THE WETLAND SOILS AROUND LAKE NAIVASHA KENYA

Characterization and ecological functions

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BY

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DEDICATION

for

Lord Jesus my saviour, my parents Mr. and Mrs. Jesaya Urassa, my beloved wife Gloria and our sons and daughters.

ABSTRACT

The research was undertaken to characterize and study ecological functions of the Wetland soils at Lake Naivasha. These soils have an important ecological function as they act as a chemical and physical buffer to pollution of the Lake.

With the use of the air photograph interpretation (AIP) and field study, the Wetland soils at Lake Naivasha were identified in the low and lowest terraces of the lacustrine plain. They occupy map units PL443, which is almost flat to flat (% slope 0-2), and PL444 which is characterized by deep papyrus swamps. Some parts map unit PL443 are recently flooded, while map PL444 is permanently flooded. The estimated total area of the wetland soils is 3652 ha. The dry soils in the map unit PL443 classify as loamy semectite Typic Xerochrepts (USDA Soil Survey Stuff, 1996) while the recently flooded soils classify as loamy smectitic Aquic Xerochrepts USDA Soil Survey Stuff, 1996). In the map unit PL444 the soils classify as Hydric Medihemists (USDA-Soil Survey Staff, 1996) and as Fibric-Hisotosls, sodic phase (FAO-Unesco, 1998).

The Wetland soils are moderately well drained to imperfectly drained in the dry area of map PL443 and poorly to very poorly in the flooded soils of PL443 and PL444. The textures vary from sandy loam to sandy clay in the topsoils and silty clay loam to sandy clay loam in the sub soils. In the map PL444 histic materials were found in the topsoils. The colour of the soils range from very dark gray to, very dark grayish brown in topsoils and olive brown to gray in the sub horizons. The chroma range from 1 to2 values 3 to 4 and hue 2.5Y to 5Y.

At total of six sample areas with nine transacts were established and 164 samples collected for the determinations of redox potentials (Eh), electrical conductivity (ECe) and pH. The cation exchange capacity (CEC), organic carbon and exchangeable bases were determined in the dry area, at the waterline and flooded areas at a depth of 50 cm. Statistically these parameters differ significantly at 5% level and have significant correlation at 1% and 5% levels. The redox potentials (Eh) values ranged from +412mV in the dry to -280mV in the flooded areas. The electrical conductivity (ECe) values varied from 0.11mS/cm in the flooded to 2.99 mS/cm in the dry areas (not saline). Most of the pH values range from 8.68 in the dry to 6.57 in the flooded areas, which are very slightly acid, to strongly calcareous. However in the Marula sample areas pH values vary from 4.70 to 5.30 (very strongly acid to strongly acid). The CEC at the depth of 50 cm varied from low 8.80-12.20 meq/100g to medium13.80-25.40 meq/100g to high 26.40-30.60 meq/100cm,(low, medium and high adsorption capacity). The % carbon values at the depth of 50 cm are very low to low values ranging from 0.09 to 1.16%.

The graphs of Eh, ECe and pH values show a general trend of being high in the dry areas, low in the waterline (wet) and even lower, but tend to increase in the subsoils in the flooded areas. The study has shown that the most important ecological functions of the wetland soils is their natural buffer potentials and filtering mechanisms which maintain the quality and quantity of the Lake Naivasha water. Other functions are ground water recharge and storage, water supply, flooded water storage, sediment trapping and wildlife habitat. The study also has shown that the Wetland soils are not vulnerable to pollution from salinity and the agricultural chemicals and fertilizers from the surrounding flower and vegetable farms. Formation of mottles, gley properties and dilutions effects on Eh, ECe, pH and mobility of toxic ions such Fe^{2+} are influenced by the Lake water fluctuations.

Nature and game reserves as a major a land use is suitable and recommended in the Wetland soils and the surrounding areas especially for the purpose of conserving and protecting this soil-scape soils as well as for the quality and quantity of Lake.

ACRONYMS AND ABRIVIATIONS

API	Air photographs interpretation
BP	Before present
CEC or AEC	Cation exchange capacity or Anion exchange capacity
Corr.Coef	Correlation of Coefficient
Cm	Centimeter
DOS	Dean of student
df	degree of freedom
ESM	Environmental Systems Analyses and Monitoring
Eh	Redox potentials
ECe	Electrical conductivity of saturation extract
FAO	Food and Agricultural Organization of the United Nation
GPS	Global Positioning System
GIS	Geographical Information Systems
GRS	Ground water resource survey
ITC	International Institute for Aerospace Surveys and Earth sciences
ILWIS	The Integrated Land and Water Information Systems
ISRIC	international Soil Reference information Center
KWS	Kenya Wildlife Service
LNRAO	Lake Naivasha Riparian Association Owners
m.a.s.l	mean above sea level
M	Meter
NOC	non-organic compounds
OM	Organic matter
PL	Lacustrine Plain
pe	$-\log[e^-]$
pH	$-\log[H^+]$
%C	percentage or total carbon
RS	Remote sensing
t	Tabulated values (statistics)
TM	Thematic mapper (Landsat)
SPSS	Statistical package for social studies
Sig.	Significant deference
UTM	Universal transversal Macerator
USDA	United State Department of agricultural
YMCA	Young missionaries Christian association

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ABRSTRACT ..... **ii**
ACRONYMS AND ABBRIVATIONS ..... **iii**
ACKNOWLEDGEMENTS ..... **iv**
TABLE OF CONTENTS ..... **v**
LIST OF FIGURES ..... **x**
LIST OF PLATES ..... **xi**
LIST OF TABLES ..... **xii**
LIST OF APPENDIXES ..... **xiii**

TABLE OF CONTENTS

CHAPTER 1
1.0 INTRODUCTION **1**
1.1 Problem formulation 3
1.2 Research hypothesis 3
1.3 Research objectives 4
1.3.1 Broad objective 4
1.3.2 Specific objective 4
1.4 Research questions 4

CHAPTER 2
2.0 BACKGROUND INFORMATION **6**
2.1 Background information of the problem 6
2.1.1 Importance of the Lake Naivasha to Kenya 6
2.1.2 Lake Naivasha management systems 6
2.1.3 The Ramsar Site 1995 7
2.1.4 Threats to Lake Naivasha's resources 7
2.4.4.1 Inappropriate activities on the Riparian Land 7
2.4.4.2 Threats from within the catchment 8
2.1.4.3 Water pollution 8
2.2 Size and location of the study area 9
2.3 Relief 11
2.4 Geology and geomorphology 11
2.4.1 Geomorphology 11
2.4.1.1 The lacustrine plain (Pl) 11
2.4.1.2 The volcanic plain (Pv) 11
2.4.2 Geology 12
2.5 Climate 14
2.5.1 Rainfall 14
2.5.2 Temperature 16
2.5.3 Evaporation 16
2.5.4 Radiation 17
2.5.5 Soil climate 17
2.5.5.1 Soil Moisture Regime (SMR) 17
2.5.5.2 Soil temperature regime (STR) 18
2.6 Landuse and Vegetation 18
2.6.1 Vegetation 18
2.6.2 Agriculture 19
2.6.3 Wildlife 21

2.7 General soils of the Lake Naivasha..... 21
2.8 Hydrology..... 22
2.9 Lake Naivasha water fluctuation..... 23

CHAPTER 3
3.0 LITERATURE REVIEW..... 25
3.1 Soil ecological functions..... 25
3.1.1 Soil minerals..... 25
3.1.2 Soil organic matter..... 26
3.1.3 Soil water..... 27
3.1.4 Soil atmosphere..... 28
3.1.5 Soil temperature..... 29
3.2 Wetland soils..... 30
3.2.1 Definition of Wetland..... 30
3.2.2 Wetlands Identification..... 30
3.2.3 Importance of the Wetlands..... 32
3.3 Anaerobic processes..... 33
3.4 Soil pH..... 34
3.5 Soil electrical conductivity..... 35
3.6 Soil redox potential..... 35
3.6.1 Eh versus pH..... 37
3.6.2 Determination of redox potential in the soil..... 38
3.6.3 Use of the redox potential..... 38
3.7 Gleying processes..... 39
3.7.1 Groundwater gley or normal gley..... 39
3.7.2 Surface water gley or pseudogley..... 40
3.8 Vulnerability of the soil and water to pollution..... 42
3.8.1 Source of pollution..... 42
3.8.2 Contaminants of water and soils..... 43
3.8.3 Behaviour of some inorganic contaminants in the soils..... 43
3.9 Importance of soils characterization..... 44
3.10 Definitions of terminology..... 44

CHAPTER 4

4.0 MATERIALS AND METHODS..... 46

4.1 Pre-fieldwork phase..... 46

4.1.1 Problem analysis..... 46

4.1.2 Identification of data needs..... 47

4.2 Fieldwork phase..... 47

4.2.1 Primary data..... 47

4.2.1 Secondary data..... 49

4.3 Post fieldwork phase..... 49

4.3.1 Data entry to the data base..... 49

4.3.2 Data analysis..... 49

4.4 Field and laboratory techniques..... 50

4.5 Instruments and materials..... 50

CHAPTER 5

5.0 RESULTS AND DISCUSSIONS..... 52

5.1 General introduction..... 52

5.2 Statistical analysis..... 52

5.2.1 Introduction..... 52

5.2.2 Test of normality..... 52

5.2.3 Non parametric test..... 53

5.2.4 Non parametric correlation..... 53

5.2.5 Test Statistic..... 54

5.2.5.1 Redox potential (Eh) 54

5.2.5.2 pH..... 55

5.2.5.3 Electrical conductivity (ECe) 55

5.2.6 Discussion..... 55

5.2.7 Conclusion..... 56

5.3 Identification, description and classification of the Wetland soil..... 57

5.3.1 Introduction..... 57

5.3.2 Mapping Unit PL443..... 57

5.3.2.1 Sample area 1: KWS Annex..... 57

5.3.2.2 Sample area 2: YMCA Club..... 58

5.3.2.3 Sample area 3: Longonot farm..... 59
5.3.2.4 Sample area 4: Yatch Club..... 59
5.3.2.5 Sample area 5: Marula farm..... 60
5.3.2.6 Sample area 6: Delamere farm..... 60
5.3.3 Mapping Unit PL444..... 61
5.3.2.1 Sample area 1: KWS Annex..... 61
5.3.4 Discussion..... 61
5.3.5 Conclusion..... 63
5.4 Characterizsation..... 65
5.4.1 Introduction..... 65
5.4.2 Physical Characterization..... 66
5.4.2.1 Soil Colour..... 66
5.4.2.2 The soil s texture..... 66
5.4.2.3 The soil structure..... 66
5.4.2.4 The Mottles..... 66
5.4.2.5 Gley..... 67
5.4.3 Chemical characterization..... 67
5.4.3.1 Cation Exachange Capacity (CEC)..... 67
5.4.3.2 Organic Carbon (%C)..... 67
5.4.3.3 Redox potential (Eh)..... 67
5.4.3.4 Electrical conductivity (ECe)..... 69
5.4.3.5 pH..... 70
5.4.3.6 Discussion..... 71
5.4.3.7 Conclusion..... 74
5.5 Ecological functions of the Wetland soils..... 75
5.5.1 Introduction..... 75
5.5.2 Buffer and sediment trapping roles..... 75
5.5.3 Groundwater and storage..... 76
5.5.4 Water supply..... 77
5.5.5 Flooded water storage..... 77
5.5.6 Wildlife habitat sites..... 78
5.5.6 Conclusion..... 78
5.6 Vulnerability of Wetland soils to pollution..... 78
5.6.1 Introduction..... 78

5.6.2 The pH..... 79
5.6.3 Eh-pH diagram..... 79
5.6.4 Electrical conductivity..... 80
5.6.5 Cation exchange capacity (CEC)..... 80
5.6.6 Organic matter..... 81
5.6.7 Discussion..... 81
5.6.8 Conclusion..... 82
5.7 Effects of Lake water fluctuation on the Wetland soils..... 82
5.7.1 Introduction..... 82
5.7.2. Discussion..... 84
5.7.2.1 Effects of Lake fluctuation on biota..... 84
5.7.2.2 Effects on soil properties..... 84
5.7.3 Conclusion..... 85
5.8 Evaluation of Wetland soils to other uses..... 85
5.8.1 Introduction..... 85
5.8.2 Discussion..... 85
5.8.3 Conclusion..... 86

CHAPTER 6
6.0 FINAL CONCLUSIONS AND RECOMMENDATIONS..... 87
6.1 Conclusions..... 87
6.2 Recommendations..... 91

REFERENCES..... 92
APPENDIXES..... 99

LIST OF FIGURES

Figure1.1	Problem analysis of the study area.....	5
Figure2.1a	Location of Kenya in Africa	10
Figure2.1b	Location of the study area.....	10
Figure2.2	Base map of the study area.....	10
Figure2.3	Topographic map of the Lake Naivasha.....	11
Figure2.4	Geological map of the Lake Naivasha.....	14
Figure2.5	Bar graph mean monthly rainfall for Naivasha.....	15
Figure2.6	Naivasha rainfall trends 1960 –90.....	16
Figure2.7	Monthly temperature of the Naivasha.....	16
Figure2.8	Climatic graphs.....	17
Figure2.9	Landuse map.....	21
Figure3.1	Eh versus pH characteristics of the soils.....	38
Figure3.2	Precipitation sites of iron and manganese oxides in normal and pseudogley.....	41
Figure3.3	Threshold redox potential	41
Figure3.4	Anthropgenic pollution of the soil-plant and animals.....	42
Figure4.1	The major time phases.....	46
Figure4.2	An example of transact I in the Wetland soil at KWS annex.....	48
Figure5.1	Distribution of the Wetland soils at Lake Naivasha.....	64
Figure5.2	Location of the transacts and sample areas.....	65
Figure5.3	Major Wetland soils in the low and lowest terraces of the lacustrine plain at Lake Naivasha.....	64
Figure5.4	Redox potential (Eh) variations with transacts1 in the KWS Annex sample area.....	68
Figure5.5	Redox potential (Eh) variations with depths in the transact I of KWS sample areas.....	69
Figure5.6	Electrical conductivity (ECe) variations with transact I in the KWS Annex sample area.....	69
Figure5.7	Electrical conductivity (ECe) variations with depth in transact I of KWS Annex sample areas.....	70
Figure5.8	pH variations with transact I in the KWS Annex sample areas..... ...	70
Figure5.9	pH variation with depth in the transact I at the KWS Annex sample areas.....	71
Figure5.10	Perched watertable depths along the transacts in the Wetland soils.....	77
Figure5.11	Eh-pH characteristic of the Wetland soils at Lake Naivasha.....	79
Figure5.12	Iron mobility in the Wetland soils at Lake Naivasha.....	80
Figure5.13	Historical Lake level fluctuation of the Lake Naivasha.....	83

LIST OF PLATES

Plate 1. KWS Annex: South of transact 2. Buffaloes feeding in the recently flooded area..... 19

Plate 2. Longonot sample area; Landuse in the low terrace of map PL443. Note sprinkler irrigated cabbage, beans and tomatoes..... 20

Plate 3. KWS Annex: South North of the transact II, buffaloes in the recently flooded area in the lower terrace map unit Pl443..... 21

Plate 4. Yacht Club transact runs from left to right. (dry land to recently flooded areas in the low terrace map unit pL443..... 23

Plate 5. KWS Annex, transact1, view south recently flooded riparian area with water hyacinth (fore-ground) depth 20 to 50 cm) grass vegetation (water depth 0-20 cm) and dry land..... 24

Plate 6. KWS Annex, transact view NW; showing irregular waterline area and recently flooded areas of low terrace map unit PL443..... 24

Plate 8. KWS Annex, transact II view West, showing sequence from dry to recently flood riparian zone. In the background papyrus vegetation..... 50

Plate 9. KWS Annex, transact 3; observation in the permanently flooded area, in the papyrus zone..... 51

Plate 10. Collecting soil samples from observation in KWS Annex, transact no 3. Note ranger on the guard up against buffaloes and hippos..... 51

Plate 11. Yacht club sample area map unit PL443. Note recently flooded areas... 83

LIST OF TABLES

Table2.1	Potential source of pollution at lake Naivasha.....	9
Table2.2	Major volcanic and deformation episodes.....	12
Table2.3	Analyses of pumice from Lake Naivasha.....	13
Table3.1	Soil moisture tolerance levels for different microbial activity.....	28
Table3.2	The realtion between soil pore necksize and pore water availability to plant roots.....	28
Table3.3	Criteria for hydric soils.....	31
Table3.4	Description terms and proposed buffering mechanisms of various soil pH ranges.....	34
Table3.5	The USDA classification of the affected salts.....	35
Table3.6	Redox reaction.....	36
Table3.7	Sequence of terminal electron acceptors used in the soil environment with associated redox potential scale at pH 7.0.....	37
Table5.1	Test of normality.....	52
Table5.2	Non parametric correlations.....	54
Table5.3	Test Statistics[a,b].....	55
Table5.4	Analytical data of transact I at the KWS Annex sample area.....	68
Table5.5	Exchangeable cation values ratings (meq/100g).....	74
Table5.6	Rating of the organic carbon.....	74
Table5.7	Evaluation of the physico-chemical evaluation by CEC measurement...	81
Table5.8	Lake water fluctuation.....	84
Table5.9	Summary of land characteristic of the Wetland soils at Lake Naivasha.....	86

LIST OF APPENDIXES

Appendix I	List of the chemical used around Lake Naivasha.....	99
Appendix II	Histogram and relation hips of variable of variable in the transacts.....	100
Appendix III	Description of the observations in the KWS Annex sample area	101
Appendix IV	Description of the observations in the YMCA Club sample area.....	110
Appendix V	Description of the observations in the Longonot farm sample area.....	114
Appendix VI	Description of the observations in the Yacht Club sample area.....	118
Appendix VII	Description of the observations in the Marula farm sample area.....	122
Appendix VIII	Description of the observation s in the Delamere area.....	124
Appendix IX	Graphs of the redox potentials (Eh) variations for the KWS Annex transacts II and III, YMCA Club, Longonot farm, Yacht Club, Marula far and Delamare sample areas.....	128
Appendix X	Graphs of the electrical conductivity (ECe) variation for the KWS Annex transact II and III, YMCA Club, Longonot farm, Yacht Club, Marula farm and Delamere farm sample areas...	131
Appendix XI	Graphs of the pH variations for the KWS Annex transact II and III, YMCA Club, Longonot farm, Yacht Club, Marula farm and Delamere farm sample areas.....	134
Appendix XII	Analytical data of the transact II and III in the KWS Annex sample areas.....	137
Appendix XIII	Analytical data of the YMCA Club sample area.....	138
Appendix XIV	Analytical data of the Longonot farm sample area.....	139
Appendix XV	Analytical data of the Yacht Club sample area.....	140
Appendix XVI	Analytical data of the Marula farm sample area.....	141
Appendix XVII	Analytical sample areas of the Delamere transacts I and II.....	141
Appendix XVIII	Exchangeable cation of the Wetland soils.....	142

CHAPTER 1

1. INTRODUCTION

Due to the environmental and socio-economic benefits of Wetland resources to the society, there is a growing concern in tropical Africa and the world over for protection and preservation of these areas through national policies. The rate at which these Wetland resources are used has led to research on identification and assessment of their distribution and use potential.

Since there are different types of wetlands, a single definition can not be used to characterize adequately these ecosystems (Gowardian *et al.,* 1979). In tropical Africa, Wetlands have been described as ***"areas of land that are permanently, seasonal or occasionally waterlogged with fresh, saline, brackish or marine waters including both natural and man made areas that support characteristics biota"*** (Denny, 1985) and Njuguna *et al.*, 1996). The important single features that most Wetlands share is soil that is, at least periodically, inundated by a rising water table or flooding (Reddy and Patrick, 1993).

The Wetlands are important natural resources of the biosphere. The values and functions of these areas include groundwater recharge, water supply, floodwater storage, sediment trapping, pollution control and wildlife habitat storage (Mitsch and Gosselink, 1986).

The Wetlands at Lake Naivasha are National and International recognized as a "*Ramsar site"* with a rich biodiversity.

"A Ramsar site is a wetland designated as the Ramsar list of Wetland of International importance especially as a waterfowl habitat, and also significant in terms of ecology, botany, zoology, liminology, or hydrology. It is bound by the Ramsar Convention which provides a framework for international cooperation for the convention and wise use of the Wetlands (Frazier, 1996)."

Other areas in Lake Naivasha designated as the *Ramsar sites* include agricultural, horticultural and game reserve areas around the Lake.

The major Wetland soils at Lake Naivasha in relation to the Riparian zone are those areas surrounding the Lake, which are subjected to water fluctuations as Lake water levels increase or decrease for many years. They include flooding areas almost flat to flat (% slope 0-2) in the map unit PL443 and the deep papyrus swamps in the map unit PL444. The flooding areas are important for receiving excess water from the Lake, water from the rivers, sediments and wastes from agricultural farms. The papyrus swamp areas are important for the existence of a papyrus. The distribution and location of the characteristic, species *C. papyrus* in the Wetland soils indicates the hydrological regime for specific area and is known to modify water quality. They are also the habitat for numerous birds and animals.

The increasing awareness of the value resource of the Wetlands in Lake Naivasha has necessitated for the improvements in the management and conservation through the promotion of awareness and policy guidelines on sustainable utilization. However, lack of appropriate information for this purpose is a major limitation. Despite the fact that a considerable amount of relevant research has been relevant on the Lake (LNROA, 1995) much of the work has left the management with yet numerous questions to answer.

In The Environmental Impact Assessment (John Goldson Associates, 1993) identified several information gaps. One of which is within the program of monitoring pollution, should receive particular attention including control of irrigation run off, papyrus maintenance, and pesticide and plastic use and disposal. Wetland soils are important receiving sites of pollutants. Therefore the present research on Wetland soils will provide important soil and water information, which will assist the management in monitoring pollution around the lake and catchment areas.

1.1 Problem formulation

There is a direct interrelationship between the Wetland soils, the water level of Lake Naivasha and human activities. Due to their ecological functions, the Wetland soils play an important role in keeping balance within fragile ecosystems. The system is subject to natural fluctuating Lake water levels on one side, and to intensive human activities that induce pollution and Lake water volume reduction due to extraction of the water, on the other site (LNROA, 1995)

The available natural resources and the Lake's environs support large and vitally important variety of economic activities around the Lake. They include intensive irrigation-based agriculture, geothermal power, fishery and tourist industries. The Lake Naivasha area is reported to be a major contributor to Kenya's GDP (Gross Domestic Product), employment effort as well as to socio-economic development of the country as whole (LNROA, 1995). Also the rivers and groundwater sources provide water supply to Naivasha and Nakuru Township.

However, these activities put heavy pressure on the Lake and its environment. Intensive use of the land and Lake waters in a closed basin system, makes it susceptible to pollution hazards from farm lands, settlement, industries, and river inflows (LNROA, 1995). Lal and Stewart (1994) indicated that agricultural activities could have adverse effects on quality on surface and groundwater and on consumptive use. Also improper handling and disposal of agricultural chemicals, fertilizers and wastes in the soils may cause pollution (Tan, 1994).
The divers ecological cause/ effect relationships of the Lake Naivasha are schematically presented in Fig. 1.1

The retained chemicals may change some soil properties such as soil pH, Electrode potential (Eh) and electrical conductivity (ECe). In a research carried around Lake Naivasha, (Kwacha, 1998) observed that pH, C, Ca, ECe, Mn, Na and P are liable to

change. He concluded that these changes mighty be caused by continuous land use (flower and horticultural cultivation) and intensive use of agrochemicals

The lake is also under threat of nutrient enrichment from urban and agricultural activities in its catchment and surroundings. The loss of Papyrus between 1983 and 1988 has been due solely to clearance for both large-scale and subsistence agriculture as the lake levels declined (Harper *et al.,* 1990). It is inevitable that this process has increased the nutrients levels in the lake both through leaching and runoff directly from the farmed area (Njuguna., 1982) and through the loss of the swamp's buffering effect in the inflowing river (Gaudent, 1980). Nutrient concentrations measured in the Lake had approximately doubled between August 1984 and august 1988, e.g. from a median of 45 to 125 mg per m^3 of soluble nitrogen and from 5 to 12 mg per m^3 of soluble phosphorus (Harper *et al.,* 1990).
Discharges from highly fertilized agricultural lands give rise to nuisance growth of aquatic plants such as algae blooms, resulting from increased nutrients load of Phosphorus and Nitrogen, leading to decreased water transparency and decrease in dissolved oxygen concentrations. Harper *at al.,* (1990) observed changes in the rooted aquatic vegetation, had been an increase in the phytoplankton; the standing crop biomass had risen from around $20mg/m^2$ in 1987. The transparency of the Lake's water measured by Secchi Disc, decreased over the same time period from a mean of the 164 cm to 40 cm and the lake is now displaying signs of eutrophication (Harper *et al.,* 1990)

Inappropriate activities such as construction of permanent structures, drainage of land for land cultivation, especially intensive irrigated agriculture and the use of agrochemical in the Riparian zone of lake Naivasha, may have great impact on the lake and its surrounding environment. Riparian zone is fringing zone around Lake Naivasha, which most Wetland soils found. The present research focuses on the Wetland soils around the Lake, their characterization and ecological functions. Information on these soils and understanding their ecological functions will assist the LNRA management plan to properly monitor soil and lake water pollution as suggested by the Environmental Impact study.

1.2 Research Hypothesis

The Wetland soils act as a chemical and physical buffer to pollution of Lake Naivasha

1.3 Research Objectives

1.3.1. Broad objective

To characterize Wetland Soils and study their ecological functions in relation to the Lake Naivasha environment and recommend appropriate measures which can be applied to improve practical management of Wetland soils and associated areas.

1.3.2 . Specific objective

1.3.2.1. Identify, describe and classify the major Wetland soils in the lake Naivasha area

1.3.2.2. Characterization in terms of their physical and chemical properties

1.3.2.3. Assess their role as a buffer in relation to Lake water quality and quantity

1.3.2.4. Assess their vulnerability to pollution and contamination

1.3.2.5. To find out 'if any' the effect of lake water (hydrology) fluctuations on the Wetland soils and Lake environment

1.3.2.6. Evaluate their suitability for other uses

1.4 Research questions

1.4.3.1 What are the major soils types on the Wetland soils of the Lake Naivasha?

1.4.3.2 What are the soil properties/parameters, which are most affected by application of agrochemical and responsible for buffering effects of the Wetland soil?

1.4.3.3. What are the roles/ ecological functions of Wetland soil to Lake and associated areas?

1.4.3.4.What are the different activities/(land uses) are being carried and agrochemical used on the Wetland soils and around lake Naivasha?

1.4.3.5 What are the effects of lake water fluctuations on the Wetland soils and environment in general?

1.4.3.6.What are consequences/effects of expansion of agriculture activities to the Wetland soil, to lake and environment in general?

1.4.3.7.What are the ways in which pollutants/agrochemical move to the Lake and observable impact of pollution to the Wetland soils, Lake and surrounding environment?

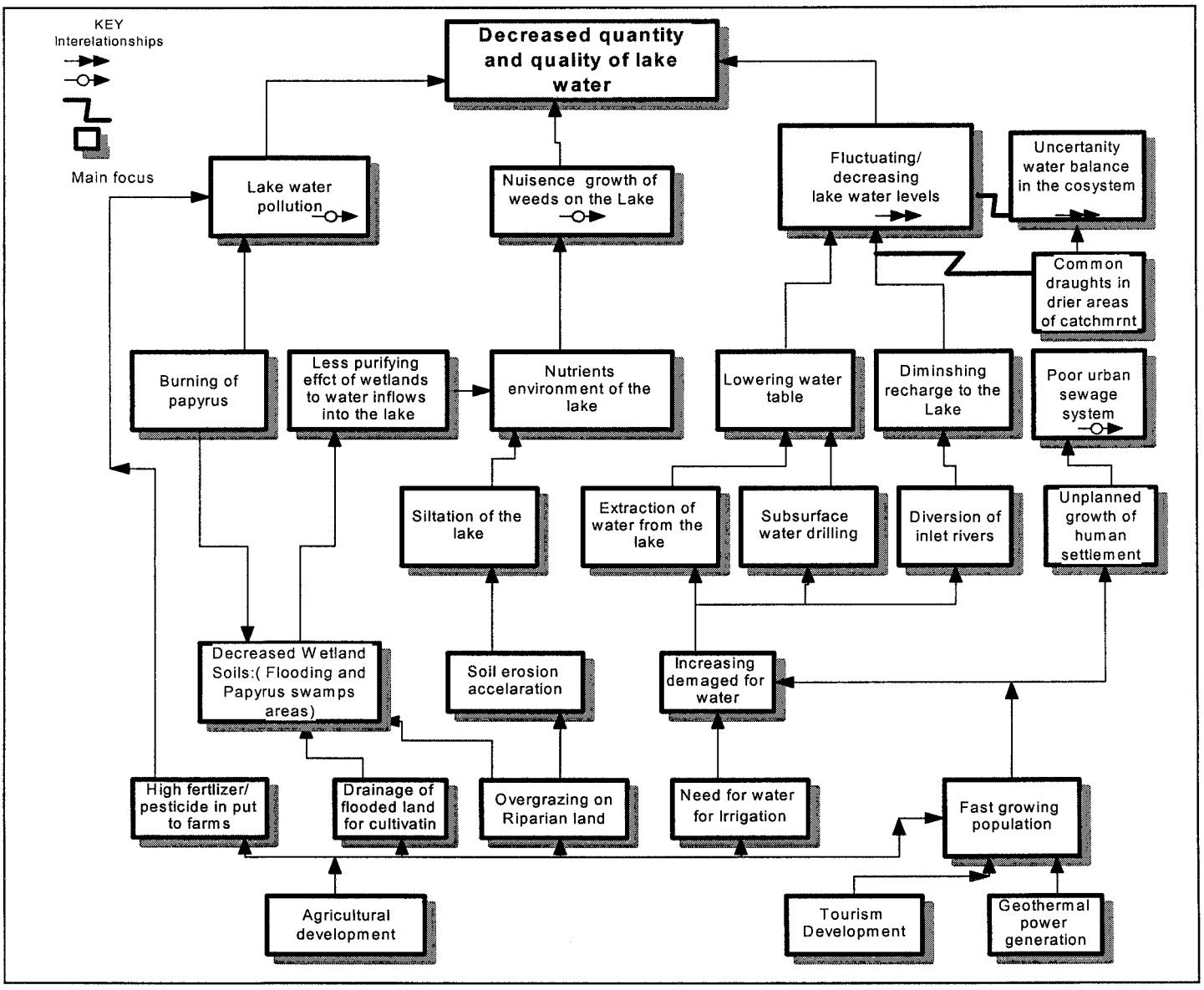

Fig. 1.1 Problem analysis of the study area (around Lake Naivasha)

CHAPTER 2

2.0 BACKGROUND INFROMATION

2.1 Background information of the problem

2.1.1. Importance of Lake Naivasha to Kenya

Lake Naivasha is an important freshwater resource for Kenya's foreign-earning agriculture and tourism and for water supply (Harper *et al.*, 1990; LNROA, 1995). It is also an important ecological site to Kenya, due to its diversity of flora and fauna in the range of vegetation-zones associated with the Lake and its hinterland, which is greater than that of any other rift valley lake (Lincer *et al.,* 1981). The area of Lake Naivasha also has high economic value; cattle-watering by Maasai in former times has given way during the past century to settled agriculture- including the raising the present of export cash crops around its shores- although this agriculture is heavily dependent upon Lake water for irrigation.

Lake Naivasha is also a focus for tourism and recreation, which has been growing in volume ever since the first sport- fishing began in the late 1920s. Its catchment streams provide the main water supplies for both Naivasha and Nakuru towns. Most recently, the area has become industrially significant as a consequence of the development of Olkaria, just to the south of the Lake as a site for geothermal energy generation producing about 43 meg-watts, which is 15% of the Kenya's total energy consumption (Harper *et al.*, 1990).

The key to both ecological and economical values is the freshness of the Lake's water, in contrast to most of the eastern rift valley lakes, which are saline. This is due in part to the large catchment area in the Nyandarua Mountain range and part to outflow processes. Gaudet and Melack (1981) and Ase (1987) showed that the lake was hydrologically a seepage lake, with input via ground- water seepage in the northern area and outflow in the southern area. They concluded that the Lake remained fresh partly because of the biochemical and geochemical sedimentation removing certain ions such as Sulphate and Carbon.

2.1.2. Lake Naivasha management systems

Two bodies have a direct control over some aspects of Lake Naivasha (Harper *et al.*, 1990; LNROA, 1995). The Department of Fisheries manages the fishery by the issue of licenses and enforcement of mesh-size regulations. The Ministry of Water Development issues licenses for the water abstraction for irrigation . Several other bodies have interest in the Lake, such as local government agencies at Provincial, District and Town council, levels; national bodies, such as the President's commission on the Soil conservation and Afforestation, and local bodies such as the Lake Naivasha Riparian Owner's Association are the main ones. The Department of Wildlife Conservation and Management now has an increasing local interest as two areas adjacent to the lake-Longonot Volcano and Njorowa Gorge (Hell's Gate)- were declared National Parks 1983.

In 1931, Government granted the land fringing Lake Naivasha (Riparian land) to the adjacent landowners to conserve, as long as there was no permanent structure installed (John Goldson Associates, 1993). The landowners through the Lake Naivasha Riparian Owners Association (LNROA, have concerted efforts to direct the activities through a management plan of 1995. The prime objective is to manage the existing human activities in the Lake ecosystem through voluntarily adopted sustainable "wise use" principles to ensure its conservation.

For the purposes of the management plan, the area around Lake Naivasha was divided into two zones: The Lake zone, which comprises wetlands and riparian area around Lake Naivasha, which covers about 30,000 ha. and the catchment which is the drier and steeper zone, covering about 3,200 km. sq. The particular plans pertaining to Riparian land include:
-protect and where necessary re-establish the Papyrus fringe around the Lake and allow its natural growth
-discourage the reclamation of the flooded land, intensive irrigated agriculture, and building of permanent structures, below the 1906 lake level or 1893.3 masl, (6210' contour):
-establish accepted codes of practice in pest use, publish a list of acceptable products and monitor their use, publish a list of unacceptable chemicals and outlaw their use.

2.1.3. The Ramsar Site 1995

In 1995 the Lake Naivasha Wetland was designated as a Ramsar site. Frazier (1996) indicated that under Articles 3.1 of the Ramsar convention, of which Kenya is a contracting party, the country is obliged to develop a national wetland policy and include wetland conservation and wise use considerations within their land use planning plus maintaining the ecological character of the site.

2.1.4 Threats to Lake Naivasha's resources

The Lake Naivasha management plan of 1995 (LNROA, 1995) indicated several threats to sustainable utilization of Lake Naivasha freshwater resources. For the purpose of this study the following threats have been explained.

2.1.4.1 Inappropriate activities on Riparian Land

The following activities were considered as inappropriate or illegal on Riparian land i.e. land below the 1906 Lake level or 1893.3 masl, (6210' contour):
-construction of permanent structures including buildings, sewage works, septic tanks and cattle dips ;-drainage of land for cultivation;-destruction of Papyrus;
-conversion of the buffer zone behind the Papyrus fringe from other than its natural state;
-intensive irrigated agriculture particularly involving the use of fertilizers or pesticides.

2.1.4.2 Threats from within the catchment

Increasing population growth and intensive land utilization in the catchment is likely to: -accelerate the rate of soil erosion and consequently cause increased siltation and nutrient enrichment in the Lake; -impoverish the soil, hence increase the need for agrochemicals as farm inputs; - increase destruction of forest cover to open steep slopes to cultivation, charcoal burning; -encourage unplanned growth of human settlements in Naivasha town and other satellite areas; -increase demand for food thus promoting intensive farming practices that may cause high water use and runoff pollution into, the rivers;-increased demand for water abstraction from the rivers for domestic and power generation purposes.

2.1.4.3 Water pollution

The 250,000 people living around Lake Naivasha (often inadequate housing and unsanitary living conditions) are potential threat to soil and water pollution (LNROA, 1995). Due to lack of resources, the Council has failed to compound the problem of urban sewage system, which has broken down causing sewage effluent. Impervious surfaces and storm runoff will increase as the population of the municipality grows and the opportunities for increased industrial pollution of the Lake may rise.

Increased use of pesticides also threats the life of the lake, especially through bio-magnification in the food chain. This needs to be addressed by promoting knowledge about and commitment to environmental issues amongst the farmers. Unchecked commercial fishing activities have also the potential to seriously pollute the Lake water. Table 2.1 summarizes the potential sources of the pollution to Lake Naivasha and its environments unless properly managed.

Table 2. 1 Potential sources of pollution

Source of Pollutants	Estimated Magnitude	Remarks
Agriculture	Significant	Mainly agro-chemicals and silt
Municipal and domestic	Significant	Expected to increase with adequate water supply to the town and others settlements
Rivers and Catchment	Significant	Sediment discharge into the Lake cause siltation and delta formation at the river mouth
Industrial	Significant	Mainly from flash floods from town, industrial developments, air and river pollution
Airborne	Negligible	Acid rain reported but not substantiated
Recreation & Touring	Negligible	Little evidence at present

Source: LNROA, 1995

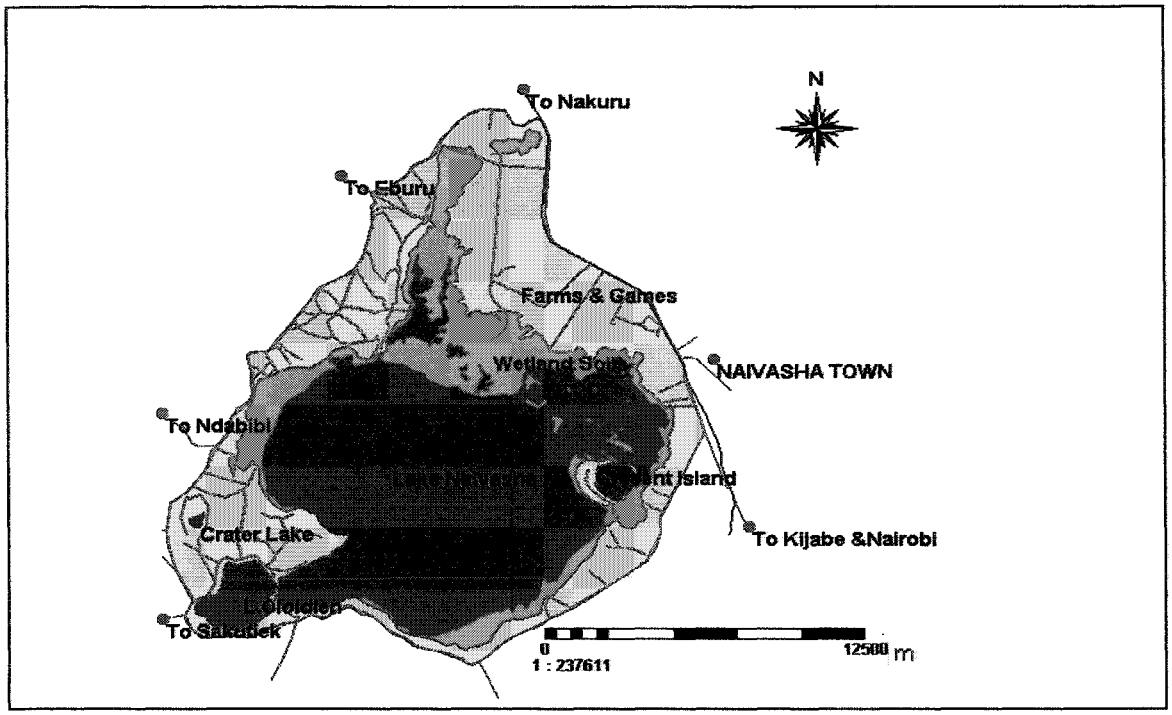

Fig. 2.2 Base map of study area

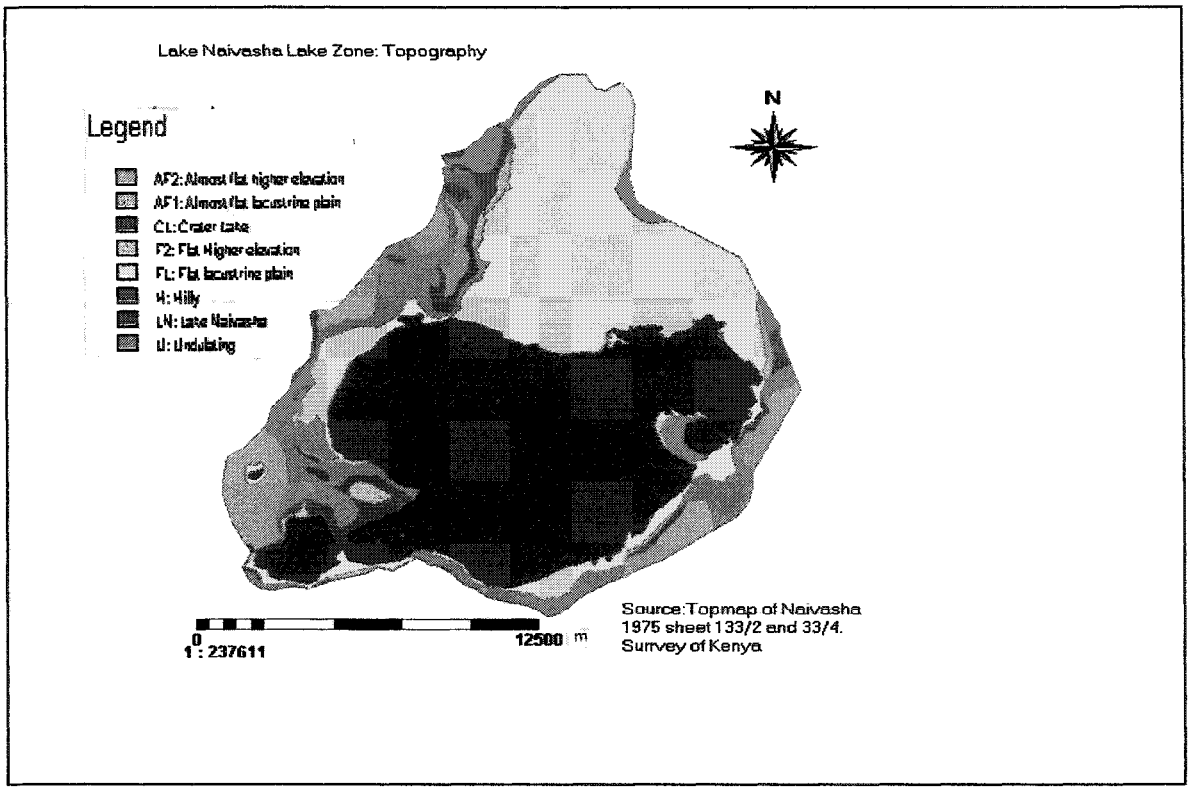

Fig. 2.3 Topographic map of Naivasha

The Lake Naivasha has an altitude, which ranges from 1900 to 2060 m.a.s.l. The associated area is basically a lacustrine plain with a topography that is predominantly flat to gently sloping. Parts of the western offshore areas are moderately.

