LAKE VICTORIA ENVIRONMENTAL MANAGEMENT PROJECT

MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

PROJECT DRAFT FINAL REPORT

BUFFERING PROCESSES AND CAPACITY OF WETLANDS IN THE KENYAN PORTION OF THE LAKE VICTORIA BASIN

10 MAY 2005

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ACN 065 475 149

Project Number: 58303

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ACKNOWLEDGEMENTS

A large number of people have made various contributions to this report who were not members of the SMEC team, but made valuable contributions to the project that were greatly appreciated and should therefore be acknowledged.

Mr Stephen Katua as LVEMP Wetlands component coordinator; Mr Stanley Ambasa as buffering capacity coordinator; Mr Henry Njuguna for availing rainfall data, flow and water quality data for the lake basin area; Mr Morris Otieno for allowing use of his classification ideas; Mr John Okungu, the LVEMP Water Quality coordinator for allowing access to the LVEMP water quality laboratories; Rose Angweya as LVEMP wetlands component laboratory manager; Mr Ali Mohamed as deputy director, NEMA for marine and fresh waters and national wetlands manager; Dr Jane Wamuongo as KARI head office coordinator; Dr Gelas Muse Simiyu, Moi University School of Environmental Studies for assistance in identifying issues at the Chepkoilel Eldoret wetland and for providing rainfall and other water quality data at Eldoret Chepkoilel wetland; Mr Arap Kogo, Ms Lillian Kogo and the Kogo family for allowing access through their property to the Chepkoilel wetland and for providing site security for the automated monitoring equipment at the site; Mr Zephania Ouma as DEO Kericho; Ms Joan Nyarombe as DEO Kericho; staff of the Kericho Muncipal Council, particularly the town clerk and town engineer; Mrs Nancy Muui as DEO Eldoret; Mr Kangogo and management at Equator Flower Farms for providing site access and security for monitoring equipment; Mr Ken Kirui and all at JFK ARD for providing rainfall and other site related data; the head teacher and taff at the Township Primary for providing site access and security for the weather station at Kericho; Dr Charles Ngugi of Moi University for access to the wetland via the aquaculture facilities and for providing the aerial photographs used in Figures 4.5 and 4.8; Dr Stephen Njoka as LVEMP Project coordinator; Mr David Njoroge as LVEMP procurement officer

EXECUTIVE SUMMARY

This report details the methodology and findings of a twelve month project undertaken by SMEC International for the National Environmental Management Authority (NEMA), Lake Victoria Environment Management Project (LVEMP) Wetlands Component under the administration of the Kenya Agricultural Research Institute (KARI)-LVEMP secretariat. The purpose of the study was to determine the extent to which wetlands within the Kenyan portion of the Lake Victoria Basin are able to sustainably reduce and delay the transmission of key pollutants (suspended sediments and nutrients) into the lake, that is, to determine the buffering capacity of the wetlands of the Kenyan portion of the Lake Victoria Basin.

In broad overview, the project was carried out by performing the following tasks:

(1) field studies of the water quality and hydrology at two pilot wetlands within the lake basin, one at Kericho, known as the Dionosoyiet wetland and the other near Eldoret called Chepkoilel,

(2) developing a model to describe buffering processes of wetlands;

(3) a mapping exercise to describe the two pilot wetland sites and to determine the extent of wetlands in the study area,

(4) in coordination with task (3) it was necessary to use remote sensed data (LANDSAT and Quickbird) to develop a database of environmentally sensitive wetlands in the basin.

(5) upscaling results from the pilot wetland sites to the whole basin to determine the buffering capacity of wetlands across the study area,

(6) conisidering tasks (1) and (2), it was necessary to determine the buffering mechanisms that apply within wetlands

(7) making recommendations for the management of the two pilot wetlands as well as wetlands across the lake basin area, and

(8) technology transfer conducted in order that officers develop the capability to conduct further studies to build on the outcomes of the project into the future.

Key outcomes of the study are as follows:

- Through a combination of monitoring and modelling at both sites it was observed that both wetlands removed significant amounts of suspended sediment, nitrogen and phosphorus under low and medium flow conditions.

- It was observed that under some high flow conditions, exports of one or more of sediments, nitrogen and/or phosphorus could occur; however these exports are considered to be limited occurrences and are viewed overall to be of smaller magnitude than the removals which typically occur. The nett impact of removal under low and medium flow conditions is slightly lessened by these limited number of cases of pollutant export under high flow conditions.
- By modelling the wetlands it was seen that rates of removal for sediments, nitrogen and phosphorus were all quite high for the Eldoret Chepkoilel wetland; however the Kericho Dionosoyiet wetland showed that only a moderate amount of Nitrogen removal occured. This is most likely due to a combination of two factors: (1) the short residence time of the Kericho Dionosoyiet wetland and (2) the absence of *Cyperus papyrus* in the wetland.
- Mapping of wetlands was performed by onscreen digitisation of high resolution Quickbird images for the pilot wetland sites and from a LANDSAT mosaic image for the lake basin region. The pilot wetlands consisted of emergent vegetation only at Kericho Dionosoyiet wetland and a combination of emergent vegetation and *Cyperus papyrus* at Eldoret Chepkoilel wetland. The wetlands could be internally described as consisting of an inlet zone where processes are dominated by inflows, a transition zone where flow becomes modified from inflow dominated to linear, a linear zone where flow occurs in a linear manner from the inlet zone towards the outlet, with processes such as sedimentation and nutrient cycling occurring in a steady manner and an outlet zone where flows and processes are dominated by the outflow, Environmentally significant aspects of the two sites were that both sites perform significant buffering of suspended solids, nutrients and flows, both are habitat for a variety of birds, particularly the crested crowned crane (*Balearica reulorum).* Both sites are also extremely important for the local communities and are used widely by the communities especially for access to water.
- At a basin wide level, wetlands were described in terms of their vegetation as being dominated by *Cyperus papyrus* vegetation, by other emergent vegetation or by open water. Furthermore, based on their geographic location, wetlands were classed as lake shore zone wetlands, wetlands in proximity to forested/conservation areas, high intensity agricultural area wetlands and wetlands in proximity to dense human land use. Wetlands in each of these geographical classes had different sets of environmental values associated with them. Being so classed, all wetlands in the basin had significant environmental values associated with them and therefore all wetlands were found to be environmental sensitive wetland areas (ESWAs).

- The most significant buffering mechanisms that take place in the wetland in order of importance are enhanced sedimentation, nutrient cycling (especially for Nitrogen) and plant uptake processes. The lack of significant native grazer populations in both the wetlands means that very little renewal of plants takes place, consequently this limits the extent to which plant uptake processes are effective. Controlled harvesting of above ground biomass is therefore recommended for both wetlands in order to remove biomass thus promoting growth of plants and higher plant nutrient demands.
- A process based model for wetlands buffering was obtained, modified, calibrated and handed over for further use. The model, which has been named the LAVINKS-WEB (**LA**ke **Vi**ctoria **N**EMA **K**enya **S**MEC-**W**etlands **B**uffering) model is based on a model developed by the Cooperative Research Centre for Freshwater Ecology known as POND (**PO**llutant **N**utrient **D**ynamics) and is implemented through Microsoft Excel. It is able to model flows, suspended solids and dissolved solids for nutrients for the wetlands as required under the ToR, given simple inputs of the size, shape, vegetation, soils and rainfall that occur for a given wetland. In addition to these, it is also able to model Phosphorus and Nitrogen given the above inputs. The model was calibrated for the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetland wetlands for which cases the model was run over an 11 year period (1994 to 2004). Versions of the model were also developed to represent (a) a typical wetland in the Lake basin, and (b) the combined buffering capacity of all wetlands in the Kenyan portion of the basin.
- The buffering capacity of wetlands across the basin was determined using the basin wetlands representative model described above. This modelling was performed for a seven year period. The results show that the wetlands of the basin buffer suspended sediments and total phosphorus by approximately 70% and total nitrogen by approximately 60%. Wetlands preservation in the Kenyan portion of Lake Victoria is therefore vital in ensuring sustainability of the basin. Steps should be taken to prevent possible destruction of wetlands in the future and to encourage the restoration of degraded wetlands in the basin to ensure they continue to play this vital role.
- Recommendations for Use/non use of wetlands of the pilot wetlands is dealt with through the development of draft Management Plans for both the Kericho Dionosoyiet and Eldoret Cheopkoilel wetlands
- Guidelines for wetlands use are presented as a Management Planning Framework. It is critical that wetlands are recognised as dynamic ecosystems which will change with or without proactive management. In order to promote sustainability or buffering processes

and other desirable ecosystem attricutes, it is recommended that wetlands are protected and rehabilitated where required, within the framework that has been presented here.

- Technology Transfer was performed through a series of workshops held between July 2004 and April 2005 on topics including logistics and planning for wetlands investigations, values and functions of wetlands, water quality and wetlands, wetlands mapping, use of automated equipment for wetlands investigations and wetlands buffering capacity modelling. All sessions were well attended by officers from a wide range of LVEMP components. Positive feedback from participants indicated that they found the workshops valuable. In addition to formalised workshops, technology transfer was also enacted through the involvement of NEMA officers in pilot stage field activities.

1. Introduction

1. INTRODUCTION

A Contract for the Buffering Processes and Capacity of Wetlands on the Kenya side of Lake Victoria was signed in February 2002 between the Lake Victoria Environment Management Project (LVEMP) National Secretariat, Ministry of Environment and Natural Resources, Government of Kenya and SMEC International.

Due to a series of administrative changes, commencement of the project became delayed. SMEC eventually mobilised in May 2004, by which time the Kenya Agricultural Research Institute (KARI) had responsibility for the secretariat of LVEMP.

1.1 Lake Victoria Basin Water Quality Issues

Lake Victoria is by surface area the largest freshwater lake in Africa and the second largest fresh water lake in the world. It has a 68,800 km^2 surface area with an approximately oval shape as shown in Figure 1.1. The depth profile of the lake is relatively shallow and it is relatively well mixed in the vertical. The Lake:

- represents a major fishery resource for Kenya, Uganda and Tanzania;
- is a major waterway supporting trade, communication and tourism;
- generates substantial power at the Owen Falls Hydro-electric Station; and
- is important in supporting a large and diverse ecological community; and
- forms the headwaters of the River Nile, the longest river in the world and a vital water resource for the countries of Uganda, Sudan and Egypt.

Approximately 30 million people live in the lake's catchment and the lake is utilized for fish production, transport and power generation Ntiba *et al*., (2001). Approximately 2 million people depend directly or indirectly on fish from the lake (Ntiba *et al*. 2001). Water quality in the lake has declined significantly over recent decades. One of the causes of declining water quality is increasing loadings of nitrogen and phosphorus entering the lake due to anthropogenic inputs (see Aloo, 2003; van der Knaap *et al*., 2002; Lung'ayia *et al*., 2001; Mwanuzi *et al*., 2003;

Verschuren *et al*., 2002). It has been established that a significant proportion of the nutrients entering the lake arise because of changing patterns of human land use activities which have exerted huge pressure on environmental resources in recent decades. Human activities on the catchment that comprise nutrient sources of particular concern include:

(i) non point source agricultural activities, such as broad scale cropping, grazing and intensive activities such as horticulture;

(ii) stormwater from both informal human settlements and formalised urban areas;

(iii) industrial discharges; and

(iv) effluents from urban sewage treatment plants, a large number of which are in very poor repair.

Linked with increased nutrient loads, changes in land-use management within the catchment (particularly deforestation) have led to increased erosion, resulting in increased sediment loadings on the lake (Verschuren *et al*., 2002). A reversal of these processes will require better catchment management practices, including erosion control and the wise use of the remaining wetlands within the catchment.

These increases in the sediment, phosphorus and nitrogen loads entering the lake are most difficult to address; nutrient load increases result in increased nutrient concentrations within the lake and lead to ecological disturbances such an increased abundance of nuisance plant species in waterways.

Indeed it has been observed that such changes have occurred in the lake ecosystem including:

- A tenfold increase in algal biomass in the lake. Nutrient enrichment of the lake has led to increased phytoplankton production and a switch in dominance from diatoms to cyanobacteria (blue-green algae) (Lung'ayia, et al., 2000; Verschuren *et al*., 2002). ;
- A shift in the make up of algal species occurring in the lake towards a greater abundance of potentially toxic blue green algae;
- The appearance of extensive mats of water hyacinth (*Eichhornia* spp) in the lake. Water hyacinth is an exotic nuisance species but biological control of this weed has been reasonably successful (see Opande *et al*. 2004, Njoka 2005).
- The deep waters of the lake now experience low oxygen conditions for prolonged periods of time and
- Eutrophication of the lake has also resulted in lowered oxygen concentrations in deeper lake waters and some fish kills have been reported (Lung'ayia *et al*., 2001).

The three riparian countries, Kenya, Uganda and Tanzania are responding to these and other issues of concern for Lake Victoria such as fisheries viability, land use and socioeconomic matters through the Lake Victoria Environmental Management Project (LVEMP).

Some of LVEMP's most important activities are specific regional and national programs to promote sustainability within the Lake Victoria Basin. Project components deal with a variety of sustainability issues including management of fisheries, fisheries research, water hyacinth control, soils and erosion control, reafforestation, water quality, community engagement and of course wetlands, the prime focus of this study.

Waterways of the Kenyan portion of the Lake Victoria basin flow in a generally southwesterly direction towards the Lake. They drain the area between the Kenya-Tanzania border in the south East, the Kenya Uganda border in the northwest and the highlands that separate the lake basin from the rift valley in the northeast. A true colour satellite image (LANDSAT mosaic) shown in Figure 1.2 shows the extent of the Kenyan portion of the basin.

Within Kenya, 8.4% of the total area of the country falls within the Lake Victoria Basin. However this area's fertile agricultural soils support a dense and rapidly growing human population (population growth rate has been above 3% per year in recent years). For example, the population of Nyanza Province went from 1 million in 1962 to 2.1 million in 1969 and 4.5 million in 1993 (Kairu, 2001). The most widespread land-use within the Kenyan Lake Victoria basin is small-scale agriculture but there are also commercial-level farming operations such as large tea estates and flower producers.

In Kenya, wetlands support many rural economies and approximately 7 million people depend upon them (Gichuki, 2000). The Kenyan LVEMP Wetlands Management Component works closely with communities to conserve wetlands and use them sustainably. Component objectives include the development of weland management plans, wetland mapping, improving the understanding of the buffering capacity of wetlands and improving the sustainability of wetlands use on economic, environmental and social grounds.

Wetlands within the Kenyan part of the Lake Victoria catchment include a series of highland wetlands in high rainfall areas as well as large wetlands adjacent to Lake Victoria. Wetland areas occur along slow-flowing stretches of rivers that drain into Lake Victoria. Major rivers wholly within the Kenya basin are the Sio, Nzoia, Yala and Sondu Mirui. The Kuja-Migori and Malaba Rivers rise in western Kenya but enter Lake Victoria in Uganda. The Mara River rises in southern Kenya and discharges to the lake in Tanzania. The Nzoia and Yala Rivers flow through Yala wetland before entering Lake Victoria and the Nyando River discharges into Winam Gulf through the Nyando wetland.

Wetlands in southwestern Kenya are undergoing significant stress as a result of land-use changes resulting from the rapid population growth cited above that has taken place over the last three decades within the area (see Kairu, 2001). Many wetlands within the area have been completely destroyed through conversion to agricultural land and others have been degraded through altered hydrological regimes, increased nutrient and pollutant loads and grazing.

Yet wetlands within Kenya have significant values worth preserving. Wetlands are among the country's most significant tourist attractions as sites for bird and game watching and thereby are of significant economic importance. Furthermore, wetlands within the Kenyan portion of the Lake Victoria basin provide significant ecological and community services including: fish; plant resources that can be used for weaving, traditional medicines, food and grazing; and sediments suitable for building materials. Water from wetlands is used for human consumption, washing, recreation, irrigation and for livestock.

Significantly also, wetlands act as buffers of flow and water quality, reducing the extent of flooding and curtailing loads of nutrients entering the lake. The value of wetlands can be most dramatically illustrated by a very objective measure of value: water quality improvements that take place as water flows through a wetland, especially nutrient load reductions. Quantification of these load reductions justifies most ardently the need to preserve wetlands in the basin area. This then provides the motivation for the present study as detailed in the following section.

1.2 Wetlands and Water Quality Issues in the Lake Victoria Basin

The Ramsar Convention defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters." In Kenya, the National Wetlands Standing Committee defined a wetland as "areas of land that are permanently, seasonally or occasionally waterlogged with fresh, saline, brackish or marine waters at a depth not exceeding six meters, including both natural and man-made areas that support characteristic biota" in consistency with Ramsar.

For many years positive values and functions of wetlands have been poorly understood. As a result, the total acreage of wetlands has been greatly reduced and the role they play as natural pollution buffering agents has declined.

Wetlands make these improvements in the quality of water flowing through them by a number of physical, chemical and biological mechanisms. Wetland plants provide a physical barrier that slows water flow and enhances sedimentation. This not only results in improved water quality through a reduction in suspended solids but also removes the nutrients both within the particles and adhered to them. As plants grow they may remove nutrients from the water column, and following senescence of the plant, the nutrients may accrete in the sediment as peat. Wetland plants also provide a surface for the development of biofilms (bacteria and algae that grow in a thin layer on the surface of the submerged parts of aquatic plants). These biofilms have significant potential for nutrient uptake and also for denitrification. To maximize these processes, wetland hydrology, suspended solids and nutrient loading need to be careful managed so that the buffering capacity of the wetland is not exceeded.

Wetlands then provide significant mechanisms for nutrient removal by: (1) removing nutrients from inflowing waters and permanently storing them in sediments, (2) through denitrification, nitrogen loss from the wetland to the atmosphere can be promoted and (3) by the nutrient uptake capacity of wetland plants as demonstrated in the papyrus swamp in Lake Naivasha (see Gaudet, 1976a, 1979).

