AN ASSESSMENT OF THE SPATIAL AND TEMPORAL DISTRIBUTION OF A PAPYRUS SWAMP

The application of remote sensing, GIS, and a Decision Support System for the monitoring and management of the wetland vegetation of Lake Naivasha, Kenya.

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The Netherlands

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ERRATA

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iii	Last sentence	Mecerator	Mercator
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11	Paragraph 1	dependant	dependent
21	First paragraph	Naivaha	Naivasha
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44	Third paragraph	Paired comparison t-test	t-test
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53	Paragraph 1 (Shrubland change rate)	108 ha/yr	166.9 ha/yr
54	Paragraphs 2 and 3	Section 5.3	section 5.4
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for

My parents, Mr. and the late Mrs. Cecilia Rwashote and their grand children
Joan and Phyllis.

ABSTRACT

The wetlands at L. Naivasha are reputable for the existence of the papyrus swamp. The distribution and condition of the characteristic species *C. papyrus* plays an important role in the hydrological regime of the area and papyrus swamps act as silt traps and nutrient filters. They are also the habitat for numerous birds and animals. Losses in the surface area of papyrus swamps are therefore a direct threat to the communities depending on these papyrus swamps for their livelihood.
In the Management Plan of 1996, a serious decline in area of the papyrus swamp at Lake Naivasha was identified and the subsequent call for a monitoring programme on the distribution of the swamp was the justification for the present research.

Through the integration of Remote Sensing, GIS, and a Decision Support System, the spatial and temporal distribution of papyrus swamps has been assessed for the period 1967, 1984 and 1995. Three major processes were undertaken : land cover mapping, monitoring and risk modeling.

Since 1967, the papyrus swamp at Lake Naivasha has decreased with 2,607 ha, a loss of 71.4%. Most of the papyrus area (60%) was lost between 1967-1984. Between 1984-1995 the swamp reduced with 29%. Fluctuating lake water levels have a large impact on the spatial distribution of papyrus, but this process is reversible. Between 1967-1984 a large area (1959 ha) of the papyrus was inundated, while a decrease in lake water level in the period 1984-1995 resulted in an increase of 823 ha of papyrus. Dying papyrus stands will be mainly taken over by shrubland or grassland and finally woodland. Between 1967-1984 100.8 ha (2.8%) of papyrus was converted into agricultural fields and this increased with 387.5 ha (26.4%) between 1984-1995, an overall loss of 488 ha since 1967. So far, built-up area has no direct impact on the distribution of papyrus.

The impact of other land cover types on the distribution of the papyrus swamp was modeled based on two scenarios, one involving all the land cover types, and a scenario excluding open water. Three criteria were used: a papyrus risk index, based on distance of the land cover types to papyrus, the change rate for each land cover type, and the total change in area (ha) of papyrus. In scenario 1, when open water was included, the potential risk levels were found relatively high throughout the whole area, varying between medium to high. When open water was excluded (scenario 2), the potential risk to papyrus was found to be lower, ranging from low to medium and high.

In the study it was found that the papyrus swamp was also influenced by other factors like topography, ground water levels, and soil conditions, plus human activities such as grazing and burning. This was achieved by statistical inference.

Three proposed management measures were assessed. Under the present land use system papyrus is hardly protected. An area of 1673 ha was recommended for re-establishment of papyrus, mainly in the northern part.
Within the proposed buffer zone of 50 m from the papyrus fringe, an area of 254 ha, agricultural fields cover 35% and shrubland 55%. As both land cover types were found with high risk to papyrus, a more flexible buffer zone than 50m was recommended.
Though reclaiming of flooded land, intensive irrigated agriculture, and building of permanent structures below the 1906 lake level (1893.3 m contour) are discouraged in the Management Plan of 1996, agricultural fields and build up areas were found to cover 80.2% of the area, about 4,000 ha and 175 ha respectively.

Bemigisha J.R., 1998

ACRONYMS AND ABBREVIATIONS

AVHRR	Advanced Very High Resolution Radiometer
API	Aerial Photo Interpretation
ERS-1	European Radar Satellite
DEM	Digital Elevation Model
DEFINITE	A support system for Decisions on a Finite set of Alternatives (software)
DSS	Decision Support Systems
DRSDS	Department of Resource Surveys and Remote Sensing
GIS	Geographic Information Systems
GPS	Global Positioning System
HH	Horizontal transmit and horizontal return (radar polarization)
ILWIS	The Integrated Land and Water Information System (software)
JERS	Japanese Earth Resource Satellite
KWS	Kenya Wildlife Service
LNRAO	Lake Naivasha Riparian Owners Association
NOAA	National Oceanic and Atmospheric Administration
ISRIC	International Soil Reference Information Center
MAPCALC	Map calculation
MCE	Multi-criteria Evaluation
RADAR	Radio Detection and Ranging
RS	Remote Sensing
TM	Thematic Mapper (Landsat)
SAR	Synthetic Aperture Radar
UTM	Universal Transverse Macerator

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1. INTRODUCTION

There is growing concern in Tropical Africa and the world all over, about the rate at which wetland resources are degenerating such that identification and assessment of their distribution become crucial. Wetlands in Africa have been defined as *"areas of land that are permanently , seasonally or occasionally waterlogged with fresh , saline , brackish or marine waters including both natural and man made areas that support characteristic biota"* (Njuguna et al. 1996).
Lake Naivasha has captured both National and International recognition not only as a wetland *Ramsar site* [1] with a rich biodiversity, but also for fresh domestic water supply, support to intensive agricultural development, geothermal power generation, and tourism (LNROA, 1996).

The wetlands at L. Naivasha are reputable for the existence of a papyrus swamp. The distribution and condition of the characteristic species *C. papyrus* indicates the hydrological regime for a specific area and it is known to modify water quality (Roggeri, 1995). They are also the habitat for numerous birds and animals. Losses in the surface area of the papyrus swamp is therefore a direct threat to the communities depending on these swamps for their livelihood. The diverse ecological cause/effect relationships of Lake Naivasha are schematically presented in a problem tree in appendix 1a.

Monitoring the papyrus swamp area at Lake Naivasha has become significant due to a serious decline in its area, especially in the last ten years. A Presidential ban on the destruction of Papyrus, was made in 1987. However, Harper et al. (1995) indicated one major decline in 1987 from a former 12 Km^2 to only 2 Km^2. Johnson (1997) recorded a decrease of 10.6 % in two years, from 1987 to 1989.

The increasing awareness of the valuable resource the papyrus swamp, has opened avenues for improvements in the management and conservation through the promotion of awareness and policy guidelines on sustainable utilisation. However, lack of appropriate information for this purpose is one of the major limitations. Though a considerable amount of research is carried out relevant on the lake, much of the work has left management with yet numerous questions to answer. *If the lake is to be managed, research has to be guided into areas where results and data are needed in order to refine management planning*(John Goldson Associates, 1993).

In the Environment Impact study (John Goldson Associates, 1993) diverse information gaps were identified (pp. 57-59) including a monitoring program for crucial parameters in water, vegetation, flora, and fauna, and specifically for Papyrus maintenance (see also appendix 1b). The needs of a management plan and management body were brought forward.

The above mentioned need for a monitoring programme on the distribution of the papyrus swamp was the justification for the present research. An important aim of the research will therefore be to collect information that can help rationalise management planning by answering questions like "What is the present status of the papyrus swamp, and how much is lost in time ; what are the factors influencing the distribution, and where are the hot spots (areas undergoing extraordinary dynamic changes); and what is the implication of the status to conservation planning?"

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[1] A Ramsar site is a wetland designated for the Ramsar list of Wetlands 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 conservation and wise use of wetlands (Frazier, 1996).

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1.1   Conceptual framework

There is a special interrelationship between the papyrus swamp, the L. Naivasha waters and the human activities in the area because of the functional roles that the characteristic species *C.papyrus* plays in keeping a balance within the "fragile" ecosystem . The system is subject to natural fluctuating lake water levels on the one side, and to intensive human activities that exhibit pollution and lake water volume reductions due to extraction of water on the other site (Lake Naivasha Riparian Owners Association, 1996). Outlined below are the functions of the papyrus swamp in reference to Lake Naivasha..

1.1.1 Functions of the papyrus swamp

● *Indicator of hydrological regimes*: According to Thompson et al. (1978), *C.papyrus* has a restricted distribution and is mostly poorly developed when seasonal flood regimes consistently exceed 3-4 m in amplitude, and when localities are subject to flash flooding or very low water levels during dry seasons. The most extensive papyrus swamps are associated with large, shallow lake systems with slow response times during wet seasons. The distribution is largely associated with flooding duration, but in some cases it will form floating mats of up to 1.5m thick that are largely independent of water depth. There has been an established relation between water levels and conditions of Papyrus evidenced by the 1980 and 1987 lake level changes. When the lake level went down by 4m, reducing the volume of water by $550 \times 10^6 \, m^3$ the papyrus dried (John Goldson Associates, 1993).

● *Modification of water quality*: Papyrus swamps are buffers between terrestrial and aquatic ecosystems acting as silt traps and nutrient filters due to the role they play in the modification of water quality that passes through them by absorbing excess nutrients. The swamp influences the whole ecosystem through uptake of nutrients and sediments from the inflow rivers and subsequent slow release to the lake water as fine organic particulate matter and accumulation as peat (Gaudet 1997; Harper 1992).

The process counteracts the pollution from agricultural activities involving pesticide and fertiliser applications around L. Naivasha. In addition, the high population that has sprouted in the catchment compounds the problem. The use of disposal plastic sheeting, and human waste disposal from the developing labour camps and Naivasha town itself with poorly maintained sewage system, and the effluent that finds its way to the lake water contribute to lake water pollution. The water hyacinth is present though it has not exploded . This could still happen if the nutrient level and temperature of the lake rises (John Goldson Associates, 1993).

The papyrus swamp in the Northwest of L. Naivasha has been reported by Gaudet (1979) as having considerable effect on water quality, especially the littoral zone. It is said to filter and store nutrients therefore the explanation of the higher levels of nutrients in the rivers than in the lake. The freshness of L. Naivasha is attributed to the removal of the salts by the fringing swamps, in addition to the burial and deflation by underground seepage (Richardson and Richardson, (1972) cited by John Goldson Associates, (1993)).

● *Habitat for numerous animals and birds* : In the process of regulating nutrient flow and

recycling, papyrus swamps process an organic output at the expense of an inorganic nutrient input. The organic input serves 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 swamp are the most important aspect of nutrient relations between the swamp and other aquatic ecosystems. The swamps supply large amounts of fixed nitrogen to tropical lakes and rivers allowing an increase of animal and plant production at swamp edge. As such, the lake Naivasha wetlands 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 (John Goldson Associates, 1993).

1.1.2 The present management

The management of Lake Naivasha wetlands is instituted by three major frameworks:

a)   *The LNROA management plan of 1996* : In 1931, the land fringing lake Naivasha (riparian land) was granted by Government to the adjacent land owners to conserve as long as there was no permanent structure erected (John Goldson Associates, 1993). The land owners through the Lake Naivasha Riparian Owners Association have concerted efforts to direct their activities through a Management Plan of 1996. The major objective is to manage the existing human activities in the lake ecosystem through voluntary adopted sustainable wise use principles to ensure its conservation, where the importance of the wetlands is an important feature. For purposes of the management plan, the area has been divided into two regions:
- The lake zone which is an open water wetland and Riparian area around Lake Naivasha. The study focuses on this zone which covers about 30,000 ha.
- The catchment which is the drier and steeper region covering about 3,200 km sq.

Particular plans pertaining to wetlands conservation include:
  ⇒ Protection and where necessary re-establish the papyrus fringe around the lake and allow its natural growth.
  ⇒ Maintain and where necessary restore to a natural state a minimum of 50 metre buffer zone on the land side of the papyrus edge
  ⇒ To discourage the reclaiming of flooded land, intensive irrigated agriculture, and building of permanent structures below the 1906 lake level (6210' or 1893.3 m contour)
  ⇒ To research, monitor and gather information to support their program .The parameters relevant to the research that are considered for monitoring are:
    - area covered by *salvinia molesta*, water hyacinth, water lily and papyrus
    - land use, vegetation and soil erosion

There is a Trust to be established by LNROA that will provide an institutional framework for the management of the lake . The Trust will appoint a committee consisting of institutions that share the same interest in the catchment. They include: National Wetlands Standing committee of Government; Kenya Wildlife Service, International Union for Conservation of Nature, Kenya Power Company; Naivasha Municipal council, The District Environment Office, and Agriculture/Horticulture Government representation.

b)   *The Ramsar Convention 1971:* In 1995 the Lake Naivasha wetland was designated a Ramsar site. Frazier (1996) indicates that under Article 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. According to Article 3.2 the contracting party should advise the Convention Bureau of any change in the ecological character of a listed site. For this purpose the "Montereux Record" of Ramsar sites where changes in ecological character have occurred, are occurring, or are likely to occur was established as a mechanism to focus attention on sites that needed positive conservation or remedial action (Frazier, 1996).

c)   *The Kenyan Government :* In the prospect of the Ramsar convention and interest in sustainable resource management, the Kenyan Government has established a National Wetlands Standing Committee which is in the process of establishing a Wetlands Policy for the country. In the neighbouring country Uganda, where the policy is established the major objective is "to promote wetlands conservation in order to sustain their values for the present and future well being of the people"(Ministry of Natural Resources, 1995). Inventory and monitoring plus guidance to management planning are emphasized, and a national wetlands database is under establishment for this purpose.

1.1.3 Threats to Lake Naivasha's resources

Out of the general issues mentioned in the Management Plan (LNROA, 1996), the following key issues affecting the papyrus swamp were identified (see also figure 1.1):
- Expansion of (irrigated) agriculture within the Lake Zone and the whole catchment
- Decrease in lake water levels, due to:
    - ⇒ Out of basin water transfer from any river inflow, particularly the main river, the Malewa, resulting in a water deficit
    - ⇒ Water abstraction from the lake itself for domestic, industrial and agricultural use
- Water pollution and nutrient enrichment from increasing urban and agricultural activities, aggravated by reducing lake water levels.
- Potential of lake water to become more sodic in dry spells.

1.1.4 Specific problem

Inappropriate activities on the riparian land including construction of permanent buildings, drainage of land for cultivation, especially intensive irrigated agriculture, destruction of papyrus and conversion of the 50 m buffer zone behind the papyrus fringe.
Changes in the lake level will change the position and extent of the papyrus fringe and therefore the position of the 50 m buffer zone.
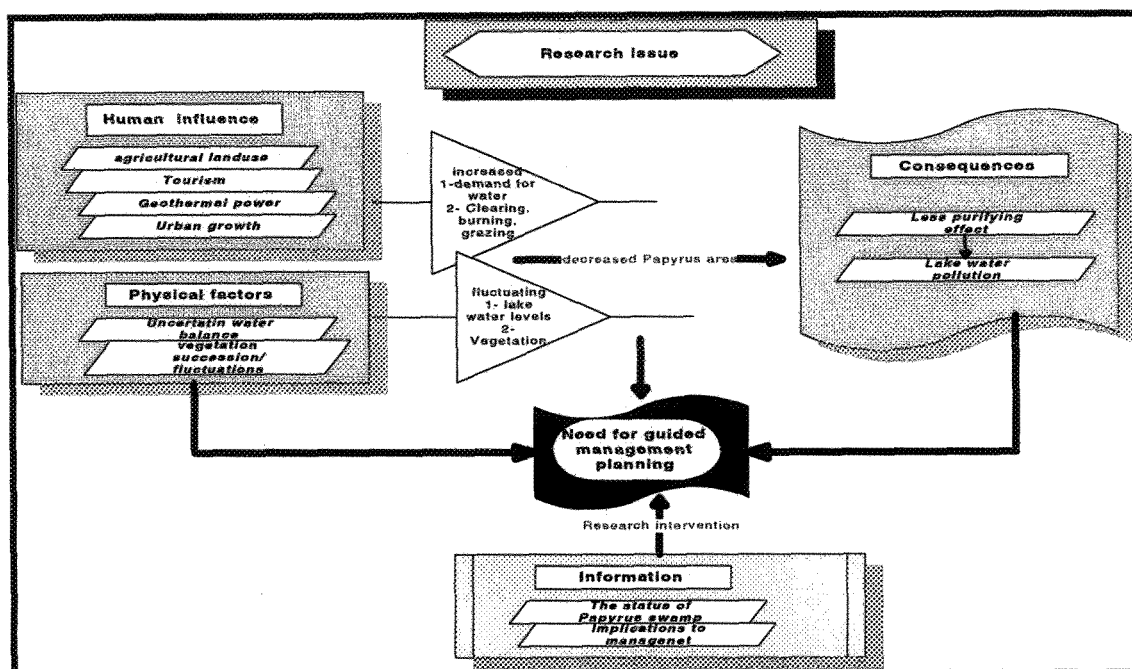
Figure 1.1 The Research issue

In summary, the presence of the fringe of Papyrus around the lake and the maintenance of the Malewa papyrus swamp is essential to the continued well being of the lake particularly the freshness of the water. Water, flora and fauna are in a continuing flax and it is important that research and monitoring continues on the lake in order that the ecosystem is fully understood (John Goldson Associates, 1993). Rational management interventions are the long term expectations of this research.

1.2   Research Hypotheses

1- The distribution of the papyrus swamp can be explained by the influence of the neighbouring   land cover types.
2- The variation in the influence is a function of the rate in which a land cover types changes, the overall conversion of papyrus by a particular land cover type, and the distance to the papyrus, for each individual land cover type.

1.3   Research objectives

Major Objective:
To monitor and assess the distribution of the papyrus swamp, using remote sensing, GIS and a decision support system.

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Specific objectives:

1- To establish the spatial and temporal distribution of the papyrus swamp.
2- To model the potential risk of the land cover types to the papyrus swamp area.
3- To assess other factors influencing the distribution of the papyrus swamp.
4- To assess if the present land use activities are in line with the papyrus conservation options prescribed in the LNROA plan of 1996.

1.4   Research questions

ad.1   What is the spatial and temporal distribution of the papyrus swamp for the period 1967-1995?
ad.2   What is the relative potential risk of the land cover types to the papyrus swamp area?
ad.3   What other factors can explain the distribution of papyrus?
ad.4   What is the status of papyrus in terms of preservation and re-establishment?
        What land use activities take place within a proposed 50m buffer zone from the papyrus swamp?
        Are the land use activities in the area below the 1906 lake level in harmony with the proposed management measure?

A monitoring process that integrates Remote Sensing, GIS, and a Decision Support Systems (DSS) will be applied in this study to capture the diverse capabilities of these systems in mapping, monitoring and modelling of potential risk areas and to assess the proposed papyrus swamp management options.
The research will be focused on a "direct" assessment based primarily on measuring the spatial and temporal distribution of the papyrus swamp (section 5.2). The "direct" assessment connote only onsite factor assessment (land cover types) provided in the form of land cover maps. Floating/ submergent vegetation is not considered because of the difficulty posed by drifting.
The identification of areas within the papyrus swamp that will have a high risk to be taken over by another land cover type will be described in section 5.3.
Also, an attempt was made in this research to explain the influence of other factors like water level, soil, and topography by statistical inference (section 5.4).
Whether the present land use activities are in line with the proposed management measures, will be presented and discussed in section 5.5.

2.   LITERATURE REVIEW

2.1   Introduction

The assessment and monitoring of the papyrus swamp of Lake Naivasha was designed and implemented with reference to diverse principles and methods, ideas and guidelines that exist in literature. Presented in this chapter are the subjects reviewed and their application in the study. They include: the typology of papyrus swamps; monitoring changes in wetlands vegetation ; the principle indicators for the study; land cover mapping ; explanatory factors for the distribution of papyrus swamp; the role of RS, GIS and DSS; integration of statistical inference; and database uncertainty .

2.2   The typology of the papyrus swamp

The typology of papyrus swamps in this study was defined for the purpose of assisting in the image interpretation. This was aimed at enabling land cover mapping with specific emphasis on the identification of papyrus swamps. The primary consideration was the working definition   of wetlands indicated in section 1.1 of the thesis. The general typology of wetlands has been given by Lillesand and Kiefer (1995) and could be used as reference as well.

The detailed definition by Njuguna et al. (1996) refer to swamps as wetlands with water above ground with emergent vegetation reaching at least one meter above the water surface. Wetlands in Kenya, as defined by the same author do not include deep lakes, fast flowing rivers and deep ocean rivers. The definition further suggests the "waterlogged" aspect referring to the saturation of soil or substrate with water (above or below ground level) for a period that is long enough to select for characteristic biota (animals, plants and organisms) that have adaptations to survival and growth in wetland conditions including water logged soils.

Rogerri (1995), established major criteria in the classification of wetlands vegetation as:
* the source of water and nutrients (geomorphologic units) and
* the ecology of the wetlands especially vegetation.
The wetlands of Naivasha have been studied and identified with the lake shore, characterised by floating or rooted vegetation which is dominated by C. papyrus species (e.g. Thompson et al. 1978; Gaudet 1977; Gaudet 1980; Harper et al.1995; Harper 1992).

The characteristic plant , C. papyrus is a predominantly tropical sedge. Njuguna (1982), describes it as the largest herbaceous perennial emergent macrophyte. Macrophytes are defined by Denny (1985) as "plants that grow in water or found in wet places or wetlands". These include swamps, marshes, and sometimes plants of flood plains due to their characteristic tolerance to flooding. In optimum conditions, C. Papyrus roots and rhizomes are often under water while its culm (stem) and umbel (inflorescence) emerge above the water surface. It can however be rooted in soil on dry land or float on water. The rhizome bears at any one time 4 to 8 leafless green culms with an average height of 5m, capped by brush like umbels of photosynthetic brachteoles. C. papyrus propagates by both seeds and rhizomes (Njuguna, 1982).

-The typology provided guidance on the following:
* selection of variables to assess versus the swamp characteristic species C.papyrus.

- the stratification of papyrus swamps in the land cover mapping process by integrating ancillary geographic data (topography).
- Discussion and conclusion on the results.

2.3   Monitoring wetlands vegetation

Monitoring is defined by Tomas Vives (1996), as *"the systematic collection of data or information over time in order to ascertain the extent of compliance with a predetermined standard or position.*

The ultimate aim of assessing or monitoring wetlands vegetation is to analyse and explain the changes in the ecological character that may occur in these ecosystems. Knapp (1974) indicates that studies on vegetation dynamics are increasing in importance since vegetation changes also affect the life of mankind directly. A framework for monitoring wetlands has been designed in *'MedWet'* (Tomas Vives, 1996). The framework stresses the identification of the variables (indicators) that indicate the state of the ecosystem varying from physical to biological. Special reference is given to biological indicators for their role as not only of indicative value but also intrinsic as well as of conservation and economic value. Similar attention is given to species that are either rare, indicator for environmental conditions or undesirable (Keddy, (1991) cited by Tomas Vives, 1996)). Monitoring can supply information which signals that change is imminent, is taking place, or has occurred based on time series demonstrating that change has occurred or not (Frazier, 1996).

A typical wetlands monitoring programme addresses the processes of ecological change and analyses the causes of adverse change. The processes include : Changes in Wetlands area; Changes in the water regime; Changes in the water quality; Unsustainable exploitation of wetland products; Introduction of alien species and Management , neglect and restoration.

According to Grillas (1996), monitoring of changes in the wetlands area primarily concerns habitat losses and habitat transformation issues , that is surface area of wetlands and per habitat for example achieved through repeated inventories, including mapping on the same sites every 5-10 years. This can be derived from a number of indicators at different levels. One of the indicators is the trends that is the rate of wetland loss or gains over time.

2.4   The principal indicators for the study

Grillas (1996) defines indicators as measurable variables for characteristics of an ecosystem and suggests the following possible indicators for changes in wetlands area: list of different habitats; habitat patchiness, surface area per habitat, fragmentation, river length and ; trends. The indicators chosen for this research were:
- the surface area per habitat
- trends

Surface area per habitat was selected hoping it could be translated into change rates of the surface area of papyrus swamp relative to other land cover types. Trend analysis reveals the rate of wetlands area loss or gain over time (Grillas, 1996). In this case, a temporal analysis was done for land cover maps for 1967, 1984, and 1995, and a change detection done at two year sets, 1967/1984, and 1984/1995. Potential risk levels for papyrus area were identified.

One of the objectives of this study was to establish the compliance to the papyrus conservation options of the 1996 LNROA plan. The indicator identified for this purpose was *land use* . Land

use can be surveyed through inventory, classification and mapping   (Groten et al. 1995). The function: *Landuse = f(Image Object , Cover)* if verified can be used for inference of land use by land cover (de Bie 1996; Fresco et al. 1994). This function was used in the study because the land use data collected could not be used for the analysis due to limited samples collected. The land cover map of 1995 was used.

2.5   Land cover mapping

It is after the identification of the landscape characteristics that monitoring of the target component in the system can be possible. In a spatial context, the process takes the form of land cover mapping. Groten (1995) refers to land cover as *"the different features covering the earth's surface, such as water, forest, other vegetation, bare rock, or sand, man made structures, etc."* Land cover mapping has proved very useful in vegetation monitoring studies. The AFRICOVER project by FAO (FAO, 1997) is directed to the establishment for the whole of Africa, a digital geo-referenced database on land cover to support among other things, vegetation monitoring and changes in biodiversity. Chandra and Surendra (1995) have used land cover mapping for the identification of hot spots or areas undergoing major transformations. From land cover mapping the monitoring of wetlands vegetation in Asian-Pacific region has been done (Yashuoka et al. 1993).

Land cover mapping was the process selected to prelude the monitoring and modelling processes of the current research.

2.6   Explanatory factors for the distribution of papyrus

From literature, numerous factors are shown to influence vegetation distribution. Factors that could influence the distribution of papyrus swamp such as water , relief, climate, soil, other vegetation and the role of human activity are explained as follows:

Ground water level : The depth to the ground water table is able to explain the dominance of typical wetlands vegetation (Kazda, 1995). In this research, the level at which water was intercepted while auguring was recorded and assessed versus *C.papyrus* attributes.

Relief : Wetlands vegetation is typically identified by elevation gradient. Roggeri (1995) has included geomorphology in the typology of papyrus swamps, while de Leeuw (1992); and Van der Valk and Welling (1988) associated salt marshes with the tidal flood that is determined by the elevation. In this research, the factor of relief is translated into topography based on slope steepness in percentage using the FAO gudelines (FAO & ISRIC, 1990) as follows:

Flat	**0 - 0.2% slope**
Almost flat	**0.5 - 2%**
Gently undulating	**2 - 5%**
Undulating	**5 - 0%**
Rolling	**10 - 15%**
Hilly	**15 - 30%**
Steeply dissected	**> 30% moderate range of elevation**
Mountainous	**> 30% great range of elevation (>300m).**

Climate: All wetlands have a seasonal abundance of water that may come from direct precipitation or sometimes indirectly characterized by over bank flooding or surface water runoff (Lillesand and Kiefer, 1994). On the other hand, water uptake of most tropical warmer countries is found to be reduced at $10°$ - $15°C$ and suspended at below $5°C$, while plant germination optimum temperature ranges from - 15 to 30 $°$ C (Larcher , 1980). This indicates that an interaction of the precipitation and temperature, if not balanced may impair the vital functions and limit the distribution of a species. Local influences identified by Larcher (1980) include: terrain, evaporation, radiation, and micro-organisms.

At lake Naivasha, the climatic influence on the lake is manifested in the lake levels which again influence the succession along the topography gradient (Gaudet, 1977).

Water inundation /flooding: Changes in water level effect change in the position and extent of wetlands vegetation (Van der Valk and Welling,1988). At lake Naivasha, Guadet (1977) studied the influence of the water level on the lake shore vegetation based on draw-down and flooding regimes with its effects on the primary production of papyrus. It was found that the production of bands of papyrus swamp along the lake edge was correlated with the larger cycles of drying and flooding which occur on the lake. In an experiment on the effect of flooding, papyrus seedling survival was found to be higher on wet mud than inundated area. The same was with cumulative growth (Gaudet, 1977). Appendix 7 gives more information.

Heinrich (1971) has indicated that the zonation of the swamp vegetation near Entebbe in Uganda is related to lake Victoria water levels (Lind and Visser (1992)cited by Heinrich (1971)). In the study of the dynamics of salt marsh vegetation de Leeuw (1992) found that the marsh displayed a zonation that depended on the degree of tidal flooding, among other factors and concluded that salt marsh vegetation would be sensitive to changes in tidal inundation.

Vegetation fluctuation and/or succession: Every year is peculiar in meteorological, hydrological and other conditions, important for plant growth, and as a consequence the changes in phytocoenoses occur (Rabotnov, 1974) . Major (1974) gives an account of the kinds of changes in phytoceonoces as corresponding to time dimensions as follows:
• tens of years to several tens: changes based on weather cycles leading to changes in productivity, seed supply, cover etc. of annuals to changes in species vitality with age.
• several to hundreds of years where the changes are characterised by replacement cycles within the individual community and changes leading to development of a new community.

In the case of zonation, historical aspects in the coenocline development is related to earmarked events that have to occur in a particular sequence, and at a specific time and place, before a species become established along a gradient (Van der Valk and Welling, 1988). The study of Gaudet (1977) gives an account of primary succession on the wet mud at the lake edge of Naivasha which was related to the drop in the lake level referred to as "natural drawdown" (Appendix 8). Gaudet (1977) however mentions other factors important in the succession such as the soils, seed viability, growth, and grazing.

In this study, through mapping and risk assessment it was hoped it would be possible to draw suggestive conclusions on the fluctuation/succession that could be influencing papyrus swamp distribution.

Lake Water abstraction: The abstraction of water from the lake may insinuate a reduction in the lake level if done at higher levels than replenishment . It has been reported that the economic activities dependant on lake Naivasha such as irrigated agricultural farms and urban service acutely threaten the lake especially in prolonged dry seasons (LNROA, 1996).

Diversion of River water : River water can be an important source of recharge into lakes and other wetland places, thus its diversion can contribute to reducing of lake water volume. The planned diversion of Malewa and Turasha rivers for Greater Nakuru Water supply has been predicted as a potential disaster to lake Naivasha (LN ROA (1996); John Goldson Associates (1993)).

 To analyse this factor would need an integration of an indirect or off-site study. It was not done in this research. The same was with abstraction.

Soil characteristics: These include substrate type and condition; drainage, depth, pH, Salinity, and nutrients.
Substrate type and condition: Different substrate support different species. At lake Naivasha, the volcanic sands support only a small number of deep rooted plants, while the mud and sludge of the Hydrosoils and papyrus mud are characterized by *papyrus spp*. Substrate conditions have been found to influence *Cyprus spp* cover by Gaudet (1977). The condition referred to wetness which was based on the flood regime. The regime corresponded to dry, beginning of flood, and flood condition, within which papyrus cover showed variation.

Soil drainage: Drainage is related to soil water capacity. Fine grained soils store more water than coarse grained soils (Larcher, 1980). Excessive soil moisture may have an indirect effect through reduction of aeration while the reverse may hold. Different species have evolved different tolerances to this phenomena, and therefore variability in the distribution (Kellman, 1975).

In this research the FAO guidelines (FAO & ISRIC,1990), were used for drainage description which is inferred from texture , mottling, color (gley features), and topographic position. A soil sample is described as very poorly drained if characterized by very shallow water table, at depressed site (Flat topography), if mottled and if the color 'value' is >3, and the 'croma' < 2. On the other hand, a soil sample is described as excessively drained if without mottles, is located on undulating - steep slope and if sandy textured. If samples surpass the criteria the guideline recommend intermediate classes .

Soil depth: Some plants are sensitive to soil depth (Jalal, 1997).In the current study the FAO guideline (FAO & ISRIC,1990) was used. By the guideline, general effective soil depth classes are:

Very shallow	**<30 cm**
Shallow	**30- 50**
Moderately deep	**50- 100**
Deep	**100-500**
Very deep	**>150**

Soil pH: pH is important for plant nutrition. This is the concentration of hydrogen ions in the soil solution and at specific levels for different plants, the pH can be toxic (Larcher, 1980). At below pH 3 and above pH 9, the protoplasm of the root cells of most vascular plants is severely damaged (Larcher, 1980) . For *C. Papyrus*, Heinrich (1971) has indicated a threshold of pH 5.5 to 6.4.

Salinity/sodicity: Soils with high sodium levels are referred to as sodic soils, while saline soils occur where the supply of salts, exceeds their removal for example by leaching or flooding (London, 1991). Excessive salts hinder crop growth not only by toxicity effects but by reducing water availability through osmotic pressure and sometimes nutrient uptake (London, 1991). At Lake Naivasha, Guadet (1977) indicated an effect of salinity to papyrus growth. According to London (1991), soil electric conductivity (EC) measurements can be used as indicators of the total quantities of soluble salts in the soil (table 2.1)

Table 2.1   The USDA classification of the salt affected soils

Soil salinity/sodicity	$Ec_{e\,(ms}\,m^{-1}$	pH usually observed
Saline soils	>4	< 8.5
Saline - sodic	>4	<8.5
Sodic soils	<4	>8.5

Source: London (1991)

• *Soil nutrients*: Thompson et al.(1978) have studied the distribution of papyrus swamp at Naivasha considering two major soil nutrients, phosphorous and Nitrogen. These two nutrients influence productivity of vegetation because they are involved in the metabolic machinery of plant cells (Lutttge, 1997). Gaudet (1977) added cations (potassium, sodium, calcium & magnesium) plus total iron and manganese as important for papyrus swamps growth.

