phases of the soil types, along with the contour map, table 5.9.

Table 5.9

Soil Mapping Units

Mapping unit	Area	
	Ha	%
VT (10)	6,624	69
VTd (30)	2,315	24.1
VTg (40)	288	3
Vc (20)	288	3
D (50)	86.4	0.9

VT = Typic Haplusterts

d = seasonally flood (receiving, shallow depressions)

g = gently undulating (2 – 3%)

VC = Chromic Haplusterts

Detailed descriptions and area occupation in ha of each mapping unit are briefly discussed below.

5.11.2 Mapping Unit VT (10)

This unit refers to the flat plain areas, it occupies 6624 ha and forms 69% of the study area. The slope of the land units ranges from 1 – 2%. The soils are deep (> 200 cm) with moderately well drained and dark brown to dark greyish brown (10 yr $^{3}/_{2}$) colour on surface. They have clay texture class throughout profile pits. Their consistency is very sticky and very plastic wet and has moderate, medium and coarse sub-angular blocky structure.

The soils are non-saline and non-sodic with average ECs of 0.3 ds/m and ESPs of < 4%. The soils have high CEC, more than 64 meg/100g soils and medium base saturation percentage, which is on average greater than 50%. The average available P content ranges from 9.5 to 13.1 ppm, which is medium. The organic carbon and total nitrogen percentage of the surface soils are very low on average 0.575 and 0.051 respectively. The C/N ratio value ranges from 8-14 (table 5.7). The relative proportion of Ca to Mg in the exchange complex of the surface soil is moderately high, which is very favourable soil for agriculture developments. For representative profile and analytical data see Appendix B, Profile pit WMP01.

5.11.3 Mapping Unit VTd (30)

This unit occupies the seasonally flooded receiving sites of the plain with an area extent of 2,315 ha about 24.1% of the study area. The soils are very deep (> 200 cm), with moderately well drained and dark greyish brown (10yR $^{3}/_{2}$) colour throughout the profile. They have clay texture. Their consistency is very hard dry, firm moist, very sticky and very plastic wet. The pH of the soils is slightly alkaline with an average value of 7.5. The average organic carbon and total nitrogen values at top 30 cm depth are 0.681 and 0.058 respectively. The determined values of both elements are very low and decrease gradually with depth.

The soils have high CEC, more than 75 meq/100g soils. They are non-saline and non-sodic soils with ECs of < 0.5 ds/m and ESPs of < 5%. The average available P content on the top 30 cm depth is 2.29 ppm which is low high but it decreases to 0.5 ppm. For representative profile and analytical data see Appendix B, profile MWPo3.

5.11.4 Mapping Unit Vc (20)

This unit occupies significant portion of the study with an area extent of 288 ha which is about 3% of the study area. It is located in the plain with a slope range of 0 – 2%. The soils are developed on alluvial parent material. The unit is currently used for forest.

The soils are very deep and moderately will drained. The texture of the soils class clay throughout. The surface soils are characterized by medium and coarse sub angular blocky structure. When the soils are wet they have sticky and very plastic consistency and when they are moist their moist their consistency is became very firm.

The pH of the soils is slightly to moderately to alkaline with an average value of 7.8. The average organic carbon and total nitrogen values at 30 cm depth are 0.6 and 0.05% respectively. The determined values of both elements are very low and decrease gradually with depth. The soils are non-saline and non-sodic. The top soil has an average value of ESP <4% and EC of < 0.3 ds/m, and have 5.7% $Ca\ Co_3$. The average values of exchangeable calcium and magnesium of the top soil are 54.4 and 24.3 meg/100g soils respectively and they are at a high level.

For representative profile and analytical data see Appendix B, profile pit WMPo5.

Table 5.10

Summary of Physical and Chemical properties of Mapping Units

Mapping Unit Symbol	pH Av. Top Paste 30 cm	EC ds.m Av. top 90 cm	CEC meg / 100g Av. top 30 cm	O.C % Av. top 30 cm	TN % Av. top 30 cm	C : N Av. top 90 cm	ESP % Av. top 90 cm	P_2O_5 ppm Av. top 30 cm	$CaCo_3$ % Av. top 90 cm	Bd g/Cm^3	AWC Cm/m	Infiltration Rates Cm/hr Measured	Infiltration Rates Cm/hr FAO stand.	Hydraulic Conductivity Cm/hr Measured	Hydraulic Conductivity Cm/hr FAO stand.	Area ha	Area %
VT	7.7 7.6– 7.7	0.2 0.2- 0.3	73 64- 86	0.575 0.560- 0.58	0.051 0.042- 0.065	10 8-14	3 2 – 4	1.09 0.9– 1.31	5.8 4.8- 7.3	1.87 1.58- 1.88	23.6 20.5-26.8	1.8	0.8	0.86 0.32-191	0.1	6,624	69
VTd	7.5 7.3- 7.8	0.5 0.3– 0.7	81 75- 87	0.681 0.552- 0.810	0.058 0.047- 0.070	12 12–13	5 3 – 6	2.29 0.95- 3.68	5 5 – 6	1.87 1.81- 1.93	24.8 23.6-26.0	2.0	0.8	0.98 0.35-2.04	0.1	2,400	25
VTg	7.6 7.3- 7.9	0.4 0.2- 0.7	85 82- 88	0.590 0.580- 0.606	0.048 0.041- 0.055	12 11–13	4 2 - 7	1.13 0.92– 1.34	7.3 5.6- 9.0	1.83 1.87- 1.80	21.5 18.0-25.0	1.8	0.8	0.43-1.73	0.1	288	3
VCd	7.8 7.7- 7.9	0.3 0.2- 0.4	88 75- 88.1	0.6 0.421- 0.718	0.05 0.04- 0.06	13 11-14	4 2 - 9	2.3 1.48- 2.52	5.7 5-8.8	1.89 1.72- 1.88	24.4 22.9-26.0	0.9	1 - 2	0.75 0.22-3.83	0.5	288	3
D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	86.4	0.9

5.11.5 Mapping Unit VTg (40):

The soils of this mapping unit occupy convex to gently sloping sites. They are deep, clay texture, hard dry, friable moist, very sticky and very plastic wet, moderate very coarse prismatic breaking into angular blocky and sub-angular blocky structure.

The soils are non-saline and non-sodic with average ECs of 0.4 ds/m and ESPs of 4%. The soils have high CEC, more than 82 meg/100g soils and medium base saturation, which is on average greater than 50%.

The average available P content ranges from 0.92 – 1.34 ppm, which is low. The organic carbon and total nitrogen percentage of the surface soils are very low on average 0.590 and 0.048% respectively. The C/N ratio value ranges from 11 – 13, table 5.7. The relative proportion of Ca to Mg in the exchange complex of the surface soil is moderately high, which is favourable soil for agriculture developments. For representative profile and analytical data see Appendix B, profile pit WMPo6.

5.11.6 Mapping Unit D (50)

It is approximately 86.4 ha (0.9 %), mostly VT occupying very low receiving sites (Mayas).

5.12 Soil Survey: Conclusions and Recommendations

5.12.1 Conclusions

The soils study of Wad Miskien irrigation development area was carried out at a feasibility level for about 10,000 ha (net 7,500 ha) of land using the methods of topographic maps and imagery interpretation reviewing previous studies and conducting field survey, a soil map 1: 10,000 scale and a narrative soil report were produced.

In the course of the study soil/ Land mapping units were verified and representative soil samples have been collected to determine the chemical and physical properties. As a result, a total of 96 auger holes were described, and 6 profile pits have also been studied and sampled. In addition of using the available data from previous studies (96 auger sites from HTS, and 4 profile pits from SSA).

The data cites of the study area pertaining to the profiles and auger holes including their location, coordinates have been recorded with help of GPS. Land form, land use/cover, soil drainage, erosion hazards have also been evaluated in the field. Furthermore, internal soil characteristics such as soil depth, texture, structure, colour and mineral nodules were noted on each auger hole description formats.

Soils of the project area are classified based on soil Taxonomy (USDA, 1999) and Keys to Soil Taxonomy (USDA, 2006), Vertisols cover the whole survey area.

They are very deep (> 2.0 m) cracking clays with a smectitic mineralogy formed under a semi-arid climate. Two soil units has been identified "chromic' if they are brownish or greyish coloured and "Typic" if they are very dark coloured. The soils of the area are mainly "Typic" with very few sites identified as "Chromic".

With regard to fertility status based on laboratory test results detailed assessment has been carried out. Accordingly, fertility status of soils of study area is found to be poor in major nutrients like nitrogen, phosphorous and organic carbon. However, the soils have high cation exchange capacity (CEC) varying from 70 to 88 meg/100g soil, indicating that they have high potential to supply plants with nutrients when add as a fertilizer, particularly nitrogen. The soils also have high available water holding capacity (Table 5.6), thus they can be irrigated at longer intervals like other parts of the irrigated clay plain.

Because the soils are fine textured and have high clay content water movement through and down is quite slow, as can be seen by the infiltration values shown in Table 5.9 which vary from 0.9 to 2.0 cm/hr.

However the cracks in these soils (resulting from the shrink – swell phenomena due to the high content of smectitic clay minerals(allow large amounts of irrigation water to enter and move down the soil before the soils swell and close. The bulk densities in the top layer of the soils vary from 1.72 to 1.89 gram/ cm^3/ indicating that the soils become hard and compact particularly during the dry season.

5.12.2 Recommendations

1. The study area is covered with Vertisols. During the wet season the clays of these soils swell and cause pressure in the sub-soil. Therefore, to use these soils properly for future agricultural development, vertisols management technologies like, broad – maker should be considered.
2. The management of Vertisols may pose serious problems, the soils become very hard when dry, and very sticky when wet. This means high power consumption when dry and compaction of soils when wet. This should be consider in the cultivation practices.
3. From laboratory result electrical conductivity values of all soils of the study area have an average value of 0.5 ds/m which is very low. These are for below the threshold critical values and therefore, salinity will not cause any restriction on plant growth in the project area.
4. The total nitrogen content and phosphorus of the project area are very low with an average value of 0.05 % and 2.2 respectively, therefore, the application of nitrogen fertilizer are recommended.
5. Crop residues should be incorporated in the soil to increase organic matter content and improve the physical properties by increasing the biological activity.

The investigation results of the current study shows that the project area can be used for irrigation purposes, bearing in mind that application of some of the corrective measures recommended are implemented in order to improve the production of crops sustainably.

5.13 Land Evaluation: Introduction

5.13.1 Background

Land is a broader concept than soils. The land characteristics include all reasonably stable of the environment: soil, underlying geology, relief, hydrology, vegetation and impact of human activities. The land evaluation assessment, which is part of land resources study, aims to translate land resources data into an expression of suitability of land units (land units map) for a defined use. The soil report and map are the valuable tools and a major land resource database for the anticipated land evaluation assessment. Therefore, in order to carry out land evaluation assessment, it is indispensable to determine potential users and other beneficiaries, for considering whether the benefits will be sustained without irreparable damage to the environment.

5.13.2 Objectives

The main objectives of the land evaluation study are:

- To identify area of land suitable for irrigated agriculture that is simultaneously to be technically feasible, economically viable and socially acceptable.
- To evolve most appropriate and suitable techniques for irrigated agricultural farming with appropriate remedial measurement to improve the deficiencies, if any.
- Optimize agricultural production from the available land and water resources in a sustainable manner without causing any adverse impact on soil and the overall environment.
- Prepare land suitability map at a scale 1:10,000.

5.13.3 Scope of Work

The scope of work for the land suitability evaluation is summarized as follows:-

- Utilize all existing older datasets on soil surveys.
- Using the results of the soil survey to prepare a land evaluation report at feasibility level.
- Compare major land quality of the project area with land use environmental requirement of LUTs considered.
- Produce land suitability maps.

With these objectives in mind, a gross area of approximately 10,000 ha (7,500 ha net) in the Wad Misken to Hawata was investigated and using the soil and land resource data for land evaluation assessment.

5.14 Methodology and Approach

5.14.1 General

The land evaluation assessment was made based on the methodology outlined in the FAO framework of Land Suitability for Land Evaluation (1976) and has been adapted for Sudan by Van der Kevie & El Tom (2004) "Manual for Land Suitability Classification for Agriculture with Particular Reference to Sudan.

The FAO framework indicates that it is necessary to evaluate land not just soils. Thus, the suitability of soils for irrigated crops is useful information but it is inadequate for making decisions about land use development. Therefore, all relevant land characteristics including soils and landforms, climate, topography, water resources, and also socio-economic conditions and infrastructure have been considered in the suitability assessment of the project area.

Land suitability must therefore be assessed and classified with respect to specified kinds of land use i.e. irrigation and management system. It is obvious that the requirements of crops and irrigation and management methods differ, so the suitability of any land unit may be classed differently for various uses. In the evaluation process, the values of each land quality/

characteristic are checked against the class limits of land use requirements for irrigated agricultural development.

5.14.2 Land Suitability Classes and Sub-Classes

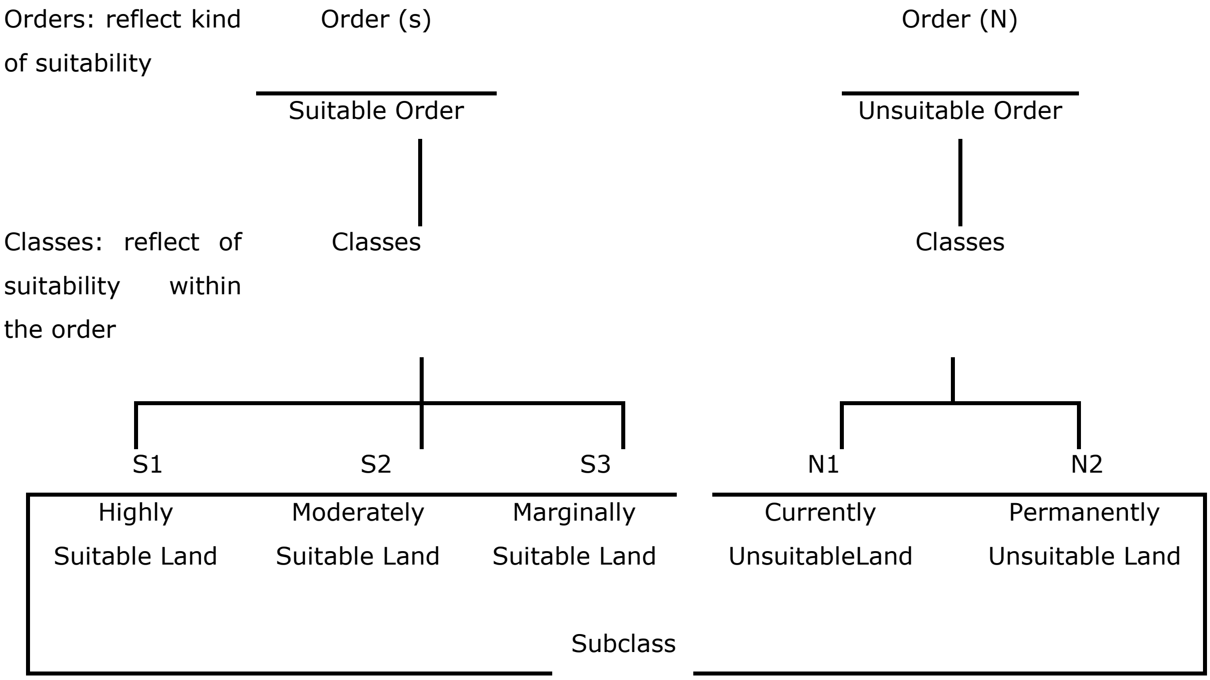
The basis of the FAO (1976) evaluation system is land orders and land classes defined by calculated or inferred potential productivity levels. There are two orders of land: suitable land has favourable soil and site characteristics such that for the proposed LUT at least the recurrent investments will eventually be recouped through productivity. Not Suitable land has characteristics that preclude sustained use because of an unacceptable level of recurrent or development inputs. The Not Suitable order of land is divided into two classes to differentiate land that is potentially suitable pending some major improvement (class N1) from land that is permanently unsuitable (class N2, see table 5.11).