So the wetlands of the Lake Victoria basin are extremely important to the water quality cycles that occur in the basin's waterways through roles such as:

- reducing and delaying highly polluted flood flows entering the lake,
- trapping suspended sediments and nutrients, and
- cycling nutrients between sediments, biota and the water column.

These buffering functions are more evident when wetland systems are located strategically to pollution sources.

Wetlands are also a favourable means of improving water quality compared with other water quality improvement options as they have addition benefits including that they:

- form a rich resource base for the local communities;
- have low input requirements in terms of energy, building engineering infrastructure and chemical additives;
- support ecosystem functions that are often lost when land use development occurs, for example by providing habitat for migrating, rare and endangered species, and
- are resilient to a wide range of water level and flow fluctuations.

Wetlands are dynamic systems and change (ecological succession) is a natural process that is driven by many processes that occur naturally within them. Natural change processes in wetlands are usually relatively slow in comparison with changes that are driven by human-induced causes. Gaudet (1976a, 1976b, 1977, 1979 and 1980) studied the aquatic vegetation of Lake Naivasha and, with the exception of the introduction of *Salvinia molesta*, demonstrated that this vegetation had change little over four decades. Conversely, a mere ten years later, Harper *et al*. (1990) described the rapid changes that took place as this ecosystem became stressed through eutrophication, excess water abstraction and the impact of introduced plants, crayfish and fish.

As such, wetlands enhance the functioning of the basin wide catchment - lake water, sediment and nutrient cycles and the welfare of the local communities; however human impacts such as clearing wetland vegetation and accelerated rates of sediment acccumulation due to anthropogenically increased sediment loads present significant threats to wetland buffering. Close attention is therefore required to manage these important natural resources well and wisely.

1.3 Definition of Wetlands Buffering

For the purposes of this study, wetland buffering is defined as the nett improvement in water quality between the inlet(s) and outlet(s) of a wetland. This project has focussed most strongly on sediment and nutrient buffering, parameterising buffering of these in terms of nett long term reductions of loads flowing through the wetland.

This definition allows statements to be made about improvements in water quality without invoking a detailed knowledge of the exact processes occurring within the wetland. This definition is consistent with that used by the Ugandan Wetlands Inspection Division and has been adopted here in light of the expressed desire of LVEMP for harmonisation of monitoring, methodologies and procedures.

Given this definition, the focus of this study is on monitoring and analysis of inflows and outflows of suspended solids and the nutrients nitrogen and phosphorus, with other aspects supporting the interpretation of the inflow and outflow loads of these contaminants.

The definition provided above represents a very strict definition of buffering, which may also be seen in terms of reductions and delays in peak loads; however, such a strict focus will implicitly require reductions and delays in peak loads.

1.4 Project Overview

The wetlands buffering capacity project was conceived as a study to obtain a preliminary assessment of the capability of wetlands in the lake basin area to retain sediments and nutrients, thereby preventing them from entering the lake where they may contribute to eutrophication (ecological degradation of a waterway). From its conception, the project has aimed to:

(i) identify gaps in the knowledge of wetlands hydrology in the Kenya portion of Lake Victoria;
(ii) perform pilot studies in wetlands to determine their buffering capacity;
(iii) describe the important buffering processes taking place within the pilot wetlands;
(iv) develop a model that is able to represent the buffering processes in the pilot wetlands and other wetlands in the Lake Victoria Basin;
(v) map the pilot wetland sites;
(vi) identify, describe and map environmentally sensitive wetland areas (ESWA) in the Kenya portion of Lake Victoria;

(vii) derive a preliminary estimate of the buffering capacity of the wetlands in the Kenyan portion of the basin based on existing information, through pilot wetland study results, and with the mapping outputs;

(viii) perform technology transfer with local officers to ensure that continuing ongoing investigations of buffering capacity are able to be performed in the long term;

(ix) make recommendations for the use/non use of the pilot wetlands; and

(x) prepare preliminary guidelines for the use/non-use of wetlands.

In pursuing these aims to their ends, this report is set out as follows. Section two describes in detail the project scope that was developed around these aims and the methodology used to address the scope. Section 3 presents the data and information review performed. Section 4 describes the pilot wetland sites that were selected, then sections 5 and 6 report the findings of hydrology and water quality monitoring performed in the wetlands. Section 7 assesses the findings from sections 4 to 6 in determining buffering processes within the pilot wetlands. Section 8 presents the development, use and results of the modelling, Section 9 presents the technology transfer aspects. Section 10 presents the buffering capacity estimation for the Kenyan portion of the lake basin. Sections 11 and 12 describe the use/non use recommendations for the pilot wetlands and wetlands generally across the basin. Finally section 13 presents recommendations following from the study and section 14 draws conclusions.

2. Project Scope and Methodology

2. PROJECT SCOPE AND METHODOLOGY

Originally conceived as a 12 month study in 1999, it has taken significant efforts from a number of dedicated people within NEMA, KARI and SMEC to see the wetlands buffering capacity project to its completion. Steps involved in determining project scope and performing the study are outlined in Figure 2.1 Following below is a description of the scope of work developed and the framework adopted for the active stages of the project and the methodology adopted.

2.1 Scope of Work

The original Terms of Reference specified the objectives of the consultancy generally as to determine:

- buffering processes in selected wetlands;
- the buffering capacity of the wetlands;
- the flow path, speed of water flow, water discharge and sampling points in the selected wetland sites;
- the flow path, speed of water flow, water discharge and sampling points in the selected wetland sites;
- the buffering processes (filtration and purification) for selected physical, chemical and biological parameters in the water regime of the selected wetland sites;
- the macrophytes and soils/sediments for storage and movement of nutrients and pollutants that enter and leave the selected wetlands;
- the mechanism involved in the storage and movement of nutrients and pollutants; and
- the conditions and size of wetland required to offer a buffering capacity for the lake.

Within this scope of work, specific objectives for the project were developed that covered aspects for the whole lake basin generally and for the pilot wetlands in particular. These objectives and the outcomes they are to result in are described below.

SPECIFIC OBJECTIVES

Specific objectives under the project can be considered under two main headings – activities for the whole of the lake basin area and activities for the pilot wetlands as described below.

A. Activities covering the Kenyan-portion of the Lake Basin

The requirement of the project to estimate the contribution wetlands make to buffering inflows to the lake at a basin wide level meant a number of activities were required to characterise the wetlands at basin scale. These activities were:

- i Identify gaps in the knowledge of the hydrology of wetlands in the Kenya portion of Lake Victoria.
- ii Develop a suitable data management format and reporting procedure that is compatible with (and perhaps included within) the database being developed under the harmonized database modules of LVEMP for the three countries;
- iii Based on existing information and the detailed work to be done on the pilot wetland study sites, undertake a preliminary estimate of the buffering capacity of Lake's wetlands in Kenya;
- iv Identify, describe and map the most important wetland-based Environmentally Sensitive wetland Areas (ESWA) in the Kenyan portion of Lake Victoria basin;
- v Based on existing information and detailed work on pilot wetland areas prepare preliminary guidelines for use/non-use of wetlands.

B. Detailed Studies of One Large or Two Small "Pilot" Wetlands

Because of the large extent of the basin and the numerous wetlands it contains, it was necessary to focus on a limited number of wetlands in order to derive feasible relationships for buffering capacity within the time scale of the project. These sites were then referred to as the "pilot" sites for the study. Activities performed for pilot wetland site studies were:

- i. The selection of one large or two smaller wetlands as pilot wetland sites for detailed evaluation. The methodologies developed for detailed hydrologic assessment of these pilot wetlands will be used, in the future, to develop a thorough understanding of each wetland. Selection should be based on the importance of the wetland to local people, to the hydrology of the lake and because if/they contain one or more ESWA.
- ii. List equipment needed to undertake the detailed survey of pilot wetland(s) and determine if additional equipment needs to be procured (as a separate item and under the wetlands

component of the Lake Victoria Environmental management Program) by the counterpart Ministry.

iii. Prepare a land use/capability map of the pilot wetland areas at suitable scale that provides details of wetland soils types, appropriate use (or non-use) of these various soils, vegetation-type and cover, ESWA's (habitat for rate, endangered or poorly represented animals, sites serving as nursery and rearing areas, etc.). important areas for buffering flow and filtering/reducing suspended and dissolved solids and areas of human use/cropping.

iv. Based on the land use/capability map, prepare recommendations for any improved use or non-use (conservation areas) of the land in the pilot wetland (s), including identification of land uses that are particularly non-sustainable. Non-use recommendations could be based on biodiversity or because of the area's importance as a buffer of flood flows or because of its role in nutrient/pollutant stripping.

v Design and undertake a detailed discharge monitoring program that includes time-based estimates of water entering and discharging from pilot wetlands. Particular attention should be paid to comparing the peaks of flood hydrographic and residual low flows of rivers entering the wetland and water discharging from the wetland to the lake to determine the buffering capacity of the wetland.

vi. Design and undertake detailed suspended and dissolved solids monitoring within the pilot wetland to determine change both horizontally and at right angles to the lake shoreline, and with depth.

vii. Determine the mechanisms involved in the storage and movement of nutrients and pollutants within the wetland.

viii. Based on the detailed monitoring program, prepare a preliminary predictive model of how wetlands buffer floods and low flows, and suspended and dissolved solids. Outputs of the model would probably include probability estimates of expected flows, and dissolved/suspended solids concentrations out of a wetland given input discharge, type of soil and vegetation, vegetation cover and area of wetland and so on.

ix. Train and work with a selected team of officers/scientists who will implement and monitor the program.

EXPECTED OUTPUTS

Given these objectives, a number of outputs were required to be delivered by the SMEC as the consultant to LVEMP wetlands as the client. These were:

1. An Inception Report- Due 8 weeks after contract signing and describing a detailed workplan and identifying pilot wetland(s) for the study.
2. A Midterm report-due 6 months after contract signing containing preliminary data on the wetlands as a whole (Section 2.0 "A" as described above).
3. An Interim Report- due 8 months after contract signing and containing initial results of the detailed monitoring program of the pilot wetland and the outline of the modeling procedure being developed.
4. A Draft final report- due at 12 months.
5. AFinal report- due at 13 months.

During the contract negotiations that took place in December 2000 and March 2001, a number of amendments to the proposal were requested by LVEMP and agreed to by SMEC. Some of the major changes were as follows:

- It was agreed that the collection and despatching of the samples to the laboratories and analysis was the responsibility of SMEC with the involvement of LVEMP officers as trainees. In the original TOR and SMEC's proposal, it had been specifically stated that sampling and analysis was the Clients responsibility. There was no increase in the contract price.
- It was recommended that the interim report was not necessary as it followed the mid-term report by only 2 months.
- In the original TOR Section B (i) second paragraph, it was stated that the Consultant should prepare an "inventory of the equipment needed to undertake the detailed survey of pilot wetland(s) and determine if any additional equipment needs to be procured (as a separate item and under the wetlands component of the Lake Victoria Environmental Management Program) by the counterpart Ministry.

In response, the SMEC proposal stated that the Consultants would evaluate all existing information during the inception stage to prepare an inventory of equipment and material for pilot study. The inception report was to make a "recommendation on the list of equipment and materials for pilot study" as one of the outputs.

At the negotiations, it was agreed that the statement "recommendation of the list of equipment and materials for pilot studies" as appeared in the SMEC proposal should read "identify the list of equipment and materials for pilot studies". This change was to ensure that the Consultants were to identify a specific piece of equipment instead of recommending something very general. In the case of a specific piece of equipment, the procurement is direct and therefore it can be concluded quickly. Equipment specified in a general manner may have to go to tender, which may delay the monitoring program.

2.2 Study Methodology

In order to clarify how the scope of work as defined by the terms of reference has been met for the study, Table 2.1 below contains an outline of the tasks involved and where these are addressed in the project documentation. As can be seen from the document, all aspects of the work have been clearly and thoroughly addressed by SMEC through the present report and previous reports such as the inception report and mid term report.

The study methodology was broken into three distinct phases, the inception phase, the pilot phase and the reporting phase as specified under the terms of reference. Activities performed in each of these three phases are discussed separately below.

2.3 Inception Phase and Review of Existing Data

The Inception Phase was conducted over the period 10 May to 10 July 2004. During this phase a detailed analysis of the status of knowledge for basin wetlands was performed and discussions were held with stakeholders and experts including the LVEMP wetlands component officers, other NEMA officers, researchers from universities and other relevant institutions.

The inception phase culminated in the production of an inception report in which the methodology as proposed in the original proposal subject to ground truth was fine tuned. The pilot wetlands were identified and a list of the equipment necessary to carry out the monitoring and sampling was compiled. Significant findings from the inception report are detailed below as they relate to background information on Kenyan wetlands, review of existing data and pilot wetland site identification.

Table 2.1: Outputs in Response to the Scope of Work

TASK NUMBER	TASK DESCRIPTION	WHERE ADDRESSED	COMMENTS
1.1	Inception meeting	Inception Report	
1.2	Review of existing data Identify gaps in Knowledge Develop suitable data management format Identify wetlands for pilot study Inventory of equipment and material	Section 3, this report and Inception Report	
1.3	Inception Report		Submitted 10 July 2004
2.1	Prepare land use/land capability maps of pilot wetlands	Section 10, this report	
2.2	Design and undertake hydrologic monitoring of wetlands for a dry/wet periods	Section 5, this report	
2.3	Design and undertake water quality monitoring of wetlands for a dry/wet periods	Section 6, this report	
2.4	Determine the buffering mechanisms and processes involved in the movement of nutrients and pollutants	Section 7 this report	
2.5	Prepare a preliminary prediction model of the buffering capacity from monitored results	Section 8 this report	
2.6	Train and work with a select team of officers/scientists	Section 9 this report	
2.7	Prepare recommendations for improved use or non-use of the pilot wetlands using the land capability map and monitored results	Section 13 this report	
2.8	Identify, describe and map the important Environmentally Sensitive Wetland Areas (ESWA) in the Kenyan portion of Lake Victoria coastal zone	Section 10 this report	
2.9	Estimate the buffering capacity of the wetlands in the Kenyan portion of the Lake Victoria coastal zone using existing and monitored data	Section 11 this report	
2.10	Prepare preliminary guidelines for use/non-use of wetlands using existing information and pilot studies	Section 12 this report	
2.11	Midterm Report		Submitted 10 November 2004
3.1	Draft Final Report		Submitted 10 May 2005 (This document)
3.2	Final Report		To be submitted 10 June 2005

Background Information on Kenyan Wetlands

The following data directly relevant to the study on the Kenyan side of Lake Victoria were collected and studied:

- seven reports relating to the "Rapid Assessment of the wetlands of Kuja, Migori, Nyando, Sondu-Miriu, Yala, Nzoia and Sio river systems", carried out by the Wetlands Component;
- maps relating to the Lake Basin, both 1:250,000 and 1:50,000 pertaining to the possible pilot study areas;
- reports on the Water Quality Studies of Lake Victoria provided by the Water Quality Component;
- the Buffering Capacity Study Report carried out for Tanzania;
- digital data and maps provided by ICRAF; and
- Africover and other digital data provided by Regional Centre for Mapping of Resources and Development (RCMRD), a UN sponsored organisation with the head office in Nairobi.

Apart from the above, a number of research publications and reports relevant to the study of wetlands in Kenya in particular and the region in general, were reviewed. These are listed in the bibliography (section 16).

Review of Existing Data

The review of existing data accounted for recent advances in knowledge of wetlands in the Lake Victoria basin from the Kenyan, Ugandan and Tanzanian perspectives, including:

- the ability of natural as well as constructed wetlands to treat or polish domestic waste water, industrial effluent, agricultural runoff and mine drainage have been studied and reported in scientific publications;
- contributions from the LVEMP wetlands components in the three countries, with the Rapid Assessments undertaken by the Kenyan component being especially significant;
- research by Universities in the three countries;
- the proceedings of the International Conference on Wetland Systems for Water Pollution Control, hosted by the constructed wetlands research group associated with the University of Dar es Salaam in 2002;

- advances in mapping capability with the establishment of the Research Centre for Mapping and Resources Development (RCMRD) and the development of the Africover GAre database of land use types;
- hydrology and water quality studies of the lake basin has been studied in detail with the aim of understanding the lake water balance over the last 50 years by the Consultants to the Water Quality Component (COWI, 2002); and
- data on materials mass balance for particular natural wetlands, relating to sediments and nutrient fractions, reported from studies in Uganda and Tanzania for dry weather flow or low flow periods.

From these sources, the state of knowledge for wetlands in the Kenyan portion of the Lake Victoria Basin was assessed and knowledge gaps were identified as described in Section 4.

Pilot study site identification

In the present project, as required under the terms of reference, two small pilot wetlands were selected and studied for three reasons:

1) to conduct field experiments where the external input/output conditions such as flow of water and nutrients can be controlled and measured reasonably accurately to derive qualitative and quantitative relationship of the buffering processes;
2) results from pilot areas can be applied to more complex situations with more certainty; and
3) to allow field data to be collected of a number of variables and over time in a controlled manner, and for these study areas to act as a reference sites.

Following from the reasoning above, the selection of the pilot wetland sites was guided by the following key aspects:

- the sites selected reflected the existing land use patterns in the lake basin such as urban, municipal, industrial and agricultural use,
- the site selected are representative of the existing wetland vegetation,
- the site are easily accessible and secure for installation of expensive and sensitive equipment,

- for a pilot study, the wetlands selected have clear boundaries with clearly defined inlets and one outlet, so that the hydrological and material mass balances can be established reasonably accurately, and
- the pilot study areas have clear boundaries as above so that the results obtained from the study are reasonable and accurate so that it is applicable elsewhere.

SMEC with the assistance of the LVEMP wetlands component visited five possible sites with the LVEMP Wetlands Component. Of these sites, the Nyalanda wetlands near the Kisumu sewerage works, Kingwal Swamps near Nandi Hills and Saiwa wetlands near Kitale were not considered for further investigations due to reasons such as large size, lack of definition, encroachment, large scale encroachment of exotic species, inflow of diffuse pollution during wet weather and lack of hydrological control.