In the current study, the soil drainage and depth were sampled and grouped for analysis based on the FAO guidelines (FAO & ISRIC,1990). The pH sampling was not possible due to lack of equipment, and EC sampling failed because of poor calibration.

Clearing for cultivation : Clearing of land for cultivation is both directly and indirectly related to habitat transformation. Mannion (1995), attributes high rates of loss of biodiversity and natural habitat in low latitudes (tropics and subtropics) to agricultural expansion which is related to land tenure, rapid population growth and resettlement policies. The land tenure issue is related to economic factors through the encouragement of foreign investments to boost export earnings (Mannion,1995). The investments in combination with the ready markets in the developing countries have led to massive expansion of cattle ranching and horticulture. This is happening in Naivasha (John Goldson Associates (1993); Stuttard et al. 1995).

Monitoring surface area cultivated is one of the constituents of trend analysis as an indicator to wetlands vegetation loss or gain (Grillas,1996). In the current research loss and gains to papyrus swamp by agricultural fields are measured by area per habitat and trends through land cover mapping and monitoring.

Livestock grazing: Wetlands vegetation are subject to direct disruption of habitat structure and reduced plant productivity if intensively grazed by livestock. Hippo and cattle graze on the young papyrus at Naivasha (Gaudet, 1977). Grillas (1996) has identified the following indicators for grazing pressure :
• numbers of animals present on site
• grazing calendar by the expression of animal -days for a month or season.
• amount of supplementary fodder which is evidence that the number of animals is too large for the present forage.
• number of animals seen along a line transect or counting along fixed transects

- Counts of dropping density or dropping accumulation
- spatial distribution of grazers. This is related to selective feeding for example preferred land scapes and species.

The impact of grazing on vegetation can be evaluated from measurements of the vegetation structure (species composition, height, and total cover) and others include percentage of bare ground (Grillas, 1996). In this study, the factor of grazing was based on absence or presence from signs: trampling, droppings, and presence of animals on site and evaluated against the papyrus attributes as ground cover % , height, inflorescence cover and culm diameter

Burning: Kruger (1984), indicates that all vegetation attributes ; pattern, biomass, cover, height, species composition , and the relative proportion of woody to herbaceous species are more or less sensitive to fire regime and intensity. Kruger (1984) found that fire intensity influenced pyric succession while the season in which fire occurred affected subsequent structure of vegetation because of its interactions with plant phonology, and post fire plant survival plus reproduction. He concluded that the more frequent the fire, the greater the herbaceous component and the less frequent the fire, the more abundant the woody component.

There is however no general principles to explain vegetation response to fire. This is because vegetation community diversity changes with succession and fire regime response varies across different biomes and across specific species (Kruger, 1984). Contrary to the effects outlined, Kruger (1984) has noted that for some vegetation types, species richness increases with fire frequency. Luttge (1997) holds the same view. However, Luttge (1997) again indicate that fire may lead to losses especially of Nitrogen in the form of volatile oxides mostly from vegetation (Luttge, (1997).

For papyrus species, the inflorescence is the photosynthetic tissue of a mature plant and with the disturbed structure, light interception may be limited, therefore primary production reduced. In the current research the effect of fire on papyrus species was assessed based on absence or presence of burning (signs like ashes, and scars).

2.7   The role of Remote Sensing , GIS and Decision Support Systems

Remote sensing (RS)
Vegetation mapping and analysis will continue to depend on RS systems because of their spectral characteristics that enable discernment of diverse features. Lillesand and Kiefer (1994) have provided an account of the role chlorophyll absorption plays in the application dwelling on the energy absorption in the different wavelength bands. At about 0.45 and 0.67 μm, and towards the near infrared portion of the spectrum (about 0.7 μm), the reflectance of healthy vegetation increases dramatically. Plant reflectance in the range 0.7 to 1.3 μm, results primarily from the internal structure of plant leaves and the variability of the structure between plant species permits better differentiation (Lillesand and Kiefer, 1994).

RS applications in wetlands vegetation studies indicate authors' preferences to specific imagery based on varying spectral as well as spatial characteristics. For Grillas (1996); Rogerri (1995); Johnson (1997) ; and Kellman (1975) , infrared aerial photographs appear to be the most accurate tool for wetlands.

Another author, Travaglia (1997) has used the ERS Synthetic Aperture Radar(SAR) images in monitoring of the seasonal changes of the wetland areas of the lake Bangwelu system in Zambia and compared the capability with the NOAAH AVHRR. His finding was that the two are complimentary to each other with the following advantages for SAR:

● It could be used to define differences and interpret areas of changing vegetation and other land cover types within a wetland system at resolution of 12.5 m resolution.

● the ability to obtain information despite weather conditions, cloud or rain.

On the other hand the NOAA AVHRR had the following advantages:

● thermal inertia approach which is effective in monitoring wetland system

● could give an overall idea, given that only one image is needed for a small area

In their argument for RADAR imagery for wetlands monitoring, Buchroithner and Granica (1995) indicate that the SAR imagery has demonstrated its capability in locating boundaries of vegetated wetlands and coastal wetland regimes more reliably than Infrared sensors Preference has been made of the X-band HH (like polarization) for the SURSAT project in Manitoba and Saskatchewan involved with marsh land delineation (Buchroithner and Granica, 1995).

Yasuoka et al. (1993) used NOAA and AVHRR for a global/continental level scale and LANDSAT TM, SPOT HRV, MOS MESSR, J-ERS SAR , and OPS, ERS-1 SAR for specific wetlands (local scale) on the basis that a model could be formulated to relate the low spatial resolution of the former group to the higher spatial resolution of the later. The integration was very useful in fire monitoring especially using TM, and monitoring general land cover conditions including soil moisture by J-ERS and ERS SAR.

Lillesand and Kiefer (1994) recommend the use of color films in aerial photography as having more advantages over the panchromatic film because the human eye can discriminate many more shades of color than it can tones of gray, therefore better interpretation results. Color infrared aerial photographs have been used in the classification and inventory of wetlands in the southern Appalachian states (USA), and the status and trends have been established (Hefner and Storrs, 1994). Color infrared photographs at a scale of 1: 58,000 permits the delineation of wetlands as small as 0.5 hectares and linear wetlands as narrow as 8 meters (Hefner and Storrs, 1994).

Capabilities of remote sensed systems in vegetation science and other applications are advancing. A few examples can been cited (e.g Lillesand and Kiefer 1994 ; Guyot et al. 1992) especially the *Imaging spectrometry or hyperspectral scanner* : These are instruments that acquire multispectral images in many, very narrow, contiguous spectral bands through out the visible, near-IR and mid-IR portions of the spectrum .The systems can collect 200 or more channels of data and some have been identified with the following advantages:

● construction of an effectively continuos reflectance spectrum for every pixel in the scene

● discrimination among earth surface features that have diagnostic absorption and reflection characteristics over narrow wavelengths intervals which are often lost in the relatively coarse band widths of the conventional multispectral scanner.

● automatic in-flight logging of GPS data and the image data to facilitate GIS compatibility Systems like the Airborne Imaging spectrometer(AIS), and the Visible -Infrared Imaging Spectrometer (AVIRIS) have been applied in vegetation studies like in the multitemporal analysis of the Calfornia Live Oak (Lillesand and Kiefer, 1994).

The tremendous support that Remote sensing has rendered to vegetation science and specifically to wetlands vegetation monitoring should however not avert our acknowledgment for the supportive data ancillary data and techniques like ground surveys and experiments. Roggeri (1995); and Hefner and Storrs (1994) , support the argument that the tools are complimentary rather than adversaries.

It can be seen that an evaluation is needed for selecting the right imagery for example images that fit the spatial and temporal scale. Based on availability, temporal RS imagery (Aerial photographs (panchromatic) of 1967 and 1984 plus a TM satellite imagery of 1995) were used for the study.

Geographic Information Systems (GIS)

A GIS technique is particularly suitable for comprehensive storage of data at different geographical scales and permits cross analysis of data especially involving time series analysis and spatial statistics (Cluis, (1992) cited by Grillas (1996)). GIS can provide not only important information on vegetation patterns in time, but also information on the spatial variation of management variables themselves in relation to land attributes and management decisions (Miller, (1994) cited by Verweij, (1995)). GIS has been applied in wetlands inventory, and monitoring (e.g Yasuoka et al. 1993; Johnson 1977 ; Travaglia 1997)

The current study was designed based on the mapping, monitoring and modelling, as well as assessing the implications of the status to management. Diverse data from aerospace, topographic, and functional relations based on spatial analysis, had to be integrated. A GIS was used in all the processes.

However despite the proliferation of GIS software systems and the surge of public interest in the application of the system to resolve real world problems, the technology is commonly seen as complex, inaccessible and alienating to decision makers (Eastman et al. 1995). Neither can the technology suffice for the suggested papyrus distribution model without the support of RS and DSS.

Decision Support Systems (DSS)

A Decision Support System is an interactive , flexible and adaptable Computer Based Information System, (CBIS) specially developed for supporting the solution of a particular management problem (Sharifi, 1996). Some of the capabilities of DSSs are :
- utilisation of various data that involve one or more criteria[2] ,
- provides easy user interface
  allows for the decision maker's own insight,
- utilises models
- DSS is built by an iterative process therefore supporting decision making at all levels.

DSS applications have in the past been dominated by the sociological and economic oriented problem evaluations. The emphasis of the pre- 1990 authors like Voogd (1983) was focused on urban and regional planning. The trend to ecological problem solving has picked up in the 1990s. Some systems have been specifically designed for wetlands management. Examples include the

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[2] The basis for a decision that can be measured and evaluated or evidence upon which a decision is based (Eastman, 1995).

WETLAND-USE by Oellemann et al .(undated) for analysing grazing versus wetlands management practices in South Africa. Osmond et al. (undated) have outlined the application of DSS in the integration and Use of Wetlands and riparian areas in the USA.

Developments are currently towards spatial DSSs (e.g Eastman et al.1995). The systems integrate DSS and GIS with an advantage that both the modelling capability in the DSS and the spatial visualization in a GIS are harnessed. Meijerink et al. (1993) integrated an erosion-sedimentation hazard assessment model with a decision rule[3] base in a GIS to assess the extent of environmental degradation in a catchment. An integration of a DSS and GIS have been used to model the grasslands reduction due to bush encroachment (Patrono and Oriolo (1995), cited by Patrono 1995)). This model is used as reference in the current study. Appendix 12 gives more information on how the model works.

Multicriteria Evaluation (MCE) in DSS: The actual process of applying the decision rule is called evaluation (Eastman et al. 1995). In order to meet a specific objective, it is frequently a case that several criteria will need to be evaluated, thus the inception of Multicriteria Evaluation methods. The methods serve to investigate a number of choice possibilities in the light of multiple criteria and conflicting priorities (Voogd, 1983). MCE s are recommend for planning based on their flexibility and the following functions:
- Analytical - for example an analysis of the spatial system.
- Selection - selection of options from a pre defined set of alternative options.
- Accountability - accountability for a proposed line of action.
- Testing - testing the likely appropriateness of a certain policy.

According to Eastman et al. (1995) two most common procedures for MCE are:
- weighted linear combination
- Concordance -discordance analysis.

Unfortunately, concordance-discordance analysis is computationally impractical when a large number of alternatives is present such as with raster data in which each pixel is an alternative (Eastman et al. 1995).

In the weighted linear combination, each factor is multiplied by a weight and then summed up to arrive at a final suitability index, while in the concordance-discordance, each pair of alternatives is analyzed for the degree to which one outranks the other on the specified criteria. Janssen and Herwijnen (1994) outline the following methods: Weighted summation, Electre, Regime, Expected value, and Evamix. The selection of the method depends on:
- the characteristics of the problem for example the purpose of the study, the quality of available data, and the time available for analysis.
- The features of the method for example the assumptions, the nature of the out put, the required measurement, transparency, and amount of calculation required.

The Regime method which is based on concordance-discordance was used in the current study to generate ranks for the non spatial criteria. The weighted summation (based on weighted linear combination) was used for the final model that included both the spatial and the non spatial criteria. The grassland reduction / bush encroachment model (Patrono and Oriolo (1995), cited by

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[3] The procedure by which criteria are combined to arrive at a particular evaluation and by which evaluations are compared and acted upon (Eastman et al. 1995).

Patrono (1997)) which is based on the *weighted summation* MCA , was used as reference because of the possible spatial application.

The weighted summation: The assumptions by Voogd (1983 are :
● the criterion weights can be determined on a quantitative measurement scale;
● the effective scores are determined on a ratio scale,
● the aggregation of the information takes place by addition.
The mathematical expression for the method is given in equation 4.8 (chapter 4).
In the DEFINITE software, (Janssen and Herwijnen, 1994) the method generates a ranking of alternatives. All effects scores are standardized, an appraisal score is calculated for each alternative by first multiplying each standardized effect score by its appropriate weight followed by summing the weighted scores of all effects. Its limitation is that it is difficult to find quantitative weights which reflect the relative importance of the various units of criterion scores (Voogd, 1983).

Regime method : The assumption is that it is sufficient to order the effects from most to least important and the method is related to ordinal generalization of pairwise comparison (concordance) analysis (Sharifi, 1997) It uses a random generator for each pair of alternatives to estimate the probability that one alternative ranks above the other (Janssen and Herwijnen, 1994). The mathematical expression is given in chapter 4 (Equation 4.6).
The output is the ranking of alternatives. The advantage is that both qualitative and quantitative scores can be analyzed.

Karatunga (1997) has outlined the basic principle of the MCE method and the order followed in the decision making process which are executed as :
1. generation of alternatives or choice alternatives
2. definition of criteria
3. construction of an evaluation matrix. This is sometimes called a decision table. Its elements reflect the characteristics of a given set of choice possibilities that are determined by means of a given set of criteria;
4. determine criterion scores
5. Standardization to harmonize the measurement scales for example area (ha) with %
6. Execute the evaluation through aggregation by an MCE method.
7. Sensitivity Analysis to check the consistency of the results
8. Final recommendation.

The determination of criterion scores can be by quantitative (ratio, interval) or qualitative (ordinal, binary, nominal). According to Voogd (1983), the following scales can be used: pair wise comparison; complete ranking; rating ; partial ranking; and a Seven Points scale.

In the current study *complete ranking* was used. It involves ranking of all the criteria with units on a cardinal scale. The weights can be obtained by standardizing the rank orders. Group weights can then be determined by averaging the weights for all the members of a group. Practical applications show that this method is very attractive because of its great simplicity (Karatunga, 1997). Its draw back is that the accuracy decreases with the increase in the number of criteria to be ranked.

2.8 Integration of Statistical analysis into the spatial and temporal analysis

After spatial pattern recognition and description properly designed experiments provide stronger inference about underlying mechanisms than observed patterns themselves (Leps, 1989). Monitoring takes the form of continuos investigation , therefore statistical methods become supportive through iterative hypotheses. An initial hypothesis leads by a process of deduction to certain consequences that may be compared with data. A second cycle will then be initiated (induction) to modify the hypothesis in case the data and the hypothesized model do not agree, thus getting into a feedback loop (Box et al. 1978).

Analysis of variance (ANOVA) method of statistical inference: Statistical inference is carried out to establish whether there is a discernible difference in the means of the dependent variable classes. The basic question here is 'how probable is it that the differences between observed results and those expected on the basis of a hypothesis have been produced by chance alone (Sokal and Rohlf, 1987). ANOVA was used in this research to establish the variability in the papyrus attributes across different factor classes like topography and soils. The analysis can be used where the variation between the means is compared to the average variation within groups and when you want to test hypotheses about specific cell means (Wilkinson et al. 1992).

The main assumption of ANOVA is that the *variance of the response variable is constant across treatments* (Cauchley and Sinclair, 1994). The same authors have established that ANOVA can deal with both frequencies and with continuos measurements while other analyses like the χ^2 tests are used only for frequencies (counts that come only as whole numbers) . Some tests share the ANOVA assumptions like the *"t"* test (Cauchley and Sinclair , 1994).

The Anova Assumptions and the sampling design for wetlands : A randomized arrangement has been preferred for providing data whose estimate of the population is statistically sound. Kellman (1975) has these arguments on the subject:

- the accuracy of the estimate of the vegetation population taken as a whole is attained.
- but the absence of a thorough dispersion of plots throughout the sample area may prevent the recognition of spatial pattern within it, and this is the aim of analysis.
- if some postulated spatial patterning is specified prior to sampling, a stratified random sample may be utilized, with randomization within each stratum.
- where gradients in the vegetation, such as those associated with topography are of prime concern, a regular arrangement may take the form of one or more lines of quadrats oriented along the gradient.
- continuos belt transects may be used if an intense sample is required.

A transect based stratified representative sampling was selected for the current research in an attempt to accommodate the interest of the distribution of vegetation along the gradient.

2.9   Database Uncertainty

Errors propagated in the process of mapping (interpretation errors) , automation (slivers and spurious polygons) and the definition of assumptions, thresholds and weights represent enormous deviation from reality. Eastman et al.(1995), indicates *Fazzy set theory* as one possible remedy to handling such uncertainties, while Wiemker (1997) promotes an Iterative Spectral -Spatial Bayesian Labelling Approach especially for change detection studies. Map data consistency within RS and GIS applications have been checked by *accuracy assessment* (Skidmore, (1997); Shrestha, (1996)) The land cover and land use classification system by the USGS require a minimum level of accuracy at least at 85% (Lillesand and Kiefer, 1994). On the other hand, the data exploration in statistical analyses can check recording inconsistencies while within the DSS, the sensitivity analysis establishes the consistency level of the results based on inputs, and methods of evaluation (Sharifi, 1997).

• *Integrating of knowledge into a classification* : The spectral characteristics of a feature may not necessarily be the predicted reality therefore dependency on spectral reflectance alone can be considered inadequate for accuracy purposes. Much more typical problems are encountered when an out of date image is used, therefore necessary to integrate contextual information or knowledge (Mariamni, 1997) . In a GIS manipulative logical expressions can be used to differentiate vegetation types that have been misclassified. "Iff" and "logical" expressions > , = , < etc. can be used to indicate another parameter in this case elevation or slope or distance (Shrestha, 1996). *Patch filtering by shape and size* is another attempt and is based on the principle that if the patch size is smaller than a given threshold, it would be generalized into its neighbor patch which has more connected pixels to it, and the attributes of the current patch and its neighbors are ignored. Then shape can be taken into consideration such that linear features like roads and rivers get accepted while linear forest or agricultural edges are not.

In the current research , the knowledge based interpretation as well as the rule based change evaluation were integrated to take these advantages (Appendix 11).

• *Data exploration in Statistical analysis.*
Before statistical analysis, the process of data exploration involves the identification of the nature of data distribution which can indicate strange occurrences or recording irregularities.
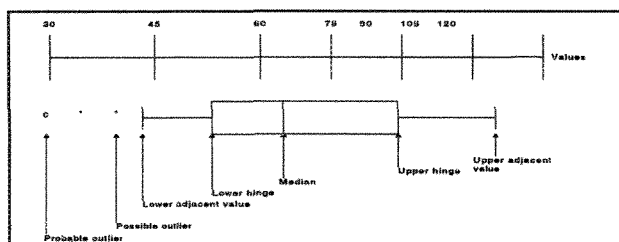
Figure 2.1 The structure of a Box and whisker plot . *source: Andrew Skidmore, 1997*

In addition to frequency tables and graphs , box and whisker plots (figure 2.1) were used in this study because they can graphically show the median indicating the point of central tendency, while the hinges and adjacent values permit an impression to be gained of skewness of the data. The location of possible extraordinary values are also marked (Skidmore, 1997).

Sensitivity analysis in DSS : A sensitivity analysis in a DSS is an a tempt to account for the uncertainty that ensue in the analysis process. The kinds of uncertainties mentioned by Janssen and Herwijnen (1994) concern the Multicriteria Analysis methods, the weighting scheme to mention but a few. An example of the weight uncertainty problem is analyzed by assessing the sensitivity for final ranking obtained by the selected MCE method, for uncertainty . In this case, an uncertainty percentage (provided by the analyst) for each weight is the maximum percentage by which you expect the scores to deviate from the values included in the effects or decision table. For example a weight of 0.5 assigned to an effect, at an uncertainty of 10 % indicates that you are confident the weight is between 0.45 and 0.55
(Janssen and Herwijnen, 1994). The resultant probability table is summarized into a conclusion that shows the ranking order. The analyst can then compare the rank ordering with the results of the MCE. A deviation may necessitate that the analysis is redone.

2.10 Conclusion

The assessment of the distribution of wetlands vegetation connote diverse considerations ranging from the definition of the target component, measuring scales, its dynamic characteristics and all the influences in the system. An attempt to assess the distribution of papyrus swamp can be supported by the integration of RS, GIS, and DSS . The supportive techniques like statistics and data error management are appreciated. It is the hope of the current research that the principles and techniques reviewed can help establish and explain the distribution of papyrus swamps because through their application, environmental systems including wetlands vegetation have been assessed and monitored.

3.   STUDY AREA

3.1   Size and Location

The study was undertaken on the Lake Naivasha riparian area referred to as the Lake Zone of Lake Naivaha. It is bound by the Lake road and the Nairobi - Nakuru roads (figure 3.2).
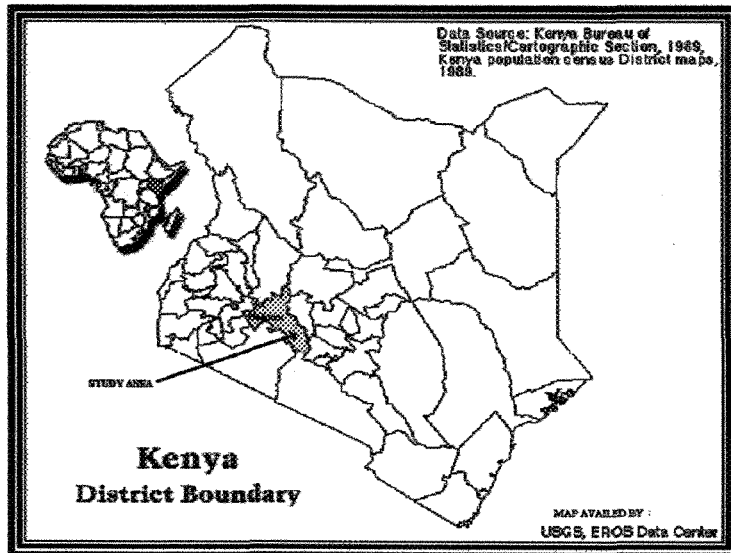
The total land and water area covers about 30,000 ha.
It is located in the eastern rift valley of Kenya , about 100 kms north west of Nairobi city, between 194000mE, 9932000mN, 215000mE, 9908000mN.

Administratively, the area is located in the Naivasha Division of Nakuru District in the Rift Valley Province of Kenya (figure 3.1)

Figure 3.1   Location of study in Kenya, Africa.

3.2   Relief

The altitude ranges from 1900 to 2060 m.a.s.l. The area is basically a lacustrine plain with a topography that is predominantly flat to gently sloping. Parts of the western offshore areas are moderately steep (figure 3.3)
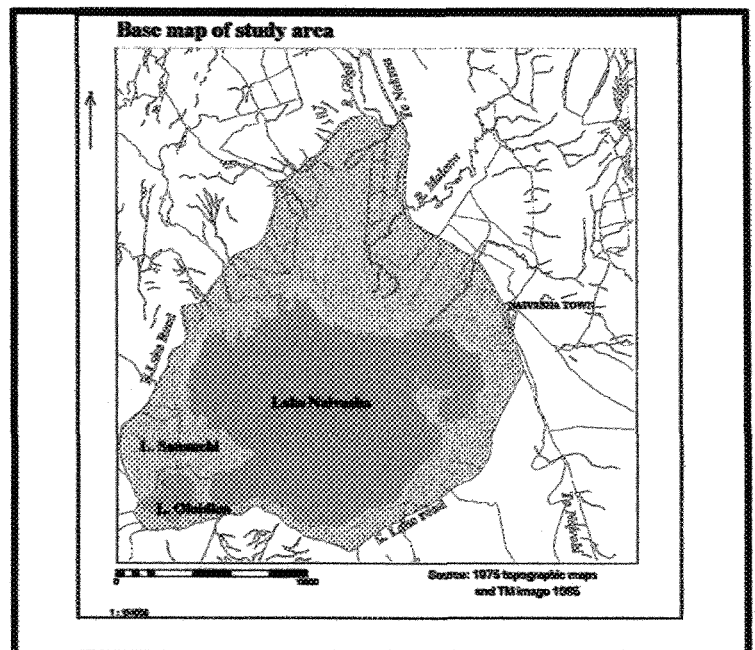
Figure 3.2   Base map
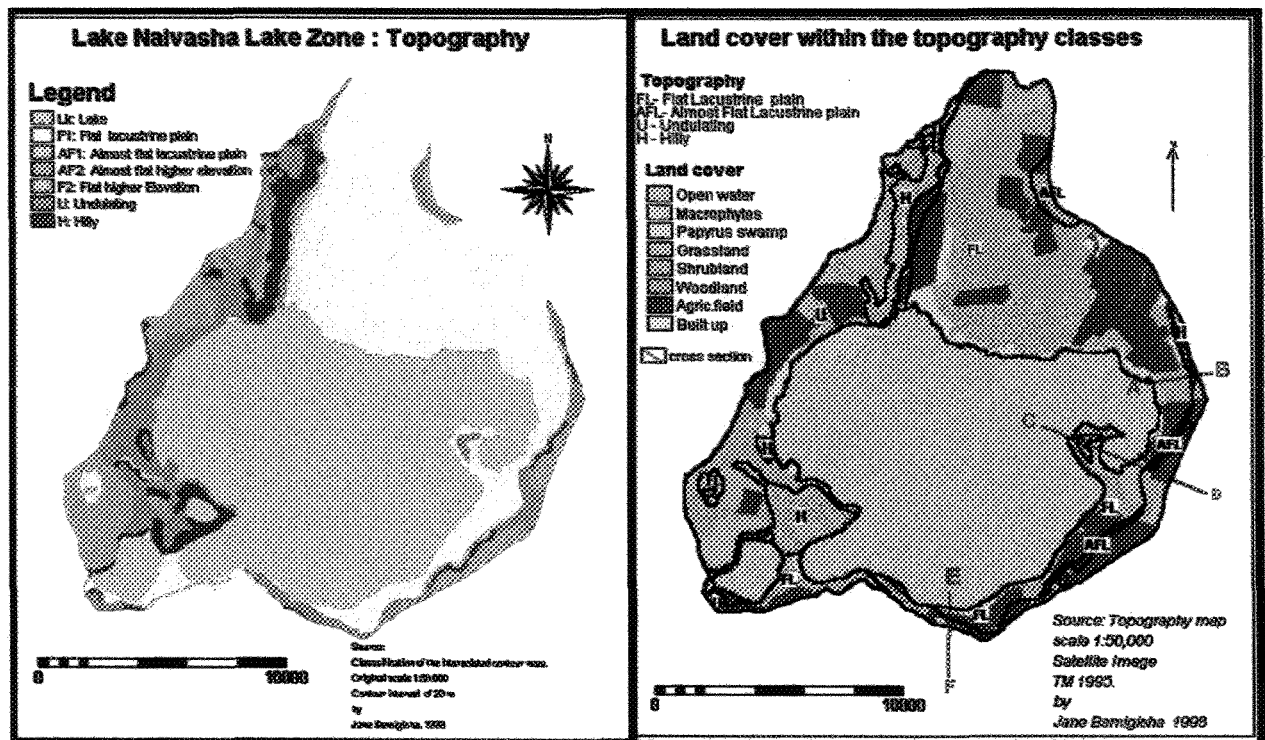
Figure 3.3   Topography and land cover (the topography classes are generalized on the land cover map.)
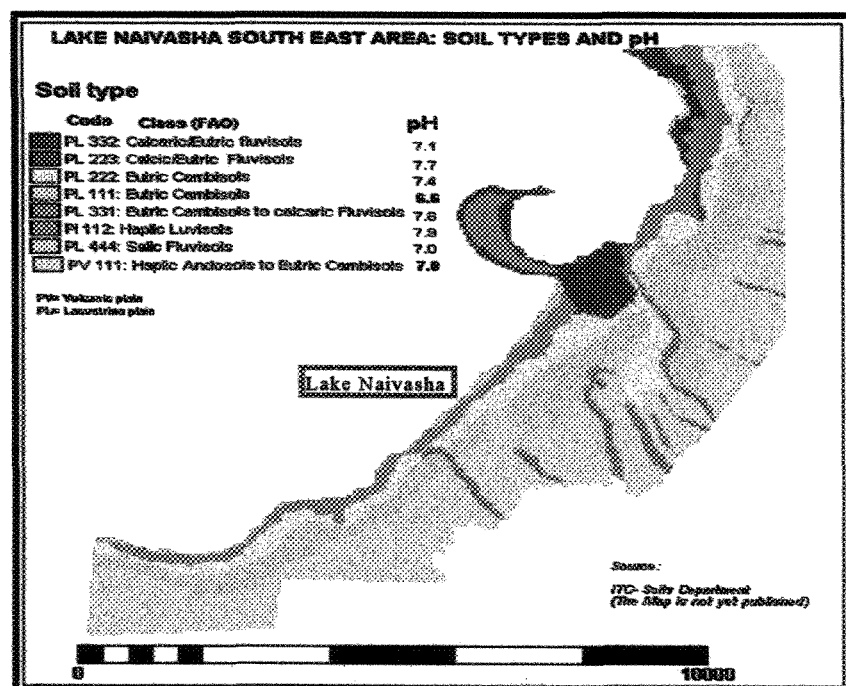
Figure 3.4   Soil map of south east Lake Naivasha area

3.3   Drainage

According to John Goldson Associates (1993), the Lake Naivasha ecosystem consists of the main Lake Naivasha, a shallow fresh water crater lake, a smaller sometimes separate Lake Oloidien plus the smallest crater Lake Sonachi. L. Oloidien is a soda lake with three times the salinity of the main lake, while L. Sonachi has an alkalinity five times that of Oloidien. Two main rivers, R. Gilgil and Malewa flow into the main lake from the north. The drainage is characterised by an internal system without surface outlets. In addition to the rivers, underground water inflows contribute to the freshness of the main lake.

3.4   Soils

The soils have developed on sediments from the volcanic ashes. They vary from well to poor drained, fine to sandy silts and clay loams of varying colour, sometimes sodic or saline. Gaudet has described the Soils at the lake edge of Naivasha as composed of :
1- *Hydrosoils*
a) *Lake edge mud:* It is loose, dark coloured and mostly consist of the remains of benthic and planktonic algae. It has high Ca. level due to calcite deposition.
Sludge: At 2-3 m depth in front of the swamp-lake interface underneath the floating edges of papyrus, one finds a loose fine particled light brown organic material interspersed with large pieces of rotting papyrus. The sludge represents a layer lying directly over a light gray, clay-silt layer.

2- *Papyrus mud soil*: In front of papyrus fringe, swamps during periods of low lake level a black organic, fine-particled mud is exposed referred to as papyrus mud soil. This is the most common soil at the lake edge during drawdown composed of organic and silt horizons.

3- *Volcanic sand*: This overlies pumice and when kept wet, it is a good substrate for *Cassia didymobotrya* and *Hibiscus diversifolius*. The volcanic sand is less saline than the exposed papyrus mud and has a high P content. It is however deficient in N and organic matter. Figure 3.4 shows the soil types for the south east area./

3.5   Climate

Temperature: The ambient mean monthly maximum temperatures range from 24.6 to 28.3°C with the highest temperatures in January and February. Mean minimum range from 6.8 to 8.0°C. Mean monthly temperatures range from 15.9 to 17.8°C with coldest months in July and August. There is a big diurnal variation and a definite cold season as a result of cold air coming down from the Nyandarua range (Jeatzold and Schmidt (1993) cited by John Goldson Associates (1993)).