2.4 Geology and geomorphology

2.4.1 Geomorphology

Thompson *et al.,* (1958) indicated three main geomorphological units in the study area. They are Escarpment to the west, the Kinangop Plateau to the east and in between the highlands, the Rift valley plains. According to geopedological approach (Zink, 1988) two main landscapes can be identified in Lake Naivasha area.

2.4.1.1 The lacustrine plain (Pl)

The lacustrine plain occurs around the Lake and extends between an altitude of approximately 1850 to 1920 m.a.s.l. The plain is largely covered with sediments derived from erosion of the surrounding volcanic rocks of the rift margins. The sediments have been formed in the lacustrine environment during the Gamblian stage of the Pleistocene period, and are commonly referred to as Gamblian sediments. Despite their extensive distribution, the lake sediments are not thick and rarely exceed 30 m (Thompson *et al.,* 1958). At the level of relief and molding, low, middle and higher terraces differentiate the plain. The terraces have been formed by the fluctuations of Lake Water Levels that have occurred in different periods. The lithology of the plain includes sand and pebble beds, and gravels comprised of the pumice clasts (Stuttard *et al.,* 1996). Quaternary alluvial also forms a minor part of the Naivasha. Treads and risers were also identified at landform level and the area is flat to gently undulating topography (slope up to 4%) non-dissected and no distinct drainage channel.

2.4.1.2. The volcanic plain (Pv)

The volcanic plain is associated with the lacustrine plain. The plain has resulted from the lava flow from Longonot and wind deposition of pyroclastic materials (Thompson *et al,* 1958). At the relief level the plain can be divided into slightly undulating lava, long ridges and extensive non-to slightly dissected Plain. The lithology of the plain consists of pyroclastic materials and Akira pumice on the long ridges. Thompson *et al.,* (1958) explained the lithology of the volcanic rocks of the Naivasha area which can be classified as basalts, tephrites, phonolites, trachytes, thyolites, tomendites and tyroclastics. The topography is non-dissected to slightly dissected with slopes of about 5%.

2.4.2. Geology

2.4.2. Geology

The Lake Naivasha area is covered by two types of Quaternary deposits of mainly lacustrine deposits and volcanic origin (Thompson *et al.,* 1958). According to Ministry of Energy (1990) the area around Lake Naivasha is geologically very young, with all rocks and structures having formed during the past 4 Ma (million years). Baker *et al.*,(1988) also indicated four major periods of volcanic activities (VI - V4) and faulting (FI- F4) which led to present situation. Table. 2.2 summaries these activities.

Table 2.2 Major Volcanic and Deformation Episodes.

EPISODE		ACTIVITY	AGE RANGE
V4	F4	Late Quaternary to recent salic volcanoes Extensive minor faulting of rift floor	0.4 - 0 Ma 0.8- 0.4 Ma
V3	F3	Quaternary flood lavas of rift floor Renewed faulting of rifting margins	1.65-0.9 Ma 1.7 Ma
V2	F2	Early quaternary flood trachytes Formation of steep faults(narrowing of graben)	2.0- 1.8 Ma 3-2 Ma
V1	F1	Pliocene ash flows Major faulting of eastern rift margin	3.7 -3.4 Ma 4 - 3 Ma

Source: Ministry of Energy, 1988.

According to Thompson *et al.,* (1958) and Clarke (1990), Quaternary deposits of lacustrine and volcanic origin, are found on the study area. The deposits in addition to clays and silts also contain a large proportion of volcanic material in the form of ashes. The oldest rocks found in situ in Naivasha area have been described as belonging to the Tertiary era and some rock fragments ejected by numerous volcanoes in the in the area may be of the an older age. The volcanic rocks in the area consist of the tephrites, basalt, trachytes, phonolites, ashes, tuffs, agglomerates and the acid lavas, rhyolites, comendites and obsidian. (Thompson *et al.,* 1958).

Volcanic rocks can be classified according to their nature of composition (i.e. acid and basic) determined by the presence of SiO_2, colour and grain size. The volcanic rocks that contain less SiO_2 are basic, unstable and easily weathered while those with high SiO_2 are acid, more stable and less weathered.

The parent materials around Lake Naivasha have influenced soil formation. The textures of soils, loam and clay have been formed from the weathering products of the volcanic rocks.

Table 2.3 Analyses of pumice from Lake Naivasha area

Minerals	Percent composition
SiO_2	70.35
Al_2O_3	16.53
Fe_2O_3	-
MgO	trace
CaO	0.54
Na_2O	not determined
K_2O) (by diff.)	not determined
H_2O	not determined
Loss in ignition	4.00

Source: Thompson *et al.*, 1958

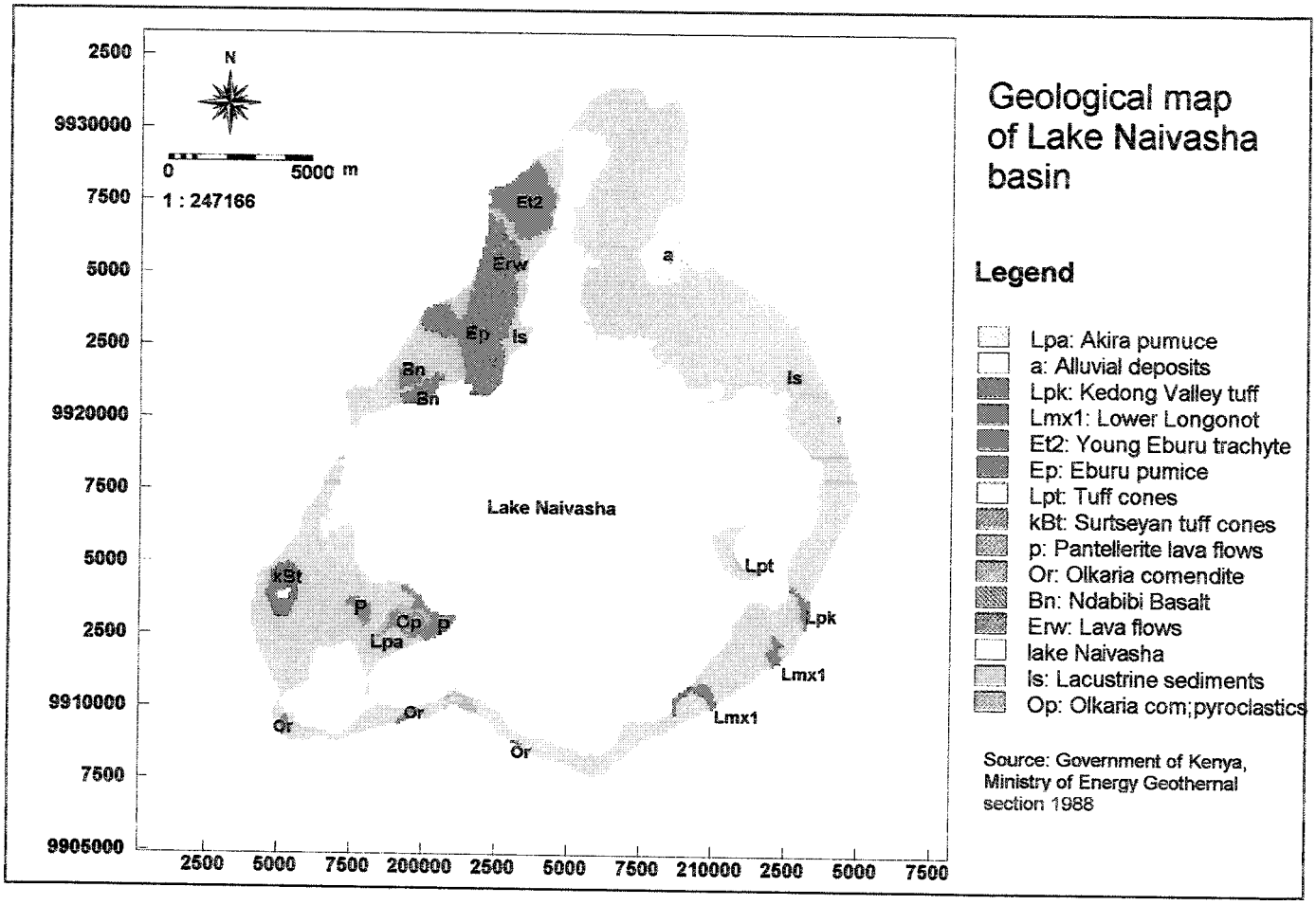

Fig. 2.4 Geological map of Lake Naivasha area

The term 'climate' denotes a generalized integration of weather conditions over a defined period of time in a given time area (Agriculture Compendium, 1989). The accepted registration period of weather conditions to arrive at classification of climate is 30 years. Climatic criteria are based on mean values of long-term observation series. Thornthwaite and Koppen made a classification of climates. Koppen and Geiger (1936) based climatic classification on precipitation and temperature, while Thornthwaite (1955) on the difference between precipitation and the mean potential evapotranspiration.

The principal elements of climate are temperature, pressure, humidity wind, solar radiation and precipitation, (Thornthwaite and Mather, 1955). Radiation evaporation and precipitation are climatic factors of major importance. Climate deals with the conditions of temperature and moisture of the soil and with their interactions between soil surface and atmosphere. The major aspects of climate that affect plant growth are the balance between rainfall and evaporation and temperature (Thornthwaite and Mather, 1955, Sombroek *et al.*, 1980). With regard to rainfall, the length and intensity of rainy and dry seasons and their variation from year to year, are of particular importance.

Climate is the principal factor governing the rate and type of soil formation as well as being the main agent determine the distribution of vegetation and the type of geomorphological processes, (FitzPatric, 1980). The climate forms the basis of many classification phenomena including soils.

2.5.1. *Rainfall*

The Lake Naivasha area has semi- arid type of climate with bimodal pattern of rainfall (Kamoni, 1988), (Bemigisha, 1998) and (Sombroek *et al.,* 1980). The long in rainy season also known as the main rainy season is experienced form March to May and the short rainy season from November to January as shown in Fig. 2.5. The average annual rainfall of the area is about 627 mm./year. Naivasha D.O station at altitude 1900.43 m is the nearest representative weather station for the study area.

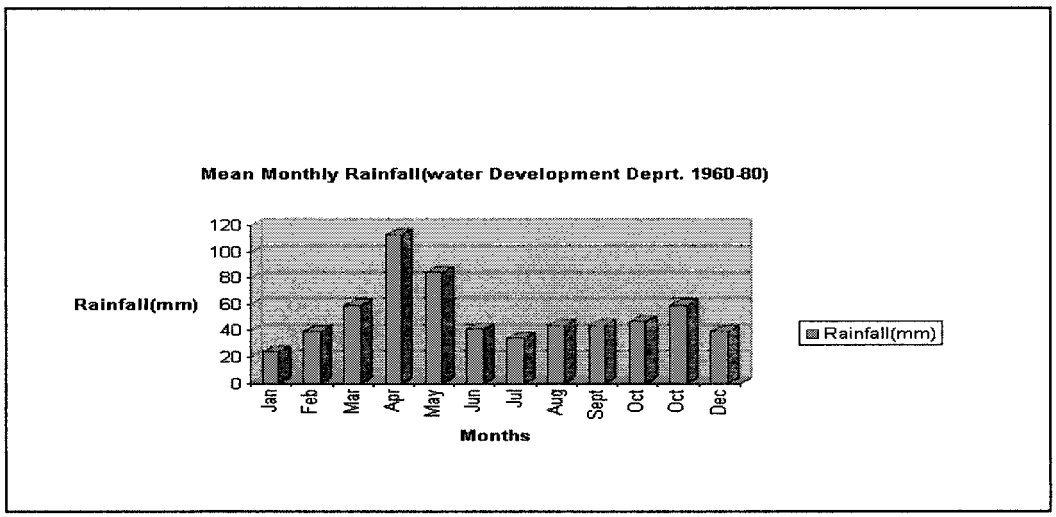

Fig .2.5 Bar. Graph: Mean Monthly Rain fall for Naivasha. Source- Ministry of Land reclamation, Regional and water development, Kenya.

The inter-annual rainfall is irregular and the local rainfall around the whole catchment fluctuates as shown in Fig 2.6. The rainfall is only a third of the evapotranspiration rate in the area (John Goldson Associates, 1993).

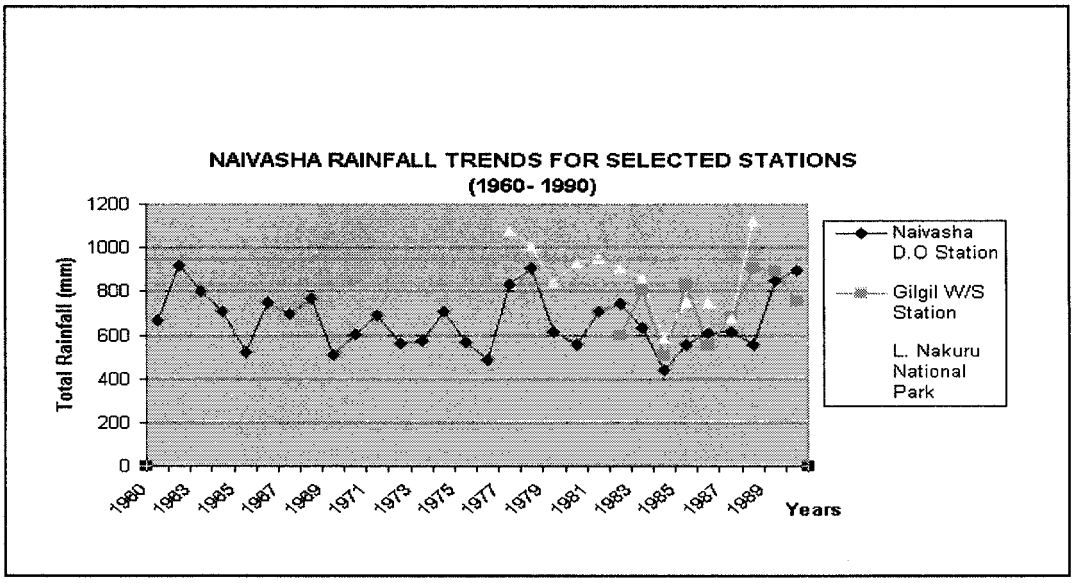

Fig. 2.6 Naivasha Rainfall trends (1960–1990). Source: Ministry of Land Reclamation and Water development.

The mean monthly temperatures range from 24.6 ^{0}C to 28.3 ^{0}C with the highest temperature in January and February. Mean minimum temperature range from 6.8 ^{0}C to 8 ^{0}C. Mean monthly temperature range from 15.9 to 17 .8 ^{0}C with coldest months in July and August. Fig. 2.8 shows both mean monthly minimum, maximum total temperature.

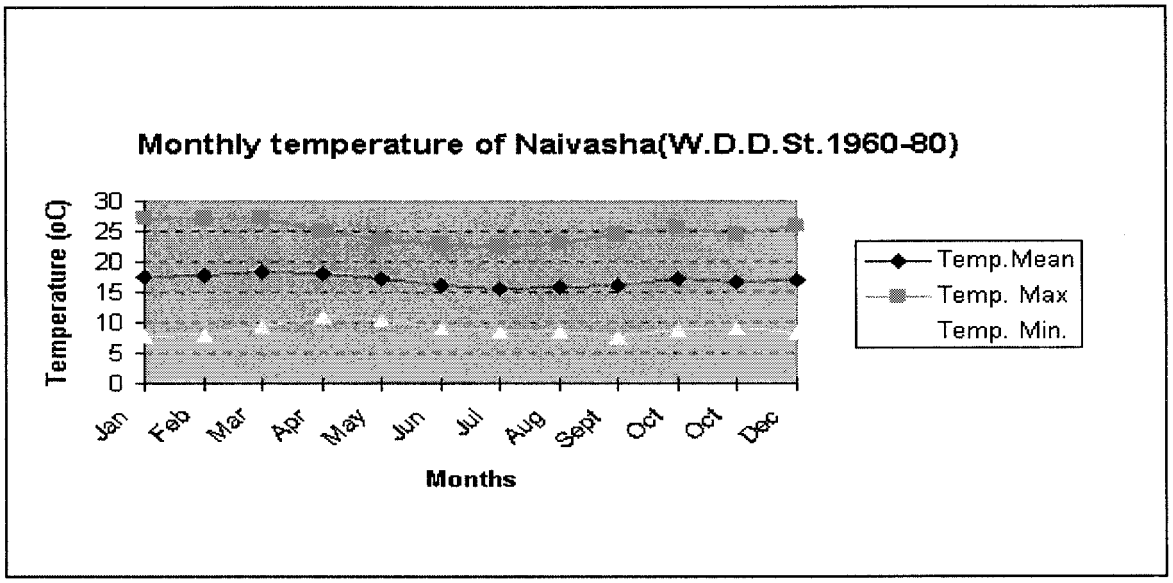

Fig.2.7 Monthly temperature of the Naivasha, Source: Ministry of Land Reclamation, Regional and Water development.

2.5.3 Evaporation

Weather conditions, properties of the soil and the vegetation determine evaporation from the surface (Agriculture compendium, 1989). Evaporation from a land surface covered with vegetation and with sufficient soil water is called potential evaporation (p.e). Evaporation occurring in the field is called actual evaporation (a.e). Evapotransipiration is widely used in agriculture denoting the sum of water physically evaporating from the soil and physiologically evaporated (transpired) by plant. Around Lake Naivasha local rainfall is exceeded by evapotranspiration (Harper et al 1990). Fig.2.8 summaries the inter-relationships between mean monthly rainfall, mean monthly potential evaporation and mean monthly evapotranspiration of Naivasha. High temperatures circulate with low rainfall inducing high evapotranspiration.

2.5.4 Radiation

Incoming short-wave, or solar, radiation has most of its energy contained in the wavelength range from 0.1 to 4 ***um*** (Brutsaert, 1982), and approximately one percent lies in wavelengths longer than 4 ***um***.The amount of incident solar radiation that reaches the earth's surface is determined by extra-terrestrial solar radiation, which depends on the "earth- to-sun" distance, atmospheric condition, which is mainly governed by the presence or absence of clouds, and earth' surface configuration. Solar radiation is the principal source of heart energy for the evaporation (E) and evapotranspiration (Et). The radiation or sunshine around Lake Naivasha, on average, the daily, sunshine duration is about 5 hours with maximum (5.9 hours and minimum (4.2 hours), values occurring in February and July respectively.

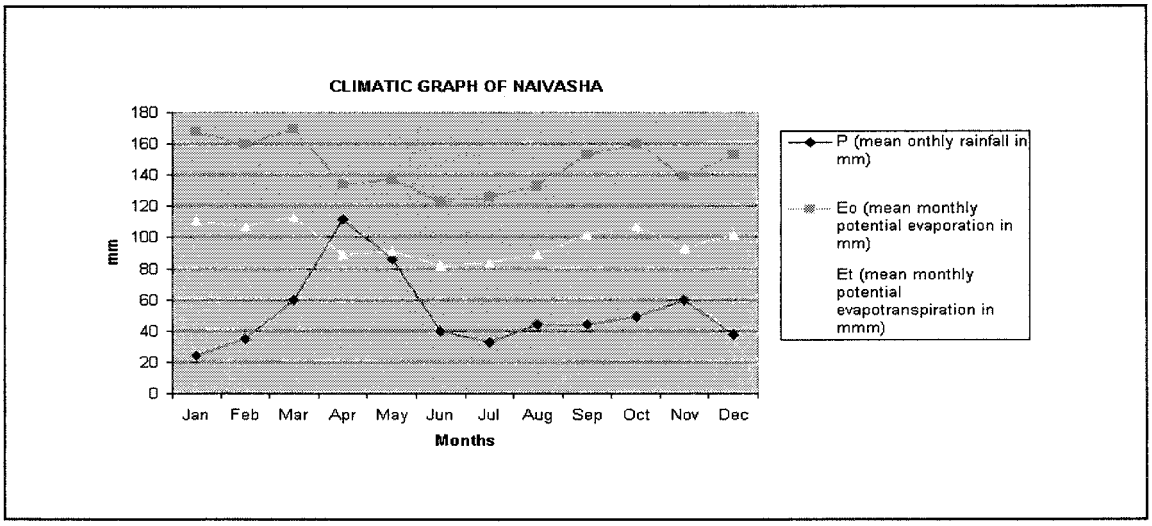

Fig. 2.8 Climatic graphs: mean monthly rainfall, mean monthly potential evaporation and mean monthly potential evapotranspiration in mm. Source: Ministry of Land Reclamation, Regional and Water development

2.5.5 Soil climate

Soil climate deals with soil climate in terms of soil temperature and soil moisture, which are defined according to Soil Survey Staff (1996).

2.5.5.1 Soil Moisture Regime (SMR)

Soil Survey Staff (1996) defines soil moisture regime as the presence or absence either of ground water or water held at a tension of less than 1500k Pa, in the soil, or in specific horizons, by the period of the year. A soil may be continuously moist in some or all horizons either throughout the year or for some part of the year. The soil moisture regime is a function of the water balance of the soil as related to the soil's capacity to store,

retain, transport and release moisture for crop growth and/ or to the soil permeability and drainage characteristics (FAO, 1978).

The soil moisture control section facilitates estimation of soil moisture regimes from the climatic data (Soil Survey Staff, 1996). The upper boundary of this control section is the depth to which a dry (tension of more than 1500kPa, but not air- dry) soil will be moistened by 2.5 cm of water within 24 hours. The lower boundary is at the depth to which a dry soil will be moistened by 7.5 cm of water within 48 hours.

The soils of the Lake Naivasha area have a Xeric soil moisture regime. However Wetland soils experience water saturation or wetness during almost all the seasons of the year. According to the Soil Survey Staff (1996), soil moisture regime in Wetland soils is classified as "aquic moisture regime'. The aquic moisture regime signifies a reducing regime in a soil that is virtually free of dissolved oxygen because it is saturated by ground water or by water of the capillary fringe. Very commonly, the level of groundwater fluctuates with the seasons; it is highest in the rainy season and decreases during the dry season.

2.5.5.2 Soil temperature regime (STR)

Soil temperature regimes are used in defining classes at various categorical levels in the taxonomy, (Soil Survey Staff, 1996). The soil temperature regime of Naivasha is classified as Isothermic, with average annual temperature of 15-20 ^{0}C (Sombroek *et al.*, 1980).

2.6 Landuse and Vegetation

2.6.1 Vegetation

Bemigisha (1998), Gaudet (1977) and Njuguna (1982) have indicated that the Lake Naivasha area displays a vegetation zonation along the topographic gradient. The major vegetation components from the lake to north lake road are as following:

1. Non papyrus Macrophytes mainly *Elichhconica crappies, sphaerantheus and Juncus spp.*
2. The papyrus fringe dominated by *Cyprus Papyrus*. Other species include *Polygonum spp, sphaeranthus spp*. In some parts the zone is interspersed with *Cyperus rindigifolia.*

3. Shrubland next to the papyrus is mainly composed of S*enna didymoborya, Polynum spp*, and C*onyza spp*, while at higher elevation *Tarchonanthus camphoratus* dominate

4. Woodland dominated by *Acacia Xanthophleoa* interspersed with Grasslands mainly T*hermeda spp, Pennisetum, Eragrostis Hyparrhenia, Setaria and Cynadon pleictostachyym.*

Plate 1. KWS Annex: South North of Transact2. Buffaloes feeding in the recently flooded area of map unit PL443. Note Papyrus vegetation and acacia bushes.

There are also seasonal as well as inter-annual variation of vegetation lushes in the lake Naivasha area. In monitoring seasonal cycles of vegetation growth in Lake Area Stuttard *et al.* (1995) identified two annual peaks; a minor one in January/February and a major one in July, corresponding to the short and long rain seasons.

2.6.2. Agriculture

Lake Naivasha was in the 18th century used as grazing land and watering point of livestock by Maasai- pastorals (Harper *et al.,* 1990 and LNROA, 1995). The land use pattern has changed over the years with the arrival of sedentary farming and ranching. The pastoral activities have given way to intensive irrigated farming, land subdivisions and intensive use of agrochemicals and, deforestation.

Flowers for commercial production are grown under green houses. The main species of commercial flower is roses and account for 60% of cultivated lands (deSilva, 1998). Horticulture is also actively carried out on the shore of Lake Naivasha (Kwacha, 1998). Beans and cabbages vegetables are grown in rotation four times a year i.e. two times cabbages and two times beans (de Silva, 1998).

Plate 2. Longonot sample area: Landuse in the low terrace of map PL443. Note sprinkler irrigated cabbage, beans and tomatoes.

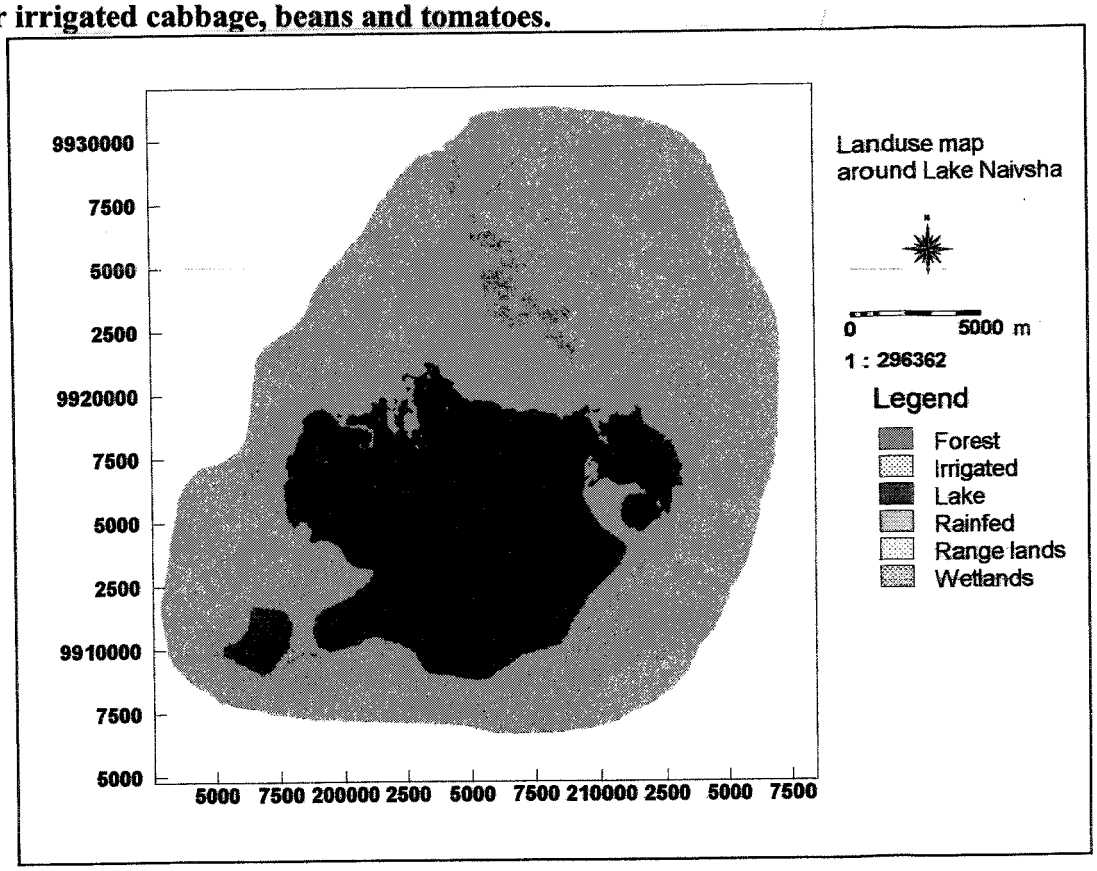

Fig. 2.9 Land use map

2.6.3. Wildlife

A number of game parks and game reserves are found in the Lake Naivasha area. In the Wetlands/ Riparian zones a variety of wild animals is found which include buffaloes, water bucks, giraffes, hippos, impala, zebra and many others.

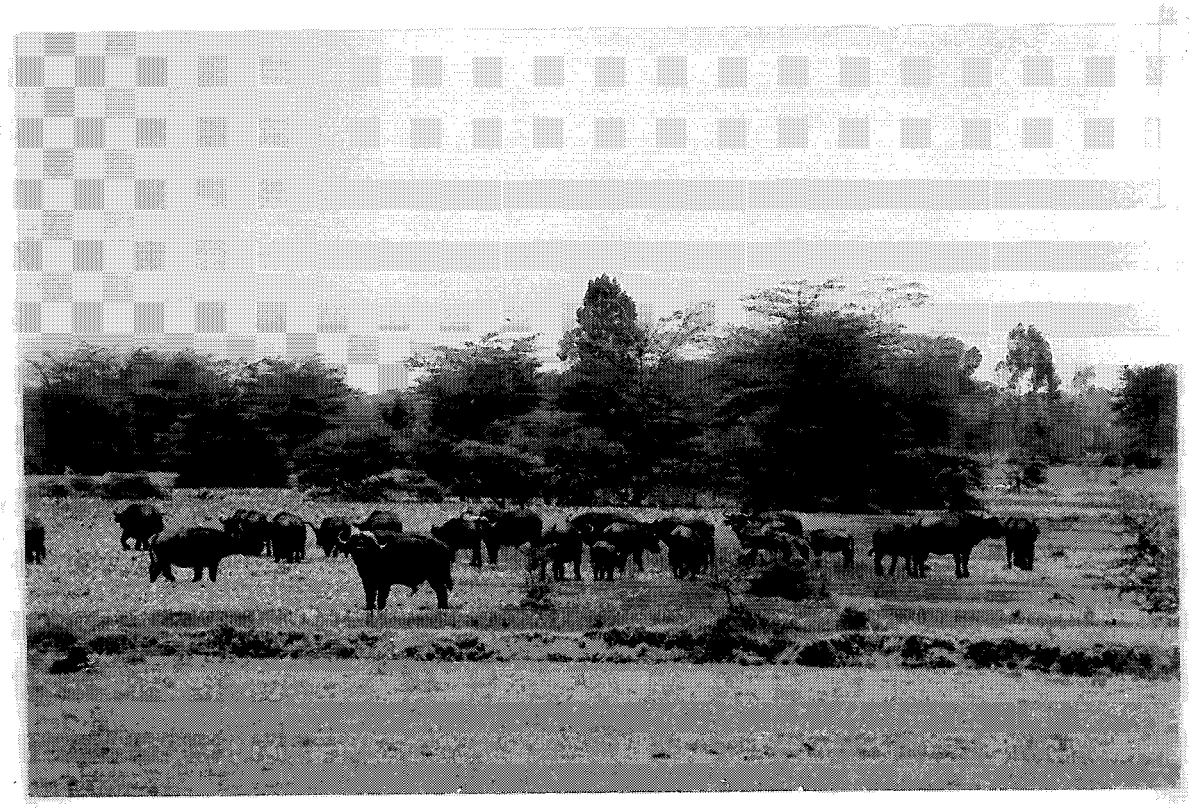

Plate 3. KWS Annex: South North of the transact II buffaloes feeding in the recently flooded area in the low terrace map unit PL443.

2.7 General soils of the Lake Naivasha

Lake Naivasha and its environs have been subjected to research in the past especially in the late 70's and 80's (LNROA, 1995). Different soil scientists with various levels of intensity have carried researches particularly on the soil in the area. Sombroek *et al.*, (1980) indicated that the distribution of the soils in Lake Naivasha area is complex and influenced by intensive variation in relief, climate, volcanic activities and underlying rocks. The soils are formed mainly from weathered volcanic and pyroclastics. Lake Naivasha soils can be grouped into soils developed on the lacustrine plane and soils developed on volcanic plain.

The soils developed on the lacustrine plain are moderately well to well drained, very deep, very dark grayish brown to pale brown, silt clay to clay loam. The soils classify as Andic Xerorthents, Typic Xerochrepts (clay over sandy), Typic Xerochrepts (fine- loamy over clay), Andic Haploxeralfs, Typic Eutrochrepts, Typic Haploxeralf and Calcaric Haploxeralfs.

The soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non calcareous to moderately calcareous topsoil, and moderately to strongly calcareous deep soil. The soils were classified as Andic Xerochrepts, Calcaric Xerorthents and Lithic Xerorthents.

Generally the soils in the southeastern and eastern part of the Lake are more clayey than those found on the southern and western lakeshores (coarse and fine loamy family). Sombroek *et al.,* (1980) described the soil of Lake Naivasha as follows: -Soil developed on sediments from volcanic ashes and other source of the lacustrine plain as imperfectly drained to poorly drained, very deep, dark grayish brown to dark brown, firm to very firm, slightly to moderately calcareous, slightly to moderately saline, moderately to strongly sodic, silt loam to clay; in many places, with a humic top soil; subcresent lake edge of central Rift Valley (undifferentiated Solonetz, saline phase).

-Soils developed on sediments mainly from volcanic ashes as complex of: -well drained, moderately deep to deep, dark brown, friable and slightly smeary, fine gravely, sandy clay loam to sandy clay, with a humic top soil (ando- haplic Phaeozems);-imperfectly drained, moderately deep to deep, strong brown, mottled, firm and brittle, sandy clay to clay (Gamblian lake of he central Rift Valley), (gleyic Cambisols, fragipan phase);-soils developed on undifferentiated Tertiary volcanic rocks (olivine basalt, rhyolites, andesites) of the hills and minor scarps (slope 16%) as well drained shallow, dark reddish brown friable very calcareous, bouldery or stony, loam to clay loam; in many places saline (Llithosols; with calcic Xerosols, lithic, bouldery and saline phase and rock outcrops).

Siderius (1980) described the soils developed on the lacustrine deposits as well drained, deep, dark grayish brown to brown sandy loams to sandy clay loams. He classified the soils as (eutric Cambisols). He indicated that the levels of Potassium are high in the soils while Nitrogen and Carbon are low and have high supply of Phosphorus, Calcium and Magnesium.

2.8 Hydrology

The Lake receives drainage water from two perennial streams; the larger of these is the river Malewa, draining the Nyandarua Mountains (drainage area 1,730 Km^2), while the smaller Gilgil drains the Rift valley floor from the north (drainage area (420 Km^2). Several ephemeral streams drain the Lake in the southern part (Harper *et al.,* 1990). The Lake is also hydrologically a seepage lake with input via ground water seepage in the northern area and outflow in the southern area (Gaudet & Melack, 19981) and (Ase, 1987). Other sources of water input include rainfall that occurs direct over the Lake.

still fresh and non-alkaline, however with recent agricultural development is at risk of pollution and siltation. The quantity of Lake water fluctuates due to the water abstraction for and long dry periods that occur at Naivasha area.

2.9 Lake water fluctuation

Lake Naivasha has always experienced considerable water level fluctuations as consequence of irregular rainfall patterns that are affected by continental-scale climatic events, and its communities, particularly aquatic plants which were adapted to these changes (Harper *et al.,* 1990). The local rainfall around Naivasha is exceeded by evapotranspiration. This also gives the lake an area that fluctuates with inflow.

According to Heper *et al.*, (1990) the water level fluctuated 7 times several meters this century and by 4 m in the past decade. The Lake- level fluctuations do not show a general relationship with local rainfall, except during periods of exceptionally high rainfall. In statistical analysis, however, Vincent *et at.,* (1979) suggested that the Lake's level is an indicator of the long-term pattern of high-level climate- particularly the penetration of equatorial westerlies and their influence on the land above 2,5000 m asl.

Plate 4. Yacht Club transact runsfrom left to the right. (dry land to recently flooded area) in the low terrace map unit PL443.

Plate 5. KWS Annex, transact I, view south recently flooded riparian area with water hyacinth (fore-ground) depth 20 to 50 cm) grass vegetation (water depth 0-20 cm) and the dry land.

Plate 6. KWS annex, transact view NW; showing irregular water line area and recently flooded areas of low terrace map unit PL443.

CHAPTER 3

3.0 LITERATURE REVIEW

3.1 Soil ecological functions

The ecological functioning of the soil directly refers to the way in which the soil ecosystems operates (Haan, 1987). The soil ecosystem is then described as the whole of the biotic soil community including its mutual relationships and interdependencies. It thus embraces the complexity of interactions between biotic and abiotic components of the soil. These interactions are highly dependent on the chemical and physical condition of the system. Soil life comprises all organisms, which spend one or more stages of their development in soil. Usually a distinction is made in this respect between soil flora and soil fauna. Algae, fungi, yeasts, bacteria and actinomycetes constitute the soil flora. The soil fauna consists of primitive and highly developed forms of life. Examples are amoebae and other unicellulars, earthworths, snails, slugs and moles.

According to Haan, (1987) the most important part of ecological functioning of the soil to the preservation of life is its contribution to the cycling of elements, especially of nitrogen, carbon, sulphur and phosphorus. The nitrogen, carbon, sulphur and phosphorus cycles have been explained by (Brady, 1984 and Killham, 1995).

Soil consists of mineral material, the roots of the plants, microbial and animal biomass, organic mater in various states of decay, as well as water and a gaseous atmosphere (Killham, 1995). The uneven distribution of these components provides a great variety of conditions at all levels of scale from the field to the soil micropore. The whole spectrum of interacting physical and chemical factors contributes to the varied nature of the soil habitat and hence determines the composition and activity of the soil biota at a particular site and time. Important soil chemicals and physicals that affect the interactions of biota and abiota on the ecosystem care discussed below.

3.1.1 Soil minerals

According to the Killham (1995), the soil biota obtains a significant proportion of its nutritional requirement from the weathering of soil minerals, predominantly secondary minerals. The secondary minerals such as secondary silicates and oxides of iron and manganese tend to be present in the fine silt and clay fractions of the soil. Nutrients from the weathered minerals enter the soil solution and then reach the site of biological activities through a combination of mass flow and diffusion.

The main importance of clay minerals is their extremely high surface area found per gram of clay mineral. The surface area can range from 50 - 100 m^2 per gram of kaolinitic clays to 300 -500 m^2 for vermiculite, and to 700 - 800 m^2 for well- dispersed semectites (Russell, 1973). These impressive large surface areas can play a pivotal role in adsorbing and desorbing inorganic and organic constituents of soils.

According to the Sparks, (1995), clay minerals can be used to retain organic contaminants. Recently there has been much interest in using clays, particularly smectites, because of their high surface areas, for removal of organic pollutants from water. It has been found that if the metal ions are exchanged with large cations clay on the surface, such as long chain alkylamine cations, the clay surface becomes hydrophobic organophilic, such as organo clays, which are very effective in sorbing organic pollutants such as non-ionic organic compounds (NOC).

3.1.2 Soil organic matter

The organic matter content of the soil, consisting of plant, animal and microbial residues in various stages of decay, represents the dominant source for microbial nutrition (Killham, 1995). A major biological importance of soil organic matter on the total ecosystem results from its role as a source of plant macronutrients, nitrogen, phosphorus and sulphur (Tate III, 1987). Mineralization of soil organic matter releases organically bound nutrients, particularly nitrogen, phosphorous and sulphur that had previously been incorporated into living tissue, as has been explained by Killham, (1995), Tan, (1994), Brady (1984)and TateIII, (1987).
A considerable source of carbon and nutrients in soil organic matter is in the form of plant root exudates. The quantity and quality of root exudates depends on a host of environmental (e.g. temperature, pH, light, etc.) and plant related (e.g. plant type, stage of development, health, mycorrrhizal infection) factors and root exudation generally represents about 5% of the carbon that plants photoassimilate (Lumbers, 1987) as cited by (Killham, 1995).

The soil microbes and the soil macrofauna are also of great ecological importance in terms of breaking down soil organic matter to access this considerable nutrient reservoir (Killham, 1995). The soil macrofauna not only breaks down soil organic matter for themselves, but are also particularly important in consuming organic material that they process through their guts. Soil animals (saprophagous) are also involved in the break down of dead soil organic matter, which include earthworms, termites ants, and millipedes.

Both mineral content and soil organic matter have usually a high number of exchange sites, which affect the capabilities for nutrient retention, important for primary producers in all soils. (Coleman, 1996). Tan (1984) indicated that the soil organic fraction affects physical, chemical and biological condition in soils.

Apart from being a source of nutrients, soil organic matter also plays an important role in retention of pesticides and other organic substances by humic substance. It has an important effect on the bioactivity, persistence, biodegradability, leachability and volability of pesticides (Sparks, 1995). The amount of the pesticides that can be added to the soil is strongly affected by the quantity of soil organic matter. The factors that affect the retention of pesticides by soil organic matter are: number, type and accessibility of humic substance functional groups. Others factors are the nature of the pesticides, properties of the soil including types and quantity of clay minerals and other soil

components such as pH, exchangeable cations, moisture and temperature (Stevenson, 1982) as cited by (Sparks 1995).

Adsorption of pesticides on humic substance occurs via ion exchange and protonation, H-bonding, van der Waal forces. Soluble humic substances can enhance the transport of pesticides in the soil and ground water (Sparks, 1995). Fluvic acids have low molecular weight, high acidity and more soluble than humic acids and therefore, can transport pesticides and other organic materials quite effectively. Humic substances can also serve as a reducing agent and chemically alter pesticides (Sparks, 1995). The alteration is enhanced by the presence of reactive groups such as phenolic, carboxyl, enolic, heterocyclic, aliphatic- OH, and semiquinone, like those contained in Fluvic acid and Humic acid.

3.1.3 Soil water

Brady (1984) indicated that plant roots and microbes largely complete their life cycle in the soil and consequently are influenced significantly by soil-water relations. By exacting a major control on the soil aeration, soil water influences the types of the micro-organisms present in the soils, their numbers and activities. The movement of bacteria, protozoa, and certain spores (zoospores) ceases at the moisture tension level of about 5 bars. Nitrification and sulphur oxidation may continue until the tension of about 40 bars is reached, while the growth of some fungi may continue to a moisture tension of up to 400 bars (Brady, 1984). The influence of soil moisture tension on selected soil microorganisms is shown Table 3.2.

The degree to which the soil pore space is filled with water is of fundamental importance in determining soil biological activity (Killham, 1995). Soil bacteria and protozoa tend to live in the soil water at all times. When the soil dries out, this water is restricted to thin films around the soil particles (Table 3.2). Soil fungi can grow across the air- filled pore spaces and large soil animals, such as earthworms, tend to occupy the largest pore spaces that are generally filled with air and only become water filled when the soil is saturated.

The nature of the pores holding the soil water also determines the availability of this water and soil aeration, as well as the supply of soluble nutrients, and regulates osmotic potential, as well as the pH and Eh of the soil solution (Killham, 1995). Table 3.2 shows, which pore sizes, can provide water to plants, freely or under gravity, and where plants can with draw it. The pore size distribution is critical in the water supply to roots of growing plants. Ideally, a soil should have a reasonable number of large pores to facilitate root extension, but also a large number of small pores (0.3-30 um) to sustain water supply to the roots during periods of drought.

Table 3.1 Soil moisture tolerance levels for different microbial activity

Tension tolerance	Example of microbial activity in soil
5	Protozoa, zoospores, and bacteria move
15- 40	Nitrification, sulphur oxidation
100	Fusarium fungal growth
400	Aspergillus fungal growth

Source. Brady, 1984

Table 3.2 The relation between soil pore necksize and pore water availability to plant roots (Source. Killham, 1995)

Pore neck size (*u*m)	Water potential and availability to plants when pores are water filled
Aprox. 30 or greater	> - 10kPa. Free supply under gravity
0.3 - 30	-1000 to - 10kPa. Can be withdrawn by absorbing roots
0.4 < 0.3	< - 1000kPa. Can not be withdrawn by roots

3.1.4 Soil atmosphere

According to Killham, (1995) the degree to which the soil pore space is filled by water has a profound influence on both the gaseous composition of the soil air and on the composition of dissolved gases in the soil water itself.