The sites in Kericho and Eldoret were selected to be studied in detail as they are well defined in extent, have obvious and easily accessed inputs and outputs, have a mix of vegetation across the two sites that makes them representative of a very wide range of wetlands across the basin, they are both located in proximity to major urban centres making logistics and access straightforward and both have a number of stakeholders with positive attitudes towards programs seeking improved wetlands management.

2.4 Pilot Stage Tasks

Tasks undertaken in the pilot stage formed the most substantive aspects of the project. These included:

- descriptions of the pilot wetland sites, their location, environmental setting, hydrology, soils, vegetation and land uses, the two pilot wetland sites being the Dionosoyiet Wetland in Kericho and the Chepkoilel Wetland in Eldoret
- Preparation of land use/land capability maps for the pilot wetlands
- Designing and undertaking hydrologic monitoring of wetlands for a dry/wet period
- Designing and undertaking water quality monitoring of wetlands for a dry/wet period
- Determining the buffering mechanisms and processes involved in the movement of nutrients and pollutants

- Preparing a preliminary prediction model of the buffering capacity from monitored results
- Training and working with a select team of officers/scientists for Technology Transfer
- Preparing recommendations for improved use or non-use of the pilot wetlands using the land capability map and monitored results
- Identifying, describing and mapping the important Environmentally Sensitive Wetland Areas (ESWA) in the Kenyan portion of Lake Victoria coastal zone
- Estimating the buffering capacity of the wetlands in the Kenyan portion of the Lake Victoria coastal zone using existing and monitored data
- Preparing preliminary guidelines for use/non-use of wetlands using existing information and pilot studies

2.5 Reporting Tasks

Reporting tasks identified as necessary under the TOR and subsequent negotiations required to be submitted were an inception report, mid term report, draft final report and final report.

The Inception Report was submitted as required on 10 July 2004. This report detailed the approach that would be used for the substantive parts of the study. The LVEMP wetlands component and secretariat received the report favourably and made the associated payment as per the contract.

The Mid Term Report was submitted as required on 10 November 2004. This report detailed the progress to date on pilot activities. The LVEMP wetlands component and secretariat received the report favourably and made the associated payment as per the contract.

The Draft Final Report is this document, submitted 10 May 2005.

The Final Report is due on 10 June following the submission of the draft final report and is to incorporate comments as requested by the client.

3. Information and Data Review

3. INFORMATION AND DATA REVIEW

This section describes the information and data review process that was undertaken for the project. Information and data are considered as knowledge of wetlands of the Kenyan portion of the basin, including consideration of the common types of wetlands and wetland vegetation within the basin, distribution of wetlands in the basin, satellite image classification, wetlands values and controlled experiments on wetlands for water quality. Following this assessment of the state of knowledge, data gaps that were identified are discussed.

3.1 State of Knowledge of Wetlands in the Kenyan Portion of the Lake Victoria Basin

While this study is the first attempt to determine the buffering capacity of wetlands of the Kenyan portion of the Lake Victoria Basin, a significant amount of literature is available internationally and regionally that contribute to the state of knowledge of this area.

The references section provides a listing of numerous studies and research works on wetland systems relevant to the East Africa region. The references show that industrial and municipal waste water have been the main focus of most of the studies in the region. The list includes academic research works, investigations from institutions and individual initiatives.

Wetlands of the Lake Victoria Basin

The Kenyan portion of the Lake Victoria basin has a wedge like catchment with waters flowing sorthwesterly towards the lake. The area is bordered to the west by Uganda, to the South by Tanzania and to the north east by the highlands separating the basin from the Kenyan rift valley. Owing to the related climatic, geological and hydrological variation over the catchment, wetland types and the macrophytes within the basin vary significantly in terms of hydrology, soils and ecology.

Common types of wetlands in the basin and the region in general include:

(i) Permanent highland swamps in upland, high rainfall areas such as in the vicinity of Kericho, Kisii, Eldoret, Nandi, Kapsabet and Kitale. These wetlands often constitute headwaters for the main rivers.

(ii) Permanent low lying wetlands associated with the lake shores such as Yala swamp and Dunga swamp.

(iii) Freshwater marshes and palustrine/riverine wetlands found along the key river flood plains where the topography is mild. These are particularly prevalent along the course of the Nzoia river.

(iv) Seasonal swamps are found mainly in the areas between the highlands and the lake shores where rainfall is highly seasonal. Characteristics of these wetlands will depend on rainfall patterns which determine the type of vegetation is present. These swamps are often found in large open grassland areas such as in the Masai Mara reserve.

Wetlands in the basin are connected by rivers draining into the lake. The ecological characteristics of these rivers and hence the wetlands are determined by the land use at the respective locations along the way towards the lake shores. Njuguna (2000) reported that the buffering capacity as well as their role in species maintenance is unknown. He also reported little is known on their types and distribution in the lake basin.

The wetlands component of LVEMP carried out a rapid assessment of the wetlands in a number of river basins among them Nyando, Kuja Migori, Sondu-Miriu between the year 2000 and 2001. Most of the wetlands identified had been encroached by human activities including farming and settlement. Owing to this the nature of the wetlands including plant species has been significantly altered through removal or degradation of the original wetland flora and introduction of exotic species. For example, most wetlands in the Kuja Migori River Basin have eucalyptus tree planted around them resulting in diminished water storage capacity.

As part of the rapid assessments, some of the wetlands identified were geo-referenced and an attempt to describe the physical location was made, but more work on specific wetland information is required to enable effective mapping.

Key plant species in the Kenyan portion wetlands identified during the rapid assessments and expected to have high value for wetlands buffering included:

(i) *Cyperus* spp. including *papyrus*, *triadra, immensus* and *rotundus*. Widespread on wetter grounds and fresh waters and in areas with significant permanent water. *Cyperus papyrus* in particular is the most abundant wetland species in the Lake Basin. It dominates the lake shores and low land wetland sites. *Cpyerus papyrus* is the dominant wetland plant in the lake basin area and has high significance for both wetlands buffering capacity and for wetlands products.

(ii) *Phragmites* spp. mainly found in the southern zones of the Kenyan part of the lake basin around Kisii and in the rivers systems in the north western portion of the Kenyan part of the basin. *Phragmites* spp are common along riverine systems and in seasonal wetlands or sections with intermittent water cover and are significant as they have a high buffering capacity.

(iii) *Typha* spp are widespread in the basin, especially in low lying marshy areas and are significant in that they have a high buffering capacity for pollutants.

(iv) *Eucalyptus* spp. is present mainly in degraded swamps. These are of high value for wood production; however as a rapidly colonising non indigenous species with a high capacity to take up water, they are also considered to be a major threat to wetlands in the basin.

(v) Other wetland plants are *Vossia* spp*, Potamogeton* spp*, Ceratophyllum demersum* and *Echinochloa* spp

Wetlands Distribution in the Lake Victoria Basin

Surveys and inventories carried out within the basin have identified most wetlands to be linked to the lakeshore (beaches, estuaries, bays and inlets), floodplains and delta of affluent rivers and streams. The channels of main rivers are fringed by a narrow belt of macrophytes and small patches of riverine forests while those in the river catchments consist of springs, water storage dams, fish farms or ponds and valley bottom marshes (Katua and Mmayi 2001; Gichuki et al.,2001; Raburu, 2002).

River discharge has profound influence on the size and stability of the floodplain and deltaic wetlands which dominates the Lake Victoria Basin. River Yala has the largest deltaic wetland, the wetland here being known as the Yala swamp. The swamp extends over a stretch of 25 km from W-E and 15 km from N-S at the lakeshore from 0°07'N-0°01'S/33°58'-34°15'E. It encompasses the Nzoia Delta as well as the Yala delta, all the lakeshore south to Ugowe Bay, land eastward to Lake Kanyaboli and extends up the Yala River in the south for quite some distance. Size estimates for this enormous wetland range from 38,000 – 52,000 ha depending on wetland delineation methodology. It including includes several minor open water areas large enough to be termed Lakes, the largest of which is Lake Kanyaboli (1500 ha).

Other major deltaic wetlands include:

- the Nyando which measures 15 km from W-E and some 6 km from N-S with an area of 14,400 ha, situated at the mouth of the Nyando River at Nyakach Bay, extending back onto the Kano Plains (0°11-0°19'S/34°47'-34°57'E),.
- Sondu-Miriu which is 3,500 ha in area located at 0°18'-0°21'S/34°45'-34°48'E and
- Kuja with an area of 4,062 ha at 0°54'-0°-58'S/34°08'-34°11'E,

There are numerous isolated wetlands that depend on seasonal floods of rivers and subsurface water flow. These wetlands include the Kamandi floodplain (480ha), Gucha-Migori floodplain (726 ha), Homa Bay swamp on Nogusi River (55 ha) and Kisumu Swamp (623 ha). There are approximately 483 small pond wetlands on the Kano Plain. The rice paddy fields of west Kano (436 ha) can be considered to constitute a significant wetland on the basis of the wetland definition given in Section 1.2 (Katua and Mmayi 2001); however, their ecological and buffering values are most likely very limited. All these rivers have catchments in high rainfall zones with prolonged wet seasons thus forming extensive swamps on the lakeshore.

Other small wetlands, including seasonally flooded areas and permanent swamps, occur on the upper courses of these rivers and their tributaries. The most important of these are found at the foot of the dip slopes on the west side of the Rift Valley, from the Cherangany Hills south to the equator.

Wetlands Distribution Mapping

Broad scale mapping of wetlands across the lake basin has previously been performed by RCMRD in conjunction with FAO as part of the development of the Africover Landuse Database System. This is available as an interactive database through the internet for a number of countries in the region, including Kenya. This project was done in Kenya for the Ministry of Environment and Natural Resources. The Africover landuse system classifies the landuse in Kenya into 18 different classes, of which, wetlands form one class.

Africover describes subclasses of wetlands as permanently inundated, temporarily inundated and open water areas. The classification considers wetland vegetation types as *Cyperus papyrus* in both its floating and emergent forms, as these are indistinguishable from above the plant canopy, emergent species (sedges and principally rushes), floating species and open water. The resolution is quite coarse and accuracy is at times questionable as the Africover project was not focussed specifically on wetlands mapping.

Otieno (2004) performed supervised and unsupervised classification for the Yala wetland within the Kenyan portion of the Lake Victoria basin based on LANDSAT TM imagery. Otieno (2004) investigated composite images over bands 2, 3 and 4 and over bands 3, 4 and 6 and found the best results coming from bands 2, 3 and 4. The study showed that both supervised and unsupervised classification of LANDSAT TM images could be used to derive and map spatial land cover types of the Yala swamp to a 30 m resolution; however the supervised technique could not be used for classification because some spectral classes had inadequate number of pixels required by the computer to successfully process the statistics for a training site.

The wetlands of the Tanzanian portion of the basin were mapped using a similar methodology under the Tanzanian LVEMP wetlands component buffering capacity study (ARCADIS, 2001).

Wetlands and Water Quality in the Lake Victoria Basin

Okurut (2000) observed that wetlands throughout the world have been used as disposal sites for many types of waste. Ngirigacha (2000) also reports on the application of wetlands as surface run-off regulators, sinks and transformers of materials from societal wastes as well as silt traps in agricultural catchments. Most of the wetlands in the Lake Victoria basin receive surface run-off and municipal waste water from the towns along the coast line and far high into the catchment. Okurut (2000) reports on the unpredictability of the wetlands in performing water quality improvement. Among the factors reported to cause this unpredictability of performance of natural wetlands in waste water treatment is the variability of treatment processes resulting from external effects. These effects include,

(i) difficulties in managing and optimising the functionality of natural wetlands with respect to influent waste water, hydraulic flow patterns, plant characteristics, wetland geomorphology and other variables,

(ii) management of wetlands must account for other roles, which may at times be competing against their functions in water quality improvement Bio-diversity conservation, habitat and breeding grounds, hydrologic and hydraulic functions are among the other functions that must be considered.

Owing to the above limitations, constructed wetlands are a preferred means in water quality improvement since the conditions within a constructed wetland can be controlled better to suit the targeted waste water quality.

Kansiime and Nalubega (1999) did significant work on the hydrology and water quality of Nakivubo swamp, a natural wetland on the shore of Lake Victoria at Kampala, Uganda. The Nakivubo swamp receives wastewater from a number of sources and discharges directly to the lake. The study in particular focussed heavily on water quality and hydrodynamics within the wetland through the use of a number of transects through the wetland. This very close focus on internal processes was necessary in that study due to the diffuse nature of sources of water and pollutants entering the wetland and the indistinct interchanges of water between the wetland and the lake. Consequently water quality and hydrology processes internal to wetlands in the Lake Victoria Basin can be seen to be well understood and there is little need to focus on this aspect in the present study.

Controlled Experiments on Water Quality Processes in Wetlands

Significant work has already been carried out under controlled conditions to give the actual process taking place in a wetland environment while treating waste water. Among the widely studied species include *Cyperus* spp, *Typha* spp, *Phragmites* spp. Others are *Eichhornia* crassipes and *Pistia stratiot*. Of all species, *Cyperus papyrus* seems to be the most studied in all the three East African countries, and particularly in Uganda. Given its ubiquitous occurrence in East Africa and the promising results it has yielded for water quality improvement, this is not surprising.

Studies on growth patterns and capacity of various wetland plant species in the Lake Victoria Basin to remove pollutants from waste water include Heines and Lye, (1983); Howard-Williams and Gaudet, (1985); Kansiime and Nalubega, (1999); Okurut, (2000); Ngirigacha, (2000); Kiwanuka, (1996). Studies have also been carried out to characterise the impact of increased nutrient inputs and hydrological change on tropical wetland systems (Osborne and Totome 1992, 1994). These results while immensely valuable for the insights they afford to the potential for wetlands to improve water quality in the Lake Victoria Basin must be applied with caution as most of these studies, were carried out at bench scale or constructed wetland-cell levels.

Studies at the Selected Pilot wetland sites: Kericho Dionosoyiet and Eldoret Chepkoilel Wetlands

Koech (2003) studied the water quality of the Dionosoyiet River. He observed that the head waters of the river and its tributarties upstream of Kericho have relatively low nutrient, organic and suspended solids concentrations but there are significant increases in all of these as they flow past the town. Urban runoff and effluent from the sewage treatment plant are the main contributors to this trend.

No previous studies could be identified with regard to the Chepkoilel wetland site at Eldoret.

3.2. Knowledge Gaps

From the above literature and data review, two significant knowledge gaps emerged: lack of knowledge of urban runoff impacts and lack of knowledge of inflow to outflow nett changes in water quality occurring under wet weather conditions.

Of all the pollutant runoff from the land use practices that are present in the lake basin and threaten the ecological integrity of Lake Victoria and its coastline and embayments, only urban runoff pollution has not been studied in detail. While urban runoff would have been a source of pollution in Nakivubo swamp, the work by Kansiime and Nalubega (1999) focussed on sewage sources instead. The genesis of urban runoff pollution and the processes associated with its buffering by the natural wetlands in the lake basin has not been studied before. This is considered a significant gap in existing knowledge.

There are some hydrologic data pertaining to wetlands in the rapid assessment reports. There are also limited water quality data. However, the hydrologic data is limited to a single inflow and out flow measurement at the time of the visit. In the same manner, the water quality analysis is also limited to a grab sample at the time of the visit. They give the state of the wetland at a particular time only. Further, not all rapid assessment reports give such detailed data.

There are no established gauging stations with recorded flow data for any wetland sites in the Kenyan portion of the basin. However, there are some data on materials mass balance for particular natural wetlands, relating to sediments and nutrient fractions, reported from studies in Uganda and Tanzania. These studies predominantly relate to dry weather flow or low flow periods, having used discrete grab sample analysis and flow rating methodology to arrive at mass balances.

Detailed studies on the performance of wetlands under wet weather conditions and collecting a reasonable number of samples to represent the flow hydrograph, have never been done. The paucity in flow and water quality data collected at short time intervals during wet weather events is a serious knowledge gap. The possibility of net export of sediments and nutrients to the lake from the wetlands during wet weather events has never been tested. The possibility of existence of such phenomena and therefore their effects on the management of wetland performance and lake water quality could be a serious draw back.

One critical reason for this knowledge gap is that automated continuous flow measurement devices integrated with automatic sampling equipment have never been used in wetland studies around the lake region. Auto samplers were procured for the LVEMP Water Quality Component a few years ago, but they were never deployed in wetland studies. Further, they were not procured with flow monitors that can be integrated, making them less useful for monitoring wet weather flow events.

The studies performed here therefore concentrated on these two aspects. Selection of pilot wetland sites took into account the possibility of using sites where urban runoff is significant, as described in Section 4. Hydrology and water quality monitoring techniques were adopted that addressed nett changes in water quality of wetlands from inflow to outflow including over storm periods as described in Sections 5 and 6.

4. Pilot Wetland Site Descriptions

4. PILOT WETLAND SITE DESCRIPTIONS

As described earlier, a significant aspect of the study was associated with the selection and monitoring of pilot wetlands sites over the course of the project. This section reports on the selection of the pilot wetland sites, descriptions of the pilot wetland features, catchment settings for the wetlands and the monitoring networks established for the wetlands.

4.1. Pilot Wetlands Site Selection

Following from the objectives set out in the terms of reference, at inception stage it was necessary to select pilot wetland sites in which direct hydrology and water quality measurements could be made. The purpose of selecting pilot wetland sites was to identify locations where field experiments could be conducted with suitable external input/output conditions such that flow of water and nutrients were able to be measured accurately enough to derive qualitative and quantitative relationship of the buffering processes.

The suitability of sites from a view point of measurements accuracy was critical so that reasonable confidence is then associated with the results. Thus the results so derived from pilot areas can be applied to more complex situations with more certainty and allows upscaling to basin wide level as described in Section 11.

Pilot wetland site section was guided by key selection criteria as described below.