Rainfall: Lake Naivasha area receives an average of 608 mm per annum of rainfall. The rainfall is bimodal with major peaks experienced in April/May, and in November as shown on figure 3.5.
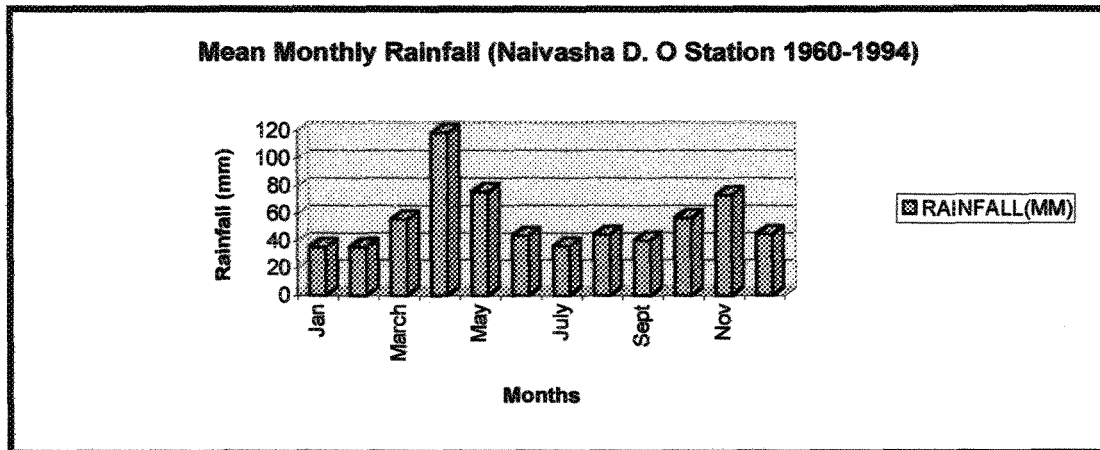
Figure 3.5   Bar Graph : Mean Monthly Rainfall for Naivasha . *Source- Ministry of Land Reclamation , Regional and Water development, Kenya.*

The inter-annual rainfall is irregular and the local rainfall around the whole catchment fluctuates as illustrated on figure 3.6. The rainfall is only a third of the evapotranspiration rate in the area (John Goldson Associates, 1993).
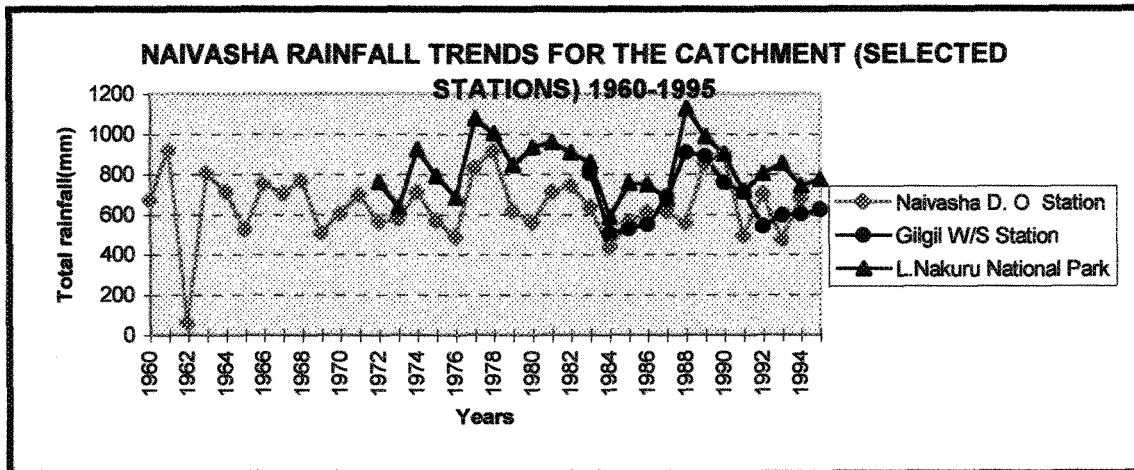
Figure 3.6   Naivasha Rainfall Trends 1960-1995. *Source: Ministry of Land Reclamation Regional and Water development, Kenya.*

3.6   Lake Level Changes

The Lake Naivasha covers 132 km^2 at mean conditions (LNROA, 1996). According to John Goldson Associates (1993), there has been a 15 meter level change during this century and three meter differences over short periods of a few months ; the last recorded was during the 1984 -1995 period. Stuttard et al 1995, confirms that Lake Naivasha varied by almost three meters over the period 1984 to 1992. The records of the lake fluctuations reported by John Goldson Associates (1993) indicate the following trends:

● A decline from 1896 m.a.s.l in the period (1880 - 1895) to 1,882 m.a.s.l in the period of (1945-55).

● An increase in 1961- 1963 to just over 1,887m, then a decline of 2-3 m in the early 1970s. An increase occurred thereafter and exceeded 1,887m in the years 1882 - 1984.

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- An increase in 1961- 1963 to just over 1,887m, then a decline of 2-3 m in the early 1970s. An increase occurred thereafter and exceeded 1,887m in the years 1882 - 1984.
- A decline since early 1984. By January 1988, it was below 1983 m. a. s. 1. The level continued to decline till 1988 when the onset of the long rains brought an end to the decline in 1990.

3.7   Vegetation

The vegetation of Naivasha display a zonation along a topographic gradient. The major components from the lake to the north lake road can be described as follows:
1- Non papyrus Macrophytes mainly *Eichhconia crassipes, sphaeranthus* and *Juncus spp*
2- The papyrus fringe dominated by *Cyperus Papyrus*. Other species include *Polygonum spp.* and *sphaeranthus spp.* The zone in some parts is interspersed with *Cyperus ridigifolia.*
3- Shrubland next to the papyrus is mainly composed of *Senna didymoborya, Polygonum spp,* and *conyza spp,* while in the higher elevation *Tarchonanthus camphoratus* dominates
4- Woodland dominated by *Acacia Xanthophloea* interspersed with Grasslands mainly *Thermeda spp, Pennisetum, Eragrostis Hyparrhenia, Setaria* and *Cynadon pleictostachyum* .

Gaudet (1977), came up with almost a similar sequence of vegetation species from the submerged hydrophytes in the lake, working toward the Acacia-grasslands (Appendix.7). Njuguna (1982) and Edward and Bogan (1951) , cited by John Goldson Associates (1993) had similar findings.

There is a seasonal as well as inter-annual variation of vegetation lushness in Lake Naivasha area. In a monitoring study of the area, (Stuttard et al, 1995) seasonal cycles of vegetation growth were identified with two annual peaks; a minor one in January/February and a major one in July corresponding to the short and long rains. The study further showed an inter annual variation with 1986 as characterized by low vegetative growth , 1988 with high variation in the year and 1990 with high levels of growth.

The vegetation zonation and other land cover along the topography gradient: The vegetation zonation outlined above is interspersed by other land cover such as agricultural fields, and built up area (figure 3.3). Cross sections (figure 3.7) show that where there is no human interference, the distribution displays a zonation from the lake comprising floating /emergent vegetation (other macrophytes), papyrus, shrubland, and woodland on the Flat lacustrine plain. In other areas, a composite of woodland grassland and shrubland span the gradient from the flat to the hilly area (figure 3.3, and 3.7). The cross section 2 (figure 3.7) does not have the papyrus swamp zone. Shrubland fringes the lake on the Flat lacustrine plain starting the zonation, then grass land and woodland on the island (Crescent island). Flat higher elevation is mainly covered by agricultural fields.

Salinity is one limiting factor for papyrus (section 2) At Lake Oloidien, where much more salinity has been recorded (electrical conductivity (EC) of 1000 micromhos per centimetre (Gaudet, 1977)) , the papyrus is limited to an area where it de-touches the main lake Naivasha. The distribution is much more realised on the lake Naivasha shore which is comparatively lower in salinity (EC of 330 micromhos per centimetre)
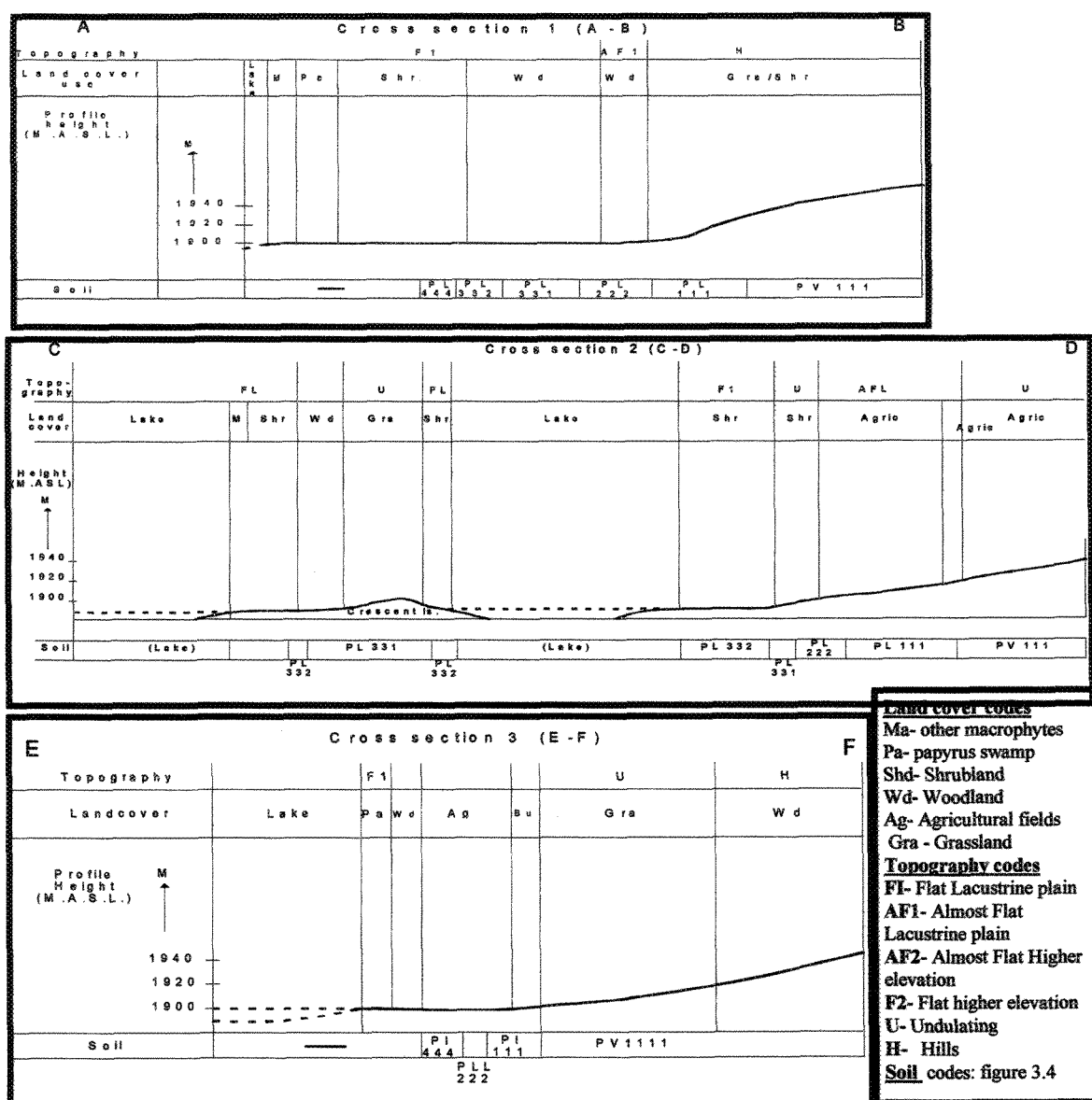
Figure 3. 7 Cross sections showing land cover along the gradient

Source : Topographic map scale 1: 50,000 with a contour interval of 20 m and Satellite image (TM 1995) were used. The soil characteristics, are from figure 4.3. Note: The cross sections are not drawn to scale. They were originally drawn at a scale of 1: 25,000 and 1: 2000 respectively. The lake level was found to have changed between the date of the soil map and the land cover map 1995. Part of the area shown as the lake in figure 3.4, is occupied by natural vegetation (figure 3.3).

3.8   Human activities and the papyrus swamp at Lake Naivasha

Lake Naivasha has attracted diverse activities because of its fresh water in the valley dominated by sodic lakes and an imbalance in the climatic regime that makes dependence on the lake water a critical issue. The activities that are related to the papyrus swamp include: fisheries, agriculture, burning, tourism/recreation , geothermal production and urbanisation.

• **Fisheries:** The present fish populations in the L. Naivasha are totally made up of introductions by man. Black bass (*Micropterus salmoides*) and Tilapia species (e.g *Tilapia zillii*) form the basis of the gill net fishing industry (John Goldson Associates, 1993) . Cray fish (*Procambaras clarkii*) is another popular catch. A large number of unlicensed fishermen operate on the lake effecting disturbance on the landing sites.

• **Agriculture** : The principle land use in Lake Naivasha area is agriculture, which has changed in system over time. Originally most of the area was occupied by pastoralists (from the 18th century) but the farming system has given way to intensive livestock and irrigated crop farming, leading to land subdivision, and intensive use of agro-chemicals. In addition dykes have been made in some farms to combat flooding risk to the farms. Ditches are dug for barring animal (especially hippo) invasion to residences and to get water to pump houses.

Crop cultivation:: At present the lake is surrounded by intensive horticultural farms (figure 3.8). The main crops include: flowers; vegetables (carrots, beans and cabbages); plus fruits (grapes, strawberries, oranges, and apples). On improved livestock farms, fodder crops include Lucerne, Rhodes grass , and maize. Some farmers have directly converted the swamp by extending their farmlands to the papyrus swamp as shown on figure 3.8.

Grazing: Extensive or range grazing takes place on grasslands, open woodlands, and wetlands as well. Figure 3.9 shows cattle grazing within the papyrus swamp. Intensive livestock farms for beef and dairy are also characteristic on the area (figure 3.9)
Gaudet (1977) indicate that grazing of papyrus at Lake Naivasha is mainly by hippo, and cattle. They both graze the young papyrus plants. It is only when the plants grow tall that the effect gets minimal. How ever, another effect, trampling will affect the papyrus at all stages.

The impact of agricultural land use to the papyrus takes the following dimensions : the direct conversion by extending the farms and grazing ; and the indirect impact through irrigation, supply to livestock farms, dykes, and drainage channels.

• **Burning:**
Fire scars are a common feature at L. Naivasha swamp. The burning is mainly done for facilitating clearing for cultivation as well as poaching of wild game (e.g. deterring buffalo attacks by illegal fishermen as gathered from local sources).

The effect of fire to *C. Papyrus* plants is further elaborated on figure 3.10, and analysed in chapter 5. The ashes generated could be pollutants to the lake (LNROA, 1996).

Figure 3.8   Conversion of papyrus swamp to crop cultivation

Figure 3.9   Cattle grazing in the papyrus swamp

Figure 3.10   Burnt papyrus swamp
The fresh burn (top) and recovering papyrus (bottom).

- *Conservation* : The lake Naivasha wetlands are a Ramsar site, and are a rich spot of animals and birds. The animals include Kongoni, Hippopotamus, Buffalo, Thompsons, Grants Gazelles and Impala . According to John Goldson Associates (1993), there are over 350 bird species and a study conducted on the distribution and habitat for birds found that the swamp formed the largest habitat. One apparent dilemma for conservation is the grazing of the swamp vegetation including papyrus by Hippo. It also does damage through trampling.

- *Tourism:* Tourism is the most important foreign exchange earner in Kenya. Lake Naivasha wetlands are one of the best bird watching sites in the country. The area is reputable for sport fishing especially the historic Black bass fish (Gaudet, 1980). There are also two national parks in the neighbourhood , Longonot and Hells Gate that are reputable. The impact of tourism on the papyrus area is one subject that could interest investigation due to the indirect effect by expanding built up areas through resorts to accommodate them.

- *Geothermal power production:* To the south of the lake (not on the study area) is the Olkaria Geothermal Power. The plant is a source of employment for local people, and Geothermal energy is one of the most environmentally friendly sources of power. The activity could have an indirect effect to the papyrus swamp through the populations attracted for employment.

- *Urban and domestic water supply:* Lake Naivasha is a source of domestic water supply not only to Naivasha but also to Nakuru towns and adjoining human activities.
The urban growth has numerous indirect effects on the swamp through demand for water which has led to a need for diversion of rivers and direct extraction. Figure 1.1 and Appendix 1 give more information. The Malewa river almost contributes 95% of the input to the lake (Gaudet, 1979). The threat of its diversion has been mentioned in chapter 2. The importance of papyrus here is that the freshness of the water is partly attributed to the purification function of the papyrus swamp (Gaudet 1977).

- *Research and educational development:*
The wetlands support the Agricultural research centre of the government and the private Elsamere Conservation Centre. It also supports the Wetlands programme of the Kenya Wildlife Service Institute.

4.   MATERIALS AND METHODS

The research was carried out according to three major phases; pre-fieldwork, fieldwork, and post fieldwork (figure 4.1) . In this chapter the methods are described accordingly.
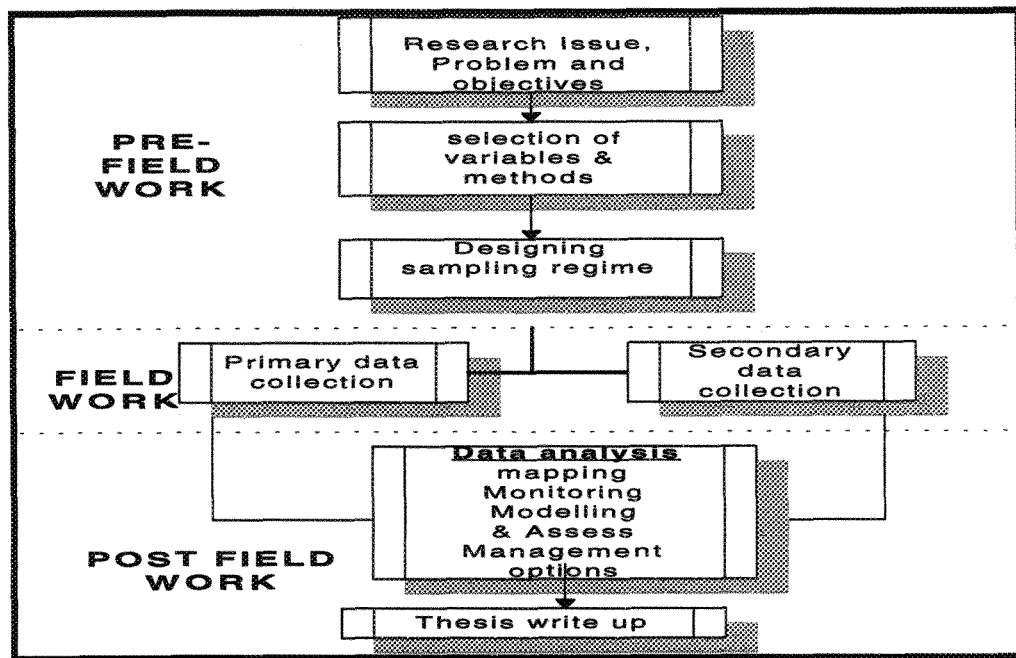
Figure 4.1   The major phases and activities

4.1   Pre-fieldwork

The major activities in this phase comprised: the definition of the research issue including problem analysis, and identification of data needs ; and reparation for field work including sampling design, image processing and interpretation. The activities are outlined below and illustrated in figure 4.2

4.1.1 Problem analysis

From literature, the problem was analysed using the problem tree approach (appendix 1 and figure 1.1). The analysis formed the basis for identification of research objectives and data needs.

4.1.2 Identification of data needs

Literature on the following subjects was reviewed: Wetlands definition including the typology of papyrus swamp; vegetation data collection and analysis; Background information on study area such as vegetation, geology, land use, population, hydrology, biophysical and anthropogenic factors that influence vegetation (specifically papyrus swamp) distribution ; Remote Sensing, GIS

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and Decision Support systems and their applications; and supportive techniques such as statistics and accuracy assessment.

Two major categories of data needed were identified as land cover and , land use both in terms of maps and attribute data corresponding to the selected indicators in section 2.4. Other data included rainfall. More information on the data will be presented in section 4.2.
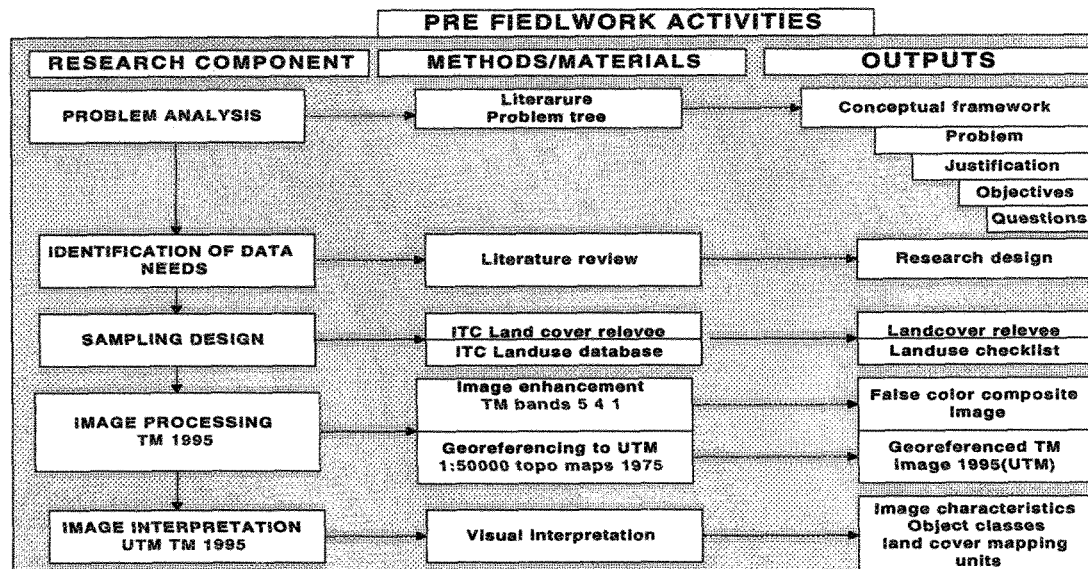
Figure 4.2   Pre fieldwork activities and outputs

4.1.3 Sampling Design

● **Sampling method** : Stratified Representative Sampling based on a TM 1995 satellite image (figure 4.4) was used. The method is very cost /time efficient and practical when : there is more than one type of data to be collected ; when the number of strata is high; and when parts of the area are not accessible so that some areas have to be interpreted from image characteristics, which have been related to relevees in another accessible part of the map unit (Bronsveld, 1996). These situations were expected as the study area comprised a swamp, wildlife and intensive fenced farms.

The design integrated Linear transect sampling from the lake up to the lake road . A transect is a line along which samples of vegetation are taken and is convenient for areas where there are rapid changes in vegetation and marked environmental gradients (Kent and Coker, (1992); Bronsveld (1996)). The basic criteria is the principal variations within the vegetation such as growth form and structural layers. The zonations on the study area identified by Gaudet (1977) and Herper et al. (1995) supported the integration of the method.

● **Sample size determination:** For vegetation, determination of the sample size was based on the principle of homogeneity of the structural classes . The following dimensions were considered: 5*5m for homogeneous grass cover; 10*10m homogeneous shrub cover; 20*20m heterogeneous (grass/shrub/wood) cover; and 25*25m dense homogeneous woodland. The ITC scheme (Groten et al. 1995) was used as major reference.

• **Preparation of relevee sheet and checklist:** Land cover data collection and land use survey sheets were designed referred to as relevee sheet and checklist respectively based on the ITC scheme (Groten et al. 1995). Appendixes 3, and 4 contain sample sheets.

4.1.4 Satellite image Processing and Interpretation

• **False Color composite:** A false color composite of the TM image was produced by combining image bands for enhancement purposes (Shrestha, 1996). Image bands, 5, 4, and 1 corresponding to the Near Infrared, Red and blue were used. The process assigns them the red, green and blue colours respectively.

• **Geo referencing :** The image was georeferenced using 1:50,000 scale topographic maps of 1975. The selected 'tie points' in UTM were used to transform the image into UTM (X, Y) co-ordinate system. The co-ordinates in the UTM system are in meters.
For easier orientation in the field, a grid was overlaid with same reference as the 1:50,000 topographic map.

• **Digital elevation model (DEM) :** A DEM, was created primarily for the purposes of interpretation and classification of land cover. From a topographic map scale 1:50,000, a contour map was digitised and an INTERPOLATION function in ILWIS 2.1 used. It is required that a difference in the X and Y directions be calculated and this was done using the gradient LINEAR FILTER function to obtain the DFDX and DFDY maps respectively. The slope map was then derived using the following map calculation expression:

"hyp(dxnaiv2,dynaiv2)/100)*100   (Eq. 4.1)

Where hyp is the hypotenuse and 100 is the pixel size .
dxnaiv2 = difference in x direction
dynaiv2= difference in y direction

The output was expressed in slope percentage (%) by multiplying by 100.
A SLICING function was run in the same program to classify the slope as described in the FAO guidelines (FAO & ISRIC, 1990). Section 2.6 indicates the scales by the guidelines.

• **Image interpretation :** The processed TM image of 1995 was printed and visually interpreted by defining first main strata based on topography classes, and expected land cover. Image characteristics as color, shape, texture and pattern were used as indicated in Appendix 2.1. Sixteen types of image objects were identified and reclassified into eight image object classes that were delineated to make a preliminary image legend.

4.2   Fieldwork Phase

The fieldwork was done for 5 weeks (9th May to 16th June , 1997). Two kinds of data were collected:
1) Primary, and secondary data. Primary data collected included vegetation structure and composition, *C. papyrus* attributes (ground cover, inflorescence cover, height and culm diameter),

explanatory variables such as ground water level, soil drainage, soil depth, topography, and human influence(grazing and burning). Data were collected for the following major aims :
● assisting land cover classification by verification of the interpreted TM 1995 image.
● Explaining papyrus distribution.
2) Secondary data included, rainfall, soil, remote sensed imagery,, maps and literature. The major aim was to:
● describe the study area, and
● support conclusions from the analysis.

4.2.1 *Primary data collection*

The primary data variables and methods for collection are described in this section. More illustration is given in figure 4.2 and Appendix 4

● ***Identification of Sample points :*** Based on the eight image object classes, twenty representative samples were targeted for each strata, making a total of 160 sample plots. 5 samples were estimated to be done per day. Due to accessibility constraints, only 117 plots could be sampled. Figure 3.2 shows the distribution of the sample plots.

● ***Reconnaissance survey:*** A reconnaissance trip through the fieldwork area for familiarisation and testing the sampling design was made. The suitability of the relevee sheets was verified and necessary changes made. The survey indicated change in the expected land cover so, it was decided the sampling would include areas not specifically represented on the image, but locally showed remarkable variations in the area. This was decided with the idea that more recent aerial photographs at a scale of 1:50, 000 would be availed.
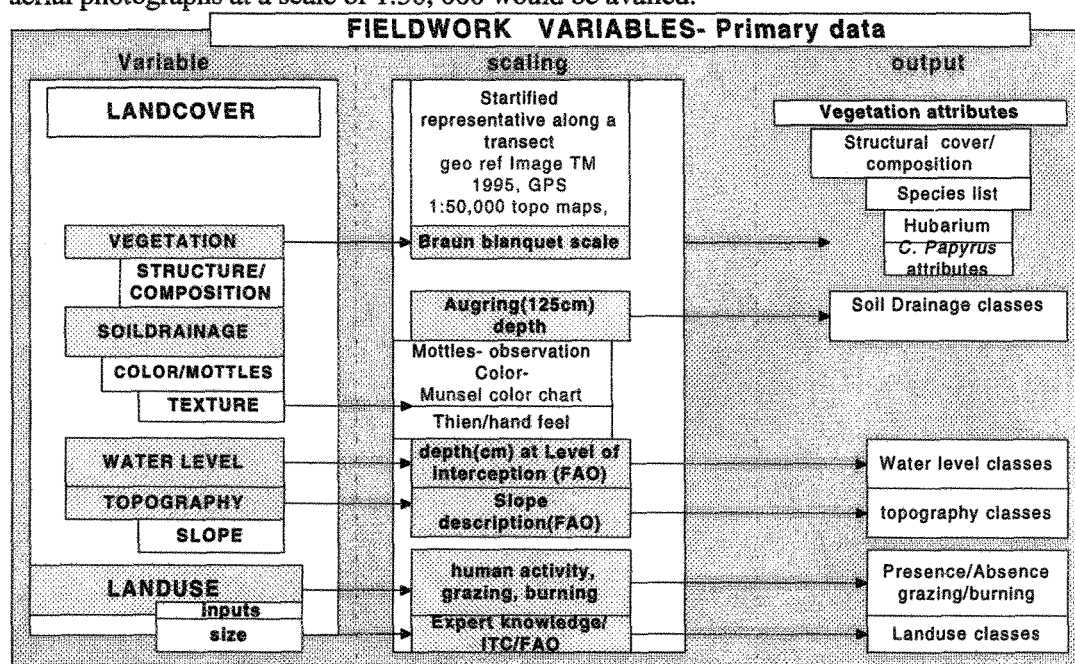
Figure 4.3   Primary data collected during field work

● ***Orientation:*** In conjunction with the satellite image, a Global Positioning System (GPS) with 30 m accuracy and topographic maps were used for orientation and location of sample plots.
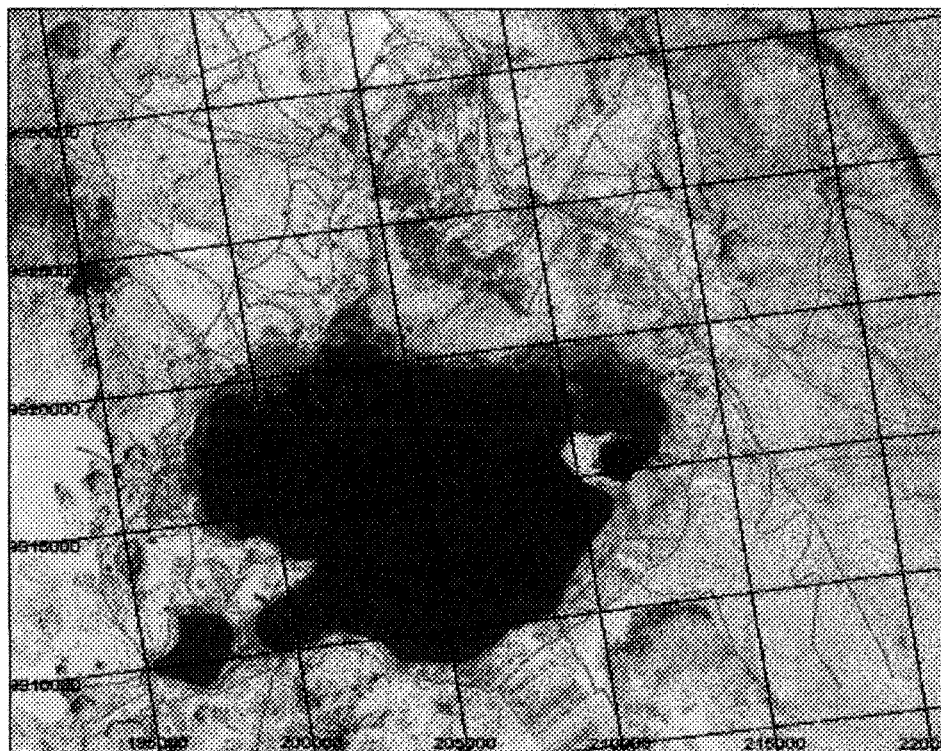
Figure 4.4   Sample distribution on the TM 1995 (False Color Composite :bands 5 4 1)

- *Vegetation structure and composition:* Vegetation Structural cover classes were recorded as well as Species composition and abundance according to Braun -Blanquet scale (average height, growth form, and cover (%) per species (Kent and Coker, 1992). More information is contained on the sample relevee in Appendix 3.
- *C.Papyrus attributes* : Average culm diameter at breast height was measured for ten species of one stand/clump. The actual measurement was the circumference (C), which was then transformed to diameter (D), using π:

$C = 2\pi r$, $r=C/2\pi$, and $D =2r$ *(Eq. 4.2)*

where π=3.14 and r is the radius)

Thus , $D = C/3.14$.   *(Eq. 4.3)*

Inflorescence cover (%) of the plot was estimated using the same scale as ground cover.

- *Soil :* The 1977 FAO guidelines (FAO & ISRIC, 1990) were used as reference (section 2.6). Soil auguring was done up to 125 cm depth. Soil depth , ground water level, soil drainage (texture, mottles and color) were recorded along the profile with intervals of 25 cm. The soil texture sampling was done using the 'thien' method (Appendix 6). For Soil colour, a Munsell colour chart was used to indicate the gley features while presence and absence of mottles was recorded as visually observed.
- *Topography :* Topography was described based on the FAO guidelines (section 2.6).
- *Human influences* : the following traces of human influence were recorded :

Grazing : animal droppings, trampling and onsite grazing were the indicators and where they existed it was recorded as grazing present and where not, as absent.

Burning : It was recorded as present if there was presence of fire scars and ashes and the reverse recorded as absent.

Cultivation: drainage channels and clearing were recorded if observed on the sample plot or adjacent area.

Land use Survey

The survey was undertaken with the following major objectives:

- to describe the study area
- to make a land use map for assessing the compliance to the papyrus conservation options of LNROA 1996 Plan.

The survey was conducted at plot level (de Bie (1996); Fresco et al. (1992)) by interviewing the land users, owners and care takers. The following was collected: locations of the farms, material and labour in puts; implements used, the production achieved and conservation efforts. The sample checklist (Appendix 4) gives more information.

The interpreted TM of 1995 satellite image was used based on the assumption that *Landuse = f(Image Object , Cover)*, meaning possible inference from land cover. Support data such as topographic map and literature were used for confirmation of the sampling locations. Field guides included the staff of the department of Agriculture, the Naivasha Riparian Owners Association secretariat.

- *Apriori classes:* Predefined land use classes used as base for sampling were: Crop cultivation; Grazing; and Conservation/recreation.

4.2.2 Secondary data collection

The secondary data collected and the respective uses in the study are given in table 4.1.