Table (5.11)

FAO land suitability classification levels (FAO, 1983)

Order	Class	Designation	Definition
S		Suitable	The land can support the land use. Benefits justify inputs without unacceptable risk of damage to land resources.
	S1	Highly Suitable	Land without significant limitations. The potential yield level expected is 85% or more of optimum yield.
	S2	Moderately suitable	Land having limitations that either reduce productivity or increase the inputs needed to sustain productivity levels compared with those needed on S1 land. The potential yield level expected is 60 – 85 % of the optimum yield.
	S3	Marginally suitable	Land with limitations so severe that benefits are seriously reduced and/or the inputs required to sustain productivity are such that this cost is only marginally justified. The potential yield level expected is 40 – 60 % of the optimum yield.
N		Unsuitable	Land that cannot support the land use sustainable or land on which benefits don not justify inputs.
	N1	Currently not suitable	Land with limitations to sustained use that cannot be overcome at currently acceptable cost.
	N2	Permanently not suitable	Land with limitations to sustained use that cannot be overcome.

Figure. 5.3 – Land suitability classification system adopted



Subclasses: reflect kinds of major limitations within a class (Moderately suitable land with physical and topography limitations)

Units: reflect differences in production capacity and/or management requirements within a subclass

To determine the suitability levels, the physical factors are rated by the evaluation of the land qualities. The latter are combinations of individual land characteristics which together act in a way clearly distinct from other land qualities in their influence on the suitability of the land for a specific kind of land use. This rating determines the subclass, class and order levels according to the severity of limitations evaluated using numerical tables. The limitations are shown by lower case letters following the case symbol e.g. subclass "S3 mdf" showing a marginally suitable land due to moisture limitation (m), soil shallow depth (d) and low fertility (f) in order of severity i.e. (m) is the most severe one. The system shows a clear distinction between the suitable order "S" and the unsuitable order "N" at the highest level of classification.

5.14.3 Current Land Suitability of the Project Area

The land suitability Classification system described above is applied to the Wad Miskien proposed irrigated project area. The land qualities rated according to the severity of their limitations for each of the mapping units of the project area are:-

- Chemical soil fertility; when low shown by limitation, "f".
- Vertisolic characteristics limitation, "V".
- Topography; limitation due to unfavourable relief limiting the use of the land, "t".
- Wetness, limitation due to water logging caused by slow permeability or shallow surface drainage or combination of these, "W".
- Inundation, limitation due to inundation (flooding) of the land from rivers (i).

Accordingly, land suitability for irrigated agriculture, high capital intensity, demanding high value crops was evaluated as shown in Table (5.12).

Table 5.12

Current land suitability for irrigated agriculture high capital intensity, Demanding high value crops in Wad Misken Project

Land Quality	Mapping Units				
	VT (10)	VC (20)	VTd (30)	VTg (40)	D (50)
Moisture availability to plants	1	1	1	1	4
Chemical soil fertility	2	2	2	2	4
Condition for seed establishment	2	2	3	2	4
Drainage conditions in the growing season	2	2	3	2	4
Flooding hazard	1	1	3	1	4
Workability	2	2	3	3	4
Erosion hazard (water)	1	1	1	1	4
Salinity	1	1	1	1	4
Sodicity	1	1	1	1	4
Adequacy of topography for gravity irrigation	2	2	3	3	4
Soil drainability	2	2	3	3	4
Current land suitability classes	S2	S2	S3	S3	N2
Current subclasses	S2vf	S2vf	S3wvf	S3 tvf	-
Limitations	V, f	V, f	W, V, f	T, V, f	i

Rating: 1 = No or slight hazard 2 = Moderate hazard 3 = Severe hazard 4 = Very severe hazard

The results of the land evaluation are plotted in the land suitability classification map attached to this report. The results are summarized below:

5.14.3.1 Land Class S2 Moderately Suitable Land for Irrigated Agriculture

- Subclass S2 VF (6,912 ha)

This soil has moderate limitations of Vertisolic characteristics due to high swelling clay content in addition to some fertility limitations that can be corrected by addition of nitrogen and phosphorous fertilizers.

Also need for potassium fertilizers may arise. This subclass comprises mapping units 10 and 20 (72% of the area).

5.14.3.2 Land Class S3 Marginally Suitable Land for Irrigated Agriculture

- Subclass S3 Wvf (2,315 ha)

These are marginally suitable lands because of the limitations of the workability (W), Vertisolic characteristics (V), and fertility limitations (f). This subclass comprises mapping unit (30) (24.1 % of the area).

- Subclass S3 tvf (288 ha)

Marginally suitable land due to the limitations of topography (t), Vertisolic characteristics (V), and fertility (f). This subclass comprises mapping unit (40), 288 ha, (3.0% of the area).

- Permanently not suitable (N2) lands

5.14.4 Potential Land Suitability Classification

The land classification made above (Table 5.12) is an evaluation of the current status of the land of the project area. However, development of land for irrigated agriculture takes into consideration, preparation of the land in the manner which is required for efficient irrigation and farming practices. Land amelioration is a usual practice for removal of current limitations identified on new land intended for development. The removal or reduction of the severity of any limitation would obviously improve the land suitability for farming and consequently up-grade its class and subclass. In essence, land has a certain class/ subclass before development indicating its current suitability, and a different class/ subclass which indicate its potential suitability after limitations are removed or reduced. This study, recommends amelioration of the land for development as well as recurrent amelioration practices as an integral part of the farming system. The proposed amelioration treatments are:

A. Levelling the area to fill in the concave and depression sites so that irrigation water could be evenly distributed.
B. Use of form machinery at optimum soil moisture level to avoid deformation of soil structure and/or soil compaction.
C. Installation of good drainage system (particularly in mapping unit 30) to avoid over pounding with water and/or water logging conditions.
D. Additions of N, P, and K (if necessary) fertilizers at the required doses for the specified crops in the rotation.

If the above proposed treatments are applied, the soil potential will be improved and the current suitability classes would be improved or even upgraded as can be seen in Table (5.13).

Table 5.13

The potential land suitability classification for high capital intensity irrigated agriculture in the area.

Mapping unit	Current land suitability classification	Proposed treatment	Potential Land Suitability classification
10	S2 vf	B + D + C	S2 V
20	S2 vf	B + D + C	S2 V
30	S3 wvf	B + D + C + A	S2 V
40	S3 tvf	B + D + C + A	S2 V

5.14.5 Land Suitability for Irrigation

Under semi arid climate, such as the study area, irrigation is an important input likely to improve agricultural production.

Sustainable gravity irrigation demands the minimization of water, uniform in-field water distribution and adequate drainage. All of short channel / furrow lengths, drop structures, seepage, irregular water distribution and build-up of salts should be avoided. For this, the critical land requirements are gentle and smooth slopes (< 3%), water-retentive top soils and deep, water-retentive but permeable sub soils. Soils that is coarse-textured and/or stony in the upper 0.5m, generally equating with high infiltration rates (above about 60 mm/hr are not suitable for gravity irrigation because an even distribution water is difficult to maintain without very short furrows or very small basins.

Sprinkler irrigation is more suitable for sandy soils and slopes up to about 20% . Water can be applied more evenly and more frequently and there is far less or no need for land levelling or for furrows. Deep, permeable sub soils are still required.

Both gravity and sprinkler irrigation are suited to saline or alkaline soils that require reclamation by leaching and drainage, so long as there is sufficient drainable soil depth. For drainage, hydraulic conductivity values of 8 m/hr are normally considered the lowest acceptable (note; Van der Kevie & El Tom's (2004) minimum value of 0.5 mm/hr is, we believe, an error).

Normally, drip irrigation is preferred for small areas of high-value crops especially trees and vines, rather than for widespread general agricultural developments, although it is successfully used for sugarcane in Swaziland, for example. The advantage of drip over other forms of irrigation is its greater efficiency. More exact water control can minimize deep percolation and the attached risks of a rising water table and mobilization of salts and precise amounts of water and fertilizer can be applied as and when needed. Thus, so long as land is free from salinity and sodicity at the outset drip irrigation can in theory be used on shallow soils.

Drip irrigation cannot be used on sandy or very gravelly soils because there are insufficient tensions to allow lateral distribution of water between emitters. Neither are drip systems particular suited to slopes above 8%" because of potential pressure differences in the distribution pipes.

For agriculture, the requirements may be summarized as land sufficiently flat and fertile to permit sustained, mechanized and profitable cropping of a range of climatically adapted crops. The ability of the soil to retain and make available to crop nutrients/ fertilizer is indicated by its pH and its "CEC". A very alkaline soil is likely to be highly sodic and/or will limit the availability of many nutrients and micronutrients. The soils having a "CEC" below '8.0" me/1OOg will retain few nutrients and will demand frequent fertilization; usually such low CECs are associated with very sandy soils.

Seedbed preparation, germination, workability and mechanized tillage are all seriously hampered by soils having very stony (> 40% volume) upper horizons. Critical salinity (EC) and sodicity (ES!', SAR) values for the top "060" m of soil have been set specifically for the range of crops being considered for this study, at '12.0' ds/m and 24 respectively higher EC and ESP *I* SAR values are permitted but on the proviso that reclamation is effected prior to agriculture. The soils of project area are non-saline and non-sodic (EC less than 1 ds/m and ESP less than 3%)

Otherwise, for farming, the land should be sufficiently drained and free from serious risks of flooding and erosion. Limitations to use should be surmountable through normal husbandry and conservation practices at acceptable cost.

Summarizing the above, table 5.14 presents a layman's guide to irrigation options. It shows that gravity irrigation is restricted to flat land with deep, loam or clayey soils having moderately low infiltration rates. Drip irrigation is fairly restricted, too, to non-saline loamy or clayey soils on slopes to 8%. It is, however, a suitable option for non-saline shallow soils (Lahmeyer, 2005).

Table 5.14

Suitability of irrigation systems for key land/soil characteristics

Particulars	Gravity	Sprinkler	Drip
Flat slopes (< 3%)	Yes	Yes	Yes
Undulating slopes, (<8 %)	No	Yes	Yes
Rolling slopes (8-15%)	No	Yes	No
Rolling slopes (16-20%)	No	Centre-pivot	No
Non-saline soil, depth (<2.0m)	No	Centre-pivot, conditionally	Yes
Saline or sodic soils	Yes	Yes	No
Sandy top soils	No	Yes	No
Sandy soils	No	Yes	No
Very gravelly (>40%) top soil	No	No	No
AWC (>90 mm/m)	Yes	Yes	Yes
Minimum AWC (50-75) mm/m	No	Yes	No
CEC (<8 me/100g)	No	No	No
Permeability (< 8 mm/hr)	No	No	No
Infiltration (> 60 mm/hr)	No	Yes	Yes

The most versatile option is sprinkler irrigation, especially by centre- pivots. These can be used on any soils on slopes to 20%' and under proven good management, on soils "1.5 m deep.

It is apparent from table 5.11 that there are very few instances where drip irrigation will be the only option. For most soils and landforms either gravity or sprinkler systems, especially centre-pivots, are suitable. For trees and for some shallow soils, though, drip irrigation may be preferred.

In order to evaluate land suitability for irrigation in the study area a parametric system (Sys, et, al, 1991) was applied: this method is based on the standard granulometrical and chemical-physical characteristics. The factors influencing the soil suitability for irrigation can therefore be subdivided in the following four groups:

i. Chemical properties: that interferes in the salinity sodicity status such as soluble salts and exchangeable Na.
ii. Physical properties: that determine the soil-water relationship such as permeability and available water content (both related to texture, structure, soil depth and calcium carbonates status).
iii. Drainage properties
iv. Environmental factors such as slope

The different land characteristics that influence the soil suitability for irrigation are rated and capability index for irrigation (Ci) is calculated according to the formula:

Ci= A/100*B/100*C/100*D/100*E/100*F/100

Where:

Ci capability index for irrigation

A rating of soil texture

B rating of soil depth

C rating of $CaCo^3$

D salinity sodicity

E draining rating

F slope rating

The capacity classes are defined according to the value of the capability (or suitability) index Ci as in table 5.15

Table 5.15

Capability indexes for the Different capability classes

Capability	Class	Definition
>80	I	Excellent
60 -80	II	Suitable
45 -60	III	Slightly suitable
30 -45	IV	Almost unsuitable
<30	V	Unsuitable

For slope class, texture, soil depth, calcium carbonate status, salinity and alkalinity, drainage a weighted average was calculated for the upper 100 cm of the soil profile. In applying the above equation after rating each parameter separately, the following suitability classes for irrigation identified in the study area are shown in table 5.16

Table 5.16

Suitability classes of the mapping units for irrigation in the study area

Unit number	Suitability for irrigation class	
	Class	Definition
VT 10	I	Excellent
VC 20	I	Excellent
VTd 30	II	Suitable
VTg 40	II	suitable

5.14.6 Crop Suitability

The suitability of the soils to agricultural crops comes as a subsequent step to a group of mapping procedures. Which start with the study of the different soil and land characteristics and end up with determining the suitability of the land to agriculture. These characteristics include the study of the soil, the available water resources, climate and vegetation cover. Then after this stage, soils suitable for agriculture are delineated and non-suitable lands are excluded.