In well-aerated soil, oxygen concentrations rarely will drop below 20% and CO_2 concentrations will increase to above 1% (Russell, 1973). Killham (1995) showed a typical range of concentration of the gaseous constituents of the soil. A typical soil air concentration ranges from 79%(N_2), 20-21%(O_2) and 0.1 - 1.0 % (CO_2). If a soil has pronounced clay texture and/ or is waterlogged, with a high level of biological activity, carbon dioxide concentrations as high as 10% may result. A depth profile of carbon dioxide in the soil shows that concentrations generally increase with depth. Maximum biological activity however is usually close to the soil surface as oxygen supply by diffusion is greatest. Maximum biological activity generally occurs at soil water potential approximating to 40% of the water- holding capacity, a condition found either soon after a rain event or just above water table.

The dissolved gasses of most importance to the ecological swamps are oxygen, carbon dioxide, methane and hydrogen sulphide (Denny, 1985). The free-carbon dioxide in tropical swamps is greatly influenced by throughflow. Thus in floating vegetation, free carbon dioxide varied from 27 -58 mg dm-3 (e.g. Lake Victoria), to 75 mg dm-3 in a more stagnant valley swamps (Denny, 1985).

The soil atmosphere is a source of carbon and nutrient to the soil microbial growth in soils where supply of the available carbon and nutrients is often very low (Killham, 1995). Growth under these conditions is known as oligotrophy and is probably a common feature of microbial growth in soils where supply of available carbon and nutrients is often very low, particularly at microsite level. It is assumed that at very low carbon concentrations in the soil solutions, the soil atmosphere may represent an additional carbon supply. The shape and distribution of the soil pore space is of fundamental importance in determining the rate of oxygen and carbon dioxide diffusion to and from the zones of biological activities.

3.1.5 Soil temperature

Temperature, a soil property of greatly biological importance, not only directly affects the rate of physiological reactions, but also has many indirect effects on soil biological activity through temperature-induced changes to other aspects of the soil physicochemical environment, such as diffusion rates, mineral weathering rates, redox potential, and water activity (Killham, 1995).

Factors controlling the soil temperature regime, including diurnal and seasonal effects as well as factors such a vegetation status, moisture and soil depth (Russell, 1973). In most soils with a mesophilic microbial community, there is an approximate doubling of microbiological activity as a result for each 10^0C rise in temperature between 0^0C and 30^0C / 35^0C (Killham, 1995). Only a few degrees above the optimal temperature, there is a dramatic fall in activity as a result of thermal denaturation of proteins and membranes (thermorphillic soil organisms possess great heat stability of these components).

Plant root systems are particularly sensitive to changes in soil temperature. A rise in soil temperature of as little as 1^0C can markedly stimulate both root and shoot growth and plant nutrient uptake (Killham 1995). These mechanisms of growth effects due to changes in soil temperature, are complex and include changes in water uptake, nutrient absorption, the budget of growth- related substances, and the temperature of the apical root meristem (Scott Russell, 1977).

Soil temperature generally interacts with other factors such as soil moisture to regulate biological activity. A rise in soil temperature, for example, can only have a marked stimulatory effect on soil biology activity if the moisture status of the soil is not limiting. Similarly, the re-wetting of drought- affected soil will only markedly stimulate biological activities when the temperatures permit.

3.2 Wetland soils

3.2.1. Definition of wetland

Various authors have defined the wetland areas. The following three definitions given by different authors have been considered. The Ramsar Convention sponsored by UNESCO in Ramsar, Iran, 1971), defined Wetlands as are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh or salt, including areas of marine water the depth of which at low tide does not exceed six metres."

Denny (1984) defined "Wetlands areas" as "vegetation areas which are flooded either permanently or seasonally". There may be areas of open water (shallow lake) in a wetland, but these are generally less than the area of vegetation. Wetland is collective terms for permanently or temporarily wet areas, shallow- water and land-water interfaces. The water may be fresh, brackish or saline.

The Environmental Council (1984) defined Wetlands as "a collective term for permanently or temporarily wet areas, shallows-water and land-water interfaces". The water may fresh, brackish or saline, and wetlands are characterized by their natural state, by plants and animals, which are adapted to living in wet conditions.

3.2.2 Wetlands Identification

A jurisdictional Wetland (i.e. a Wetland protected by law) must meet the criteria for hydric soil (Table3.3). Hydric soils can be identified by the presence of one or more of the following properties: - gley colours with low-chroma matrix (less than or equal to 2) and mottles below the A horizon; a significant accumulation of organic matter on the surface (e.g. a histic epipedon); Fe-Mn concretions and H_2 gas; or numerous oxidation root channels.

The most accurate methods for demonstrating hydric conditions involve monitoring soil moisture, water table fluctuations, soil O_2 content, reduction-oxidation (redox) potential, or Fe^{2+} activity (Veprasha and Wilding, 1983; Faulkner *et al.,* 1989). However these methods are impractical for routine Wetland identification, hydric soils are therefore commonly identified by the presence of one or more field indicators, including a low-chroma matrix or a surface high in organic matter.

The use of field indicators to determine moisture regimes assumes strong correlations to exist between redox potential, O_2 content water table depth, and physical features such as chroma. These relationships however physical, will break down if microbial activities is limited by pH, temperature or low organic matter (Bouma, 1983).

Long-term nutrients accumulation in Wetland ecosystems is determined by the balance between inputs and outputs. Nutrients in the Wetlands undergo several biochemical transformations, some resulting in loss of certain nutrients as gaseous end products or

through accumulation with the ecosystems. Nutrient accumulation can occur through mineral or organic matter sedimentation. In peat-dominated Wetlands, a major portion of the nutrients is stored in leave and detrital plant tissue, microbial biomass, and stabilized soil organic matter. Nutrients stored in vegetation and microbial biomass can be readily released through natural death and decomposition (Davis, 1991). In herbaceous wetlands, nutrient storage in vegetation is usually short term (Reddy and De Busk, 1987), while in forested wetlands incorporation of nutrients into woody tissue of trees can result in long-term storage (Richardson and Davis, 1987).

As carbon and nitrogen are cycled through a Wetland, a portion can be lost as gaseous end products. For example, organic C is converted to CO_2 and CH_4 and is lost from the system. The process is influenced by the hydrological regime of the system, with frequent wet and dry cycles increasing decomposition rates and loss of carbon (Reddy and Patrick, 1975). The level of reduction in the submerged soils is normally measured by determination of the Eh (Patrick and De Laune, 1977). Aerated soils have a characteristic Eh in the range of +400 mV, whereas flooded soils exhibit Eh values as low as –300 mV. Oxygen is usually absent from flooded soils at Eh values below-350 (De Laune and Pezeshk., 1991).

Table 3.3. Criteria for Hydric soils[+]:

1. ***All Histosols excepts folists***
2. ***Soils that are frequently*[1] pounded or flooded grater or equal to 7 consecutive days during the growing season***
3. ***Soils in the Aquic or Abolls surbrders, aquic subgroups, Salorthids great group, Pell great groups of vertisols, Parchic subgroups or Cumulic subgroups that are:***
   a. ***some what poorly drained and have a frequently occurring water table within 15 cm of the surface for a significant period*[2] during the growing season, or***
   b. ***Poorly drained or very poorly and have either:***
      (i) ***a frequently occurring water table within 15 cm of the surface for a significant period during the growing seasons if the textures are coarse sand, sand or fine sand in all layers within 50 cm or for soils within other textures.***
      (ii) ***A frequently occurring water table within 30 cm of the surface for a significant period during the growing season if the permeability is greater than 15 mh^{-1} in any layer within 50 cm, or***
      (iii) ***A frequently occurring water table within 45 cm the surface for a significant period during the growing season if permeability is less than 15* m h^{-1} in any layer within 50 cm.**

Source: (Magonical J.P W.H. Patrick, Jr., and S.P Faulkerner (1993), in Soil Science Society of America Journal.

+ From the hydric soils lists (Soil Conservation Service)
**[2] Significant period is usually greater than 2 weeks.*
**[1] Frequently is defined as occurring in 50 out of 100 years*

3.2.3 Importance of the Wetlands

The wetlands areas are internationally recognized and protected areas by the Ramsar Convention and they are known as Ramsar sites. Frazier (1996) indicates that under Article 3.1 of the Ramsar Convention, the country is obliged to develop a national Wetland policy and include wetland conservation and wise use considerations within their land use planning, plus maintaining the ecological character of the site. According to Article 3.2 the contracting party should advise the Convention Bureau of any change in the ecological character of a listed site.

Wetlands are complex systems that are poorly understood relative to the terrestrial and aquatic systems (Reddy and Patrick 1993). Difficulties in characterizing Wetlands reach beyond the problem of variability associated with natural systems, owing to the fact that Wetlands frequently are situated in the landscape between terrestrial and aquatic systems and therefore posses characteristics of both.

Wetlands function as an important link between the terrestrial and aquatic systems by serving as sinks, sources, and transformers of nutrients and chemical contaminants, and thus have a significant impact on downstream water quality and ecosystem productivity (Reddy and Patrick, 1993).

According to Worthington (1994) the socio- economic importance of the wetland can be from two sides. The credit side is that, the wetland habitats, which water plants have done much to create, attract and protect a wide variety of wildlife; they provide grazing and useful plant products; and supply feeding, breeding and refuge areas for fish of commercial purpose. On the debit side, aquatic vegetation interferes with water flow and drainage: it obstructs fisheries transport and recreation and favours water-related diseases; and competes with cultivated rice.

The presence on the Papyrus swamps in the wetland soils has been reported to have a buffering effect for the leaching of nutrients from the agricultural lands around the swamps. An example is Lake Naivasha quoted by various researchers (Harper *et al.*, 1990, Gaudet, 1980 and Mavuti, 1981).

The three major components of the wetlands are ***water, vegetation, and soils***. However the single feature that most Wetland soils share is ***soils*** that is at least periodically inundated by rising water table of flooding (Reddy and Patrick, 1993).

Wetland research has traditionally been centered on vegetation, wildlife, and systems ecology. Past studies of Wetland process and system functions have given little or no attention to soil- related processes or the role of soils in Wetland ecosystems. The soil component is often ignored, (Reddy and Patrick, 1993). Unfortunately, even the important committees which are responsible for evaluating, the science, technology, and publicity policy related to the restoration of Wetlands, have failed to include a soil scientist on the their activities. Too often, the policies made on Wetlands at the national and international levels have minimum input from this discipline.

Increased emphasis on the importance of wetlands at local, state, and national levels demands thorough study of all components of Wetlands including soils. According to Reddy and Patrick (1993) soil scientists can and must play a major role in research areas like:
(i) Hydric soil characterization and delineation (ii) Wetland biogeochemical processes, (iii) Agronomic aspect of the Wetlands, (iv) Use of natural and constructed wetlands for water treatment and (v) Other environmental and ecological impact.

The role of soils is a major consideration when Wetlands are used as sinks for pollutants. The ability of Wetlands to retain or to release pollutants is affected by the physical, chemical and biological characteristics of associated soils.

In this study, the Wetland soils characteristics will be considered which might be a result or influenced by wetness condition and different processes taking place in these soils. The following characteristics and processes that are typical for Wetland soils will be discussed: anaerobic processes, pH, electrical conductivity, redox potential and gleying processes.

3.3 Anaerobic processes

Anaerobic processes are induced under anaerobic conditions and occur particularly in Wetland soils. These are conditions free of molecular oxygen in soils which are caused by excess water or wetness (FitzPatrick, 1980). Anaerobic processes are carried by the anaerobic organisms, which live in an environment without molecular oxygen. In anaerobic processes, certain micro-organisms, called anaerobes, decompose organic matter in the absence of oxygen. Respirations by microorganisms decomposing organic matter in wet soil consume oxygen faster than it can penetrate the soil mass and only the surface layer is aerobic.

Facultative anaerobes adapt their respiratory pathways and function in either the presence or absence of oxygen. The terminal electron acceptors for anaerobic respiration may be organic or inorganic compounds. According to Boyd (1995) nitrate ions, manganese, sulphate and carbon dioxide are used as electron acceptors or oxidants in respiration. The by- products of anaerobic respiration are soluble organic compounds, carbon dioxide, ammonia nitrogen gasses, ferrous iron, manganous, manganese, hydrogen sulphide, hydrogen, and methane. These substances are transported within the soil profile and water above the soil by diffusion, seepage and sediment disturbance.

Subsequent to O_2 depletion in the flooded soils, anaerobic conditions ensue a sequential reduction of the inorganic redox system consisting of the alternate electron acceptors (NO_3^-, Mn^{4+}, Fe^{2+}, SO_4^{2-} and finally CO_2) as predicted by thermodynamic principles, (Stemm and Morgan, 1981, Ponnamperuma, 1984). The NO^{3-}, $Mn4^+$ and Fe^{3+} utilized by facultative anaerobes and reduced to N_2 or N_2O, Mn^{2+}, respectively, while SO_4^{2-} and CO_2 are utilized by obligate anaerobes under intensity reduced conditions and reduced to H_2S and CH_4 respectively.

3.4 Soil pH

Soil pH has often been called the master variable of soil and greatly affects numerous soil chemical reactions and processes (Sparks, 1995). It is an important measurement in deciding how acid a soil is, and can be expressed as **pH = - log (H^+).** It is therefore, a measure of the concentration of the hydrogen ions in soil water. The degree of acidity (or alkalinity) of soil is expressed in terms of the pH scale, from 2 to 10 (FitzPatrick, 1980). Soils that have a pH < 7.0 are acid, those with a pH > 7.0 are considered alkaline, and those with pH of 7.0 and are assumed to be neutral.

Soil pH range can be classified as given in Table 3.4. The most important ions of soil acidity in mineral-organic soils are H^+ and Al^{3+} with H^+ being more important in soils except for those with very low pH values (< 4). Soil pH significantly affects the availability of plant nutrients and micronutrients (Killham, 1995, Sparks, 1995). At low pH, Al, Fe, and Mn become more soluble and may become toxic to plants. As pH increases their solubility decreases and precipitation occurs. Plants may suffer deficiencies as pH rises above neutrality.

Table 3.4 Descriptive terms and proposed buffering mechanisms of various soil pH ranges

Descriptive terms	pH ranges	Buffering mechanism
Extremely acid	< 4.5	Iron range (pH 2.4 -3.8)
Very strongly acid	4.5 - 5.0	Aluminum/iron range (pH 3.0 - 4.8)
Strongly acid	5.1 - 5.0	Aluminum range (pH 3.0 - 5.0)
Moderately acid	5.6 - 6.0	Cation exchange (pH 4.2 - 5.0)
Slightly acid to neutral	6.1 - 7.3	Silicate buffers (all pH 4.2 - 5.0)
Slightly alkaline	7.4 - 7.8	Carbonate (pH 6.5 - 3.8)

Source: Sparks, 1995

Buffering and buffering capacity of soils have been explained by (Brady, 1984). Wild, (1995) indicated that the buffering of soil pH is due several soil properties, the effect of which is to make the drop in pH less than an equivalent volume of water, when acid is added. The buffer properties of soils are reaction of acids with calcium and magnesium carbonates; cation exchange; proton adsorption by clay minerals, and hydrated aluminum and iron oxides; proton adsorption by aluminum ions; and solubility of soil minerals.

The importance of buffering is stabilization of soil the pH and to guide the quantities of amendments required (Brady, 1984). A marked change in pH affects the availability of several plant nutrients and the levels of other elements that may be toxic to high plants and micro-organisms. Thus, high plants and micro-organisms may be affected by rapid changes in pH either directly due to change in H+ ions concentration, or due to nutrient difference or chemical toxicities. The stabilization of soil pH through buffering seems to be an effective guard against these difficulties.

In Wetland soils where reduced conditions prevail, anaerobic processes by micro-organism are dominant. Under anaerobic soil conditions, oxidation- reduction (Redox) is a continuous process and can lower the pH. Denny (1984) observed that generally the pH of swamp waters is lower than those of adjacent open waters in both tropical and temperate swamp communities. The drop in pH most likely due to the formation of dissolved carbon dioxide and humic acid formed from organic decomposition. In African papyrus swamps with dense peat deposit, the characteristic drop in pH has also been attributed to the release of H^+ ions (Denny, 1984), which have been exchanged from decomposing peat for other ions in solution.

3.5 Soil electrical conductivity (ECe)

A generally accepted parameter of salinity is the electrical conductivity at 25 °C of the saturation extract, denoted as ECe (Agricultural Compendium, 1989). Electrical conductivity (ECe) measurements are used as an indication of quantities of soluble salts in soils, see Table 3.5 (Landon, 1991). The quantities of the salts that pass into solution depend on the relative amounts of the soil and water used, but the relationships are variable.

Soils with high sodium levels are referred to as "sodic soils" and may or may not be strongly alkaline (i.e. have high pH). Saline soils occur where the supply of salts from rock weathering, capillary rise, rainfall or flooding exceeds their removal by leaching or flooding. They tend to coincide with areas where evapotransipiration exceeds precipitation and where there is no long rainy season. Excessive salts hinder crop growth not only by toxicity effects, but also by reducing water availability through the action of osmotic pressure; nutrient uptake may also become unbalanced.

Table 3.5 The USDA classification of the salt affected soils

Soil salinity/sodality	ECe mS/cm	pH usually observed
Saline soils	**> 4**	**< 8.5**
Saline-sodic	**>4**	**<8.5**
Sodic Soils	**<4**	**>8.5**

Source: Landon (1991)

3.6 Soil redox potential

The redox potential is defined as the potential of a chemically inert electrode, which is reversible to electron. Usually it is determined with a platinum or graphite electrode and a saturated calomel electrode. In a water- logged soil the rate of oxygen of supply by aerobic microorganisms is greater than the rate of supply, which results in very low oxygen pressure. In this situation, anaerobic organisms become active. These use various inorganic compounds as electron acceptor in the oxidation of the organic substances, from which they derive the energy they need. The compound which is reduced is more or

less specific, some organisms using nitrites, others sulphates, nitrites etc. the result of water logging will thus be reduction.

Soil chemicals reactions involve some combination of proton and electron transfer (Sparks, 1995). Oxidation occurs if there is a loss of electrons in the transfer process while reduction occurs if there is a gain of electrons. The oxidized component or oxidant is the electron acceptor and the reduced component or reductant is the electron donor. Redox reactions of soil oxidant can be defined conventionally by the following general half-reduction (Patrick *et al.,* 1995).

Ox + mH$^+$ + *ne*$^-$-------Red,

Where **Ox** is the oxidizing component or electron acceptor, **Red** is the reduced component or electron donor, ***m*** is the number of hydrogen ions participating in the reaction, and ***n*** is the number of electrons involved in the reactions. In soils, soil organic matter is the primary source of electrons. Thus to completely describe Redox reaction, an oxidation reaction must balance the reaction. The following examples inTable3.6 illustrate the redox reaction

Table 3.6 Redox reaction

$4Fe(OH)_3 + 12H^+ + 4e^-$ --------- $4Fe^{2+} + 12H_2O$ (reduction) 1
CH_2O+H_2O----------CO2+4H$^+$+4e$^-$ (oxidation) 2

$4Fe(OH)_3$ + CH2O + 8H$^+$---------- 4Fe2+ + 11 H2O (net reaction)

where equation CH_2O is soil organic matter. Equation 1 represents the reduction half- reaction and equation 2 represents the oxidation half- reaction.

The acceptor is determined by the soil Redox potential, which is a measure of likely wood of a substance to gain electron (reduction) or loose (oxidation) electrons as shown by simple Nersnt-type equation (Killham, 1995)

Eh = Eo +0.059/ n log [Ox]/ [Red]). Where **Eh** is the measured platinum electrode potential (mV)
Eo is the standard potential of the system
n is the number of electrons in the system
[Ox] is the electrons lost
[Red] is the electron gained

Source: Sparks 1995

Eh is positive and high in strongly oxidizing systems while it is negative and low in strongly reducing systems (Sparks 1995). Eh is a function of pH (Eh is measured relative to a standard potential from the hydrogen electron, assigned a value of 0 V at 1 mole, pH 0) (Killham, 1995). There is a broad Eh range in which each reduction step may occur because of possible variation in soil pH.

The sequence of reduction of reduction of terminal electron acceptors in the soil environment is shown in table 3.6 with the approximate Redox potential at which each reduction steps occurs.

Table 3.7 Sequence of terminal electron acceptors used in the soil environment with associated redox potential scale at pH

Terminal electron acceptor and ultimate reduced product	Environmental process	Redox potential at pH 7 (mV)	Soil biota involved
O2 + e⁻-- H2O	Anaerobic Respiration	+820	Plant roots aerobic, microbes, animals
$NO3^-$ + e⁻---N_2	Denitrification	+420	*Pseudmonas,*
$Mn4^+$ +e⁻ ---Mn^{3+}	Manganese reduction	+410	*Bacillus*
Organic matter +e⁻----- organic acids	Fermentation	+400	*Clostridium* etc.
$Fe3^+$ + e⁻ -----$Fe2^+$	Iron reduction	-180	*Pseudomonas*
$NO3^-$ + e⁻ ----$NH4^+$	Dissimilatory Nitrate reduction	-200	*Achromobacter*
$SO4^{2-}$+ e⁻ ----H_2S	Sulphate reduction	-220	*Desulfovibrio*
CO2 + e⁻ ---- CH4	Methanobacterium	-240	Methanobactrium

Source: Spark, 1995

3.6.1 Eh versus pH

The diagrams of Eh versus pH can be very useful in delineating the Redox status of a system (Sparks, 1995). The pH range is narrower in reduced soils (negative Eh) than in oxidized soils (positive Eh). Based on these results one can divide the soil into three categories: normal (oxidized), wet (seasonally saturated), and waterlogged (semipermanently saturated), as illustrated in Fig. 3.1.

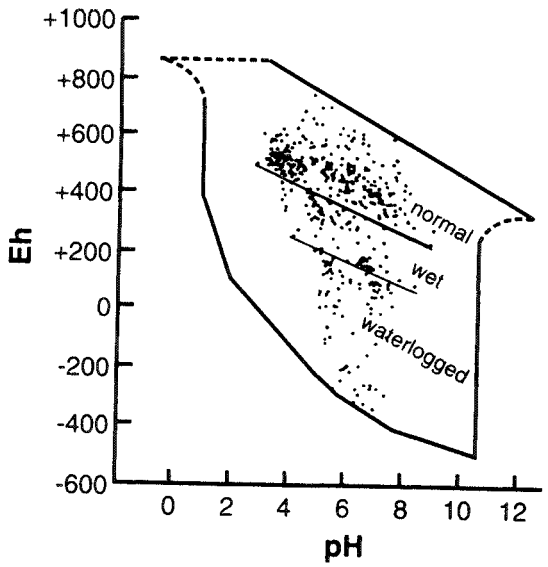

Fig. 3.1 Eh versus pH characteristics of the soils (Source. Sparks 1995)

3.6.2 Determination of redox potential in soil

Various authors have explained the procedure to determine of redox potential in soil. The determination can be done in the field and or in the laboratory, both of which require a special electrode. According to Sparks (1995), the measurement of the redox potential in soil is usually done with a platinum electrode. The electrode will transfer electrons to or from the medium, but it should not react with the medium. Once the platinum electrode is combined with a known potential, reducing systems will transfer electrons from the electrode.

The redox potential, Eh, is ordinarily used to denote the intensity of reduction. The capacity factor, on the other hand, describes the quantity of redox species undergoing reduction and is equivalent to microbial respiratory to the total amount of electrons accepted by soil oxidants in microbial respiratory activity (Kludze and De Laune, 1995)

3.6.3 Use of redox potential

Patrick *et al.*, (1995) indicate that redox potentials can be useful in characterizing the oxidation- reduction status of the soil. Oxidized soils have Redox potential of +400 to +700 mV. Seasonally saturated soils have Redox potentials of +400 to +700 mV (oxidized) to highly reduced (-250 to -300).

Redox potential can help to predict when reducing conditions will begin due to depletion of oxidants such as Oxygen, and Nitrate, and the initiation of the oxidizing conditions when oxygen is reintroduced in the soil. redox potential can also provide information on conditions that are favorable for increased bio-availability of heavy metals, changes in plant metabolism, distribution of the plant species and location of wetlands (Sparks, 1995).According to Sparks (1995), if redox potential data are combined with other information such as depth to water table and oxygen content of the soil, even more accurate information can be obtained about the wetness of an environment. In nonwetland environments the Eh and oxygen content do not change much during the year. Transitional areas may be either oxidized as the water table rises and falls. The Redox potentials are low until after the water is drained and oxygen moves through the soil. Wetland sites that have low redox have had long periods of flooding and soil saturation (Patrick *et al.*, 1995).

Redox data are also useful in understanding the morphological and genesis of the soil (Sparks, 1995). The colour of a soil and the degree of mottling can reveal much about the soil's moisture status. Both colour and mottling depend on the Redox chemistry of Fe in the in the soil. When the soil is saturated for a long time, Fe oxides are reduced under low Redox potentials, and the soil will exhibit a gray colour. Soils that undergo alternative oxidation and reduction cycles are usually mottled (Patrick *et al.*, 1995).

3.7 Gleying processes

When (part of) a soil remains saturated with water for sometime (not all the time) it is subjected to gleying (van Reeuwijk, 1997). Saturation with water does not mean that all oxygen is immediately excluded as some can be dissolved in water. However, the micro-organisms that use it for their metabolisms will quickly use up oxygen. Under such conditions the Redox potential (Eh) is lowered. It may reach the stage (below about 250mV) that certain soil components are reduced, notably oxidation of iron and manganese, but also nitrate, sulphates and elemental sulphur. This can happen because after depletion of gaseous oxygen, anaerobic and facultative anaerobic micro-organisms take over from the aerobic species and they are able to use the oxygen of oxidized components for their metabolism.

Reduction gives soils characteristics greenish or bluish shades (van Reeuwijk, 1995). The most distinctive feature of gley is scattering greenish or bluish mottles. They result from a long- term seasonally alternating dry and wet conditions causing alternating oxidation and reduction. Precipitation of newly oxidized compounds takes place on already existing oxide surface. The zones where gleying is most active are along the wider pores in the soil, since those are the first to be filled with water when the rain starts and also the first to be emptied when conditions become dryer.

According to van Reeuwijk (1997) two fundamentally different types of gley can be distinguished: gley caused by groundwater or normal gley and gley caused by a perched (hanging) water table i.e. surface water gley or pseudogley (Fig. 3.2).

3.7.1 Groundwater gley or normal gley

This type of gley is due to wetness caused by a groundwater table and thus results from limited external drainage (van Reeuwijk 1997). At the end of the wet season the ground water is at its highest level and the solum is in reduced state. After the dry season has started, the groundwater is lowered. The soil dries and forms crack. These cracks and other large pores will be filled with air and thus oxygen enters the soil. The reduced F^{2+} and Mn^{2+} ions, present in the soil solution in the smaller pores along the cracks will oxidize and precipitate along these cracks, forming brown and black coatings. As a result, the concentration of Fe^{2+} and Mn^{2+} ions in this zone is lowered whereas in the matrix it is still high. Consequently, Fe^{2+} and Mn^{2+} ions diffuse from the interior of the structural units toward the air-filled spaces and, arrived at these places, oxidize. In this way diffusion contributes to the already started precipitation and accumulation of iron and manganese oxides and hydroxides.

The interior of the structural units is therefore gradually deprived of iron and manganese oxides and its colour turns into the colour of the soil minerals, which are usually white, gray or green. After air entrance into the wider pores, some oxygen will diffuse into the still wet matrix causing precipitation at some distance from the ped surface. Here segregation of the Fe and Mn oxides will occur because Fe^{2+} oxidizes easier (at lower Eh or oxygen partial pressure) (Fig.3.2) so that generally the Fe oxides occur further away

from the cracks than the Mn oxides. Below the lowest groundwater table the soil remains always saturated with water: oxygen never enters into this system and oxidation never occurs. Gradually the subsoil will be deprived of iron and thus obtains its homogeneous gray, green or blue colour.

3.7.2 Surface water gley or pseudogley

Surface water gley is caused by wetness due to limited internal drainage of the profile, causing a perched or hanging water table. Such impeded drainage is usually caused by stagnating layer somewhere in the profile, e.g. a textural horizon or parent rock, or the soil material itself when it is sufficiently heavy textured (van Reeuwijk, 1995).

At the end of the dry season the season the surface soils are dry and the subsoil still somewhat moist. The whole solum is well aerated. Narrow cracks are observed between structural (frequently prismatic) units. The water follows preferably the paths of least resistance (the cracked and worms racks) and moisten the soil along these pathways. At the water- stagnating layer, the cracks are completely filled with water. The new situation is that water-saturated layers surround the structural units. The inside of the units remains relatively dry.

Because of the swelling of the saturated layers, the cracks narrow and close; the roots are deprived of O_2 and die. Upon microbial attack of the dead roots and other organic matter present, the oxygen is rapidly is rapidly consumed and strongly anaerobic conditions are created along the former cracks. Fe (III) and Mn (IV) oxides are reduced to Fe (II) and Mn(II) ions which diffuse to the interior of the structural units where condition are still aerobic. The Fe^{2+} and Mn^{2+} ions are then re-oxidized at those places where O_2 is present or where Eh is high enough. In this way the immediate surroundings of the cracks are deprived of iron and Manganese and a rim of Fe (III)-oxides is formed at some distances from the cracks. The Mn^{2+} ions diffuse further away than the Fe^{2+} ions, as Mn^{2+} ions need a high Eh to be oxidized than Fe^{2+} ions (Fig 3.2). As a result, the MnO2-separations are observed in the innermost parts of the structural units: the place of highest O_2-pressure. When this process is frequently repeated, broad white or gray tongues are formed along the cracks with a clear rim of iron oxide separations where the manganese oxides accumulations are found in the very centre of the structural units. Fig 3.3 indicates threshold redox potentials at which oxidized species become unstable.

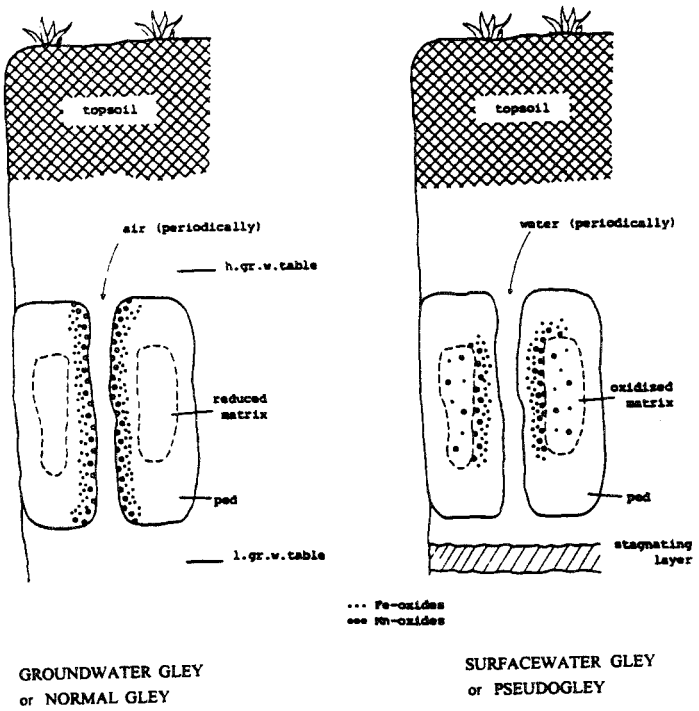

Fig.3.2 Diagram indicating the sites of precipitation of iron and manganese oxides in normal and pseudogley

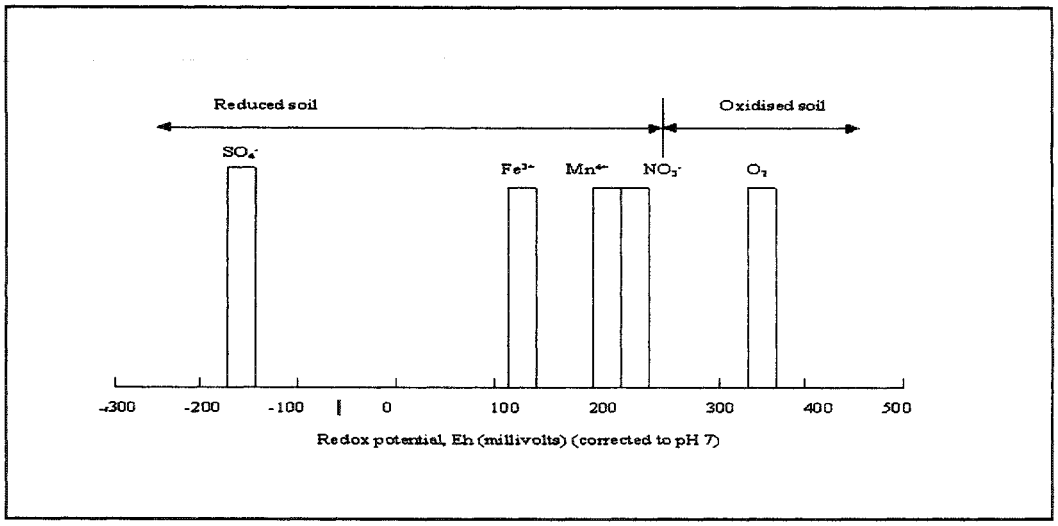

Fig. 3.3Threshold redox potentials at oxidized specie become unstable (Source. van Reeuwijk (1997)

3.8 Vulnerability of soil and water to pollution

Soil and water resources are vulnerable to pollution from either agrochemical or industrial wastes. Ground water vulnerability to pollution may be defined as the sensitivity of their quality to anthropogenic activities which may prove detrimental to the present use and /or intended usage- value of the resource (Bachman and Collin, 1987). On the other hand soil vulnerability to pollution can be explained as sensitivity of their quality to anthropogenic activities which may prove detrimental to present use and /or intended use. Vulnerability assessment aims at providing preliminary information and criteria for decision- making concerning management of water resources and land use as related to water quality control (Bachman and Collin, 1987). Vulnerability mapping is the technique of quantifying the assessment of vulnerability and displaying it a fashion, which make it useful and convenient for actual application in the decision- making process.

3.8.1 Source of pollution

There are two basic types of pollution i.e. point and non-point pollution (Sparks, 1995). Point pollution is contamination that can be traced to a particular source such as industrial sites, septic tanks, or wastewater treatment plants. Nonpoint pollution results from large areas and not from any single point and includes both natural and human activities. Sources of non-point pollution include agricultural, human, forestry, urban, construction, and mining activities and atmospheric deposition. There is also naturally occurring nonpoint source pollution that is important. These include geologic erosion, saline seeps, and breakdown of minerals and soil that may contain large quantities of nutrients.

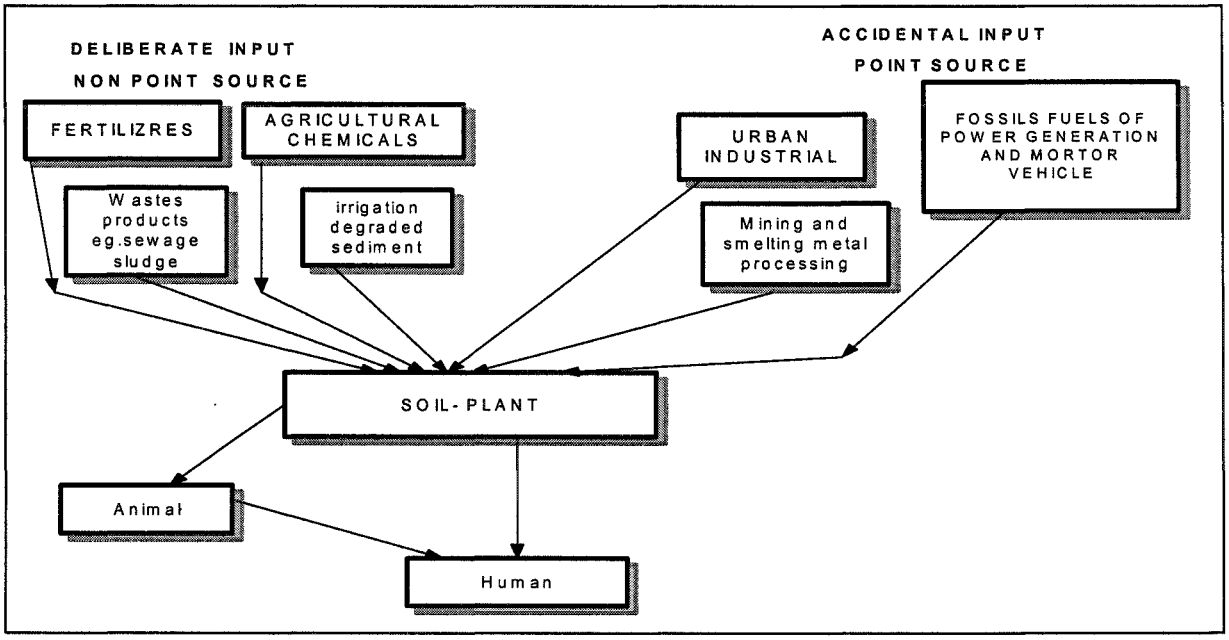

Fig. 3.4 Anthropogenic pollution of the soil- plant- animal system (source. Tiller, 1989)

3.8.2 Contaminants of water and soils

There are a number of inorganic and organic contaminants that are important in water and soils (Sparks, 1995). These include inorganic species such as nitrate and phosphate; heavy metals such as cadmium, chromium, and lead; organic chemical; inorganic acids; and radionuclides. The sources of these contaminants include fertilizers, pesticides, acidic decomposition, waste material and radioactive fallout.

Nitrates and phosphates are of great concern in surface and ground water. In sandy soils that contain little clay, Al or Fe oxides, or organic matter, phosphate can leach through the soil and impact ground water quality. The greatest concern of phosphorous is contamination of streams and lakes via surface run and erosion. Such water contaminations can results in eutrophication and death to aquatic life. Phosphate contamination of surface waters can result from the application of phosphorus fertilizers, as well as from the application of agricultural and industrial organic wastes. Nitrate is weakly held by soils and readily leaches in soils. Contamination of groundwater with nitrates is major problem in areas that have sandy soils. High concentrations of nitrate in ground water can cause methomolobnemia or " blue baby" syndrome in infants (Brady 1995).

Pesticides can be classified as herbicides, those used to control weeds, insecticides, to control insects, fungicides, to control fungi, and other such as nematicides and rodents. They include lead, arsenic, copper, and zinc salts and naturally produced plant compounds such as nicotine. These are used for insect and disease control on crops. Others include 2-4-D a herbicides and DDT, an insecticides. However increased use of pesticides concerns were expressed about their appearance in water and soil, and their effects on humans and animals

3.8.3 Behaviuor of some inorganic contaminants in the soils

Zinc, copper, manganese and nickel have similar chemical characteristics and undergo similar reactions in soil (Brady, 1984). The pH, organic matter content and oxidation-reduction status of the soils affect the reaction of these elements in soils. At pH values of 6.5 and above they tend to be only slowly available to plants, especially if they are present in their high-valent or oxidized forms. Consequently, most soils will tie up relatively large quantities of these elements if the soil pH is high and drainage is good.

The tendency of the cations of these elements to" chelate" in the presence of organic matter influences their behaviour. The relative strength of chelation is generally copper > nickel > zinc> manganese. Since iron is more tightly adsorbed than any of them, its presence in soluble form reduces the chelation tendency of all these elements.

3.9 Importance of soil characterization

Many soils are fragile and whatever capability they have for sustained productivity this can be rapidly lost by mismanagement (Greenland, 1981). If the soils are to continue to produce sufficient crops to the increasing population, it is essential that they are properly used and for this purpose they should be fully characterized and classified. Therefore a best understanding of soils is important and a prerequisite for proper management. Understanding soils can be achieved through soil characterization. Soil characterization involves characterizing soils in terms of their physical and chemical properties.

According to Greenland (1981) the physical properties of soil which determine their ability to sustain plant growth are those which determine the extent of root proliferation and air and water movement and those which control the amount of water they can store and which is available to crops. Lal, (1981) indicated the physical characteristics of soils that influence plant growth and need to be considered in relation to land evaluation and soil classification; they include texture, structure, bulk density, erodibilty and factors affecting it, pore-size distribution, consistence, water-retention and transport characteristics and thermal properties of the soils.

In wetland soils the most important physico-chemical characteristics are soil texture, soil structure, water table depth, pH, Redox, organic carbon and CEC.

3.10 Definitions of terminology

The following terminology and concepts are considered important in this study:

Agricultural Chemicals: Agricultural chemicals are metal containing sprays used to control pests, diseases and weeds in horticultural and vegetable crops. They include zinc salts, copper and lead arsenate and metal-organic compounds. Pesticides are another group of agricultural chemicals used, in crop production, to control pests and diseases. They include insecticides, fungicides, nematocides, rodenticides and herbicides (Tan, 1994). Their potential as a pollutant depends on their bio-degradability and toxicity to animals and people and also to the soil.

Fertilizers: These are inorganic fertilizes (or commercial fertilizers) added to soil to provide the necessary major nutrients essential to increase crop production (Tan, 1984). The use of inorganic fertilizers, though essential to increase crop production, can also prove to be hazardous to the environment. e.g. nitrate(NO_3^-) fertilizers or fertilizers that can be converted into nitrates. Ammonium ($NH4^+$) fertilizers for example, when used in well-drained soil, may be conserved into nitrates. Commercial fertilizers may contain a great range of heavy metal but the highest values of heavy metals are found in phosphate fertilizers. Excessive use of phosphate fertilizers may leach into streams and lakes. An over enrichment of Lake water with phosphate and nitrate ions causes excessive growth of the unwanted aquatic plants, a process called eutrophication.

Soil: Soil is defined as three dimensional natural body on the landscape, developed or developing from initial parent materials by the activities of the living organisms as influenced by the climate and relief over a given period of time (Zinck, 1986/87). Soils are the basis for production of biomass in the form of the of food, fodder and renewable energy. Soils also filter, buffer and transform adverse compounds, thus protecting the food chain and the groundwater from pollution and comprise a gene reserve which is more compressive in quality and quantity that all the above ground biota together (Lal, *et al.,* 1998).

Soil Pollution: Soil pollution refers to the cases where contamination has become severe and adverse effects have become unacceptable and leading to malfunctioning of the soil and consequently to soil degradation (De Haan et al, 1993). Pollution can also be defined as the reduction in the quality of the environment by the introduction of the impurities

Soil Contamination: Soil contamination is considered as any addition of compounds that results in adverse effect on soil functioning. Both soil contamination and pollution reflect only a difference in degree of damaged to soil system. The behaviour of contaminants in soils is not only associated with the process affecting mobility and retention in soils but also with their physicochemical forms and their uptake by plants soil organisms in the system (Lal et al, 1998). The important processes influencing mobility and retention of metals are weathering solubility, precipitation, chelation, uptake by plants, immobilization by soil organisms and leaching. Organic matter content and redox reactions in the soils primarily affect these processes.