Selection Criteria for the Pilot wetland sites

(i) The pilot wetland sites should reflect the existing land use patterns in the lake basin such as urban, municipal, industrial and agricultural use,

(ii) The pilot wetland sites selected should contain wetland vegetation typical of the lake basin area,

(iii) The pilot wetland sites should be easily accessible and be easily secured for installation of expensive equipment, and

(iv) the pilot wetland sites need to have clear boundaries preferably with one inlet and one outlet, so that the hydrological and material mass balances can be established reasonably accurately

Wetlands that were inspected by SMEC in conjunction with the LVEMP wetlands component with a view to establishing pilot wetland sites included:

- **Nyalenda wetlands, Kisumu Area**
  Key sources of pollution are municipal sewage and urban run-off. The wetlands are mainly dominated by *Cyperus papyrus* and *Typha* spp, but they have been seriously encroached by human settlement, and receive considerable amount of diffuse sourced pollution, making the boundary conditions of the wetland very uncertain.

- **Dionosoyiet Wetland, Kericho**
  Land use in the surrounding areas are basically agricultural and urban. In this regard, the main pollutants are input via urban runoff, agro-chemical residues and municipal sewage. Sections of the wetland were protected by the Wetland Component and KWS arboretum (downstream of the town). The study are has five permanent inlets and a well defined single outlet.

- **Nandi Hills Wetlands**
  The area is wholly agricultural with the Kingwal swamp being the main wetland in the area. Wetlands here are dominated by *Cyperus papyrus* and scattered *Typha spp, Cyperus immensus* and other species. The wetlands in this area generally have well defined outlets, but many inlets.

- **Eldoret Area Wetlands**
  Eldoret is located climatic region as Nandi Hills, however topography here is much flatter. The vegetation here is mainly *papyrus*. Chepkoilel swamp is the main wetland, it receives pollutants from mainly from stream inflows through the Misikur river with the Moi University Chepkoilel campus waste water treatment ponds also discharging into the wetland. The wetland here has well defined inlets and outlet.

- **Kitale Area Wetlands**
  Saiwa wetland is a conservation wetland under KWS within the headwaters of the Nzoia river system. The wetland receives water from a purely agricultural area spanning as far as Cherangani hills. Difficulty was encountered in defining the inlet for this wetland.

After careful consideration of these wetlands, the two pilot wetlands chosen were the Dionosoyiet riverine wetland at Kericho and the Chepkoilel wetland near Eldoret.

The Dionosoyiet wetland is well suited for monitoring as a pilot wetland. It has well defined inlets, outlets and a clear perimeter. It is convenient in size and access for ease of monitoring and local stakeholders were quite supportive of the study. Furthermore, selection of the Dionosoyiet site was favoured by the fact that most studies in regard to wetlands as pollutant sinks in the region have been carried out on those receiving inflows from municipal, industrial or agricultural activities. Very few studies have assessed wetlands receiving urban run-off. . Urban and peri-urban runoff is considered to be a very critical and increasingly detrimental source of nutrient and sediment input delivery into the Lake Victoria. After preliminary assessment of the wetlands in the basin, it was established that most natural wetlands receiving inflow from urban centres have been encroached by settlement, urban activities or agriculture disrupting their boundaries and creating multiple and diffuse inlets and outlets.

The Kericho Dionosoyiet wetland however had:

- clear boundaries and well defined entry streams as mentioned above
- good site protection through a fencing project carried out by the LVEMP wetlands component
- from a research support perspective, there is a very active stakeholder and local community; and
- from a logistic perspective, the wetland is in very close proximity to a major town centre (Kericho) and is conveniently located not far from the main road between Nairobi and Kisumu where the selected laboratory for analysis at the Ministry of Water were located.

The wetland was therefore seen to have excellent potential to yield clear results for buffering capacity.

The Chepkoilel wetland at Eldoret was chosen as a second pilot wetland site for the following reasons:

- the wetland is dominated by *Cyperus papyrus*, which is absent at the Kericho Dionosoyiet wetland site. Papyrus is the dominant aquatic plant in the lake basin area. As desribed in Section 4, Papyrus is also known to be a major contributor to wetlands buffering capacity in the Lake Basin region;
- the wetland has well defined monitoring points at the stream inlet, the Chepkoilel campus Sewage Treatment Plant and the downstream bridge;
- the proximity to a major town centre at Eldoret; and
- Easy access to Kisumu, Kericho and Nairobi.

4.2 Pilot Wetland Site Descriptions

Descriptions for the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands, based on observations made in the field are contained below.

The Dionosoyiet Pilot Wetland in Kericho

The Kericho-Dionosoyiet wetland is located 1 km northeast of Kericho town and it is a relatively small wetland of 34 ha in a catchment of 23 km^2. The wetland is located in the upper reaches of the Sondu-Miriu river system. This is a permanent riverine wetland. It lies in a wide flat valley bottom separating steep undulating topography on both sides. As shown in Figures 4.1 and 4.2, the surrounding land use consists largely of smallholder agricultural land and commercial tea (*Camellia sinensis*) plantations but with significant urban and peri urban components. Subsistence agriculture includes maize (*Zea mays*), potato (*Solanum tuberosum*) and various market vegetables. The wetland catchment includes the Nyagacho housing area to the east and a significant proportion of the Kericho town area to the south and east. The area is not fully sewered and solid waste disposal is limited.

The wetland comprises a dense, diverse mosaic of wetland plants dominated by *Cyperus* spp. (*C. immensus, C. triandra*) with some *Typha* spp. (*T. domingensis* and *T. capensis*) and *Polygonum* spp. (*P. senegalense, P. pulchrum*). *Potamogeton sweinfurthii* grows in areas where emergent vegetation is absent such as near the inflow streams at the head of the wetland and in small areas near the outflow monitoring point. Wetland vegetation is lush and is notable for its heterogeneity and lack of zonation. A full list of vegetation known to be present in the wetland is given below.

The wetland is known to be used as habitat by a few species of wetland birds, most notably grey crested cranes (*Balearica reulorum*). Anecdotally, the local community consider that the wetland also harbours snakes and small nocturnal omnivorous mammals (ratel *Mellivora capensis* and common genet *Genetta genetta*). The eastern bank of the wetland is an arboretum recently planted with a variety of trees that was established through the LVEMP wetlands component, now administered by the Kericho Municipal Council. The site has been fenced off but grazing by goats and cattle has not been completely eliminated. The western bank has secondary scrub forest that is mostly indigenous but has significant incursions of blue gum (*Eucalyptus saligna*).

Figure 4.1 shows typical land use activities in the vicinity of the wetland ranging from urban to rural on the catchment as determined by the mapping exercise (refer to Section 11 for further details). Figure 4.2 shows typical scenes from around the Dionosoiyet wetland catchment. The major inflows to the wetlands draining the catchment are:

(i) A spring in the northeastern extremity of the wetland that discharges with a very consistent flow. The discharging water is clear and does not seem to be affected by rainfall. The spring develops into a stream that flows into the wetland about 30m away. The spring is used by the local community for bathing and washing.

(ii) A storm water drain running along the main road from the town centre towards the Northern extremity of the wetland. The drain collects surface runoff from the north eastern end of the town including the market area, industrial area, residential houses and road surface among other areas. Discharges from the drain are heavily laden with soils, sand, plastic materials, polyethylene bags, textiles, paper, wood and metallic refuse. These materials clog the free flow of water into the wetland as can be seen in Figure 4.3.

(iii) The main stream, officially marked on survey maps as the Dionosoyiet River is known by the local community as Tionysoet by the local community, the name meaning "place of water buffalo". Water from the stream enters the wetland system that runs from the eastern direction. The catchment covers an agricultural area mainly with tea, and scattered residential houses. The catchment topography is comprised of steep slopes and valleys with permanent streams.

(iv) The Ainaptindinyetin stream is the fourth inflow, coming from the Northern direction. It drains an agricultural area with a rural settlement setting. Like the above, the catchment is also steep sloped.

(v) The fifth inflow is known as the Ainabtindinyiek stream enters the wetland from a northwestern direction. It drains a catchment mainly comprising urban settlement in the immediate vicinity of the wetland and agricultural activities further upstream.

(vi) Minor ephemeral road side drains enter the wetland along its western edge.

During storm events, there is considerable and rapid run-off from the paved, urban areas. Under these conditions the inflows at the storm drain from town and minor drains on the eastern side of the wetland have high sediment concentrations and carry high gross pollutant loads such as plastic bags. Minor temporary diversion works were considered to combine flows from the minor drains and force them to flow towards the western most permanent inflow stream, the Ainabtindinyiek.

The outlet of the wetland is a seven-cell culvert 4 lower culverts and three higher culverts as can be seen in Figure 4.4. The culverts are set in an embankment that is used as a walkway by the local community between Kericho town and Nyagacho. A side spillway allows high flows to exit the wetland as the top three culverts begin to be submerged. Under extreme flows the embankment itself would also be submerged and act as a broad crested weir, although the integrity of the structure itself is questionable and there is considerable risk that failure of the embankment could occur under high flow conditions.

Although significantly wider at inlet than outlet, the study site can be construed as a linear wetland approximately 400 m long by 80 m wide. Protection works for the wetland carried out by the LVEMP wetlands component have created an excellent study site that could be used for long-term assessment and research. The results as presented in Sections 5 and 6 therefore provide particular insight into the hydrologic and water quality functions of a highland wetland in tropical East Africa.

The wetland has been declared an Environmentally Sensitive Wetland Area (ESWA). It is under the jurisdiction of the Kericho Municipal Council but there is considerable use by local communities as a source of potable water, for bathing, laundry, car washing, gathering traditional medicinal herbs and recreation. The keen interest and widespread use of the site by the local community is a further attraction of the site as there is a lower risk of theft and vandalism at sites with high community engagement than at remote sites in isolated areas where community engagement is poor.

Land Use Setting

Distinct patterns of catchment activities were observed immediately around the site, depending on their bearing from the wetland as follows:

South and East

Kericho town is located to the southeast of the site, with the town cemetery lying between the wetland and the town centre. The town represents one of the most significant diffuse sources of pollution to the wetland. Key areas within the town from which pollutants are likely to be derived are:

(i) The market place, located about 500m from the southern most point of the site, and spans about 5 ha. Some of the activities at the market include open air sale of fresh food, grains, used and new clothes and household utensils. In addition, there is a terminal for public transport vehicles in the middle of the market area. The market area and matatu terminal are therefore likely to be significant sources of nutrients, sediments and gross pollutants.

(ii) To the east of the open air market, there is an informal cottage industrial site where artisans fabricate a wide range of items including cooking pots, farm implements, vehicle spare parts, furniture and collection of recyclable materials among other products. Again this site is likely to contribute significant amounts of sediments, and gross pollutants.

(iii) Further south is the town centre with various commercial activities. These include general shops, hardware shops, food outlets, service stations, garages, pharmacies and numerous workshops. Nutrients, gross pollutants, suspendended solids and heavy metals are likely to be high from this area.

(iv) The town's industrial area is located between the town centre and the pilot wetland site. However, there are limited manufacturing factories, most of them being cottage industries. Again as for the town centre, nutrients, gross pollutants and suspended solids are likely to be quite high from this area.

(v) There are residential houses to the south west of the site. The roads in this area are unpaved so suspended solids, nutrients are likely to be high here.

(vi) a large number of the roads around the town have no formalised footpaths and many are unsealed. The town area is served with a sewer network connected to the main municipal sewerage works to the far western end of the town.

Effluent from the KEWASCO Sewage Treatment Plant is discharged into the wetland; however the outlet point of the wetland was deliberately chosen to be above this discharge point so that municipal sewage inputs will not form a load into the section of the wetland studied as it was desired to concentrate on the treatment of urban and agricultural runoff by wetlands for this study, rather than the treatment of sewage effluents.

North

The key features to the east of the site include;

(i) a primary school located about 200m from the site,

(ii) tea plantations beyond the school in the far North East,

(iii) the Kericho greens stadium is also located here with an informal

(v) a small number of informal residences close to the wetland.***North West***

The northern and western sides of the wetland mainly consist of informal residential settlements, especially in the Nyagacho area. This area is densely populated and hosts a wide range of economic activities such as shops, garages, food outlets and butcheries. The area is not sewered, nor are there organised solid waste collection systems. Much of the area drains into the pilot wetland site.

Site Works Performed

In order to allow for flow measurements and sampling for water quality parameters, the following activities were undertaken in the Kericho Dionosoyiet wetland:

- clearing vegetation around the inlets including the spring;
- excavation of the silted inlets and opening of the blocked culverts;

- laying sand bags at the surface runoff inlets along the road drainage so that the runoff can be diverted to only one inlet upstream of the transect;
- the laying of the sand bags along the bridge to ensure water level control;
- the removal of the excavated and cleared materials from the inlets and dumping them at the proper sites;
- channeling runoff from the blocked culverts;
- blocking the diversion culvert and digging a diversion channel from the culvert point;
- an inspection of the wetland to identify potential ground water seepage areas and springs;
- geo-referencing of the various gauging/sampling points using a Global Positioning System (GPS);
- GPS geo-referencing of points along the wetland edge;
- Establishment of a transect approximately 200 m downstream of the Northern extremity of the wetland to allow access to the wetland interior;
- Installation of water level gauges for flow rate measurements at the 5 permanently wet inlets, transect and outlet;
- catchment characterization of Kericho Dionosoyiet wetland; and
- reinforcement of the embankment to prevent leakage in order to ensure a higher reliability of flow measurements at the outlet

Monitoring of the Kericho Dionosoyiet wetland was performed at up to eight sites comprising the inlets listed above, the transect and the outlet. These are listed below and listed in Table 4.1.

Inlet Station 1 **(IK1):** The spring situated at the head of the wetland on the eastern edge towards Kericho town centre. The spring discharges ground water that enters the wetland, about 20m downslope of the spring.

Inlet Station 2 **(IK2):** The storm water drain flowing from the town centre towards the wetland from the eastern end, alongside stadium road (the main route between Kericho and Nyagacho). The water is highly coloured with soils residues, turbid and a high gross pollutant load. The stormwater from the main market, mechanics sheds, some residential areas and roads surfaces enters the wetland from here,

Inlet Station 3 **(IK3):** A culvert under stadium road through which the Dionosoyiet stream enters the wetland from the northeast. The water in the stream was generally clear, though with slight turbidity perhaps due to infiltration from surface run-off from agricultural land.

Inlet Station 4 **(IK4):** A culvert under stadium road through which the Ainaptindinyetin stream enters the wetland from the north. Visual characteristics of this stream are similar to IK3.

Inlet Station 5 **(IK5):** A culvert under stadium road through which the Ainabtindinyiek stream enters the wetland from the northeast. Visual characteristics are similar to IK3 and IK4.

Inlet Station 6 **(IK6):** An ephemeral storm water stream comprised of run-off from the road and the settled area. All upstream drain entry points were blocked as described earlier so that if flows were generated through storm events, they would enter the wetland from this point. At no time through the monitoring were any significant flows observed to enter the wetland though this inlet.

Transect
Station 7 **(TK7):** Given the large number of entry points, a transect was constructed across the wetland immediately downstream of the inlets to allow monitoring of the combined effects of the inflows on nett water quality and hydrology of the wetland close to its upstream extremity. The transect was found to intersect a fast flowing stream in the centre of the wetland where highly channelised flow carries most of the flow of water and most of the pollutant loads through the wetland (see Section 6). Two slotted pipes were installed along the transect to enable profile monitoring; however initial monitoring performed found that water quality was uniform across the transect so profiling was not required.

Outlet
Station 8 **(OK8):** This is the outlet from the wetland at the embankment used by the community to access between Kericho and Nyagacho. The water discharging from this point is homogenous, clear and with little visible suspended matter unlike the inflows described above. There was evidence that there is significant underflow through the causeway and possbily over the bridge during heavy storms.

Table 4.1: Geographical Location of Permanent Inflow points, Transect and Outlet at the Kericho Dionosoyiet wetland

Site Name and Description	UTM Coordinates (km)	
	Easting (36750000+)	**Northing (9900000+)**
Inlet IK1 Spring	4019	60150
Inlet IK2 Urban stormwater drain	4023	60177
Inlet IK3, Eastern Stream, Dionosoyiet	3982	60231
Inlet IK4, Northern Stream, Kenongo	3903	60280
Inlet IK5, Western Stream, Ainabtindinyiet	3811	60251
Transect TK7	4417	58594
Outflow at bridge OK6	3625	59907

To monitor these stations, the following works were performed after consultation with the Kericho Muncipal Council Town Engineer:

(i) Clearing the vegetation around the inlets to enable easy measurement of flow rates and sampling,

(ii) Excavation of the silted inlets and opening of blocked culverts to facilitate free flow of water into the wetland system,

(iii) Clearing the main storm water drain of debris such as polythene materials, plastics, papers, textiles, wood and mud,

(iv) Sand bagging the numerous minor storm water inlets on the western side of the wetland to force all surface water from the informal housing area to enter the wetland from the uppermost point,

(v) Sand bagging on top of the embankment at the outlet to reduce the risk of overtopping, to make access easier and so that in the event of overtopping, flows would be better controlled.

Subsequent to finishing extended duration monitoring in February 2005, the sand bags were removed from the minor storm water inlets on the western side of the wetland so as not to cause any risk of flooding.

Vegetation Types Present

Screening for plant species was done by comparing samples taken from the wetlands against those held in the National Museum of Kenya (NMK) Herbarium with reference also to officers of the Department of Resource Survey. Predominant flora have been determined for the wetlands, however, it should be noted that the lists are not exhaustive and will require updating and ongoing review, in recognition of the dynamic nature of the wetland plant communites. For, the Kericho Dionosoyiet wetland, the bulk of the vegetation is dominated by *Cyperus* spp.(sedges) followed by well scattered *Polygonum* sp. of different types.