Then the recurring question crops out: what are the crops, which should be selected? *Or* what is the suitability of the different soils to grow a certain group of crops under the availability of the required water and the local climate?. However, many parametric systems e.g. productivity index, suitability index, productivity rating or suitability rating have made some attempts to answer such question.

To help the users of the soil survey report and attached maps, the different kinds of the soil have been rated relatively to their suitability for production of crops common to the area. These rating are called crop suitability classes and range from class CSI for the most suitable soils to class S4 for the least suitable.

The difference between the crop suitability classes and the land suitability classes is that a rating for crop suitability is as evaluation for individual crop. Where the land suitability is rating based upon the limitations of the soils and overall crop production and risks of damage for defined use alternatives.

Each kind of soil has some chemical and physical characteristics which affect its response to management and influence crop yields e.g. soils which are best suited for wheat might not be suitable for foolmasri due to their different requirements. Therefore, a certain kind of soil with land suitability S1 may be well suited for specific crops (crop suitability CS1) but moderately suitable for another crop (crop suitability CS2) tables 5.17 shows crop suitability in current land suitability classification.

5.14.6.1 Assumptions:

Before using crop suitability ratings given below, the following assumption should be taken into consideration.

1. It is assumed that crop will be grown with an above average level of management and the cost of management necessary to grow the indicated crop. A very high level of management subclass that practiced on agricultural research stations is not assumed.
2. It is assumed that the cost of the management necessary to grow the indicated crop on the management necessary to grow the indicated crop on the specific soil would be within economic limits of crop production based upon long term price trends. That is, over the long run the value of crop yield must be expected to exceed the cost of its production.
3. The crop suitability ratings are based on present level of agricultural technology. As this technology changes so well the crop soil rating change.
4. The list of crops given only examples of several representative crops. Absence from the list should not be taken as indicating a lack of adaptation to local conditions.
5. The ratings are very tentative and are based mainly on general experience. Therefore, a research trial on identified soils is necessary to make more reliable rating management.

5.14.6.2 Levels of crop suitability:

They are defined as follows:

CS I— well suited:

With average management the crop will produce relatively high yield. For the crop under consideration, the soil has favourable physical characteristics, has good to moderate fertility level and it responds to good management.

CS2 — moderately suited:

With the same management but not necessary the same management techniques as in class Si, the crop will produce moderate yield. The soil may have less favourable physical or chemical characteristics for the crop under consideration, a medium to low fertility level or be only moderately responsive to good management.

C S3 — poorly suited:

With the same amount but not necessary the same management techniques as in class Si, the crop would only produce poor yields. Such as water relations, fertility, salinity, sodicity, toxic conditions or other conditions are unfavourable for the crop under consideration. Response to management is low.

C S4 — Unsuited:

With the same amount, but not necessary, the same management as in class SI, little if any production would be expected from the crop under consideration. As rating of S3, for example, for a given crop does not mean that crop cannot be produce. It does indicate, that some favourable characteristics such as low fertility or other special treatments. The economics of such corrective measure would need to be evaluated carefully. Current Crop suitability of the project area. In the light of the above discussion crop suitability as indicated in table 5.17.

Table 5.17

The Current suitability ratings for some selected crops adapted to the project area

Mapping Unit	Current land Suitability Class	Area Ha	Crops				
			Cotton	Sorghum	Groundnuts	Vegetables	Citrus
VT 10	S2 vf	6,624	CS 2	CS 2	CS 2	CS 2	CS 2
VC 20	S2 vf	288	CS 2	CS 2	CS 2	CS 2	CS 2
VTd 30	S3 wvf	2,315	CS 3	CS 2	CS 3	CS 3	CS 3
VTg 40	S3 tvf	288	CS 3	CS 2	CS 2	CS 2	CS 2

5.15 Soils and Land Management

5.15.1 General

The properties of vertisols affect their management, the high clay content of these soils affect the trafficability and cultivation especially at high moisture content. Vertisols are known to be of high potential for rainfed agriculture because of their high water holding capacity which allows crop to survive mid-season draught periods or to grow long after the rains have ended. Most of the Vertisols of the study area are occurring in relatively flat landscapes and require a minimum effort to be commanded by water supply systems and to be irrigated by flood or furrow.

5.15.2 Soil Fertility

Based on the laboratory test results of the soil of the project area, the soils are poor in nitrogen (N), phosphorus and organic carbon in any standards. However, the soil samples major cations like calcium, magnesium and potassium values are found to be moderate to high. One of the important challenges in vertisols management is how to maintain their organic matte (OM) level upon cropping.

Decline of OM is the reason of lowering N status of the soils. Part of the cause of decline in OM with cropping is that crop residues may be burned or removed for animal feed, fuel or other purposes. Crops stubble retention and minimum tillage night be suitable to increase the OM equilibrium level. Planting tree species that are capable of fixing atmospheric nitrogen can improve soil fertility and reduce dependency on chemical fertilizer. In addition, improved agricultural practices such as crop rotation, alley cropping and the use of green manure provide additional nutrient for plant growth.

5.15.3 Soil Cultivation

Cultivation is often more likely to impair than is ploughing. It is employed more frequently during the rotation, is performed by many types of implements, and drastically influences the upper furrow-slice that is so susceptible to deregulation. Hence, in the preparation of a seedbed only the minimum of cultivation should be applied after ploughing, leaving the soil with a granular structure suitable for seeding yet coarse enough at the surface to resist erosion and puddling effects of beating rains.

Comparing to other soils Vertisols are hard and difficult to cultivate when dry and impossible to break to fine tilt and when wet become very sticky and very plastic. Therefore, these soils should be cultivated when the soil moisture content is not too high or too low. Furthermore, to use these soils properly for future agricultural development, Vertisols management technologies like, broad bed – maker should be considered.

5.15.4 Soil Erosion

Soils erosion is the removal of surface material by wind or water. Structural degradation is known to be of important impact on yield reduction in Vertisols, moreover, sever erosion of cultivated vertisols is undesired phenomenon in lands with slope $\geq$ 3%. In such cases conservation measures should be implemented to minimize erosion. During the time the survey team has observed high deforestation action in the project area. This kind of misuse of natural vegetation will have brought high ecological disparity. Therefore, to develop these areas properly and sustainably the prevailing deforestation action has to be stopped and proper management will have to be undertaken especially along the incised stream channels and gully cuts.

5.15.5 Drainage

Draining the land promotes many conditions favourable to higher plants and soli organisms. The removal of excess water also lowers the specific heat of soil, thus reducing the energy necessary to raise the temperature of the layers thus drained. It is perhaps in respect of to aeration that the greatest benefits, both directly and indirectly are derived from drainage. The heavy black clay vertisols of the project area raised a problem of poor drainage and workability when wet. Comparing to other soil types they have relatively low infiltration and hydraulic conductivity rates, and thus due to water logging during most rainy season or heavy irrigation. In such cases surface drainage has to be carefully maintained. Irregular micro topography leads to irregularity in moisture distribution and in this case the use of suitable techniques to obtain a regular slope is important.

5.16 Conclusions and Recommendations

5.16.1 Conclusions

The Wad Misken project area has been identified and proposed for irrigated agricultural development at feasibility level. The soil survey conducted enabled to identify two land units. The soil physical and chemical characteristics of the project area were intensively investigated and classified. As a result of this, the land evaluation assessment has been undertaken for each land unit, and separate land suitability map were prepared at 1:10,000 scale.

According to the land evaluation assessment, a total area of 6,912 ha and 2.688 ha are moderately and marginally suitable for surface and overhead irrigation development. The suitable lands includes area of land that will be reduced eventually for infrastructure (for irrigation canals and other infrastructures).

5.16.2 Recommendations

Most soils has been identified in the Wad Misken project area found to be moderately suitable for surface and overhead irrigated agriculture. The limitations are fertility, workability and adequacy of topography for gravity irrigation. It should be emphasized that the present land suitability evaluation results are guidelines for future agricultural development activities. Therefore, it is important noting the following remarks:

- Maintain organic matter level upon cropping. Crops suitable retention a minimum tillage might be suitable to increase organic matter. Fertilizers are efficient when applied to a soil with abundant organic matter and logically sound and well structured.
- Surface drainage has to be carefully maintained.
- The soils should be cultivated when the soil of moisture content is not too high or too low.

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6. GEOTECHNICAL INVESTIGATIONS

6.1 Introduction

The Eastern Nile Technical Office has awarded the preparation of Wad Misken Irrigation System Complementary Surveys to BRLi and Shoraconsult Co. LTD.

Conducting the Geotechnical Investigations was among the principal components of the assignments that have to be carried as part of the complementary survey activities of the study, to provide the basic data and working document for all the feasibility design tasks of the project that are planned to be carried out subsequently.

Engineering Service and Design (ESD), geotechnical office was contracted to undertake the geotechnical soil investigations for the proposed project.

The geotechnical field exploration was carried out in two stages. The first stage during the period 30th of May 2009 to 28th of June 2009 and the second stage during the period 2nd to the 8th of March 2010.

A qualified geologist had supervised the drilling of the boreholes and the excavation of the pits and performed the logging of the borings and pits on site during the field work.

The laboratory testing was performed in the certified testing laboratory of ESD under the supervision of qualified engineers.

All the soil investigations performed are in conformation with the requirements of TOR at a feasibility level.

This report presents the findings of geotechnical investigations for the proposed project.

Analysis of test results and recommendations for the design and construction of the project components are also presented.

6.1.1 Scope of Works:

The scope of works consists of the following:

1. Collection of available information and maps particular to the project site.
2. Making inspection visit to the project site to collect first hand information about the surface topography, geological features etc
3. Carrying out field work by:
   - Drilling of 5 boreholes each 20 m depth at the proposed location of Rahad barrage
   - Drilling of 5 boreholes each 20 m depth at the proposed location of Dinder barrage
   - Drilling of 3 boreholes each 10 m depth at the proposed location of Khor Atshan (Siphon crossing with the link canal
   - Excavation of inspection pits along the route of the canal linking Dinder to Rahad. Depths of the pits are limited to 3 m and 5 m.

- Excavation of inspection pits along the route of the proposed main canal. Depths of the pits are limited to 3 m and 5 m.
- Carrying out in-situ testing and sampling of disturbed and undisturbed samples
- Checking on the quantity, quality, availability & proximity of local construction materials & fill materials and access conditions.

4. Carrying out all the necessary laboratory tests.
5. Performing engineering analysis of field & laboratory testing.
6. Developing conclusions and recommendations for safe & economic design and construction of the project components e.g. foundations of the structures, excavation, backfilling, compaction etc.

6.1.2 Existing Information

The following maps and reports were available and used for data processing purpose:

- Topographic map 1: 25,000
- The topographical survey map for the proposed land for irrigation between Rahad River up to Jebel Al Faw with a grid of 200 x 200 m.

The aim of the geological and geotechnical study is to obtain sufficient information about the ground conditions for project optimization and cost assessment at the current survey level.

Detailed geological and geotechnical mapping of the project area shall give information on ground conditions for project components, including assessment of:

- The top soil formation
- Information on the possible sources of construction materials such as aggregate and sand
- Information on possible sources of soil materials to be used in potential fill materials.

6.1.3 Location and Accessibility

The project area is about 7,500 ha Located in Gadarif State between Al Hawata town and Wad Meskin on the eastern side of the seasonal Rahad River.

The project area can be reached by using the highway from Khartoum to Al Faw town; the travel distance is about 270 km. This is followed by 160 km. from Al Faw town up to Al Hawata town through badly paved road. Then using about 70 km. rough unpaved road from Al Hawata town to Wad Meskin village "Rahad River Barrage site". Then from Wad Meskin village to Dinder barrage site through very rough unpaved road about 60 km.

During the rainy season, normally from June to October, it is very difficult to access the project area because the heavy clay soils make the roads inaccessible between Al Hawata onwards to the project sites.

6.2 Regional Geology

Except of isolated Inselberges hills of basement complex rocks at the eastern boarder (Jabel Siraj 13 km east of Wad Miskeen) the area was covered with un consolidated superficial materials with thickness ranging from few meters near Jabel Siraj up to 80m near Hawata City. Most of geological information obtained were collected from the few basement exposure, drilled boreholes (core & auger), faces of pits and ditches. The following types of rocks are observed in the study area:

6.2.1 Basement Rocks

The basement rocks observed study area either as isolated out crops at the further southern east part around Gala Elnahal as syntectonic granites as pinkish porphyritic granites, they are massive bouldery rocks intensively jointed and exfoliated patches and xenoliths of older gneissic rocks had been found engulfed in the granitic boulders.

6.2.2 Meta- sediment

These are sedimentary rocks that show evidence of having been subjected to metamorphism , this observed in Jebel Gala El Bager which in form of Pelite and Semi pelite which originally mud stone and siltstone subjected to metamorphism, also observed at a depth more than 20m at Rahad Barrage in form of highly weathered mud stone.

6.2.3 Syn- tectonic granites

Occurs in form of a series of isolated hills running in the north south direction parallel to Rahad River, mainly with light pinkish colour, coarse grained, massive closely to medium spaced jointed. Jebel Siraj 13 km from Rahad Barrage.

6.2.4 Upper Cretaceous Sandstone Deposits:

This formation comprises conglomerates sandstone and mudstone deposits uncomfortably overlain basement complex and characterized by the distinctive red and brown colours.

6.2.5 Atshan Formation:

Which of Tertiary – quaternary age, weakly consolidated and characterized by rapid facies change composed mainly of rounded to sub rounded quartz sand with some mica and dark minerals.

6.2.6 Recent Superficial Deposits:

Mainly of clayey material called black cotton soil which is mainly of high plastic clay with or without fine sand and silts and varies in thickness from 12m at Segai Salsal to less than 1m at Jebel Gala El Bager.

6.3 Planning and Procedure used for Site Investigations

The general initiative is to deal with important geotechnical issues necessary to establish, to a feasibility study level, the technical and economic feasibility of the scheme, with sufficient level of investigations. Relevant information was collected from the available records, maps and from the visual examination of the project sites and from the observations of the nearby Rahad Irrigation Project. Analysis of sufficiency was made and related to the actual structures in consideration.

Based on the existing information, expectation model was developed and important site related problems were identified. Consequently, ground condition parameters considered appropriate for technical optimization were defined.