Table 4.1   Secondary data collected and sources

Organisation	Data type	format	scale	use in research
DRSDS, Kenya	Aerial photographs	hard copy	1:50,000	land cover mapping 1967
			1:12,500	land cover mapping 1984
	Contour map (in ft)	hard copy & digital	1:50,000	reference
IPL section -ITC	Satellite image TM 1995	Hard copy & Digital		Field sampling & Land cover mapping 1995
ITC	Topographic maps	Hard copy	scale 1:50,000 1975, map sheets: 133/2 (Naivasha) & 133/4 (Longonot)	Field orientation DEM Base map, Satellite Image for geo-referencing
Soil division, ITC	soil types, pH, and EC, Phosphorus and organic Nitrogen	map	1: 50,000 (covering only south east of study area	study area description & explanation to the papyrus distribution
		table %ges	referring to the map	
RRWD, Kenya	Rainfall	table R/F (mm)/day	1959-1994	study area description assist in explanation to papyrus distribution
Elsamere Conservation Centre, Kenya	Literature- various	text		study area description/ assist in explanation to the papyrus distribution
KWS, KENYA	Literature- various	"		"
LNROA Secretariat NAIVASHA KENYA	literature on land ownership &	text		background study area description/
	management plan			land use map classification
Wetlands International NETHERLANDS	Literature - various	text		research Indicators

4.3   Post field work phase

In this phase, data entry, analysis and thesis writing were the major activities. In this section the major processes are presented (excluding write up) as : mapping and monitoring to establish the spatial and temporal distribution of the papyrus swamp; risk modelling to assess the effect of other land cover; statistical inference to explain other factors ; and the assessment of management options.

4.3.1 Maps and attribute data input into the database

Digitizing was done in ILWIS 2.1 for the base map (roads, major towns, lakes, rivers), and contour lines. Land cover and land use attribute data was entered into EXCEL spreadsheet.

4.3.2 Analysing the spatial and temporal distribution of papyrus swamp

Area per habitat and *trends* as major indicators of the distribution of the papyrus swamp were derived by land cover mapping using remote sensed imagery and monitoring (change detection) for 1967, 1984, and 1995. Figure 4.5 Illustrates the procedures.

4.3.2.1   Land cover mapping : 1967, 1984, and 1995

(1)   1967 land cover map :

The 1967 aerial photographs (panchromatic) of scale 1:50,000 were used, and the following procedures were undertaken:

- *Identification of photo characteristics and image mapping units* :
Image mapping units were identified with image characteristics before stratification.
The characteristics identified were: Field pattern, Tone, Texture and Stereo height (appendix 2.2)
These characteristics constituted the knowledge of the textural image characteristics. It has been recommended for improving image classification (Bronsveld et al., 1994, cited by Mariamni, 1997)).

- *Stratification :*Stereoscopic based interpretation was done with an advantage that it is possible to get a three dimensional view thereby enabling identification of structural height. Topography classes were delineated first then land cover.

- *Tilt /flight error correction on the pantograph:* A pantogragh is an equipment used to correct errors in the aerial photographs generated as a result of flight irregularities such as tilt and flight height. The irregularities lead to poor fitting of the interpretation. The process also takes care of scale modification for example from big to small scale in cases where different scale maps are to be compared. For the 1967 map, the purpose was to correct the error so as to get a good fit of the photo interpreted pieces.
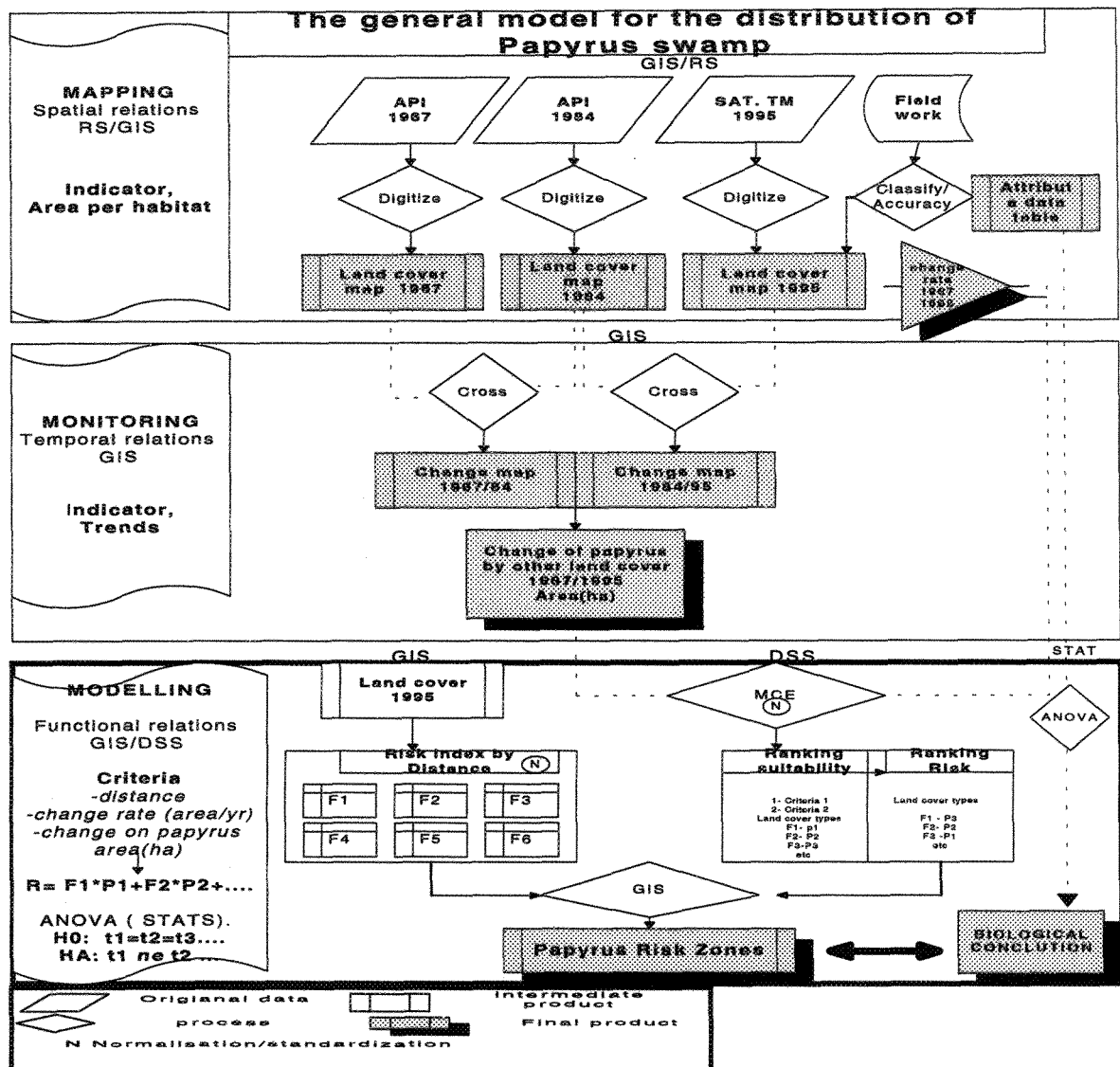
Figure 4.5   The general model for papyrus swamp distribution

- *Digitising of the interpretation and reclassification:* Digitizing was done with a consistent geo-reference and co-ordinate system (UTM) for the base map. In the process the pixel size of (50m) was harmonized with the base map. This harmony is important for overly and comparison purposes in a GIS. The river map was overlaid and the resultant map reclassified into broader land cover classes to match the TM Satellite image interpretation.

- *Calculation of areas for land cover types:* The areas for each land cover type were calculated using GIS -ILWIS 2.1   HISTOGRAM function.

(2) 1984 Land cover mapping

The 1984 aerial photographs (panchromatic) of scale 1:12,500 were used . Similar procedures as for 1967 map were followed for the identification of photo characteristics and image mapping

units. The procedure for tilt/flight error correction however included scale modification from
1:12,500 to 1:50,000 (big to small scale). This was done to enable the overlay and comparison
purpose required in the change detection. For the same reason the digitising of the interpretation
was done with the same boundary line, geo-reference and co-ordinate system as 1967.

(3) 1995 Land cover mapping

The interpreted TM 1995 satellite image was used. Similar reclassification and overlay functions as
in the maps of 1967 and 1984 were done.
To verify the interpretation, vegetation discrimination was given priority and the vegetation field
sample points were assigned to the structural classes (appendix 8). The criteria followed for
structural vegetation classification is shown on table 4.2 and figure 4.6. Each section of the
triangle correspond to the vegetation structure as defined in the table.

The sample locations for the 1997 land cover field data were then overlaid on the 1995 land
cover map, and the land cover type where the samples fell recorded. The resultant table was
summarised in a matrix showing the number of samples similar or otherwise for the 1997 versus
1995 land cover (appendix 9).

Table 4.2   Definition of vegetation structural cover types

Percent cover per layer			Expected cover class
Trees	Bushes	Grasses	
>60	n.a	n.a	Forest
20-60	n.a	n.a	Woodland
<20	>20	n.a	Bushland
<20	<20	>50	Grassland
<5	mei-20	mei-50	Sparsely vegetated
0	0	<5	Bare soil
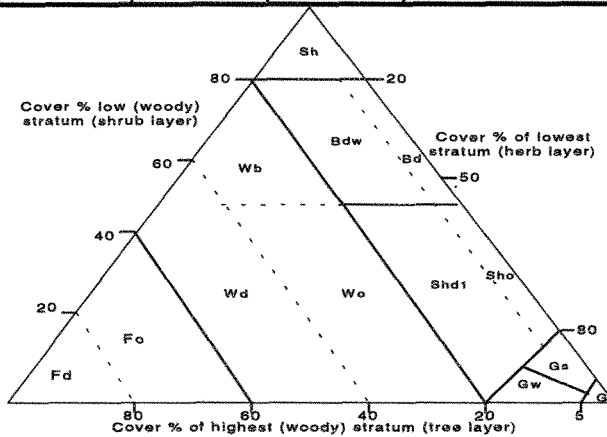
Key: Fd= Dense Forest   Fo= Open Forest   Wd = Dense woodland   Wo = Open Woodland
          Bdw = woody dense shrubland   Shd1=dense shrubland (light)   Bd dense shrubland (dark) .Shd=dense Shrubland   Sho=
          Open shrubland   G= Grassland   Gs= Shrubby grassland   Gw= Woody grassland

Figure 4.6   Vegetation Structural Classification System

4.3.2.2   Change detection

A MAPCROSS (GIS - ILWIS 2.1) function was used for change detection of the distribution of the papyrus swamps for the years 1967 to 1984, 1984 to 1995, using the respective land cover maps. The process performs an overlay of two raster maps by comparing pixels at the same positions in both maps. The output table and map show the combination of class names, their identification, the number of pixels occurring as combinations, and area of the combinations.

Aware of the limitations in the interpretation due to the change realised by using an older image (1995) for 1997 truthing, the resultant change was evaluated using 'a rule based interpretation (Mariamni, 1997). The evaluation is able to check the mapping inconsistencies based on established rules. It takes the form of :
                    'If condition then inference'
Two criteria were used to develop the rules:
1-A threshold area (a minimum of 0.01 ha) below which a change could be established was used in the evaluation with the assumption that an area that is realised as changed should be at least twice the pixel size (50m).
2- The expected change direction using own knowledge, for example a reasoning that a built up area may not change into papyrus between 1984 to 1995.

Appendix 11 shows the list of rules used in the change interpretation.

A reclassification was done on the land cover change map to amplify the targeted papyrus swamp by merging the rest of the classes that did not involve papyrus into only two classes (other change and other no change).

Using the reclassified change table, scores of (+ or -) were assigned to each land cover type that changed to or from papyrus respectively. A final tabulation indicated the positive and negative change direction with similar signs. If the change was from Papyrus to another cover type, the score would be negative (-) and if from other cover type to Papyrus the type would score (+).

4.3.2.3   Modelling the Risk of land cover types to papyrus swamp

Spatial analysis and modelling was done to assess the potential risk of the land cover types to papyrus swamp area based on the 1967-1995 status. This was aimed at establishing the variability in the dynamics of the land cover types and the potential risk the dynamism could have on the papyrus area . It was hoped the information would assist in priority management planning. An Ecological model of vegetation (Patrono, 1995) was used as reference. The principal ideas of the model are explained in Appendix 12.

The major assumption in the current study, was that in addition to distance, change in the spatial distribution of the neighbour land cover types over time will influence the distribution of the papyrus swamp. The assumption underlie the criteria for the risk assessment. DSS was integrated with GIS to derive the weights (quantified risk) of the land cover types in view of the criteria. The final risk potential map for papyrus was spatially derived by a linear additive function for all the criteria in a GIS (ILWIS 2.1).

● *Development of the rule base*
The model by Patrono and Oriolo (1995) was developed for modeling bush encroachment to pasture, ... while the the current model objective was to show the potential risk to papyrus area by neighbouring land cover types. The previous model did not incorporate the human induced factors like agriculture.
Both models use "neighbour effect" assuming that neighbour landscape or land cover have relative importance to the modification of the surveyed phenomena.

The criteria and the underlying assumptions for the current study :

1-*Distances of land cover type to papyrus areas:* . It was assumed that the nearer the papyrus to the land cover the higher the risk. Equal chance was assumed for all the land cover types meaning there was no constraint assumed.

2- *Direct papyrus change by the other land cover types* : A land cover type that had higher area in hectares changed from papyrus was assumed to have a higher potential risk to the swamp.

3- *Rate of change in area of land cover types* : The assumption was that if a land cover type was increasing at a faster rate, it had a higher threat to papyrus area.

Criterion weighting and land cover type scoring

1- *Risk based on distances to papyrus areas* (pixels)
● From the land cover map of 1995, each land cover type map was extracted using a map calculation (MCALC) function in ILWIS resulting in the respective cover type maps.
● For each land cover type map a DISTANCE function was used to characterise each pixel in the study area with the distance from the cover type resulting in respective maps showing the distance from the land cover type.
● To get the potential risk for papyrus, a Map calculation was done for each distance land cover type map to get the area of papyrus within.
● The risk index was developed from the range of the values in all the land cover maps by a normalisation process (Eastman et al. 1995) using the following formula:

$$X_i = (R_i - X_{min}) / (X_{max} - X_{min})$$ *(Eq. 4.4)*

where
X= standardised pixel
R= raw score (raw pixel value)
Xmax is the maximum pixel value
Xmin is the minimum pixel value

According to the criteria, the nearer the papyrus pixel is to a land cover, the higher the potential risk, so, the *Xmin* was translated into the highest risk, while the *Xmax* was translated into the lowest risk. The index was used to slice (reclassify) the land cover type papyrus distance maps into regular 10 classes showing respective risk levels from 1 (low level), to 10 (high level).

2- *Papyrus change in area (ha) by the other land cover types*: From the land cover change maps 1967/1984, and 1984/1995, the areas calculated for each land cover type

according to the change to papyrus (positive or gain for papyrus)or from papyrus (negative or loss to papyrus) were aggregated to get the total change to papyrus area between 1967 and 1995.

3- Change rate in area(ha) per year of the individual land cover types: Area(ha) for each land cover type was calculated for 1967, 1984, and 1995 from the respective land cover maps in ILWIS using the HISTOGRAM function . The histogram table was imported into excel for calculating the change rate using the following formula:

(y2-y1)/t   *(Eq. 4.5)*
 where:
 y1 the initial year,
 y2 the final year
 t is the difference between y2 and y1

Multicriteria evaluation for criteria 2 and 3

The process involved Criteria scoring and weighting for land cover types, for two scenarios. One that included water risk and another that did not. The details of the scenarios are given in section 5.3.4.

Weights of land cover types by Criteria 1 and 2 : In the DSS DEFINITE software, criteria 1 and 2 were evaluated using the Regime method. For criteria comparison purposes a normalisation is required, and this was done by quantitative ratio scale (Sharifi, 1996) before the evaluation process. It takes the form:

standard score (i)= raw score(i)/row maximum   *(Eq. 4.6)*

The standard score is the new criterion score standardised,
The raw score is the criterion score before standardisation
The row maximum is the maximum criterion score by the same row.

The evaluation was then executed using the Regime method which is based on the following formula:

if Cij- Cji > 0   *(Eq. 4.7)*
then alternative i is better than j.
where : C- is the criteria, i and j are the alternatives

● *Sensitivity analysis*
Sensitivity analysis is the process of ascertaining the consistency of the results of the evaluation model. The analysis was carried for effects and weights uncertainty given 20% probability. The process is explained in chapter 2.

Risk potential to papyrus swamp combining the criteria 1, 2, and 3

In most of the spatial modelling that has involved MCE, the suitability has been the target (e.g. Eastman et al. 1995). The model expression would take the form:

S= $\sum w_i x_i$ *(Eq. 4.8)*
s   = Suitability to the objective being considered

w_i = Weight of factor i

x_i = Criterion score of factor

The implication is that the ranking derived from the MCE if applied would imply suitability than the intended risk. Therefore the derived coefficients were inverted for this purpose by dividing the highest coefficient (score) by each resultant coefficient.

Finally, the final expression took the form:

Risk map = Factor1*P1 +Factor2*P2 +Factor3*P3...   *(Eq. 4.9)*

factors are the modifying factor distance risk index maps (for the land cover types)
P is the weighted position (coefficient)suggested by DSS from the rate of change of land cover types and the change in area of papyrus by the land cover types (from temporal analysis).

4.3.3 Statistical inference for other possible influencing factors

● Introduction
Statistical inference was done to expound on the conclusions about the spatial and temporal distribution of the papyrus swamp. The response variables were the *C. papyrus* attributes while the factors included : topography, ground water level, soil drainage, grazing, and burning. Before analysis, the data distribution and entry irregularities were explored.

● Exploratory data analysis
The land cover attribute data-set was imported into SYSTAT statistical soft aware for analysis. The data exploration was done by cross tabulating every combination of the dependent variable (Papyrus attributes- cover, culm diameter, height, and inflorescence cover) with each factor or independent variable class (relief, soil, water , grazing, and burning) and checking the frequency tables. Histograms were made for the dependent variables.

Box and whisker plots were used to provide an overview of the data distribution and to graphically show the relations. Outliers and irregular recordings were checked.

● Analysis of Variance (ANOVA)
A Fully factorial (M)ANOVA was used on 108 samples to compare the variation between the means of papyrus attributes as dependent variables (*C. papyrus* ground cover; Height; Culm diameter; and Inflorescence cover) with the average variation within groups of dependent variables (soil drainage; soil depth; topography; and grazing). The analysis is recommended when you want to test hypotheses about specific cell means or incorporate population weights that reflect differences in subclass size (Wilkinson, et al. 1992).
The critical value was 0.05 level of significance above which, the means would have above 95 % chance of being statistically equal. Initially the hypotheses to be tested were stated for each factor as follows:

$H_o : \eta_1 = \eta_2 = \eta_3 = \eta_4$ *(Eq 4.10)*

$H_A : \eta_1 \neq \eta_2 \neq \eta_3 \neq \eta_4$ *(Eq 4.11)*

Where the
H_o was the null hypothesis
H_A the alternative hypothesis
$\eta_{1....4}$ the mean for class 1...4

The Null Hypothesis was rejected if the 'P' value turned below the critical value 0.05, and not rejected if otherwise. If rejected, a post 'hoc' test was carried out using the Pair-wise Comparison (Scheffe method) to find out which means differed significantly from the others. The method results were matrices of pair-wise mean differences and pair-wise comparison probabilities.

When means are tested for pair-wise differences, the probability of finding one significant difference by chance alone is indicated by the 'P' value (Wilkinson, et al. 1992). The value was evaluated against the critical level, 0.05. Pairs with probabilities below the critical value were identified as having significant differences.

For the burning analysis, it was realised that the samples were very few (six samples out of 108). A paired comparison t-test was applied for the 25 samples (only samples in which Papyrus appeared) for the means of the dependent variables (Papyrus attributes) versus burning as an independent variable. The t-test is recommended when dealing with small, and more or less normally distributed samples (Sokal and Rohlf, 1987).

4.3.4   Assessment of management options for papyrus swamp

This research component was undertaken to present the implication of the status for management with the following support envisaged:
*   affirm or modify the existing management options depending on their responsiveness to the status
*   evaluate the land use types where they do not show compliance, and suggest alternatives through a land use plan

The three management options considered together with the methods used were:
*   **50 m buffer zone.** A GIS ILWIS 2.1, BUFFER function was used to compute the area (ha) that is under consideration using the 1995 papyrus spatial distribution.
*   **The 1893.3 m. contour.** An approximated 1893 contour was derived from the DEM and overlaid on the land cover map for 1995, and activities within identified.
*   **Protection and where necessary re-establish the papyrus fringe** around the lake and allow its natural growth. The identification of the possible areas for restoration was aimed at. The assumption here was that if restoration or establishment has to be done, the 1967 status could be taken as reference. The area should not be the present open water, papyrus, agricultural fields, and built up area . The 1995 status was used for the present.

Using Map calculations in the GIS (ILWIS 2.1), the area for possible restoration was isolated.

Figure 4.7 illustrates the procedures followed to get the outputs.
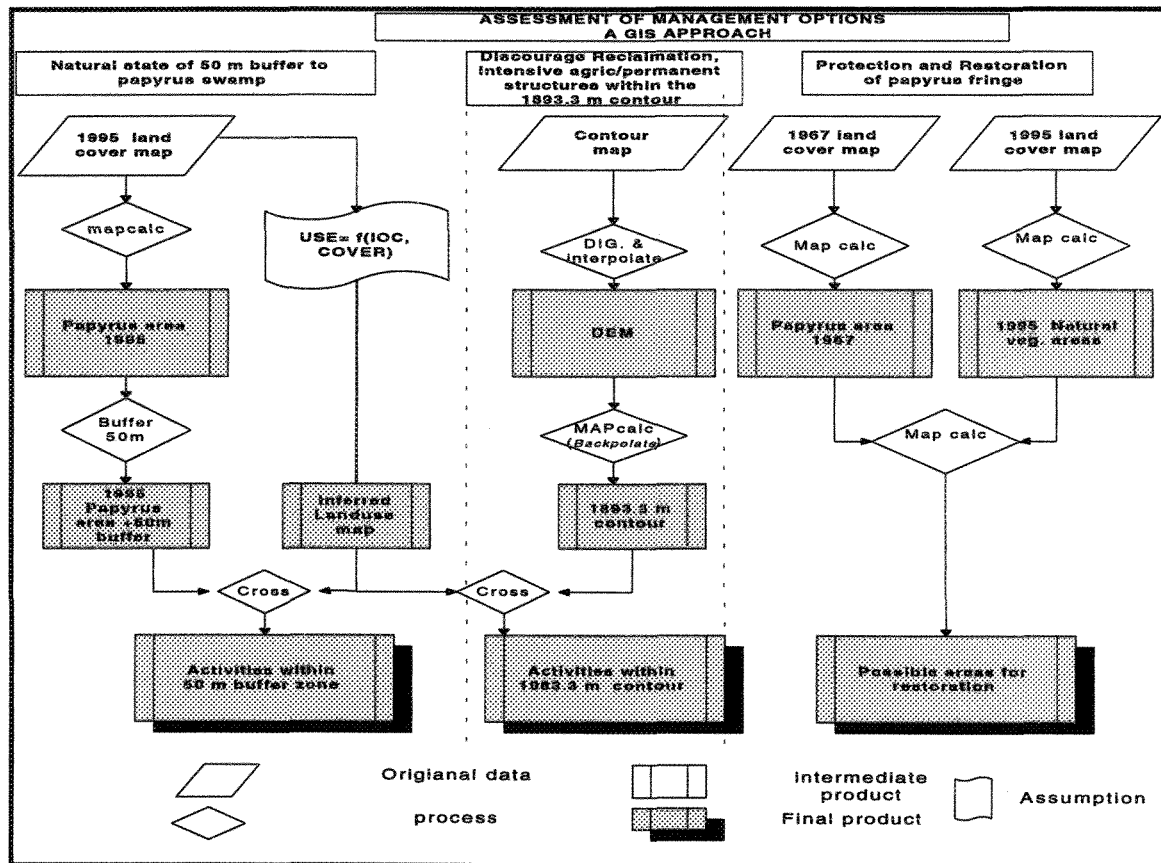
Figure 4.7   Assessing the compliance to papyrus management options in a GIS

5.   RESULTS AND DISCUSSIONS

5.1   Introduction

The major objective of this study was to monitor and assess the spatial and temporal distribution of the papyrus swamp at Lake Naivasha. This was directed to answering questions concerning the status of the wetlands vegetation in response to information gaps limiting the LNROA conservation efforts.

The major research components undertaken to achieve this objective were : land cover mapping and change detection to establish the spatial and temporal distribution of the papyrus swamp (section 5.2); risk modelling to assess the influence of other land cover types (section 5.3); statistical inference to describe other possible influencing factors (section 5.4); and the assessment of the compliance to the existing management options (section 5.5).

In this chapter, the results of each component are presented, discussed and conclusions drawn.

5.2   The spatial and temporal distribution of the Papyrus swamp

The spatial and temporal distribution of papyrus swamp at Lake Naivasha was expressed in *area (ha) per land cover type* for the years 1967, 1984 and 1995 and *changes in those land cover types* for this period. Two levels of change in papyrus cover were identified:

1- Rate of change in area (ha/year) for papyrus and other land cover types
    (the change rates are presented for the periods 1967/1984, 1984/1995, 1967/1995)

2- Spatial distribution of the changes in papyrus swamp cover(areas of change or no change, change to and from other land cover types, and how much area (ha) for the periods 1967/1984, and 1984/1995).

5.2.1 The distribution of Papyrus swamp and other land cover types in 1967, 1984, and 1995

In this section the spatial distribution of the papyrus swamp and other land cover types will be described for the periods 1967, 1984 and 1995 (Figure 5.1 and table 5.2). For the year 1995 also the relation between land cover and topography will be discussed (table 5.1) Assuming the topography did not change significantly, the topographical units are drawn as separate units within the three land cover maps in Figure 5.1.

• *Papyrus swamp distribution in 1967.*

In 1967, the papyrus swamp was mainly concentrated in the northern shore of the main Lake Naivasha, as part of the flat lacustrine plain (Figure 5.1). There were fragmented clumps on the lake especially in the eastern part . The swamp covered about 3,652 ha, which was 12% of the total land cover area of 30,148.4 ha (table 5.2 and Appendix 10). Other land cover types identified included open water covering the highest area (13,802.5. ha), while woodland dominated the natural vegetation with 5,104.8 ha, and mainly concentrated in the north.

Topography classes

FL   Flat Lacustrine plain
AFL   Almost Flat Lacustrine plain
U   Undulating (plain to upper elevation)
H   Hilly

Verification of the 1995 image interpretation
(using the 1997 field sample locations)
The verification of the image interpretation
results showed a misinterpretation of mostly
grassland and shrubland (20 samples)
grassland woodland (9 samples), grassland and
open water (9 samples) grassland and papyrus
(8 samples), and shrubland and woodland (5
samples). See appendix 9.

Figure 5.1   **Land cover maps of 1967, 1984, and 1995**

Grassland, with an area of 3,206.8 ha, could be found all over the area, often bordering the papyrus swamp. Shrubland covered an area of nearly 3,000 ha, mainly in the North-west, South-west and South-east. In 1967 agricultural fields covered only an area of 1,476.8 ha, small units scattered along the lake, except for the South-western part. No built-up area could be distinguished on the 1967 aerial photos.

- **The distribution of Papyrus swamp in 1984.**

According to figure 5.1, the 1984 papyrus swamp was still mainly concentrated in the north east flat lacustrine plain, but reduced to the river mouths of the Malewa and Gilgil . Fragmented clumps were found on the western side of the lake. The total papyrus swamp area was 1467.1 ha, comprising only 5% of the total land cover area (table 5.2 and appendix 10). In addition to the cover types observed in 1967, built up area was identified, covering an area of 158.6 ha. In 1984 the lake level was higher than in 1967, open water covering an area of 15,530.3 ha. Of the natural vegetation cover, woodland still took the highest area (3,985.6 ha), but was 1000 ha less than in 1967. Agricultural fields increased in area (3,665 ha), about 2.5 times as large as in 1967.

Table 5.1   Land cover type per topography class

Topography		Land cover types area (ha)					
code	description	Papyrus	Shrubland	Grassland	Woodland	Built up	Agricultural fields
F1	Flat lacustrine plain	755.3	2202	719.3	2745.5	123.5	3195
F2	Flat, higher elevation	0	79.3	22	0	0	0
AF1	Almost flat lacustrine plain	3.5	37.3	24.8	138.5	21.3	206.5
AF2	Almost flat lacustrine higher elevation	0	395	694	250.5	2.8	691.5
U	Undulating	245.3	902.8	418.3	625.3	58.5	823.5
H	Hilly	0	866.5	174	139.5	20.8	165.5

Source : Topography map (figure 3.3), and 1995 land cover map (figure 5.1).

- **The distribution of Papyrus swamp in 1995.**

The spatial distribution of papyrus and other land cover types will be described in relation to the topography (table 5.1). In 1995 the papyrus swamp was further reduced to an almost uniform fringe along the main Lake Naivasha, covering an area of 1044.9 ha, about 3% of the total land cover area (table 5.2 and Appendix 10). The swamp was mainly found in the flat lacustrine plain and the undulating area, the latter only in the Western part of the study area. The 16.3 ha in the hilly area was probably due to an overlaying error.

Open water covered 13276.7 ha. Of the other natural vegetation, shrubland had the highest cover (4538.4 ha), followed by woodland (3937.4 ha) and grassland (2005.2 ha). Shrubland seemed to be associated with the flat lacustrine plain, and the undulating and hilly areas, but appeared in all the topographical land units. The largest area of grassland was found in the flat lacustrine plain, the almost flat lacustrine area at higher elevation, and the undulating area. Woodland was mainly found in the flat lacustrine plain and undulating area.

Agricultural fields covered 5094.2 ha, an increase of nearly 1500 ha, compared with 1984, while built up area covered 239.2 ha, an increase of about 80 ha. The expansion of agricultural fields took

place mainly in the flat lacustrine plain, the undulating area and the almost flat lacustrine area. Most of the built-up area was found to be in the flat lacustrine plain and the undulating area.

5.2.2 Change in area (ha) of papyrus and other land cover types

Over the years 1967, 1984, and 1995, variations in the area of the different land cover types could be observed (table 5.2, figure 5.2. and appendix 10). Presented in this section are the recorded fluctuations for each land cover type and the rate of change (in ha/year) for the periods 1967-1984, 1984-1995 and 1967-1995.

Table 5.2 Land cover types, area(ha) change rate (ha/year) 1967- 1995

	1967	1984	1995	rate67/84	rate84/95	rate67/95
Agricultural field	1476.8	3665.1	5094.2	128.7	129.9	129.2
Built up	0	158.6	239.2	9.3	7.3	8.5
Grassland	3206.8	2639.6	2005.2	-33.4	-57.7	-42.9
Open water	13802.5	15530.3	13276.7	101.6	-204.9	-18.8
Papyrus swamp	3652	1467.1	1044.9	-128.5	38.4	93.1
Shrubland	2905.5	2702.1	4538.4	-12.0	166.9	58.3
Woodland	5104.8	3985.6	3937.4	-65.8	-4.4	-41.7

- **Papyrus swamp :** The area of papyrus cover decreased from 3652 ha in 1967, to 1467.1 ha in 1984, a loss of 128.7 ha/year. Between 1984 and 1995 the papyrus swamp reduced with another 422 ha, a loss of 24.8 ha per year. The overall decrease in area between 1967 and 1995 was 2,607.1 ha, giving a negative rate of change of 93.1 ha/year.

- **Open water**
The area of open water covered 13802 ha in 1967, 15530 ha in 1984 and in 1995 the lake water levels were relatively low, covering only 13276.7 ha. The change rates values calculated in table 5.2 must be looked at with care, as the lake water levels are fluctuating per year and season.

- **Grassland:** Grassland decreased in area from about 3207 ha in 1967 to about 2640 ha in 1984. There was a further decrease to about 2005 ha in 1995. From 1967 to 1995, the change rate was -33.4 ha per year.

- **Shrubland:** Shrubland covered about 2906 ha in 1967. In 1984, it declined to about 2702, a loss of 12 ha per year. However, by 1995 it increased to about 4538 ha, at a rate of 108 ha per year.

- **Woodland:** Woodland covered an area of about 5105 ha in 1967, decreased to about 3986 ha in 1984 and by 1995 it was about 3937 ha. The overall loss in area between 1967 and 1995 was 41.7 ha per year, with the highest rate of change in the period 1967-1984 (65.8 ha/year).

- **Agricultural area :** The area of Agricultural fields increased from about 1477 ha in 1967 to 3665 ha in 1984 changing at a rate of about 128 ha per year. In 1995 it covered an area of about 5094 ha, a further increase of 84.1 ha/year. Between 1967 to 1995, the change rate was 129 ha per year.