Plant species noted as present in the Kericho Dionosoyiet include:

- *Polygonum salicifolium*
- *Polygonum senegalense*
- *Polygonum pulchrum*
- *Potamogeton sweinfurthii*
- *Typha domingensis*
- *Typha capensis*
- *Mimosa pigra*
- *Ludwigia stolonifera *
- *Cyperus rotundus*
- *Cyperus laerigatus*
- *Cyperus schimperianus*
- *Cyperus latifolius*
- *Eragrostis tuneifolia*
- *Amaranthus hybridus*
- *Hibiscus* sp.
- *Echinochloa* sp.
- *Eragrostis* sp.
- *Ipomoea* sp.
- *Achyranthes schinzii*

Soils

The Kericho Dionosoyiet wetland physiographically lies on a volcanic footbridge. The area is undulating to rolling with slopes of 7 – 16%. The soils in the Dionosoyiet wetland are developed on tertiary or older basic igneous rocks such as basalts with soil depths greater than 120 cm.

Soil physico-chemical and nutrient content analyses conducted are reported in Section 6. These show that for Dionosoyiet the soil pH is acidic which is not favourable for crop growth. In order to undertake cropping, it would be necessary to neutralize the soil acidity through the application of lime prior to planting.

Soils at Dionosoyiet have a two layer horizon profile, as described below.

Soil Horizon 1

The uppermost soil horizon extends from the surface to between 16 and 30 cm depth. This clay layer ranges from dark brown to very dark grey in colour. This layer is slightly hard to very hard when dry, friable to firm when moist and plastic when wet. Grains display a medium sub anglular to angular and blocky structure slightly hard too hard when dry. There are abundant fine very fine roots present in the many micro to very fine pores that are present.

Soil Horizon 2

Below the upper horizon, a second horizon is present extending to a depth of 70 to 160 cm. This layer is dark grey to black in colour, is very hard when dry, firm to very firm when moist and firm, sticky and plastic when wet. The layer has a medium angular to subangular block structure with few micro pores and very fine pores. Very fine and fine roots are common through the structure.

Existing and Potential Land Use

Given its urban setting, the Dionosoyiet wetland is currently used by the local community for a variety of purposes including bathing, laundry, water supply, car washing and recreational activities. There is limited informal grazing by cattle and goats, but this has been curtailed by the establishment of the arboretum and associated fencing performed by the LVEMP wetlands component.

With this urban setting and other constraining factors including the poor soils present and the flood risk inherent in using the site, there are few potential land uses apart from those that are noted above as feasible.

It is recommended that the wetland be preserved in its present state with access at limited points to allow the local community to continue using the wetland washing, bathing and for recreation. Further efforts should be taken to formalise access points for the local community and to curtail livestock access to the wetland. The appropriateness of the car wash at the upstream extremity of the wetland needs further scrutiny. This activity should only be allowed to continue if access points where water is taken from the wetland are formalised and if wash waters are contained more formally. Establishment of a well maintained site car wash site with the oil-water and solids separators is required, and the ultimate aim of establishing water recycling and a zero discharge policy is recommended. These points are expanded on in the wetland management plan for the Kericho Dionosoyiet, which is discussed in Section 12 and presented in Appendix A6.

The Dionosoyiet wetland in Kericho is mainly covered with emergent vegetation particularly sedges; however as described in the review in Section 3, *Cyperus papyrus* is the most significant wetland plant in the Lake Victoria basin given its widespread occurrence, buffering abilities and socio-economic importance. As such, it was considered desireable to also monitor another wetland site where papyrus was present, so as noted earlier the Chepkoilel wetland near Eldoret was chosen as an additional pilot site. Features of the Chepkoilel wetland follow below.

Chepkoilel Wetland Site Eldoret

The Chepkoilel wetland in Eldoret is a major wetland running South - North a few kilometres North of the city of Eldoret. An oblique aerial photograph taken in late 2004 shows part of the wetland is shown in Figure 4.5. The wetland in its immediate setting is shown in Figure 4.6. Chepkoilel is a permanent, riverine wetland with a high length to width ratio, about 10 km long and about 700 m wide at the widest point. The wetland sits in a shallow trough-like valley that lies at an elevation between 2110m and 2140m above sea level. Wetland vegetation is dominated by a central band of dense papyrus (*Cyperus papyrus*) flanked on either side by shorter emergent vegetation dominated by *Cyperus* spp (*C. rotundus, C. triandra, C. laevigatus*) as shown in Figure 4.7. A full listing of vegetation recorded to be present in the wetland is given below. Shallow and ephemerally flooded sections of the wetland have been encroached by agricultural activities where tomatoes, cabbages and kale are the main crops. In these areas ditches have been dug either to drain water away or to detain water for irrigating these crops.

The local community uses the name "Chepkoilel" for both the wetland in this area and for the stream passing through it both upstream and downstream of the wetland; however the wetland is also referred to in places as "Murula", while the stream is officially recorded as the Misikuri river.

Catchment Characteristics and Surrounding Land Uses for the Chepkoilel Wetland

The 5.6 km^2 Chepkoilel wetland has a catchment area of 210 km^2 with major inflows to the wetland contributed by the Sergoit - Misikuri River system. The catchment drains areas of mild slopes ranging upto 2160m above sea level. Due the extent of agricultural activities and limited natural vegetation cover remaining in the catchment, a considerable amount of surface runoff is therefore expected to be generated during rainfall events.

The Chepkoilel wetland itself lies in wide valley bottom with low gradient slopes on both sides. The landscape immediately surrounding the wetland is flat and the land-use is predominantly agricultural consisting mostly of maize and wheat fields. Besides agriculture, immediately around the wetland there is a commercial flower farm (Equator Flower Farm) immediately adjacent to the upstream extremity of the wetland towards the South East. The flower farm utilizes water from the wetland by pumping from a small weir immediately to the upstream of the wetland as described below.

The Chepkoilel campus of Moi University is located to the west of the wetland. Effluent from Moi University (Chepkoilel Campus) sewage treatment plant is discharged into the wetland. While nutrient concentrations in effluent from the Moi University wastewater ponds are high, the loadings on the wetland are generally not significant compared to loads from stream inflows as shown in Section 5. Moi University also has a small aquaculture facility adjacent to the wetland; however discharges to the wetland from the fish ponds are rare and only very limited in flow. Livestock graze the pastures adjacent to the wetland as well as the emergent wetland plants between the pasture and papyrus stands under low flow conditions. Areas containing emergent vegetation are therefore considered to be in a degraded condition.

Urbanization in the catchment is low and limited to the two small urban centres of Chepkoilel and Kimumu which are immediately adjacent to the south of the wetland. The aerial photograph in Figure 4.8 shows a peri-urban area adjacent to Kimumu in the foreground immediately upstream of the wetland with agricultural areas on the catchment visible to the rear.

Numerous small streams rising from Kaptagat forest in Keiyo District form the source of water for the Chepkoilel wetland. The areas in which the streams are sourced consist of narrow steep sided valleys within hilly topography. These streams join to form Misikuri stream which is the main stream supplying water to the wetland. The drainage pattern is dendritic implying that this area has a relatively uniform geological structure. As the Misikuri stream enters the gently undulating topography of the Uasin Gishu District, its course become wider and less steep, increasing the stream width, while its depth of flow, velocity, and sediment load. These changes cause marshy conditions to develop and the hence the formation of the wetland.

The gently undulating terrain and reliable rainfall of the catchment favour large scale mechanized farming, so large tracts of land are either under wheat or maize. The mild climate also favours dairy farming and there are a number of large dairy farms with a large population of dairy cattle within the catchment.

Water for irrigation at the flower farm is abstracted at a weir constructed across the Misikuri stream as it enters the wetland. Outflows from the weir enter the wetland by a side spillway that discharges back into the water course immediately downstream of the weir wall. Given the limited size of the weir, it is expected to have slightly reduce high flows entering the wetland; however it would most likely significantly moderate flows under dry conditions, reducing the incidence and severity of very low flows downstream.

Typical land use activities around the wetland can be seen in the aerial photograph shown in Figure 4.4. The wetland is surrounded on all sides by agricultural activities, with urban and peri urban areas being limited.

Monitoring Stations

Four monitoring stations were established in the wetland, reflecting the major sources of inflow and potential nutrient loads entering the wetland. These stations were located as follows:

Inlet station 1 (IE1): Eldoret – Iten road bridge upstream of the wetland, now superseded by IE2.

Inlet station 2 (IE2): This is at a channel constructed by Equator Flower Farm through which stream flow entering the wetland passes. This is now the main inlet monitoring point.

Inlet station 3 (IE3): Treated sewage discharge point at Chepkoilel campus sewage treatment ponds.

Outlet station (OE4): This is a transect section located approximately 10 km downstream of the inlet at the flower farm, immediately upstream of a junction between the Chepkoilel river and another stream.

The georeferenced locations for each of these stations as recorded by GPS are given in Table 4.2.

Table 4.2: Eldoret Chepkoilel Wetland Monitoring Stations

Station Name	Description	Easting (UTM km)	Northing (UTM km)
IE1	Chepkoilel US Bridge	36758817	61544
IE2a	Flower Farm Weir, East Bank	36758576	61992
IE2b	Flower Farm Weir, West Bank	36758572	61983
IE3	Moi Chepkoilel STP	36757674	64621
OE4a	Downstream Transect West Bank	36759653	70362
OE4b	Downstream Transect Mid point	36759651	70316
OE4c	Downstream Transect East Bank	36759691	70298

Vegetation Types Present

Plant Species noted to be present in the Eldoret Chepkoilel wetland were:

- *Acmella calirrhiza*
- *Achyranthes a*sppera
- *Cyperus rotundus*
- *Cyperus papyrus*
- *Cyperus rigidfolius*
- *Cyperus laevigatus*
- *Cyperus triandra*
- *Echinochloa pyrarnidalis*
- *Epilobium hirsutum*
- *Hoehaeria vernomoides*
- *Juncus* sp.
- *Kyllinga* sp.
- *Laersia* sp.
- *Ludwigia leptocarpa*
- *Ludwigia stolonifera*
- *Nymphaea nouchali*
- *Mimosa pigra*
- *Polygonum setosulum*
- *Potamogeton sweinfurthii*
- *Polygonum salicifolium*
- *Polygonum senegalense*
- *Polygonum pulchrum*
- *Plectranthus edulis*
- *Rumex bequaentii*
- *Rumex acetosella*
- *Scheonoplectus corymbosa*
- Spp*aeranthus suareoleus*
- *Schoenoplectus corymbosa*
- *Typha angustifolia*

Exotic plants

Mimosa pigra has been recorded in wetlands in western Kenya and was observed to be growing in the Chepkoilel wetland. This exotic plant (native to Mexico, Central and South America) is an aggressive woody shrub that forms impenetrable, prickly thickets up to four to five meters high. It makes infested areas inaccessible to animals and people, and interferes with stock watering, irrigation and use of floodplains as pastures. It invades watercourses and seasonally flooded wetlands in tropical and sub-tropical regions.

Mimosa pigra favors a wet-dry tropical climate and does not appear to grow preferentially in any soil type, but is found most commonly in floodplains and riverbanks within soils ranging from black cracking clays to sandy clays to coarse siliceous river sand. It was first recorded in Kenya ca. 1945. Control can be effected by herbicide application but this is expensive and environmentally damaging. Biological control has been underway in Australia, Thailand, Indonesia and Vietnam for about 20 years with mixed results.

Two other exotic plant species that are recognised as particularly difficult to manage are *Eichhornia crassipis* and *Salvinia molesta*, as discussed below.

The most widely recognised case of exotic plant infestation in East Africa is that of *Eichhornia crassipes* (water hyacinth), which has infested Lake Victoria. Biological control using curculionid weevils (*Neochetina* spp.) has proven successful in limiting and controlling water hyacinth infestations in the lake (Njoka, 2004). This aggressive weed could also infest wetlands in western Kenya. It is capable of growing at altitudes above 2,000 m; however has not been noted as present in either the Chepkoilel or Dionosoyiet wetland.

Salvinia molesta occurs in Kenya (e.g., Lake Naivasha, see Adams *et al*., 2002). This plant is an aggressive weed but does not grow well at the colder temperatures that prevail at higher altitudes. It is probably not a threat to the highland wetlands in Kenya but could cause problems in water bodies at lower altitudes. Nonetheless, wetlands should be monitored for its presence. Effective biological control agents are available.

Soils

The Chepkoilel wetland physiographically lies on a plateau/upper level upland transition on the bottom land of the Uasin Gishu plateau. The area is gently undulating with slopes less than 8%. The geology in the area comprises of soils developed on tertiary basic igneous rocks such as olivine basalts.

The wetland had poor internal drainage and poorly to very poorly drained soils. Effective soil depth is greater than 70 cm with a two horizon structure consisting of:

Horizon 1

From 0 to 42 cm depth, the soil is very dark brown, silky clay with moderate to fine crumbs and weak. Grains are medium angular, angular and sub angular with block structure, slightly hard to hard when dry, sticky and plastic when wet. There are many micro and very fine pores but few fine pores. The pores frequently contain fine roots.

Horizon 2

From 42 to 72cm depth, the soil is very dark brown moist clay. Grains display weak, fine to medium angular and sub angular block structure. The soil is very hard when dry and firm when moist with moderate plasticity when wet. Few micropores and fine pores were present.

Soil nutrient analyses for the Chepkoilel wetland are reported in Section 6. These showed soils uniformly across the wetland and in the wetland surrounds, are thick clay based sediments with:

1. high acidity,
2. low to adequate P content,
3. adequate N content
4. low Cation Absorption Capacity
5. adequate organic content
6. high Iron content
7. waterlogging

These properties make the soils poorly suited to traditional/conventional agricultural activities.

Existing and Potential Land Use

It was also noted previously that land-use surrounding the Chepkoilel wetland is largely agricultural, with the Equator Flower farm immediately to the East of the wetland inlet and scattered maize and wheat cropping mixed with livestock grazing surrounding the remainder of the area. Tree cover is much lower than at the Kericho Dionosoyiet wetland site.

Agricultural activities extend right to the edge of the wetland and in places encroach significantly into the wetland. As the wetland is not fenced off, significant grazing activity occurs within the wetland, there is evidence of burning which may represent attempts by the local graziers to promote grazing productivity.

There are scattered low density peri urban areas to the South West of the site at Kimumu and along the western edge of the wetland at the Moi University Chepkoilel campus and associated schools. The sewage treatment plant at the northeastern corner of the campus discharges into the wetland and a small aquaculture facility is present at the South Eastern portion of the campus as mentioned previously.

Despite the very extensive agricultural activity within the surrounds of the wetland, the area is not well suited to agriculture give the poor nutrient conditions of the soils present (see below). It is expected that fertiliser applications being made by the local farmers must be quite large in order to improve soil fertility to allow agriculture to take place. Runoff from farmed areas to the wetland consequently has relatively high nutrient contentleading to the relatively high nitrogen and phosphorus concentrations in waters within the within the wetland (see Section 6).

To protect the wetland from further degradation from high nutrient levels in runoff, a perimeter riparian zone around the wetland with agricultural activities such as cropping and intensive/permanent grazing should not be permitted within a distance of 50 m of the current extent of sedges.

Suitable land use activites within the perimeter riparian zone would be silviculture and the production of hay or other fodders for drought security. Application of fertilizers in the riparian zone should be strongly discouraged.

A controlled, strategic grazing program for the wetland itself and the riparian zone should be developed in consultation with the local community. Under such a program, grazing is to be discouraged through the wet season and early parts of the dry season but encouraged at the end of the dry season and ceasing with the onset of the wet season when other pasture areas experience regrowth. From a wetland management perspective this will reduce biomass and plant litter accumulation, encourage plant vigour during the wet season and allow enhanced nutrient uptake during wet season high flows. From a community perspective, this will also be beneficial in ensuring that drought security is encouraged, reducing top soil depletion and preventing erosion and allowing a short fallow period for grazing areas used at other times through the year.

Harvesting papyrus is also encouraged at the end of the dry season in the month immediately prior to onset of the long rains for use in traditional weaving. This will provide alternative/supplementary income and employment for the local community and will encourage vigorous regrowth at the onset of the wet season.

These areas need to be set aside as wildlife corridors and for transmission of high flows during the wet season (see Section 5 below). Establishment of transects will encourage cross wetland flow mixing, however care should be taken to ensure that short circuits do not develop at such transects and to ensure that under high flow conditions mass dislodgement of plant communities does not occur via scour through the creation of high velocity channelisation.

The draft wetlands management plan described in Section 12 and provided in Appendix A7 sets out appropriate use/non use recommendations taking these considerations into account.

5. Pilot Wetlands Hydrology

5. PILOT WETLANDS HYDROLOGY

Wetlands are hydrologically complex water bodies in which both the magnitude and timings of flows of water can have drastic effects on water quality and ecology. More subtly, ecology and water quality can also both have drastic effects on wetlands hydrology. Waters etal (1994) performed a literature review and preliminary scaling analyses that examined the means by which hydrology, water quality and ecology interact within a wetland. This work was followed by Waters (1998) whereby specific effects of wetlands vegetation on flows within wetlands were examined in detail.

These studies reveal that wetlands are fundamentally distinct water bodies from a hydrologic perspective. The growth and abundance of wetlands vegetation profoundly affects wetland hydrology from inlet to outlet in ways that are still only understood to a very rudimentary extent including by the following means.

- Wetland vegetation form physical barriers to the flow, thereby (1) significantly lowering average velocities and encouraging mixing by dispersion throughout the wetland, (2) enhancing energy dissipation at the inlet which encourages settling of sediments and prevent short circuits from developing downstream of the initial mixing area.
- By shading the water surface, wetland vegetation provide wind and solar radiation shading at the water surface, thereby lowering evaporation from the water surface. Wind shading also has the effect of reducing large scale mixing induced by wind driven currents. The lowering of temperatures in vegetated areas compared to open water areas has been shown to potentially lead to temperature driven buoyancy flows between the vegetated and open water within wetlands.
- In order to perform transpiration, photosynthesis and other biological processes, wetland plants draw water from their roots. This creates a very low rate volumetric flux of water from the water column into the sediments, which enhances sediment-water interactions as more water comes into contact with the sediment layer

Feedback loops are also apparent in that wetland ecology affects hydrology which affects ecology. A simple but important example is that the presence of vegetation provides flow resistance, thereby slowing velocities of flow through the wetland. With slower flows, sedimentation is enhanced, so that nutrient bearing sediments are deposited. The bed of the wetland therereby has an increased nutrient content so that growth of vegetation is encouraged, causing higher flow resistance, slower flow velocities and thereby more deposition until a point is reached where the amount of vegetation present and flow resistance are so high that flow velocities become so low that transport of suspended sediments into the area becomes negligible so that deposition of nutrient bearing sediments stops.