6.4 Site Investigation Programme

Geological and geotechnical site investigation for the barrage sites, siphon site and link canal and main canal routes was planned, considering obtaining appropriate design parameters for these project components. Following the analysis of the available information and site assessment a site investigation programme was concluded, comprising core drilling, test pitting and laboratory testing of soil samples. In the course of implementation of the investigation activities, the conceptual expectation model of the ground is progressively improved and the remaining investigation was adjusted following the results. Results of the site investigations are summarized and interpreted in the next sub topics.

6.4.1 Exploratory Core Drilling

Because of the necessity for evaluation of ground conditions in line with the infrastructure under consideration, rotary drilling was planned at Dinder Barrage Site, Rahad Barrage site and Khor Atshan Siphon Site. The exact locations of these sites are indicated as follows:

6.4.1.1 Dinder Barrage Site

Along the axis of the barrage site across Dinder River five boreholes were drilled. Coordinates of these boreholes are:

Borehole No. 1:	N: 1407782	E: 0696652
Borehole No. 2:	N: 1407832	E: 0696633
Borehole No. 3:	N: 1407894	E: 0696607
Borehole No. 4:	N: 1407931	E: 0696604
Borehole No. 5:	N: 1407958	E: 0696597

The drilled depth of each borehole was 20.0m. Two boreholes at the eastern bank of the river, two boreholes at the riverbed and one borehole at the western bank of the river. See Figure. (6.1).

6.4.1.2 Rahad Barrage Site

Along the axis of the barrage site across Rahad River five boreholes were drilled. Coordinates of these boreholes are:

Borehole No. 1:	N: 130918.4	E: 035327.7
Borehole No. 2:	N: 130918.4	E: 035326.0
Borehole No. 3:	N: 130918.4	E: 0345324.0
Borehole No.4:	N: 130918.4	E: 0345322.6
Borehole No.5:	N: 130918.4	E: 0345320.8

The drilled depths of the boreholes vary between 20.0m to 24 m. Three boreholes at the eastern bank of the river and two boreholes at the western bank of the river. See Figure. (6.2).

6.4.1.3 Khor Atshan Site

At Khor Atshan, the proposed siphon location, three boreholes were drilled. Coordinates of these boreholes are:

Borehole No. 1:	N: 1446024	E: 0700102
Borehole No. 2:	N: 1445971	E: 0700270
Borehole No. 3:	N: 1445950	E: 0700340

The drilled depth of each borehole was 10.0m. One borehole at the eastern bank, one borehole at the western bank and the third at the centre of the Khor bed. See Figure. (6.3).

Rotary Drilling: Rotary soil mechanics drilling rig mounted on truck was used for drilling the boreholes. Power-operated continuous augers were used for advancing and cleaning the boring. Casing was used to prevent the cave-in of the soils in the encountered cohesionless layer.

During the drilling of boreholes samples of the encountered soils were examined visually and described. The details were entered in the drilling record. Other entries such as the depths at which samples were taken, results of in situ tests and observation of ground water levels were also included.. The information of the drilling records formed the basis for the preparation of the boreholes records.

Borehole Logs: The description of the soil profile was taken first from the drilling record and was subsequently checked and, when necessary, amended according to the Unified Soil Classification System (USCS), using the results obtained from laboratory testing. After the completion of the field tests and the laboratory tests, the ground conditions discovered in each borehole were summarized in the boreholes logs as shown in the Annex C.

6.4.1.4 Soil Samples

Disturbed soil samples were taken from the augers cuttings at 1m intervals and from the soil retained in the SPT sampler at 1.5m intervals for visual inspection and classification tests. Undisturbed samples were also taken from cohesive soils by a U_{100} open drive sampling tube whenever soil conditions allowed. One groundwater sample was extracted from Dinder Barrage Site for chemical testing.

6.4.1.5 Standard Penetration Test

The standard penetration test aims to determine the SPT-N value that gives an indication of the soil density and can be empirically related to the strength of the soil underlying the structures.

Standard Penetration Tests (SPT) were performed, according to ASTM D 1586, at a depth interval of 1.5m. The SPT was performed by driving an open split spoon sampler (50mm outside diameter and 450mm length) by the blows of a standard automatic hammer weighing 64kg and falling freely from a height of 760mm. First, the sampler was driven a distance of 150mm to bypass disturbed soil with the blow count recorded. Then the number of blows required for the last 300mm penetration was taken as the SPT-N value. The test results are shown in the borehole logs Annex C.

6.4.1.6 Groundwater Measurement

The groundwater levels in each borehole at Dinder Barrage Site were measured using electric meter indicator, the readings of groundwater levels are presented in Table (6.1) below. No groundwater was observed at Rahad Barrage Site and Khor Atshan Site.

Table 6.1: Groundwater Table Measurements

Location/Site	Borehole No.	Groundwater Level (m)
Dinder Barrage Site	B.H. 1	7.5 (From G. L.)
	B.H. 2	8.0 (From G. L.)
	B.H. 3	0.5 (From B. L.)
	B.H. 4	0.3(From B. L.)
	B.H. 5	9.0 (From G. L.)

6.4.2 Excavation of Test Pits

The spacing of the test pits has been decided during the inception stage; taking into consideration that the top soil formation along the route of the canals' alignment and that on the available cuts are generally homogeneous. This has been confirmed, later, by the similar soil profiles of the test pits i.e. consisting of black to dark brown silty clay of high plasticity.

The excavation of pits was carried out by means of a back-hoe mechanical excavator. In the excavation process, the test pits were sloped at safe angles and the excavated soil were removed to a reasonable distance from the edges of the test pits.

Disturbed soil samples were collected for visual inspection and laboratory testing and natural moisture content was measured at each test pit. The test results are shown in the test pits logs in Appendix (B).

6.4.2.1 Link Canal

Test pits were excavated along Dinder - Rahad link canal, and the proposed route of the main canal. Twenty nine test pit were excavated along Dinder - Rahad link canal (length about 53.8 Km) numbering from TP 1 to TP 29, the spacing between each two test pits is less than 2.0 Km, every three pits were excavated to the depth of 3.0 m and the fourth to the depth of 5.0 m

6.4.2.2 Main canal

Twelve test pits were excavated along the route of the proposed main canal (length about 37.7 Km) numbering from TP 30 to TP 41. The spacing between each two test pits is about 3.0 km, every three pits were excavated to 3.0 m depth and the fourth one to 5.0m depth.

6.4.3 Geophysical Investigation

Geophysical methods are used in preliminary investigations of subsoil strata. The methods can be used for the location of different strata and for a rapid evaluation of the subsoil characteristics. However, the methods are very approximate. For detailed and reliable investigations the conventional methods of driving a hole, taking a sample and testing in a laboratory, should give the conclusive results.

In this project the geophysical method has been excluded, since the boreholes are closely spaced and the test results of the boreholes, to a great extent, are similar.

6.5 Ground Conditions

The Geotechnical field works, at each location, reveal the ground conditions as indicated in the following sections:

6.5.1 Dinder Barrage Site

The boreholes No. 1, No. 2 and No. 5, which are approximately at the same elevation at the two banks of the river, showed relatively similar soil profile. It is consisting of top 2.5m to 4.0m layer of dark grey to dark brown silty clay of low to high plasticity (CL to CH). This is underlined by medium dense light to dark brown poorly to well graded silty sand (SP-SM/SP to SM) and medium dense light to dark brown clayey sand (SC) extended down up to 7.0m-10.0m depth. Below this very stiff to hard light brown to dark grey to yellowish brownish silty clay of high to low plasticity

(CH to CL) was encountered and extended down to the bottom of boreholes at 20.0m depth. Intermediate layer of medium dense to dense light to dark brown silty sand (SM) was observed between 13.0m and 19.0m depth.

Boreholes No. 3 and No. 4, which are at the same level at the riverbed, showed similar soil profile. Top layer of medium dense light brown to light grey poorly graded silty sand (SP) and medium dense dark to light grey clayey sand (SC) were encountered up to 5.5m depth. This is followed by continuous layer of very stiff to hard dark to light brown to yellow silty clay of high to low plasticity (CH to CL) extended down to the bottom of boreholes at 20.0m depth. Intermediate thin layers of dense to medium dense yellowish brownish to dark brown clay sand (SC) was observed between 11.5 to 17.5m depth. See Figure (6.4). No cavities were encountered in any of the boreholes down to the drilled depth

6.5.2 Rahad Barrage Site

All boreholes in this site showed similar soil profile. It is consisting of one continuous layer of stiff to hard dark brown to light brown to yellowish brownish silty clay of high to low plasticity (CH to CL) extended down continuously to the bottom of boreholes at 20.0m to 24.0m depth. Very dense yellowish brownish clayey sand (SC) was observed at the bottom 2.5m in borehole no. 1. Thin layers of medium stiff brown to black clayey silt of high to low plasticity (MH to ML) was encountered in borehole 3 between 2.5m and 7.0m depth. See Figure. (6.5). No cavities were encountered in any of the boreholes down to the drilled depth

6.5.3 Khor Atshan Site

All boreholes in this site showed similar soil stratification of one continuous layer of stiff to hard light to dark brown to dark grey silty clay of high to low plasticity (CH to CL) extended down to the bottom of boreholes at 10.0m depth. See Figure. (6.6).

No cavities were encountered in any of the boreholes down to the drilled depth

6.5.4 Test Pits

All test pits along the link canal and main canal routes show generally similar soil profile consisting of black to dark brown to brown silty clay of high plasticity (CH) extended down to the bottom of test pits. Few test pits (TP 1, TP 26 and TP 28) indicated black to brown clayey to silty sand (SC) to SM). See Annex C.

6.6 Laboratory Testing

Laboratory testing programme was conducted to evaluate the physical and mechanical properties of the soils encountered during the boring. The tests included Atterberg limits, particle size distribution, and sedimentation by the hydrometer method, the natural moisture content, UU-triaxial test, consolidation test, permeability test and chemical test for soil and groundwater. The procedure of the tests followed were in conformance with those recommended in the British Standard BS 1377 (1990).

6.6.1 Classification Tests

The objective of these tests is to reveal soil types encountered at different depths of the boreholes and test pits. The soil classification used for engineering purposes relies primarily on the grain size distribution of the coarse soils and the consistency of fine soils that is quantified by the Atterberg limits tests. Tests carried out included, Atterberg limits, size analysis and natural moisture content. All these classification tests confirmed the soil profiles shown in Annex C. Unified Soil Classification System (USCS) was followed for soil classification.

6.6.1.1 Atterberg Limits

The tests were carried out on fine soil samples taken from different depths of the boreholes and test pits. At Dinder Barrage Site, the results gave liquid limit values ranging between 22% and 81% and plasticity indices in the range of 7% to 51%. This indicated medium to high potential for swelling in this site. The results in Rahad Barrage Site gave liquid limit values between 26% and 96% and plasticity index in the range of 11% to 65%. This is generally reflecting high potential for welling in this site. Khor Atshan site showed liquid limit values between 25% and 109% and plasticity indices between 8% to 67%, this reflects high potential for swelling. The results of test pits gave liquid limit values generally between 42% to 99% and plasticity indices between 19% to 68%. This is indicated high potential for swelling. The results of this test are presented in Appendix (A) and Appendix (B).

6.6.1.2 Grain Size Distribution

The grain size distribution of the soil samples was determined in the laboratory. The results of sieve analysis and hydrometer tests are shown in Annex (C).

6.6.1.3 Natural Moisture Content

The natural moisture content for the boreholes was determined in the laboratory from the recovered undisturbed soil samples. The natural moisture content for the test pits samples was determined by weighting the samples in the field and then the test was continued in the laboratory. The test results are shown in the logs in Annex (C).

6.6.2 UU-Triaxial Test

Unconsolidated undrained (UU) triaxial tests were performed on undisturbed soil samples obtained from the boreholes to measure the shear strength of the soils. The average measured soil shear parameters (C and Ø) in Rahad Barrage Site are 85.48 kPa and 10º respectively. While the average parameters (C and Ø) in Khor Atshan Site are 191.4 kPa and 2º respectively. The results of these tests are shown in Appendix (D). No UU-triaxial tests were performed for Dinder barrage site due to the samples disturbance.

6.6.3 Permeability Test

Soil permeability (k) was determined in the laboratory by constant head method for some undisturbed soil samples. The results of this test are presented in Table (6.2) below. The permeability values are generally low to very low as indicated by the test results.

Table 6.2: Permeability Test Results

Location/Site	BH/TP No.	Depth (m)	kcm /sec	Soil Type according to USCS	Remarks
Dinder Barrage Site	BH 1	1.5	$5.09*10^{-6}$	CL	very low
	BH 1	4.5	$3.16*10^{-7}$	SC	very low
	BH 2	1.5	$7.27*10^{-4}$	CL	low
Khor Atshan	BH 2	1.5	$3.39*10^{-4}$	CL	low
	BH 3	3.0	$1.07*10^{-6}$	CH	very low
	BH 3	9.0	$1.015*10^{-6}$	CH	low
Link Canal (LC)	TP 2	1.50	$1.15*10^{-5}$	CH	low
	TP 5	1.5	$1.95*10^{-6}$	CH	very low
	TP 10	2.50	$7.72*10^{-6}$	CH	very low
	TP 16	2.0-2.20	$2.0196*10^{-7}$	CH	very low
Main Canal	TP 33	1.0-1.20	$7.38*10^{-7}$	CH	very low
	TP 40	2.5-2.8	$5.23*10^{-6}$	CH	very low

6.6.4 Swelling Pressure Test

The swelling pressure tests were conducted on undisturbed soil samples. The volume of the soil was kept constant in an oedometer cell, while the soil was saturated with water during the test. Medium to relatively high swelling pressures were recorded in the test. The results are shown in Table (6.3) below.

Table 6.3: Swelling Pressure Test Results

Location/Site	B.H. No.	Depth (m)	Swelling Pressure (KN/m^2)	Initial moisture content (%)	Final moisture content (%)	Plasticity Index (%)	Soil Type according to USCS
Dinder Barrage Site	1	1.50	10	11.67	35.17	20	CL
	2	1.50	0	43.79	59.56	21	CL
Rahad Barrage Site	1	3.0	0	28.05	32.88	22	CL
	1	7.5	120	31.36	34.83	48	CH
	2	3.0	0	28.72	37.25	31	CH
	2	6.0	10	24.95	27.15	27	CH
	3	4.5	20	42.84	42.69	27	CH
	3	6.0	10	45.43	37.45	13	ML
	3	10.5	70	35.82	39.93	62	CH
	3	13.5	20	27.01	29.995	47	CH
	4	3.0	10	23.67	46.57	13	CL
	4	6.0	30	28.65	41.99	33	CH
	4	7.5	10	37.94	35.87	36	CH
	5	3.0	0	34.63	42.01	23	CL
	5	4.5	10	32.7	37.5	39	CH
Khor Atshan	2	1.50	0	20.97	40.1	23	CL
	2	4.50	180	47.47	48.297	33	CH
	3	3.0	110	29.61	39.45	58	CH

6.6.5 Consolidation Test

Consolidation tests provide information for use in evaluating the compressibility of the soils and estimating the settlement of foundations established on these soils. The consolidation tests were performed on clayey undisturbed samples. First, the swelling pressure test was conducted on the samples, and then the samples were loaded beyond the swelling pressure to allow consolidation to proceed. The results of these tests are presented in Annex (C)..