● ***Built up area***

In 1967, there was no significant built up area, but by 1984, the area was about 157 ha and in 1995 it further increased to about 239 ha , with an increase rate of 8.5 between 1967 to 1995.
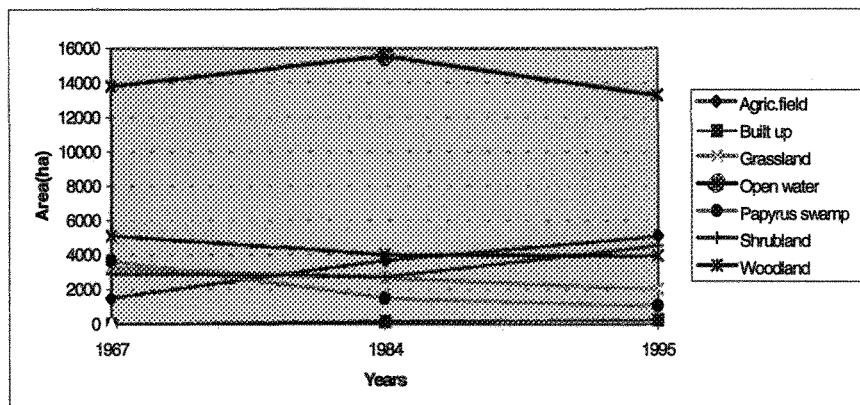
Figure 5.2   Area (ha) trends of land cover types 1967 - 1995

5.2.3 Spatial distribution of the changes in the papyrus swamp cover from 1967-1984 and from 1984-1995

In this section the changes in the distribution of papyrus will be elaborated in relation to the other land cover types, for the periods 1967-1984 and 1984-1995 (figures 5.3 and 5.4, and table 5.3). For both periods of analysis, the identified land cover types were open water, agricultural fields, grassland, shrubland and woodland. Built up had no direct effect on the distribution of papyrus. Although the total area of papyrus swamp decreased from 3652 ha in 1967, to 1467.1 ha in 1984 and 1044 ha in 1995 (table 5.2), there were also areas that showed an increase in papyrus area.
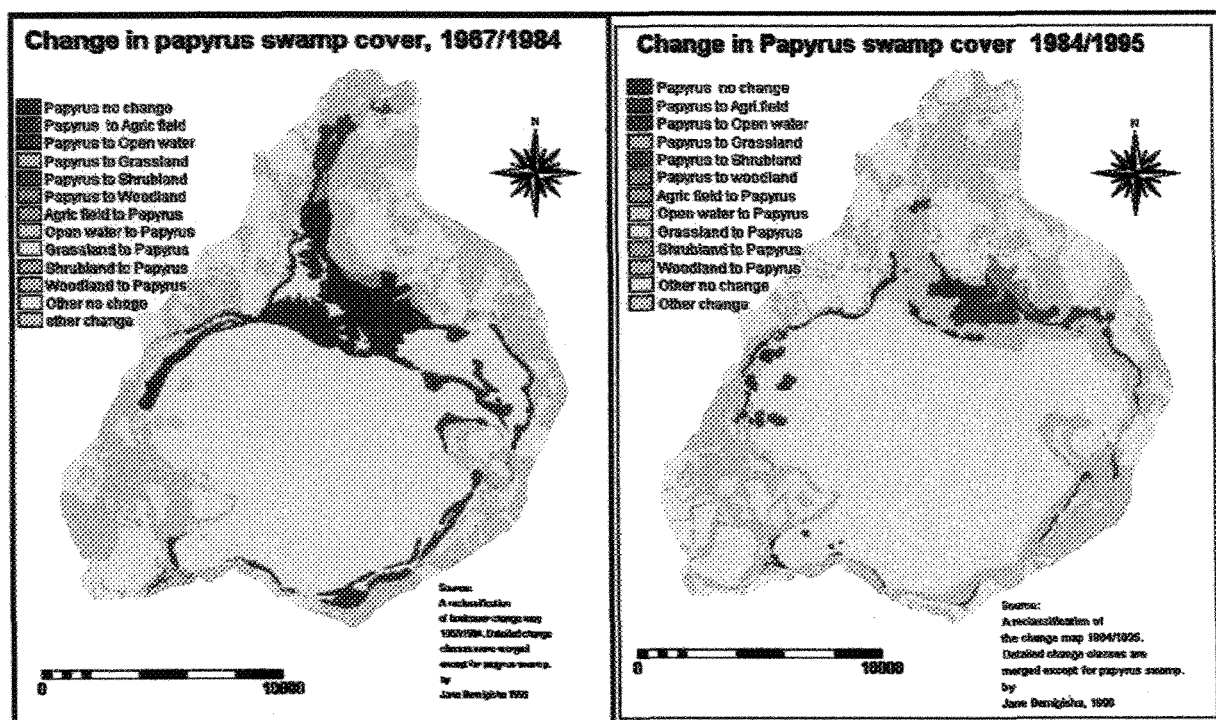
Figure 5.3   Spatial distribution of Changes in papyrus swamp cover for 1967-1984, and 1984-1995.

Table 5.3 Change of Papyrus cover by other land cover types

Papyrus cover change	Land cover score	1967/84 area(ha)	1984/95 area (ha)
Papyrus no change	P+	851.25	156
Agricultural field to Papyrus	Ag+	104.25	11.75
Open water to Papyrus	Ow+	276.75	823
Woodland to Papyrus	Wd+	109.25	12
Shrubland to Papyrus	S+	31	14.25
Grassland to Papyrus	G+	94.25	15.5
Papyrus to Agricultural field	Ag-	-100.75	-387.5
Papyrus to Grassland	G-	-254.75	-8.75
Papyrus to Woodland	Wd-	-182.25	-195.25
Papyrus to shrubland	S-	-304	-555.25
Papyrus to Open water	Ow-	-1959	-164

Source: Land cover change map 1967/1984 , and 1984/1995 (figure 5.3)
Note :Positive scores indicate positive role(gain)while negative scores indicate the reverse. The p+ indicate no change in Papyrus.

Codes: Ag = agricultural field, Ow= open water, Wd= woodland, S= shrubland, G= Grassland, Bu -Built up
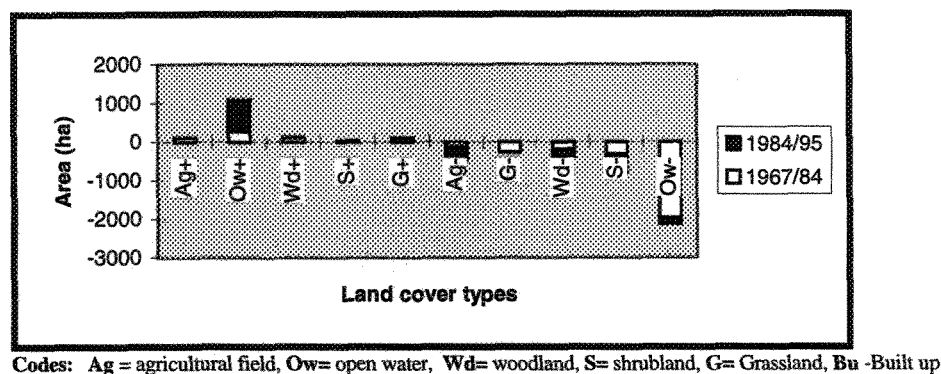
Figure 5.4   **Change of the papyrus swamp cover by other land cover types 1967 - 1995.** *Source: Land cover change 1967/84 and 1984/95 (table 5.3)*

Spatial distribution of the changes in papyrus swamp cover 1967-1984

According to figure 5.3 and table 5.3, the area of the papyrus swamp that remained without change for the period 1967-1984, comprised 851.25 ha, mainly concentrated along the North and North-west shore of the main lake. Due to high lake water levels in 1984, 1959 ha of papyrus was lost by flooding, mainly in the flat to almost flat areas. Of the natural vegetation, the largest part of the papyrus (304 ha) was converted into shrubland, followed by grassland (254.8 ha), and woodland (182.3 ha), while 100.8 ha of papyrus was converted into agricultural fields. Some areas formally fringing the swamp were changed to papyrus especially the agricultural fields (104 ha), grasslands (94 ha), and woodland (109 ha) on the north eastern shore. This might be explained by the relative high ground water levels as a result of high lake water levels and flooding of the flat plain, the abandoning of the agricultural fields and dying of trees and shrubs, while papyrus got a chance to expand "land-ward ". The 276.8 ha of papyrus in the Western part of the lake area, original open water, are probably drifting clumps of papyrus.

Spatial distribution of the changes in papyrus swamp cover 1984-1995

A small papyrus fringe of 156 ha remained unchanged between 1984 and 1995 (table 5.3). This was mainly located on the northern shore of the lake (figure 5.3). Most of the fringe that was lost to open water in the period 1967-84 was regained (823 ha), while the floating clumps in the Western part of the lake changed again into water (164 ha). Most of the papyrus was converted into shrubland (555.25 ha), followed by agricultural fields (387.5 ha), woodland (195.3 ha) and only a minor area (8.8 ha) was converted into grassland.

5.2.4 Discussion

There seemed to be a clear vegetation zonation going from the lake to the shore and adjoining higher elevation. The zonation commonly started with the lake water, then papyrus swamp, but the subsequent classes were not in consistent order. In the different years, the order was exchanged amongst grassland, shrubland, and woodland. The general vegetation distribution along the gradient (vegetation zonation) especially the one of 1967 was similar to the one identified by

Gaudet (1977), but interference from human activity was continuously increasing evidenced by agricultural fields and built up area (figures 3.6, and 5.1)

Under natural conditions, Woodland (mainly *acacia spp*) though continuously decreasing, had the highest natural vegetation area of about 5104 ha in 1967, and followed papyrus in the zonation (figure 5.1 and table 5.2) . On the other hand, shrubland (mostly *Senna didymobotry, Polygonum spp , conyza spp*, and *sphaeranthus spp*) had the fastest change rate of 108 ha per year between 1984 to 1995. It also had the highest natural vegetation area and followed papyrus in the zonation by the 1995 status (table 5.2, and figures 3.7 and 5.1). Shrubland also exhibited the highest total area change from Papyrus to natural vegetation, by 1995 (table 5.3).

This is an indication that there is a specific vegetation succession regime going on with shrubland as the main structural vegetation class currently overtaking papyrus.
The regime could be due to the indirect effect of climate and lake level or /and induced by human interference. Changes during climatic cycles have been found not to be accompanied by return to original state as a result of complete or almost complete dying off of species dominating at the beginning of the cycle or as a consequence of invasion of new more competitive species therefore leading to succession (Van de valk, and Welling, 1988). This fluctuation can be elaborated with the situation of flooding /inundation and drawdown which corresponded to the 1967/84 situation and 1984/1995 respectively.

Inundation/flooding:. Between 1967 and 1984 the Lake Naivasha water increased in extent, and most of the Northern papyrus swamp was flooded, as well as part of the natural vegetation and agricultural fields in the lower areas. Most of the north papyrus swamp changed to water, leaving a little concentration to the north east. The rest of the natural vegetation types decreased in extent as well. On a study about papyrus response to flooding, Gaudet (1977) found that the survival got minimal especially the young papyrus plants which could tolerate flooding only after reaching a certain stage of development.
On the other hand, some herb species could succumb to the flood like *Sphaeranthus* which showed a high percentage of survival due to its cell structure that is adaptable to both flood and dry conditions (Gaudet, 1977).

Drawdown: Between 1984 and 1995 the lake water levels dropped even below the 1967 level. According to Gaudet (1977), the drawdown succession should eventually succeed to a papyrus swamp. Indeed papyrus overtook the water ward immediate shore but it continued to decrease in the extent (table 5.2). The strikingly evident north swamp decreased further still below the 1984 area (figure 5.1). The zonation changed with woodland which had followed papyrus by the 1967 status, having its position taken over by shrubland after the flood in 1984, it changed faster, it had the highest natural vegetation area and exhibited the highest total area change from Papyrus to natural vegetation, by 1995, (figure 5.4 and table 5.3).

In addition to the built up area there was an extensive interference of agricultural fields on all sides which could be that farmland expansion took advantage of the receding water because of improved drainage condition for cultivation.

Summary: Lake water levels (Open water) seemed to have a high impact on the distribution of papyrus, but this process seemed reversible. The possibility is that if the water level is high, papyrus is flooded and particularly the young papyrus will die. If the lake water level goes down again, papyrus will recover and new plants will establish from seeds stored in the muddy soils. This natural process might be interrupted by human activities, for example the reclamation of riparian land by agricultural fields or grassland for grazing, or burning.

Gaudet (1977) indicate that cattle graze the papyrus especially the young ones on the study area (see also section 3. 8). The after-effects of grazing on vegetation have been studied by Verweij (1995) who found that short herb species benefited from increased light, moisture, and nutrients after the higher structural vegetation are grazed especially by cattle.
More explanation will be given on the grazing effect in section 5.3.

Burning has been found to encourage bush encroachment (Luttge, 1997). Figure 3.10 gives this indication, but the same figure shows that the effect could be temporary. This issue will be discussed further in section 5.3

Expansion of agricultural fields is a typical human impact. Between 1967 and 1984 100.8 ha of papyrus was converted into agricultural fields; between 1984 and 1995 this was 387.5 ha. It was found that presently dykes and channels are made to limit flooding on the farmlands. This process may be practically irreversible. Once a field is established, it will be hardly abandoned, and even if so, the conditions might be no longer suitable for papyrus.
Shrub species like *conyza floribunda* which seem to have high reproductive rates and wider tolerances (Gaudet , 1977) stand a higher chance to out-compete papyrus on abandoned fields.

Build-up area so far has no direct effect on the distribution of papyrus cover.

Limitations :

The study on the spatial and temporal distribution of the papyrus swamp was based on remote sensed imagery available at that moment; a TM image of 1995, and black and white aerial photographs of different scales. Initially aerial photographs of 1997 would be purchased but this was not possible. Also a chance to use hyperspectral scanner failed. Therefore, the most recent image used for field verification was the TM of 1995. Figure 5.1 has an indication of the interpretation errors. As many areas had changed, it was difficult to discriminate between a misinterpretation and an actual change in land cover.

In the comparative view of spectral and spatial resolution for different remote sensed imagery (section 2.7) it was indicated that there are images that could be used to achieve a better accuracy in the mapping of wetlands vegetation. These include High resolution aircraft multispectral scanner, infrared aerial photographs especially the colored (Johnson 1997; Rogerri 1993). Radar imagery (e.g. Buchroithner and Granica 1995 ; Yasuoka et al. 1995)
and the recent systems based on imaging spectroscopy (Guyot et al. 1992), with hyperspectral scanner systems (Lillesand and Kiefer, 1994) which could also be better options.

The available imagery could also not allow an account of the annual and inter annual variations in climate which influence vegetation condition. Stuttard et al (1995) indicates that there is a cycle of

vegetation growth leading to vegetation seasonality in Lake Naivaha area. Spectral characteristics of vegetation are known to change accordingly (Lillesand and Kefer 1994; Johnson 1997). This means that an interpretation of the image of a different date in a different season will influence the discrimination criteria by spectral characteristics like color and lead to different characterization of the same vegetation categories at different times.

5.2.5 *Conclusions*

- The papyrus swamp in Lake Naivasha is decreasing since 1967. Most (2185 ha or 60%) of the papyrus area was lost between 1967-1984. Between 1984-1995 the papyrus swamp reduced with 422 ha. The overall decrease in area between 1967 and 1995 was 2,607 ha, a loss of 71.4%.

- Fluctuating lake water levels have a large impact on the spatial distribution of papyrus. Between 1967-1984 a large area (1959 ha) of the papyrus was inundated, while a decrease in lake water level in the period 1984-1995 resulted in an increase of 823 ha of papyrus.

- Under natural conditions areas with dying papyrus can be taken over by shrubland (e.g. *sphaeranthus, conyza*, young acacia) and grassland (sedges and grasses), and finally (Acacia) woodland. This process is reversed if the area is inundated again.

- Expansion of agricultural fields has a negative impact on the distribution of papyrus in the area. Between 1967-1984 100.8 ha (2.8%) of papyrus was converted into agricultural fields and this increased with 387.5 ha (26.4%) between 1984-1995, giving a total loss of papyrus due to agriculture of 488.3 ha or 13.4%.

- There is no direct impact of build-up area on the distribution of papyrus.

In the next section the changes in the distribution of the papyrus swamp will be further elaborated to identify areas with a high potential risk.

5.3   Potential risk to papyrus swamp area by other land cover types

The purpose of this part of the study was to identify areas within the papyrus swamp that will have a high risk to be taken over by another land cover type. The identification and mapping of such high risk areas was expected to be helpful for local management purposes, for example in the selection of priority areas.

The model inputs were derived from the status of the swamp between 1967 and 1995 (the temporal analysis described in section 5.2 of the thesis). The risk modelling approach was based on multiple criteria evaluation in which relative importance is objectively given to a set of alternatives (land cover types) based on a set of criteria. The three criteria used were :

1- Papyrus risk index by each land cover types based on distance from a land cover type. Each pixel on the index map was characterized by a value which was the distance to a land cover type (figure 5.5). To represent the present status, the spatial distribution of papyrus based on the 1995 TM image was used (figure 5.1).

2- Total change in area of papyrus by other land cover types (tables 5.3 and 5.6)

3- The change rate of each land cover type for 1967-1995 (table 5.2)

To distinguish between human impacts and more natural influences, two scenarios were developed:

First the three criteria and their quantification will be discussed, followed by the risk modelling based on the two scenarios.

5.3.1   criterion (1):the distance of land cover types to the present papyrus

Papyrus risk index for each land cover type was indicated by a value in the papyrus area representing the actual distance to the land cover type. The assumption was that the nearer the papyrus pixel to an influencing land cover, the higher the potential risk to change. In order to establish the relative risk of each land cover type, the 'distance' maps were normalized according to formula 4.4. The results are shown in table 5.4.

Table 5.4 Potential Risk to papyrus swamp based on distance index

Distance (m)	Class	Assigned value	Potential Risk
1 - 800	1	10	High
801 - 1600	2	9	
1601 - 2400	3	8	
2401 - 3200	4	7	
3201 - 4000	5	6	Medium
4001 - 4500	6	5	
4801 - 5600	7	4	
5601 - 6400	8	3	
6401 - 7200	9	2	
> 7200	10	1	Low

The normalized distance maps were reclassified into 10 risk classes, from 1 (low = green) to 10 (high = red), see also tables 5.4, 5.5 and figure 5.5.

- *Agricultural fields:* The risk to papyrus swamp by agricultural fields was found to be mainly in the north east and southern areas. The potential risk ranged from medium to high for the whole area .
- *Built up area:* Built up area risk was found on the eastern papyrus swamp area . About 244 ha which was 23% of papyrus area was at low to medium risk, while 800.7 ha or 77% was between medium and high risk.
- *Open water:* The open water potential risk was manifested all around the shore. All the papyrus area was found within medium to high risk level.
- *Woodland:* The south west papyrus area was at high risk by woodland and tended towards medium in the northern area . Generally, 11.3 ha of papyrus area or 1% of the total papyrus area was found within low to medium risk potential, while 1033.6 or 99% was within medium to high risk potential.
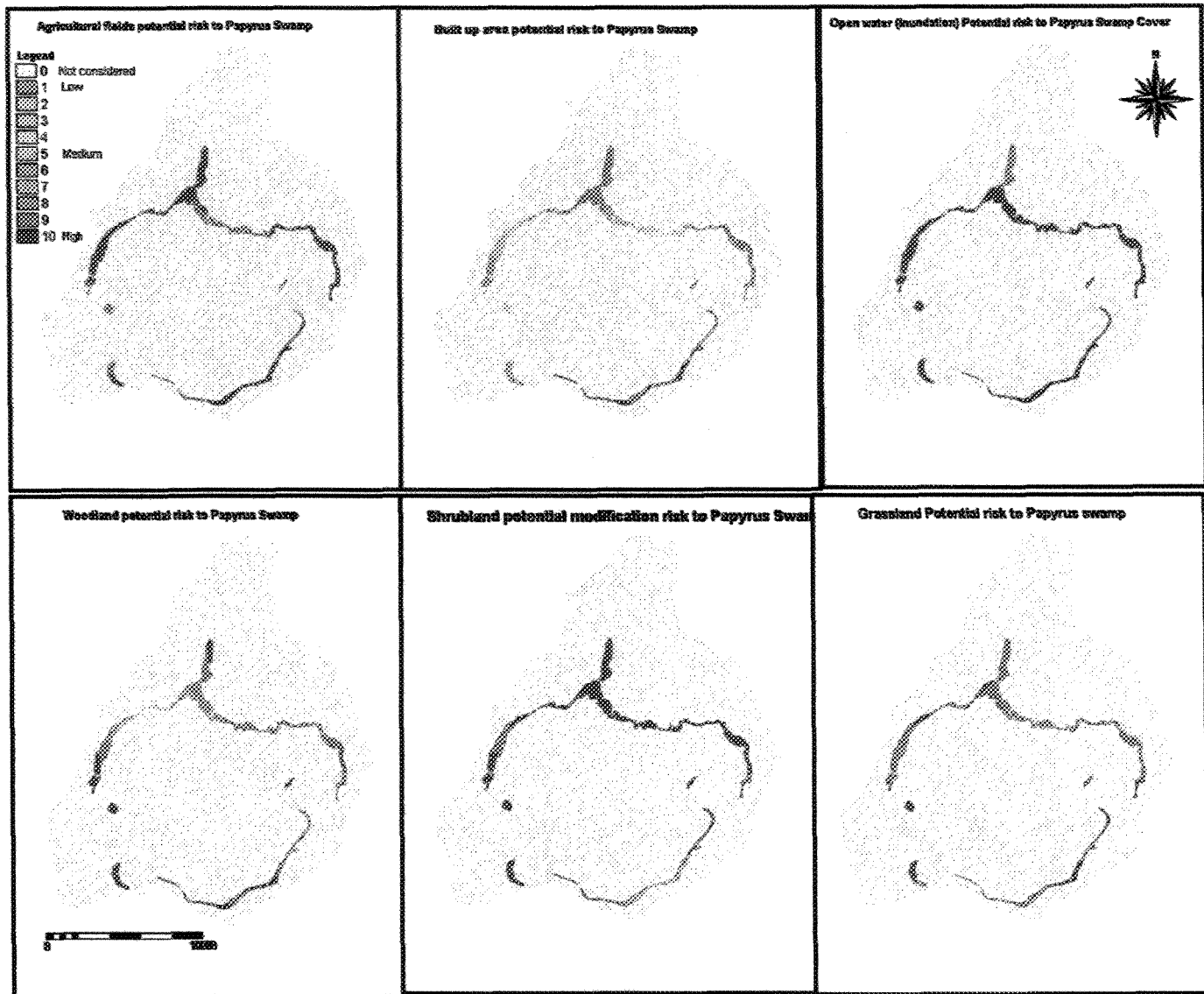
Figure 5.5 Potential risk to the papyrus swamp based on distance to a land cover type

- *Shrubland:* Most of the north swamp was at high risk by shrubland and tended towards a medium to high risk on the south western area. All the papyrus area was therefore within medium to high risk.
- *Grassland* : High risk was mainly concentrated in the southern part of the study area, while most of the area showed a medium risk.

Table 5.5   Risk of land cover types based on distance to papyrus swamp

| | Risk level | | | |
| | Low - Medium | | Medium -High | |
Land cover type	Area(ha)	%ge	Area(ha)	%ge
Agricultural fields	0	0	1044.9	100
Built up area	244.1	23	800.8	77
Open water	0	0	1044.9	100
Woodland	11.3	1	1033.6	99
Shrubland	0	0	1044.9	100
Grassland	0	0	1044.9	100

Source: based on figure 5.5

5.3.2 Criterion 2 : Change in area(ha) of papyrus by each land cover types

The assumption was that the higher the area of papyrus converted into another land cover type, the higher the risk in terms of impact on the present papyrus area. For each land cover type, the area (ha) changed into or from papyrus (table 5.3) was aggregated to get the total area changed from or to papyrus, from 1967 to 1995. The results are presented in table5.6. Open water had the highest risk (with a loss of 1023.25 ha of papyrus), followed by shrubland (814 ha), agricultural fields (372.25 ha), woodland (256.25 ha), grassland (153 ha), and built up showed no effect.

Table 5.6   Total change in area (ha) of papyrus by other land over types

	67/84	84/95	total change
Papyrus to agricultural fields	3.5	-375.75	372.25
Papyrus to open water	-1682.25	659	-1023.25
Papyrus to woodland	-73	-183.25	256.25
Papyrus to shrubland	-273	-541	814
Papyrus to grassland	-160.5	6.75	153.75
Papyrus to Built up area	0	0	0

Source: table 5.3
Note :The negative scores indicate the loss of papyrus, positive scores a gain in papyrus.

5.3.3 Criterion 3 : Rate of change

It was assumed that the higher the rate of change of a particular land cover type, the higher the risk in terms of impact on the present papyrus area. In table 5.2 the rate of change (ha/year) was calculated for each of the seven land cover types over the period 1967-1995. Agricultural fields had

the highest rate (129.2 ha/yr) , followed by shrubland (58.3 ha /yr), built up area (8.5 ha/yr), open water (-18.8 ha/yr), Woodland (-41.7), and Grassland (-42.9 ha/yr).

5.3.4 Multiple criteria evaluation

For the criteria 2 and 3, to be used in Scenario 1 and 2, a set of weights were derived using the multiple criteria evaluation module of DEFINITE (section 4.3.2.3). First an effect or decision table was created, followed by a standardization of the scores, weight assignment to each criterion and finally ranking of the land cover types from lowest to highest risk. The resulting appraisal scores were used as the weights in the final risk modelling of the two scenarios.

5.3.4.1   Establishment of weights for Scenario 1

For scenario 1, all the land cover types were considered in the effect table (table 5.7). The interest was to zone the papyrus area according to the level of potential risk given all the influencing land cover types. The rate of change values were re-expressed into positive values due to the limitation of the software DEFINITE to handle both negative and positive values in one row.
Before the actual evaluation, a standardization was done (table 5.4) using formula 4.6

Using the Regime multicriteria analysis (section 2.7 and 4.3.2.3), the relative importance of criterion 1 (papyrus change) was assigned to be higher than that of criterion 2 (land cover change rate), using the option *rank order*. Finally, the land cover types were ranked according to potential risk to papyrus (table 5.8).

The corresponding appraisal scores were inverted to express the influence (in terms of risk) of the land cover types to Papyrus thus the lower the coefficient the better (table 5.8). Shrubland had the highest potential risk to papyrus swamp (coefficient 1), followed by open water (0.85), agricultural fields (0.74), woodland (0.28), grassland (0.21), and built up (0.17).

Table 5.7   Decision table scenario 1)

Land cover types							
Criteria	ag	bu	gra	ow	shr	wdl	interpretation
papyrus change (ha)	372.3	0	153.8	1023.3	814	256.3	cost
change rate (ha/yr)	129.2	8.5	-42.9	-18.8	58.3	-41.7	cost
change rate (ha/yr) (positive values)	0	120.7	172.1	148.0	70.9	170.9	benefit

Standardized scores

Influencing land cover types						
Criteria	Ag	Bu	Gra	Ow	Shr	Wdl
Papyrus change(ha)	-0.36	0	-0.55	-1	-0.8	-0.25
Increase rate (ha/yr)	0	0.7	1	0.86	0.41	0.99

Codes: Ag - agricultural field, Ow- open water, Wdl- woodland, Shr- shrubland, Gra- Grassland, Bu -Built up

In order to ascertain the reliability of the criterion preference and weighting, the sensitivity analysis was done (section 2.7, and 4.3.2.3).

Table 5.8 Weights in terms of risk for land cover types: Scenario 1

Priority assignment to the criteria (by rank order)		
Papyrus change(ha)	1	
Increase rate (ha/yr)	2	

Ranking of land cover types			
Land cover	Rank	coefficient (the higher, the lower the risk	inverted coefficient (the lower the lower the risk)
bu	1	1	0.17
gra	2	0.8	0.21
wdl	3	0.60	0.28
Ag	4	0.23	0.74
Ow	5	0.20	0.85
Shr	6	0.17	1

Codes: Ag - agricultural field, Ow- open water, Wdl- woodland, Shr- shrubland, Gra- Grassland, Bu -Built up

● Consistency of the MCE results (scenario 1)

The sensitivity of the ranking to changes in effect and weight uncertainty was analyzed in the sensitivity analysis option of DEFINITE, using a threshold of 20%. The results were consistent for both effects uncertainty and weight uncertainty (Table 5.9). Therefore, it was decided to use the appraisal scores as weight inputs in the risk modelling.

Table 5.9   Results of the Sensitivity analysis

Effects uncertainty (20%)
Bu > Gra > Wdl > Ag > Ow > Shr
Weight uncertainty (20%)
Bu > Gra > Wdl > Ag > Ow > Shr

Codes: Ag - agricultural field, Ow- open water, Wdl- woodland, Shr- shrubland, Gra- Grassland, Bu -Built up

5.3.4.2   Weights for scenario2-(open water excluded)

A similar procedure as in scenario 1 was followed to derive the relative importance of the land cover types for scenario 2. The open water risk was eliminated to estimate the potential risk without inundation, and the criteria used remained the same as in scenario1 (table 5.10). The results

are presented in table 5.11. Shrubland was ranked first, indicating the highest risk to changes in papyrus (coefficient 1), followed by agricultural fields (0.8), woodland (0.22), grassland (0.15) and built up area (0.11).

Table 5.10   Decision table (scenario 2

Land cover types						
Criteria	ag	bu	gra	shr	wdl	Interpretation
Papyrus change (ha)	372.3	0	153.8	814	256.3	cost
increase rate (ha/yr)	129.2	8.5	-42.9	58.3	-41.7	cost
increase rate (ha/yr) (positive values)	0	120.7	172.1	70.9	170.9	benefit

Standardized scores						
Influencing land cover types						
Criteria	Ag	Bu	Gra	Shr	Wdl	
Papyrus change(ha)	-0.46	0	-0.19	-1	-0.31	
Increase rate (ha/yr)	0	0.7	1	0.41	0.99	

Codes: Ag - agricultural field, Wdl- woodland, Shr- shrubland, Gra- Grassland, Bu -Built up

Table 5.11   Weights in terms of risk for land cover types Scenario 2

Criteria Weights by rank order		
Papyrus change(ha)	1	
Increase rate (ha/yr)	2	

Ranking of land cover types			
Land cover	Rank	coefficient (the higher the lower the risk)	inverted coefficient (the higher the higher the risk)
built up area	1	1	0.11
grassland	2	0.75	0.15
woodland	3	0.5	0.22
Agricultural fields	4	0.14	0.8
Shrubland	5	0.11	1

The sensitivity analysis indicated again that the results were consistent for both effects uncertainty and weight uncertainty at 20 % probability with the following order:
Bu>Gra>wdl>Ag>Shr(Codes: Ag - agricultural field, Wdl- woodland, Shr- shrubland, Gra- Grassland, Bu -Built up)

5.3.5 Risk potential to papyrus swamp combining the criteria 1, 2, and 3

The impact of the three criteria (distance to papyrus, change in area and rate of change) resulted into an overall risk factor to papyrus. In this way, within the papyrus swamp, areas could be indicated that had a high potential risk to be taken over by another land cover type. This was done

The expression for Scenario 1 based on equation 4.9 was as follows:

Fin1=(shrmca*1+ watmca*0.85+Agmca*0.74+Wdmca*0.28+Gramca*0.21+bumca*0.17)   **_(Eq. 5.1)_**

Where: **_Fin1_** = Potential risk combining all land cover types, and the three criteria.
shrma= shrubland, _watmca_= open water, _Agma_= Agricultural fields, _Wdmca_= woodland, _Gramca_= Grassland, _Bumca_=built up area.
(see also appendix 13)

Expression for Scenario 2 using equation 4.9 was :

Fin2=(shrmca*1+ Agmca*0.8+Wdmca*0.22+Gramca*0.15+bumca*11)   **_(Eq. 5.2)_**

where: _Fin2_ = Potential risk combining all land cover types, and the three criteria
The same codes for land cover types as in scenario 1 were used.
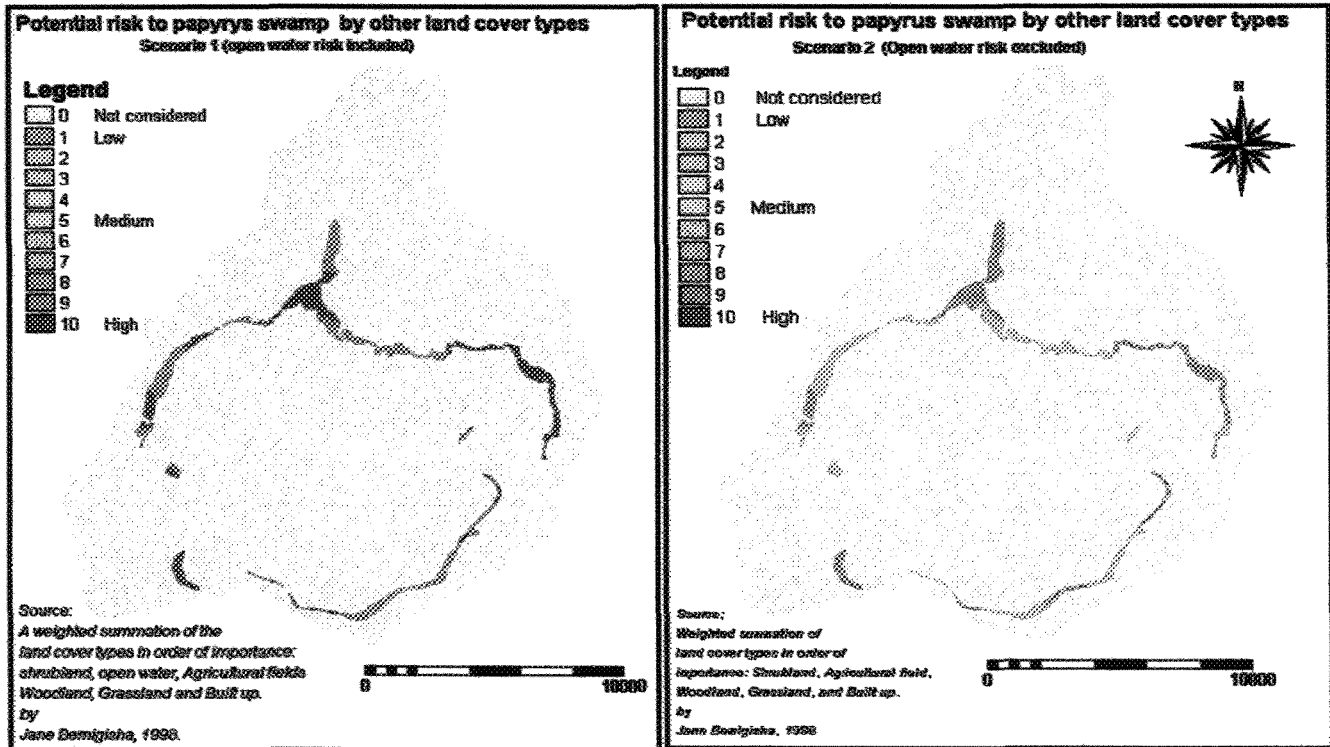
Figure 5.6   Potential risk areas of papyrus swamp Scenarios (1 (left) and 2 (right))
Note : For comparison purposes, the two scenario maps are normalized to the same scaling and simplified for
interpretation by grouping into classes 1 to 10 (Appendix 13).