Undestanding these processes is increasingly seen as important for effectively managing wetlands; however, apart from velocity and flow measurements for which techniques are well established, most of these processes are still genreally the subject of research and effective techniques for investigating them are generally not practical for operational implementation.

In this section, hydrologic monitoring is considered in two ways: firstly by monitoring inflows and outflows into and out of the two pilot wetlands over an eight month period, referred to from here as extended duration monitoring. Secondly by intensive monitoring of the response of the wetland to storm events and internal wetland processes.

5.1 Extended Duration Monitoring Techniques

Extended duration monitoring of the pilot wetlands was carried out from June 2004 to February 2005. Sampling for flow rates and physico chemical properties is carried out in the field. The activity was carried out by the SMEC team in two groups concurrently as follows:

(i) Flow measurements were taken at every inlet stream using either a current meter or other convectional methodology and the findings recorded. A qualified hydrology officer from either the LVEMP water quality component or associated with one of the district water offices and equipped with suitable instrumentation was fully involved in all measurements.

(ii) Water quality group takes and records physical measurements. An Officer from the Water Quality Component Laboratory (LVEMP) equipped with field monitoring instrumentation borrowed was fully involved in the measurements. Samples were also taken from the same points in suitable bottles and following appropriate sampling protocols, stored in cool boxes for delivery to the laboratory for analysis.

The following two sections report on the flow and water quality methods used at the two pilot wetland sites. Field measurements carried out at the sites on a monthly basis from June 2004 to February 2005 covered the following parameters:

(i) depths and flow rates for the various streams were determined using standardised hydrology techniques to quantify total pollution loadings into the wetland as described below,

(ii) temperature, electrical conductivity, dissolved oxygen, pH and turbidity were determined using a hydrolab orYSI data sonde in the field as described in Section 6.

(iii) suspended sediments, nitrogen and phosphorus were measured by taking samples for analysis at the LVEMP Water Quality Component laboratory in Kisumu

The stations at which monitoring was performed are reported in Section 4, Tables 4.1 and 4.2.

Kericho Rainfall Regime

The hydrology of wetlands in the Lake Victoria Basin such as the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands are somewhat unique from an international perspective in that with respect to the geographic location of the two sites as they are equatorial, yet both are at altitudes of approximately 2000 m. Despite their equatorial location, Lake Victoria Basin wetlands display distinct hydrologic variability on a seasonal basis due to seasonality of rainfall in the basin, as was seen in the pilot wetland studies and as described in the following sections.

Monthly average rainfall for the Kericho area for the years 1984 to 2004 was obtained from James Finlay Kenya (JFK). The data shows an annual average rainfall of 1994 mm per year. As expected, seasonality is noticeable with average monthly rainfall in April and May exceeding 250 mm per month, as shown in Figure 5.1. This period is referred to locally as the long rains. The period of October to November is known locally as the short rains. This also considered a wet period as Figure 5.1 shows. December to February is the driest period with average monthly rainfall between 80 and 120 mm.

Characteristics of Flows at Inlet and Outlet, Kericho Dionosoyiet wetland

Inflow – Outflow measurements for the Kericho Dionosoyiet wetland from June 2004 to February 2005. Summary results are presented in Table 5.1, Figures 5.2 and 5.3. Care is required in interpreting this data as it is representive only of flow conditions on the days when measurements took place. In order to give a more complete view of hydrology, the monitored data was used to calibrate a rainfall-runoff model. This allowed the hydrology over the 11 year period from January 1994 to December 2004 to be assessed for the site, as described in Section 8 below. As such results of hydrological monitoring are presented here as nett summaries only.

As expected, the streamflows dominate the total inflow with flows from the spring and from the urban drain contributing only very minor flows.

Table 5.1: Recorded Flow Rates Summary, Kericho Dionosoyiet Wetland, July 2004 to February 2005

	IK1 Spring m^3/s	**IK2 Urban Drain** m^3/s	**IK3 Eastern Stream** m^3/s	**IK4 Northern Stream** m^3/s	**IK5 Western Stream** m^3/s	**IK total (sum IK1 to IK5)** m^3/s	**Transect (TK7)** m^3/s	**OK8 Outlet** m^3/s
Maximum Flow	0.086	0.0038	0.270	0.246	0.248	0.760	0.745	0.863
Average Flow	0.023	0.0006	0.17	0.153	0.126	0.469	0.487	0.505
Minimum Flow	0.0003	0.000	0.114	0.058	0.007	0.183	0.145	0.101

From Table 5.1 it can be seen that the measured inflow and outflows are quite consistent. The flow measurements agree to within 10%, with the difference between average inflow and outflow readings being normal given that inflows to the wetland are quite unsteady and tend to pulse in response to rainfall events, while outflows tend to remain more consistent with time. These unsteady effects becomes reconciled through the modelling as described in Section 8.

A water balance misclose assessment was performed in the mid term report (SMEC 2004) and identified unsteady flows as the major factor responsible for this difference between inflows and outflows. The pilot wetland modelling reported in Section 8 confirmed this to be the case and also allowed more accurate determination of hydraulic residence time and hydraulic loading rates to be undertaken based on estimated flow rates over a 10 year period rather than just for the period of the study. The reader is referred to Section 10 for further details.

Flow Characterisation in the Kericho Dionosoyiet Wetland

The Kericho Dionosoyiet wetland displays distinct flow characteristics due to the high level of channelisation present. High velocity flows occur in the narrow open water channels immediately downstream of each inlet, and in the central channel that arises where these channels merge. These channels account for approximately 80 to 90% of the total flow rate. Through the rest of the wetland, the very dense amount of vegetation causes a high level of flow resistance and flow velocities are extremely low. This channelisation is depicted in Figure 5.4 downstream of inlet IK4.

This pattern of channelisation is manifest through five distinct sections as shown in Figure 5.5 which can be described as:

- An Inlet Section, consisting of the five separate inflow open water streams that merge to form a single central open water stream. Between the streams there are highly vegetated "dead zones" where flow is minimal. Buffering functions associated with the inlet section are sedimentation and energy dissipation. A distinct zone is to be noted immediately downstream of the stormwater drain. In this zone sedimentation has been so high that the area is overloaded with gross pollutants and sediments.
- A Transition Section where inflows become consolidated into a central stream with marshy surrounds. Flow patterns in the vegetation in this region are associated with the central stream, but are of a very irregular shape. The principle buffering functions here in are hydraulic retention and nutrient cycling.
- A Linear Section, where uniform flow occurs in the central channel and through the surrounding vegetation. Associated buffering functions are hydrologic connectivity, mixing and solids retention above the outlet.
- An Outlet Section where flow is radial towards the outlet sink. This area is largely open water. Important buffering processes here are water level control for residence time assurance and reaeration.

Other significant points to note with respect to flow patterns in the Kericho Dionosoyiet wetland are:

- There is a very uneven distribution of water as it enters the wetland. Inflows are highly channelised so it is likely that much of the upstream area is ineffective in performing buffering as most of the flow bypasses the vegetation and is very unevenly distributed
- Flows from the urban inflow are so heavily laden with sediment and other debris that at the outlet of the stormwater drain as it flows into the wetland, a delta structure has formed consisting of the deposited sediments and debris. The deposition of this debris has smothered the ground surface and prevents the propagation of vegetation in this area. Rehabilitation of this area is needed to ensure the buffering capacity of this area of the wetland is not compromised.
- Due to the limited residence time of the wetland, groundwater inputs and evapotranspiration can be neglected in determining the water balance, however they may be significant in determining flow paths in the vegetation.
- Profiles taken with the hydrolab water quality sonde (see Section 7), revealed that there were no significant temperature or salinity differences over depth or spatially within the wetland that would lead to buoyancy stratifications or buoyancy driven flows.
- The extent of the emergent vegetation canopy above the water surface will give rise to significant wind and solar radiation shading in the wetland (Waters 1998). This may give rise to reductions in DO transfer of the order of 80% compared with an open water pond.

Eldoret Rainfall Regime

Daily rainfall for the Eldoret area from 1 January 1994 to 31 December 2004 was obtained from the Moi University Meteorological station at Eldoret. Average monthly rainfall from the station is shown in Figure 5.6. From Figure 5.6 it can be seen that there is a much higher degree of variability to rainfall in Eldoret than in Kericho Dionosoyiet wetland (Figure 5.1). There is a much stronger seasonal pattern present with rainfall occurring mostly from April to August and the other months being relatively dry.

Chepkoilel Eldoret Inflows and Outflows

The Eldoret Chepkoilel wetland displays a much wider hydrologic variability than the Kericho Dionosoyiet wetland. A large discrepancy between inflow and outflow readings was observed on each of the occasions that field work was undertaken at the Chepkoilel Eldoret site, consequently misclose assessment here is an important issue as discussed below. Table 5.2 and

Figure 5.6 give ranges of inflows and outflows. Note in particular that the contribution from the Sewerage Treatment Plant at the Moi University Chepkoilel Campus is negligible.

Table 5.2: Recorded Flow Rates Summary, Chepkoilel Eldoret Wetland, July 2004 to February 2005

	IE1/2 Bridge/Equator Flower Farm (m^3/s)	IE3 Moi University Chepkoilel Campus STP (m^3/s)	OE1 Transect at downstream outlet(m^3/s)
Maximum Flow	3.530	0.062	5.026
Average Flow	1.16	0.03	1.26
Minimum Flow	0.043	0.0003	0.055

The flow ranges in Table 5.2 shows that average measured inflows and outflows in the Chepkoilel wetland again do not balance exactly. Detailed analysis performed in the mid term report (SMEC 2004) showed that the dominant cause of the misclose was unsteady basin hydraulics associated with changes in the volume of water stored within the wetland over the period of the study. As for the Kericho site, this misclose arises because of differences in response of flows in and out of the wetland to rainfall conditions over the preceding time period: that inflows to the wetland tend to respond quickly to a storm event, reach a peak level and then recede. By contrast, the flow response at the outflow lags somewhat as it takes time for the volume of the wetland to fill before a large enough volume of water is available to flow out of the wetland. This finding is verified by the modelling performed in Section 8.

Conceptual Model of the Dry Season Hydrology of the Eldoret Chepkoilel Wetland

From the above water balance considerations, a conceptual model of the Chepkoilel wetland emerges that shows the wetland to be quite distinct from that in Kericho Dionsoiyiet.

The wetland acts as a draining reservoir, with outflows determined by the amount of water that is drawn down as the water level changes as well as by inflows. Most likely the narrow section of the wetland in the vicinity of the transect acts as a neck point restricting flows, similarly to the flow out of a bottle.

During the wet season, the pattern will be in the reverse, with the inflows balancing against the amount of water being contributed to storage and the outflows. Time scales over which significant nutrient fluxes move in and out of the wetland are likely to be of the order of months to years, as opposed to a time scale of days to weeks at the Kericho Dionosoyiet site. It is unlikely that the data analysis on the results of studies at the Chepkoilel wetland under this consultancy alone will give sufficient closure to establish the nutrient buffering capacity of the wetland, further highlighting the need for modelling in order to understand how buffering takes place in the wetlands.

The time scales for two significant processes are overlapping: the residence time of the wetlands, of the order of 50 days and the time scale of the wetting and drying of the wetland, which may be approximately annual or biannual depending on the extent of rain that occurs during the short rains.

Flow Characteristics of the Chepkoilel Eldoret Wetland

The Chepkoilel wetland contains a central permanently inundated stream, upon which floats a matt of *Cyperus payrus.* Flow velocities under the papyrus matt are medium to fast under low, medium and high flow conditions.

Surrounding the central papyrus stream are two areas of ephemerally flooded emergent vegetation. Under low flow conditions, there is no flow in the emergent vegetation bands, flow being restricted purely to the central papyrus dominated stream. Under moderate to high flow conditions, the emergent vegetation bands carry overflow from the central stream and low velocity marsh flows occur through the emergent vegetation as shown in Figure 5.7.

Whereas distinct flow sections could be identified for the Kericho Dionosoyiet wetland where there were distinct differences in flow patterns, the Chepkoilel wetland displayed linear flow behaviour throughout.

The modelling performed for the Chepkoilel site again showed that this wetland can be understood entirely as a surface flow system and that groundwater has very little influence on the wetlands.

As for the Kericho Dionosoyiet wetland site, profiles taken with the hydrolab water quality sonde (see Section 6), revealed that there are no significant temperature or salinity differences over depth or spatially within the wetland that would lead to buoyancy stratifications or buoyancy driven flows. Again the extent of the emergent vegetation canopy above the water surface will give rise to significant wind and solar radiation shading in the wetland (Waters 1998), potentially leading to reductions in DO transfer of the order of 80% compared with an open water pond.

5.2 Intensive Monitoring

Intensive monitoring was undertaken to coincide with expected high rainfall periods in the 2004 “short rains” from October to November. Monitoring conducted in this period is described below. Monitoring was also conducted through the 2005 “long rains” from March to April; however at the time this document was being prepared, a complete set of laboratory results was not available. This data will be given as an addendum as soon as available.

Short Rains 2004 Hydrology

Through the short rains from October to November 2004, a series of hydrologic investigations were performed firstly to characterise inflow conditions at Kericho Dionosoyiet wetland in response to wet weather events on the catchment and secondly salinity tracer investigations to characterise flow through both the Kericho Dionosoyiet wetland and Eldoret Chepkoilel sites.

Rainfall at Kericho during the short rains

Daily Rainfall data recorded at the James Finlay raingauge for the years 1984 to 2004 shows there is a short rains period in October, with occasional carry on to November for Kericho. Rainfall data for October to November 2004 are shown in Figure 5.9. From these data, the rainfall over the two month period was 228.3 mm. This is well below the average rainfall over the short rains periods from 1984 to 2004 of 322 mm and is only marginally above the lowest recorded short rains rainfall for these years of 193 mm.

Statistical analysis of the rainfall distribution in Kericho for the short rains periods from 1984 to 2004 showed the 2004 short rains to have been the fourth lowest in this period (see Figure 5.10). Analysis by Gringorten's method (see Chin 2000), shows there is only a 17% probability of having a rainfall of this little or smaller for such a period. The 2004 short rains was therefore exceptionally dry in Kericho.

The lack of rainfall during the October – November 2004 period made characterisation of wet weather events during the intensive monitoring quite difficult. There was only one occasion when the rainfall exceeded 10 mm/day for two days in a row. This made the planning and execution of hydrologic and water quality monitoring to capture wet weather events during the short rains logistically very difficult.

Nevertheless, intensive characterisation of wetland behaviour was carried out by detailed recording of water levels at inlets, the transect and outlet, and by performing tracer investigations as detailed below with significant results obtained.

Kericho Dionosoyiet wetland Detailed Water Level Recordings

Figures 5.11 to 5.13 show the water levels recorded at the stormwater drain (Figure 5.11), the stream inlets (Figure 5.12) and at the transect and outlet (Figure 5.13). Variations in water level were not significant compared to error in readings at the spring inflow point, IK1.

The data were recorded by manual readings from staff gauges on an hourly basis during daylight hours over the short rains period. The use of such manual readings of water levels is problematic because of problems associated with (1) the timing of readings, (2) errors in reading staff heights, (3) errors in data transcription, nevertheless, the general trends of water levels confirms the paucity of streamflow during the short rains.

The poor hydrologic status of the wetland during the short rains can be seen through:

- The limited number of high flow events recorded
- The general trend of decreasing water level in the streams. This is apparent particularly at IK3, IK4 and the outlet.

The significance of wet weather flows at the stormwater drain IK2 and the difficulty in determining flow volumes associated with such events can be seen from Figure 5.11 through the very sharp rises that occur when a rain events were experienced. Generally the water level at IK2 rose in response to rainfall events for only between 1 and 3 readings before receding with increases in water level of up to 80 cm recorded. Between these events, the water level in the stormwater drain was near zero. This implies that hydrographs coming from the urban area upstream are very short and peaky, leading to pulse like inputs from this portion of the catchment. Consequently effects of inflows at the stormwater drain are likely to be minor in comparison with flows from the agricultural part of the catchment.

The stream inflows shown in Figure 5.12 at IK3, 4 and 5 also displayed only short term rises in water level from their base flows. These rises in water level were generally limited to three hours at most. In contrast with IK2, the base flows from streams IK3, 4 and 5 were significant, indicating a more consistent pattern of inflows from these parts of the catchment.

By contrast, the water levels at the transect and the outlet shown in Figure 5.13 show the buffering effects of the wetland, whereby rises in water level are much less than at the inlet, particularly at the outlet and water levels remain elevated for longer periods before receding, confirming that the wetland provides significant buffering of flows by reducing the peak flow and delaying its transmission for some hours. It is also notable that water level differences between the transect and outlet are very minor typically no more than 5 cm or so.

Hydrologic tracer investigations

Tracer experiments were conducted in November and December 2004 by mixing a solution of 10kg of sodium chloride (table salt) into 100 l of water, then adding this salt solution to the well mixed stream as a pulse flow. Tracer experiments were initiated at the Eastern, Northern and Western streams at the Kericho Dionosoyiet wetland and at the flower farm monitoring point at the Eldoret Chepkoilel wetland. Salinity measurements were made using a Palindrome conductivity probe. The probe was either inserted directly into the water column or samples were taken and stored in sealed bottles for subsequent salinity measurement using the probe. A typical breakthrough curve with fitted Gaussian dispersion model (see below) is shown in Figure 5.14.