6.6.6 Chemical Tests

A group of soil samples, taken from different locations, boreholes and depths were chemically tested. Sulphate content, chloride content and pH values were determined as results of these tests. One groundwater sample obtained from Dinder Barrage Site was also tested. All samples are alkaline with low chloride and sulphate contents. See Table (6.4) below.

Table (6.4): Chemical test results.

Location /Site	Sample Type	B.H./ T.P. No.	Depth (m)	pH	Chloride (%)	Sulphate (%)
Dinder Barrage Site	Soil	B.H. 1	3.0	8.62	0.0496	0.0846
	Soil	B.H. 3	1.0	7.78	0.0567	0.0514
	Groundwater	-	-	7.47	0.0071	0.0999
Rahad Barrage Site	Soil	B.H. 1	5.0-6.0	7.37	0.0213	0.0856
	Soil	B.H. 3	15.0-16.0	7.46	0.0355	0.1027
	Soil	B.H. 4	7.0-8.0	7.07	0.0284	0.0857
	Groundwater	-	-	7.78	0.0014	0.0034
Khor Atshan	Soil	BH. 3	3.0	8.22	0.0250	0.0171
Link Canal	Soil	T.P. 3	1.5	8.79	0.0018	0.0856
	Soil	T.P. 15	2.5	8.50	0.0807	0.1193
	Soil	T.P. 25	1.5-4.0	8.65	0.0246	0.1024
Main Canal	Soil	T.P. 32	1.5-5.0	8.53	0.0456	0.1022
	Soil	T.P. 38	2.0-3.0	8.75	0.0597	0.0343

6.7 Analysis of the Results

6.7.1 Materials Physical and Mechanical Properties

6.7.1.1 Dinder Barrage Site

It is clear from the soil profile of the boreholes at the river bank that alluvial deposits consisting mainly of top 2.5m to 4.0m layer of low to highly plastic silty clays (CL to CH) followed by well to poorly graded silty to clayey sand (SM to SC) up to 7.0 - 10.0m depth. This is underlined by silty clay of high plasticity (CH) extended to the bottom of boreholes. The boreholes at the riverbed showed top 5.5m layer of poorly graded silty sand and clay sand (SP-SM/SP to SM) and (SC). This is followed by continuous layer of high to low plasticity silty clay (CH to CL) extended to the end of boreholes with thin layers of clayey sand (SC) between 11.5m to 17.5m depth.

Groundwater levels were measured in the range of 7.5m to 9.0m depth for the boreholes at the riverbanks, while for the riverbed boreholes were measured at shallow level between 0.3m to 0.5m depth.

The SPT generally indicated very stiff to hard clays and medium dense sands, this is reflecting medium to high shear strength at this site. See Figure (6.7). The estimated values of angle of internal friction for the medium dense granular soil are in the range of 32° to 36°. The cohesion of very stiff to hard clays can be considered in the range of 200 to 300 kPa.

Low values of swelling pressure were observed for the low plastic clayey tested samples. No undisturbed samples were extracted from the highly plastic clays, which are expected to give relatively high swelling pressure as reflected by their index properties.

The permeability test showed low to very low permeability values, water seepage below the proposed structure generally is expected to be low.

6.7.1.2 Rahad Barrage Site

It is evident from the soil profile that all boreholes showed continuous layer of stiff to hard silty clay of high to low plasticity (CH to CL) extended down continuously up to the end of boreholes. Very dense clayey sand (SC) was encountered at the bottom 2.5m in borehole (1). Thin layers of medium stiff clayey silt of high to low plasticity (MH to ML) was also observed in borehole 3 between 2.5m and 7.0m depth.

No groundwater was encountered in all boreholes at the two river banks.

The SPT generally indicated medium stiff to hard clays and silts, this is reflecting medium to relatively high shear strength at this site. See Figure. (6.8). The average value of angle of internal friction for the investigated soil is about 10° and the cohesion is about 85.48 kPa.

Low values of swelling pressures were recorded for the moist low plastic clayey soils, while relatively high swelling pressures were measured for the highly plastic clays.

6.7.1.3 Khor Atshan Site

It is shown in the soil profile that one continuous layer of stiff to hard silty clay of high to low plasticity (CH to CL) was encountered and extended down to the bottom of boreholes. No groundwater was observed in the boreholes at this site. SPT N values reflecting reasonable high shear strength for the stiff to hard clays. See Figure. (6.9). The cohesion of the clays in this site can be estimated between 150 to 250 kPa. Relatively high potential for swelling is indicated by the swelling pressure test in this site. Permeability results reflecting low expected water seepage below the proposed structures.

6.7.1.4 Main Canal and Link Canal

All test pits showed highly plastic silty clay (CH) with exception of few test pits along link canal showed clayey to silty sand (SC to SM). High potential for swelling is expected based on the resulting index properties. The water seepage is generally expected to be low along these canals as reflected by the low to very low values of permeability test.

6.7.2 Materials Chemical Properties

The chemical tests most commonly called for are those which determine possible aggression to cement products; namely : pH and sulphate content. The level of chloride content is also important as it attacks reinforcement.

These can be carried out on groundwater samples and on soil extracts.

6.7.2.1 Sulphate Content

Sulphate attack to concrete is a well documented phenomena and is caused by the presence of high sulphate content either by ingress from sulphate of the surrounding environment such as foundation soils, or by the presence of sulphate in the concrete ingredients such as sand or aggregate or both. The attack results in a considerable internal expansion, which may lead to crack and disintegration of the concrete.

According to the British Code Practice 2004 for sulphate content between 0.2% - .0.5% in soil and in ground water 30 -120 parts per 100000 Ordinary Portland cement could be used

Hence, based on the chemical test results (table 6. 4) Ordinary Portland cement can be used in all the structures of the project

6.7.2.2 pH Value

The measured values of the tested samples and groundwater are above 7.0 which indicate that the soil samples are slightly alkaline. Therefore no acid attack on concrete will be encountered.

The BRE digest 363: 1991 requires no changes in the requirements of cement content and maximum water /cement ratio for the type of cement as long as the pH values remain above 5.5.

6.7.2.3 Chloride Contents

As shown in table (6.4) the chloride contents are low which suggest normal concrete cover to the reinforcing steel

6.8 CONSTRUCTION MATERIALS INVESTIGATION

The construction are required in this project for two main activities:

- Reinforced concrete of barrages and syphon structure bodies.
- Earth works which include soil replacement below the concrete structures foundations and approach ramps.

Three different sites were investigated for construction materials. Test pits of about 3.0m depth were excavated and disturbed soil samples were collected for laboratory testing. Physical tests, strength tests, durability tests and chemical tests were carried out on sand and aggregate samples as shown below:

- Physical tests; Bulk density and grading
- Strength test; Franklin point load test
- Durability tests; Slake durability test, Los Angeles abrasion test
- Chemical tests; sulphate content and chloride content

The results of these tests are presented in Appendix C7 (F).

The types and quantities of construction materials in each site are described below.

6.8.1 Dinder Barrage Site

In this site, the soil samples were collected from the bottom of Dinder River. Natural gravel and sand were encountered in this site. The rough estimated quantities of these materials are as follows:

- Natural gravel: about 7000 – 8000 cubic meters.
- Sand: about 1000 – 1200 cubic meters.

6.8.2 Nor Al Galil Site

This site at about 34 km northern Dinder barrage site. The samples were also collected from the bed of Dinder River. Natural gravel and sand were observed in this site, the estimated quantities as follows:

- Natural gravel: about 3000 – 4000 cubic meters.
- Sand: 5000 – 6000 cubic meters.

6.8.3 Gabal Serag Site

This site is located at about 13 km north-east Rahad barrage site. It is a series of mountains, crushed aggregate can be produced. The results of tests carried out on this site samples are shown in Appendix C7 (F).

6.9 Conclusions and Recommendations

According to the field and laboratory investigations, subsurface conditions, engineering analysis and practical experience, it can be concluded that the proposed structures can be satisfactory implemented if the recommendations and discussions, mentioned in the following sections, are taken into consideration.

However, these recommendations and discussions presented in this report, for the design of the foundation, should be considered as preliminary and presented for guidance purpose. It is imperative that for detailed designs, these should be properly interpreted by the design engineer, since the loads and dimensions of the proposed structures are not available

6.9.1 Foundation Recommendations

In designing foundations, the engineer must satisfy two independent foundation stability requirements, which must be met simultaneously:

1. There should be adequate safety against shear failure within the soil mass. (The working load should not exceed the allowable bearing capacity of the soil being built upon)
2. The probable maximum and differential settlements of the soil under any part of the foundations must be limited to safe and tolerable limits

In the light of the aforementioned, the recommendations for the foundation are as detailed in the following sections:

6.9.1.1 Large Rigid Raft Foundation

The proposed barrages and siphon are recommended to be supported by large rigid raft foundation constructed on selected compacted fill materials. It is recommended to excavate the barrage foundation area below the existing level of the river bed to a suitable depth before placing the selected fill materials. It is recommended to compact the original soil very well by heavy mechanical compacter before placing the layers of the fill. The soil replacement should be carried out as specified in Para 1.9.1.3.

In Dinder Barrage Site, proper dewatering (as specified in Para 1.9.1.4) should be applied before and during the construction of the foundations, this is due to the presence of groundwater table at shallow depth below the river bed.

Based on the results of the investigations, the recommended depth of excavation, and depth of fill materials for each site is shown in Table (6.5) below:

Table 6.5: Soil Replacement for the Raft Foundation

Location/ Site	Excavation Below River Bed (m)	Fill Materials Layer Thickness (m)
Dinder Site	6.0	6.0 m – Foundation Thickness
Rahad Site	5.0	5.0 m – Foundation Thickness
Khor Atshan	Siphon Height +3.0	3.0 m

6.9.1.2 Foundation of Small Structures

The foundations of the small structures along the canals' routes such as regulators, bridges etc, can be placed just below the canals' bed levels. Similar design for the foundations was practiced in the completed phases of Rahad Project, which have similar nature of soil.

However, construction on clayey soils having high plasticity index should involve measures to reduce the swelling or shrinkage of the soil below structures. This can be achieved by controlling the moisture variation. In these structures the foundations are, actually, at depths exceeding the depth of seasonal variation.

Foundation excavation should not be exposed for long time either to sun or rainfall.

6.9.1.3 Soil Replacement

This method of construction is practiced in Sudan in areas dominated by expansive soils. The imported soil material should Not be expansive, well graded composite material, free from organic matter and harmful chemicals such as sulphates or chlorides. The maximum allowed limit for the material passing sieve #200 is 35% and the minimum limit is 8%. The plasticity index for the back filling material shall be between 4% to 9%. The back filling material shall be placed in 20 cm layers moistened to about +1% of the optimum moisture content. The backfill material shall be compacted to attain 100% of the Proctor's dry density when used under the foundation. The bearing capacity of the fill below the foundation can be taken 200 kN/m2 for the design purpose, provided that the compaction control is performed as indicated in this recommendations. The total settlement is expected to be within the tolerable limit.

6.9.1.4 Methods of dewatering Excavations

According to the ground water table level, dewatering is expected only in the Dinder Barrage site. The methods of dewatering to be adopted should be chosen so that the excavation remains stable at all times i.e. slips do not occur in the sides of the excavation and excessive heaving of the base does not occur.

The method to be recommended for the lowering of the water table is the well point system. This system may consist of a single row of closely spaced well points around the site. More than one set can be installed. See Figure. 6.10

The dewatering should continue till the completion of the replacement of soil, the concreting of the foundation and other components the structure to levels just above the water table

6.9.1.5 Excavation Methods

As most of the excavation will be in a silty clay soils, conventional excavation equipment such as excavators, loaders and bulldozers will be sufficient for most excavation works.

The excavation shall be battered to a slope of one vertical to two horizontal (1V:2H) in soil formation to avoid collapse; if this recommended side slopes cannot be achieved for insufficient lateral space or for any other reason, lateral support system for the side of the excavation will be required to maintain safe working conditions.

It is recommended to carry out the excavation and the concreting of the foundation and all components of the major structures above the groundwater table during the dry season.

6.9.2 Canals' Banks

The test pits along the canals routes indicate that the soil shows highly plastic properties and the coefficient of permeability is quite low (an average of 10^{-6} cm/sec) making it quite usable as bank fill material, since the seepage expected is insignificant.

6.9.3 Reinforced Concrete

Due to the low sulphate contents and that the pH of ground water is greater than 6 (as indicated in table 6.4) Ordinary Portland cement can be used in all the project structures. Minimum cement content 330 kg/m3; maximum free water cement ratio 0.50 by weight

The chloride contents are very low, hence normal concrete cover for the steel reinforcement is sufficient.

6.9.4 Construction Process

- It is recommended to carry out the excavation and concreting of the foundation and all the components of the major structures above groundwater table during the dry season.
- The company for carrying out the dewatering process should be specialized in this field.
- A competent geotechnical engineer must supervise the quality control of materials, specifications, dewatering, excavation, and backfilling and foundation construction.