Soil degradation: Soil degradation is defined as physical, chemical and biological degradation of soil properties and its broad meaning also include both salinization and soil erosion (FAO, 1984). Chemical degradation is defined as combined negative effects of chemicals and chemical processes on those properties that regulate the life processes in the soil can be caused either by natural properties or by anthropogenic activities. Soil resilience, soil quality, climate and weather and management affect soil degradation, its severity and impact, which include land use and farming systems.

Soil quality: Is the "capacity of the (soil) to function". To expand this definition soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water (and quality) and support human health and habitation (Karlen, et al., 1997). Similar to soil degradation, soil quality also depends on inherent soil characteristics e.g. structure attributes, rooting depth, change density, nutrients reserve and soil bio-diversity Soil quality should be evaluated based on soil functions (Doran *et al.*, 1996). By focusing on how well a specific soil functions within a defined ecosystem, the concept of soil quality can be used as a bridge between the interests and concerns of our rural, urban, and suburban clientele.

CHAPTER 4

4.0 MATERIALS AND METHODS

In this chapter materials and methods used to carry out this research are presented. The research was carried out on the wetland soils of Lake Naivasha in three major time phases; pre-filed work, fieldwork and post fieldwork phase (Fig.4.1).

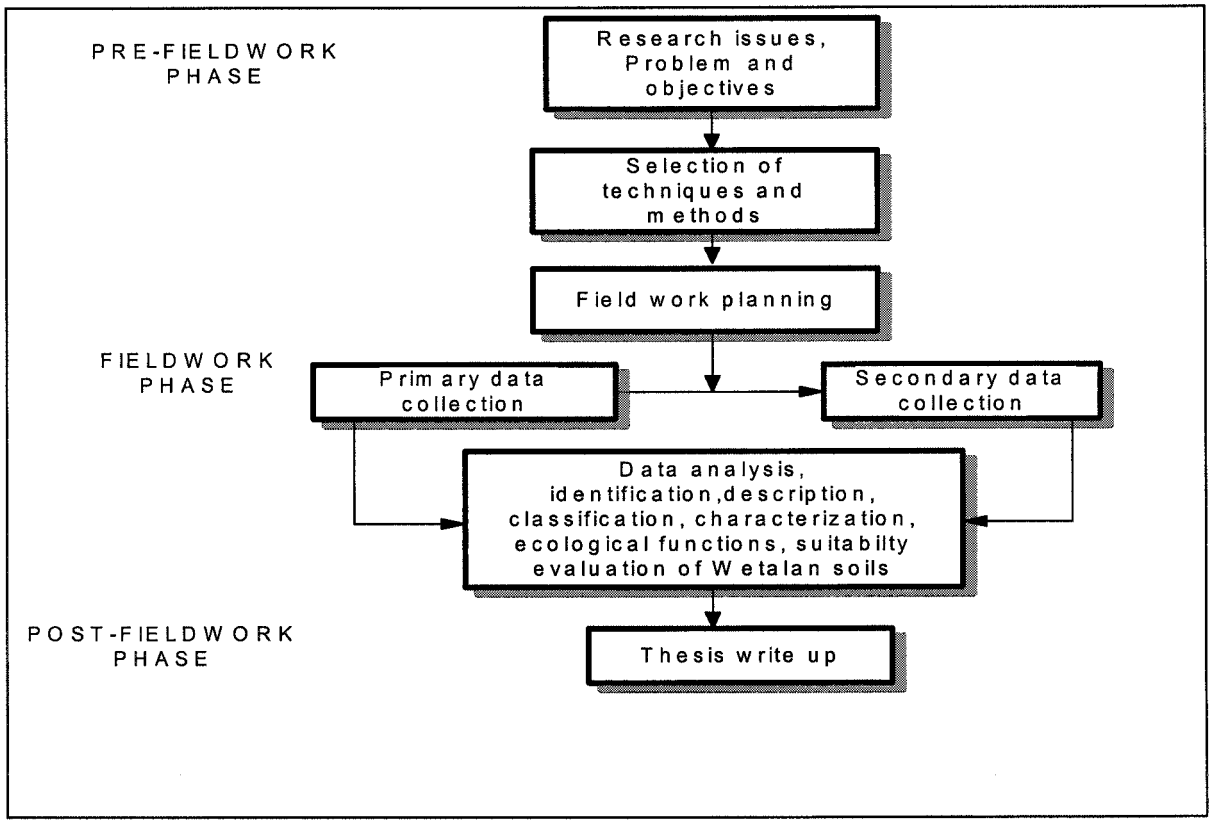

Fig.4.1 The major time phases

4.1 *Pre-fieldwork phase*

This phase include a general survey of activities such; definition of the research issues including problem formulation, objectives, hypothesis and identification of data needs, preparation for fieldwork including image processing and interpretation, air-photo interpretation.

4.1.1 Problem analysis

The problem was analysed using the problem tree approach (Fig.1.1) with the help of a literature search. This analysis formed the basis for the identification of research objectives and data needs.

4.1.2 Identification of data needs

This involved: collection of basic information such as, background information, climate data, vegetation and land use, hydrology, geology and general soil information of the study area, literature review was carried out to obtain for the information related to the subject and the study area.

The following materials of the area were studied: Geological map at the scale (1:50,000), a topographical map at the scale (1: 50,000), and air photographs at scale (1:12.500 and 1:50, 000), and satellite image TM image 1995.

The initial aerial photo interpretation was done using the geopedological approach (Zink, 1984). From this interpretation, a map was made that was used for the planning of the fieldwork and also was used in the field. Finally a soil map was prepared and published at the scale of (1:50,000).

Image processing and interpretation was done using Ilwis 2.2, which involved georeferencing, resemble, supervised classification of image and false colour composite making. The false colour composite of the TM image was produced by combining image bands for enhancement purpose (Shrestha, 1998). Image band 5, 4 and 1 corresponding to the Near Infrared and blue was used. This process was assigning them the red, green and blue colours respectively.

Georefencing of the image was done using the 1: 50, 000 topographic maps (1975). The selected 'tie points' in UTM will be used to transform the image into UTM (X, Y) coordinate system. The co-ordinates in the UTM are in meters. Using image characteristics such as colour, shape, texture and patterns helped in the image classification of the TM image.

The satellite image was used to prepare a general land use map of the study area at the scale of (1:50,000). Information on the use of agricultural chemicals and fertilizers (type, rate of application interval of application and the period of application) from the study area was collected.

4.2 Fieldwork phase

This phase involved fieldwork of 3 weeks in the study area during which a number of activities were carried as follows. Two kinds of data were collected viz-primary data and secondary data.

4.2.1 Primary data

***Reconnaissance survey*: -** A reconnaissance trip was made on the first two days on the study area for the purpose of familiarization, orientation and accessibility of the fieldwork area. Air-photos, a global positioning system (GPS) and topographic maps of the study area were used for orientation in the field.

Sample areas: - These were determined on the basis of their accessibility (roads) and nature and covered reasonable large variation of Wetland soils in the eastern and northern and southern parts of the Lake. A total of six sample areas were selected covering these parts. They included -KWS-Annex, YMCA, Longonot farm or Block Farm, Yacht Club, Marula farm, and Delamere farm (see Fig. 5.2.).

Transacts - In each sample area, one or more transacts were made depending on the size and variation of the sample area, with the help of GPS and compass. Starting from the waterline, transacts were constructed perpendicular to the shoreline and the contour. The central point (at the waterline) was fixed by a GPS reading. The direction of transact was established by compass. On each transact observations were made every 10m, the distance was measured by survey tape (See Fig.4.1). In KWS Annex three transacts were made, each 150m apart and in Delamere two transects, also 150 m apart, were made.

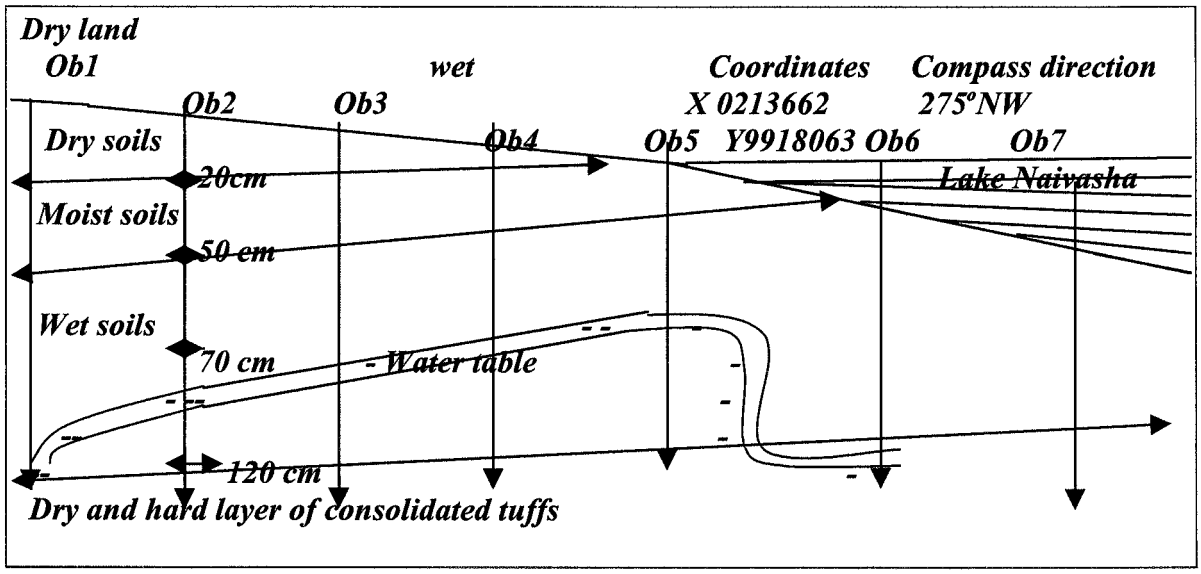

Fig.4.2 An example of transact made on the Wetlands of low terrace of map unit PL443 in the KWS Annex sample area.

Identification of observation and sample points: Observation points were studied by means of auguring and minipits at an interval of 10 m. from dry land in to the Lake. At each observation point data on soil morphological characteristics, landforms, elevation, slope gradient, parent material, vegetation, landuse and other properties related to ecological function of wetland soils were collected. The morphological characteristics include soil colour, soil structure, soil texture, soil pH, redox potential, groundwater table, soil drainage, soil depth, water permeability, organic matter, consistence, gley, mottles. A total of forty-one observations were made in all transacts.

***Minipits and auger observation*: -** Soils were studied by means minipits and auger observations (ITC approach). The (FAO, 1990) guideline for soil profile soil description was used to describe both auger observations and minipits. Colour was studied by using the colour Munsel colour chart (Munsel colour, 1994). During auger observation water table depths were also recorded in each transact.

***Soil samples:* -** A total one hundreds and sixty four samples were collected from minpits and auger observations for the determination of pH, redox potential (Eh), electrical conductivity (ECe), cation exchange capacity (CEC), texture, and colour.
The analysis of these parameters was carried out on saturated soil brought to the field laboratory.

4.2.2 Secondary data

In addition climatic data, such as rainfall, temperature, evaporation and radiation were collected. Information on landuse, including data on pesticide and fertilizers was also collected. From LNROA, first hand information was available from the secretary.

4.3 Post fieldwork phase

During this phase, data entry, analysis and thesis writing were the major activities.
The steps involved the following: data handling, compiling and statistical analysis, and transfer of the photo interpretation map into soil map and preparation of the legend, digitizing of the soil map, geological map using ILWS 2.2, landuse map from TM image.

4.3.1 Data entry to the data base

Digitizing was done in ILWIS 2.2 for the base map (roads, major towns lakes and rivers), soil maps, geology and land use map.

4.3.2 Data analysis

Soil and climatic data were entered into different software programs for analyses. The SPSS program was used for statistical analysis while the Exel program was applied for drawing graphs and histogram charts; lastly Graf4win program was used for plotting graphs of pH, ECe and Eh.

4.4. Field and Laboratory techniques

A special portable meter (18.33- 39 +13.36) with special pH, redox and electrical conductivity electrodes was used to determine pH, ECe and Eh. The meter was calibrated for each pH, ECe and Eh electrodes.

4.5 Instruments and materials

The following instruments were used in the field: Eledman auger, spade, field knife, geological hammer, hand hoe, pocket stereoscope, Special meter for measuring pH, ECe and Eh, GPS compass, surveyor tape. The materials included Mussel colour chart (1994), soil profile description forms, and guideline for soil profile description (FAO-Unseco, 1990) and USDA key to Soil taxonomy (Soil Survey Staff, 1996). Others include plastic bags, identification tags, coloured pencils, aerial photographs (1:12,500and 1:50,000), topographic maps (1:50, 000), Geological map (1:50, 000),

Plate 8. KWS Annex, transact II view West, showing sequence from dry to recently flooded riparian zone. In the background papyrus vegetation.

Plate 9. KWS Annex, transact III, observation in the permanently flooded areas (the papyrus zone).

Plate 10. Collecting soil samples from observation in the KWS Annex, transact III. Note ranger on guard against buffaloes and hippos.

CHAPTER 5

5.0 RESULTS AND DISCUSSIONS

5.1 General introduction

The major objective of this research was to characterise and study ecological functions of Wetlands Soils in Lake Naivasha. This was directed particularly to answer questions concerning status of Wetland soils in response to information gaps that may restrict LNROA efforts in monitoring pollution.

The major research components undertaken to achieve this objective were: identify, describe and classify the soils, (section 5.3); characterization in terms of physical and chemical properties and examine variations of these parameters with depth and along the transacts (section 5.4); ecological functions of wetlands soils (section 5.5); vulnerability of Wetland soil to pollution, (section 5.6); effect of Lake fluctuations in the Wetland soils, (sections 5.7); and evaluation of Wetland soils to other uses (section 5.8). Statistical analysis was also carried out, (section 5.2). In this chapter the results of each component are presented, discussed and conclusions drawn.

5.2 Statistical analysis

5.2.1 Introduction

Statistical analysis was carried to find out if the redox potential (Eh), pH and electrical conductivity (ECe) have significant difference in different sample areas or transacts. Also these parameters were tested to find out if they have any significant correlation between them, transacts and depths (see appendix II). The results of statistical analyses are presented, discussed and conclusion drawn in the following chapter.

5.2.2 Test of normality

The SPSS program version 8.0 was used to explore the data to test for normality. From the histogram and box plot (Appendix II), the data showed both positive and negative skewness. The test of normality was carried out according to Kolmogorov-Simrnov[a] from the SPSS program. The Kolmogorov-Simirnov tests strongly rejected the hypothesis of normality of the variables in all nine transact because the calculated *t* values were less than the critical or calculated (t= 1.960) at 0.05 level (Table 5.1).

Table 5.1 Test of normality

	Kolmogorov-Simirnov[a]		
	Statistics	df	Sig.
TRANSECTS (m)	0.142	163	0.000
DEPTH(cm)	0.197	163	0.000
REDOX POTENTIAL (Eh)	0.098	163	0.001
pH	0.200	163	0.000
ELECTRICAL CONDUCTIVITY (ECe)	0.090	163	0.003

[a] *.Lilliefors significant correlation*

5.2.3 Non parametric test

Based on the results of normality tests, the nonparametric test was used to carry out correlation analysis of the redox potential (Eh) and the electrical conductivity (ECe), redox potential (Eh) and pH and finally electrical conductivity ECe and pH. The nonparametric test was used because the data were not normally distributed. The nonparametric test is a distribution-free tests and does not make assumptions about the underlying distribution of the data (SPSS, 1997). The results are presented below and also shown on Tables 5.2 and 5.3.

5.2 4 Non parametric correlations

The Spearman rank correlation Sig.(2-tailed) was used to measure the strength of linear association between the redox potential (Eh), pH, electrical conductivity (ECe) with depth in transacts and between transacts.

Redox potential (Eh): The general trend was that the redox potential (Eh) had negative significant correlation with all transacts (calculated Corr. Coef. -0.185 compared with tabulated Corr. Coef. 0.138 at 0.05 significant level) (Freese, 1984); negative correlation with pH (calculated Corr. Coef. -0.025 compared with tabulated Corr. Coef 0.138 at 0.05 level); electrical conductivity (ECe) (calculated Corr. Coef-0.026 compared with 0.138); while positive correlation with depth (calculated Corr. Coef. 0.045 compared with tabulated Corr. Coef 0.138). The results are presented in Table 5.2.

pH: The pH had positive significant correlation with depth (Calculated Corr. Coef. 0.165 compared with tabulated Corr. Coef. 0.138 at 0.05significant level) and electrical conductivity (ECe)(calculated Corr. Coef. 0.475 compared with tabulated Corr. Coef. 0.181 at 0.01 level) while positive correlation (calculated Corr. Coef 0.074 compared with tabulated Corr. Coef. 0.181) in all transacts (Table 5.2).

Electrical conductivity (ECe): The electrical conductivity (ECe) had significant negative correlation with all transacts (calculated Corr. Coef -0.158 compared with tabulated 0.181 at 0.05 significant level) (Freese, 1984) while positive significant (calculated Corr. Coef. 0.219 compared with tabulated 0.181) at 0.01 level) with depth, (Table 5.2).

Table 5.2 Non parametric Correlations

			TRANSACT	DEPTH (cm)	REDOX (mV)	pH	ECe(mS/cm)
Spearman's rho	TRANSACTS	Corr. Coef.	1.000	0.000	-0.185*	0. 074	-0.158*
		Sig.(2-tailed)		1.000	0. 018	0.347	0.044
		N	164	164	163	163	163
	DEPTH (cm)	Corr. Coef.	0.000	1.000	0.045	0. 165*	0.219**
		Sig. (2-tailed)	1.000		0.571	0.036	0.005
		N	164	164	163	163	163
	REDOX (Eh)	Corr. Coef.	-0.185*	0.045	1.000	-0.029	-0.026
		Sig. (2-tailed)	0.018	0.571		0.755	0.739
		N	163	163	163	163	163
	pH	Corr. Coef.	0.074	0.165*	-0.025	1.000	0.479**
		Sig.(2-tailed)	0.347	0.036	0.755		0.000
		N	163	163	163	163	163
	ECe (mS/cm)	Corr. Coef.	–0.185 *	0.219**	-0.026	0.479**	1.000
		Sig.(2-tailed)	0.044	0.005	0.739	0.000	
		N	163	163	163	163	163

*. *Correlation is significant at the 0.05level (2-tailed)*
**. *Correlation is significant at the 0.01 level (2- tailed)*

5.2.5 Test Statistics

The Kruskal Wallis Test was used to test the significant difference of the variable redox potential (Eh), pH and electrical conductivity (ECe) in all nine transacts. The results of statistics are shown in Table 5.3.

5.2.5.1 Redox potential (Eh)

To evaluation the Eh the following approach was used.

Question: Is there a difference in Redox potential (Eh) in difference transacts?
Hypothesis: *Ho:* Redox potential (Eh) is the same in all transacts
Ha: Redox potential (Eh) is at least different in one of the transacts.
Results: Calculated Chi-square X^2 = 79.043, df =8 and p= 0.000, Tabulated Chi-square X^2 = 20.28 at 5% level.

Conclusion: The test statistics gave the Chi-square X^2 value of 79.043, which is greater than the critical value or tabulated Chi-square x^2 of 20.28 at 0.05 level. Therefore fail to accept the *Ho*: and conclude that Redox potential (Eh is different in at least one transact (Table 5.3).

5.2.5.2 pH

The pH was assessed like wise.

Question: Is there a difference in pH in different transacts?
Hypothesis: *Ho:* pH is the same in all transacts
Ha: pH is at least different in one of the transact.
Results: The calculated Chi-square X^2 = 65.607, df =8 and p= 0.000, the tabulated Chi- square X^2 =20.28 at 5% level.
Conclusion: The test statistics gave the Chi-square X^2 of 65.607, which is greater than the critical value or tabulated Chi-square X^2 of 20.28 at 0.05 level. Therefore fail to accept the *Ho*: and conclude that pH is different in at least one transact (Table 5.3).

5.2.5.3 Electrical conductivity (ECe)

Also the ECe values were evaluated as follows.

Question: Is there a difference in electrical conductivity (ECe) in difference transacts?
Hypothesis: *Ho:* Electrical conductivity (ECe) is the same in all transacts
Ha: Electrical conductivity (ECe) is at least different in one of the transact.
Results: The calculated Chi-square X^2 = 69.091, df =8 and p= 0.000, the tabulated Chi-square X^2 =20.28 at 5% level.

Conclusion: The test statistics gave the Chi-square of 69.091, which is greater than the critical value of 20.28 the 0.05 level. Therefore fail to accept the *Ho*: and conclude that Electrical conductivity (ECe) is different in at least one transact (Table 5.3).

Table 5.3 Test Statistics[a,b]

	DEPTH (cm)	REDOX (mV)	pH	ECe(mS/cm)
Chi-square	0.000	79.043	65.607	69.091
df	8	8	8	8
Asymp.Sig.	1.000	0.000	0.000	0.000

5.2.6 Discussion

Test of normality: Generally the test showed that the parameters are not normally distributed as they skewed either to the right or left. The reason could be that in nature soil properties are not normally distributed in space due to influence of many factors which may include location, parent material, climate, rate of weathering process, organisms and man kind. Transformation of the data to normal could lead to loss of some data and therefore the nonparametric test was used to analyse the data. The nonparametric test is a distribution-free test or normal distribution free and does not make assumptions about the underlying distribution of the data

[a] .*Krskal Wallis Test*
[b] . *Grouping variable: TRANSACT*

Correlation: The parameters tested showed to have some correlation with transacts, depths as well as between the parameters (Table 5.2). However the coefficients of correlation between parameters and depths were low or not significant, because only four depth observations were done and sampled which could not give many data for correlation. Redox potential had a negative correlation with pH, however the coefficient of correlation was not significant. The reason could be that pH values in the Wetland soils do not differ much from all transacts as they are in the same parent materials. Also this relation that as the pH increase the redox decrease and vice versa. The pH showed significant correlation with electrical conductivity. The reason could be that that amount of salts in the wetland soils had strong influence pH.

Test statistics: From statistical analysis, the parameters tested showed to differ significantly along transacts as well as in the depths as indicated by their Chi-squares (Table 5.3). The calculated Ch-squares (X^2) values were greater than that tabulated values of Ch-square (X^2) =20.28 at %5 level. These differences mighty be due to parent materials, water fluctuation and soil, time and period of flooding of Wetland soils. However parameters from transacts of the sample areas like KWS Annex and Delamere farms did not show much difference. The reason may be that, essentially the sample areas belong or consist of the same parent material and there exhibit almost the same soil properties.

5.2.7 Conclusion

Generally redox potential, pH and electrical conductivity have shown to have correlation with transacts and depths of the different sample areas. The redox potential (Eh) values have negative significant correlation at 5% level with transacts while in the was no significant correlation with depth, pH and ECe. The ECe values have negative significant correlation with transacts at 5% at level and positive correlation with depth and pH at 15 level. The pH values have significant correlation with depths at 5% level and ECe at 1% level.

Statistical analysis test of these parameters have shown that all have significant difference with transacts or sample areas at 5% level while not with depths. The Chi-square calculated for redox potential, ECe and pH are 79.043, 65.607, and 69.091 respectively at 5% level and the tabulated Chi-square at 5% is 20.28. The differences of these parameters in different transacts or sample areas may be due to parent material, influence of water fluctuation of Lake Naivasha, and management of the surrounding farms.

5.3 Identification, description and Classification of the Wetland soils

5.3.1 Introduction:

In this section, the identification, description and classification of the Wetland soils around Lake Naivasha is presented, discussed and conclusions are drawn. Generally the Wetland soils occupy a large area on the eastern, northern and north-western areas of Lake Naivasha (Fig. 5.1). These areas are more flat with the slope ranging from 0-2 percent.

With the use of air photographs interpretations (API) and fieldwork, Wetland soils at Lake Naivasha were identified into two main physiographic units of the low terrace of the lacustrine plain of Lake Naivasha. They include physiographic unit PL443, (nearly level to level, slope 0-2%) and PL444 (papyrus swamp with deep water). At the time of research the PL443 was flooded. The PL444 included papyrus swamps and has been flooded for a long period of time (Fig. 5.2). For the purpose of describing and classifying the major wetland soils, six sample areas and nine transacts were selected and studied during the fieldwork. The sample areas included: KWS Annex, YMCA Club, Longonot farm, Yacht Club, Marula farm and Delamere farm.

5.3.2 Mapping unit PL443:

This unit occupies low terrace of the lacustrine plain or riparian zone of the Lake Naivasha basin. The slope is nearly level to level (0-2%). The area is dominantly used for grazing of livestock and wild animals. There is no observable surface soil erosion and soils are very deep, moderately well drained to imperfectly drained to poorly drained. The topsoils are about 10 to 15cm thick and very dark grayish brown in colour and have a clay loam to sandy loam texture. The soils have a high supply of Calcium and Magnesium. The Potassium level is also high, while the sodium and Carbon level are low (Appendix XVIII). The sample areas and transacts under mapping unit PL443 are presented and described below.

5.3.2.1 Sample area 1: KWS Annex

Location: KWS annex sample area is located about 200m west of KWS annex offices in the low terrace of the lacustrine plain. Two transacts were established each aproximately150m apart.

Transact I was located at GPS reading 37m 0213662, UTM 9918063, 275^0 NW on the edge of the Lake Naivasha water in the lower terrace of the lacustrine plain. The area was nearly level with slope 0.5 - 1 percent. Transact was established running from dry, wet to flooded areas and observations were done at an interval of 10m from one point of observation to another (see Fig.5.2) and Plate 8.

Transact II was about 150 m west of transact I. It is located at GPS reading 37m 0213671, UTM 9918200, 280^0 NW on the edge of Lake water in the lower terrace of the lacustrine plain. Like transact I, the area in transact II is almost level with slope 0-1 percent and was established running from dry, wet to flooded areas, while observations were done at an interval of 10m between the observation points.

Description: The soils in the KWS annex sample area are developed from the lacustrine sediments derived from weathering tephra. The soils are moderately well drained in the dry area, imperfectly drained in the wet area and poorly drained in the flooded areas. The texture also varied along the transact and depth. It ranged from clay loam sandy loam topsoils to sandy clay loam at a depth of 120 cm. Along the transact texture varied from clay loam to sandy loam. On the dry area of map PL443 the soils were dry on the topsoil with moist to wet subsoil due to proximity watertable (see Fig.5.9 and Appendix III).

The soils in transact II of the KWS annex sample area are also developed in the lacustrine deposits derived from tephra. The soils are moderately well drained on the dry area, imperfectly drained in the wet area and poorly drained in flooded areas. The texture also varied from clay loam to sandy loam in the topsoils to sandy clay loam to a depth of 120 cm. The texture varied from clay loam, sandy clay loam to sandy loam along the transact. Like in transact I, dry areas of mapping unit PL443 the soils were dry topsoil and moist to wet subsoil due to proximity watertable (Appendix II and Fig.5.10).

Classification: The soils in this mapping unit were classified as **loamy smectitic Typic Xerochrepts** in the dry area and **Loamy smectitic Aquic Xerochrepts**; on the flooded area, (USDA Soil Survey Staff, 1996) and **Eutric Cambisols** (FAO-Unesco, 1997)

5.3.2.2 Sample area 2: YMCA Club

Location: YMCA sample area is located at about 300 m west of YMCA Club offices in the lower terrace of the lacustrine plain. Flower farms and a dike bound this sample area to the North, East and West. One transact was established to represent this sample area.

The transact in this sample area is located at GPS reading 37m 0206295, UTM 9918063, 300^0 NW, in the lower terrace. The area was almost level to nearly level with slope 1-2 percent. Transact was established running from dry, moist to wet areas near the dike and observations were done at intervals of 10m from one point of observation to another (Fig. 5.2). The Lake water was prevented from coming to the flower farms by a dike. The areas of Lake water around this sample area showed signs of the eutrophication.

Description: The soils in the YMCA Club sample area are also developed from the lacustrine sediments derived from weathering tuff. The soils are moderately well drained in the dry area, imperfectly drained to poorly drained in the wet areas. The texture also varied along the transact and depth. It ranged from sandy loam to sandy clay loam in topsoils, to sandy clay at a depth of 120 cm. Along the transact texture also varied from sandy loam to sandy clay loam (see Appendix IV).

Classification: The soils in the map unit Pl443 are classified as L**oamy smectitic Typic Xerochrepts** (USDA Soil Survey Staff, 1996) and **Eutric Cambisols** (FAO-Unesco, 1997)

5.3.2.3 Sample area 3: Longonot farm

Location: Longonot sample area was located at about 150 m west of the manager's office in the low terrace of the lacustrine plain. At the time of research this sample area was used for horticultural production.

The transact was located at GPS reading 37m 0209254, UTM 9910663, 274^0 NW on the low terrace. The area was almost level to nearly level with slope 1-2 percent. Like the previous transacts, it was established running from dry, wet to flooded areas and observations were done at an interval of 10m between observation points (see Fig 5.2).

Description: The soils in Longonot farm sample area developed from the lacustrine sediments derived from weathering tuff. The soils were moderately well drained in the dry area, imperfectly drained in the wet area and poorly drained in flooded area. The texture of the soils varied along the transact and with depth and it ranged from sandy loam to sandy clay loam on the topsoils to sandy clay to sandy clay loam plus to a depth of 120 cm. (see Appendix V).

Classification: The soils in this mapping unit are classified as **loamy smectitic Typic Xerochrepts** in the dry area and **Fine smectitic Aquic Xerochrepts** in the flooded area (USDA Soil Survey Staff, 1996) and as **Eutric Cambisols** (FAO Unesco, 1997).

5.2.2.4 Sample area 4: Yacht Club

Location: The Yacht club sample area is located at about 300 m east of the Yacht Club offices in the low terrace of the lacustrine plain. The area is reserved for reaction purposes among the Yacht club members.

The transact is located at GPS reading 37m 0212614, UTM 9914615, 330^0 NW on the low terrace. The area is almost level to nearly level with slope 1-2 percent. The transact was established in the same way as previous transacts (see Fig. 5.2).

Description: Soils in this sample area are developed from the lacustrine sediments derived from weathered tuff. The soils are moderately well drained in the dry area, imperfectly drained in the wet area and poorly drained in the flooded area. The texture also varied in the transact as in the previous transacts. Also the transacts was established as in the previous transacts (see Appendix VI).

Classification: The soils in this map unit are classified as **Eutirc Cambisols** (FAO Unseco, 1997) and **Loamy smectitic Typic Xerochrepts** in the dry area and **Fine smectitic Aquic Xerochrepts** in the flooded area, (USDA Soil Survey Staff, 1996).

5.3.2.5 Sample area 5: Marula farm

Location: The Marula farm sample area is located at about 500 m south of Mural's office in the low Malewa terrace of the lacustrine plain. At the time of research, bush clearing around this area was taking place. Most of the areas around the observation were dry except near the river channels.

Transact at this area was located at GPS reading 37m 0206482, UTM 9929480, 176^0 SE in the lower Malewa terrace. The area was almost level to nearly level with slope 1-2 percent. A transact was established in same way as in the previous transacts and observations were done at an interval of 20m between observation points (see Fig 5.2).

Description: Soils in the Marula farm sample areas are also developed from the lacustrine deposits. The soils are imperfectly drained to poorly drained in waterlogged area. The texture of the soils was clay loam in the topsoil to heavy clay on subsoil. Soils are very sticky and plastic. On the dry area of mapping unit PL443 the soils are dry in the topsoil and moist to wet subsoils due to ground watertable (see Appendix-VII).

Classification: The soils in this map unit are classified as **Dystric Cambisols** (FAO-Unesco, 1997) and **Fine smectitic Typic Xerochrepts** on the dry area and **Fine smectitic Aquic Xerochrepts** in waterlogged areas (UDSA Soil Survey Staff, 1996).

5.3.2.6 Sample area 6: Delamere farm

Identification: Delamere farm sample area is located at about 600 m south of Delamere office on the low terrace of the lacustrine plain. At the time of study, large the area of this sample was flooded. Two transacts were established in this sample area each about 150 m apart.

Transact I was located at GPS reading 37m 0210472, UTM 9920213, 276^0 NW in the low terrace of the lacustrine plain. The area is almost level to nearly level with slope 1-2 percent. The transact was established running from dry to wet areas and observations were done at an interval of 20m between observations points, (see Fig 5.2). Like transact I, Transact II was located at GPS reading 37m 0210696, UTM 9920255, 178^0 SE in the low terrace of the lacustrine plain. The area was almost level to nearly level with slope 1-2 percent. The Transact was established running from dry to wet areas and observations were done at an interval of 20m between observations (see Fig. 5.2).

Description: Both transacts were established in the almost level to nearly level on the flooded areas of the low terrace. Soils in Delamere farm sample area are also developed from lacustrine deposits. The soils are moderately well to imperfectly drained to poorly drained in flooded areas. The texture of the soils is clay loam to sandy loam in the topsoil and sandy clay loam to a depth of 120-cm (see Appendix VIII).

Classification: The soils in this mapping unit are classified as **Eutirc Cambisols** (FAO-Unseco, 1997) and **loamy smectitic Xerochrepts** on the dry area and **Loamy smectitic Aquic Xerochrepts** in the flooded area (USDA Soil Survey Stuff, 1996).

5.3.3 Mapping Unit PL444:

This unit also occurs as the lowest terrace of the lacustrine plain. The area is waterlogged or flooded for most of the time. The area is characterized by papyrus and is major habitat for numerous fish, birds and wild animals. The soils are very deep and very poorly drained and under more than 65cm deep water. They are very dark grayish brown in colour and have a sandy clay and silty clay loam texture with histic materials on the topsoils. They have high values of Calcium, Potassium and Sodium, (Appendix XVIII). The sample area and transact under mapping Unit PL444 are presented and discussed below.

5.3.2.1 Sample area 1: KWS annex

Location: This sample area was established in the papyrus swamps of mapping unit PL444 about 250m West of the KWS annexe's Offices. The Transact was located at 37m 0213346 UTM 9918105, 274^0 NW on the papyrus swamp of the lowest terrace of the lacustrine plain. At the time of study the water level was 65 70 cm deep. One sample area was selected to represent this mapping unit, because accessibility to other areas was difficult due high water level and wild animals (Fig.5.2 and Plates 9 and 10).

Description: The soils in transact have developed from the lacustrine sediments derived from weathering tephra. The soils are very poorly drained with swamp water. The texture is mainly sandy clay loam to silt clay loam in subsoil and histic materials found in the topsoils (see Appendix III).

Classification: The soils in this unit classify as **Hydric Medihemists (USDA-Soil Survey staff, 1996)** and as **Fibric-Histosols, sodic phase** (FAO- Unseo, 1997)

5.3.4. Discussion

The Wetland soils at Lake Naivasha are mainly found on the lower and lowest terraces of the lucustrine plain and are represented by physiographic unit PL 443 and PL444 (Fig 5.3). The Wetland soils are generally developed in the lacustrine deposits and derived from volcanic tuffs. Topography of these soils is almost level to nearly level (slope 1-2 % slope) in physiographic unit PL443 and deep to very deep papyrus swamps in the physiographic unit PL444. This topography allows storing excess water from the Lake during the long rains and deposition of materials from the surrounding farms and catchment.

The drainage conditions of the Wetland soils varied from the moderately well to imperfectly drained in the dry areas of Wetland soils. The presence of proximity groundwater leads to moist soils in the sub horizons. In the wet and flooded areas the soils are poorly drained to very poorly drained. An impervious layer (dark yellowish brown) of tuff was found after 100 cm. The presence of this layer restricted as yet that the soils were saturated beyond this depth. The reason could be that these soils are

recently flooded after long dry period and that a long time is needed to saturate the whole profile.

The texture of the soils in the sample areas varied from sand loam to clay loam in the topsoils. Silt clay loam and sandy clay loam occur in the sub horizons. The textures of these soils may have resulted from parent materials and aeolian deposits around Lake Naivasha.

The Wetland soils were classified according to the Keys to Soil Taxonomy (USDA Soil Survey Stuff, 1996) and mainly belong to the order ***Inceptisols*** and ***Histosols***. In addition these soils were classified according to the (FAO-Unesco, 1998). At the suborder level the soils were classified as having acquic moisture regime. This is because the soils are saturated with water and the reduced conditions exist. The soils have very dark grayish colours that have low chroma (chroma 2) with dark reddish brown mottles (5YR3/4). Classification at the subgroup level was based on particle size distribution and mainly ***Typic*** and ***Aquic*** was used to differentiate them. At the subgroup the soils were classified based on the texture, mineralogy, and soil temperature.

The ***Inceptisols*** are soils with one or more diagnostic horizons that can form rapidly, for example an ochric epipedon and a cambic horizon. They lack illuvial horizons. The definition of this order is complicated, but most of the common horizon sequences are an ochric epipedon overlying a cambic horizon (Creutzberg, 1992).
The ***Histosols*** are organic soils, commonly called bog soils or moors, or peat and muck. Most are either saturated with water for prolonged periods, or artificially drained.

In the recently flooded Wetland soils of Lake Naivasha (Mapping unit PL443), the surface diagnostic horizons (epipedon) are dark coloured having low chroma, however in many places the surface horizons are thin to be mollic horizon. Therefore the main epipedon on the Wetland soils is ***Ochric horizons***. ***Cambic horizons*** form most of the sub horizons. The Cambic horizon is a subsufarce horizon of alteration in which the parent material has changed into soil materials without significant illuviation. It may have been formed under wet, moist or dry conditions, resulting in a variety of somewhat contrasting forms (Creutzberg, 1992). ***Histic*** epipedon are found in the papyrus swamp areas, which have been flooded for a long period. The histic epipedon is a horizon at or near the surface horizon, consisting of peat or much and it identified by its high content of organic carbon and its thickness. The dead papyrus roots and leaves, grasses and other materials deposited to these areas from surrounding form the histic materials.

The Wetland soils in mapping units PL443 are classified as **Eutric and dystric Cambisols** and as **Fine** and **Loamy Smectite Typic Xerochrepts** in dry areas and **Loamy smectite Aquic Xerochrepts** in the recently flooded areas. The texture is "finer" in the Southeast and in the Northern areas of the Wetland soils. The clay minerals are mainly smectite with relative abundance of 3 (Siderius, 1998). Other clay minerals include Kaolinite (1), Mica (2), Mixed (2) and Feldspars (2). In mapping unit PL444 the soils are classified as **Fibric-Histsotols, sodic phase** and as **Hydric Medihemists**.

The soils of the study area mainly belong to the lacustrine plain. The Lacustrine plain was built up by thick Holocene deposits (Thompson *et al.*, 1958). The deposits are stratified with alternating different layers of volcanic ashes and some clays. The stratification was the result of volcanic flows from various Longonot eruptions and also due to changes (fluctuation) of Lake Naivasha water containing sediments. The physiograhy of Lacustrine is complex, however a number of terraces could be identified which extend along the shore of the Lake. The terraces have been grouped as: Low terraces (1880 to 1890 masl), Middle terraces (1890 to 1900 masl) and High terraces (1900 to 2000 masl). The study was carried out in the low and lowest terraces.

5.3.5 Conclusion

The major Wetland soils of Lake Naivasha are identified in the low and lowest terrace of the lacustrine plain. They are represented by soil map units PL443 and PL444. At the time study some areas of soil map unit PL443 were recently flooded while others areas were dry. The soil map unit PL444 is permanent flooded and characterized by papyrus swamp.

The wetland soils are described as moderately well to imperfectly drained in the dry area of PL443. The soils are poorly drained to very poorly drained in the recently flooded areas of map unit PL443 and very poorly in waterlogged or permanent flooded areas. The textures are sandy loam, clay loam, silt clay loam and sandy clay loam and histic material in the papyrus swamps. Generally the textures are fine loamy to coarse loamy.

The Wetland soils are classified as Eutric and Dystric Cambisols (FAO-Unesco, 1997), Fine and loamy smectitic Typic Xerochrepts in dry areas of map unit PL443, Fine and Loamy, smectitic Aquic Xerochrepts in the flooded areas of map unit PL 443 (USDA Soil Survey Staff, 1998). In map unit PL444 the soils are classified Fibric-Histosols sodic phase (FAO Unesco, 1997) and as Hydric Medihemists USDA Soil Survey Staff, 1996).