- **_Scenario 1 (Including open water):_** All the papyrus areas showed risk levels ranging from medium to high. Most of the high risk areas are in the North.
- **_Scenario 2 (excluding open water):_** In this scenario more papyrus area was found to be with low to medium classes of potential risk than in scenario1. About 543 ha of papyrus was found at low to medium risk, which was 52 % of the total papyrus area, while the medium to high risk area covered 502 ha, 48% of the papyrus area (table 5.12).

Table 5.12 Risk levels to Papyrus: Scenario 1 and 2

	Low Medium		Medium High	
	Area (ha)	%ge	Area (ha)	%ge
Scenario 1	0	0	1044.9	100
Scenario 2	542.9	52	502	48

Source: based on figure 5.6

5.3.6 Discussion

Open water risk was found to be high all around the lake. Typologically, the swamp fringes the lake and if there is an inundation, all the areas around the lake are expected to be at high risk. This was demonstrated by the 1984 situation (figures 5.1 and 5.2, and 5.3 ; and tables 5.2 and 5.3).

Of the natural vegetation, shrubland showed the highest impact on papyrus, particularly in the north east where it borders the papyrus and because of its distance to papyrus area (figure 5.1, and table 5.5). The impact of grassland was mainly based on its distance to papyrus (table 5.5), while the impact of woodland, which is according to the general vegetation zonation, separated from papyrus by a zone of grassland or shrubland, was mainly determined by the criteria change of papyrus and its rate of change. As this was also relatively low, the overall effect of woodland might be considered minimal.

The expansion of agricultural fields are a high risk for papyrus, both in terms of distance and conversion. In 1995, agricultural fields were located next to papyrus, especially in the north western and southern papyrus areas, with consequent risk levels (figure 5.1, and 5.5). Most of the papyrus in the western part of the study area was converted into agricultural fields.

This is the reverse of built up area risk which was minimal especially in the western area considering that both residential and urban area had not reached the papyrus (figure 5.1).

Limitations:

The distance function assumed equal chance for all the land cover types to change papyrus (without constraints). In reality there are many constraints like the reserve area where the built up land cover type may not have equal influence compared to natural vegetation. The same is with open water inundation which can be constrained by slope. The integration of constraint mapping involving land use related influences like reserves, and fishery landings plus topography could provide a more realistic zoning.

The aggregation of the 1967 to 1995 influences did not cater for the fact that some land cover types displayed a fluctuating situation at a bigger temporal resolution. Types like open water and natural vegetation could be assessed better taking into account their seasonal changes.

5.3.8 *Conclusions*

● Inundation (open water) has a high impact on the distribution of papyrus, both in terms of distance and conversion (change in area and rate of change). It can also be recalled that it plays a big role in the vegetation succession regime and zonation (section 5.2)

● In scenario 1, in which water was included as a land cover, the potential risk levels turned out relatively high, varying between medium to high.

● When open water was not included (scenario 2), the potential risk to papyrus was found lower, ranging from low to medium.

● Of the natural vegetation shrubland had the highest impact on papyrus, both in terms of distance and conversion. The impact of grassland on papyrus was found mainly through its distance.

● Agriculture had a high impact on the distribution of papyrus, , both in terms of distance and conversion.

● At present, build up areas show a relatively low risk to papyrus.

5.4   Other possible factors influencing papyrus swamp distribution

The aim of this research component was to put in evidence the role of other factors other than could be mapped from land cover and to help in drawing conclusions, plus establishing hypotheses for further research. The basic information sources were field work, and ancillary data (topographic map) . Factors presented include ground water level, topography, soil drainage, soil depth, grazing, and burning as they influence papyrus attributes: ground cover, inflorescence cover, height, and culm diameter.

The field data distribution for the dependent variables (*C. papyrus* attributes) showed the majority of the values in the as zero class. This indicated a non normal distribution for the field data (figure 5.13).
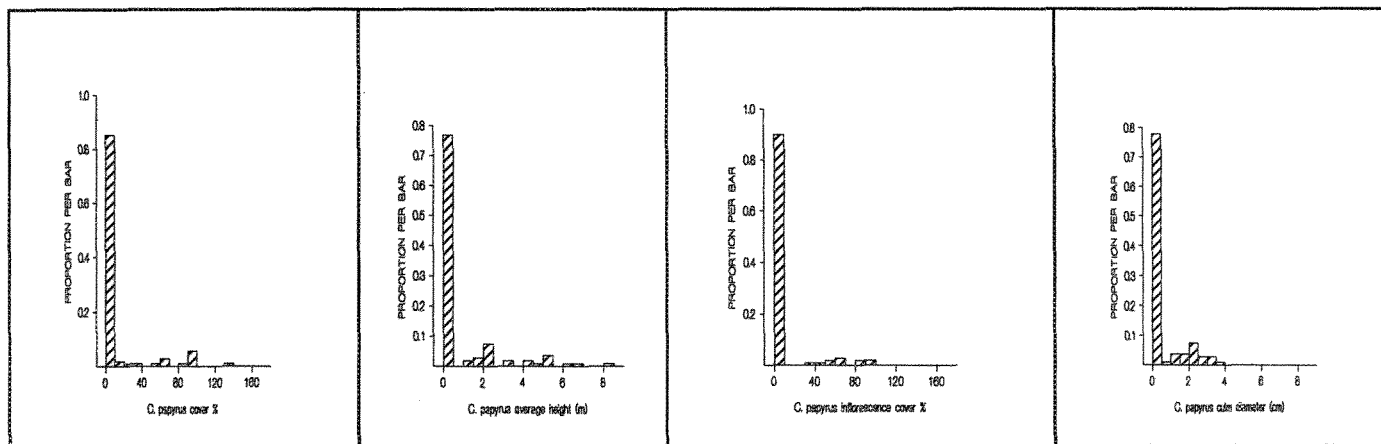
**Figure 5.13 Frequency histograms for Dependent variables (*C. papyrus* attributes)
(for 108 observations)**

a)   Ground water level

The level at which the water was intercepted while auguring was plotted in three major classes as: <50 cm -1 , 50-100 cm -2 , >100cm -3 (figure 5.14- the y-axis with the papyrus attributes, and the x-axis with the water level classes).

The highest *C. papyrus* cover percentages, average height , inflorescence cover percentage, and culm diameter were found occurring in class 1, the most shallow (<50 cm) and decreased as the depth increased.
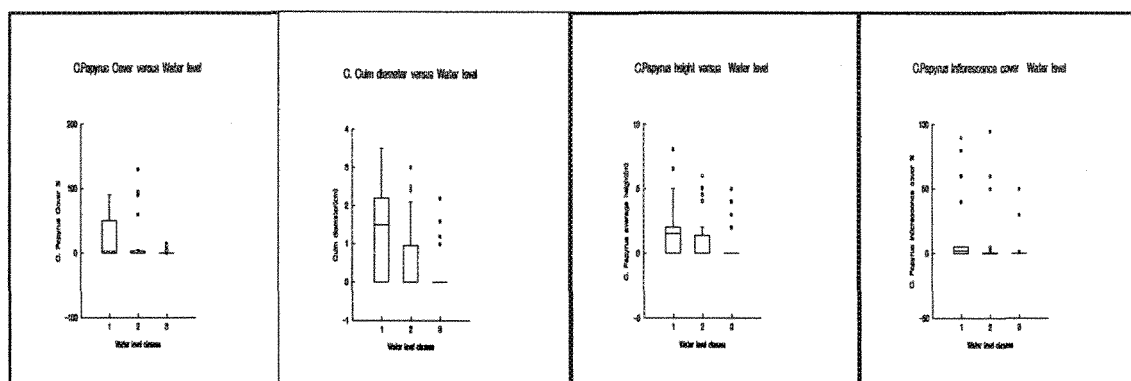
Figure 5.14   **Box and Whisker plots of** *C. Papyrus* **Versus ground water level**
                                           (for 108 observations)

By ANOVA analysis results, the distribution of Papyrus cover, culm diameter, height and Inflorescence cover was found to differ across the different ground water levels (P-values for all the *C. papyrus* attributes were below 0.05). Therefore the null hypothesis($H_o : \eta_1 = \eta_2 = \eta_3$) was rejected while the alternative ($H_a : \eta_1 \neq \eta_2 \neq \eta_3$) held. In the post hoc/pairwise comparison, *C. Papyrus* cover had remarkable mean differences occurring for class 1 and 3('P' value of 0.001) , for height class 1 and 3 ('P' value of 0.000), and Inflorescence cover, class 1 and 3 ('P' value of 0.005).

(b) Soil drainage
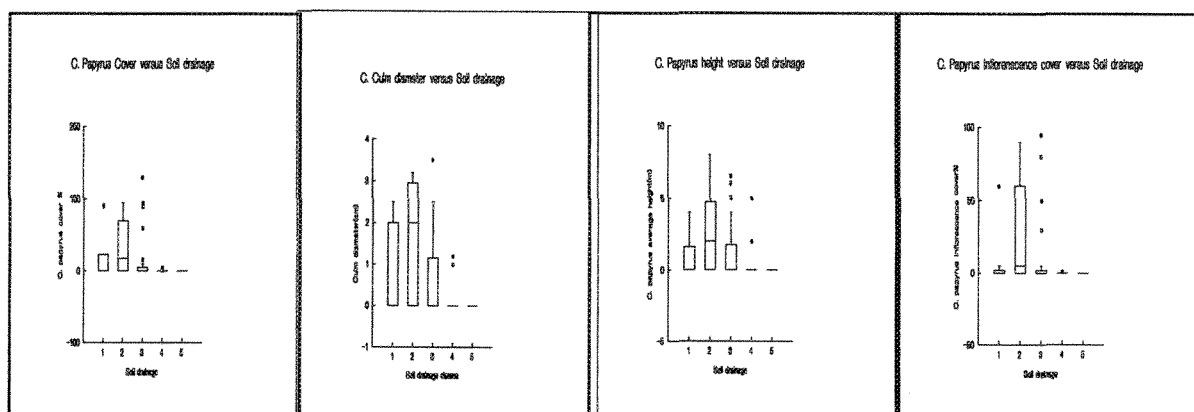
Figure 5.15   **Box and whisker plots of** *C. papyrus* **versus Soil Drainage**
                                        (for 108 observations)

The soil drainage data classified into five classes based on drainage capacities: very poor-1, poor-2, imperfect-3, 4-moderately well, 5-well- somewhat excessively drained was plotted versus all the dependent variables (figure 5.15- the y-axis with the papyrus attributes, and the x-axis with the soil drainage classes).

Highest *C. papyrus* cover percentages occurred in class 2, poor drainage. Less cover was shown for the imperfect drainage and decreased even further to the well drained class 4. Culm diameter, Inflorescence cover and average height ,had similar distributions with highest recordings in poor drained soils, less in very poor and moderately well drained, and least in well drained soils.

The ANOVA analysis results showed similar results as in water level above, and the null hypothesis was rejected. The post hoc/pairwise comparison results, indicated that for *C. Papyrus* cover, remarkable mean differences occurred for class 2 and 4 ('P' value of 0.004), class 2 and 5 ('P' value of 0.009). For Culm diameter, class 1 and 4 ('P' value of 0.034), and class 1 and 3 ('P' value of 0.047). Classes 2 and 4 were different ('P' value of 0.000). Similar results were for class 1 and 3. Inflorescence cover showed mean differences for class 2 and 4 ('P' value of 0.001) as well as class 2 and 5 ("P= 0.002).

(C) Soil depth

Soil depth classes identified were : <50 cm -1 , 50-100 cm -2 , >100cm -3 as shown on figure 5.16 below.
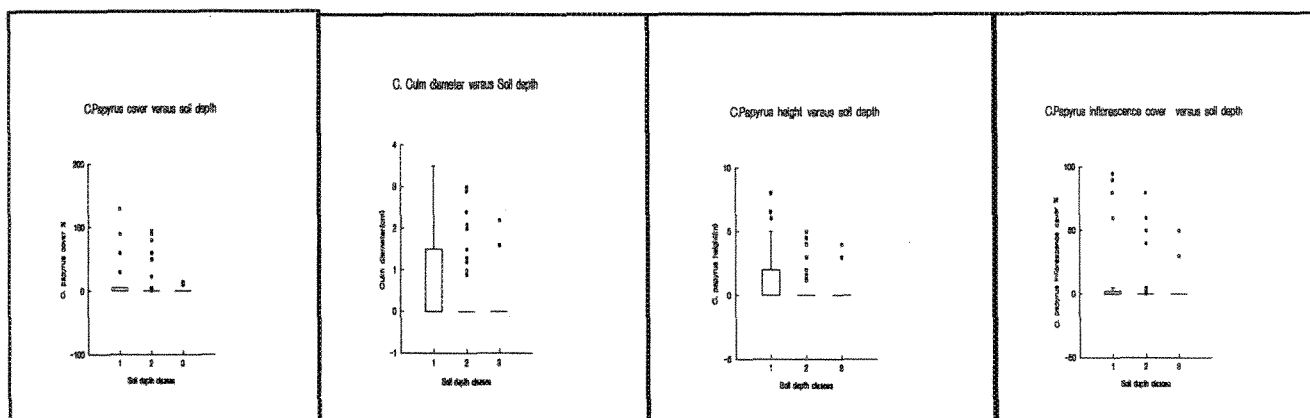
Figure 5.16   Box and whisker plots of *C. Papyrus* versus Soil depth
(for 108 observations)

The highest percentages of *C. papyrus* cover occurred in the most shallow soil class (<50cm) and similar distribution was shown for culm diameter, height , and inflorescence cover.

The distribution of papyrus cover, culm diameter, height and Inflorescence cover was found statistically equal across the different soil depth classes (all the 'P' values were above 0.05). The null hypothesis ($H_o : \eta_1 = \eta_2 = \eta_3$) was not rejected.

(d)   Topography

The relation of the distribution of Papyrus to topography was analyzed spatially by crossing the topography map (figure 3.3) with the land cover map of 1995(figure 5.1). The results (table 5.13) indicated that the highest papyrus cover was located in the Flat lacustrine plain, covering about 9% of the total topography class. The undulating class ranked second in the area cover with 8% while there was no cover for the hilly and upper elevation topography classes.

Table 5.13   Land cover composition by topography classes

Topography		Land cover types area (ha) in %					
code	description	Papyrus	Shrubland	Grassland	Woodland	Built up	Agricultural field
F1	Flat lacustrine plain	9	22	7	28	0	0
F2	Flat, higher elevation	0	78	22	0	0	0
AF1	Almost flat lacustrine plain	1	9	6	32	5	47
AF2	Almost flat lacustrine higher elevation	0	19	34	12	0	35
U	Undulating	8	29	14	20	2	27
H	Hilly	0	63	13	10	2	12

Source : Topography map (figure 3.3), and 1995 land cover map (figure 5.1).

Using field work data, topography was described according to the following classes : very flat, flat, undulating and hilly corresponding to classes 1, 2, 3, and 4 (figure 5.17).
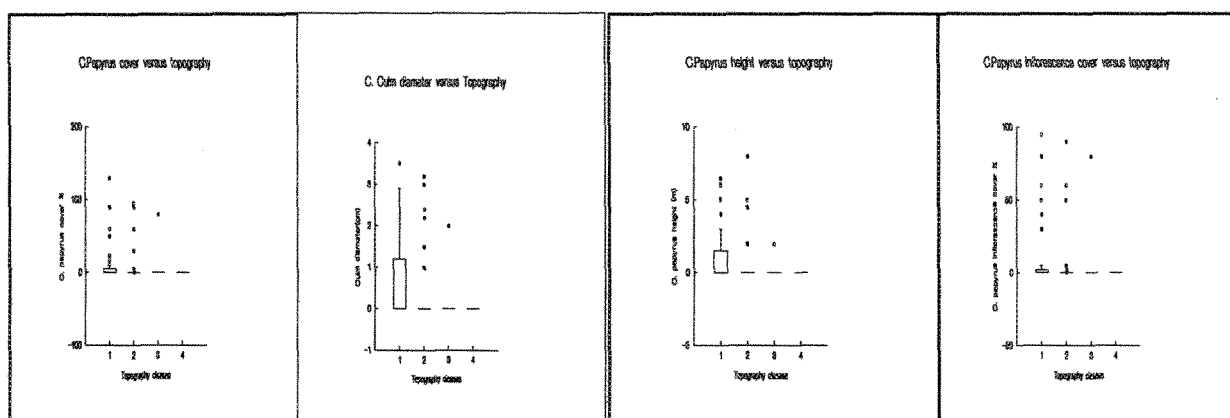
Figure 5.17   Box and whisker plots of *C. Papyrus* versus Topography
              (for 108 observations)

The highest percentages of *C. papyrus* cover occurred in class 1(very flat) and decreased towards the undulating and hilly topography. Similar distribution was shown for culm diameter, height , and inflorescence cover.

The distribution of Papyrus cover, culm diameter, height and Inflorescence cover was found to be statistically equal across the different topography classes (P-values all above 0.05). Therefore the null hypothesis ($H_o : \eta_1 = \eta_2 = \eta_3 = \eta_4$) was not rejected. The results showed that the papyrus swamp distribution may not necessarily differ across the different topography classes.

(e)   Grazing

According to figure 5.18, the non grazed areas had higher percentages of C. papyrus cover. A similar distribution was shown for culm diameter, height , and inflorescence cover.
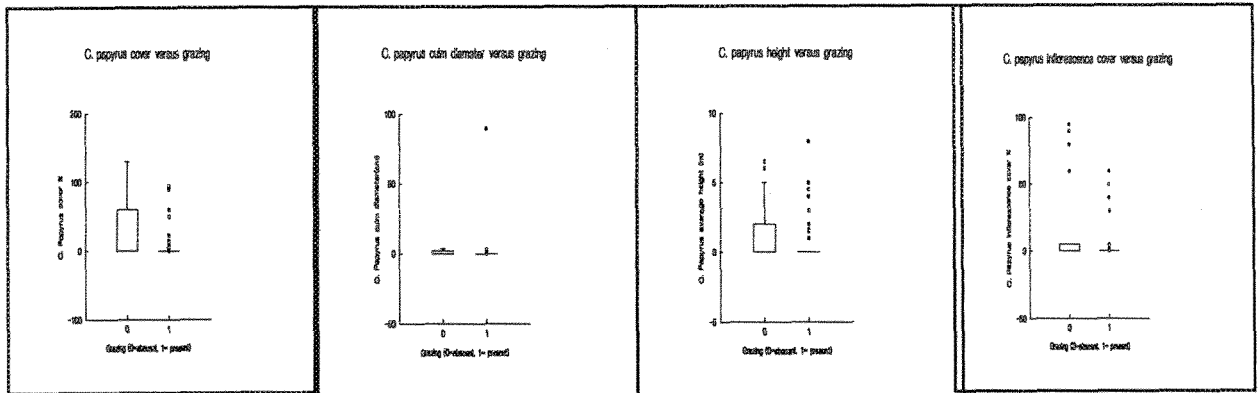
Figure 5.18   Box and whisker plots of C. Papyrus versus grazing (for 108 observations)

There were significant statistical differences amongst the means of the grazing classes at 5% level of significance (P-values for all the attributes except culm diameter were below 0.05). Therefore the null hypothesis for these classes ($H_o : \eta_1 = \eta_2$) was rejected while the alternative ($H_a : \eta_1 \neq \eta_2$) held. For culm diameter the means were not found to be equal ("p" value of 0.782) and therefore the null hypothesis($H_o : \eta_1 = \eta_2$) was not rejected.

The results showed that the distribution of papyrus cover, height and Inflorescence cover will differ between the grazed and non grazed papyrus. However, for culm diameter this difference was not observed.

The   post hoc/pairwise comparison results, indicated that C. Papyrus cover, height and Inflorescence cover had remarkable mean differences for class 1 and 2 ('P' values of 0.002, 0.029 and 0.002 respectively).

(f)   Burning

Burning data was recorded as burning present(1) and absent (0). The box and whiskers shows plots for 25 observations(figure 5.19-papyrus attributes on the y-axis and burning on the x-axis).
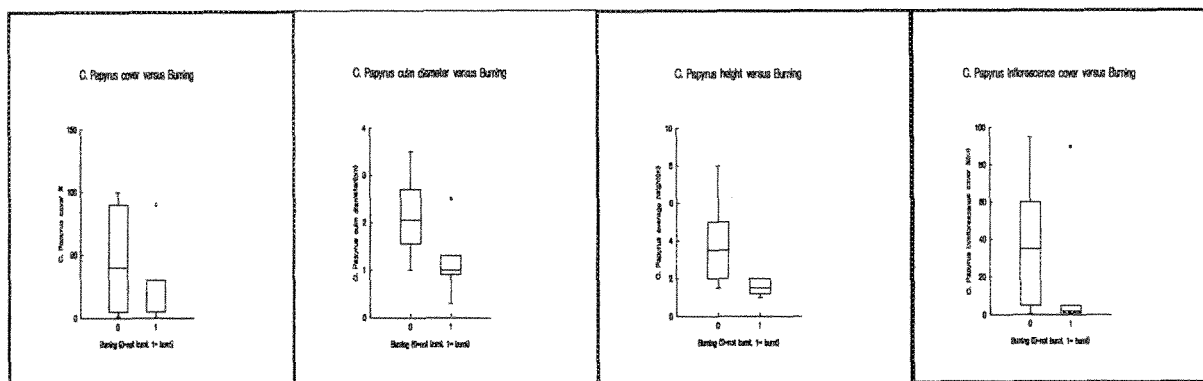
Figure 5.19   Box and whisker plots of _C. Papyrus_ versus burning (for 25 observations)

There was higher percentage of _C. papyrus_ cover in the non burnt areas. Similar distributions were realized for culm diameter , height and inflorescence cover.

In the ANOVA analysis, for _C. papyrus_ and Inflorescence cover the means for burning and no burning classes did not differ significantly ('p' value of 0.332, and 0.356 respectively). For Culm diameter and height, they differed ('P' value of 0.013, and 0.019 respectively) . The null hypothesis($H_o : \eta_1 = \eta_2$) for _C. papyrus_ cover and Inflorescence cover was not rejected while the alternative ($H_a : \eta_{1 \neq} \eta_2$) held for Culm diameter and height.

The results showed that the distribution of papyrus cover, and Inflorescence cover will differ between the burnt and non burnt papyrus. However, for culm diameter and height the difference was not observed.

5.4.1 Discussion

The variation in the _C.papyrus_ attributes versus the different gradients is an indication of the role the gradients play in the distribution of papyrus swamp.

Higher _C. Papyrus_ cover percentage was recorded in the shallow ground water < 50 cm and so were the rest of the attributes. Papyrus swamps as Macrophytes are known to be located in wet places (Denny,1985) and these are places which Roggeri (1995) characterised typologically as lake shores or flood plains. The definition by Njuguna et al. (1996) suggested the "waterlogged" aspect as one of the criteria to characterise the swamps.

Between the shallow class (<50 cm) and the deepest class (>100 cm), a statistical difference was observed in the means of the papyrus attributes with a suggestive conclusion that these attributes will decline as the ground water level increases in depth.

C. Papyrus attributes versus soil drainage showed a higher   distribution in the poor drainage class while in the very poor class it was less, then dropped towards the well drained class. Statistical mean differences were found between classes 2 and 4 and 2 and 5, indicating that there is a possible threshold between which class 2 (poor drainage) has a big influence.

The distribution of papyrus along the topography gradient had been outlined in section 3.7 and 5.1. A zonation was displayed from the lake comprising floating /emergent vegetation (other macrophytes), then papyrus mainly on the Flat lacustrine plain. Similar distribution was realized by Gaudet (1977). The cross sections (figure 3.7), the box and whisker plots (figure 5.17), plus the land cover topographic spatial analysis results (table 5.13), were in conformity.

The response to soil depth which was evidently variable in the box and whisker plots was statistically proved similar.

Apart from culm diameter, all the papyrus attributes were indicated as having statistically supported variations ('p' value <0.05) when grazed and not. The Box and whisker plots (figure 5.19) were in conformity with the variation. The findings of Gaudet (1977) that cattle graze the papyrus especially the young ones affirmed the difference.

For burning, the papyrus cover and the inflorescence cover had a statistical supported variation while it was the reverse with culm diameter and height. Figure 5.19 showed that all papyrus attributes will decline with burning. However, as indicated by figure 3.10, and Kruger (1984) plus Luttge (1997) in section 2.6, this observation does not give conclusive suggestions.

Limitations :

The sample scheme: A randomized sample design has been recommended in the collection of quantitative data for statistical analysis (Groten et al. 1995; Leps, 1990). This was not possible due to the limitations with the transect representative sample scheme aimed at the vegetation zonation and constarints of time did not allow for evaluation. Leps (1990), has recommended a *three term local quadrat variance method* for a transect based analysis of spatial patterns because it helps avoid what he calls the "possible influence of trends" on the results, meaning the steady decrease of abundance of species along a transect.

ANOVA assumptions: The statistical similarity and differences in the means across the different classes for the factors could be associated with the following ANOVA assumptions not met:
- The variance of the response variable should be constant across the treatments. (Variability in the number of samples per topography class could bring this effect)
- Normal distribution as evidenced by figure 5.13. Non Papyrus areas that were not sampled due to the representative sampling design. The papyrus land cover type represented just one of the number of classes that had to be represented.

In either case, the data would need to be transformed as some authors suggest (e.g. Skidmore 1997; Caughley and Sinclair 1994; Jongman et al. 1987).

Significance tests: Significance statements fall short of the estimation of an interval within which the value of the parameter would be expected to lie. After knowing that there will be an effect, the interest is to estimate its magnitude and calculate an interval within which the true value almost certainly lies, called a *confidence interval* (Box et al. 1989). This means that confidence intervals are more useful than single significance tests in explaining responses.

More explanations could also be offered with relational analyses like a correlation, and multivariate analysis by regression because papyrus swamps are part of an ecological system where factors in the systems interact.

The results of the fire effect indicated that the different cover, structural classes, and inflorescence cover varied across the burnt and non burnt observations. The limitation was that fire effect takes different forms, age, regime, intensity, and season (e.g. Kruger 1984; Verweij 1995). These forms were not taken into account.

The grazing inference was expected to fall short of expectation due to the fact that grazing effect can vary according to intensity (Verweij 1995; Grillas 1996).

Parameters not included

Van der Valk and Welling (1988), studied the development of zonation along a slope gradient in freshwater wetlands and concluded that the water level played a big role . However an interaction of other factors such as seedling mortality, dispersal, germination, and adult mortality provided complete explanation (Van der Valk and Welling,1988). Inferences on these factors was not integrated due to time implications for the type of experiments (controlled). Other explanatory factors like Soil pH, and soil nutrients (phosphorus and organic nitrogen) were not analyzed.

5.4.2 Conclusion

The box and whisker plots combined with ANOVA, and ancillary data (topography) have shown that Papyrus cover, inflorescence cover, height, and culm diameter will vary across most of the different gradients: ground water level; topography, soil drainage; and if burned , grazed or not. However, by ANOVA, topography and soil depth analysis did not show this difference. Neither was it shown in burning versus culm diameter analysis.

Given the status of the papyrus swamp and the possible influencing factors, it remains the management intervation because of the influence that will be presented in the next section.

5.5   Management Implications of the status of papyrus swamp

The quest for sustainable management is the foundation of the framework to integrate environmental issues into planning and development processes. Mannion, (1995) has elaborated on the problem of striking a balance between environment and development especially when conservation interests compete with sources of livelihoods like "agro-export" or industrial agriculture which is encouraged by increasing export earnings.

In its plan of 1996 the LNROA, made a special effort in this direction by identifying inappropriate or illegal activities on the Riparian Land at Lake Naivasha , envisaging the following measures (section 1.1):
- Protection and where necessary re-establish the papyrus fringe around the lake and allow its natural growth.
- Maintain and where necessary restore to a natural state a minimum of 50 metre buffer zone on the land side of the papyrus edge
- To discourage the reclaiming of flooded land, intensive irrigated agriculture, and building of permanent structures below the 1906 lake level (6210' or 1893.3 m contour)

At the same time the Ramsar site obligations (Frazier, 1996) recognize the inseparable relationships between wetlands and people but stresses the " *wise use concept[2]* " defined at the third meeting of the contracting parties to the Ramasar convention in Regina Canada, 1987.

Are the present land use activities in harmony with the proposed management measures? This question will be elaborated in this part of the research. The spatial representation of the proposed management boundaries in relation to the present land use activities are presented and discussed.

5.5.1 *Protection and re-establishment of the papyrus fringe*

Referring to the description and conclusions in the previous sections 5.2.2 and 5.2.3 it might be obvious that under the present conditions papyrus is hardly protected at all. Of the 3652 ha of papyrus swamp in 1967 (table 5.2) only 156 ha (about 4 %) can be seen as preserved in 1995 (table 5.3). In general, the papyrus swamp is decreasing since 1967. Although most of the papyrus area (40 %) was lost between 1967-1984, still a considerable area (29 %) was lost between 1984-1995 (table 5.2).

Fluctuating lake water levels seem to have a large impact on the spatial distribution of papyrus, but this is a natural phenomenon, which should be taken into account.
Expansion of agricultural fields may have a negative irreversible impact on the distribution of papyrus in the area. Although 13.4% of the papyrus area of 1967 was converted into agricultural fields, this process increased from 2.8% between 1967-1984 to 26.4% between 1984-1995. This does not include papyrus areas converted into grassland used for grazing of cattle, as it was not possible to distinguish between natural grasslands and grazing areas.

Re-establishment of papyrus is not taking place yet. During fieldwork in 1997 there were no observations of newly planted papyrus areas. In figure 5.20 (right bottom) possible areas for restoration of papyrus are indicated. The 1967 land cover map was taken as a reference. Excluded were the following present (1995) land cover types: open water, papyrus, agricultural fields and build up area (see also section 4.3.4). The total area recommended for re-establishment of papyrus was found to cover 1673 ha.

5.5.2 *Preservation of a 50 metre buffer zone*

In figure 5.20 (left upper) a 50 meter buffer zone around the present (1995) papyrus swamp area was drawn. This zone covers about 255 ha (table 5.14) of which agricultural fields cover 85.25 ha (33%), shrubland 138.5 ha (55%), woodland 29.25 ha (11%), and grassland 1.5 ha (1%). The spatial distribution of the different land cover types within the 50m buffer zone are presented in figure 5.20, left bottom.

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[2]

Sustainable utilization (human use of the wetlands so that it may yield the greatest continuos benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations) for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem (physical, chemical, and biological components e.g. soils water plants animals and nutrients and the interactions between them), (Frazier, 1995).

Taking into account the results presented in section 5.2 and 5.3, in which particularly the expansion of agricultural fields and shrubland form a high risk to papyrus, a buffer zone of 50 m might be arguable.

5.5.3 *The 1906 lake level*

The area defined below the 1906 lake level represents a total area of 5152.ha (figure 5.20, right upper) of which 1022 ha (19.8%) was papyrus swamp in 1995 (table 5.15). The activities identified within this area included agriculture, with fields taking up 3954.5 ha (76.8%), and built area covering 175.5 ha (3.4%).

Reviewing the proposed management recommendations *to discourage the reclaiming of flooded land, intensive irrigated agriculture, and building of permanent structures below the 1906 lake level*, it can be concluded that most (80.2%) of this area is actually reclaimed by agricultural fields and build-up area.

Considering the total area of agricultural fields and build up area of the lake zone (of Lake Naivasha), 77.6% of the agricultural fields appear to be located below the 1906 lake level and 73.4% of the build up area. Only for papyrus 97.8% is found in the area below the 1906 lake level (table 5.15).