Figure 6.1 Site Plan – Dinder Barrage Site

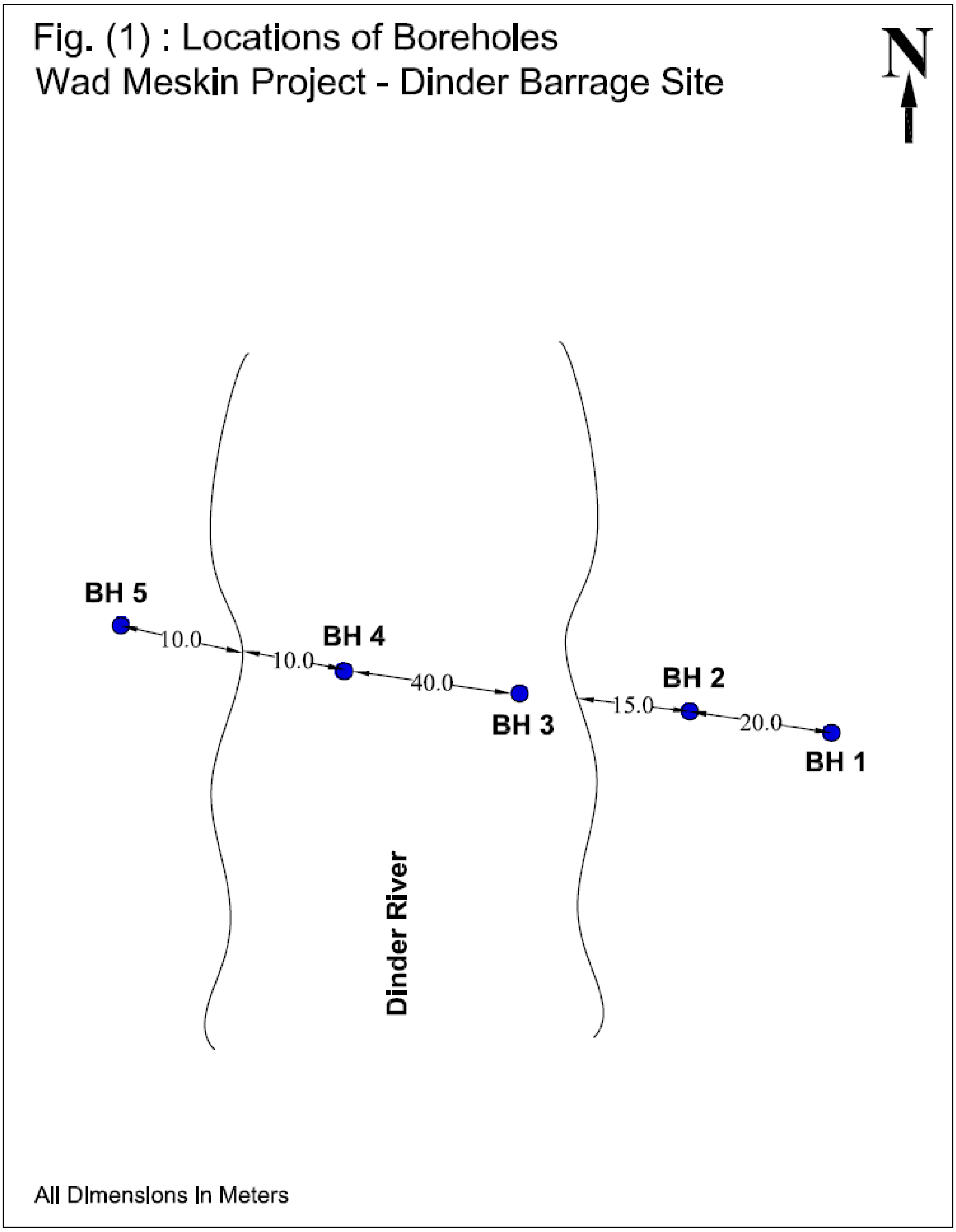

Figure 6.2 Site Plan – Rahad Barrage Site

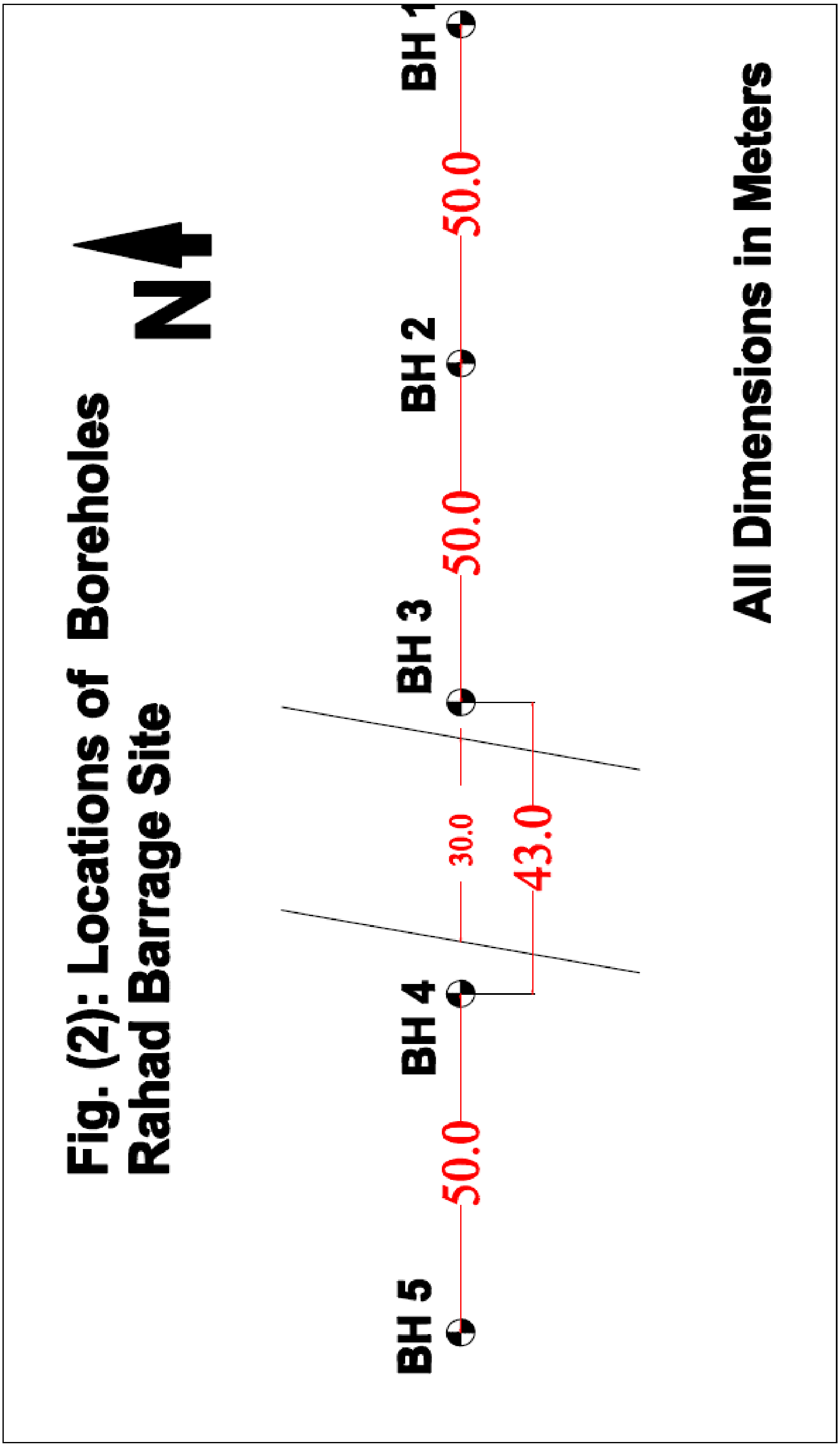

Figure 6.3 Site Plan – Khor Atshan Site

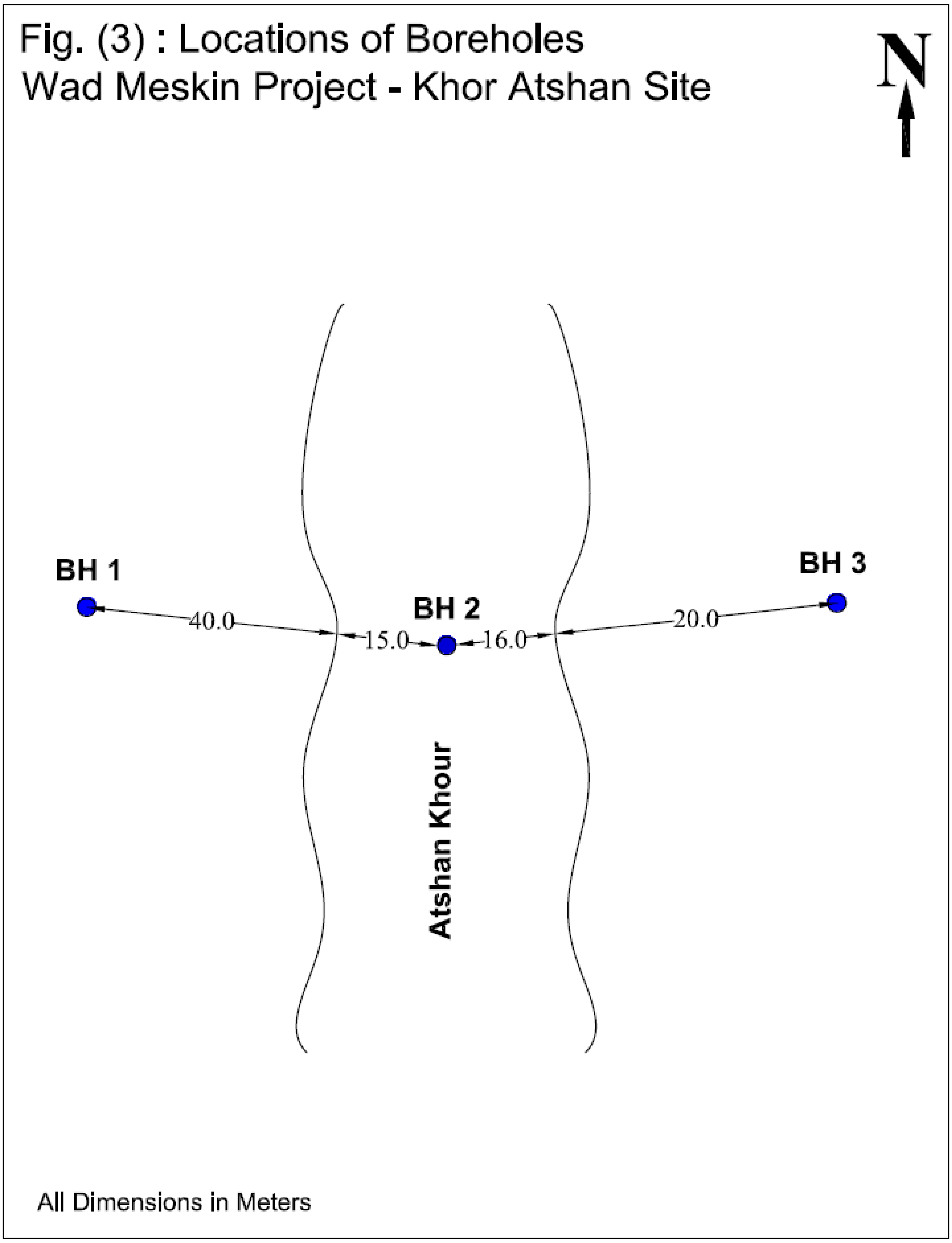

Figure 6.4 Soil Profile – Dinder Barrage Site

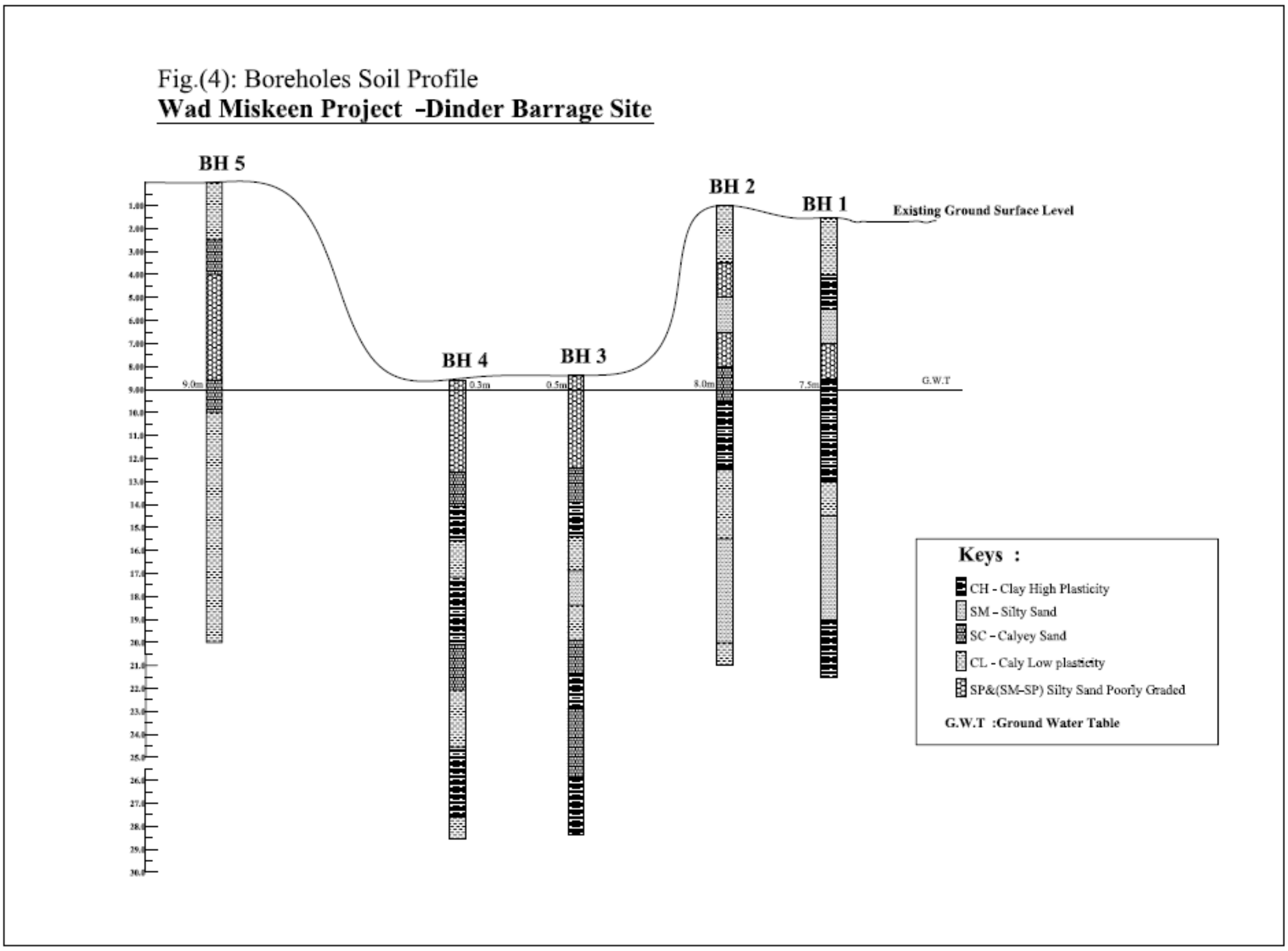

Figure 6.5 Soil Profile – Rahad Barrage Site