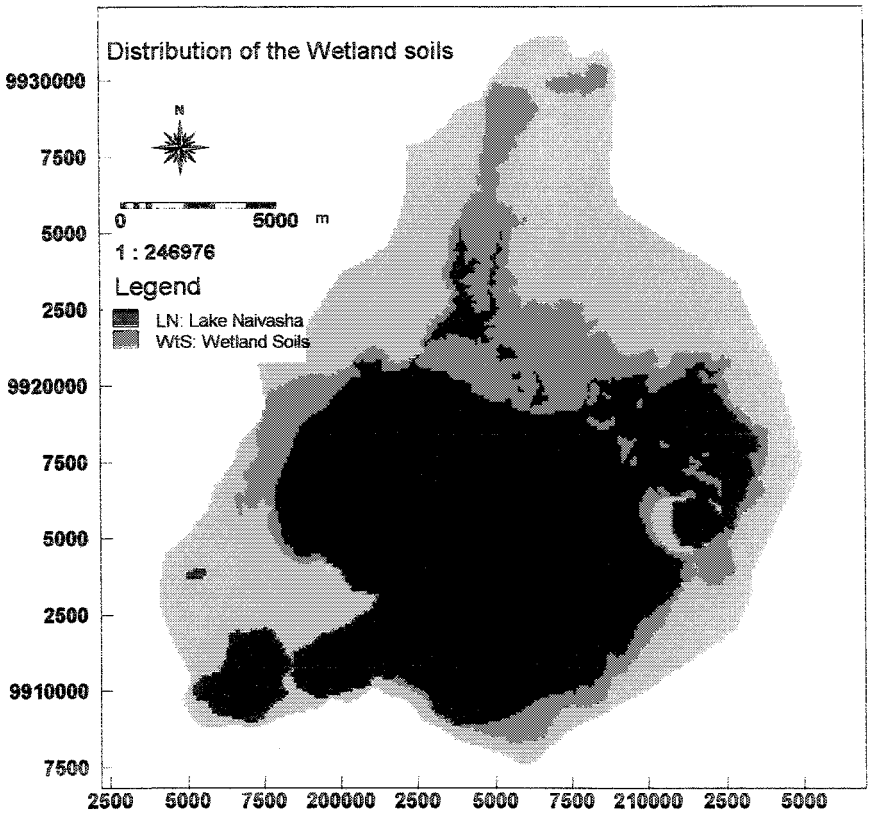

Fig. 5.1 Distribution of the Wetland soils around of Lake Naivasha

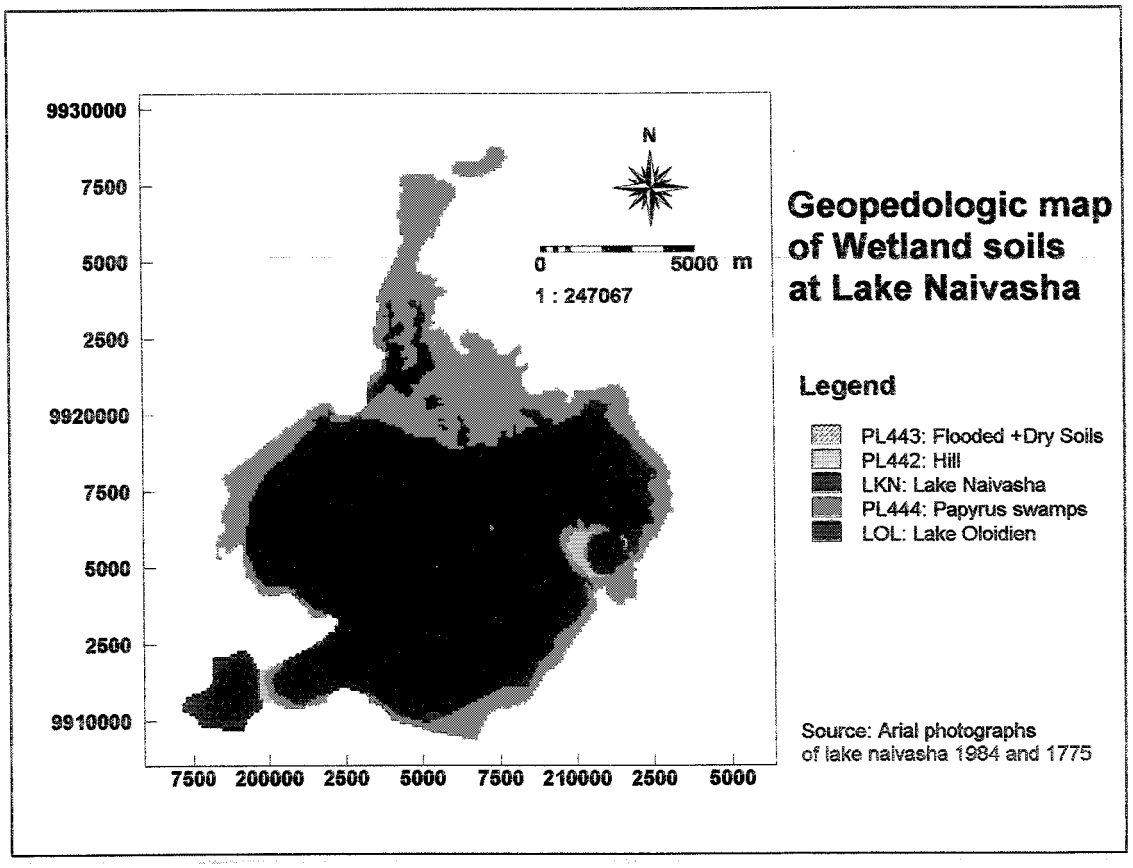

Fig.5.3 Major Wetland soils in the low and lowest terrace of lacustrine plain at Lake Naivasha

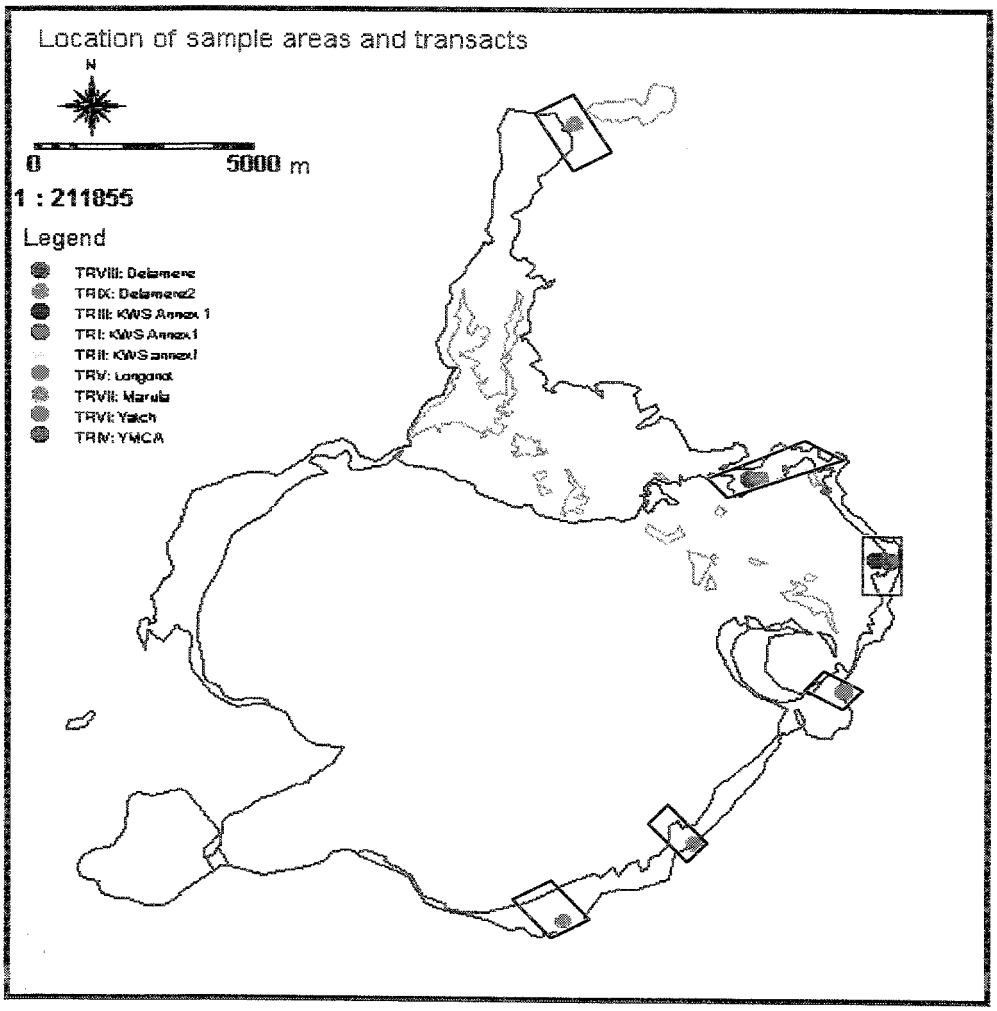

Fig. 5.2 Location of samples areas and transacts on the study area

5.4 *Characterisation of the Wetland Soils*

5.4.1 Introduction

The Wetland soils at Lake Naivasha are soils whose physical and chemical properties are influenced by the presence of the Lake water, its fluctuation, the proximity watertable and the deposition of sediments materials from the surrounding areas. For the purpose of characterizing Wetland soils at Lake Naivasha, some important physical and chemical properties (parameters) of these soils were studied and analysed. They include, texture, colour, redox potential, electrical conductivity, pH, CEC, organic carbon, mottles and gley. In this section these parameters are presented, discussed and conclusions are drawn.

5.4.2 Physical Characterization

The physical characterization includes: soil colour, texture, structure, mottles and gley properties studied in the Wetland soils during the fieldwork.

5.4.2.1 Soil Colour

Generally the amount and state of iron and/ or organic matter determine the colour of the soil. Many gray, olive and blue colours occur in the soil under partially or complete anaerobic situations and originate by the presence of iron in the reduced or ferrous state (Fitz Patrick, 1980). In the Wetland soils at Lake Naivasha, the colour varies from very dark gray to very dark grayish brown and olive gray in the topsoils and to olive brown to gray in the subsoils (see Appendix III-VIII). The chroma in most cases is low ranging from 1 to 2 while the values are 3 and 4. The hue's in most cases are 2.5Y or 5Y, few have a 10YR or 7.5YR Hue.

5.4.2.2 The soil texture

The texture of the soils refers to the "feel" of moist soils resulting from the mixture of the constituents of mineral particles and organic matter. In the Wetland soils at Lake Naivasha the texture is generally "*finer*" and varies from sandy loamy to sandy clay in the topsoils while sandy clay loam and silty clay loam are found in the lower horizons. In the papyrus swamps sandy clay to silty clay are found in the sub horizons while in the topsoil partial decomposed organic matter is found (see Appendix III-VIII).

5.4.2.3 The soil Structure

The soils structure refers to the arrangement of soils particles in-groups or aggregates (Brady, 1984). The most important structural features of the soils are the size, shape and stability of peds and their penetrabilty by water, air and root (Landon, 1991).
Most of the structures of Wetland soils at Lake Naivasha are weak to moderately, very fine to fine sub angular blocky in recently flooded area and massive in the papyrus swamps (see Appendix III-VIII).

5.4.2.4 The Mottles

These are irregular patterns of two or more colours with sharp boundaries between the different areas. Mottling is used for pattern description with mainly gray, olive or blue areas. Such patterns are interpreted as resulting from seasonal wetting and drying of the horizons. The duration of the dry state is indicated by yellow and brown areas, which become progressively larger and more frequently as aeration increases. In the Wetland soils at Lake Naivasha the subsoils showed mottles patterns. The mottles in most case are dark reddish brown and yellowish brown (Appendix III- VIII).

5.4.2.5 Gley

Reduction of oxygen gives soil characteristics greenish or bluish mottles. This result from a longtem seasonally alternating dry and wet conditions leading to alternating oxidation and reduction. In the Wetland soils especially in the papyrus swamps areas of the Wetland soils which have been flooded for long time a "Gley- bluish" properties in the deep horizons were observed. In the recently flooded areas, no gley properties were observed because the soils are slowly saturated; a process, which will take a long time before gley properties are formed.

5.4.3 Chemical characterization

The chemical characterization includes cation exchange capacity (CEC), organic carbon (%OC), redox potential (Eh), electrical conductivity (ECe) and pH.

5.4.3.1 Cation Exchange Capacity (CEC)

The cation exchange capacity (CEC) of the soils refers to the total capacity of the soil for cation exchange (cation adsorption) and is measured in milli-equivalents per 100g of oven-dry soils (Agricultural Compendium, 1989). In the Wetland soils of Lake Naivasha, the CEC were analysed from 26 soil samples taken at the depth of 50 cm. Three samples per transact in dry, waterline and flooded soils. The results of the CEC from all nine transact are presented in Tables 5.4 and Appendix XII-XVII.

5.4.3.2 Organic Carbon (%C)

Determination of the organic carbon content is important for the estimation of quantity and quality of organic matter in soils. The organic carbon in the Wetland soils was analysed at the depth of 50 cm at the three sites of each transact, viz. dry land waterline and flooded soils. A total of 26 samples were taken and analysed. The results of organic carbon are presented in Table 5.4 and Appendix XII-XVII.

5.4.3.3 Redox potential (Eh)

The redox potential results of transact 1 at KWS Annex sample area are shown in Table 5.4 and Figs.5.4-5) below. The other results of the redox potential are presented in Appendix XII and graphs of Eh variations along the transact and depths in the Appendix IX.

Table 5.4. Analytical data of transact 1 at KWS annex

Transact	Observation points	Depth (cm)	Redox potential(mV)	pH	ECe (mS/cm)	CEC (meq/100g)	% OC
37m 0213662,	1a	20	190	7.58	1.57		
UTM 9918063	1b	50	179	7.93	1.17	13.80	0.11
275^0 NW	1c	70	180	7.63	1.03		
	1d	120	190	7.5	1.05		
	2a	20	215	7.25	0.502		
	2b	50	203	7.73	1.12		
	2c	70	201	7.61	1.09		
	2d	120	200	7.5	0.801		
	3a	20	251	7.08	0.653		
	3b	50	242	7.5	0.788		
	3c	70	241	7.46	0.881		
	3d	120	227	7.37	0.831		
	4a	20	22	7.33	0.245		
	4b	50	88	7.2	0.702	12.20	0.24
	4c	70	107	7.28	0.813		
	4d	120	108	7.52	0.772		
	5a	20	-10	7.18	0.257		
	5b	50	42	7.27	0.653		
	5c	70	75	7.34	0.803		
	5d	120	90	7.38	0.846		
	6a	20	-64	7.17	0.86		
	6b	50	67	6.96	1.27	30.60	0.30
	6c	70	93	7.01	1.33		
	6d	120	108	7.03	1.21		

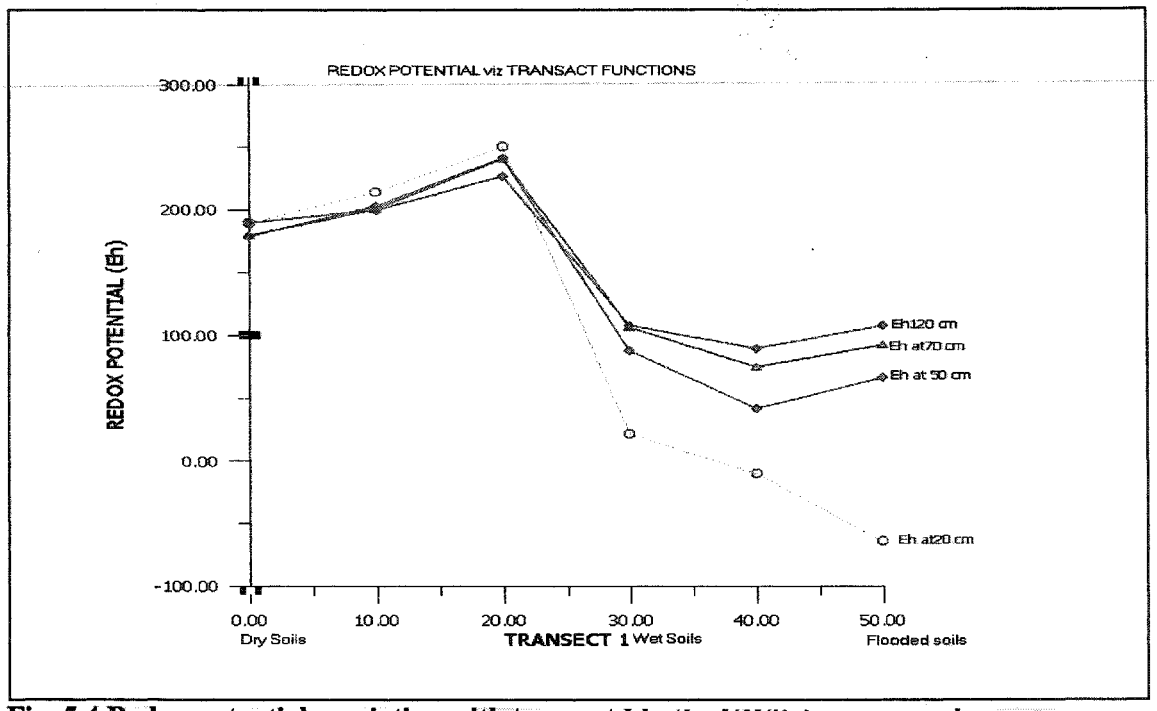

Fig. 5.4 Redox potentials variation with transact I in the KWS Annex sample area.

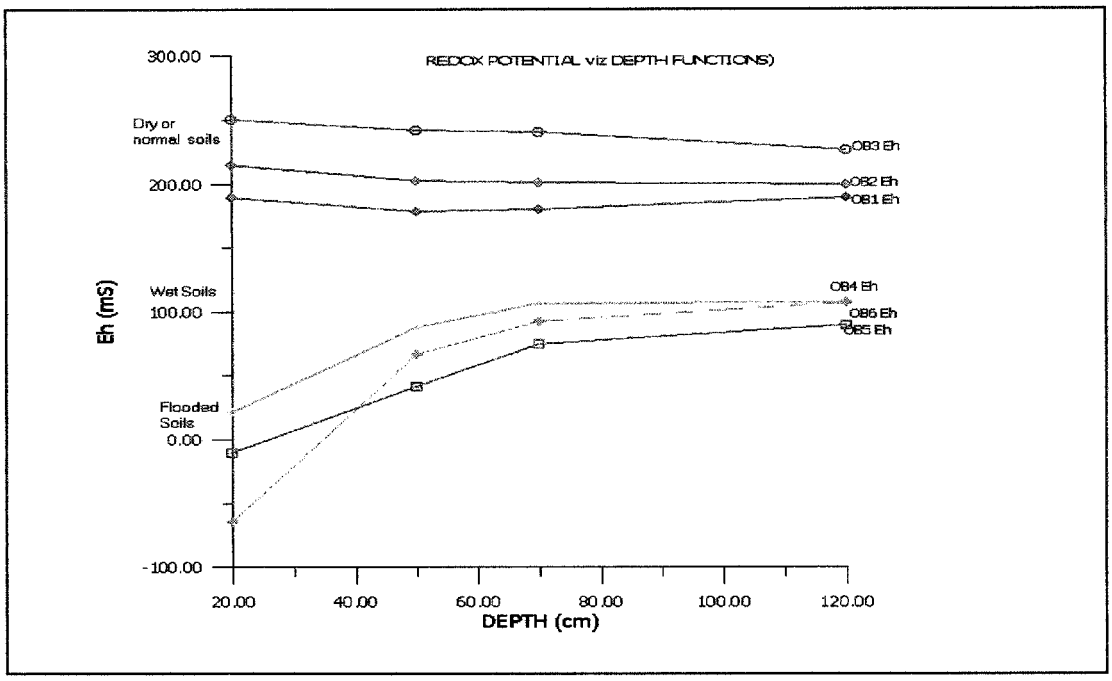

Fig. 5.5 Redox potential variations with depths in the transact I of the KWS Annex sample area.

5.4.3.4. Electrical conductivity (ECe)

The results of the electrical conductivity in transact I at KWS Annex sample area are shown in Table 5.4 and the graphs of ECe variations with distance and depths in Fig.5.6 and Fig.5.7. The other electrical conductivity results see Appendix XII- XVII and the graphs see Appendix X.

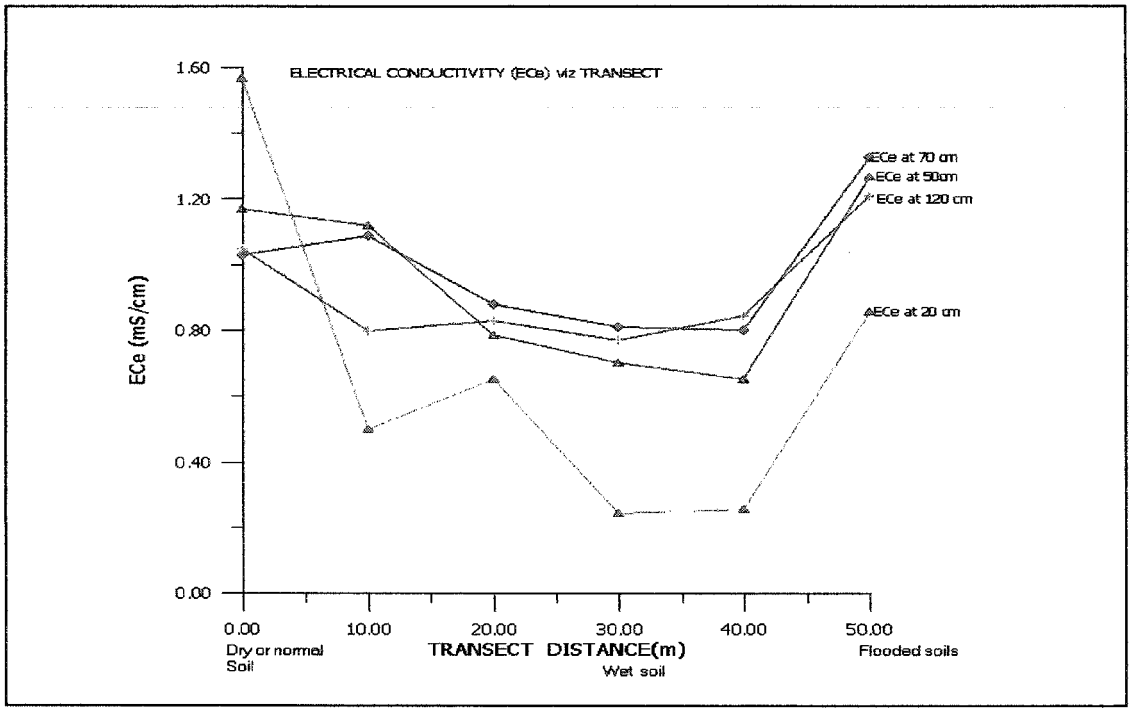

Fig. 5.6 Electrical conductivity (ECe) variations with transact I in the KWS Annex sample area.

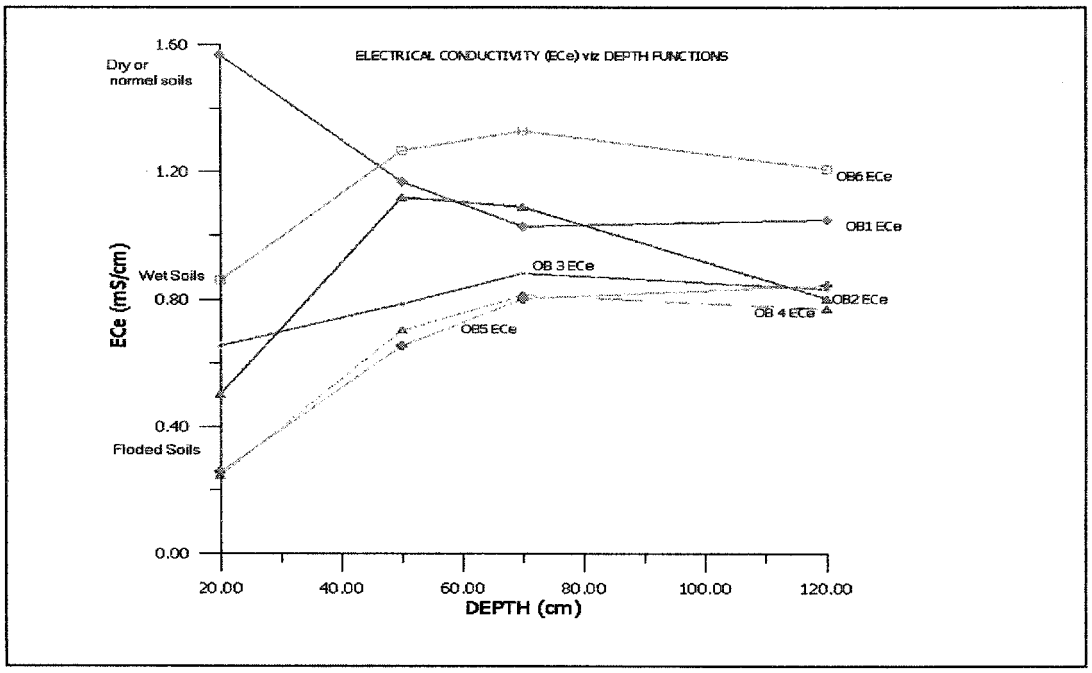

Fig. 5.7 Electrical conductivity (ECe) variations with depths in the transact I of the KWS Annex sample area.

5.4.3.5 pH

The pH results of transact 1 at KWS annex sample areas are shown in Table 5.4. The pH variations along the distance and depths are presented Fig.5.8 and Fig 5.9. The other pH results see Appendix XII-XVII and the Appendix XI.

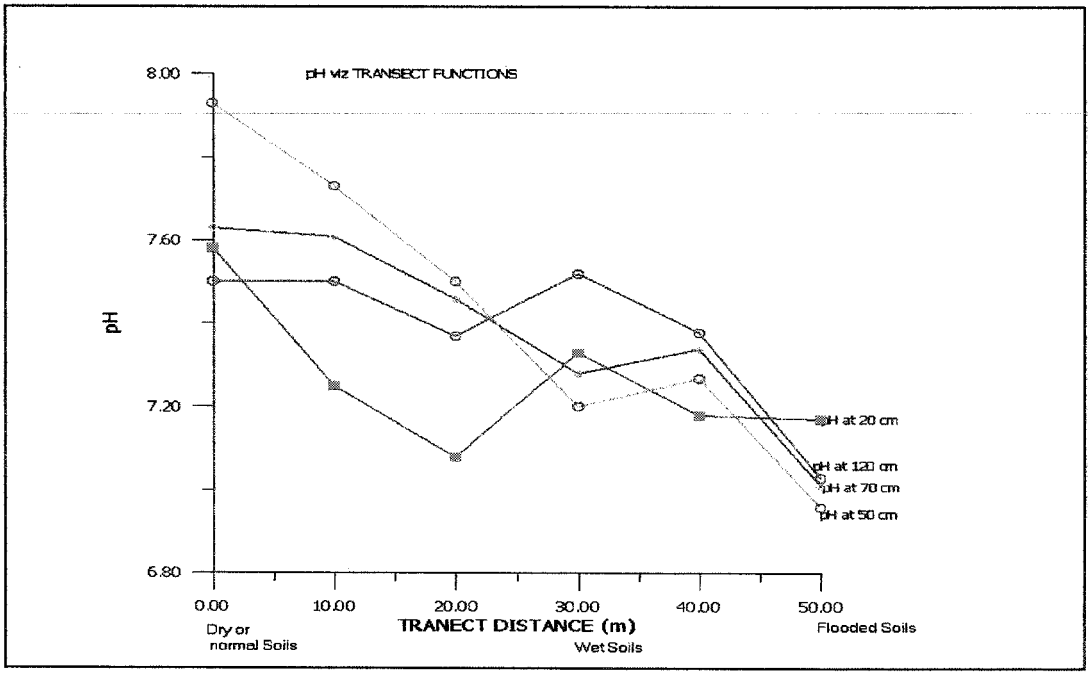

Fig. 5.8 pH variations with transact I in the KWS Annex sample area.

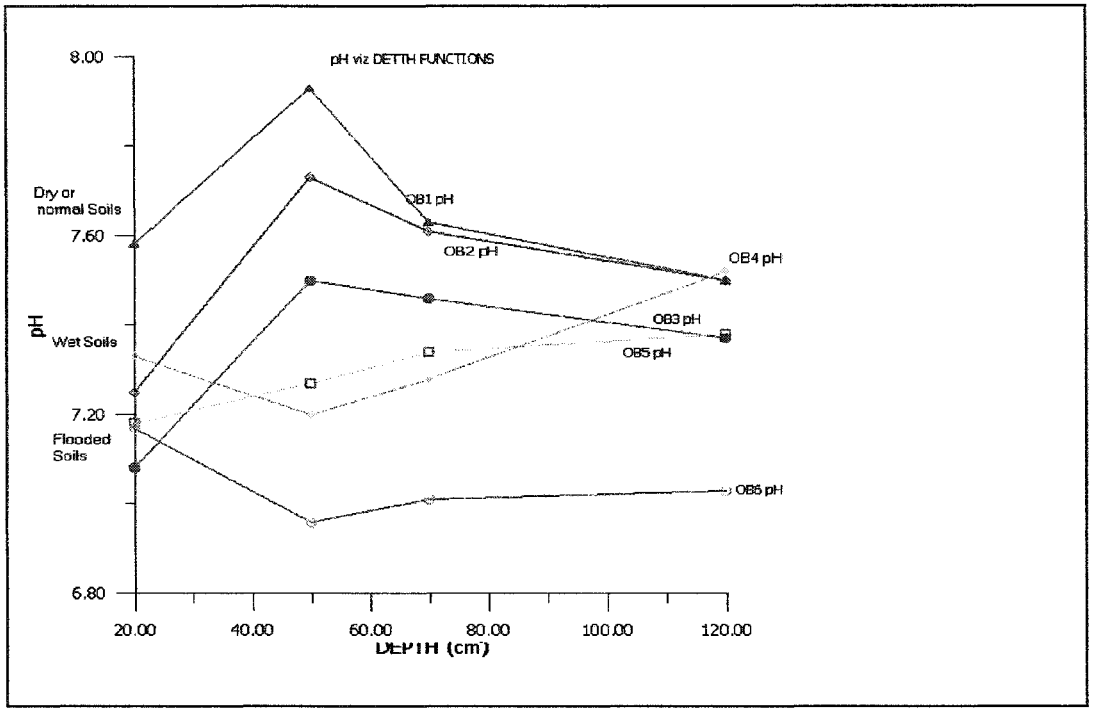

Fig. 5.9 pH variations with depths in the transact I of the KWS Annex, sample area.

5.4.3.6 Discussion

Physical characterization: The results of physical characterization of the Wetland soils at Lake Naivasha have shown that they are related to the hydric properties, which are common and criteria to wetland soils identification. In all samples areas, the soil colours have chroma less than two, which are a result of the reduced conditions and presence of organic matter. The presence of gray, olive and dark grayish matrix colour in the Wetland soils is an indication of partially or completes reduced and originate from the presence of iron. The variation in colour in the different sample areas may be due to the Lake fluctuation and different amount of organic matter accumulation. In may sample areas the gray, olive and dark gray colours were associated with dark reddish brown and yellowish brown mottles. Mottles are patterns, which are the result of seasonal wetting and drying of the horizons. Gleying properties in the papyrus swamp (map unit PL444) are an indication of long-term seasonally alternating dry and wet conditions causing alternating oxidation and reduction.

Texture is the moist permanent characteristic of the soil. It decisively influences a number of other soil properties such as: structure, consistence, soil-moisture regime, permeability, infiltration rate, run-off rate, erodibility, workability, root penetration and fertility. The textures, in most sample areas of Wetland soils are in general "finer" except in Yacht Club sample area. The soils contain more clay than sand in sample area KWS annex; YMCA Club; Longmont; Marula; and Delamere farm sample areas as percentage clay dominates, while in Yacht sample area the amount of sand in soils were more than clay. The amount of silts also varied in the sample areas. Therefore textures in sample areas KWS annex, YMCA club, Longonot farm, Marula farm and

of the parent materials (aeolian and la custrine sediments). There is also no evidence of clay illuviation in the Wetland soils leading to the argillic horizons. These results are also in line with other data, which indicated the south-east part of the Lake shore to have finer soils than the south and south west. These results also indicate poor permeability and infiltration rate as the soils are saturated by water in the profiles. The Wetland soils particularly in the dry areas of the map unit PL443 showed weak to moderately structure development in the ochric and cambic horizons. In the flooded and papyrus swamps it was not possible to determine structure as soils were saturated with water.

Chemical characterization: The chemical characteristics reflected the properties of the Wetland soils. By using these properties, Wetland soils are characterized into three categories, which are dry or normal soils, wet and flooded or waterlogged (Fig.5.11).

Redox potential: The General trends are that in the dry parts of the transacts the redox potentials values are (+ve) values and high (412 mV). These results indicate that the soils are oxidised or are normal soils. Then followed by a sharp drop of redox potential values low and (–ve) values in the waterline of the transacts indicating anaerobic conditions in these soils (-280mV). In the wet or flooded areas the redox potential values (–ve) values are even lower due to further reducing conditions existing after long period of flooding. Beyond a depth of 70 cm the redox values are low but showed a relative increase to a depth of 120 cm. The reasons are that the soils are not reduced beyond this layer due to the presence of impervious yellowish hard layer.

Redox potential values with depths also indicated general trends where the redox potential values in the dry areas are clearly separated from the wet and flooded in the graphs. The redox potential values in the dry areas are generally higher than in the wet and flooded areas. The higher values indicate that the soils are oxidised or normal soils and remain high to the depth of 120 cm. In the waterline (wet) and flooded soils, the redox potential values are low (+ve) and (-ve) values but decrease because of anaerobic conditions. In the lower depths existence of the micro-organisms which are responsible for the reduction sequence may be low and organic matter are low than in the surface horizons.

Electrical conductivity (ECe): The general trends of (ECe) are that the values are higher in the dry or normal soils, decrease in the wet soils and in the flooded soils showed relatively increased values. Generally the ECe values of Wetland soils at Lake Naivasha are low as the measured values range from 0.11 to 2.99 mS/cm, which are less than 4mS/cm the lower class of salinity (Landon, 1991). These results indicate that salinity effects are negligible to the Wetland soils and the Lake water. These results are also in line with other data obtained in previous studies at Lake Naivasha.

In KWS annex sample area the ECe, showed a general trend of having relatively high value on the dry areas and on the deep horizons, and relatively low in the wet and flooded areas. These differences may be due to evaporation of water on the dry areas and dilution effects of the salts on wet or flooded areas.

In YMCA and Longonot sample areas, the electrical conductivity (ECe) showed variation along the transacts. The values are relatively low in the dry soils of the then increased to the waterline. The values of ECe are relatively low in the flooded soils. The ECe values are higher at a depth 50-cm and remain low to a depth of 120 cm. Also dilution effects may have contributed to low values of ECe in the flooded soils.

The values of ECe in the Yacht club, Marula farm and Delamere farm sample areas show a trend of the being high in the dry areas and low in the waterline and flooded areas. The values are low at the depth 20 cm and increased at 50 cm and remain relatively unchanged to a depth 120 cm.

The pH: The pH values of the wetland soils at Lake Naivasha vary from very strongly acid to strongly calcareous or alkaline. Except for pH values in the Marula sample area, the pH values in the other samples areas, showed a general trend of being high in the dry area and relatively low in the wet and flooded soils. These trends may be also due to evaporation of water on the dry area, and dilution effects on the wet and flooded soils. At the Marula farm sample areas the pH values are low ranging from very strongly acid (pH 4.7) to medium acid (pH 5.8). At the time of this study this sample area was dry except for those areas drained by river channels especially Gilgil river. Low pH values may be due to contaminated materials carried by the rivers from the catchment and surrounding farms deposited in these areas.

At KWS annex sample areas, the pH values of the soils, are very slightly acid (pH 6.96) to moderately alkaline (calcareous) (pH 7.93) in transact1 and very slightly acid (pH 6.65) to very mildly alkaline (calcareous) (pH 7.45) in transact I. In the transact III, the pH values are neutral (pH 7.0) to very mildly alkaline (calcareous) (pH 7.8). These pH values may indicate the possible influence of soil management practices is slightly small.

At the YMCA Club sample area, the pH values range from mildly alkaline (calcareous) (pH 7.2) to strongly alkaline (calcareous) (pH 8.7). The pH values were relatively high in the at surface horizons and decreased with depth. These pH values indicated the possible influence of the agricultural practices from the surrounding flower farms.

At Longonot sample area the pH values are neutral (pH 7.0) to moderately alkaline (calcareous) (pH 8.4). In the Yacht club sample area the pH values are very slightly acid (pH 6.85) to moderately alkaline (calcareous) (pH 8.0). The pH values at these sample areas indicate little or no influence of soil management practices from the surrounding horticultural farms. At Delamere sample areas the pH values indicate very mildly alkaline (calcareous) pH (7.20) to strongly alkaline (calcareous) (pH 8.68) in the transact I and very slightly acid (pH 6.75) to moderately alkaline (calcareous) (pH 8.48) in transact II. These pH values are slightly high which may indicate possible influence of the materials from the surrounding horticulture.

The cation exchange capacity (CEC) results vary from low to high in the depth of 50 cm and have no particular tends from the dry to the flooded areas. The ratings of CEC values are based on the CEC thresholds shown in (Table 5.14). In the KWS sample area, the values are medium (13.80meq/100g) in the dry, low (12.20 meq/100g)) in

The cation exchange capacity (CEC) results vary from low to high in the depth of 50 cm and have no particular tends from the dry to the flooded areas. The ratings of CEC values are based on the CEC thresholds shown in (Table 5.14). In the KWS sample area, the values are medium (13.80meq/100g) in the dry, low (12.20 meq/100g)) in the waterline and high (30.60 meq/100g) at flooded soils of transact I. In the transact II, the CEC values are high (26.80 meq/100g) the dry, medium (18.60 meq/100g) waterline, and high (26.40meq /100g) at flooded soils. In the transact III, the CEC values are high (26.80 meq/100g) and low (10.80meq/100g). The CEC values of soils at this sample area show that at the depth of 50 cm, the capacities to adsorb cations vary from low to high. The type of clay mineralogy (mainly smectite) and amount of organic matter may influence these variations.

The CEC values, at the YMCA Club sample area are medium, (14.20 meq/100g) in the dry and remain low at waterline and flooded soils (8.50 meq/100g and 9.0 me/100g) respectively. These values indicate that the adsorption of cations by soils at this sample area is relatively low. The reasons may be due to low organic matter content in these soils. In this area topsoils were take to construct dikes, which exposed subsoils, which may have low organic matters. The CEC at the Longonot farm and the Yacht Club sample areas also vary. The values vary from 13.80 meq/100g to 15.60 meq/100g in the Longonot farm and 12.60meq/100g to 18.80meq/100 in the Yacht club sample area. These values indicate that soils at these sample areas have medium adsorption capacity at the depths of 50 cm.

In the Marula sample area the CEC values are low to medium (11.20 to 18.00meq/ 100g). It is an indication that the soils at this sample area have low to medium adsorption of the cations. At the Delamere sample area the CEC are medium, the value ranging from 15.60 to 22.00 meq/100g in transact I and in transact II the values are medium and high (25.00 to 29 meq/100g). The soils at this sample area have medium adsorption of the cations as shown by these results.

Table 5.5 Exchangeable Cation values (meq/100g of soil)

Ratings	Very high	High	Medium	Low	Very low
CEC values	> 40	26-40	13- 25	6- 12	< 6

Source: Agricultural compendium, 1989.

The total organic carbon of the most sample areas are very low to low at a depth 50 cm (Tables 5.5.12). Generally the organic matter at the depth at the depth of 50 cm are very low as indicated by the organic carbon content. Since the organic matter has influence in the CEC, its contribution to the CEC of the soil at this depth in this case may be also low.

Table 5.6 Ratings of the organic carbon

Ratings	Very high	High	Medium	Low	Very low
Total %C	>3.5	2.51- 3.50	1.26- 2.50	0.60 –1.25	<0.60

Source: Agricultural Compendium, 1989.

5.4.3.7 Conclusion

The physical and chemical characterizations of the Wetland soils at Lake Naivasha have shown to meet the hydric properties of the Wetland soils. The Colour, texture, mottles, gley, redox potential, electrical conductivity (ECe) and the pH indicated reduced conditions of the Wetland soils.

With the use of redox potentials and pH graph, the Wetland soils are categorised into oxidised or normal, wet and waterlogged soils. The oxidised or normal soils have high (+ve) values of redox potentials and low pH values. The wet and flooded soils have low and (-ve) redox potential values and neutral pH.

The redox potentials (Eh), electrical conductivity (ECe) and pH values vary along the transacts and depths in the sample areas. The values are high (+ve) in the dry soils, drop to low (-ve) values at waterline soils and lower in the flooded soils. At the depth of 120 cm where the impervious layers are found these parameters relatively increased.

The Wetland soils are not saline as the values ECe are lower than 4mS/cm and generally are moderately calcareous to strongly calcareous, except the sample area at the Marula farm which are strongly to medium acid. The texture is finer in the east and north-west areas than the south areas and south-west.

The CEC at the depth of 50 cm Wetland soils are low, medium and high which may be mainly due to the presence of smectite clay minerals as the organic matter are very low at the lower horizons.

5.5 Ecological function of Wetland soil

5.5.1 Introduction

Wetland soils at Lake Naivasha fulfil important ecological functions with respect to the Lake Naivasha ecosystem. One aspect of this research was to study some of these functions in relation to Lake and surrounding environments. In this section, buffer and sediment trapping roles, groundwater recharge and storage, water supply, flood water storage, sediment trapping, and wildlife habitat are presented discussed and conclusions are drawn.

5.5.2 Buffer and sediment trapping roles

The Wetland soils of the Lake Naivasha acts as transitional medium of the materials from the surrounding flower and vegetable farms, the reserved areas for the wild life and the Malewa catchment and the Lake. The sediment materials from these areas enter Lake through the Wetland soils. The slopes of the Wetland soils are flat and allow the materials transported from the catchment by rivers and from the surroundings by run- off to settle there before reaching the Lake water. The papyrus swamps finally filter the materials and allow cleaner water to reach the deeper parts of the Lake. In this way the Wetland soils acts as buffer of materials which may pollute or contaminate the Lake water and therefore help to maintain the quality of the Lake.

These results may indicate partly the possible influence of the materials from the surrounding areas being deposited in the upper parts of these soils before reaching the Lake. The chemical data analyses of the Lake water showed that the Lake water quality is still fresh (Johns Goldson Associattes, 19 93).

The quantity of Lake water depend on the balance of amount of water flowing into and flowing out and evaporation. Lake Naivasha receives water from the Malewa Gilgil rivers and rains, which contribute to water Lake levels. Wetland soils also play an important role in contributing to the lake water quantity. Most of water recharge and storage occur in the wetland soils, which add water to the Lake. Gaudet and Melack (1981) and Ase, (1987) showed that the Lake is hydrologically a seepage Lake with input via groundwater seepage in the northern area and out-flow in the southern area.

5.5.3 Groundwater recharge and storage

Groundwater recharge may be defined in as the downward flow of water reaching the watertable and subsequently ground water reservoir (Lerner, *et al.*, 1990). On the other hand recharge of water may occur naturally from precipitation, rivers, canals and lakes and as man-induced phenomenon via such activities irrigation and urbanisation. At the Lake Naivasha, most of ground water recharge occurs in Wetland soils by rivers and precipitation. The added water is mainly stored as ground water storage, which fluctuates. The presence of the sandy loam, sandy clay textures with sandy clay loam is an indication that they can hold or store water in the horizons. The water retention characteristics of these soils have shown that the available water percent is between 9-15 in SL and 16-22 in CL. The permeability of these soils is classified as moderately high (coarse loamy and fine loam family) with saturated hydraulic conductivity 6.17 cm/hour (Siderius, 1998). The capillary rise is also high, as the topsoils were moist due to the rising perched water.

The Lake storage is estimated to be 1000 cubic metre in wet condition, 670 cu. m in mean condition and 380 in dry (Trottman, 1998). Groundwater storage was found to represent a significant percentage of the yearly lake balance, which created a buffering effect against dry weather conditions. (At an increasing distance from the lake, the groundwater tables takes longer to react (if at all) to changes in the lake level. As result, changes in ground water storage do not immediately changes the Lake level.

According to Trottman (1998) the volume of groundwater stored in the aquifer lying within a 3km buffer zone around the lake was increased by 8.5 million m^3 in wet year. This represents 3.5% of the Lake balance for the year. In an average year, the groundwater stored in this same zone is increased by 1.4 million m^3. This represents 3% of the lake balance for the year. In a dry year the groundwater resources are depleted by approximately 2 million m^3. The volume of groundwater stored in the aquifer surrounding the lake (Wetland soils) is thus significant, and so groundwater can provide a buffering effect for dry year conditions.