Table 5.14 Land cover types within the 50 m buffer to papyrus swamp

Landcover	Area (ha)	Percentage
Agric	85.25	33
Grassland	1.50	1
Woodland	29.25	11
Shrubland	138.5	55
Total	254.5	

Table 5.15 Land cover types within the 1893.3 m contour line

Land cover type	Area (ha) within	%	Total area (ha)	%
Agricultural field	3954.5	76.8	5094.2	77.6
Built up	175.5	3.4	239.2	73.4
Papyrus swamp	1022	19.8	1044.9	97.8
Total	5152		6378.3	

Source: the tables are based on the maps in figure 5.20
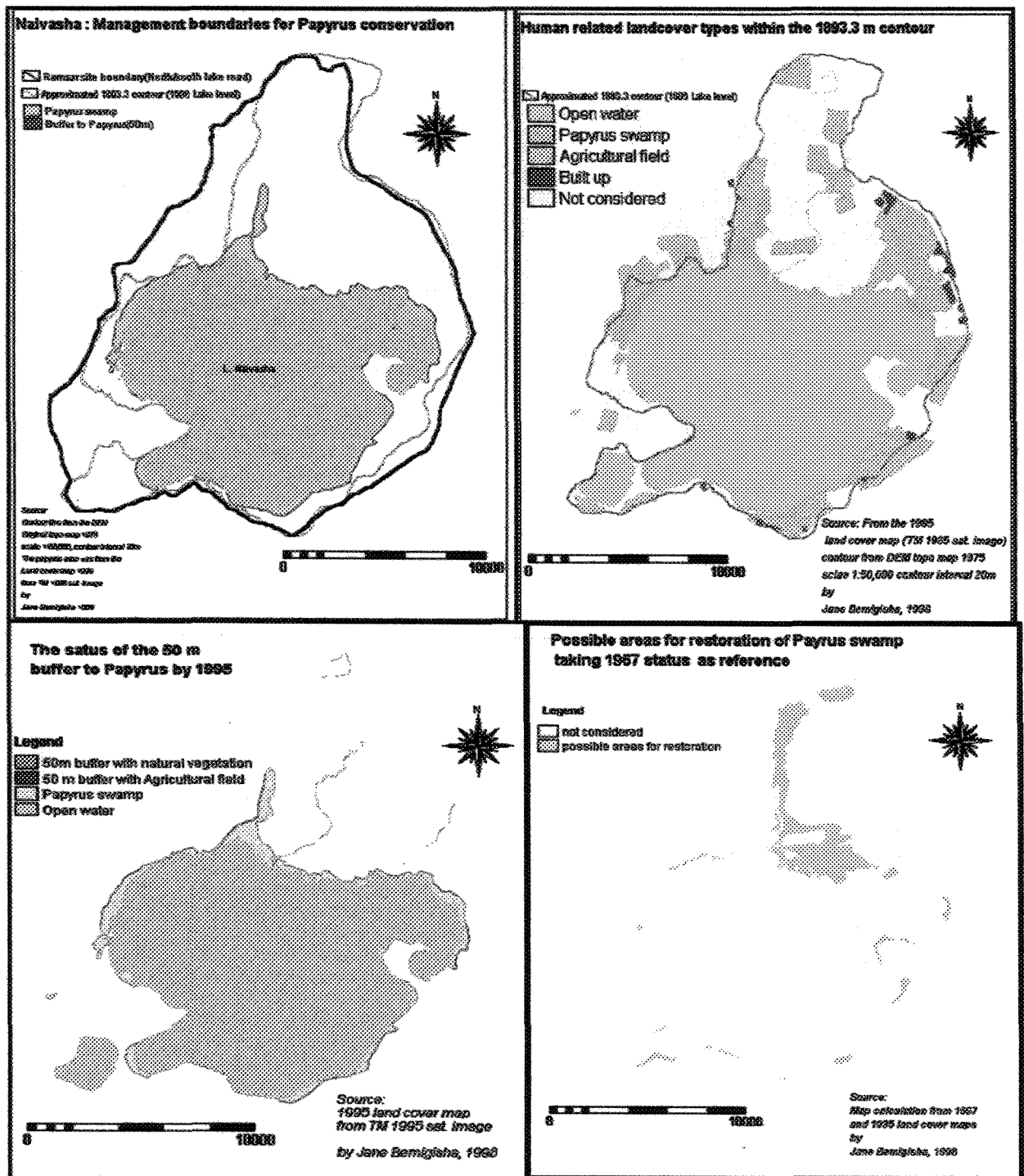
Figure 5. 20   The status of papyrus swamp and implications to management

5.5.4 Discussion

The status of the papyrus swamp in the study area (the Ramsar site and the rest of the management zones) is one of decline. The areas that have presently undergone dynamic change and are at high risk in view of the 1967, 1984, and 1995 status are part of the north, the north east, and south west. This status is attributed to both climatic influence and human interference.

- ## Climatic influence and the recharging system of the lake Naivasha
Papyrus swamp area is influenced by flooding and water recess, a natural process in which climate plays an important role. A correlation has been found between the average monthly fluctuation of the rift valley lakes including Naivasha and the precipitation regime in the Nyandarua mountains (Stuttard et al,1995). On the other hand, according to John Goldson Associates (1993) and Stuttard et al. (1995) the water inputs and outputs of lake Naivasha have complex relations due to two factors:
1- the Lake has underground seepage
2- The lake water abstraction and river diversion are not monitored.
These factors can be related to the direct human influence as will be explained after vegetation succession below.

- ## Vegetation Succession
It has been seen in section 5.1 and 5.2 that there is a succession regime with Woodland initially (1967) following papyrus in the zonation then shrubland overtaking this position by 1995. Shrubland also exhibited the highest potential risk based on the multicriteria ranking (tables 5.5, 5.10 and 5.11) The possible determinants of the regime have been indicated as :
1- Human interference especially, clearing, burning, and grazing
2- Vegetation succession through the indirect effect of climate and lake level.

In the next paragraph, these factors will be discussed in view of the flood regime and the relation to human interference.

- ## Direct Human influence

The distribution of the papyrus swamp at lake Naivasha is influenced directly by human activities like burning, grazing and cultivation (figure 3.6, 5.1, 5.2, 5.3, and 5.20) .
The observations made on the human activities, in view of the climatic regime, lake levels and succession are:

- Lake level changes can change the position and extent of the papyrus fringe and therefore the position of the 50 m buffer zone. Management decisions on the allocation and utilisation of the riparian land indicate that the above activities can advance with the receding water level and the subsequent papyrus withdrawal.

- The possibility for papyrus swamp to drawback following the inundation (flood), will increasingly get limited as dikes and ditches continue to be dug. These are not categorised as *permanent structures*, therefore continue to increase based on the principle that the riparian land can be utilised as long as there is no permanent structure.

- The assessment of the option for restoration of papyrus where it was shown that the possible area for restoration is more than the existing papyrus area. The question could be the evaluation of the suitability of the area considering the human interference and the climatic regime that is so irregular.

Limitations:

1- *The level of analysis* : A detailed land use analysis could not be integrated due to time constraint. Different land use types may have different impacts to the water regime, and the vegetation succession cycles therefore papyrus cover. A detailed land evaluation /land use plan approach (Fresco et al. 1992), integrating an EIA could yield a better assessment of the implications to management.

2-*The scope of the study* : The study was limited to the direct effect. Indirect effects of agricultural and urban expansion like chemical runoffs , plus the climatic influence may provide more explanations on prioritizing on the reconstruction and conservation of the papyrus swamp. The integration of the water quality relations to the papyrus swamp distribution could assist the examination of the distribution of the papyrus fringe in relation to important pollution sources . For management this would yield valuable information to assist in prioritizing areas for rehabilitation and conservation in order to optimize the benefits the wetland vegetation areas yield in improving water quality. Thus the buffer zone may need to be much wider in the locations with pollution problems.

The critical flooding level for papyrus could not be established in this research. It could be a good indicator of the level of risk that can be predicted by the indirect role climate and abstraction plays in controlling the water balance therefore papyrus distribution.

5.5.5 Conclusions

- Under the present land use system, preservation of papyrus is minimal.
- Re-establishment of papyrus was not observed. An area of 1673 ha has been indicated as possible for re-establishment of papyrus, mainly in the northern part.
- Within the proposed 50 m buffer zone of 255 ha along the existing papyrus area, agricultural fields cover 85.25 ha (33%), shrubland 138.5 ha (55%), woodland 29.25 ha (11%), and grassland 1.5 ha (1%).
- Most (80.2%) of the area below the 1906 lake level is reclaimed for agricultural fields and build-up area.

6. FINAL CONCLUSIONS AND ECOMMENDATIONS

In this chapter the results of the research are reviewed in relation to the objectives set in the introduction, specific conclusions are drawn and recommendations for further research made.

6.1 Conclusions

Through the integration of RS, GIS, and a DSS, the spatial and temporal distribution of papyrus swamps has been assessed for the period 1967, 1984 and 1995. Three major processes were undertaken : land cover mapping, monitoring and modeling, resulting into:

- the establishment of the spatial and temporal distribution of papyrus and other land cover types,
- the identification of areas within the papyrus swamp that will have a high risk to be taken over by another land cover type,
- the assessment of the influence of other environmental factors on the distribution of papyrus, and
- the assessment of present land use activities in relation to the proposed management measures.

During the production of spatial and temporal information 34 maps were handled , and by the implementation of the final model, 70 maps had been handled. This brought the number of maps handled to about 110 including the management related maps. It was only by using GIS that the amount of analysis was possible within the given time.

Objective 1. The spatial and temporal distribution of papyrus

The study confirmed that there was a remarkable vegetation zonation starting from the lake water, then papyrus swamp, followed by grassland and shrubland up to the Acacia woodlands at higher elevation. The zonation was interfered with by human activities as evidenced by the agricultural fields and to a lesser extend, by the expansion of build up areas.

The papyrus swamp in Lake Naivasha decreased with 2,607 ha, a loss of 71.4%., since 1967. Most (2185 ha or 60%) of the papyrus area was lost between 1967-1984. Between 1984-1995 the papyrus swamp reduced with 422 ha (29 %).
Fluctuating lake water levels have a large impact on the spatial distribution of papyrus, but this process is reversible. Between 1967-1984 a large area (1959 ha) of the papyrus was inundated, while a decrease in lake water level in the period 1984-1995 resulted in an increase of 823 ha of papyrus.
Dying papyrus stands may be mainly taken over by shrubland, grassland and finally woodland.
About 488 ha (13.4%) of papyrus swamp was converted into agricultural fields since 1967 Between 1967-1984 100.8 ha (2.8%) of papyrus was converted into agricultural fields and this increased with 387.5 ha (26.4%) between 1984-1995.
So far, papyrus was not observed to be converted into build-up area.

Objective 2   Potential risk analysis

Using Multiple criteria evaluation in a DSS, the potential risk to papyrus by each land cover type was determined based on two scenarios, one involving all the land cover types, and a scenario excluding open water.

The model inputs were derived from the status of the swamp between 1967 and 1995, using the following three criteria:

1- Papyrus risk index by each land cover type based on distance to a land cover type (the nearer to papyrus, the higher the risk).

2- Total change in area of papyrus by other land cover types (the higher the area of papyrus converted, the higher the risk)

3- The change rate of each land cover type for 1967-1995 (the higher the rate of change, the higher the risk)

When open water was included as a land cover (scenario 1), the potential risk levels were observed to be relatively high throughout the whole area, varying between medium to high (figure 5.6, left). Inundation (open water) showed high impact on the distribution of papyrus, both in terms of distance and conversion (change in area and rate of change).

For scenario 2, excluding open water, the potential risk to papyrus was lower, ranging from low to medium. The medium high risk areas were mainly in the north and north east where the most influencing land cover types have changed and which are also right after the papyrus in the zonation Of the natural vegetation shrubland was found to be with the highest impact on papyrus, both in terms of distance and conversion. The impact of grassland on papyrus was mainly through its distance.

Agriculture has a high impact on the distribution of papyrus, , both in terms of distance and conversion.

At present, build up areas show a relatively low risk to papyrus.

Objective 3   Other factors influencing the distribution of papyrus

In the study it was found that papyrus swamp was influenced by other factors like topography gradient, soils, and ground water level plus human activities such as grazing and burning. This was achieved by statistical inference using field work data.

Studied on the development of zonation along a slope gradient in freshwater wetlands have concluded more factors than considered in this study. A few can be mentioned as seedling mortality, dispersal, germination, and adult mortality (e.g. Gaudet 1977 ;Van der Valk and Welling 1988. Their findings were based on controlled experiments done for about four years. This could not be possible in this study therefore the explanations left further research gaps.

The grazing and burning data was collected based on present and absent records which made weak inference. The studies on such effects on vegetation have taken longer periods at least more than 2 years (e.g. Verweij, 1995). In this case the intensity and regime have been considered.

Objective 4   Present land use activities versus proposed management measures

In its Management Plan of 1996 the LNROA identified inappropriate or illegal activities on the Riparian Land. In this study an assessment was made.whether the present land use activities were in line with the following proposed measures in the Management Plan:

• Protection and where necessary re-establish the papyrus fringe around the lake and allow its natural growth.

- Maintain and where necessary restore to a natural state a minimum of 50 metre buffer zone on the land side of the papyrus edge
- To discourage the reclaiming of flooded land, intensive irrigated agriculture, and building of permanent structures below the 1906 lake level (6210' or 1893.3 m contour)

Protection of papyrus becomes crucial. Regardless of the Presidential ban on the destruction of Papyrus, made in 1987, the area of papyrus swamp continues to decrease. Of the 3652 ha of papyrus swamp in 1967 (table 5.2) only 156 ha (4%!!) was preserved in 1995 (table 5.3). Re-establishment of papyrus was not observed. An area of 1673 ha was recommended for re-establishment of papyrus, mainly in the northern part (figure 5.20, right bottom). The 1967 land cover map was taken as a reference. Excluded were the following present (1995) land cover types: open water, papyrus, agricultural fields and build up area.

Within the proposed 50 m buffer zone of 255 ha along the existing papyrus area, agricultural fields cover 85.25 ha (33%), shrubland 138.5 ha (55%), woodland 29.25 ha (11%), and grassland 1.5 ha (1%). Taken into account the results presented in section 5.2 and 5.3, in which particularly the expansion of agricultural fields and shrubland form a high risk to papyrus, a buffer zone of 50 m might be arguable.

Most (80.2%) of the area below the 1906 lake level is reclaimed by agricultural fields and build-up area. This in absolute not in harmony with the proposed management measure to discourage the reclaiming of flooded land, intensive irrigated agriculture, and building of permanent structures below the 1906 lake level

Major limitations
The study could not provide an explanation on the relations between the flood regime and time lag for papyrus seedling mortality, dispersal, germination, and adult mortality which influence the distribution of wetlands vegetation.

Water quality relations to the papyrus swamp distribution were not considered in this study. This could assist the examination of the distribution of the papyrus fringe in relation to important pollution sources . The information would assist in prioritizing areas for rehabilitation and conservation in order to optimize the benefits the wetlands vegetation areas yield in improving water quality .

- *Lack of appropriate image*
Lack of recent aerial photographs made it difficult to verify some of the mapping units. Based on field verification, it was realized that between 1995 and 1997 considerable changes in land cover had taken place, therefore limiting the reliability of the mapping results.

- *accessibility*
1- The physical characteristics of the wetland being too boggy in some places.
2- Insecurity by wild animals like buffalo. There were frequent chases.
3- Farm enclosures and lack of co-operation by some farmers who seemed suspicious.
The problems had timing implications and contributed to the limitation in the number of samples.

6.2   Recommendations

The distribution of papyrus should be explained by an understanding of the capacity of papyrus swamp to regain its area following the effects of the climatic regime and flooding levels. This should integrate the analysis of both direct and indirect human impact through activities such as burning, clearing, and grazing which may influence the successional cycle. The capabilities of GIS and remote sensing should be exploited.

The integration of the water quality relations to the papyrus swamp distribution should be undertaken to assist the assessment of the distribution of the papyrus fringe in relation to important pollution sources. The papyrus fringe and buffer zone may then need to be much wider in those locations with pollution problems so as to optimize the advantages of the swamp in water purification.

A more objective evaluation of the remote sensed materials and methods to be used should be prerequisite to commencing a wetlands monitoring study. The use of a Decision Support systems is one technique that can be used to evaluate the issues not only concerning scale and resolution, but cost and time.

Suggestions for further research

The outcome of the current study raised some new questions concerning information gaps, and contradictions in proposed measures, leading to the following suggestions for further research:

- Fluctuating lake water levels have an impact on the distribution of papyrus. To be able to predict the impact of inundation and recess (drawdown) on papyrus, a detailed water balance study on the area should be incorporated in the monitoring of papyrus. Specific research question can thus be drafted:
"What is the role of climate in the water balance of lake Naivasha ? How much water is abstracted by human activities? How much water is evaporated and what is the role of papyrus in this? Can water balance modelling be used to predict the re-flooding and recess risk to papyrus? "What is the role of other factors like seedling mortality, dispersal, germination, and adult mortality ?

- Conversion of papyrus into shrubland, grassland and finally (Acacia) woodland is a serious threat. A specific study on vegetation succession should be carried out in relation to human induced factors like burning (fire regime and intensity) , grazing (by natural animal populations and by livestock) and cultivation (direct conversion, application of fertilizers, pesticides and other pollutants). Inside in those factors might help to understand the regeneration capacity of papyrus (*C. papyrus*) . Questions that could be posed are:
" What is the role of human interference, burning, grazing and cultivation on the vegetation successional cycle at Lake Naivasha, and how does it affect the distribution of papyrus?
"Can this successional cycle be explained from the resistance of the different vegetation types to climatic influences and corresponding fluctuations in lake water levels? Or inducement by human activities? Or a combination?"

Referring to the proposed management measures, the following suggestions for further research are recommended:

- A detailed site selection study for protection and re-establishment of papyrus.
- The proposed 50m buffer zone along the existing papyrus fringe should be reconsidered. A detailed suitability study to determine a variable width of the buffer zone is recommended, taking into account conservation and protection values, and economic interests.
- Further reclamation of flooded land should be stopped through legal instruments. Receding lake water levels encourage reclamation of riparian land. The construction of dikes and other flood protection

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APPENDIXES

Appendix 1.   PROBLEM ANALYSIS

APPENDIX 1a : PROBLEM TREE

Conceived causal effect relations collateral to the Conceptual framework

KEY
Interelationships:
---▷▷▶
--○▶

▨ Main focus

Decreased quantity and quality of lake water

Lake water pollution ○▶

Nuisence growth of weeds on the lake

Flactuating/ decreasing lake water levels ▷▷▶

Uncertain water balance in the ecosystem

Common draughts in drier areas of catchment

Burning of papyrus

Less purifying effect of wetlands to water inflows into the lake

Nutrient enrichment of the lake

Lowering water table

Diminishing recharge to the lake

Poor urban sewage system ○▶

Siltation of the lake

extraction of water from the lake

Subsurface water drilling

Diversion of inlet rivers

Unplanned growth of human settlement

decreased Wetland vegetation area

Soil erosion acceleration

Increased demand for water

High fertilizer/ pestcide in put to farms

Drainage of flooded land for cultivation

Overgrazing on riparian land

Need for water for Irrigation

Fast growing populatin

Agricultural development

Tourism Develpment

Geothermal power generation

APPENDIX 1.b Information Gaps for Lake Naivasha conservation planning.

Recommendations of the 1993 EIA study pertaining to information gaps

1- A monitoring exercise on the lake. The requirement was to collect data which would enable an accurate water balance to be calculated at regular intervals.

2- Within the general monitoring program, pollution should receive particular attention including control of irrigation run off papyrus maintenance and pesticide and plastic use and disposal.

3- Regular monitoring of crucial parameters in water, vegetation, flora, and fauna should be started so that an overall picture of the lake and its surroundings over time can be built up. The monitoring should be designed with the needs of a management plan and management body in mind.

Source: John Goldson Associates, 1993.

Appendix 2.

2.1 Definition of Satellite image (TM 1995) mapping units

DESCRIPTION OF IMAGE OBJECTS BY THEIR IMAGE CHARACTERISTICS FOR THE 1995 SATELLITE IMAGE

Image object	Fcc color	Texture	Shape	Predicted cover
1	Bl	s	n	Open water
2	dP	s	n	open water
3	M	s	y	Agricultural field
4	B	s	y	"
5	dG	s	y	"
6	lG	s	y	"
7	R	s	y	"
8	Br	s	y	"
9	dG	s	n	Grassland
10	Br	c	n	Woodland
11	R	s	n	?
12	Br	s	n	?
13	lB	s	y	Agricultural field
14	lB	s	n	Grassland
15	lG	s	n	?
16	B	c	n	Built up
17	gB	c	n	Woodland

Code book of image characteristics

Fcc Color	Texture	Shape
R= Red	S= smooth	Y=yes
Br=Brownsh red	C= coarse	N= No
M=magenta		
dG= Dark green		
lG= Light green		
B= Blue		
lB= Light blue		
Bl= Black		
dP= Dark purple		
gB=Greenish brown		

IMAGE OBJECT CLASSES DESCRIBED BY THEIR IMAGE CHARACTERISTICS

Image object class	image characteristics			Peredicted class
	color	Texture	shape	
IOC1	dP-Bl	s	n	open water
IOC2	M-Dg-R-bR-lB	s	y	Agricultural field
IOC3	dG-lB-lG	s	n	Grassland
IOC4	Br-gB	c	n	Woodland
IOC5	R	s	n	?
IOC6	Br	s	n	?
IOC7	B	c	n	Built up

2.2 Definition of image mapping units Aerial Photographs (1967)

DESCRIPTION OF IMAGE OBJECTS BY THEIR IMAGE CHARACTERISTICS FOR THE 1967 AERIAL PHOTOGRAPHS

Image object	shape		Tone	Texture	Sterio height	Predicted cover
	Present	Regular				
1	no		d	c	yes	Woodland
2	no		g	f	yes	Shrubland
3	no		lg	s	no	Grassland
4	no		lg	c	yes	Woodland
5	yes	no	dg	s	no	Open water
6	no		d	f	yes	Shrubland
7	yes	yes	w	s/f	yes	Built up
8	yes	yes	l	s	no	Agric field
9	yes	yes	dg	s	no	Agric field
10	no		dg	f	yes	Papyrus

Code book

Tone		Texture
bl	black	S= smooth
g	gray	f= fine
w	white	C= coarse
d	dark	
l	light	

IMAGE OBJECT CLASSES DESCRIBED BY THEIR IMAGE CHARACTERISTICS

Image object class	Image characteristics					Predicted class
	Tone	shape		Texture	Sterio height	
		Present	Regular			
IOC1	d-lg	no		c	yes	Woodland
IOC2	g-dg	no		f	yes	Shrubland
IOC3	lg	no		s	no	Grassland
IOC4	dg	yes	no	s	no	Open water
IOC5	w	yes	yes	s - c	yes	Built up
IOC6	l-dg	yes	yes	s	no	Agric field

Appendix 3.   Sample Relevee' sheet

LAND COVER RELEVEE' FOR NAIVASHA FIELDWORK, MAY/JUNE 1997.

GENERAL INFORMATION

Relevee no:... ... ...

Site ... ...

Date... ... ...

Transect... ... ...

Observer(s)..................... ... ...

Sample size.....................................(m²)

IMAGE CHARACTERISTICS		GENERAL LAND USE:
Map unit:		Traces of human
Image object characteristics Field/No field		influence (present/not)
Field pattern Yes/No		Burning
Color	Texture	Grazing
R /Br /M /lG /B /lB /Bl /dP /gB	C/F/S	Animal droppings
Key: C - Coarse F- Fine S - Smooth		Footprints
:R - Red Br- Brown red M -Magenta dG - Dark green lG - Light green		Trampling
:B - Blue lB - Light blue Bl- Black dP - Dark purple gB Greenish brown		Ploughing

SITE DESCRIPTION

Location(UTM) Map - N... ... ...   E... ... ...

GPS - N... ... ...   E... ... ...

Altitude:(M.A.S.L)... ... ...

TOPOGRAPHY		SOIL DRAINAGE	FLOODING
Flat	0 - 0.2 % slope	Excessively well	Agent
Almost flat	0.5 - 2%	Well	none
Gently undulating	2 - 5%	Moderately well	rain
Undulating	5 - 10%	Imperfect	run-on
Rolling	10 - 15%	Poor	river
Hilly	15 - 30 %	Very poor	lake
Steeply dissected	>30% moderate range of elevation		
Mountainous	>30% great range of elevation (>300m)		

SOIL

Soil horizon:	Depth (cm)	Texture	Colour	pH	Mottling (Yes/No)	Ground water level(cm)	Remarks

Comments:

VEGETATION

Layer	>6 m	4 - 6 m	1 - 4 m	< 1 m
Ave. Height				
Sample size				
Cover %				

Layer	Species	Cover¹	Height²	Bare soil %	Remarks		

C. Papyrus attributes							
Inflorescence cover %							
Circumference (cm)	1... ...	2...	3...	4...	5...	6...	7... ... ...
	8...	9...	10...				

Cover¹   (+)=present; 1=1 -10%; 2=11 - 25% ; 3=26 - 50 4= 51 - 75% ; 5= 76 - 100%

Height²   1=<1 m ; 2=1m -3m ; 3=4m - 6m ; 4=>6m

Appendix 4.   Sample checklist : AGRICULTURAL LAND USE FOR NAIVASHA FIELDWORK MAY/JUNE, 1997.

A. GENERAL INFORMATION
1) Sample No................   Date................... Location(UTM)....................
2) Interviewer(s.)..................
3) Holding
3.1)Holder's name..
3.2) Name of holding..
3.3) Total holding (ha/Acres)..
3.4) Tenancy...from(date)..............
4) Reclamation:
4.1 How much land drained from swamp (ha)..........................
4.2 When drainage started(year)...
4.3 Is drainage continuing Yes/No   If yes, how much more expected to be drained (ha)................

B. PLOT INFORMATION
1) **Plot** size(ha/acres)..%ge cultivated...................
2) **CROPS**
2.1 Crop grown   ....Yield kg/ha/yr.................................
2.2 Purpose   ....
2.3 Status (commercial/subsistence/both)
2.4 Operation sequence (start - end dates)
2.4.1)Material inputs
a) Fertilizers -

b) Pesticides

c) Fungicides

d) Farm Yard manure
e)Power source for land preparation and implements

2.4.2) Irrigation
-Level of irrigation- High/medium/low
-Amount (ltrs/day)......................................
-Source-Bore-hole /pump from lake, river, canal)
- Type of Irrigation - Overhead/drip
2.4.2) Disposal system for
a)waste water from Irrigation-fertilizer combination..

b) Chemical containers...

c) Plastic material...

d) Bags...

2.4.3) If by incinerator, what temperature (^{o}C)......................................
        How much distance from lake edge(m).......................................
        How much distance from bore hole or any water source(m)................

3) Livestock

a)Animals kept	No. of animals	Purpose	output
....	....	....	....

3.2) Material in puts
3.2.1)Acaricides : Amount and quantity (per/year)...
3.2.2)Water supply-
-Amount (ml/day)..
- Source (Bore-hole /pump from lake, river, canal)

4) Infrastructure
(Farm house/ green houses/Drainage /Ditches/ River channelization , diversion, dam construction/Dikes /roads, paths/Cattle dip/Septic tank /Waste dumping site/Incinerators

Where? (within/without) riparian land
How much land involved(ha)
5) Observations by farmer
a)on-site losses : Erosion/Runoff signs(gullies/ rills/sheet) when ....
b)Soil compaction -(surface crusting/bare soil)
6) Changes in management
Inputs...........when.........................why
Infrastructure...when.................... why
What is the environmental impact of the changes?

7)**Environmental conservation** , Soil/water conservation measures (afforestation/reforestation/grass strips/terracing/wind breaks)Water conservation (recycling/rainwater tapping
8) **Remarks**

Appendix 5. Land cover field data code book

6.1 CODE BOOK FOR LANDCOVER DATA

Dataset	Column code	DESCRIPTION		Class	Class code
Relevee	NO	Relevee number			
Site	SI	Site	Fishery landing	FL	
			Rema island	RI	
			Korongo farm	KF	
			Kalandin Market	KM	
			Loldia Farm	LF	
			Malewa bay	MB	
			Brixia/Marula boundary	BM	
			KWS Annex	KA	
			Lake Oloiden	LO	
			Mundui Estate	ME	
			Marula	MA	
			Cresent Island	CI	
			Lake Sonachi	SO	
			Cunningham Raid farm	CR	
Location (UT	Coord(N)	Coordinates(UTM)	Northing	N	
	Coord(E)	in meters	Easting	E	
	TOP	Topography	Flat	F	1
			Almost flat	AF	2
			Undulating	U	3
			Hilly	H	4
Soil	TXT	Soil Texture	Sand	S	
			Sandy Clay	SC	
			Sandy Clay Loam	SCL	
			Sandy Loam	SL	
			Silty Clay	SIC	
			Silty Clay Loam	SICL	
			Silty Loam	SIL	
			Loamy Clay	LC	
			Clay Loam	CL	
	COL	Soil Color	(as read off in the munsell color chart)		
	MOT	Mottling	Yes		
			No		
		Soil drainage	Well drained	W	5
			Moderately well	M	4
			Imperfect	I	3
			Poor	P	2
			Very poor	Vp	1

Dataset	Column code	Description		Class	Class code
	DEP	Soil depth(cm)			
	DEP1			<50	1
				50-100	2
				>100	3
	WAT	Water level (cm)			
	WAT1			<50	1
				50-100	2
				>100	3
	BUR		Burning	present	1
				abscent	0
	GRA		Grazing	present	1
				abscent	0
	REC		Recreation	present	1
				abscent	0
Vegetation	BS	Bare soil %			
	PAP	C.papyrus cover %			
	DIA	Culm diameter (cm)			
	INF	Inflorescence cover %			
	HEI	Average Height (M)			
	CLASS	Vegetation structure Class	Grassland	G	
			Shruby Grasssland	Gs	
			Shrubland	Sh	
			Woody dense shrubland	Sdw	
			Open woody shrubland	Sow	
			Woody grassland	Gw	
			Dense woodland	Wd	
			Open woodland	Wo	
			Dense forest	Fd	
			Open forest	Fo	
			Open shrubland	So	
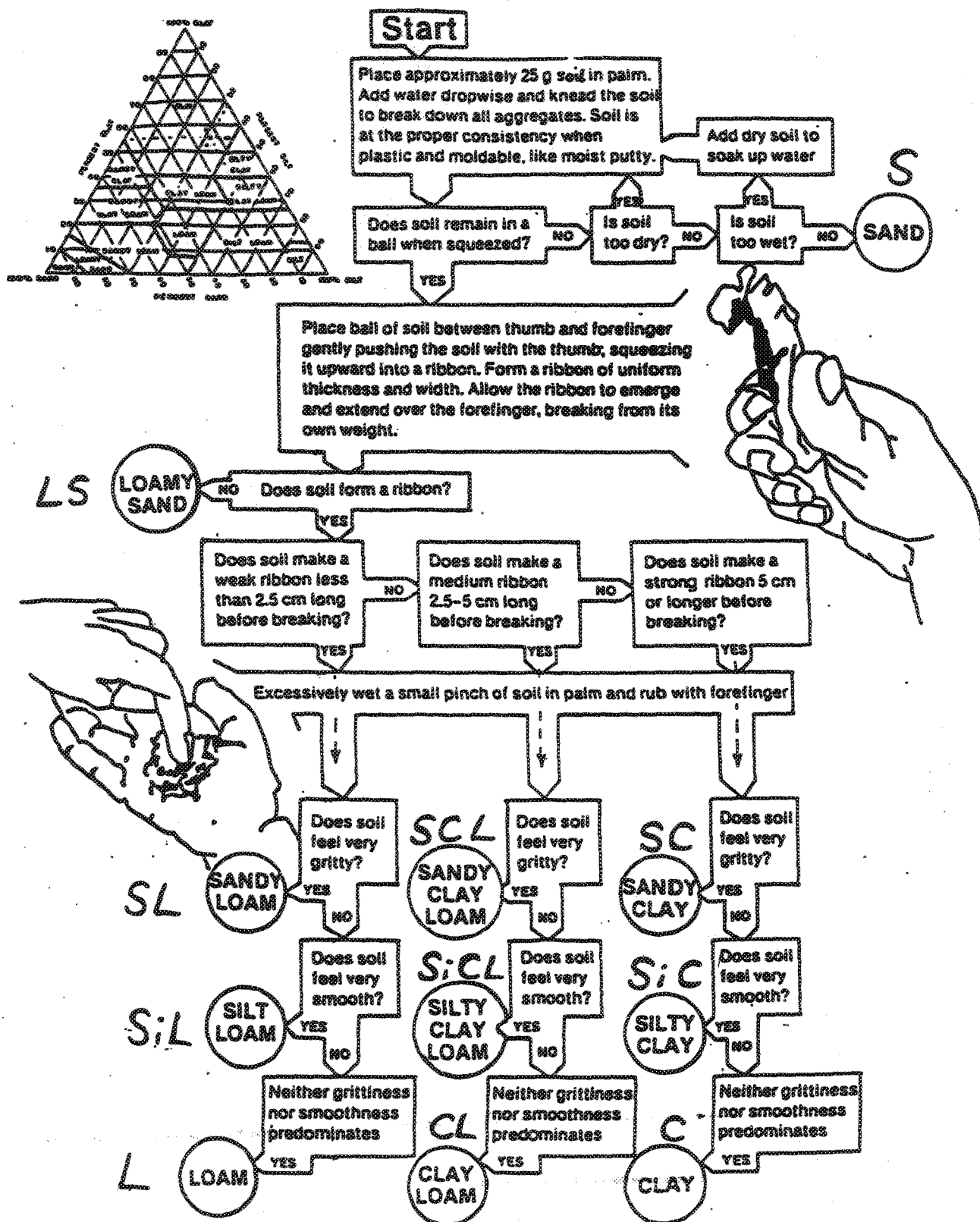
**VEGETATION ZONATION AND SUCCESSION AT
                          L. NAIVASHA BY GAUDET (1977)**