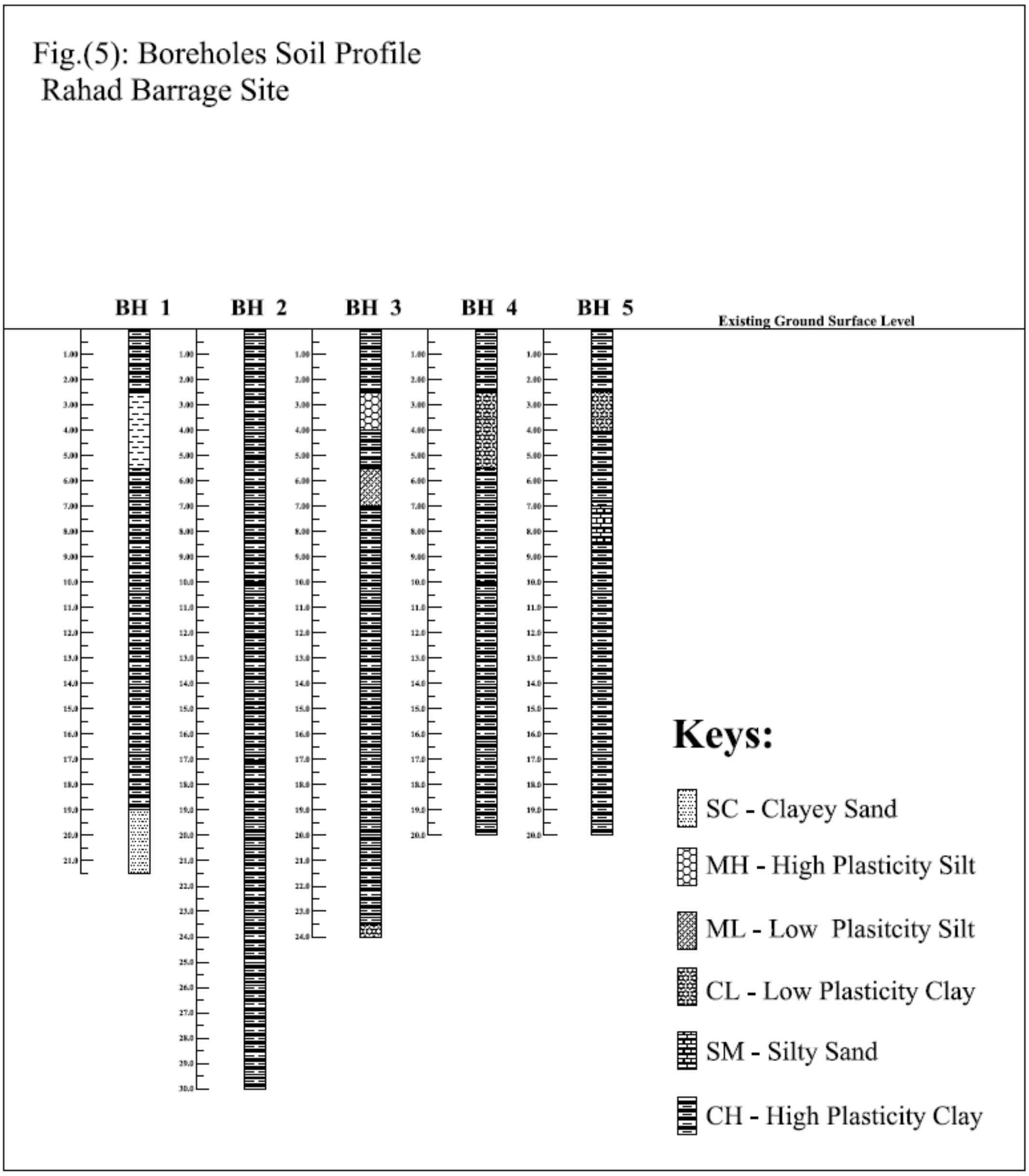

Figure 6.6 Soil Profile – Khor Atshan Site

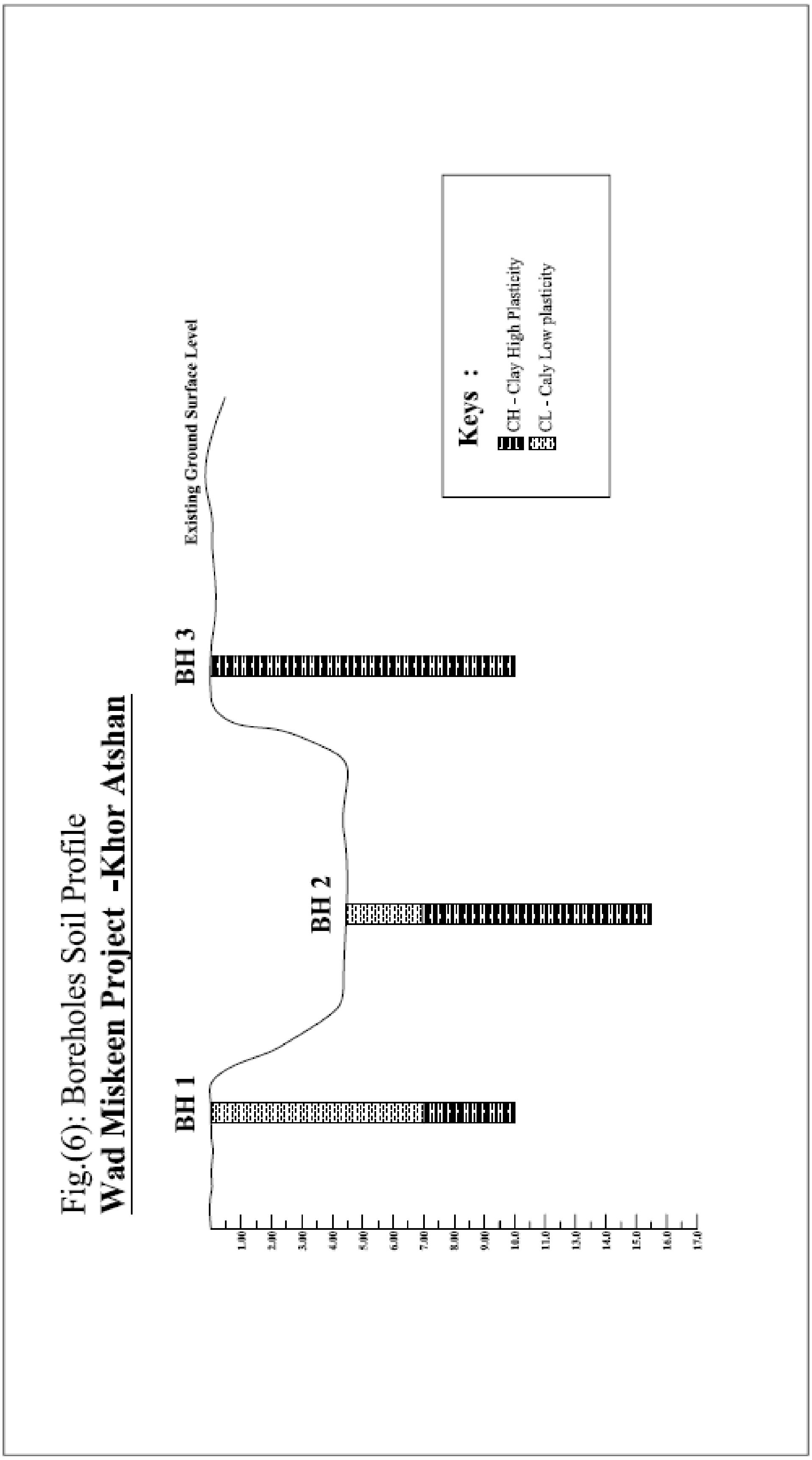

Figure 6.7 SPT vs Depth – Dinder Barrage Site

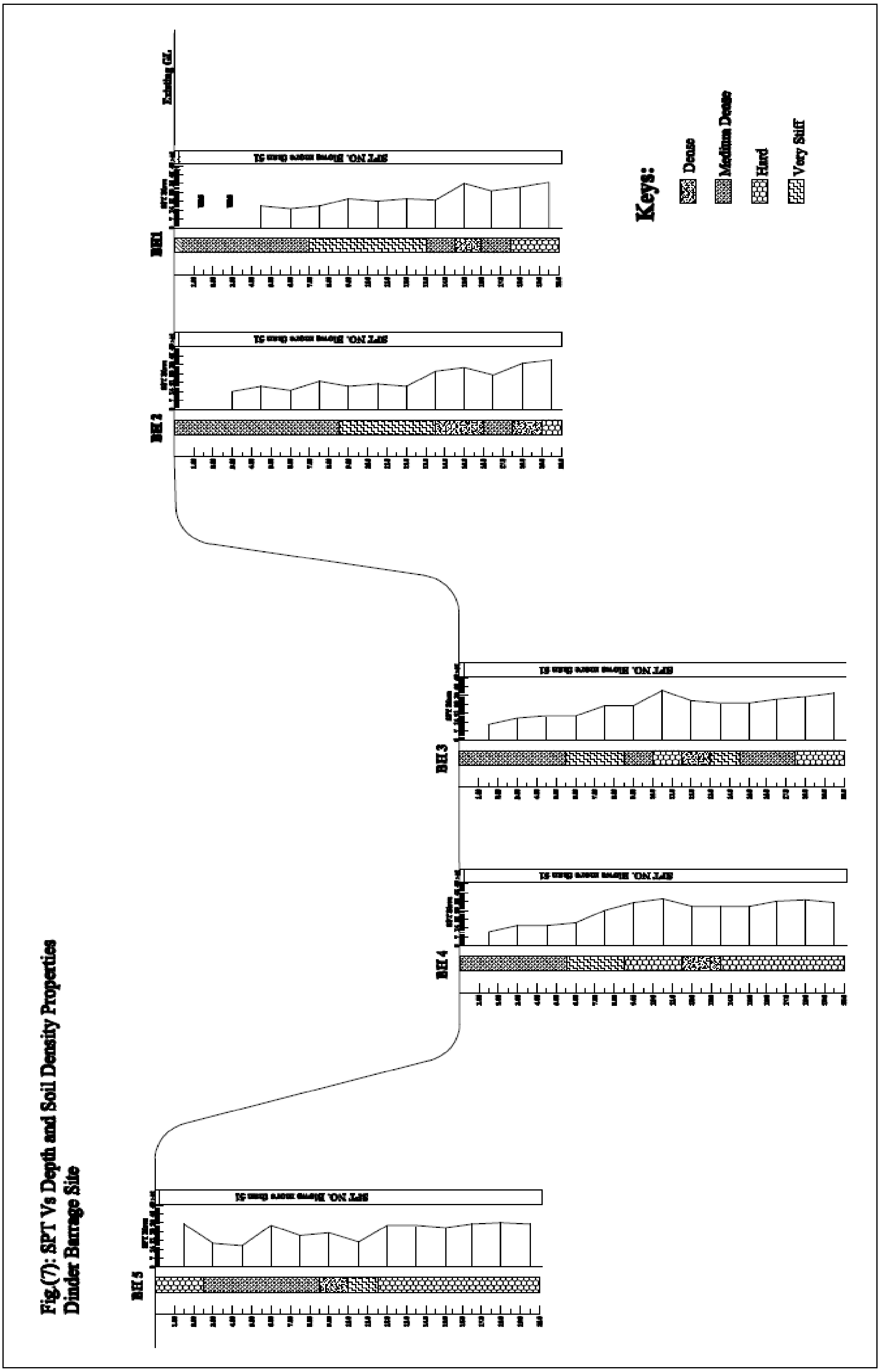

Figure 6.8 SPT vs Depth – Rahad Barrage Site

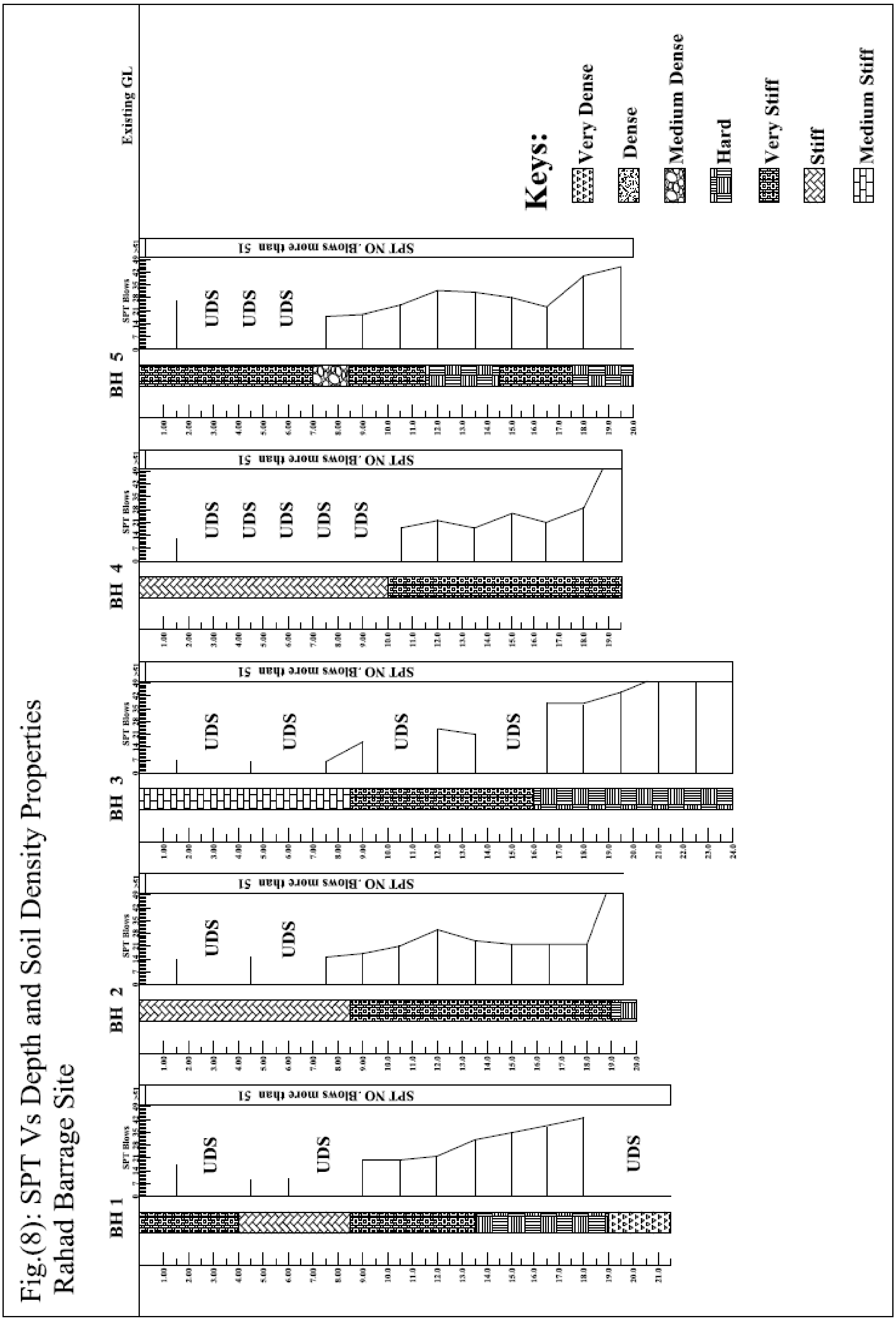

Figure 6.9 SPT vs Depth – Khor Atshan Site

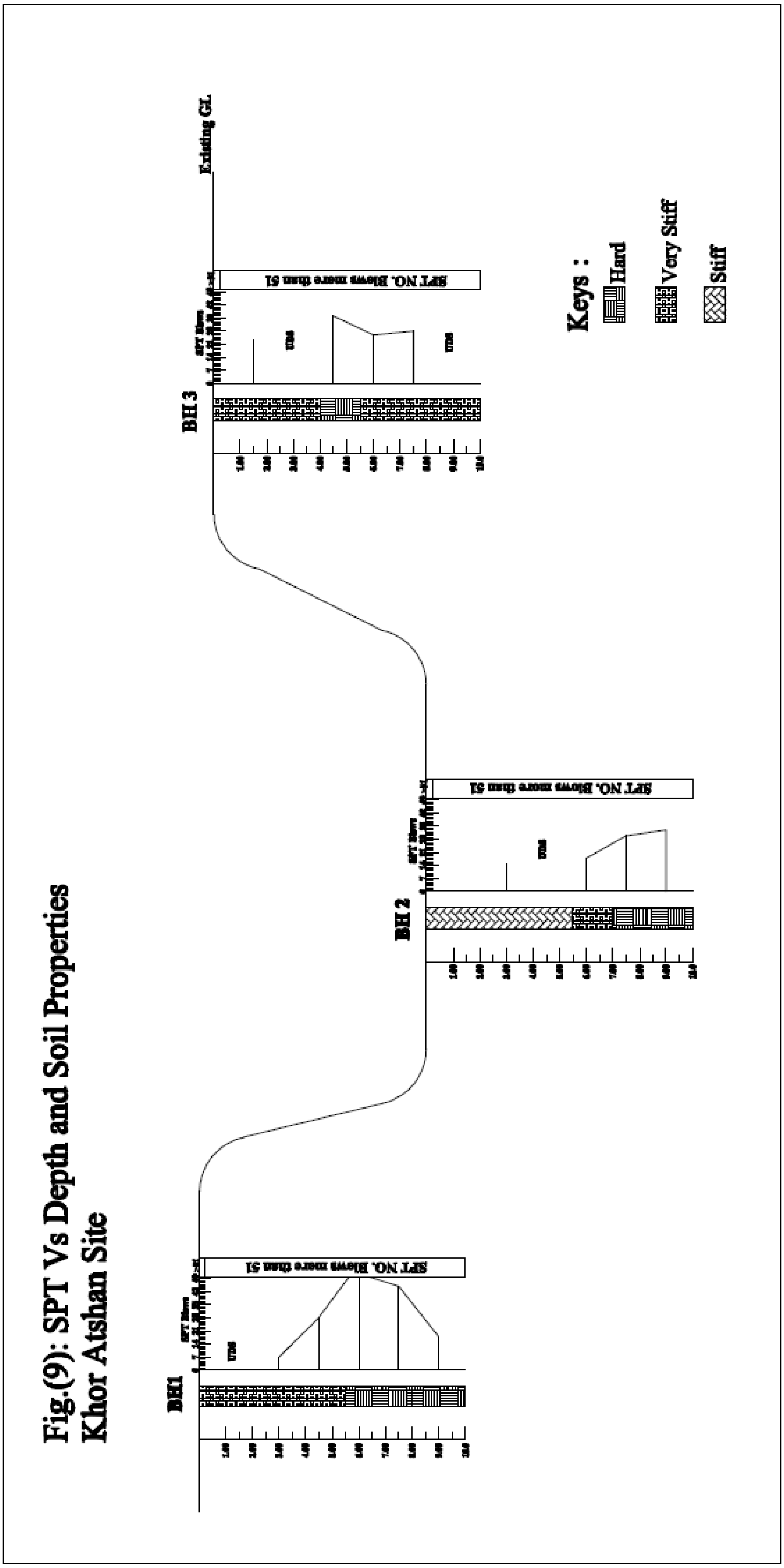