From these measurements it was possible to measure the advection and dispersion rates in the streams as shown in Table 5.4. A gaussian advection dispersion model (Waters, 2003), was fitted to the data in order to determine advection and dispersion rates. These experiments were performed for the three main streams upstream of the transect and in the main stream from the transect through to the outlet of the wetland and from inlet to outlet at Eldoret Chepkoilel with measurements at the flower farm, STP and Kuinet outlet.

The Eastern stream in Kericho Dionosoyiet wetland was studied as a single entity in order to cover the inputs from the spring (IK1), the stormwater drain (IK2) and the eastern stream (IK3). These inflows all merge very close to the upstream extremity of the wetland so it was not necessary, nor would it have been practical to differentiate the effects of the separate inflows.

Table 5.2: Tracer Experiment Results, Kericho Dionosoyiet wetland and Eldoret Chepkoilel Wetlands

	Kericho Eastern stream (IK1, 2, 3) to transect	Kericho Northern stream (IK4) to transect	Kericho Western stream (IK5) to transect	Kericho Transect to Outlet	Eldoret wetland Inlet to Outlet
Advection rate (m/s)	0.140	0.149	0.111	0.103	0.0107
Dispersion rate (m^2/s)	1.260	1.000	0.500	0.500	12

The advection rates shown in Table 5.2 are generally much lower than the direct velocity measurements made during velocity gaugings at inlet, outlet and the transect. This reflects the contribution of water flowing with quite low velocity in the vegetated areas in addition to the water flowing at fast speed as measured in the main streams at the inlets, outlet and transect. Associated with these advection rates, residence times are of the order of 90 minutes to 2 hours for the Kericho Dionosoyiet wetland, indicating that the wetland is subject to significant short circuiting.

Dispersion rates are quite low in comparison with most natural streams. This would indicate that mixing in both wetlands is poor and that large areas of the wetland do not interact with the main flow. It appears that the vegetation throughout the wetland has grown too thick to allow good mixing to take place, creating large dead zones in the wetland. The creation of dead zones significantly reduces the ability of the wetland to perform treatment. It is apparent then that a selected harvesting program is required to thin out the vegetation, thereby improving mixing, reducing the extent of dead zones and thereby increasing effective hydraulic retention. This should lead to improved buffering of flows, suspended solids and nutrients.

A tracer experiment was also conducted for the Eldoret Chepkoilel wetland from 17 November until mid December. Tracer profile modelling results for the Chepkoilel Wetland at Eldoret are shown on Figure 5.15. From this experiment it was found that the mean advection through the wetlands was 0.0116 m/s with a dispersion coefficient of 5 m^2/s. This indicates that for the Eldoret Chepkoilel wetland, the residence time is 10 to 11 days, again indicating some short circuiting is taking place. The high dispersion coefficient means there is good mixing across the wetland so there are few dead zones and water is able to circulate throughout the whole wetland for Eldoret Chepkoilel.

The tracer tests reveal that the Eldoret Chepkoilel wetland is in much better condition hydrologically than the Kericho Dionosoyiet wetland Dionosoyiet wetland. It appears that strategic harvesting is necessary at Kericho Dionosoyiet wetland in order to improve the internal hydrology in order to achieve better mixing across the wetland, to reduce the extent of dead zones and to increase residence times.

Long Rains 2005 Hydrology

One of the recommendations made at inception stage in July 2004 was that equipment held by the LVEMP wetlands component needed to be supplemented with automated water quality samplers and weather stations and that this equipment should become available for wet weather monitoring during the short rains in order for monitoring to proceed. All efforts were made to expedite the procurement process in a timely manner to make the equipment available in this time frame; however unexpected delays did occur through no fault of LVEMP or SMEC meant the equipment was unavailable at that time.

Given these issues, SMEC undertook to perform limited water quality monitoring at the Kericho Dionosoyiet wetland in the early part of the long rains in March 2005 despite the very short time available, then to analyse and assess the resulting data within the time frame of the study period. There would have been very little value in attempting measurements at the Eldoret Chepkoilel wetland given the long time scales associated with hydrology and water quality processes at Chepkoilel. Hydrology results were able to be analysed and reported here. Water quality results will be provided when available.

Automated Monitoring Equipment

To perform characterisation of wet weather events, two ISCO 686710070 Model 6712 full-size portable samplers were used for automated water quality sampling. Each autosampler is fully self contained and includes a controller, top cover, centre section, base, distributor arm, two pump tubes, instruction manual and pocket guide.

As stand alone instruments, the autosamplers can be programmed to take samples according to the clock time of the instrument. Standard programming schedules are for constant time interval sampling where a discrete volume of water is deposited into a single sample bottle, typically once an hour; however more sophisticated sampling schedules are possible that allow duplicate and composite samples to be taken, irregular time scheduled or even random timed sampling to be performed. External triggering by other instruments is also possible.

Both autosamplers were fitted with ISCO 686700050 Model 730 Bubbler Flow Modules to allow water level recording to be performed. By recording water level, it is possible to depth trigger the autosamplers so they respond to water level rise, ensuring that wet weather conditions are sampled more systematically.

With two autosamplers available, one was installed at the transect that was and the other immediately upstream of the outlet causeway so that an assessment of the change in water quality laterally through the wetland could be performed during storm events.

The Nyagacho area has acute problems for poverty, unemployment and crime, therefore great care was taken to ensure the instruments were fully secured. This was achieved through the use of 2.5 gauge plate steel boxes that the instruments were housed in. The steel housing were fitted with flanges at the base and buried to half their height to immobilise them. Padlocks were fitted to the top of the boxes to ensure the autosamplers would be secure within the boxes. The instruments were installed on the well treed and secluded southeastern side of the wetland. The boxes were then camouflaged using the local vegetation and sample tubes were buried to minimse their visibility. Figure 5.16 shows the instrument that was installed at the transect in its housing. In addition to these precautions, any night that the instruments were left in the field, two watchmen from the local community were hired to guard the equipment.

Indeed these precautions were proved necessary, there having been an incident on the evening of March 29 when the watchmen came to the site to commence night duties and encountered a number of youths at the site approaching the site where autosampler had been installed at the transect. Upon being disturbed the youths immediately left the scene, a thorough inspection of the site showed that there had been no disturbance of the autosampler or its housing.

Meteorological data was collected with a watchdog model 900ET weather station (cat #3350wd). The weather station was installed in the grounds of the Township Primary School a short distance from the wetland site. The township school was chosen because of ideal features for meteorologic measurements: it was in close proximity to the wetland, is on flat terrain with few surrounding trees and has a watchman at the site 24 hours per day. Figure 5.17 shows the weather station being installed at the Township Primary School.

Rainfall at Kericho during the Long Rains

Figure 5.18 shows the rainfall events recorded at the Kericho site using the watchdog weather station during the long rains intensive monitoring period. The figure reveals that rainfall in Kericho tends to occur as very short intense bursts, typically in the late afternoon or evening. The highest one hour rainburst that was encountered was 23.3 mm/hr which fell in the hour to 6 pm on 7 April. This burst contributed towards the largest storm event encountered which was 40.8 mm over a five hour period from 4 pm to 9 pm on 7 April.

In total 181 mm of rain was experienced between 22 March and 9 April 2005, which is nearly as much as fell dirng the whole of the short rains period from October to November 2004, as seen in the section above. Thus a number of wet weather events were experienced which made monitoring for wet weather hydrology and water quality feasible.

Kericho Dionosoyiet Wetland Long Rains Hydrologic Monitoring

Water levels were monitored over the period 18 March to 7 April 2005 at the transect and outlet of the Kericho Dionosoyiet wetland. Instrumentation used were the ISCO bubbler flow modules installed on board the ISCO 6712 automated water quality samplers. Deployments of the autosamplers were discontinuous due to battery life limitations and a cautious approach to deployments for security reasons. Consequently water levels recorded were not continuous over the monitoring period; however a number of individual storm events were captured during the monitoring period.

Water levels at the transect and the outlet did not show significant differences so outlet recorded water levels were adopted for analysis. Figure 5.19 shows water levels recorded over the period 19 to 22 March. It can be seen from Figure 5.19 that water level rises occur sharply and then fall away more slowly as is typical of hydrographs arising in response to storm events.

Figure 5.20 shows typical response of the wetland to rainfall through two storm events that took place on 6 April in the form of a low pass filtered water level time series plotted with rainfall. In the first event, 30.3 mm of rain occurred over a 2 hour period from 14:00 to 16:00. Rainfall peaked over the period 14:00 to 15:00 with a maximum intensity of 16.8 mm/hr. In the second event, 7.1 mm of rain fell over a 2 hour period from 17:00 to 19:00, maximum intensity rainfall for the second event was 4.8 mm/hr in the first hour.

In response to the first of these events, the raw water level data from the wetland as recorded at the outlet appeared to rise and fall sharply with a period of approximately 120 s. This behaviour lasted for 33 minutes from 15:08 to 15:41, then ceased with the water level dropping back to its base level.

Such rapid rise and fall in water level is clearly due to some dynamic effect associated with the measurements made rather than to rise and fall in water level across the whole wetland. Given that this rapid signal occurred with nearly the same periodicity as the measurement interval (one minute), it is not possible to fully determine the reason for the apparent rise and fall in water level, however, two possible causes are:

- Short wave effects on the water surface, although this is most unlikely as the most common source of energy for short waves is wind. The presence of extensive emergent vegetation and a thick canopy would prevent wind energy being transferred to waves in the wetland; and
- "Seiching" within the wetland, that is, standing waves that occur across the length or width of the wetland at the resonant frequency of the wetland. Seiching is analogous to the "sloshing" water level variations that occur in a bathtub if water is forced from one end of the bathtub towards the other. Seiching is theoretically possible in wetlands but

the amount of vegetation present is likely to very quickly dampen any seiche that may develop.

What ever the cause of the dynamics within the signal for the period from 15:08 to 15:41, clearly:

- the storm event causing it took place over a much shorter time frame than the one hour interval at which rainfall was logged by the watchdog; and
- the response time of the catchment and wetland to storm events is very rapid.

In order to assess nett water level changes within the wetland arising from changes in the volume of water in the wetland, the high frequency signal described above was removed by passing the water level time series through a standard moving average 10 point low pass filter. From Figure 5.20 it is clear that the response time of the catchment and wetland to rainfall events is approximately one hour. It can also be seen from Figure 5.20 that the first and larger rainfall event resulted in a quick and dramatic rise in water level in the wetland that then also dropped away quite rapidly. By contrast the second smaller rain event resulted in a slower rise in water level that was sustained over a longer period.

Analysis of the impacts of rainfall events and associated water level rises observed in the long rains intensive monitoring on water quality buffering in the wetland are performed in Section 6.

5.3 Summary of Hydrologic Observations

Assessment of rainfall, flows in, through and out of the wetlands, and variations in water level of the wetlands for the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands have been described. In summary the following points can be made.

The Kericho Dionosoyiet wetland due to its small size was seen to respond within minutes to hours to rainfall events. The wetland does not display significant wetting/drying behaviour due to the consistency in inflows from the three surface streams that feed into it.

Flows through the Dionosoyiet wetland generally represent a balance between surface inflows and outflows. Flows from the storm drain, the spring and groundwater have almost no influence on the hydrology of the wetland. The residence time of the wetland is very short, of the order of a few hours. The very dense vegetation that is present within the wetland causes high flow resistance and thereby severely moderates flows. Most of the flow is transmitted by through a dendritic open water stream network within the wetland that comprises of five streams arising at each of the inlets which merge within the first few hundred metres of the length of wetland into a single stream that flows through the centre of the wetland to the outlet. Apart from these limited number of fast flowing streams, water in the vegetated sections of the wetland is near stagnant.

The Eldoret Chepkoilel wetland due to its large size takes days to weeks to respond to storm events. The wetland displays significant wetting drying behaviour due its setting on the flat terrain of the Uasin Gishu plateau and because of the much larger seasonal fluctuations in flow rates experienced in the Chepkoilel river.

As for the Dionosoyiet wetland, flows into and out of the wetland balance well over the extended duration monitoring; however the large size of the wetland means it has significant storage. Inflow from the Misikuri river completely dominates all other sources of inflow such as surface runoff from the surrounding areas, effluent discharges from the Moi University Campus Chepkoilel STP and groundwater.

The large size of the wetland means that outflows from the wetland are determined more by changes in the volume of the wetland than by inflows. These changes in volume take place over time scales of weeks to months. Flow patterns within the wetland are also strongly influenced by the changes in wetland volume. Under low water level conditions, flow is only seen in the central stream over which the central papyrus matt floats while the surrounding emergent vegetation remains dry. Under high water level conditions the emergent vegetation becomes flooded and shallow marsh flows in these areas in addition to the flow down the central stream.

Impacts of these hydrologic phenomena on water quality buffering processes are examined in the next Section.

6. Pilot Wetlands Water Quality

6. PILOT WETLANDS WATER QUALITY

Water quality processes in wetlands have long been recognised to be highly significant for:

1. the effective functioning of wetland ecosystems and
2. the roles they play in moderating water quality processes within catchments generally.

Distinct aspects of wetlands water quality cycles include plant and biofilm uptake rates, low velocities, high residence times, enhanced sedimentation rates, sediment-water interface processes moderated by the highly reducing conditions in the wetlands due to the high organic content of the beds and due to the low reoxygenation rates applying at the surface.

Water quality processes cannot be examined in isolation but must be considered in conjunction with hydrology processes in order for nutrient and other pollutant loadings to be properly characterised. To address this necessity, water quality monitoring was conducted in conjunction with hydrology monitoring as reported in Section 5, with both extended duration monitoring and intensive monitoring investigations were performed. These water quality monitoring investigations are discussed separately below.

6.1 Extended duration Monitoring

Extended duration Sampling Methodology

Water quality was been monitored at the two sites from June 2004 to the February 2005. Eight full sets of monitoring were performed at both sites over this period. The results compiled provide a significant set of water quality data for the two sites. Each monitoring event was carried out in two phases as follows:

(i) Physical assessment involving on-site measurements for pH, electrical conductivity and total dissolved salts, temperature, turbidity and dissolved oxygen. These parameters were analysed using either a Hydrolab or YSI probes both of which were calibrated regularly for reproducibility of results,

(ii) Chemical parameters including nitrogen, phosphorous, and total suspended solids were analysed in laboratories of the LVEMP Water Quality Component in Kisumu. For nitrogen and phoshorus, both total concentrations and speciations were performed; however the susbsequent assessments performed focus mostly on the total concentrations as it is the total load entering/leaving the wetland that is of most interest and because these are the analytes subject to the least amount of error.

(iii) Physical observations were also undertaken noting the general environmental conditions at the time of the sampling and measurements. Among the observations made were rainfall, prevailing activities around the monitoring stations and any relevant observations about the nature of water flowing in the stream – odour, colour etc,

Measurements were made in coincidence with hydrologic assessment of flow rates for the streams as reported in Section 5 to enable quantification of the inflow loads. The full range of parameters monitored are reported in Table 6.1. All water samples were collected in pre rinsed plastic bottles for the above parameters and held in cooler boxes for transport to the laboratory.

Laboratory Analytical Methodologies

Analyses reported here were conducted by the Ministry of Water Kisumu Water Quality Laboratory (LVEMP Water Quality Component). The procedures used by the laboratory are summarised in Appendix 1. The full set of data results obtained is given in Appendix 2.

Extended duration Monitoring Results

Figures 6.1 to 6.3 summarise the water quality data for the key parameters of interest, Suspended Solids (SS), Total Phosphorus (TP) and Total Nitrogen (TN) respectively for the Kericho and Eldoret Chepkoilel pilot wetlands, these being the parameters of most concern for this study. Further details of all individual parameter results obtained are described in detail below.

Temperature

The ambient insitu measured temperature range of the water was generally between 15 and 20^{o} C for all sampling points at both sites, which is typical of water in tropical inland streams at these altitudes. Temperatures varied depending on the prevailing weather on the monitoring days. In both wetlands, no significant temperature gradient was observed between monitoring stations, nor between the inlet and outlets points. For both wetlands, the consistency in temperatures recorded indicates that thermodynamic conditions do not influence water quality processes.

Table 6.1: Parameters Monitored, Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands

Item	Sample Type	Parameters	Remarks
1	Water	Physical parameters measured in the field were pH, temperature, electrical conductivity, turbidity, dissolved oxygen, and ammonia. Nutrients and speciation analysed were total nitrogen, nitrates, dissolved nitrogen, ammonia, total phosphates, orthophosphates, filtered phosphates and suspended solids.	Undertaken for both the dry and wet weather monitoring.
2	Sediments	pH, Organic Content, total nitrogen, total phosphorus.	Samples were collected and analysed by the Kenya Soil Survey laboratory
3	Biomass	Total nitrogen, total phosphorus, heavy metals. Plant species speciation for the two sites is also scheduled to be carried out during the course of the studies.	Biomass analysis will be done once or twice during the project. Speciation completed. samples have been collected and analysed by the Kenya Plant Health Inspectorate Services.

pH

Insitu measured pH from all the monitoring stations vary somewhat. Water from the spring at IK1 is generally acidic, with pH ranging from 5.5 to 7.5, while inflow at the stormwater drain tended to be alkaline with pH ranging between 6.8 and 9.8. The pH of the surface runoff streams at the Kericho Dionosoyiet wetland site were between 6.5 and 8.5, while at the transect and outlet they were slightly lower, generally not exceeding 7.5.

There did appear to be a trend of decreasing pH from inlet to outlet in the Kericho Dionosoyiet wetland, which is what might be expected given the high amount of organic matter within the wetland, decomposition of which would lead to conditions becoming more acidic as water flows through the wetland.

At the Eldoret Chepkoilel site, pH ranged between 6.4 and 9.4 with no significant differences between pH at inlet and outlet. Elevated pH data are considered to have reflected epiphytic phosynthetic productivity within the system.