THE ZONATION AT L. NAIVASHA
Gaudet (1977) identified the following zones and species:
1. Lake Edge: *Ceratophyllum demersum, Sphaeranthus suaveolens* and *Nymphaea caerulea* .
2. Draw down area : *Cyperus spp,*
3. Papyrus fringe swamp: *Cyperus papyrus, polygonum spp*
4. Bushland: *Polygonum spp, conyza spp*, grasses, and shrubs(*Lotus, lantana,* etc
5. Acacia woodland: *Acacia Xanthophloea* and grasses.
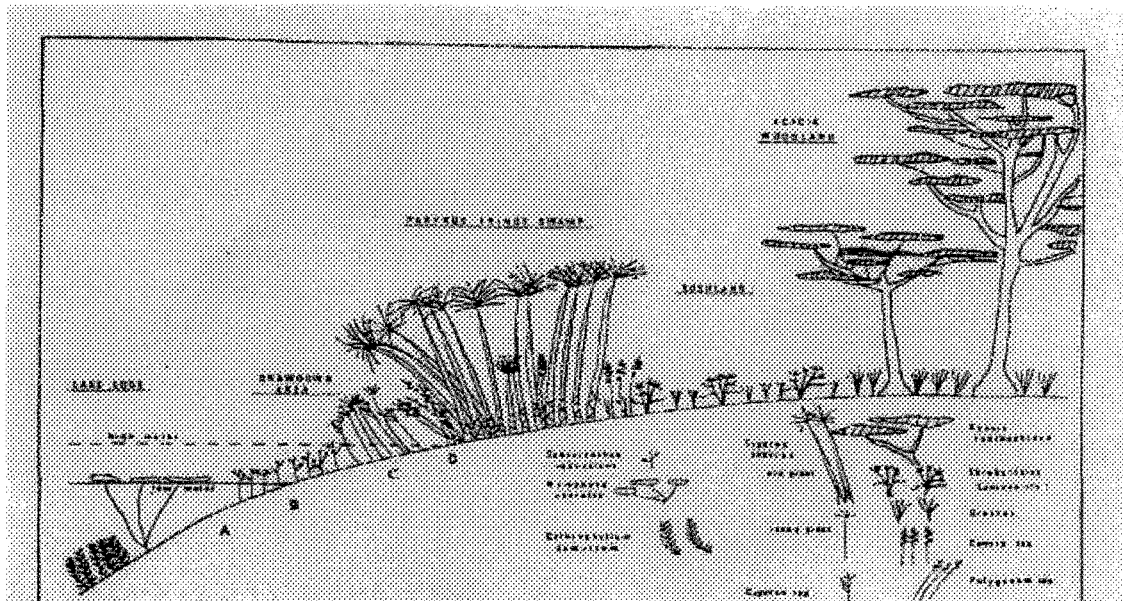
Source (Gaudet, 1977)

VEGETATION SUCCESSION AT LAKE NAIVASHA (**Summary of the stages in the succession between (1971- 1975)**
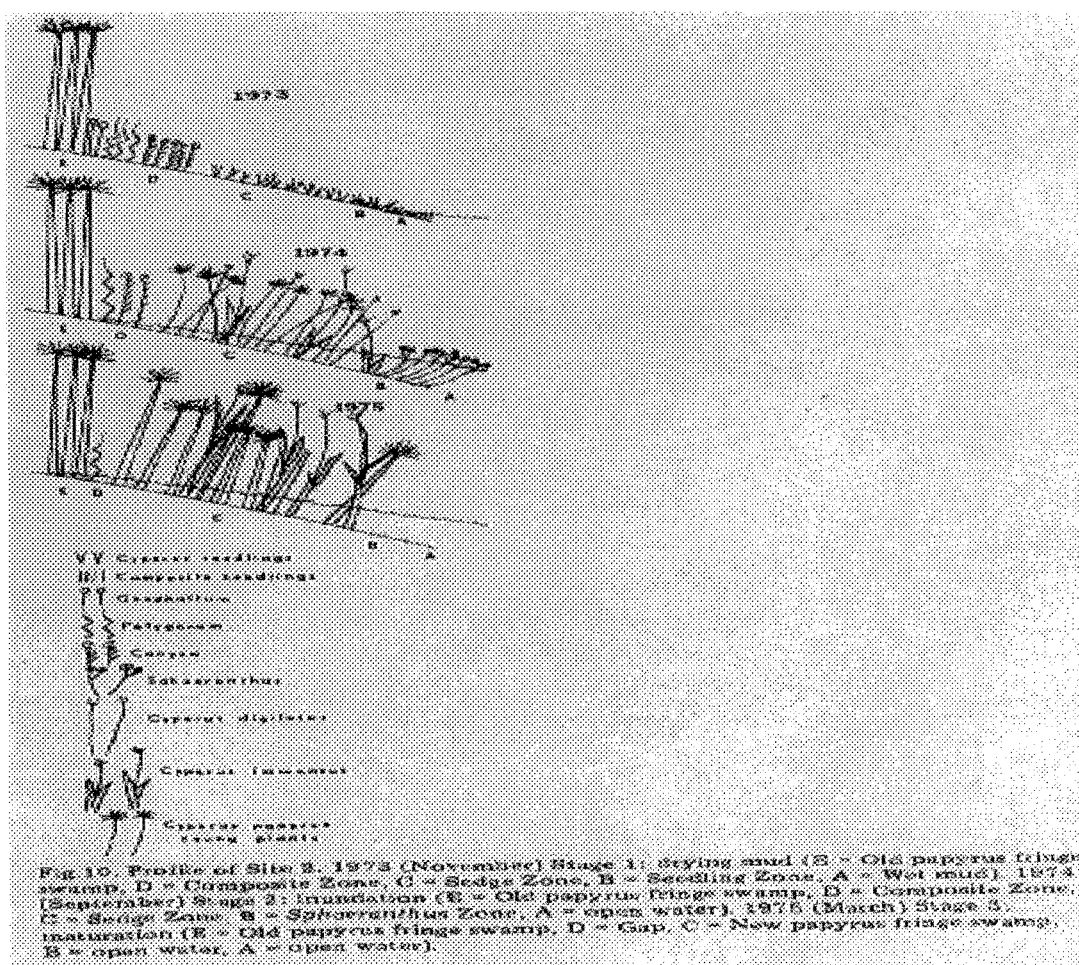

source: Gaudet 1977

a) Early stage of Succession in the drawdown region (1971- 1973)

A long period of low lake levels led to a band of exposed *papyrus soil* in front of the lake side papyrus fringe swamps, and different plants develop in the substrate according to seedling, grass-sedge, leguminous and composite zones. For example:

1) volcanic sand: e.g *Sesbania sesban, cyperus laevigatus, cyperus rigidifolius, cassia didymotrya*

2) Papyrus mad: *Cyperus spp, cyperus papyrus, sphaeranthus suaveolans polygonum spp, Nympphaea caerula* , conyza spp, etc.

The zones can be characterized by: seed viability, stage of plant development, density of species, biomass, and type of litter.

The average length of stems was at a minimum in the seedling zone, intermediate in the sedge zone and maximum in the composite zone.

b) Intermediate stage- With the beginning of the rainy season, (in April), the lake level

began to rise, the zonation almost remained the same. Cyprus still dominated the sedge zone. By September, most regions inundated , species number did not change but decrease in abundance was observed. . The *sphaeranthus* plants increased and dominated what was formally the seedling zone .*Conyza* and *Gnaphaluim* died. Some places recorded higher

biomass, but papyrus not to expectation. Probably grazing is intensive now because papyrus is still young therefore palatable to hippo and cattle.

c) Later stage

After the replacement of the seedling zone by *sphaeranthus* zone, zonation became more discrete, and sharply delimited rather than the gradual zonation seen previously.
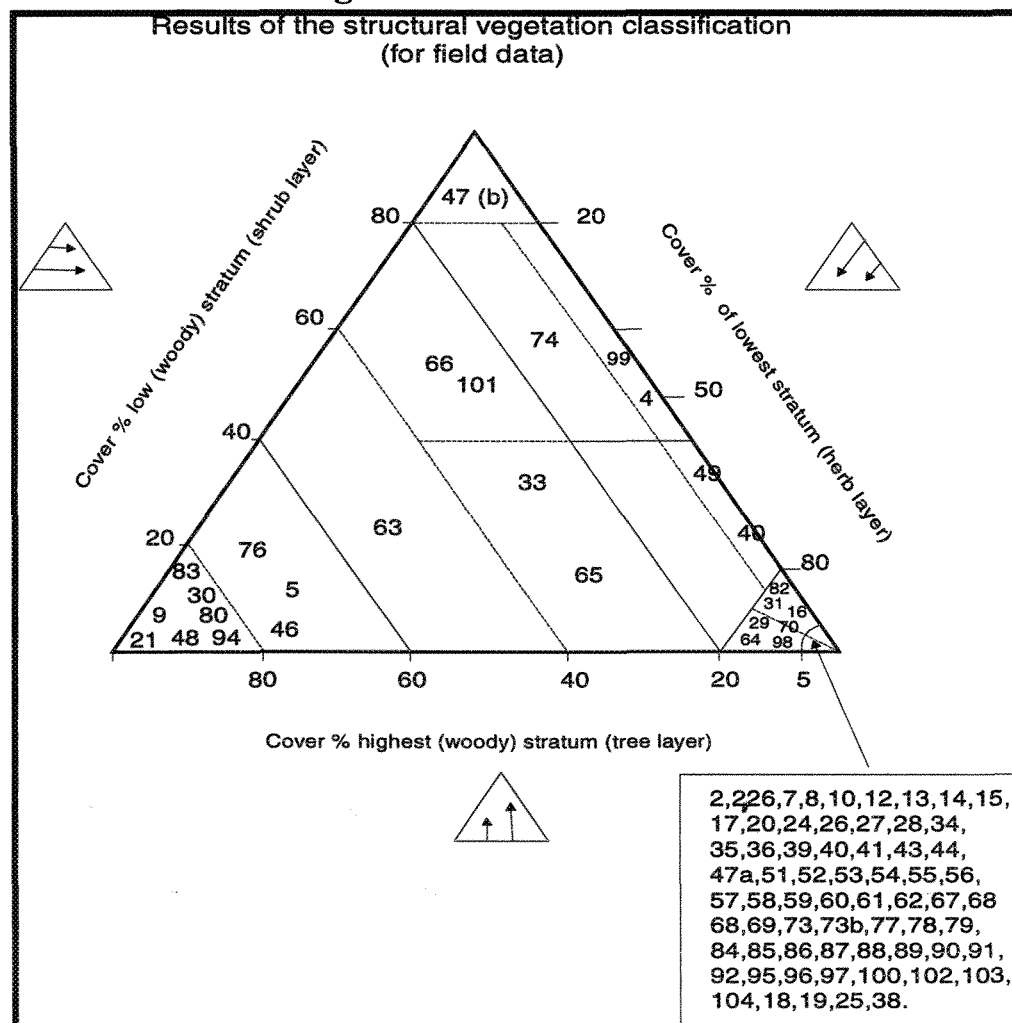
Conyza and *polygonum* had become well established in the composite zone, some *cyperus species* (including papyrus) had developed within the lake sedge zone where *Sphaeranthus* took over.

Inundation: *Cyperus* occurring outside the sedge zone had a high chance of survival if in the composite Zone but no chance if in the *sphaeranthus* Zone. High survival was due to the fact that germination of sedge seed continued in the composite Zone right up to the time of inundation which indicate that young papyrus plants tolerate flooding only after reaching a certain stage of development. *Sphaeranthus* at this stage of development did very well initially when flooded and showed a high percentage of survival. Its cell structure is adaptable to both land conditions and water.

d) Last stage : towards the end of 1974 when the water level had began to recede

The drawdown succession eventually succeeded to a papyrus swamp. The progressive stage are shown on the figure 10 above. 6B shows the nearly final stage, that is a young papyrus fringe swamp

APPENDIX 8   Vegetation structural classification results

Results of the structural vegetation classification
(for field data)

2,226,7,8,10,12,13,14,15,
17,20,24,26,27,28,34,
35,36,39,40,41,43,44,
47a,51,52,53,54,55,56,
57,58,59,60,61,62,67,68
68,69,73,73b,77,78,79,
84,85,86,87,88,89,90,91,
92,95,96,97,100,102,103,
104,18,19,25,38.

APPENDIX 9 Verification of the 1995 satellite image interpretation using the 1997 field sample locations.

Verification of interpretation of 1995 satellite image
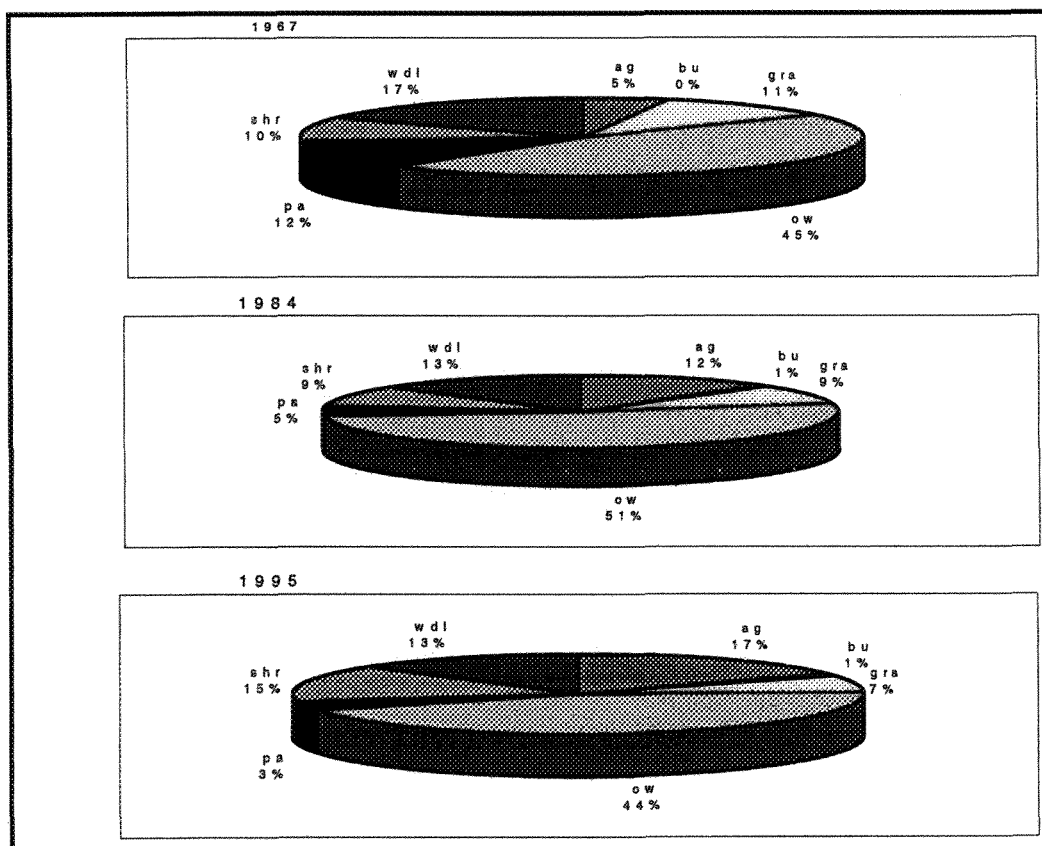with the 1997 sample locations

1995 land cover / 1997 samples	Ag	Ow	G	Shr	Wdl	Pa
Ag	9	0	0	0	0	0
Ow	0	0	0	0	0	0
G	1	9	14	20	9	8
Shr	1	1	0	4	2	0
Wdl	2	3	0	5	5	1
Pa	1	1	0	4	0	17

Samples per mapping unit

Land cover	Number of samples
ag	9
Ow	0
G	56
Sh	8
Wd	18
Pa	25
bu	0

Codes: ag = agricultural fields, Ow = Open water, G= Grassland, Shr= Shrubland, Wdl= Woodland, Pa=Papyrus
The figures represent the number of samples

APPENDIX 10 Proportions of land cover for 1967, 1884 and 1995

1967
wdl 17% ag 5% bu 0% gra 11%
shr 10%
pa 12%
ow 45%

1984
wdl 13% ag 12% bu 1% gra 9%
shr 9%
pa 5%
ow 51%

1995
wdl 13% ag 17% bu 1% gra 7%
shr 15%
pa 3%
ow 44%

Codes: Ag - agricultural fields, Ow- open water, Wdl-woodland, Shr- shrubland, Gra- Grassland, Bu -Built up, Pa - Papyrus
Source: Land cover maps, 1967, 1984, and 1995 (figure 5.1)

APPENDIX 11   ASSUMPTIONS/RULES FOR LAND COVER CHANGE
INTERPRETATION

"A change area of less than 2 pixels, 0.01 ha is discarded"
"If Initial class is papyrus in Year1 and Papyrus in Year 2, the realized class is papyrus"
"If Initial class is water in Year1 and Papyrus in Year 2, the realized class is papyrus"
"If Initial class is Papyrus in Year1 and water in Year 2, the realized class is papyrus"
"If Initial class is grassland in Year1 and Papyrus in Year2 the realized is papyrus"
"If Initial class is papyrus in Year1 and grassland in Year2 the realized is grassland"
"If Initial class is woodland in Year1 and Papyrus in Year2 the realized is papyrus"
"If Initial class is papyrus in Year1 and woodland in Year2 the realized is woodland"
"If Initial class is shrubland in Year1 and Papyrus in Year2 the realized is papyrus"
"If Initial class is papyrus in Year1 and shrubland in Year2 the realized is shrubland"
"If Initial class is agricultural field in Year1 and Papyrus in Year2 the realized is papyrus"
"If Initial class is papyrus in Year1 and shrubland in Year2 the realized is shrubland"
"If Initial class is built up area in Year1 and papyrus in Year2 the realized is built up area"
"If Initial class is papyrus in Year1 and built up area in Year2 the realized is built up area"

APPENDIX 12   THE WORKING OF THE VEGETATION DYNAMISM
MODEL (Patrono, 1995) pp 67 - 71
(The text is summarized).
The original Ecological model by Favretto and Poldini (1986) was modified by Patrono and Oriolo, (1995) to analyze the grassland reduction due to bush encroachment and to forecast the extinction time of pastures.
The process of bush encroachment may be described by a logistic model that takes into account the following:
- two different moments considered (in years)
- bush encroachment of pastures in the year t (in ha)
- free pasture area in the year t (in ha)
- the total available area
- model parameter influencing the curve slope

Assumptions:
- In the past pastures under consideration appeared completely free from bush encroachment while in reality there has never been an absolute absence of bushes.
- Bush encroachment does not increase indefinitely in an asymptotic way but ceases in finite times by total coverage of the available area

Mult-temporal remote sensed data can be used to adapt and fit the model to peculiar/local situations

The distribution curve that quantifies the theoretically modified areas can be computed and spatially define which areas are going to change status in a given year. The factors involved in similar dynamism and which have to be considered for the spatial analysis concern neighbor vegetation type.
Related factors are : slope, aspect, geomorphology and neighbor position.

Using basic GIS functions, a map can be created to show the probability of changing status for each possible modifying area. For every factor, a probability map is created describing the contribution of the factor itself in the process.

The probability index is computed using a "neighbor effects modeling and mapping approach as follows:
- A series of values is provided for all the possible classes of the considered factor. Higher values mean higher importance in influencing positively the phenomenon. The values are dimension less; in the range e.g. 1 - 100 where 100 represents the class with the highest possible contribution
- A moving window is put to stress the position factor. The dimension has to be related to the extent of the investigated phenomena. Higher weight mean higher influence. The values are set in the range 0-1 and their sum is 1.
- A final factor influence map is created applying the following formula:

$$NPIX = \sum_{y=1}^{5} \sum_{i=1}^{5} (X_{y_i} W_f)$$

where
Npx = the new cell value

$X_{y,i}$ = the position y, i weight
W_f = the importance value of type f

When the effective influence of several factors is studied simultaneously, before combining the resulting maps, it is generally advisable to normalize them .

The importance values are then estimated using either knowledge/ evidence on the role of the considered landscape types. The assessment of the values can be performed using empirical methods based on "user" expert knowledge when it is not possible to quantify them directly. Decision Support System provides similar methods like the Analytical Hierarchy Process (AHP) by Saaty (1980) ; Janssen and van Herwijnen , (1992) within the DEFINITE soft ware (Janssen and van Herwijnen , 1992).

The method derives quantitative weights from qualitative statements on the relative importance of criteria obtained from comparison of all pairs of criteria.

The application of the method results in the production of maps giving unit by unit the contribution of the single factor in terms of probability, of modifying the pixel status. The maps obtained have to be combined by an additive model using the following formula: **Final map = Factor1*P1+Factor2*P2+Factor3*P3 +Factor4*P4 etc.**

The numerical coefficients **Px** are used in order to stress the different importance of the factor contributions. The final map provides unit by unit (characterized by the presence of pasture) the score of an index representing the probability of changing into bush. The higher the score obtained for a pixel, the higher the probability of being affected by bush encroachment.

APPENDIX 13   MAP DATA USED IN THE MONITORING & RISK MODELING (only major outputs are presented)

Land cover maps used in the temporal analysis

1- Fin1967h - land cover map for 1967
2- Fin84h2 - land cover map for 1984
3- Fin1995h - landcover map for 1995

Change maps and tables (reclasssified by attribute in table)

1- Pch6784 from cr6784(crossed map of 67 and 84)
2- pch8495 from cr8495(crossed map of 84 and 95)

Individual land cover type maps

Pap - Papyrus cover type map
wat95 - Open water cover type
agri95 - agricultural fields map
gra95 - grasslands map
shr95 - shrublands map
wdl95 - woodlands map
bu95 - built up area

Source maps (for input to distance calculation)

Wat951 - distance from water
agri951 - distance from agricultural field
shr951 - distance from shrubland
wdl951 - distance from woodland
bu951 - distance built up area

Distance from land cover type maps

Watdist - distance from water
agridist - distance from agricultural field
shrdist - distance from shrubland
wdldist - distance from woodland
budist - distance from built up area

land cover type risk maps - not normalised

Watpap- water risk
agripap- agricultural field risk

shrdist - shrubland risk
wdldist- woodland risk
budist - built up area risk

<u>**The normalized land cover type risk to papyrus area maps using the distance index:**</u>
 a) **Watpg** - Final map of open water risk got by slicing of watpap
 b) **agripg**- Final map of agricultural potential risk got by slicing of agripap
 c) **grapg**- Final map of grassland potential risk derived by slicing of grapap
 d) **Shrpg**- Final map of shrubland potential risk derived by slicing of shrpap
 e) **Wdlpg**- Final map of woodland potential risk derived by slicing of wdlpap
 f) **Bupg**- Final map of built up area potential risk derived by slicing of bupap

<u>**Final risk scenario maps**</u>

finrisk2- Scenario 1 final risk map by a weighted summation of **Watpg, agripg, grapg, shrpg wdlpg, & Bupg**

Finrisk3- reclassification of risk map of scenario 1
(Combined risk including water , finrisk3 from slicing of finrisk2 at the following levels:

Potential risk value range	Class	Risk level
1 - 27.5	1	Low
27.6 - 28	2	
28.1 - 28.5	3	
28.6 - 29	4	
29.1 - 29.5	5	Medium
29.6 - 30	6	
30.1 - 30.5	7	
30.6 - 31	8	
31.1 - 31.5	9	
>31.5	10	High

Finrisk4 -Scenario 2 final risk map by a weighted summation of **agripg, grapg, shrpg wdlpg, & Bupg**

Finrisk5 - reclassification of risk map of scenario 2
(Combined risk excluding water , finrisk5 from slicing of finrisk4at the following levels:

Potential risk value range	Class	Risk level
1 - 18.5	1	Low
18.6 - 19	2	
19.1 - 19.5	3	
19.6 - 20	4	
20.1 - 20.5	5	Medium
20.6 - 21	6	
21.1 - 21. 5	7	
21.6 - 22	8	
22.1 - 22.5	9	
>22.5	10	High

Map finr31 and finr41   The Standardized finrisk3 and 4
(Standardised Risk zonation for both scenarios)

Potential risk value range	Class	Risk level
1 - 18.5	1	Low
18.6 - 20	2	
20.1 - 21.5	3	
21.6 - 23	4	
23.1 - 24.5	5	Medium
24.6 - 26	6	
26.1 - 27.5	7	
27.6 - 29	8	
29.1 - 30.5	9	
> 30.5	10	High

DICOTYLEDONS

ACANTHACEAE
Hypoestes aristata (Vahl) Roem. & Schultes
Hypoestes forskalei (Vahl) R.Br.
Monechma debile (Forsk.) Ness

AIZOACEAE
Glinus lotoides L.X oppositifolius (L.) A.D.C

AMARANTHACEAE
Achyranthus aspera L.

Amaranthus angustifolium
Amaranthus graecixans L.

ANACARDIACEAE
Rhus natalensis
Rhus vulgaris Meikle

APIACEAE
Hydrocotyle ranunculoides L.F

ASCLEPIADACEAE
Gomphocapus friticosus (L.) Ait.f
Gnmphocarpus physocarpus E.Mey
Gomphocarpus semilunatus A.Rich.
Pentarrhinum insipidum E. Mey.
Sarcostemma viminale (L.) R. Br.

ASTERACEAE
Aspilia mossambicensis (Oliv.) Wild
Aster muricatus Less
Circium vulgare (Savi) Ten.
Conyza bonariensis (L.) Cronq
Conyza floribunda H.B.K.
Conyza hypoleuca A. Rich

Conyza steudiii A. Rich
Conyza stricta Willd.
Crassocephalum picridifolium (D.C.) S.Moore
Felicia muricata (Thunb.) Nees
Galinsoga parviflora Cav.
Gnaphalium luteoalbum L.
Gnaphalium undulatum L.
Helichrysum globosum Sch. Bip.
Melanthera scandens (Schumach.&Thonn.)
Pluchea ovalis (Pers.) D.C.

LENTIBULARIACEAE
Utricularia gibba L.
Utricularia inflexa Forsk.
Utricularia reflexa Oliv.

ASTERACEAE (continued)
Psiadia punctulata (D.C) Vatke
Senecio discifolius Oliv.
senecio moorei R.E. Fries.
Senecio nandensis S. Moore
Senecio petitianus A. Rich
Senchus oleraceus L.
Sidons pilosa L.
Sphaeranthus confertifoliuus Robyns
Sphaeranthus gomphrenoides
O.Hoffm.
Sphaeranthus napierae Ross -Craig
Sphaeranthus suaveolens (Forsk.)
D.C
Tagetes minuta L.
Tarchonanthus camphoratus L.
Vernonia auriculifera (Welw.) Hiern.
Vernonia glabra L.

BORAGINACEAE
Cordia monoica Roxb.
Heliotropium steudneri Vatke

BRASSSICACEAE
Erucastrum arabicum Fisch.&Mey
Gynandropsis gynandra (L.) Briq.

CACTACEAE
Opuntia vulgaris L.

CAPPARACEAE
Maerua endlichii Gilg & Bened.
Maerua Triphylla A.Rich.

CARYOPHYLLACEAE
Polycarpon prostratum (Forsk.)
Aschens&Schweinf.

CHENOPODIACEAE
Chenopodium album L.
Chenopodium ambrosiodes L.
Chenopodium carinatus
Chenopodium murale
Chenopodium opulifolium Koch &Ziz
Phytolacca dodecandra L'Herit

SCROPHULARIACEAE
Cycnium tubulosum (L.f.) Engl.
Rhamphicarpa montana N.E.Br.

DICOTYLEDONS (continued)

MALVACEAE
Abutilon mauritanum (Jacq.) Medic.
Abutilon rehmannii (Jacq.) Medic.
Hibiscus diversifolius Jacq
Hibiscus flavifolius Ulbr.
Hibscus fuscus Garcke
Malva parviflrola L.
Pavonia elegance Garcke
Sida tenuicarpa Vollesen

NYMPHAECEAE
Nymphaea caerulea Savigny

OLEACEAE
Olea Africana (Mill)

ONAGRACEAE
Ludwigia stolonifera (Guill. et. Perr.) Raven

OXALIDACEAE
Oxalis obliquifolia A. Rich

PASSIFLORACEAE
Commicarpus pedunculosus (A. Rich.) Cuf.

PLOYGONACEAE
Oxygonum sinuatum (Meisn) Dammer
Polygonum pulchurum Blume
Polygonum salicifolium Willd.
Polygonum senegalense Meisn. f.
Polygonum strigosum R.Br.
Rumex usambarensis (Dammer) Dammer

PORTULACACEAE
Portulaca oleracea L.

RANUNCULACEAE
Clematis brachiata Thunb.
Ranunculus multifidus Forsk.

RUBIACEAE
Pentas lanceolata (Forsk) Deflers
Rubia cordifolia L.

RUTACEAE
Teclea nobilis Del.

SOLANACEAE
Solanum Incanum L.
Solanum nigrum L.
Physalis peruviana L.

TILIACEAE
Grewia similis K.Schum.

URTICACEAE
Urtica massaica Mildbr.

VAHLIACEAE
Kanlachoe densiflora Rolfe

VERBENACEAE
Lantana camara L.
Lantana trifolia L.
Verbena officinalis L.

ZYGOPOHYLLACEAE
Tribulus Cistoides L.

MONOCOTYLEDONS

ARACEAE
Pistia stratiotes L.

CYPERACEAE
Cyperus alopecuroides Rottb.
Cyperus digitaris L.
Cyperus dives L
Cyperus exaltus L
Cyperus immensus C.B.CL.
Cyperus laevigatus L.
Cyperus papyrus L
Cyperus rigidifolia Sted.
Cyperus stuhlmannii C.B.CL.

Kyallinga alba L.
Kyallinga cylindrica L.
Pycreus mundtii Nees
Scirpus inclinatus (Del.) Aschers. &Schweneinf.

DRACAENACEAE
Sansevieria suffruticosa N. E. Br.

LEMACEAE
Lemna perpusilla Torrey
Lemna triscula L.
Spirodela polyrhiza (L.) Schleid
Wolffia arrhiza (L.) Wimmer
Wolffiopsis welwitschii (Hegelm.) den Hartog& v.d.
Plas

NALADACEAE
Naias pectinata (Perl.) Magnus

ORCHIDACEAE
Eulophia paivaena (Reichb. f.) Summerh. ssp.
borealis Summerh.

POACEAE
Aristida kenyensis Henr.
Bracharia jubata (Fig. & De Not.) Stapf
Cenchrus ciliaris L.
Chloris gayana Kunth
Cynadon dactylon (L.) Pers.

Cynadon plectostachyus (K.Schum) Pilg.
Dactyloctenium aegyptium (L.) Willd.
Digitalia Milanjiana (Rendle) Stapf
Digitaria scalarum (Schweinf.) Chiov.
Eragrostis tenuifolia (A.Rich.) Steud.
Eragrotiis Pilosa (L.) P. Beauv.
Oropetium capense Stapf
Panicum maximum Jacq.
Pennisetum clandestinum Chiov.
Pennisetum stramineum Peter
Psilolemma jaegeri (Pilg.) S.M Phillips
Setaria verticillata (L.) P. Beauv.
Tragus berteronianus Schult.

Wolffia arrhiza (L.) Wimmer
Wolffiopsis welwitschii (Hegelm.) den Hartog& v.d.
Plas
Eichornia crassipes (C.Martius) Solms-Laub.

POTAMOGETONACEAE
Potamogeton octandrus Poir.
Potamogeton pectinatus L.
Potamogeton schweinfurthii A. Bennett
Potamogeton thunbergii Cham. &schlecht

TYPHACEAE
Typha domingensis Pers.
Typha latifolio L.

FERNS

ADIANTACEAE
Pteris dentata Forsk.

AZOLIACEAE
Azolla africana Desv.

MARSILEACEAE
Marsilea gibba A.Br.

SALVINIACEAE
Salvinia molesta Mitch.

THELYPTERIDACEAE

Thelypteris confluens (Thunb.) Morton

MOSSES

AMBLYSTEGIACEAE
Drepanocladus sparsus C. Mull.

LIVERWORTS

RICCIACEAE
Ricciocarpus natans L.

ALGAE

CHARACEAE
Chara braunii Gmel.
Nitella oligospira Br.
Nitella knightiae Gr. et St.