Figure 6.10 Wellpoints Used for Dewatering

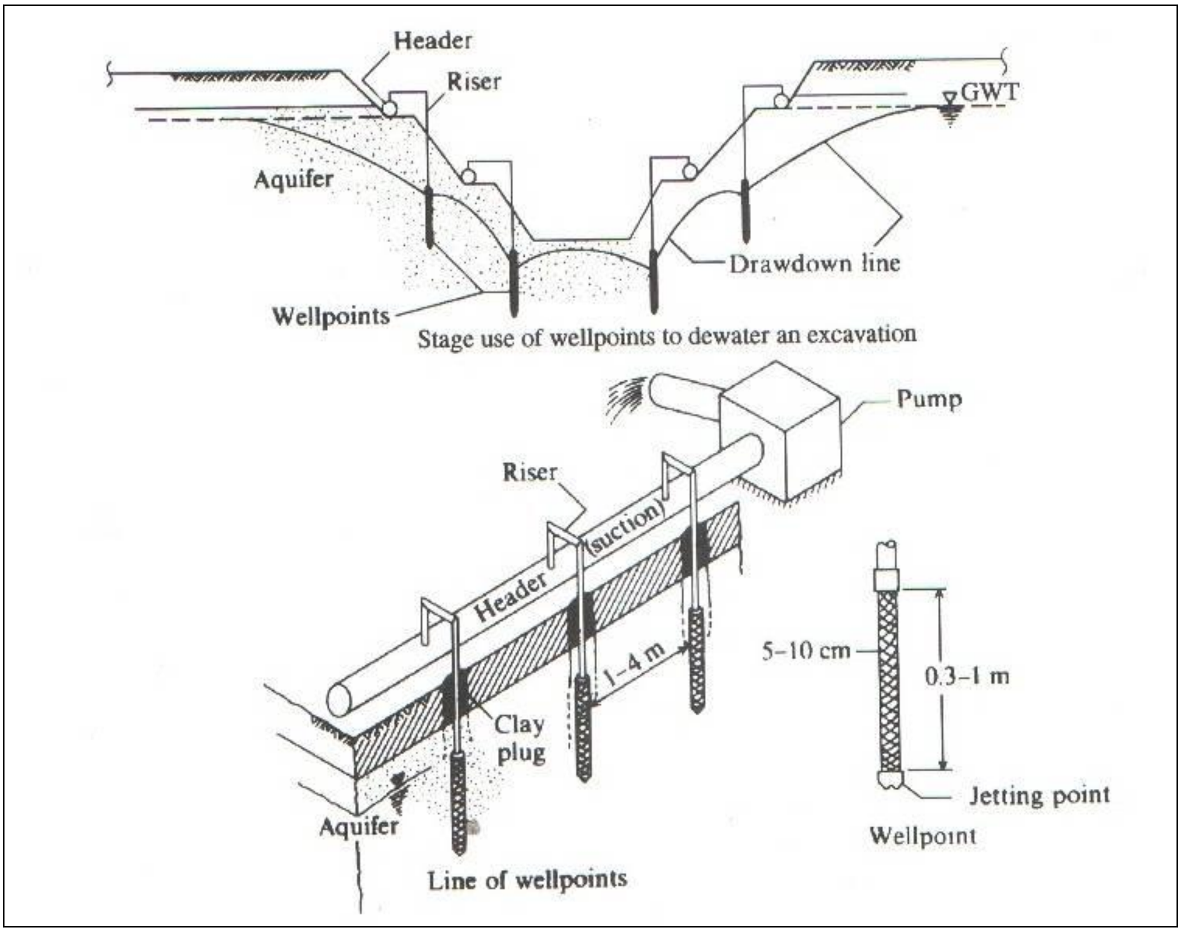

Figure (6.10): Wellpoints Used for Dewatering

Figure 6.11 Plasticity Chart for USCS

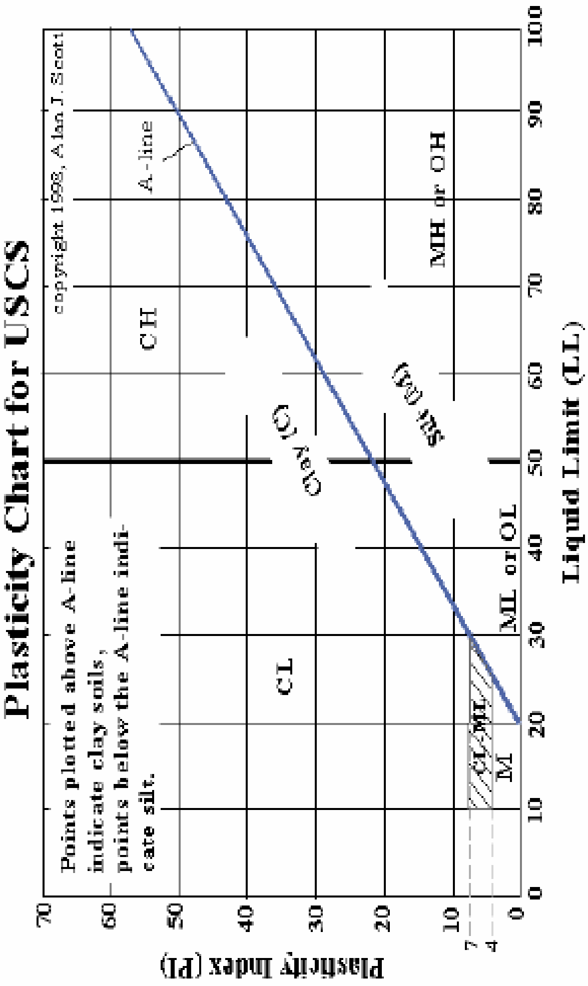

FIG. A-1

Figure 6.12 USCS Procedures

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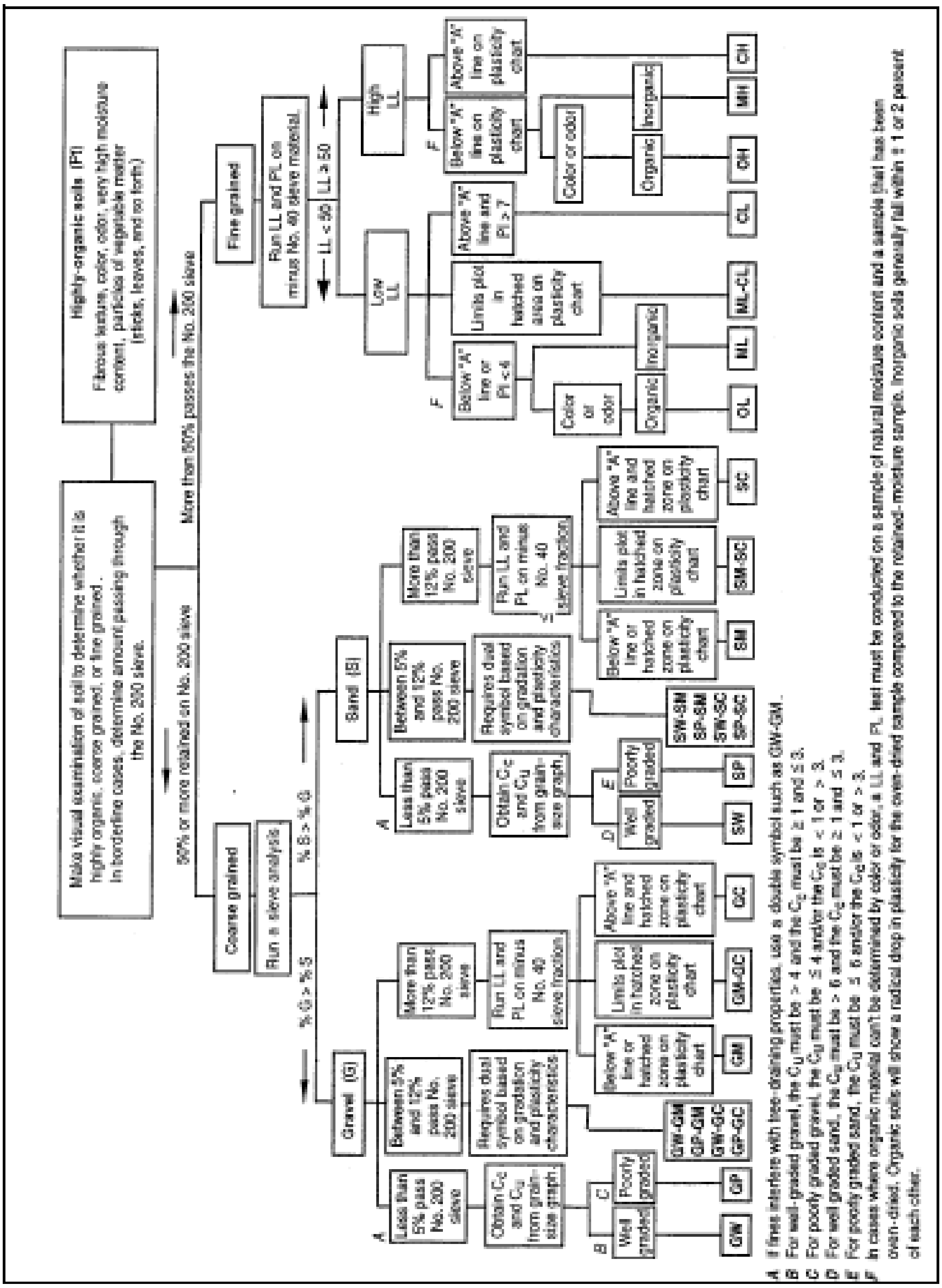

Figure B-1. USCS procedures

Unified Soil Classification System B-3