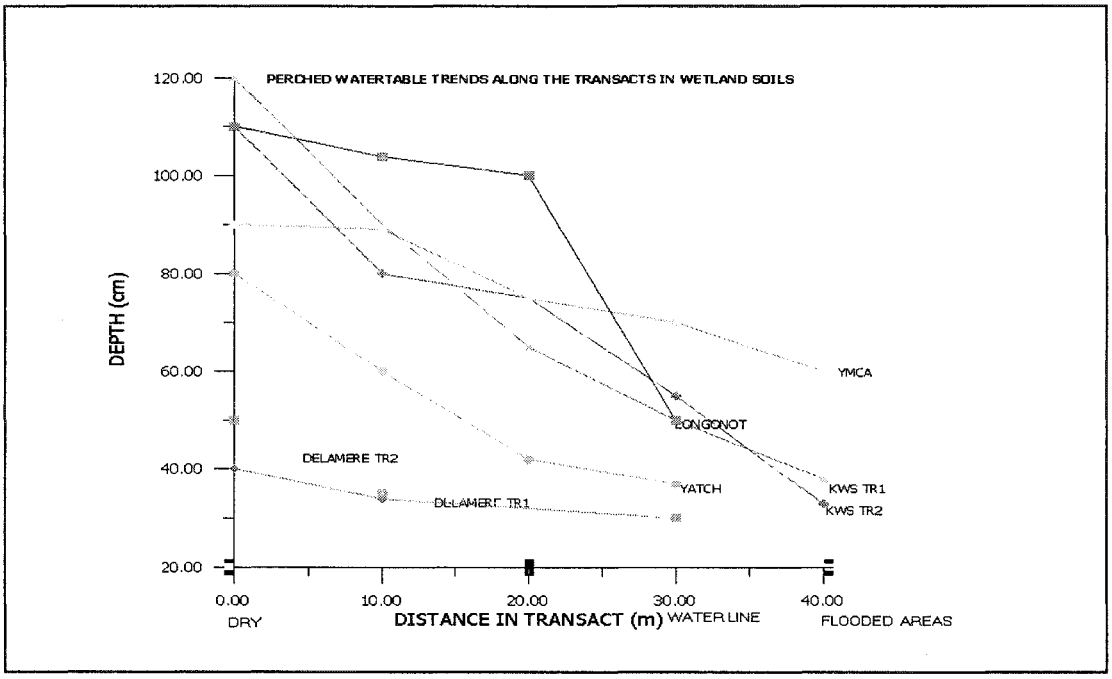

Fig. 5.10 Perched watertable depths along the transacts in the Wetland soils.

In the Fig. 5.32 perched watertable seems to be high in the northern part of the lake than in the eastern parts. The general trends are that the perched watertables are deep in the dry areas and are high when approaching the waterline (wet) and flooded areas. However it was not possible to determine the points at which these perch water enter the Lake via Wetland soils due to the presence of flood.

5.5.4 Water supply

Lake Naivasha is still a fresh water lake as compared to other rift Valley lakes (Johnson Goldson Associates 1993; LNRAO, 1995). The quality of the Lake water depends on the materials coming into the Lake from the surrounding areas and the Malewa catchment. Wetland soils and the Lake supply fresh water for domestic use to 250000 people living at Naivasha town and surrounding villages. Apart from supplying water for domestic use, the Wetland soils also supply water for irrigation. Flowers and vegetables farms are irrigated by water pumped from the boreholes and surface water in the wetland soils. The Wetland soils also supply water for livestock and wildlife. At the time of study surface water for the Naivasha-Nairobi road construction was taken from the flooded areas. For the irrigation purposes water abstraction from the Wetland soils and Lake was estimated to be 33.8 million m^3 wet conditions, 44.6 million m3 normal condition and dry condition 53.2 million m^3 (LNROA, 1995).

5.5.5 Flooded water storage

At the time of the study, the Lake water had risen to 3m about 10ft after long rains of 1997/1998. All the excess water from the lake and floods from the surrounding areas inundated formally drier parts of the riparian land. Map unit PL444 and some parts of

map unit PL443 is flooded (see Fig. 5.3 and Plates 1-11). The Wetland soils area is estimated to cover 3,652 ha, which is 12% of the total land cover area of 30,148.4 ha.

5.5.6 Wildlife habitat sites

In the process of regulating nutrient flow and recycling, the papyrus swamps process an organic output at the expense of an inorganic nutrients input. The organic input serve as an energy source to a very diverse tropical fauna and flora, which in turn supports a profitable shallow water fish industry in many parts of Africa (Njuguna, 1982). Gaudet (1980) indicates that the small organic particles (detritus) from the swamps area is the most important aspect of nutrient relations between the swamp and other aquatic ecosystems. The swamps supply a large amount of fixed nitrogen to tropical Lakes and rivers allowing an increase of animals and plants production at the swamp edge. As such the lake Naivasha and the Wetland soils are important for their rich biological diversity. The reputation is based on the wide variety of animals, fish and numerous bird species. There are over 350 bird species, while the Hippopotamus represent the biggest animals on the Wetland soils in addition to other wild animals such as zebra and various types of antelope (John Goldson Associates, 1993). buffaloes, hippos, waterback and masai giraffes were encountered in the wetland soils (see plate 1 and 3).

5.5.7 Conclusion

Generally the Wetland soils at Lake Naivasha are ecologically important to Lake and the surrounding. The most important ecological functions are maintaining of the quality and quantity of Lake Naivasha water through natural filtering and sedimentation processes.

The Wetland soils act as a transitional medium and buffer of the materials from the surrounding environment and Lake water. Other functions include water supply for domestic use and irrigation, groundwater recharge and storage, floodwater storage and habitat sites for wildlife animals.

5.6 Vulnerability of Wetland soils to pollution

5.6.1 Introduction

One of the LNROA management concerns is pollution and the monitoring thereof in the Lake Naivasha (Goldson Associate, 1993, LNROA, 1995)). The Lake is under threat of nutrients and pollution from urban and agricultural activities in its catchment and surrounding. Discharge from highly fertilised agricultural lands give rise to the nuisance growth of aquatic of plants such as algal blooms resulting from increased nutrients load of phosphorus and nitrogen. The results/effects may lead to the decreased water transparent and decreased in dissolved oxygen concentration. In the Wetland soils at Lake Naivasha, vulnerability was assessed basing on the some soil parameters studied during the fieldwork. These parameters are presented, discussed and conclusions are drawn.

5.6.2 The pH

A well known effect of waterlogged of soils is that the pH of the acidic soils increases, and that of alkalinity soils decreases, while the pH generally stabilises at values between approximately 6 and 7 after several weeks or months of flooding. For the pH discussion see para 5.4.2.6.

5.6.3 Eh-pH diagram

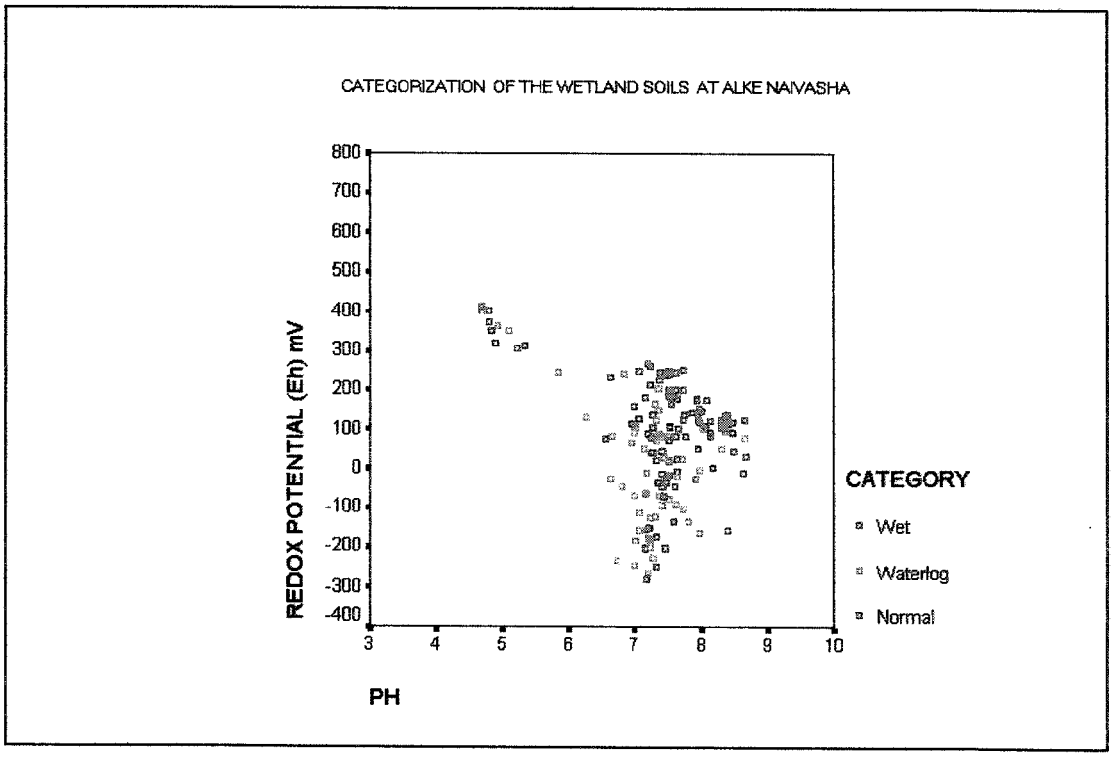

Fig. 5.11 Eh-pH characteristic of the Wetland soils around Lake Naivasha

The data on Eh and pH were plotted using a SSPS program Fig.5.11. The graph is useful to delineate the redox status of the Wetland soils. Generally at the pH range, the redox potentials values are high (+412mV) and decreased and concentrate around pH 6.5 to 8.5 (see Fig.5.11). Based on these results the wetland soils of Lake Naivasha are divided into three categories: normal (oxidised), wet (seasonally saturated), and waterlogged (semipermanently saturated). These data were collected after flooding of the Wetland soils for almost six months. Probably after a longer period of flooding and water saturation of these soils may be further reduced and therefore pH and Eh range may also decrease.

The Eh-pH diagrams are invaluable in determining the mobility of various ions in the environment (Hounslow, 1995). They show fields (areas) where different ions exist within the boundaries set by pH and pe or Eh limit. The results of Eh-pH diagram indicated the mobility of iron in the Wetland soils at Lake Naivasha is low (see Fig 5.12). However these results may change after a long period of flooding and saturation of these soils.

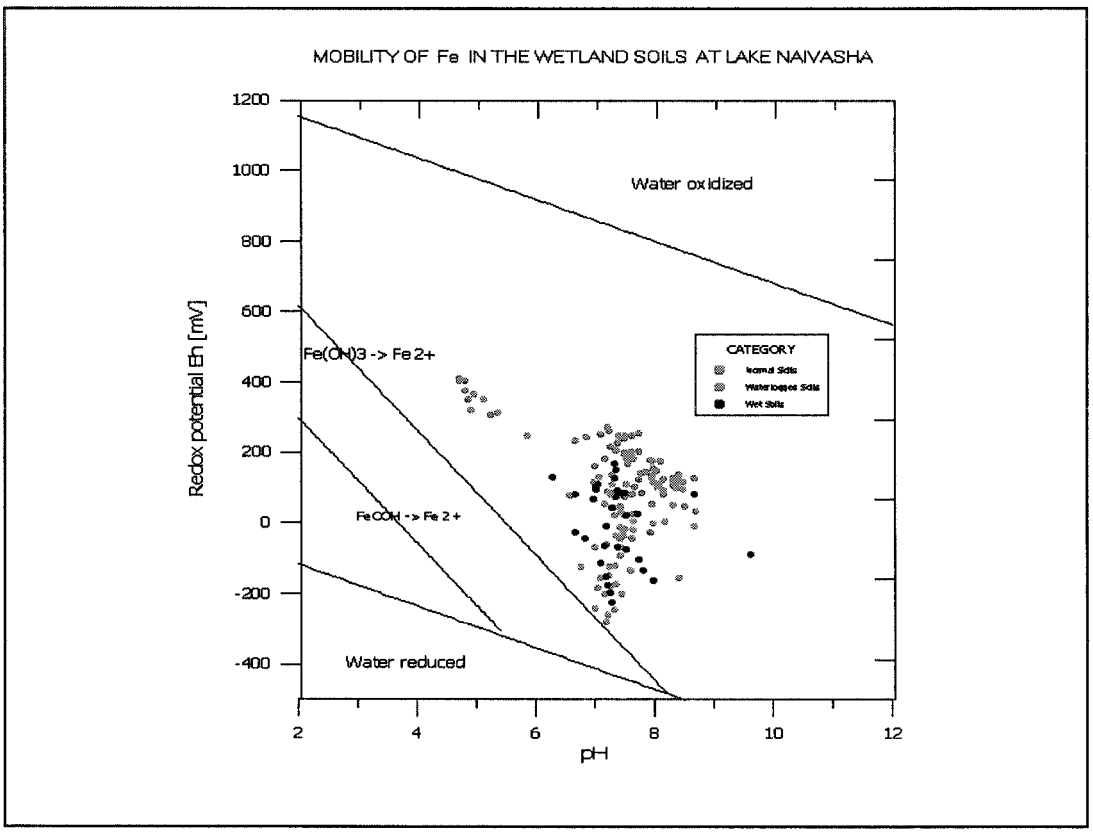

Fig 5.12 Iron mobility in the Wetland soils at Lake Naivasha

5.6.4 Electrical conductivity

Generally the electrical conductivity (ECe) may indicate the quality soils as well as that of Lake. The results of electrical conductivity (ECe) in the Wetland soils showed that are not polluted by salts since they are not saline (less than 4mS/cm). However results Delamere farm (map unit PL443) and KWS Annex (map unit PL444) sample areas show relatively high electrical conductivity 2.47 and 2.99 mS/cm respectively. Flowers and vegetables farms surround these sample areas. Probably the use of agricultural chemicals on these farms may have influenced the salinity of these soils.

5.6.5 Cation exchangeable capacity (CEC)

The Cation exchange capacity (CEC) results were determined at 50 cm see Appendix XII- XVII. These results showed that, wetland soils have CEC values range from low, medium and high. There were no particular trends from dry area, waterline and recently flooded areas. The size of the CEC and AEC mainly depends on the clay content and type, organic matter content and type, and soil pH. The evaluation of the physico-chemical buffer potential of the soils by CEC measurement has shown by (Blum *et at.*,1989). Generally the soils with high CEC have very high physico-chemical buffer and low CEC have low.

Table.5.9 Evaluation of the physico-chemical buffer potential of the soils by CEC measurement

CEC ($meqKg^{-1}$)	Physico-chemical buffer potential	Possible clay mineral
< 50	Very low	Kaolinite
50-100	Low	Illite
100-200	Medium	Vermiculite
200-300	High	Muscovite
> 300	Very high	Organic matter

Source: Batjes and Bridges, 1989

5.6.6 Organic matter

The percentage organic carbon was determined at 50cm depth see Appendix XII-XVII. The results show low level of % carbon (0.09 to 1.16 %) and hence low level of the organic matter. However the topsoils may have high organic matter content as they have very dark grayish colours.

5.6.7 Discussion

The Wetland soils at Lake Naivasha at present seem not to be vulnerable to pollution. The soil parameters have shown that the wetland soils are generally not vulnerable to salinity, acidity, alkalinity, fertilizers and agricultural chemicals from the surrounding farms. The pH values in most sample areas are high (very slightly acid to moderately calcareous). At these pH levels some of these soils are free from acidity and alkalinity. In the Marula farm where the pH values are low (very strongly acid to strongly acid) there is a possibility of an increase of the heavy metals solubility and micronutrients especially iron. Also the CEC may decrease and the microbial composition and activities may be affected in these soils.

The iron and other micronutrients seem also to be stable as indicated by the Eh-pH diagram (Fig. 5.12). There is no much mobility of the iron ions in the Wetland soils, however there is possibility of iron mobility to occur ($FeOOH$-Fe^{2+}) see Eh-pH diagram) with time since saturation processes are still taking place. According to Ponnamperuma (1972), redox potential may decrease to a value characteristic of the soils, usually after 8- 12 weeks of submergence. The greatest value of redox potential occurs in the acid soils and not observable in neutral soils with high soil organic matter (Sparks, 1995).

The electrical conductivity (ECe) values did not show that the Wetland soils are saline, since the values are low than 4mS/cm. The effects of solubilization of the toxic chemical by altering the iron-exchange equilibrium are low in these soils because salinity is also low. Also at present there are no effects of the increase soluble complexation and decrease chemical thermodynamic activities as well as decrease microbial activities due to the electrical conductivity.

The Wetland soils have medium to high adsorption capacities as reflected by the medium and high CEC at depth of 50 cm. Based on these results, generally at the depth 50 cm the Wetland soils have medium to high capacity to retain cations such as heavy metals. The physico-chemical buffer potentials of the Wetland soils also are

medium to high because the physico-chemical buffers potential range 10 -30 meq/100 meq/100g. The organic matter as reflected by the organic carbon values are very low in the depth of 50 cm. The low organic matter may reduce cation exchange capacities and soil pH buffering capacities of these soils. Also the sorption capacities for toxic organic compounds may be reduced at these depths.

5.6.8 Conclusion

The Wetland soils are not vulnerable to salinity, acidity, alkalinity as well as fertilizers and agricultural chemicals. The soils have buffering capacity to pollution hazards as reflected by the redox potentials. electrical conductivity , pH and CEC. These soils have generally medium to high capacity to retain cations and heavier metals, which may be present in the fertilizers and agricultural chemicals.

The physico-chemical buffer potential of these soils is general also medium to high as indicated by CEC values. Also these soils have low iron mobility as indicated by the Eh-pH diagram. The soils have low organic matter at lower depths, which may reduce they capacity to retain agricultural chemicals, and fertilizes from the surrounding farms if percolate to the lower horizons.

5.7 Effects of Lake water fluctuation on the Wetland soils

5.7.1 Introduction

In this study, the Wetland soils also are considered to be those areas which Lake fluctuations occur at Lake Naivasha. They include both map units PL443 and PL444 (Fig 5.3) in the low terrace of the lacustrine plain. In general the Lake's ecology is largely influenced by natural fluctuations in water levels, a phenomenon currently aggravated by human activities.

The level of the Lake Naivasha has fluctuated widely over the past 113 years, from a minimum of 1881.5 masl in 1975 to a maximum of 1896.5 in 1895 as shown in Fig.513 (Trottman, 1998, Goldson associate, 1993). Due to the Naivasha lake basin being shallow, relatively small changes in lake levels results in large changes in open-water surface. At the time of the study, the Lake level had increased by 10ft or 3m after heavy rains at end of 1997 and early 1998. Therefore most of the areas which have been dry for a long time especially in the map unit PL443 are flooded see plate 11. In this section some of the Wetland soil properties, which may have been influenced by Lake water fluctuations are presented, discussed and conclusions are drawn.

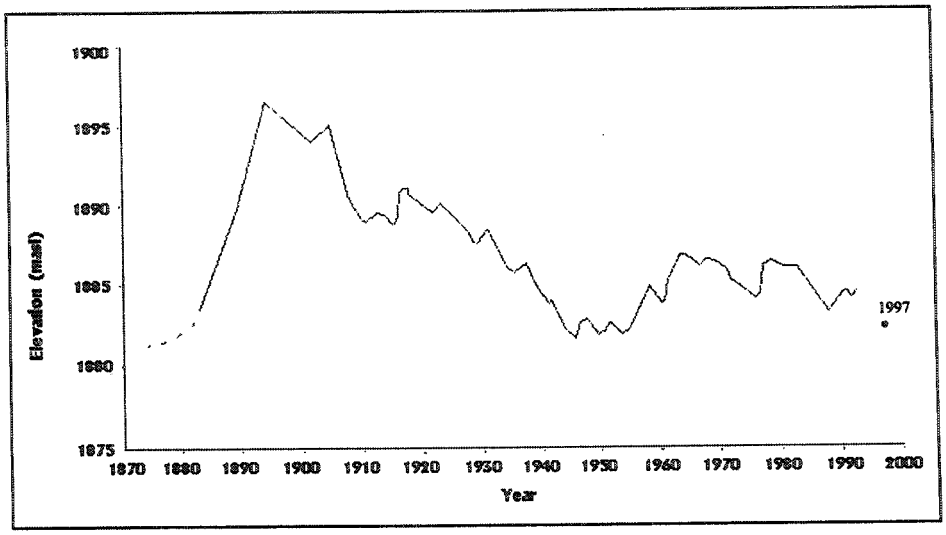

Fig. 5.13 Historical Lake level fluctuations

Plate11.Yacht Club sample area map unit PL443. Note recently flooded areas which once were dry.

Table 5.8 Lake water fluctuation

AREA	YEAR	LAKE WATER LEVELS (masl)	SURFACE AREA (sq.km)
1	1956	1882.5	128
2	1973	1884.0	189
3	1930	1887.5	217
4	1895	1896.5	282
5	10-12,000 BP	high level of water	

Source: Vincent et al 1979

Some of the wetland soil parameters that are considered in section are redox potential (Eh), pH, electrical conductivity (ECe) and colour and mottles. The results of these parameters have been discussed in section 5.4

5.7.2 Discussion

5.7.2.1 Effects of Lake fluctuation on biota

Generally until 1970's there was no indication that the considerable Lake-level fluctuations had any major effect upon the biota (Harper *et al.*, 1990). Change of animals species between 1930s and 1970s was also slight (Beadle, 1932) as cited by Harper *et al.,* (1990). Water level fluctuations have been the driving force behind swamp development and decline (Harper, *et al.*, 1995). Decline followed water level decrease or stability when the farmers are able to follow the water down with burning and cultivation or grazing. Any period of water level rise provides greater uncertainty over crop loss from waterlogging, so that a partially recovery of the natural vegetation follows. The major event of *Cyperus* species germination is the particular period of a rapid water level decline (soil and seed drying) followed by a rapid rise. This re-flooded a band of bare soil provide ideal conditions for *Cyperus spp.* Germination which require damp-rich soils nutrient (Thompson, 1985).

Water levels fluctuations are probably also responsible for the spread and recession of the floating rafts (Harper *et al.*, 1990). A period of water level fall strands portions of the raft whenever they are blown to shore by wind. A period of water level rise releases nutrients from re- flooded soils, which were previously dried and oxidised.

Water quality is linked to water level. Quality is moderated by the presence of swamp vegetation at the inflows which then to retain sediment and nutrients and thus smooth out seasonal fluctuations. Lake level rise provides further nutrient influx from flooded soils while lake level fall result in concentration of nutrients. Land uses probably also affects the extent to which runoff influences the Lake directly and also the nutrient content of the flooded soils.

5.7.2.2 Effects on soil properties

The Lake water fluctuations in Wetland soils at Lake Naivasha generally have direct influence on the soil properties. Water fluctuations can cause variations of the both physical and chemical properties. For discussion of these properties see section 5.4.

5.7.3 Conclusion

Seasonally alternating dry and wet conditions or Lake fluctuations have impact on the Wetland soil properties as well as the biota. The major possible influences are on the increase or decrease of parameters such as the redox potential, the electrical conductivity and pH. Oxidation and reduction, which is caused by the Lake water fluctuations have an effect on the colours of the soil matrix, induce mottles and gley properties in the highly reduced conditions.

5.8 Evaluation of Wetland soils for other uses

5.8.1 Introduction

A general suitability assessment is given basing on the results of the parameters analysed and soil survey out during fieldwork. The purpose of the assessments is to give some recommendations on how best to use, conserve and protecting of Wetland soil at Lake Naivasha. Suitability for crop production or construction is not considered in this study mainly because of risk of pollution hazards and water abstraction that may reduce quantity and quality of Lake water. Also the Wetland soils at Lake Naivasha are internationally recognised and protected under Ramsar laws. The Wetland soils are also under riparian zone, a zone of about 50 m fringing the Lake which is prohibited for any activities involving agriculture and construction (LNROA, 1995). Therefore evaluating Wetland soils suitability for agricultural or construction purposes will contradict to the LNROA management as well as the Ramsar laws.

Suitability evaluation involves relating land mapping units to specified Land use, due to the fact that different kinds of Land use have different requirement (FAO-Unesco, 1976). Suitability also refers to use on sustainable basis, which requires that environment to be preserved in a completely unaltered environment. The results of suitability assessment indicate potential suitable or limits of the land for particular land use.

5.8.2 Discussion

The Wetland soils are permanently waterlogged particularly in mapping unit PL444 and flooding regularly occurs in the mapping unit PL443. Therefore relating these map units to specific land use is important for the purpose of maintaining and protecting these soils and vegetations as the LNROA management requires. Nature and game preservation or reserve (FAO-Unesco, 1990) is considered to be suitable land use for both map units of the Wetland soils for the purpose of protecting these soils and surrounding environment. Nature and game reserve is characterised by the vegetation of different species, shrubs, and acacia tries and wildlife animals. Nutrients and water supply are mainly from the Wetland soils and surrounding environment. The summary of Land characteristic of Wetland soils area shown in table 5.12.

Table 5.9 Summary of land characteristics of Wetland soils at Lake Naivasha

Land quality	Land characteristics	Units	Land map units (PL443&PL444)
Temperature regime	Mean air temperature for growth	°C	24.6 to 28.3
Moisture availability	Mean annual rainfall	mm	627
Oxygen availability to root	Soil drainage class	class	moderately well, poor to very poor
Rooting conditions	Minimum rooting depth	cm	>120
	Stone and gravel	%	2-5
	Soil texture	class,	Sl, Sc, Scl, Sicl
Erosion Hazard	Slope	%	1-2
	Observed erosion	class	0
Nutrient availability	Soil reaction	pH	6.9 to 8.5
Excess of salts	soil salinity	mS/cm	> 3

There is no available information, which could provide the requirements of the proposed landuse. However nutrients cycling in the ecosystems are sufficient for the existence of this kind of land use. It does not require much input or supply of nutrients like fertilizers and the amount of rainfall, water from underground and rivers can support growth. Apart from nature and game reserve, the dry parts of map unit PL443 are suitable for other irrigated crops such vegetables, maize, beans and wetland rice. However no details of these crops are given because of the fact that they are not allowed, although illegally are grown in some areas of riparian zone (Wetland soils).

5.8.3 Conclusion

The nature and game preservation or reserve is recommended in the Wetland soils. This kind of landuse does not disturb nature and require minimum input especially, nutrient supplementary such organic fertilizers. Land characteristics of the Wetland soils can support the existence of this landuse.

More importantly this kind of land use can attract the tourist sector which is an important foreign exchange earner for Kenya. However management practices particularly in the protection of wildlife animals and Wetland soils from cultivation of crops, vegetables and flowers, agricultural chemicals and fertilizers are necessary. Replanting of vegetation especially papyrus species on the cultivated areas on the shore of the Lake need to be given priority by LNRAO management.

CHAPTER 6

6. FINAL CONCLUSIONS AND RECOMMENADTIONS

In this chapter the results of the research are reviewed in relation to the objectives set in the Introduction.

6.1 Conclusions

With the use of the RS through (air photographs interpretation), GIS (ILWIS) and fieldwork survey, the Wetland soils have been identified and characterized. The redox potentials (Eh), the electrical conductivity of saturation paste (ECe), the pH, the CEC and % carbon are the main parameters used to characterize the Wetland soils. Ecological functions were also studied during the fieldwork in conjunction with these parameters and other available information about the Wetland soils and the Lake in general. A total of six sample areas and nine transacts were studied and 164 samples were collected and analysed. The results have been indicated in the maps, graphs and tables. A total of 62 graphs have been produced.

Objective I. Identify, describe, and classify the major Wetland soils

The study confirmed the existence of fresh Wetland soils with hydric properties and were identified in the low and lowest terraces of the lacustrine plain. These soils occupy the map unit PL443, which is almost flat to flat (% slope 0-2) in the low terrace and the PL444 which are deep papyrus swamps in the lowest terrace. Some parts of the map unit PL443 were recently flooded, while soils in the map unitPL444 are permanently flooded. The estimated total area of the Wetland soils is 3652 ha and about 12% of 30,148 ha the total area of Lake Naivasha.

The soils are described as moderately well drained to imperfectly well drained in the dry parts of map unit PL443 and poorly to very poorly in the flooded areas of PL443 and PL444 respectively. The textures are general "finer" and vary from sandy loan to sandy clay in the topsoils and sandy clay loam to silt clay loam in the sub horizons in the map unit PL443. In the map unit PL444 the topsoils are characterized by the histic materials underlying the mineral soils in the sub horizons.

The Wetland soils classify as loamy smectititc Typic Xerochrepts (USDA, Soils Survey staff, 1996) and Eutric Cambisols (FAO-Unesco, 1998) in the dry parts of PL443 and loamy smectitic Aquic Xerochrepts in the recently flooded parts of the map unit PL443.In the map unit PL444 the soils are classified as Hdyric Medihemists (USDA-Soil Survey Staff, 1996) and as Firbric Histosols, sodic phase (FAO-Unesco, 1998).

Objective 2. Characterization in terms of the physical and chemical properties

Selected physical and chemical parameters related to hydric conditions of the Wetland soils were studied and analysed in the laboratory. The chemical parameters included the redox potentials (Eh), the electrical conductivity of the saturated paste (ECe), the

pH, the CEC and % Carbon. The physical parameters were colour, texture, mottles, gley and structure. These parameters confirmed the hydric properties of the Wetland soils at Lake Naivasha. These parameters were tested statistically and are significant different at 5% level and also shown significant correlation with transacts and depth at 1% and 5 % levels.

The redox potential (Eh) values generally range from –280mV in the flooded areas to +412mV in the dry areas of the Wetland soils. The redox potential values were plotted against distance of the transacts (m) and in the depths (cm). The general trends were that the redox potential values were high in the dry areas, then decreased sharply to low from the waterline to the flooded areas. However there were relative increases of redox potential values between 70 to 120 cm, due to the presence of impervious layers. With depth there were clearly separation of the values in the dry and flooded areas, respectively high and low.

The electrical conductivity (ECe) values are general low ranging from 0.11mS/cm to 8.68 mS/cm. These values confirm that the soils are not saline because they are below the lower class of salinity of 4 mS/cm. Like the redox potentials, the electrical conductivity values were high in the dry areas and low from the waterline to the flooded areas. The cause of these variations was found to be dilution effects in the flooded areas and crystallization of salts in the dry areas due to evaporation..

Most of the pH values of the Wetland soils were ranging from 6.57 in the flooded areas and 8.68 in the dry areas. These values indicated that the wetland soils are very slightly acid to strongly calcareous. In the Marula sample areas the pH values were low ranging from 4.70 to 5.30, that is very strong acid to strong acid. The general trends of the pH values indicate that, they are high in the dry area and low at the waterline and flooded areas. The CEC values were determined at the depth 50 cm, they indicated that soils at these depths have low medium to high adsorption capacity of the cations. The values range from low (8.80 -12.20 meq/100g), medium (13.80 - 25.40 meq/100g) and high (26.40 - 30.60 meq/100g). Generally the organic matters content ranges from very low to low at these depths as indicated by the very low to low % Carbon. The values range from 0.09 to 1.16%.

The colour varies from very dark gray to very dark garyish brown and olive gray in the topsoils and olive brown to gray in the sub hrizons. The chroma is generally low ranging from 1 and 2 and the values from 3 and 4. The hues are 2.5Y or 5Y, few are 10YR and 7.5YR. The mottles are mainly dark reddish brown to yellowish brown. Gley properties were found in the papyrus swamps. In the dry part of map PL443 the structure of the soils was weak to moderately very fine to fine sub angular block.

Objective 3. Assess their role as a buffer to the in relation to the Lake water quality and quantity

The study confirmed that the Wetland soils acts as buffer to the physical and chemical in relation to the Lake water quantity and quality. The assessment was based on the buffering potentials, ground water recharge and storage, floodwater storage, sediment trapping and pollution control and other information gathered during the fieldwork.

Generally the study confirmed that the Wetland soils are ecologically important to the Lake and surrounding environment. The most important ecological function was found to be maintaining the quality and quantity of Lake water at the one hand through natural filtering and sediment trapping and buffering potentials of materials and fertilizes and agricultural chemicals from the flowers and vegetable farms on the other hand. The processes begin in the map unit PL443 which reduces the speed of the materials and allow the incoming materials to settle (% slope 0-2) before reaching map unit PL444, where the natural filtering and sediment trapping finally done by papyrus swamps.

The Wetland soils also act as a transitional medium of the materials and buffer of the materials from the surrounding. Other functions are the supply of fresh water to the people at Naivasha town and surrounding villages and irrigation for the flower and vegetable farms. Also maintain the Lake water quantity by groundwater recharge and storage of flooded water. The Lake and wetland soils storage is about 1000 millions of cubic metre in wet conditions, 670 millions cubic metre in the mean condition and 380 millions cubic metre in the dry conditions. The water recharge storage at wet year is estimated to be 8.5 million cubic metres at 3 km buffer zones. The available water percentage is between 9-15 and sandy loan and 16-22 in clay loam in the soil profile. The riparian zone also habitat sites for the hippos, buffaloes, and fish breeding ground.

Objective 4. Assess their vulnerability to pollution and contamination

The vulnerability of the wetland was assessed on the basis of the physical and chemical parameters such as the redox potentials (Eh), the electrical conductivity ECe) and pH. Other parameters include CEC, organic matter and field observations in general. The study confirmed that at present, the Wetland soils are not vulnerable to pollution fertilizers and agricultural chemicals from the surrounding flower and vegetable farms. The soils have generally medium to high capacity to retain heavy metals from the fertilzers and agricultural chemicals as indicated by CEC values at 50cm depth (13.80-25.40 meq/100g medium to 26.40-30.60 meq/100g high). Also they have medium to high physico-chemical buffer potentials as mostly CEC measurement range by 10-20meq/100g medium and high 20-30 meq/100g.

The study has confirmed that soils have not been polluted by the accumulation salts as the salinity levels are low than the lower class of salinity (<4mS/cm). The electrical conductivity (ECe) values were low 0.11m/cm and 2.99 mS/cm. The Eh-pH diagram also show that the there no mobility of the iron ions or toxic ions which may pollute the soils. The organic matters in the depths of 50cm are low as indicated by the low % carbon (0.09-1.16). The low organic matter may affect the capacity to retain heavy metals from the fertilzers and agricultural chemicals if percolate to the lower horizons.

Objective 5. To find out "if any" the effects of the Lake water (hydrology) fluctuations in the Wetland soils

The assessment was based on the physical and chemical properties of the Wetland soils. The study confirmed that seasonal alternating (dry and wet condition) or Lake water fluctuations have impact on the soils properties. The possible influences are

mainly dilution and concentration effects, which may cause variations of soil properties such as redox potentials, electrical conductivity and pH and mobility of toxic ions. Other effects observed were the formation of the dark reddish brown, yellowish mottles and bluish gley properties, which was mainly due to the reduction of iron. These effects may affect the quality of these soils. Other effects, which are not related to the soil properties, are the destruction crops during the high level water and influence on the papyrus seed germination during the low level or dry condition. The high water level encourages the fishing breeding areas considerable.

Objective 6. Evaluate their suitability to others uses

A general suitability assessment was done based on the available information and survey done during the fieldwork. Evaluation of these soils for crop production and construction was not considered in this study because of risk of pollution hazards and water abstraction which my affect the quality and quantity of the Lake Water. Also the wetland soils at Lake Naivasha are under Ramsar List, which recognises and protects the Wetland soils in all country members. The Wetland soils are also part of riparian zone, which is prohibited for any activities involve agricultural and constructions.

The nature and game preservation landuse was found to be appropriate and therefore proposed due to continue for the following reasons:

The nature and game reserve landuse will ensure protection from pollution and conservation of nature and wildlife resources available at the Wetland soils.
This kind of land use will be used for recreation purposes and is important for touristism sector, source of foreign exchange for Kenya.

Major limitations

The study was carried out on some selected physical and chemical properties to assess the status of the Wetland soils. Therefore it could not provide an explanation or quantification on other aspects such as effect of Lake water fluctuation on the phosphorus, nitrogen and copper iron concentrations in the wetland soils.

Lack of appropriate images

Lack of the recent image and air photographs made it difficult to prepare an up to date Wetland soils map and land use map, which may affect the reliability of the maps with the present situation.

Accessibility

The physical characteristics of the wetland soils being too boggy and deep water especially in the map unit PL444 and flooded parts of map unit PL443, prevented extensive observation. Insecurity by the wild animals like buffaloes and hippos especially in the wetland soils restricted the movement in the area.

Farm enclosures especially by electrical fences and lack-co-operation of some farmers and farm managers who seemed suspicious prevented some of the data to be collected.

6.2 Recommendations

Monitoring of the pollution should be done regularly especially by studying the soil properties such redox potential, pH and ECe, which may give important information on the status of the Wetland soils. Such information will help in the management Wetland soils and Lake in general.

For the purpose of protecting and conserve Wetland soils nature and game reserve and use is proposed. This type of land use can be use to protect, conserve the Wetland soils from pollutions and distractions by farmers.

Further reclamation of the flooded area by building dike should be reconsidered and if possible stopped because of the negative effects, which may lead to the Lake pollution.

Enforce restriction laws on the use of the riparian zone especially in the reclaimed Wetland soils for flower and vegetable farms.

Replanting papyrus vegetations in the reclaimed area of the Wetland soils

Suggestion for further research

The outcome of this study raised some new questions concerning the status of the Wetland soils.

Research on selected the heavy metals such as copper and Arsenic and other elements such as phosphorous and Nitrogen especially in those areas which have shown the signs of eutrophications.

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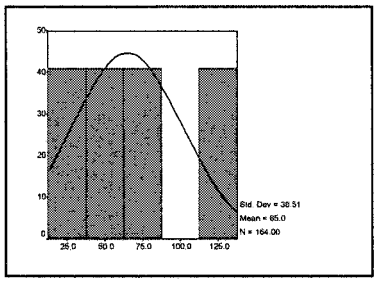
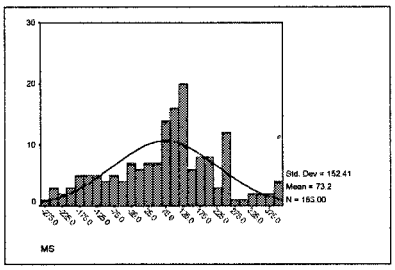
Annex I. **Pesticide and other Agrochemical data inventory in Lake Naivasha Farms.**

Chemical Name	Mode of Action	Dose (ha^{-1} $month^{-1}$)	Solubility in water (ppm)	Half-life(d) in soil	Crops applied
Abamectin	Insecticide	0.027 lit	0	2	Flowers
Acrinathrin	Insecticide	0.023 lit	0.09	52	Flowers
Alachlor	Herbicide	2 lit	242	18	vegetables
Amitraz	Insecticide	0.67 lit	1	0.5	Flowers
Azocyclotin	Acaricide	0.013 lit	0.9	7	Flowers
Bacillus Thuringiensis	Insecticide	0.033 lit	0	2	Flowers
Benomyl	Fungicide	0.13 lit	2	270	Flowers
Bitertanol	Fungicide	1 lit	5	2	Flowers
Chlorothalonil	Fungicide	0.013 lit	0	60	Flowers
Chlorpyrifos	Insecticide	0.5 lit	2	90	Vegetables
Clofentezine	Acaricide	0.033 lit	0.9	55	Flowers
Cyproconazole	Insecticide	0.1 lit	140	90	flowers
Deltamethrin	Insecticide	0.067 lit	0.02	11	flowers
Dichlorofluanid	Fungicide	0.08 lit	1.3	3	Flowers
Dicofol	Acaricide	0.267 lit	0.8	5	V & F
Dienochlor	Acaricide	0.033 lit	0	2	Flowers
Endosulfan	Insecticide	1.33 lit	0.42	3	Flowers
Ethion	Acaricide	0.1 lit	0	2	Vegetables
Etridiazole	Fungicide	0.013 lit	50	3	Flowers
Fenarimol	Fungicide	0.267 lit	13.7	3	Flowers
Flufenoxuron	Insecticide	0.5 lit	0	3	Vegetables
Gibberelic Acid	Fungicide	0.007 lit	5	600	Flowers
Iprodione	Fungicide	0.53 kg	13	90	Flowers
Lambda-Cyhalothrin	Insecticide	0.5 lit	0.01	56	Vegetables
Linnuron	Herbicide	0.007 lit	81	105	Vegetables
Mancozeb	Fungicide	1.33 lit	200	11	V & F
Metaldehyde	Molluscide	1.33 lit	230	13	Flowers
Methomyl	Insecticide	0.63 lit	57.9	4	V & F
Methyl Bromide	Soil Sterilants	6.67 kg	13.4	1	Flowers
Myclobutanil	Fungicide	0.067 lit	142	3	Flowers
Oxycarboxin	Fungicide	0.0267 lit	1000	3	Flowers
Pirimiphos-Methyl	Insecticide	0.01 lit	5	29	Vegetables
Sodium Floroalcetate	Rodenticide	1.6 kg	400	1	Flowers
Sulfur	Fungicide	3 kg	0	1	V & F
Thiophanatemethyl	Fungicide	0.133 lit	26.6	1.5	Vegetables
Tolclofos-Methyl	fungicide	0.033 lit	0.35	1.5	Flowers
Triadimefon	Fungicide	0.05 kg	260	120	Flowers
Triadimenol	Fungicide	0.133 lit	95	120	Vegetables
Triforine	fungicide	0.133 lit	6	21	Flowers
Vinclozolin	Fungicide	0.033 kg	3.4	650	Flowers

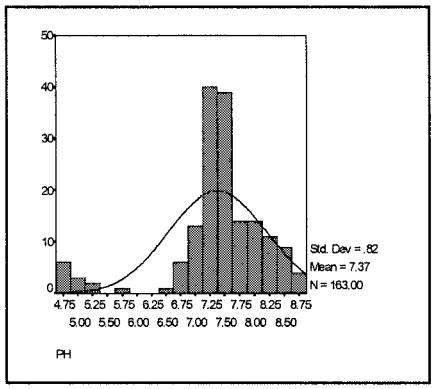
Appendix II: Histograms and relationships of variables in the transacts



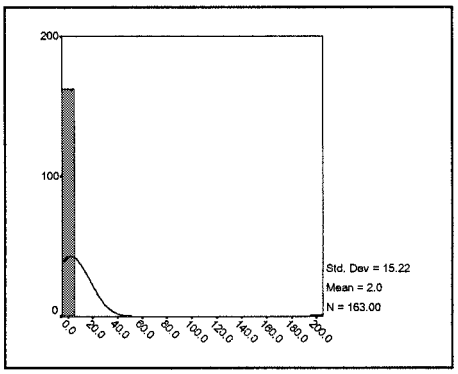
Histogram of soil depth in the transacts



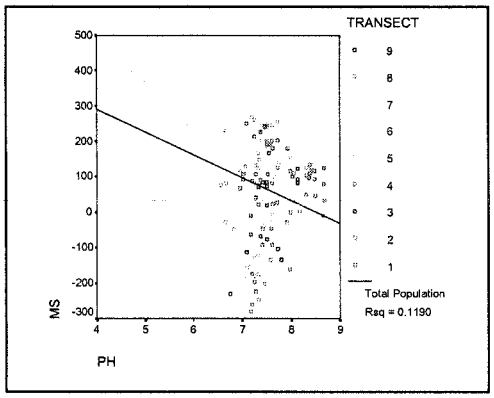
Histogram of redox potential in the transacts



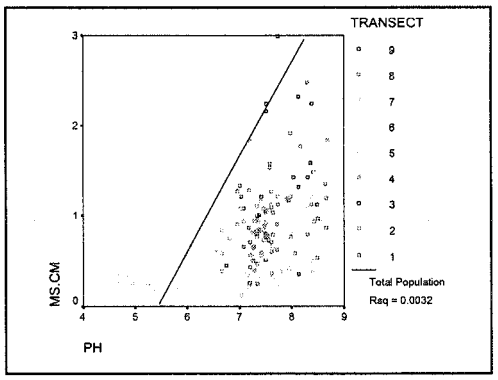
Histogram of soil pH in the transacts



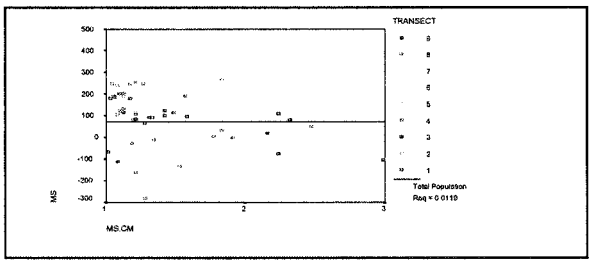
Histogram of ECe in the transacts



Relationship between soil pH and Redox potential



Relationship between soil pH and Redox potential



Relationship between ECe and Redox potential

Appendix III

Min pits and augurs descriptions transact 1 in the KWS annex sample area.

Observation 1

Mini pit observation, transact 1 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 1October 1998
Author: Urassa and Siderius
Location: 37m 021362, UTM 9918063, 275^{0}NW and 40 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of Riparian zone
Surrounding landform: Almost level
Slope: Almost level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Soil was dry from 0-7cm, 7-40 cm moist, and 40- 80cm wet
Depth to groundwater table: 80 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: abandon small farms

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-7	Very dark gray (2.5Y3/1) moist and very dark grayish brown (2.5Y3/2) dray; clay loam; fine moderately subangular blocky moderately calcareous; pH 7.58;
Ah2	7-20	Very dark grayish brown (2.5Y3/2) moist; sandy loam; fine weak subangular moderately calcareous; pH 7.93; few dark reddish brown (5YR3/4) mottles;
Bwg1	20-40	Very dark gay (2.5Y3/2) moist; sandy loam -coarse fragments; fine Weak subangular; moderately calcareous; pH 7.63 few dark reddish brown (5YR3/4) mottles;
Bwg2	40-60	Very dark grayish brown (10YR3/2) moist; silt loam; moderately calcareous; pH 7.6 few dark reddish brown (5YR3/4) mottles;
Cg1	60-80	Very dark grayish brown (10YR3/2) moist; clay loam; dark reddish brown (5YR3/4) mottles;
Cg2	80-120 +	Dark brown (7.5YR3/3) moist; clay loam; few dark reddish brown (5YR3/4) mottles.

NB: Fine to coarse gravels (tuffs) were found on the horizons.

Observation 2

Augur Observation, transact 1 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Typic Xerochrepts

Date of examination: 1October 1998
Author: Urassa and Siderius
Location: UTM 0213662, UTM 9918062, 275NW and 30 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level
Slope: Almost level 1%
Land use: Game sanctuary

General information on soil
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Soil was dry from 0- 6cm, -36 cm moist, and 36-75cm wet
Depth to groundwater table: 75cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: about 20 m east of the transact there small abandon farms

Profile description:
The sequences of horizons were similar to previous observation.

Observation 3

Auger observation, transact in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 1October 1998
Author: Urassa and Siderius
Location: 37m 0213662, UTM 9918063, 275^{0}NW and 20 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level
Slope: Almost level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Soil was dry from 0-7cm, 7-40 cm moist, 40-80cm wet
Depth to groundwater table: 56cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: About 25m small abandon farms

Profile description:
The sequences of horizons were similar to previous observation

Observation 4

Auger observation, transact 1 in the KWS Annex sample **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 1October 1998
Author: Urassa and Siderius
Location: 37m 0213662, UTM 9918063, 275^{0}NW on the edge of Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level
Slope: Almost level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Soils were wet, partly flooded
Depth to groundwater table: 43cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: About 30 m east of the transact there small abandoned small field.

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Black (2.5Y2.5/1) moist; clay loam; moderately calcareous; pH 7.33;
Bwg1	20-50	Dark graish brown (10YR4/2) moist; sandy clay loam; moderately calcareous; pH 7.20; few reddish brown (5YR4/3) mottles;
Cg1	50-70	Dark graish brown (10YR4/2) moist; sandy loam; moderately calcareous; pH 7.28; few reddish brown (5YR4/3) mottles
Cg2+	70-120+	Dark grayish brown (10YR4/2) moist; clay loam; moderately calcareous; pH 7.52; very few reddish brown (5YR4/3) mottles.

Observation 5

Auger observation, transact 1 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 1October 1998
Author: Urassa and Siderius
Location: 37m 0213662, UTM 9918063, 275^{0}NW and 10, from the edge inside the Lake water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level
Slope: Almost level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Soils were wet
Depth to groundwater table: Flooded area
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: About 40m east of the transact there small abandoned small field

Profile description:
The sequences of horizons were similar to previous observation

Observation 6

Auger observation, transact 1 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, Aquic Xerochrepts

Date of examination: 1October 1998
Author: Urassa and Siderius
Location: UTM 0213662, UTM 99180630, 275^{0}NW 20m inside Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level
Slope: Almost level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Soil was wet
Depth to groundwater table: Flooded soils
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: None

Profile description:
The sequences of horizons were similar to previous observation

Min pits and augurs descriptions transact 2 in the KWS annex sample area.

Observation 1

Augur Observation, transact 2 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 2 October 1998
Author: Urassa
Location: 37m 021371, UTM 9918200, 280^{0}NW and 40 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%

Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: well to moderately well drained
Moisture condition in the profile: Soils were dry, moist and wet
Depth to groundwater table: 90 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: abandon small farms

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Olive brown (2.5Y4/3) dry and dark grayish brown (2.5Y4/2) moist; clay loam; very slightly acid; pH 6.65;
Bwg1	20-50	Dark grayish brown (2.5Y4/2) moist; sandy clay loam; very mild calcareous; pH 7.20; few dark reddish brown (5YR3/4) mottles;
Cg1	50 -70	Olive brown (2.5Y4/3) moist; sandy clay loam; Very mildly; calcareous; pH 7.28: few dark reddish brown (5YR3/2) mottles
Cg2	100 -120+	Olive brown (2.5Y4/4) moist; Sandy clay; mildly calcareous; pH 7.52 few dark reddish brown (5YR3/2) mottles.

NB. From 125 cm the impervious tuff layer was found which was dry to moist .

Observation 2

Augur Observation, transact 2 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts
Date of examination: 2 October 1998
Author: Urassa
Location: 37m 0213671, UTM 9918200, 280^{0}NW and 30 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: Well drained to imperfectly drained
Moisture condition in the profile: Soils were dry, moist, wet
Depth to groundwater table: About 64cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Small abandon farms

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Dark grayish brown (2.5Y4/2) moist and light olive brown (2.5Y5/3) dry; sandy clay loam; very mildly calcareous; pH 7.20;
Bwg1	20-50	Very dark grayish brown (2.5Y3/2) moist; sandy clay loam; mildly calcareous; pH 7.73; few reddish brown (5YR4/3) mottles;
Cg1	50-70	Dark yellow brown (10YR3/4) moist; sandy loam; mildly calcareous; pH 7.61; few reddish brown (5YR4/3) mottles;

Cg2	70-120+	Dark grayish brown (10YR3/2) moist; silt clay loam; mildly calcareous; pH 7.46; reddish brown (5YR4/3) mottles.

NB: From 125-cm impervious layer soils, which were dry to moist and few cutans (10YR 4/6) found on the dead roots.

Observation 3

Min pit observation, transact 2 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 2 October 1998
Author: Urassa
Location: 37m 0213671, UTM 9918200, 280^{0}NW and 20 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: Moderately well drained to imperfectly drained
Moisture condition in the profile: Soil was dry, 0-16cm, 16-32 cm moist, 32-58cm wet
Depth to groundwater table: 58cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: abandon small farms

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-16	Very dark grayish brown (2.5Y3/2) moist and dark olive brown (2.5Y3/3); clay loam; moderately fine to medium subangular. blocky; slightly hard (dry),friable (moist) and slightly sticky and slightly plastic (wet) ; very mildly calcareous pH 7.24;
Bwg1	16 -32	Very dark grayish brown (2.5Y3/2) moist; clay loam; weak to moderate, fine and medium subangular blocky; slightly hard (dry), friable moist, slightly plastic and slightly plastic (wet). mildly calcareous; pH 7.50; common reddish brown (5YR4/3) mottles;
Bwg2	32-55	Very dark grayish brown (10YR3/2) moist; sandy loam; weak and medium sub angular blocky; slightly hard (dry), friable (moist) and slightly sticky and slightly plastic; mildly calcareous; pH 7.40;
Cg1	50-70	Dark yellow brown (10YR3/4) moist; sandy loam; mildly calcareous; pH 7.45; few reddish brown (5YR4/3) mottles;
Cg2	70-120+	Dark grayish brown (10YR3/2) moist; silt clay loam; mildly calcareous; pH 7.45; common reddish brown (5YR4/3) mottles.

Observation 4

Auger observation, Transact 2 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 2October 1998
Author: Urassa
Location: 37m 0213671, UTM 9918200, 280^{0}NW on the edge of Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level
Slope: Almost level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: Poorly drained
Moisture condition in the profile: Wet soils
Depth to groundwater table: Flooded soils
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Abandoned small fields.

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Very dark grayish brown (2.5Y3/2) wet; sandy loam; very slightly acid calcareous; pH 6.57;
Bwg1	20-50	Dark graish brown (2.5Y4/2) moist; sandy clay loam; moderately calcareous; pH 6.96; few reddish brown (5YR4/3) mottles;
Cg1	50-70	Dark graish brown (2.5Y4/2) moist; silty clay loam; moderately calcareous; pH 7.07; reddish brown (5YR4/3) mottles
Cg2	70-120+	Yellowish brown (10YR5/4) moist; silty clay loam; Very mildly calcareous; pH 7.28; few reddish brown (5YR4/3) mottles.

Observation 5

Auger observation, transact 2 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Typic Xerochrepts

Date of examination: 2October 1998
Author: Urassa
Location: 37m 0213671, UTM 9918200, 280^{0}NW and 10, from the edge inside the Lake water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: Poorly drained
Moisture condition in the profile: Soils were wet
Depth to groundwater table: Flooded area
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: None

Profile description:
The sequences of horizons were similar to previous observation

Observation 6

Auger observation, transact 2 in the KWS Annex sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitc Aquic Xerochrepts

Date of examination: 2October 1998
Author: Urassa
Location: 37m 0213671, UTM 9918200, 280^{0}NW 20 m inside Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Soil was wet
Depth to groundwater table: Flooded soils
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: None

Profile description:
The sequences of horizons were similar to previous observation

Augurs descriptions transact3 in the KWS annex sample area.

Observation 1

Augur Observation, transact 3 in the KWS Annex sample area Map **unit: PL 444**

Information on the site:
High category classification:
FAO: Fibric-Histosls, sodic phase
USDA: Hydric Medihemists

Date of examination: 2 October 1998
Author: Urassa and Siderius
Location: 37m 0213346, UTM 9918105, 274^{0}NW on papyrus swamp of Lake Naivasha water.
Land form: Physiographic position: on riparian zone
Surrounding landform: water
Slope: deep water
Land use: Game sanctuary and fishing

General information on soil:
Parent material: Lacustrine deposits
Drainage: Poorly drained
Moisture condition in the profile: Soils were wet
Depth to groundwater table: Flooded soils, 65-cm water level
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike

Profile description:

Horizon	Depth (cm)	Description
Oa??	0-20	Very dark gray (2.5Y3/1) wet; unconsolidated leave matter debris and plastic; moderately calcareous (pH 7.8);
Bw1	20-50	Very dark grayish (2.5Y3/2) moist; sandy loam; moderately calcareous; pH 7.73; to very strongly calcareous (pH 9.12)
Bw2	50-70	Dark grayish brown (2.5Y4/2) wet; silty clay loam; mildly calcareous; pH 7.51;
C2	70-120+	Dark yellowish brown (10YR4/6) wet, sandy clay; mildly calcareous; pH 7.42;

Observation 2

Augur Observation, transact 3 in the KWS Annex sample **Map unit: PL 444**

Information on the site:
High category classification:
FAO: Fibric-Histosls, sodic phase
USDA: Hydric Medihemists

Date of examination: 2October 1998
Author: Urassa and siderius
Location: 37m 0213346, UTM 9918105, 274^{0}NW on the papyrus swamp of Lake Naivasha
Land form: Physiographic position: on riparian zone
Surrounding landform: water
Slope: deep water
Land use: Game sanctuary and fishing

General information on soil
Parent material: Lacustrine deposits
Drainage: Poorly drained.
Moisture condition in the profile: wet
Depth to groundwater table: Flooded soils
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike

Profile description:
The sequences of horizons were similar to previous observation

Appendix IV

Min pits and augurs descriptions transact in the YMCA Club sample area.

Observation 1

Mini pit observation, transact in the YMCA Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Typic Xerochrepts

Date of examination: 5October 1998
Author: Urassa
Location: 37m 020295, UTM 9908624, 300^{0}NW and 40 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of Riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Floricultural

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Soil was dry from 0-30cm, 30-55 cm moist and 55 120 cm wet
Depth to groundwater table: 90 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Flowers farms around 50 m east and west of the observation point
Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Olive gray (5Y4/2) moist and olive (5Y4/3); sandy clay loam; strongly calcareous; pH 8.49;
Bw1	20 -50	Olive gray (5Y4/2) moist; sandy clay loam; strongly calcareous, pH 8.37;
Bwg2	50-70	Olive gray (5Y4/2) moist; sandy loam -coarse fragments; moderately calcareous, pH 7.72; few dark reddish brown mottles;
Cg	100-120+	Gray (5Y5/1) moist; silt clay loam; moderately calcareous pH 7.6 few dark reddish brown (5YR3/4) mottles.

Observation 2

Augur Observation, transact in the YMCA Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts
Date of examination 5October 1998
Author: Urassa
Location: UTM 0206295, UTM 9908624, 300^{0}NW and 65m from the dike.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Floriculture

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained

Moisture condition in the profile: Soil was dry from 0- 30 cm, 30 -56 cm moist, and 56-75cm wet
Depth to groundwater table: 80cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Flowers farms, about 50 m east and west of the observation point

Profile description:
The sequences of horizons were similar to previous observation.

Observation 3

Auger observation, transact in the YMCA Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Typic Xerochrepts
Date of examination: 5 October 1998
Author: Urassa
Location: 37m 0206295, UTM 9908624, 300^{0}NW and 55 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Flowers farms, about 50 m east and west of the observation point

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly drained
Moisture condition in the profile: Soils were dry from 0-30cm, 30-50 cm moist, 50-70cm wet
Depth to groundwater table: 75cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Flowers farms, about 50 m east and west of the observation point

Profile description:
The sequences of horizons were similar to previous observation

Observation 4

Min pit observation, transact in the YMCA Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 5 October 1998
Author: Urassa
Location: 37m 0206295, UTM 9908624, 300^{0}NW and 35 m from the dike.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level
Slope: Almost level 1-2%
Land use: Floriculture

General information on soil:
Parent material: Lacustrine deposits
Drainage: Moderately well drained imperfectly drained
Moisture condition in the profile: Soils were 0-12cm dry, 12-50 cm moist, and 50- 70 cm wet
Depth to groundwater table: 70cm
Presence of surface stones, rock outcrops: None

Evidence of erosion: None
Human influence: Flowers farms, about 50 m east and west of the observation point

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-12	Dark grayish brown (2.5Y4/3) moist and olive brown (2.5Y4/2); sandy loam; moderately very, fine to medium subangular blocky; slightly hard , friable, slightly sticky and slightly plastic clay loam; moderately calcareous; pH 8.48;
Bwg1	12-30	Olive brown (2.5Y4/2) moist; medium gravel, sandy clay loam; moderately, very fine , fine to medium, subangular blocky; slightly hard dry, friable moist, sticky and plastic; moderately calcareous, pH 8.42; many fine prominent sharp to clear reddish brown (5YR 4/4) mottles;
Bwg2	30-60	Olive brown (2.5Y4/2) moist; sandy clay loam; moderately, very fine , fine to medium, subangular blocky; slightly hard dry, friable moist, sticky and plastic; moderately calcareous, pH 8.06; common fine prominent sharp to clear reddish brown (5YR 4/4) mottles;
Cg	70-120+	Gray (5Y5/1) moist; silt clay loam; mildly Calcareous, pH 7.41; few dark reddish brown (5YR3/4) mottles.

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Observation 5

Auger observation, transact in the YMCA Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 5 October 1998
Author: Urassa
Location: 37m 0206295, UTM 9908624, 300^{0}NW and 15, from the edge inside the Lake water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Floriculture

General information on soil:
Parent material: Lacustrine deposits
Drainage: Imperfectly drained to poorly drained
Moisture condition in the profile: Soils were dry 0-25 cm, 25- 50 cm moist, 50 -60 cm wet
Depth to groundwater table: 60 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Flowers farms, about 50 m east and west of the observation point

Profile description:
The sequences of horizons were similar to previous observation

Observation 6

Auger observation, transact in the YMCA Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 5 October 1998
Author: Urassa
Location: UTM 020625, UTM 99108624, 300^0 NW and about 6 m from the dike.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Floriculture

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Soils were dry 0-25 cm, 25 -50 cm moist, and 50- 60 cm wet
Depth to groundwater table: 45 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Flowers farms, about 50 m east and west of the observation point

Profile description:
The sequences of horizons were similar to previous observation

Appendix V

Min pits and augurs descriptions transact in the Longonot farm sample area

Observation 1

Augur Observation, transact in the Longonot farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy semctitic Typic Xerochrepts

Date of examination: 6 October 1998
Author: Urassa and Siderus
Location: 37m 0209254, UTM 9910663, 274^{0}NW and 40 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Horticulture

General information on soil:
Parent material: Lacustrine deposits
Drainage: Well drained
Moisture condition in the profile: Soils were dry from 0- 100 cm moist, and 100-110 cm wet
Depth to groundwater table: 110 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Farming of the vegetables and fruits

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Very dark gray (10YR3/1) moist; sandy loam; mildly calcareous; pH 7.66;
Bwg1	20 -50	Dark grayish brown (2.5Y4/2) moist; sandy clay loam; mildly calcareous, pH 7.77; few dark reddish brown (5YR3/4) mottles;
Cg1	50-70	Dark olive gray (5Y3/2) moist; sandy clay loam; mildly calcareous, pH 7.95; few dark reddish brown (5YR3/4) Mottles;
Cg2	100- 120+	Dark olive gray (5YR3/2) moist; sandy clay loam; mildly Calcareous, pH 7.47; few dark reddish brown (5YR3/4) mottles.

Observation 2

Min pit observation, transact in the Longonot farm **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 6 October 1998
Author: Urassa and Siderius
Location: UTM 0209254, UTM 9910663, 274^{0}NW and 30 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Horticulture

General information on soil
Parent material: Lacustrine deposits
Drainage: Well drained
Moisture condition in the profile: From 0- 28cm dry, 36-100 cm moist, and 100- 104cm wet
Depth to groundwater table: 104cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Horticultural farm Farming of the vegetables and fruits

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-28	Very dark gray (10YR3/1) moist and very dark grayish brown (10YR 3/2) dry; sandy loam; moderately very fine to fine sub angular block ; slightly hard dry, friable moist, slightly sticky and slightly plastic; mildly calcareous; pH 7.75;
Bwg1	28 -50	Olive gray (5Y4/2) moist; sandy clay loam; moderately very fine to fine medium angular and sub angular blocky; slightly hard dry, friable moist and sticky and plastic wet; moderately calcareous, pH 8.31; common very fine distinct diffuse dark reddish brown (5YR3/4) mottles;
Cg1	50-70	Dark olive gray (5Y3/2) moist; sandy clay loam; moderately calcareous, pH 8.40; common dark reddish brown (5YR3/4) mottles;
Cg2	100- 120+	Olive 95YR4/3) wet; sandy loam; moderately calcareous; pH 8.39 common dark reddish brown (5YR3/4) mottles.

Observation 3

Auger observation, transact in the Longonot farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 6 October 1998
Author: Urassa and Siderius
Location: 37m 0209254, UTM 9910663, 274^{0}NW and 20 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Horticulture

General information on soil:
Parent material: Lacustrine deposits
Drainage: Well drained
Moisture condition in the profile: Soil was dry from 0-7cm, 7-40 cm moist, 40-80cm wet
Depth to groundwater table: 100cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Farming of the vegetables and fruits

Profile description:
The sequences of horizons were similar to previous observation

Observation 4

Auger observation, transact in the Longonot farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 6 October 1998
Author: Urassa and Siderius
Location: 37m 0209254, UTM 9910663, 274^{0}NW on the edge of Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Farming of the vegetables and fruits

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: partially flooded
Depth to groundwater table: 50cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Farming of the vegetables and fruits

Profile description:
The sequences of horizons were similar to previous observation

Observation 5

Auger observation in the Longont farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 6 October 1998
Author: Urassa and Siderius
Location: 37m 0209254, UTM 9910663, 274^{0}NW and 10, from the edge inside the Lake water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Flat
Slope: Flat 0-1%
Land use: Horticulture

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: Flooded area
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Farming of vegetables and fruits

Profile description:
The sequences of horizons were similar to previous observation

Observation 6

Auger observation, transact in the Longonot farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Xerochrepts

Date of examination: 6 October 1998
Author: Urassa and Siderius
Location: UTM 0209254, UTM 9910663, 274^0 NW 20m inside Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Flat
Slope: Almost level 0-1%
Land use: Horticulture

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: Flooded soils
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Farming of the vegetables and fruits

Profile description:
The sequences of horizons were similar to previous observation

Appendix-VI

Min pits and augurs descriptions transact in the Yacht club sample area

Observation 1

Augur Observation, transact in the Yatch club sample **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 9 October 1998
Author: Urassa
Location: 37m 02126614, UTM 9914615, 330^{0}NW and 40 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: well drained
Moisture condition in the profile: 0-50cm moist, 50 80 cm wet
Depth to groundwater table: 80 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike, Fencing wire

Profile description:

Horizon	Depth (cm)	Description
Ah1	0 –20	Very dark gray (2.5Y3/2) moist; sand loam very mildly calcareous, pH 7.17;
Bw1	20-50	Very dark gay (2.5Y3/2) moist; sandy clay loam; strongly calcareous; pH 7.94;
C1	50-70	Dark grayish brown (2.5Y4/2) moist; sandy clay loam; strongly calcareous; pH 7.86 few dark;
C2	100-120+	Very dark grayish brown (10YR3/2) moist; sandy clay loam; mildly calcareous; pH 7.43.

Observation 2

Augur observation, transact in the Yacht Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination 9 October 1998
Author: Urassa
Location: UTM 0212614, UTM 9914615, 330^{0}NW and 30 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary, fishing

General information on soil:
Parent material: Lacustrine deposits

Drainage: imperfectly poorly drained
Moisture condition in the profile: moist and wet
Depth to groundwater table: 60cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike, fencing wire

Profile description:
The sequences of horizons were similar to previous observation.

Observation 3

Min pit observation transact in the Yacht Club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 9 October 1998
Author: Urassa
Location: 37m 0212614, UTM 9914615, 330^{0}NW and 20 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary, fishing

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly drained
Moisture condition in the profile: Soil was dry from 0-7cm, 7-40 cm moist, 40-80cm wet
Depth to groundwater table: 42cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike, fencing

Profile description:

Horizon	Depth (cm)	Description
Ah1	0 –10	Very dark grayish brown (10YR3/2) moist and grayish brown (10YR5/2) dry; sand loam; weak to moderate very fine to fine sub angular blocky; slightly hard friable, non sticky and non plastic; moderately calcareous, pH 7.95;
Ah2	10-20	Very dark grayish brown (2.5Y3/2) moist; sandy loam; weak to moderate very fine to fine sub angular blocky; slightly hard, friable and non sticky and non plastic; moderately calcareous, pH 7.95;
Bw1	20-34	Dark grayish brown (2.5Y4/2) moist; sandy clay loam; weak to moderate, very fine to fine sub angular blocky slightly hard, friable, slightly sticky and slightly plastic; mildly calcareous, pH 7.52 few dark;
Bw2	34-50	Olive brown (2.5Y4/3) moist; sandy clay; weak to moderate fine, sub angular blocky, slightly sticky and slightly plastic; mildly calcareous; pH 7.52; common fine, distinct, clear yellowish red (5YR4/6) mottle;
Cg1	50-70	Dark grayish brown (2.5 Y4/2), moist; sand loam; mildly calcareous, pH 7.5; common fine, distinct, clear yellowish red 5YR4/6) mottle;
Cg2	100-120+	Olive (5Y5/6) moist, sandy loam; common fine, distinct, clear yellowish red 5YR4/6) mottle.

Observation 4

Auger observation, transact in the Yacht club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Aquic Xerochrepts

Date of examination: 9 October 1998
Author: Urassa
Location: 37m 0212614, UTM 9914615, 330^{0}NW on the edge of Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary and fishing

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: 37cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike.

Profile description:
The sequences of horizons were similar to previous observation

Observation 5

Auger observation, transact in the Yatch club sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Aquic Xerochrepts

Date of examination: 9 October 1998
Author: Urassa
Location: 37m 0212614, UTM 9914615, 330^{0}NW and 10, from the edge inside the Lake water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Flat
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary and fishing

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: Flooded area
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike

Profile description:
The sequences of horizons were similar to previous observation

Observation 6

Auger observation, transact in the Yacht sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Aquic Xerochrepts

Date of examination: 9 October 1998
Author: Urassa
Location: UTM 0212614, UTM 9914615, 330^0 NW 20m inside Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Flat
Slope: Almost level 1-2%
Land use: Game sanctuary
General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: Flooded soils
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Dike

Profile description:
The sequences of horizons were similar to previous observation

Appendix-VII

Min pits and augurs descriptions transact in the Marula farm sample area

Observation 1

Min pit observation, transact in the Marula farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Dystric Cambsols
USDA: Fine smectitic Typic Xerochrepts

Date of examination: 10 October 1998
Author: Urassa
Location: 37m 0206482, UTM 9929480, 176^{0}SE and about 500m south of Marula Office
Land form: Physiographic position: on the low Malewa catchment
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly to poorly drained
Moisture condition in the profile: Moist, and wet
Depth to groundwater table: waterlogging areas
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Bush clearing

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Very dark gray (10YR3/1) moist; clay loam; strongly acid, pH 5.24;
Bwg1	20 -50	Very dark brown (7.5Y2.5/2) moist; clay; Very strongly acid, pH 4.80; many fine prominent yellowish red (5YR5/8) mottles;
Bwg2	50-70	Dark brown (7.5Y3/2) moist; clay; very strongly acid, pH 4.70; many fine prominent clear yellowish red (5YR5/8) mottles;
Cg1	100-120+	Very dark gray (7.5YR3/1) moist; clay; very strongly acid, pH 4.94; many fine prominent yellowish red (5YR5/8) mottles.

Observation 2

Augur observation, transact in the Marula farm **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Dystric Cambsols
USDA: Fine, smectitic Typic Xerochrepts

Date of examination: 10 October 1998
Author: Urassa
Location: UTM 0206482, UTM 992948, 176^0 SE and 500 m south of the Marula office.
Land form: Physiographic position: on the low Malewa catchment
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: poorly drained
Moisture condition in the profile: Moist and wet
Depth to groundwater table: Water logging area
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Bush clearing

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-10	Very dark brown (7.5YR2.5/2) moist; clay loam; moderately fine angular and sub angular blocky; strongly acid, pH 5.34; slightly hard, friable, sticky and plastic;
Ah2	10 -50	Very dark brown (7.5Y3/2) moist; clay; very strongly acid, pH 4.89; common fine prominent clear yellowish red (5YR5/8) mottles;
Bwg2	50-70	Dark brown (7.5Y3/2) moist; clay; very strongly acid, pH 4.70; many fine prominent yellowish red (5YR5/8) mottles;
Bwg2	100-120+	Very dark gray (7.5YR3/1) moist; clay; very strongly acid, pH 4.84; many fine prominent yellowish red (5YR5/8) mottles.

Observation 3

Auger observation, in the Marula farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Dystric Cambsols
USDA: Fine smectitic Typic Xerochrepts

Date of examination: 10 October 1998
Author: Urassa
Location: 37m 020642, UTM 9914615, 176^0 SE and 500m south of the Marula Office.
Land form: Physiographic position: on the low Malewa catchment
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Moist and wet
Depth to groundwater table: Waterlogging area
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Bush clearing

Profile description:
The sequences of horizons were similar to previous observation.

Appendix-VIII

Descriptions of Min pits and augurs observation transact I in the Delamere farm sample.

Observation 1

Min pit observation, transact I in the Delamere farm **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Aquic Xerochrepts

Date of examination: 12 October 1998
Author: Urassa
Location: 37m 0210472, UTM 9920213 276^0 NW and about 600 from the Delamere Office.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: Poorly drained
Moisture condition in the profile: Moist and wet
Depth to groundwater table: 35 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Fence established about 50 m west of the transact

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Very dark grayish brown (2.5Y3/2); sandy loam; very mildly calcareous; pH 7.18;
Bw1	20-50	Very dark grayish (2.5Y3/2) moist; sandy loam; very mildly calcareous; pH 7.33; few dark reddish brown (10YR3/2) mottles;
Bwg2	50-70	Dark grayish brown (2.5Y4/2) moist; sandy clay loam; strongly calcareous; pH 8.65 few dark few dark reddish brown (10YR3/2) mottles;
Cg	100-120+	Dark grayish brown (2.5YR4/2) moist; sandy clay loam; moderately calcareous; pH 7.6 few dark reddish brown (10YR3/2) mottles.

Observation 2

Augur observation, transact I in the Delamere farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitic Aquic Xerochrepts

Date of examination 12 October 1998
Author: Urassa
Location: UTM 0210472, UTM 992213, 276^0 NW and 500m south of the office.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level

Slope: Almost level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly drained
Moisture condition in the profile: dry, moist, wet
Depth to groundwater table: 5cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Fence established about 50m west of the transact

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-12	Very dark gray (10YR3/1) moist; sandy clay loam; moderate very fine to fine sub angular block, slightly hard, friable, slightly sticky and slightly plastic; very mildly calcareous; pH 7.34;
Bwg1	12-50	Very dark grayish brown (2.5Y3/2) moist; sandy clay loam; moderate very fine to fine sub angular block, slightly hard, friable, slightly sticky and slightly plastic; mildly calcareous; pH 7.45; few fine faint dark reddish brown (5YR3/4) mottles;
Bwg2	50-70	Dark grayish brown (2.5Y4/2) moist; sandy loam; mildly calcareous, pH 7.58 few fine distinct dark reddish brown (5YR3/4) mottles;
Cg	100-120 +	Olive brown (2.5Y4/3) moist; sandy loam; moderately calcareous; pH 8.17 very few fine distinct sharp dark reddish brown (10YR3/2) mottles.

Observation 3

Auger observation, transact I in the Delamere farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitc Aquic Xerochrepts
Date of examination: 12 October 1998
Author: Urassa
Location: 37m 02101472, UTM 990213, 276^0 SE and 20 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Soil was dry from 0-7cm, 7-40 cm moist, 40-80cm wet
Depth to groundwater table: 55cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Bush clearing

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-20	Black (2.5Y2.5/1) moist; clay loam; very mildly calcareous; pH 7.20;
Bwg1	20-50	Very dark grayish brown (2.5Y4/2) moist; sandy clay loam; mildly calcareous; pH 7.25;

Bwg2	50-70	Dark grayish brown (10YR4/2) moist; sandy clay loam; mildly calcareous, pH 7.98 few fine distinct dark reddish brown (5YR3/4) mottles;
C	100-120+	Olive brown (10YR4/4) moist; sandy clay loam; moderately calcareous; pH 8.30 few fine distinct sharp dark reddish brown (5YR3/4) mottles.

Descriptions of Min pits and augurs observation transact 2 in Delamere farm sample area.

Observation 1

Min pit observation, transact1 in the Delamere farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination: 13 October 1998
Author: Urassa
Location: 37m 0210696, UTM 9920255, 178^{0}SE and 500 m from Delamere Office.
Land form: Physiographic position: on the edge of riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level to nearly level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: dry, moist and wet
Depth to groundwater table: 85 cm
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Fence established about 200 m west of the transact

Profile description:

Horizon	Depth (cm)	Description
Ah1	0- 20	Dark grayish brown (10YR4/2) moist; clay loam; moderately calcareous; pH 8.13;
Bwg1	20- 50	Olive (2.5Y4/3) moist; sandy clay; moderately calcareous; pH 8.48, few dark reddish brown (5YR3/4) mottles;
Bwg2	50-70	Dark grayish brown (10YR4/2) moist; sandy loam; moderately calcareous; pH 8.43; few dark reddish brown (5YR4/2) mottles
Cg1	100-120	Dark yellow brown (10YR4/4) moist; sandy clay loam; moderately calcareous; pH 8.13 few dark reddish brown (5YR3/4) mottles.

Observation 2

Augur observation, transact I1 in the Delamere farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy smectitic Typic Xerochrepts

Date of examination 13 October 1998
Author: Urassa
Location: UTM 0210696, UTM 9920255, 178^0 SE and 30 m from the edge of Lake Naivasha water.
Land form: Physiographic position: on the riparian zone

Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary

General information on soil:
Parent material: Lacustrine deposits
Drainage: Poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: Partially flooded
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Fence established about 200m west of the transact

Profile description:

Horizon	Depth (cm)	Description
Ah1	0-15	Dark grayish brown (10YR4/2) moist; sandy loam; moderate very fine to fine sub angular block, slightly hard, friable, slightly sticky and slightly plastic; very slightly acid; pH 6.75;
Bwg1	15-43	Very dark grayish brown (10YR3/2) moist; sandy clay loam; moderate very fine to fine sub angular block, slightly hard, friable, slightly sticky and slightly plastic; very mildly calcareous; pH 7.33; common fine distinct clear dark reddish brown (5YR3/4) mottles;
Bwg2	43-70	Dark grayish brown (10YR4/2) moist; sandy loam; moderately calcareous, pH 8.03 common fine distinct dark reddish brown (5YR3/4) mottles;
Cg	100-120+	Dark yellowish brown (10YR4/4) moist; sandy loam; moderately calcareous; pH 8.17 few fine distinct sharp dark reddish brown (5YR3/4) mottles.

Observation 3

Auger observation, transact 1I in the Delamere farm sample area **Map unit: PL 443**

Information on the site:
High category classification:
FAO: Eutric Cambsols
USDA: Loamy, smectitc Xerochrepts

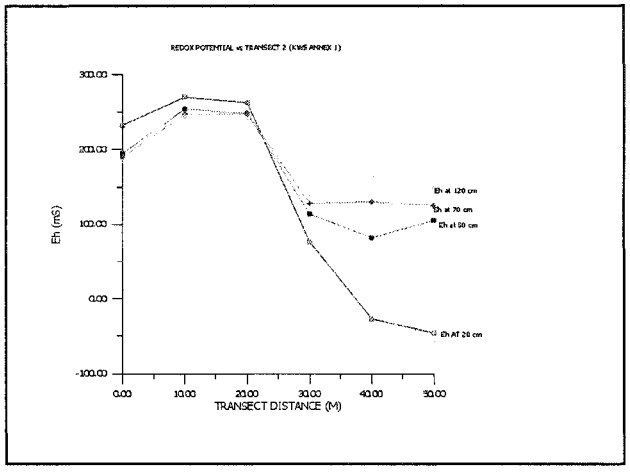
Date of examination: 13 October 1998
Author: Urassa
Location: 37m 0210696, UTM 9920255, 178^0 SE and 500m from the Delamere office.
Land form: Physiographic position: on the riparian zone
Surrounding landform: Almost level to nearly level
Slope: Almost level 1-2%
Land use: Game sanctuary

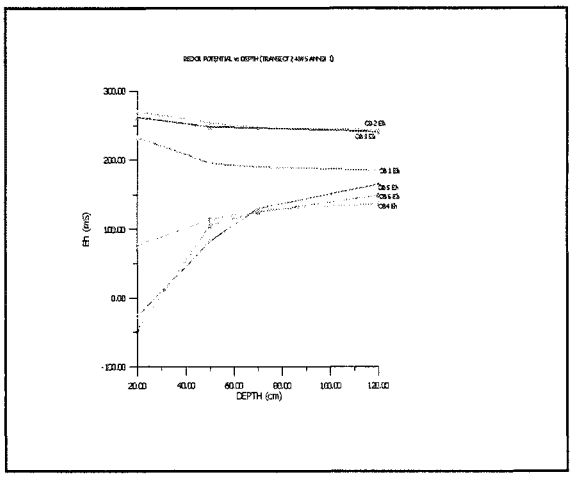
General information on soil:
Parent material: Lacustrine deposits
Drainage: imperfectly poorly drained
Moisture condition in the profile: Wet
Depth to groundwater table: Flooded
Presence of surface stones, rock outcrops: None
Evidence of erosion: None
Human influence: Fence established about 200m west of the transact

Profile description:
The sequences of horizons were similar to previous observation

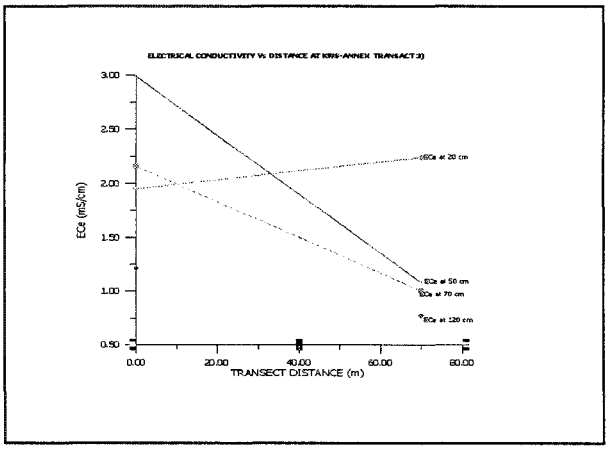
Appendix IX

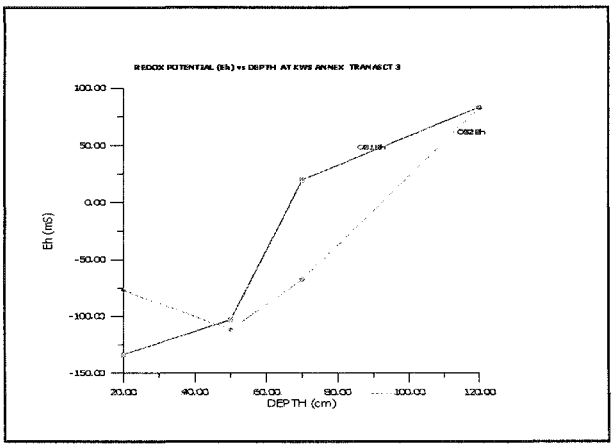
The redox potential of different transacts are presented below



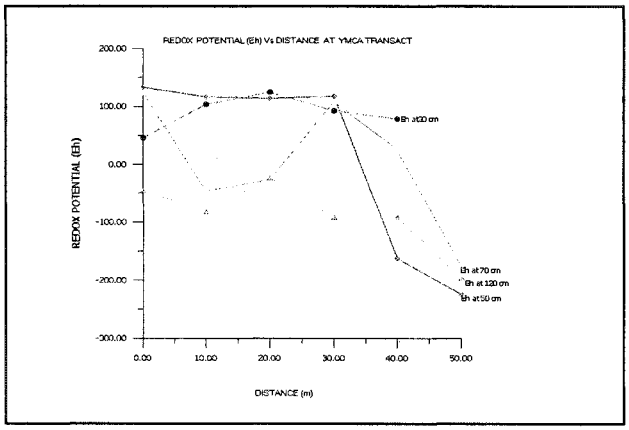


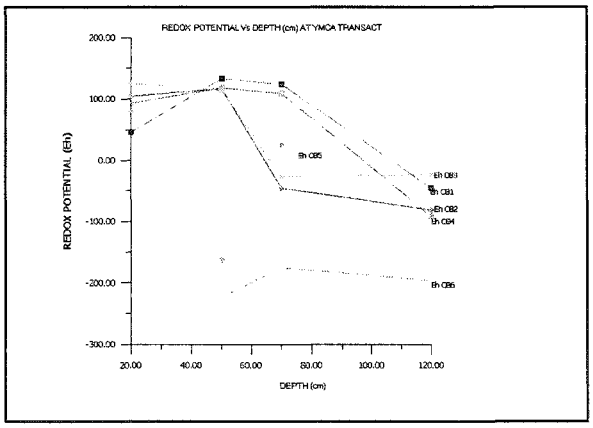
Graphs: Redox potential (Eh) variations along and with depth in KWS annex transact2.



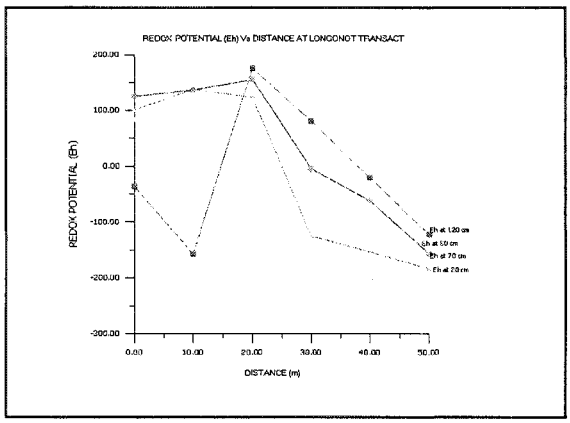


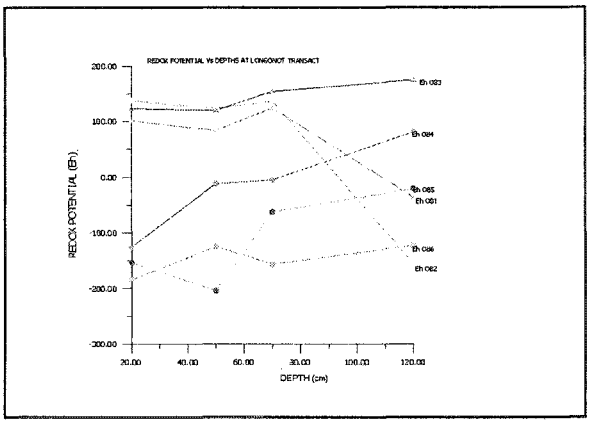
Graphs: Redox potential (Eh) variations along and with depth in KWS annex transact 3.



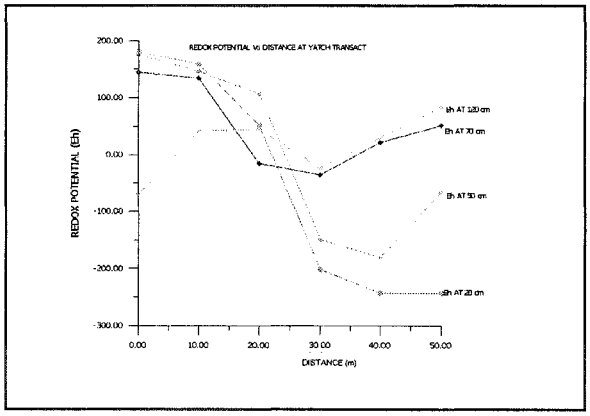


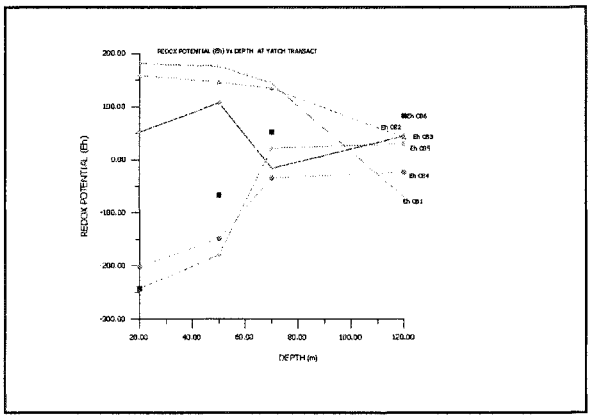
Graphs: Redox potential (Eh) variations along and with depth in YMCA transact.



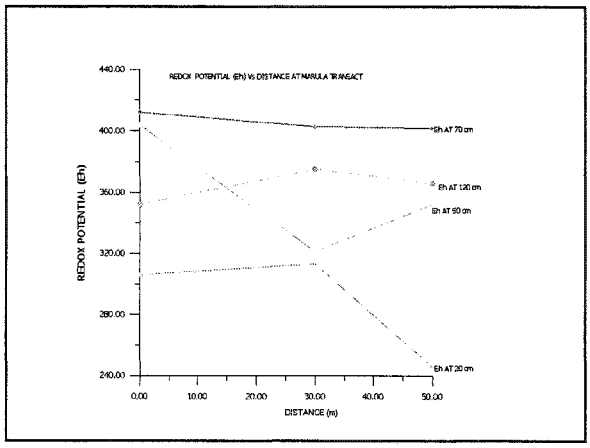


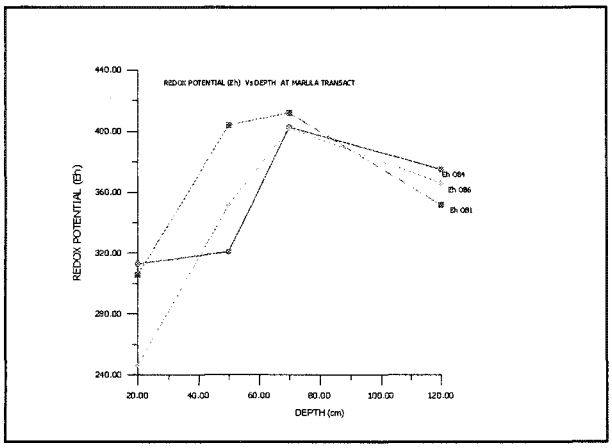
Graphs: Redox potential (Eh) variations along and with depth in Longonot transact.



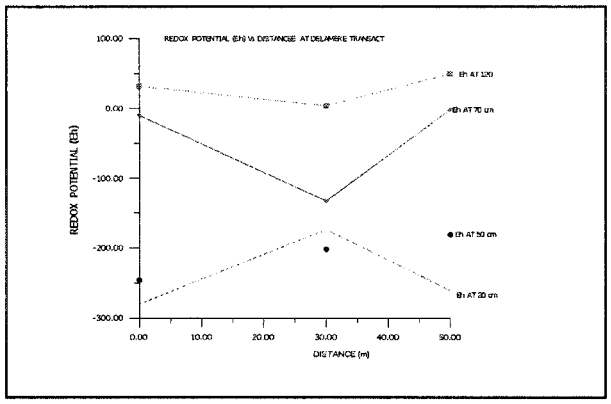


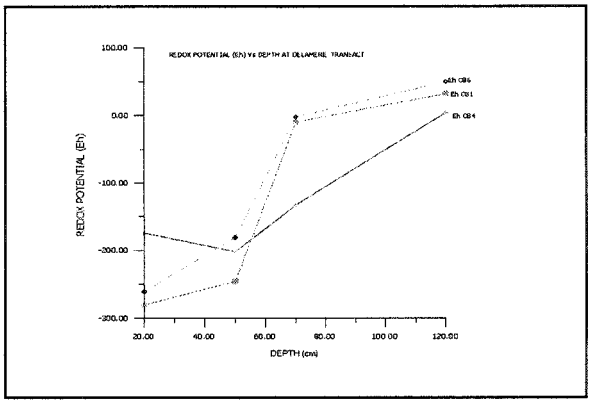
Graphs: Redox potential (Eh) variations along and with depth in Yatch transact.



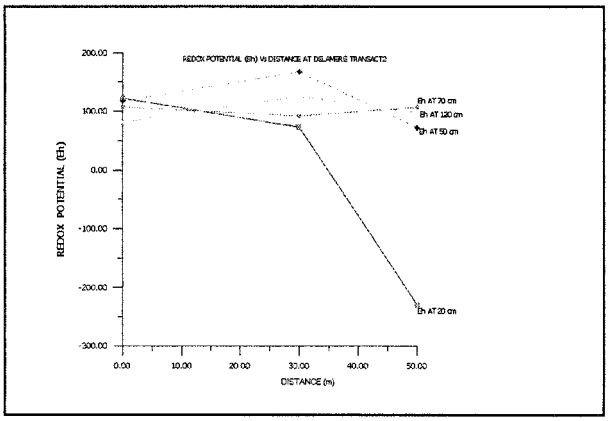


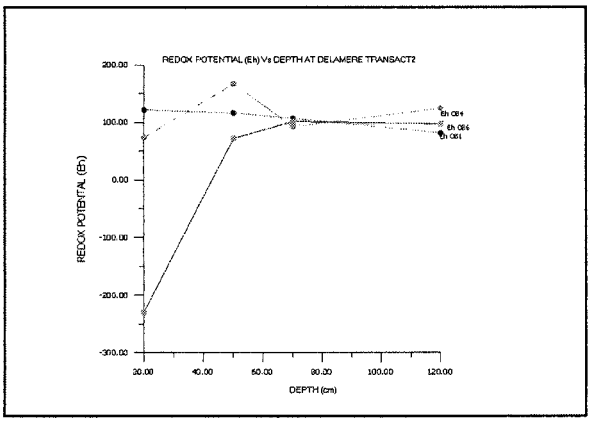
Graphs: Redox potential (Eh) variations along and with depth in Marula transact.





Graphs: Redox potential (Eh) variations along and with depth in Delamere transact 1.

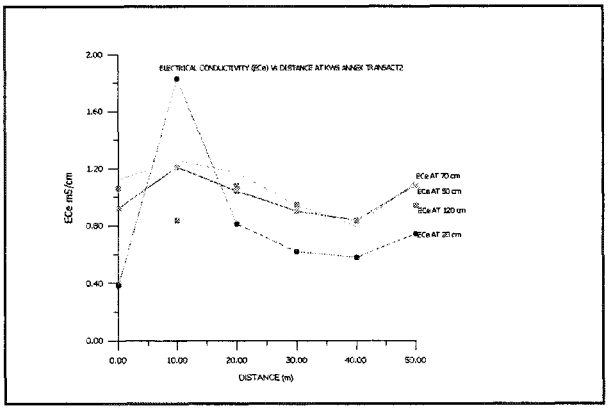


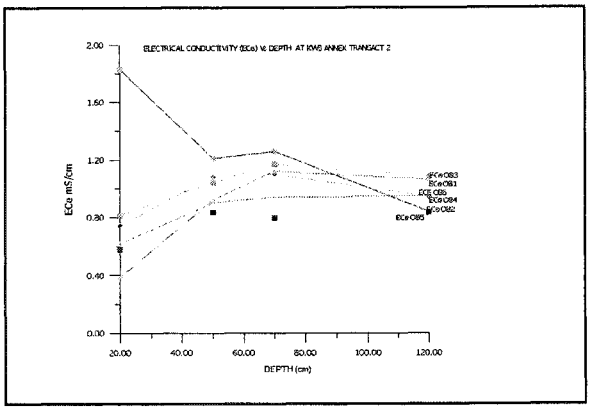


Graphs: Redox potential (Eh) variations along and with depth in Delamere transact 2.

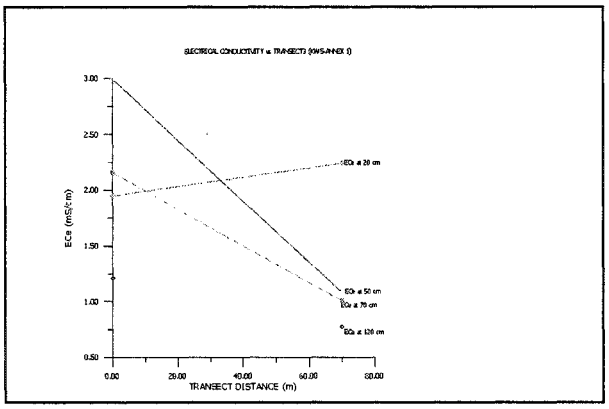
Appendix X

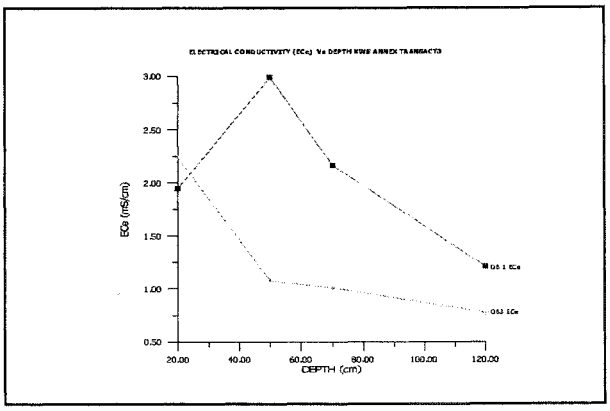
Electrical conductivity (ECe) of different transacts are presented below



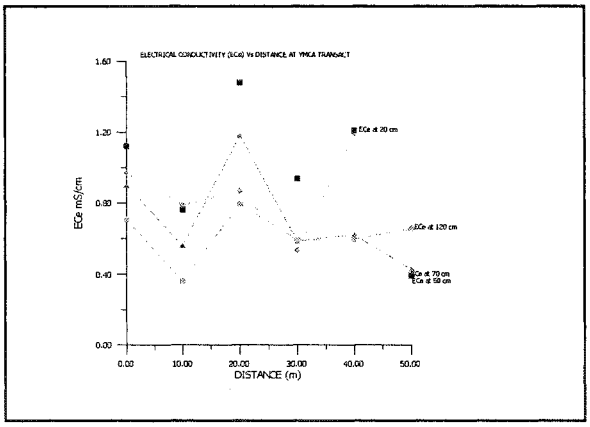


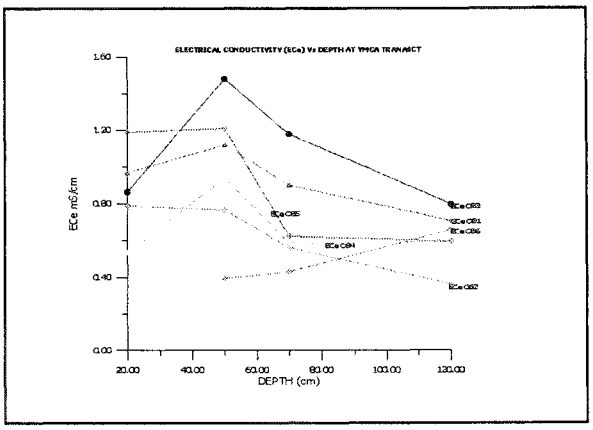
Graphs: Electrical conductivity (ECe) variations along and with depth in KWS annex transact 2.



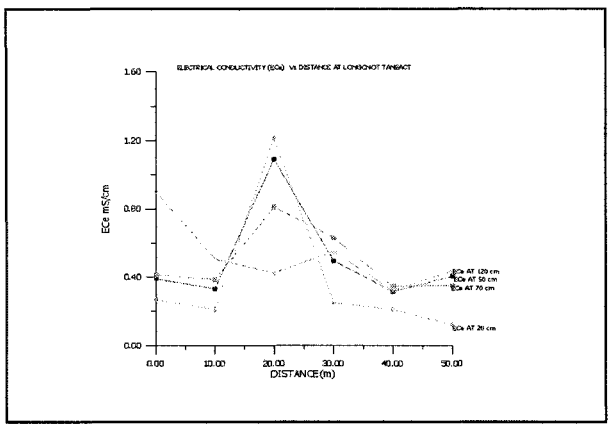


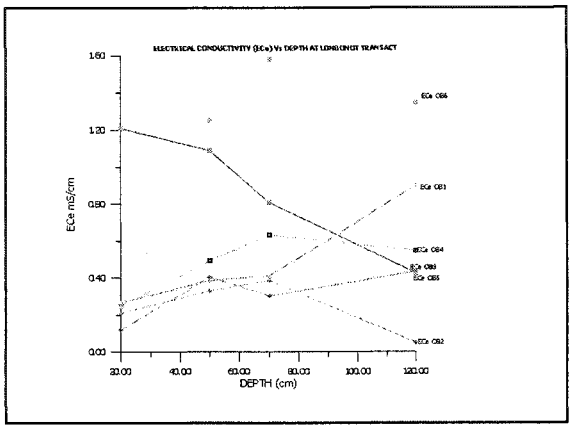
Graphs: Electrical conductivity (ECe) variations of along and with depth in KWS annex transact 3.



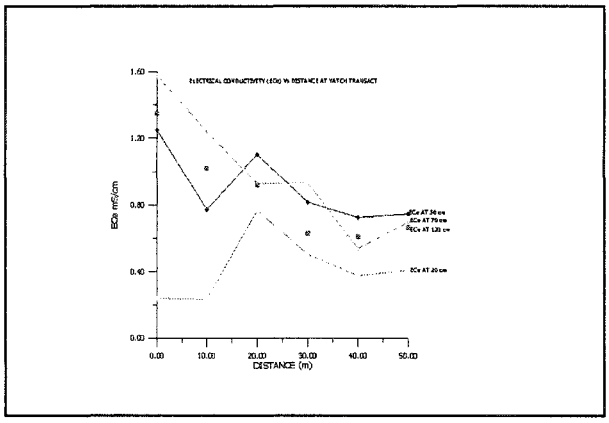


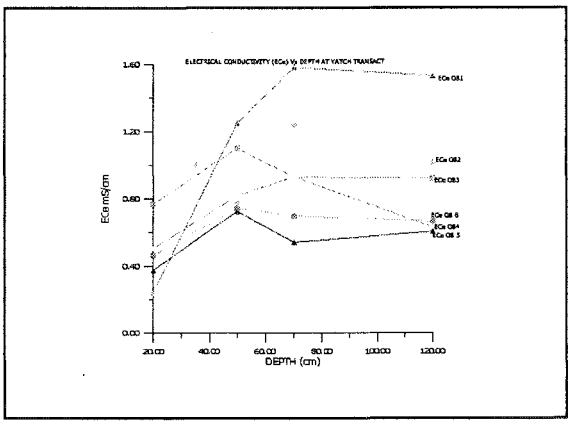
Graphs: Electrical conductivity (ECe) variations along and with depth in YMCA transact.



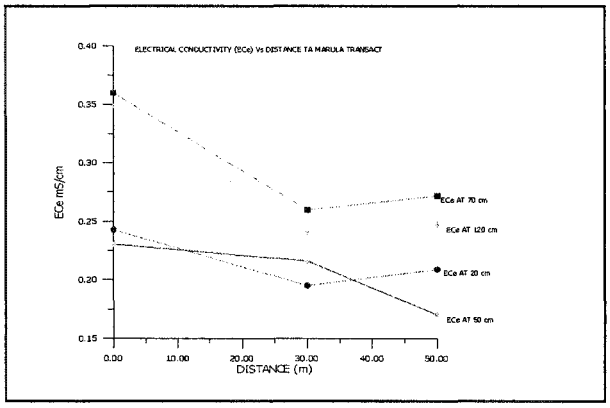


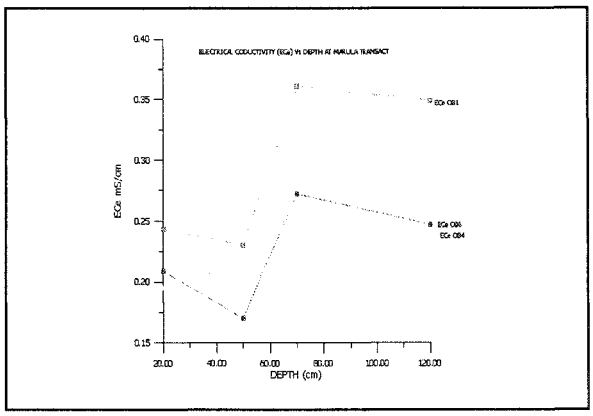
Graphs: Electrical conductivity (ECe) variations along and with depth in Longonot transact.



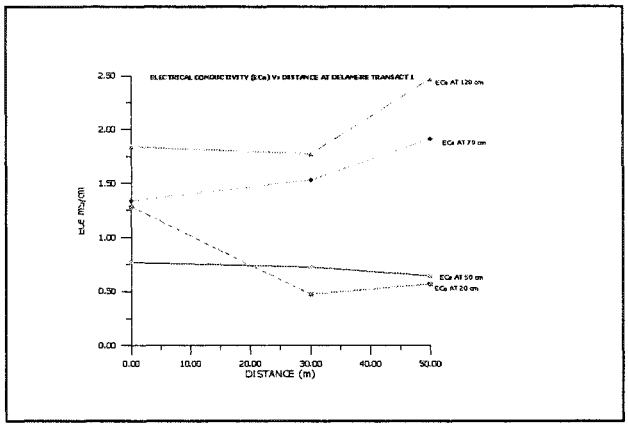


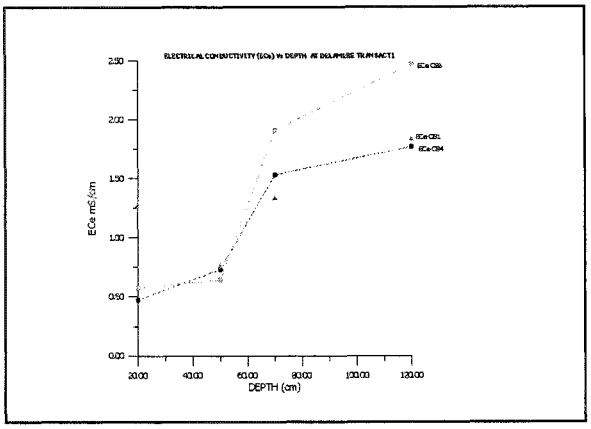
Graphs: Electrical conductivity (ECe) variations along and with depth in Yatch transact.



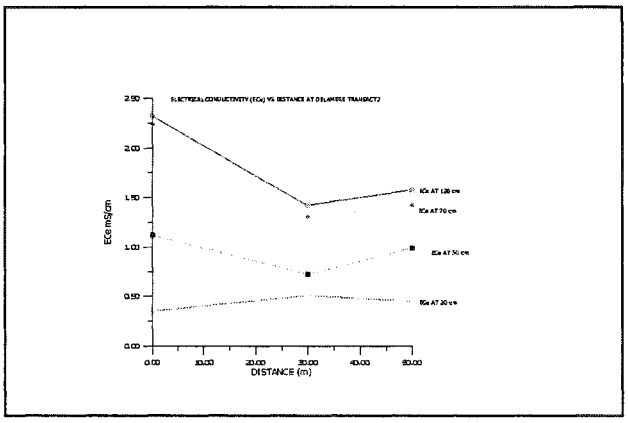


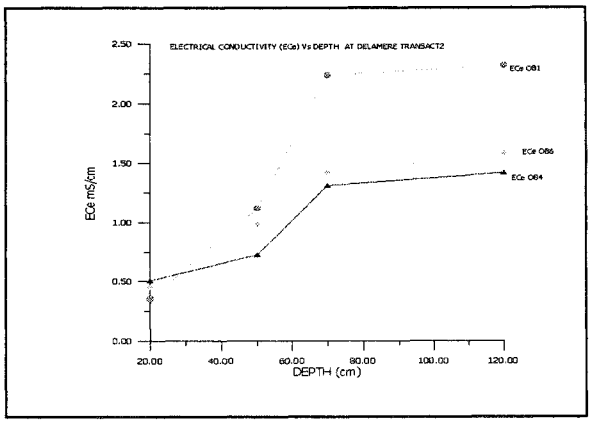
Graphs: Electrical conductivity variations (ECe) along and with depth in Marula transact.





Graphs: Electrical conductivity (ECe) variations along and with depth in Delamere transact 1.

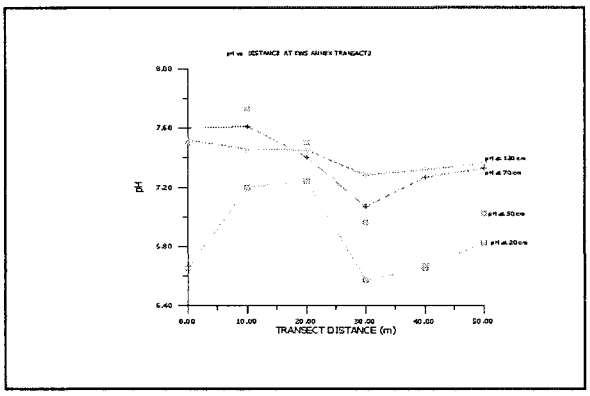


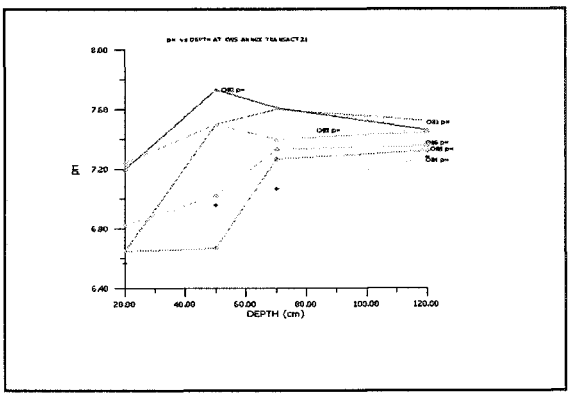


Graphs: Electrical conductivity (ECe) variations along and with depth in Delamere transact 2.

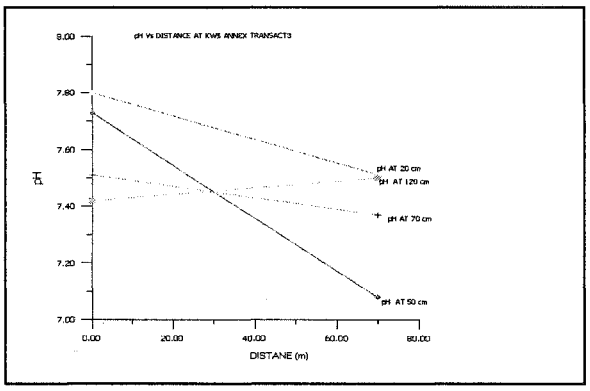
Appendix XI

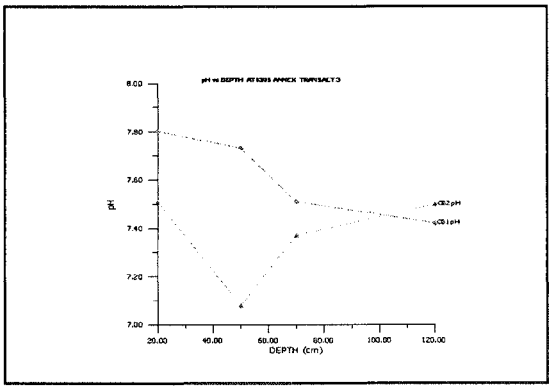
The pH of different transacts are presented below



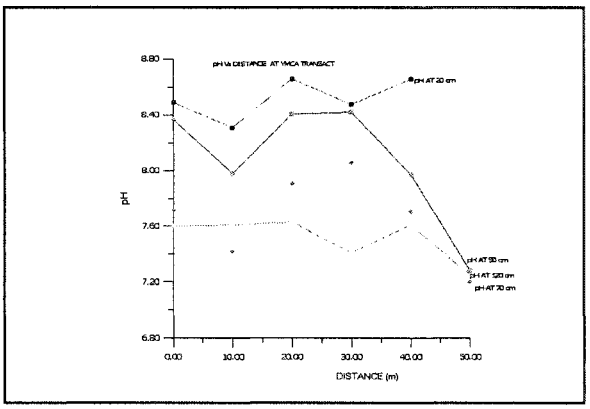


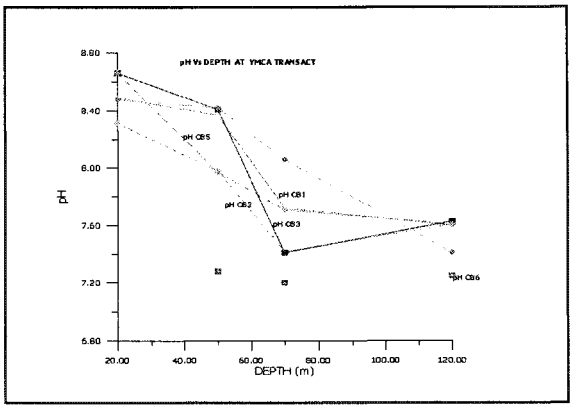
Graphs: pH variations along and with depth in KWS annex transact 2.



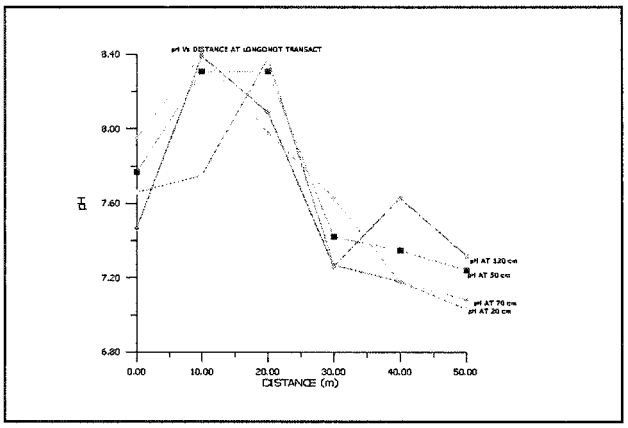


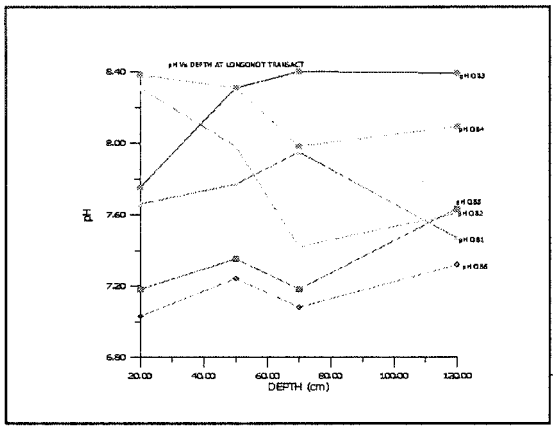
Graphs: pH variations along and with depth in KWS annex transact 3.



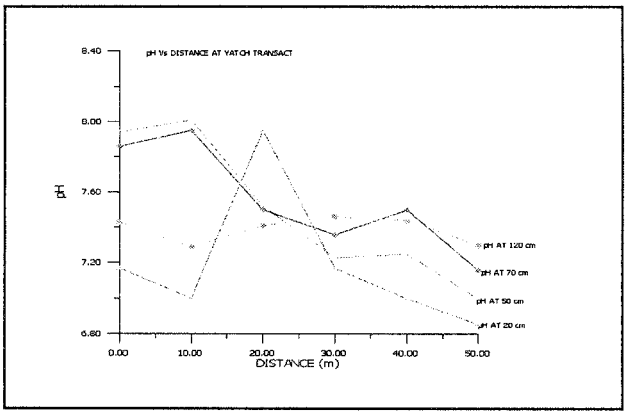


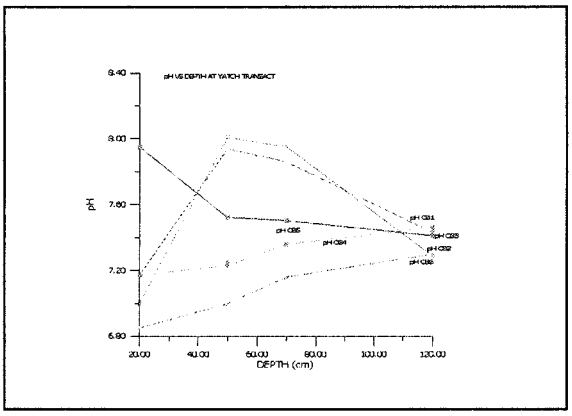
Graphs: pH variations long and with depth in YMCA transact.



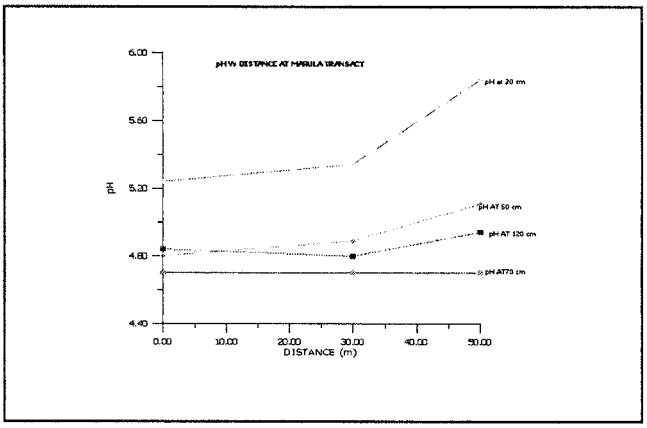


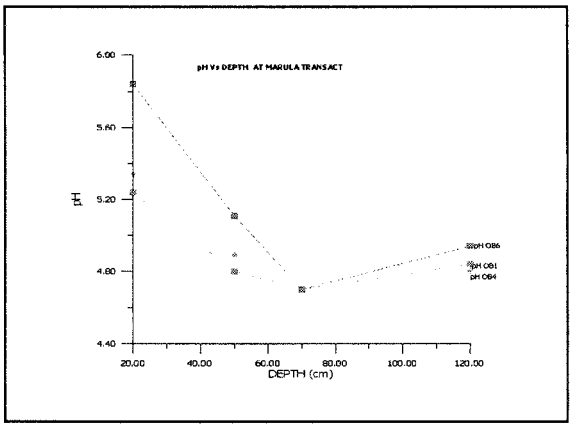
Graphs: pH variations along and with depth in Longonot transact.



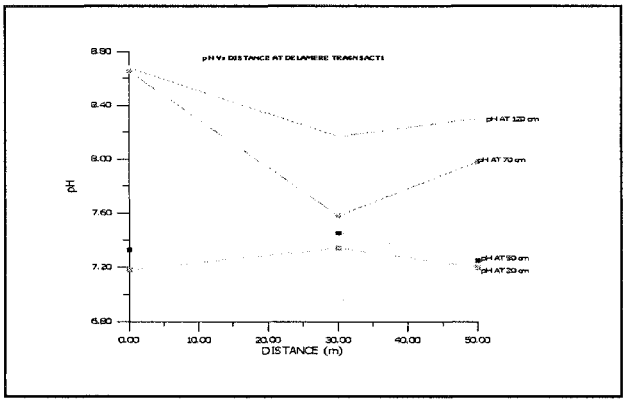


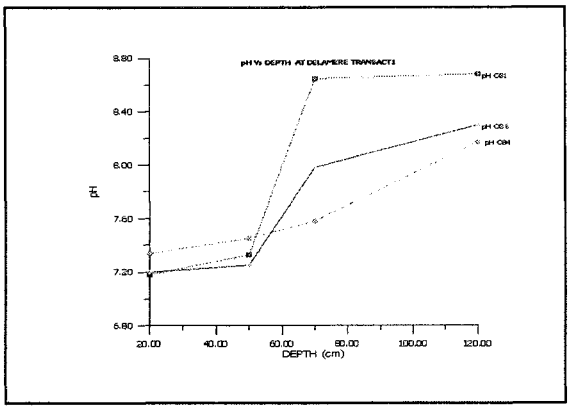
Graphs: pH variations along and with depth in Yatch club transact.



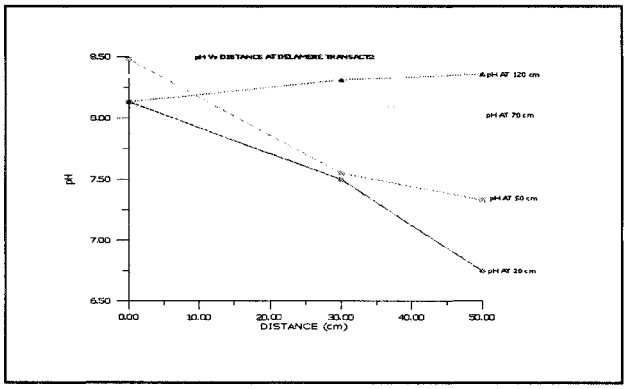


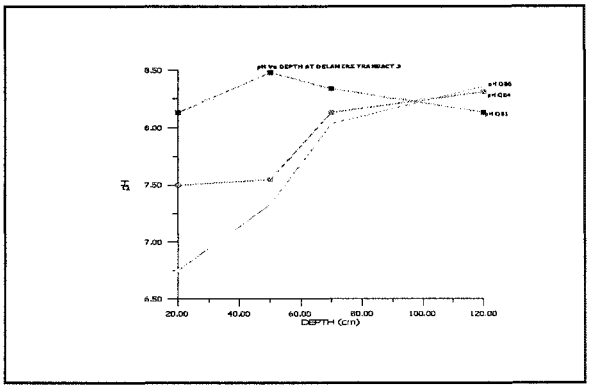
Graphs: pH variations along and with depth at Marula transact.





Graphs: pH variations along and with depth at Delamere transact 1.





Graphs: pH variations along and with transact at Delamere transact 2.

Appendix XII

Table. Analytical data of transact 2 of KWS annex sample area

Transact	Observation points	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/100g)	%OC
37M0213671	1a	20	232	6.65	0.387		
UTM9918200	1b	50	195	7.5	0.922	29.20	0.23
280^0 NW	1c	70	190	7.6	1.12		
	1d	120	185	7.52	1.06		
	2a	20	270	7.2	1.83		
	2b	50	254	7.73	1.21		
	2c	70	247	7.61	1.26		
	2d	120	244	7.46	0.835		
	3a	20	262	7.24	0.812		
	3b	50	248	7.5	1.04		
	3c	70	247	7.4	1.17		
	3d	120	240	7.45	1.08		
	4a	20	76	6.57	0.617		
	4b	50	114	6.96	0.902	18.60	0.25
	4c	70	128	7.07	0.94		
	4d	120	137	7.28	0.946		
	5a	20	-27	6.65	0.58		
	5b	50	82	6.67	0.838		
	5c	70	130	6.27	0.796		
	5d	120	165	7.32	0.831		
	6a	20	-46	6.82	0.745		
	6b	50	105	7.02	1.08	26.40	0.17
	6c	70	125	7.33	1.1		
	6d	120	149	7.36	0.94		

Table. Analytical data of transact 3 of KWS annex sample area

Transact	Observation points	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/100 g)	%OC
37M0213346	1a	20	-134	7.8	1.95		
UTM9918105	1b	50	-103	7.73	2.99	26.80	0.29
274^{0}NW	1c	70	20	7.51	2.16		
	1d	120	83	7.42	1.21		
	2a	20	-77	7.51	2.24		
	2b	50	-112	7.08	1.08	10.80	1.43
	2c	70	-67	7.37	1.01		
	2d	120	83	7.5	7.71		

Appendix XIII

Table. Analytical data of YMCA transact

Transact	Observation points	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/100)	%OC
37M0206295	1a	20	46	8.49	0.97		
UTM9908624	1b	50	133	8.37	1.12	14.20	0.26
300^0 NW	1c	70	124	7.72	0.9		
	1d	120	-46	7.6	0.707		
	2a	20	104	8.31	0.788		
	2b	50	117	7.98	0.766		
	2c	70	-46	7.42	0.56		
	2d	120	-82	7.61	0.363		
	3a	20	125	8.66	0.866		
	3b	50	114	8.41	1.48		
	3c	70	-27	7.91	1.18		
	3d	120	-24	7.63	0.795		
	4a	20	93	8.48	0.536		
	4b	50	118	8.42	0.94	8.80	0.40
	4c	70	109	8.06	0.587		
	4d	120	-92	7.41	0.595		
	5a	20	79	8.66	1.19		
	5b	50	-162	7.97	1.21		
	5c	70	26	7.71	0.621		
	5d	120	-91	7.61	0.596		
	6a	20	-	-	-		
	6b	50	-224	7.28	0.395	9.00	0.85
	6c	70	-175	7.2	0.43		
	6d	120	-197	7.25	0.658		

Appendix XIV

Table. Analytical data of Longonot Transact

Transact	Observation point	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/100g)	%OC
37M0209254	1a	20	101	7.66	0.266		
UTM9910663	1b	50	84	7.77	0.387	15.60	0.60
274^0 NW	1c	70	125	7.95	0.413		
	1d	120	-36	7.47	0.9		
	2a	20	138	7.75	0.21		
	2b	50	124	8.31	0.33		
	2c	70	137	8.4	0.386		
	2d	120	-157	839	0.507		
	3a	20	124	8.38	1.21		
	3b	50	120	8.31	1.09		
	3c	70	155	7.98	0.809		
	3d	120	175	8.09	0.424		
	4a	20	-125	7.24	0.248		
	4b	50	-12	7.42	0.495	13.80	0.13
	4c	70	-5	7.63	0.632		
	4d	120	81	7.26	0.547		
	5a	20	-153	7.18	0.211		
	5b	50	-204	7.35	0.315		
	5c	70	-62	7.18	0.345		
	5d	120	-20	7.63	0.324		
	6a	20	-184	7.03	0.119		
	6b	50	-124	7.24	0.404	14.00	0.17
	6c	70	-156	7.08	0.349		
	6d	120	-122	7.32	0.434		

Appendix XV

Table. Analytical data of Yacht transact

Transact	Observation point	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/ 100g)	%OC
37M02126614	1a	20	181	7.17	0.243		
UTM9914615	1b	50	175	7.94	1.25	15.20	0.52
330^0 NW	1c	70	144	7.86	1.58		
	1d	120	-70	7.43	1.35		
	2a	20	159	7	0.231		
	2b	50	146	8.01	0.773		
	2c	70	134	7.95	1.24		
	2d	120	42	7.29	1.02		
	3a	20	52	7.95	0.768		
	3b	50	107	7.52	1.1		
	3c	70	-16	7.5	0.93		
	3d	120	45	7.41	0.92		
	4a	20	-202	7.17	0.506		
	4b	50	-149	7.23	0.817	12.60	0.81
	4c	70	-36	7.36	0.932		
	4d	120	-24	7.46	0.63		
	5a	20	-243	7	0.375		
	5d	50	-180	7.25	0.725		
	5c	70	22	7.5	0.54		
	5d	120	30	7.44	0.607		
	6a	20	-243	6.85	0.461		
	6b	50	-67	7	0.749	18.80	0.80
	6c	70	52	7.16	0.698		
	6d	120	83	7.3	0.665		

Appendix XVI

Table. Analytical data of Marula transact

Transact	Observation point	Depth (cm)	Redox potential (mS)	pH	ECe (mS/cm)	CEC (meq/100g)	%OC
37M0206482	1a	20	306	5.24	0.243		
UTM9929480	1b	50	404	4.8	0.23	11.20	1.24
176^{0}SE	1c	70	412	4.7	0.361		
	1d	120	352	4.84	0.349		
	2a	20	313	5.34	0.195		
	2b	50	321	4.89	0.216	18.00	0.92
	2c	70	403	4.7	0.26		
	2d	120	375	4.8	0.241		
	3a	20	246	5.84	0.209		
	3b	50	352	5.11	0.17	14.80	1.16
	3c	70	402	4.7	0.272		
	3d	120	366	4.94	0.247		

Appendix XVII

Table. Analytical data transact 1 of Delamere sample area

Transact	Observation point	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/100g)	%OC
37M0210472	1a	20	-280	7.18	1.28		
UTM9920213	1b	50	-246	7.33	0.77	15.60	1.52
276^0 NW	1c	70	-10	8.65	1.34		
	1d	120	32	8.68	1.84		
	2a	20	-174	7.34	0.471		
	2b	50	-202	7.45	0.729	22.40	0.80
	2c	70	-133	7.58	1.53		
	2d	120	4	8.17	1.77		
	3a	20	-261	7.2	0.57		
	3b	50	-181	7.25	0.64	21.00	0.70
	3c	70	-2	7.98	1.91		
	3d	120	50	8.3	2.47		

Table. Analytical data transact -2 of Delamere sample area

Transact	Observation point	Depth (cm)	Redox potential (mV)	pH	ECe (mS/cm)	CEC (meq/100g)	%OC
37M210696	1a	20	122	8.13	0.355		
UTM9920255	1b	50	117	8.48	1.12	25.40	0.75
178^{0}SE	1c	70	107	8.34	2.24		
	1d	120	82	8.13	2.32		
	2a	20	73	7.5	0.508		
	2b	50	167	7.55	0.725	25.00	0.20
	2c	70	92	8.13	1.31		
	2d	120	125	8.31	1.42		
	3a	20	-230	6.75	0.45		
	3b	50	72	7.33	0.989	29.00	0.09
	3c	70	102	8.03	1.42		
	3d	120	97	8.36	1.58		

Appendix XVIII

Table. Exchangeable cation of the Wetland soils

(Sample area) (transact)	Observation point	Depth (cm)	Exchangeable cations Ca	Mg	K	Na
			---------- meq/ 100g----------			
KWS transact1	1b	50	30.0	4.80	2.92	5.45
	4b	50	33.1	5.09	3.72	3.15
	6b	50	27.3	4.0	2.35	3.65
KWS transact2	1b	50	19.40	3.79	2.72	3.45
	4b	50	25.20	4.06	3.14	1.85
	6d	50	26.7	4.69	2.92	1.95
KWS transact3	1b	50	16.20	2.37	12.32	24.95
	2b	50	17.50	2.38	5.52	4.95
YMCA transact	1b	50	8.60	0.50	3.72	0.45
	4b	50	27.10	1.88	6.52	7.45
	6b	50	8.80	0.16	3.32	2.22
Longonot transact	1b	50	41.70	0.42	2.72	1.65
	4b	50	16.40	0.53	2.32	1.70
	6b	50	11.00	1.08	3.34	1.75
Yatch transact	1b	50	10.60	2.22	4.92	7.45
	4b	50	15.60	2.49	4.92	3.00
	6b	50	26.50	3.25	3.32	3.25
Marula transact	1b	50	12.20	2.53	0.54	1.80
	4b	50	18.60	3.04	1.04	0.20
	6b	50	14.90	4.25	0.62	0.05
Delamere transact1	1b	50	29.30	3.63	4.32	3.15
	4b	50	34.90	4.38	4.14	3.65
	6b	50	22.90	3.89	3.54	6.95
Delamere transact 2	1b	50	37.60	4.99	2.32	7.45
	4b	50	40.90	9.10	7.12	8.45
	6b	50	17.0	2.72	3.52	2.76