Electrical Conductivity

The Electrical Conductivity (EC) of the inlet streams was measured insitu. EC was found to vary from one stream to the other and depending on the origin of the water. At the Kericho Dionosoyiet wetland, the spring has clear fresh water that was been uniform with respsect to EC over the monitoring period at 80 – 100 uS/cm. The three surface streams showed little variations between themselves and had the lowest conductivity levels during the dry weather conditions (30 – 65 uS/cm). The same fluctuation ranges and characteristics were observed at the outlet. The storm water drain, however, showed high EC ranging from 180 – 300 uS/cm during the wet days up to 1,012 uS/cm during the relatively dry days. The latter scenario was particularly so during the months of September and October when very little rainfall was experienced in Kericho.

In the Eldoret Chepkoilel site, no significant difference was observed between the inlet electrical conductivity levels and those at the outlet points at an average of 50 – 70 uS/cm during the monitored period. The treated sewage from the University discharging into the wetland system, however, has an average total dissolved solids concentrations of 370 – 420mg/l giving a conductivity range of 500 – 650 uS/cm. The flow into the wetland system is relatively low and it did not seem to affect the overall level in the system.

Dissolved Oxygen

Dissolved Oxygen (DO) was also measured insitu. Both sites were found to have adequately oxygenated inflow and outflow water with DO levels all generally within a range consistent with an oxidised environment due to the free flowing nature of both wetlands allowing good oxygen transfer at the water surface, and good mixing through the water column. No fixed trends could be defined for the oxygen levels through the wetland systems. There was no obvious correlation either temperature or pH. The low gradient in oxygen levels through the two systems was significant in that it indicated well-oxidised conditions, which would be expected considering the free flowing water in both, allowing good aeration to take place.

Total Suspended Solids

Total Suspended Solids (TSS) was measured in the laboratory using techniques as described in Appendix 1. Summary plots of TSS concentrations throughout the two pilot wetland sites are given in Figure 6.1 and 6.2 along with TP and TN concentrations.

Of the six inlets in the Dionosoyiet wetland at Kericho, the storm drain IK2 registered the highest TSS levels at an average of 15 – 20mg/l during dry conditions and up to 200mg/l during and immediately after heavy rainfall. However as described in Section 5, inflow at IK2 was generally much lower than the surface inflow points, thus the TSS load from the storm drain contributed very little to the combined TSS load entering the wetland system.

The spring-water at IK1 was generally visually clear at all times, with an average TSS level of 1 - 3mg/l, with lower values occurring during dry weather periods.

The three surface streams IK3, 4 and 5 were monitored to have an average of 5 – 15mg/l TSS during dry weather periods and up to 25 - 30 mg/l TSS during and immediately after heavy rains.

Overall the monitoring showed there was significant reduction of TSS levels between the inlets and outlet of the wetland; however detailed quantification of TSS removal is addressed in the modelling section, Section 8, in which the wetland's buffering capacity for suspended sediments is assessed across a full range of environmental conditions.

For the Chepkoilel wetland at Eldoret, the water at the entry point was relatively clear, with an average TSS of 8 – 15mg/l for both dry and rainy conditions, while the inlet at the seweage treatment plant discharge point showed higher TSS levels (35 – 45 mg/l). A significant feature was the determination of a slight rise in TSS levels at the middle of the system and then a decrease towards the outlet transect where levels are below 10mg/l. As noted with respect to pH values, this may reflect epiphyte and planktonic algal productivity. Quantification of buffering capacity is addressed below in the modelling section.

Nitrogen

Nitrogen was investigated in forms of ammonia, ammonium ions, nitrates, total dissolved ions and Total Nitrogen (TN). It is important to note that load estimates will be more meaningful when continuous flow and autosampler equipment enables the monitoring of both base-flow and storm flow hydrograph and pollutograph dynamics. The trends for the various forms varied between the streams and sites as follows:

Total Nitrogen

At the Kericho Dionosoyiet wetland, total nitrogen concentrations in the inflows were generally higher than at the outflow points. It was highest at the storm drain (IK2) reaching 6.5mg/l in July (wet conditions) and as high as 14mg/l in September (dry conditions). The concentrations then decreased gradually towards the transect followed by a slight rise at the outlet point (0.7 – 0.9mg/l) as seen in Figure 6.1.

A similar pattern of TN values was observed at the Eldoret Chepkoilel wetland as shown in Figure 6.2, with higher concentrations at inlet than outlet. Load calculations at Eldoret Chepkoilel however were problematic given the variability of inflows and outflows and their time synchronisation. The large size of the wetland meaning that there are significant delays in flow and loads passing from inlet to outlet through the wetland as discussed in Section 8.

Nitrates

At the Kericho Dionosoyiet wetland, the trends in nitrate concentrations in the monitoring data indicate levels in the spring (IK1), the storm drain (IK2) and dionosoyiet stream (IK3) at an average of 0.11 - 0.27 mg/l, while the other two streams show slightly higher levels at an average of 0.5mg/l. However, it seems during the dry conditions, the storm water drain has higher nitrate levels than other streams a situation attributed to lower flow, allowing time for nitrification. Across the system, the nitrate levels are lower at the transect and then rises slightly towards the outlet, although lower than the inlet concentrations. This implies significant mineralisation takes place through the wetland.

Similarly at the Chepkoilel wetland, nitrate levels were found generally to decrease through the wetland, implying that nitrogen uptake and dentrification are taking place in the wetland. High concentrations of Nitrates were observed at the STP; however these contributed very little to the total load given the small flow rates involved.

Dissolved Nitrogen

Dissolved nitrogen was higher with the spring and the storm water drain. During rain events the concentration ranges were 4 to 5mg/l while dry conditions drove the levels up to above 6mg/l.

Between the transect and the outflow, the concentrations were found to be rather constant, ranging between 0.5 – 1mg/l.

At Chepkoilel, dissolved nitrogen tended to increase, often quite significantly from inlet to outlet. This was presumably due to the breakdown of organic nitrogen associated with plant matter decay.

Ammonia/Ammonium

Ammonia concentrations were determined to be very low through the both the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands. This is considered to reflect the relatively oxidised conditions through the system, promoting nitrification.

Phosphorous

Concentrations and speciation of phosphorus was determined during laboratory analyses, Dissolved Phosphates and Total Phosphorus (TP), as described below.

Total Phosphorous

As shown in Figure 6.1, total phosphorous in the Dionosoyiet wetland was highest at the storm water drain, where the concentrations were as high as 0.55mg/l during wet conditions and 0.2mg/l during dry conditions. Other inlet flows were relatively low in total phosphorous, with almost negligible inputs during dry conditions. Settlement of particulate material and associated phosphorus,before the transect, was considered to be effective (see total suspended solids trends).

Figure 6.2 shows that trends in Chepkoilel wetland were somewhat different. The inlet point was found to have quite low total phosphorous concentrations during dry conditions (0.06mg/l), while at high flows the concentrations reached 0.33mg/l. The sewage treatment plant discharge point was found to have high concentrations of total phosphorous as would be expected, however, the input was considered to make little contribution to the total P load to the system due to high overall flow.

Orthophosphates

In the Dionosoyiet wetland, orthophosphate levels were higher at IK2 compared to other inflow channels, considered to reflect the high total suspended solids observed above for the sampling station. There was then a uniform level through the rest of the system, through to the outlet point. Concentrations were lowered between the inlets and the transect from a maximum of

0.445mg/l and 0.1mg/l down to 0.023mg/l and 0.02mg/l for the wet and dry months respectively and then remained low through to the outlet. .

Similar trends were observed in Chepkoilel wetland, with an exception of concentrations of phosphorus at the sewage treatment plant discharge point, with discharges of between 0.45mg/l and 2.9mg/l. The flows were, however, very low and made very little contribution to the over all concentrations in the system. Again levels across the system were found to be higher during the wet months compared to the dry periods, reflecting disturbance of loosely held sediments.

Dissolved phosphorus

Dissolved phosphates were more significant during wet conditions, mainly because of the phosphorus association with particulate matter during high flows. Flows in the Dionosoyiet wetland showed significant presence of dissolved phosphates through the system during wet conditions, however, levels during dry conditions were negligible.

6.2 Intensive Monitoring

Intensive monitoring was carried out at the two pilot wetlands from October to November 2004 and again from March to April 2005. The primary aim of the intensive monitoring was to characterise the hydrology and water quality trends in the wetlands through wet weather events. It was also necessary to undertake detailed sampling of soils and vegetation to characterise the nutrient and heavy metals status of these compartments of the wetland in order to fully understand the buffering processes taking place. Below are reported the results of monitoring undertaken to determine nutrient contents of sediment substrates and plant biomass, and results of intensive water monitoring undertaken by rising stage sampling, manual sample collection and automated sample collection.

Sediment Substrate Properties

Soil is formed as a result of combination of factors that acts on rocks over geological time scales. It is therefore important to note that the parent material determines the nature of soil formations, soil properties in general and the chemical composition of soil.

Soil surveys were conducted for the Dionosoyiet and Chepkoilel wetlands to provide information on the soil characteristics and classification as discussed below.

Investigative methods

Augerhole observations were made along longitudinal transects in both wetlands. At each observation point, sediment characteristics were assessed insitu to identify soil mapping units. Samples from the augerholes were submitted for analysis to the Kenya Agricultural Research Institute Kenya Soil Survey (KSS) laboratory in Nairobi, where they were analysed according to methods described by Hinga et al (1980).

Samples were air–dried, aggregates were broken and sieved through 2mm sieves. Following sieving, the following standard analyses were performed:

- Texture – the soil texture was analyzed, using a hydrometer
- pH
- cation absorption capacity
- organic carbon
- calculation of based saturation
- estimation of electrical conductivity of saturation extract Ece
- exchange sodium percentage
- nitrogen
- phosphorous

Dionosoyiet Wetland

The Kericho Dionosoyiet wetland physiographically lies on a volcanic footbridge. The area is undulating to rolling with slopes 7 – 16%. The soil parent materials influences soil formation and properties. The soils in the Kericho Dionosoyiet wetland developed from tertiary or older basic igneous rocks such as basalts with soil depths greater than 120 cm.

Soil analysis results reported in Table 6.2 and 6.3 for the Kericho Dionosoyiet wetland show the soil pH is acidic and thus generally unfavourable for crop growth. In order to undertake cropping, it would be necessary to neutralize the soil acidity through the application of lime at least three weeks before planting. The phosphorus and organic matter content would also need to be improved and maintained regularly by applying 80 kg/acre of triple superphosphate (TSP) together with 1 t/acre of well decomposed farmyard manure or compost.

Soil test results for Chepkoilel wetland show the soil pH is even more acidic than Kericho Dionosoyiet wetland, which again is not favourable for crops. The wetland soils are quite deficient in nitrogen, phosphorus and organic matter. In order to perform cropping these would need to be improved by applying up to 120 kg/acre of compound N:P:K fertilizer 23:23:0 together with 4 t/acre of well decomposed farmyard manure or compost.

Profile descriptions

Dionosoyiet Wetland Soils

The soil's parent materials are tertiary or older basic igneous rocks of the Kericho area that are present in the immediate vicinity of the site. Soils are imperfectly to poorly drained.

Soil Horizon 1

The uppermost soil horizon extends from the surface to between 16 and 30 cm depth. This clay layer ranges from dark brown to very dark grey in colour. This layer is slightly hard to very hard when dry, friable to firm when moist and plastic when wet. Grains display a medium sub anglular to angular and blocky structure slightly hard too hard when dry. There are abundant fine very fine roots present in the many micro to very fine pores that are present.

Soil Horizon 2

Below the upper horizon, a second horizon is present extending to a depth of 70 to 160 cm. This layer is dark grey to black in colour, is very hard when dry, firm to very firm when moist and firm, sticky and plastic when wet. The layer has a medium angular to subangular block structure with few micro pores and very fine pores. Very fine and fine roots are common through the structure.

Chepkoilel Wetland Soils

The Chepkoilel wetland physiographically lies on a plateau/upper level upland transition on the bottom land of the Uasin Gishu plateau. The area is gently undulating with slopes less than 8%.

The geology in the area comprises of soils developed on tertiary basic igneous rocks such as olivine basalts.

As Figure 6.2 shows, profiles at the Chepkoilel wetland were quite similar in their observed characteristics. The soils of the wetland are derived from basic igneous rocks.

The wetland had a poor internal drainage and recorded a grouped water level of ranged from poorly to very poorly drained soils. Internal drainage is poor to very poorly drained. Effective soil depth is greater than 70 cm

From 0 to 42 cm depth, the soil is very dark brown, silky clay with moderate to fine crumbs and weak. Grains are medium angular, angular and sub angular with block structure, slightly hard too hard when dry, sticky and plastic when wet. There are many micro and very fine pores but few fine pores, frequently with fine roots.

From 42 to 72cm depth, the soil is very dark brown moist clay. Grains display weak to moderate fine, fine to medium angular and sub angular block structure. The soil is very hard when dry and firm when moist with moderate plasticity when wet. Few micropores and fine pores are present.

Plant Biomass Nutrient Characteristics

Samples of the dominant macrophyte species, *Cyperus immensus* and *Cyperus papyrus* respectively for the Kericho Dionosoyiet wetland and Eldoret Chepkoilel sites, were collected from the already defined transects and sent for analysis at the Kenya Plant Health Inspectorate Service (KEPHIS). Results of testing on Rhizomes sample are reported in Table 6.3. The samples were cut into small pieces and dried at 80%c for 48 hours. The plant tissues were ground to pass 1mm sieve, dried to constant weight and analyzed as described by (Gaudet 1979).

Plant Heavy Metal Content

Heavy metals such as cadmium, lead, iron and copper are used increasingly for industrial purposes despite that they present significant human health risks and are known environmental pollutants. The presence of heavy metals in plant rhizome samples was noted for both wetlands, so care is required in management of wetlands in the future. Lead levels in particular were observed to be relatively high. Industries upstream of both wetlands should be encouraged to dispose of their wastes more diligently and careful attention is required to activities that may directly add heavy metals to the wetlands such as car washing.

Table 6.2 Soil Physical and Mineralogic Characteristics, Kericho Dionosoyiet Wetland and Eldoret Chepkoilel Wetland

	Kericho Dionosoyiet	**Eldoret Chepkoilel**
Sand %	12 to 22	16 to 28
Silt %	26 to 24	14 to 54
Clay %	50 to 58	24 to 70
PH-H_2O 1:2.5 Suspension	4 to 5	3.6 to 4.5
EC (mmhos/cm) 1:2.5	0.04 to 0.12	0.03 to 0.12
C%	2.7 to 3.5	0.3 to 2.4
Ca Exch. cap (me/100g)	12 to 18	14.7 to 17.5
Ca (me/100g)	1 to 5	5.5 to 11.4
Mg (me/100g)	0.5 to 1.4	1.1 to 2.6
K (me/100g)	0.18 to 0.52	0.36 to 0.92
Na (me/100g)	0.50 to 0.60	0.40 to 1.20
Sum (me/100g)	2.6 to 7.4	7.54 to 24.23

Table 6.3 Soil Fertility Characteristics, Kericho Dionosoyiet Wetland and Eldoret Chepkoilel Wetland

	Soil Analytical Data			
Site	**Kericho Dionosoyiet**		**Eldoret Chepkoilel**	
Fertility results	value	class	value	class
Soil pH	4.1 to 5.1	Extreme to medium acid	3.8 to 4.8	extreme acid
Total nitrogen %	0.27 to 0.38	adequate	0.06 to 0.18	adequate
Org. Carbon %	2.4 to 3.5	Adequate to moderate	0.29 to 2.35	moderate
phosphorus ppm	15 to 30	Low to adequate	17 to 29	low
Iron ppm	1300 to 1600	Adequate to high	640 to 1184	high
Elect. Cond. mS/cm	0.12 to 0.20	adequate	0.10 to 0.20	adequate

Table 6.4 Plant Rhizome Nutrient and Heavy Metals Analysis

	Kericho Dionosoyiet Average Rhizome Composition	Eldoret Chepkoilel Average rhizome Composition
Nitrogen (N)%	0.28	.1
Phosphorus (P)%	0.83	0.1
Copper (Cu)ppm	11.5	2
Iron(Fe)ppm	5318	320 to 2320
Zinc (n)ppm	157	29 to 56
Cadmium (Cd)ppm	Not detectable	3 to 7
Lead (Pb)ppm	25.95	78 to 184

Rising Stage Sampling, Short Rains 2004, Kericho Dionosoyiet Wetland

Given the lack of availability of automated monitoring equipment through the short rains, a rising stage sampler was devised to capture water quality samples through the short rains 2004. Rising stage samplers are a well established means of sampling water quality studies in catchment and streamflow studies (Gordon etal, 2004). A photograph of the sampler is shown in Figure 6.3 and a diagram showing its design. By taking composites from samples obtained, Event Mean Concentrations (EMCs) of TSS, TP and TN were able to be established at inlet and outlet. Given that the total volume going in and out of the wetland must be the same for a given event, the difference between the EMCs at the transect and outlet gives an indication of the buffering capacity of the wetland for that storm event.

As was reported in the hydrology section, it was expected that rainfall would be significant over this period; however, rainfall was unusually low, consequently no detailed sample by sample analyses were undertaken.

The rising stage sampler yielded results for seven events in Kericho Dionosoyiet wetland. As discussed in Section 5, the time scales of hydrology and water quality processes in the Chepkoilel wetland are long, so the wetland here was not well suited to water quality assessment with rising stage samplers.

Figure 6.4 shows TP, TSS and TN for these events at inlet and outlet graphed against rainfall experienced on each of the days for which samples were obtained.

From Figure 6.4, it can be seen that there are apparently 2nd order non linear relationships between water quality EMCs and rainfall. As rainfall increases, water quality EMCs tend initially to become higher, however under high rainfall events, the EMCs each appear to reduce slightly. This is reasonable given that with increasing rainfall, initially water quality will become worse as pollutant generation processes require energy from rain and flow of water to mobilise pollutants. For larger events however, it seems that a dilution effect occurs – the increase in volume of water is higher than the increase in the amount of pollutants mobilised, therefore the concentration decreases slightly.

The results shown in Figure 6.4 for buffering capacity reveals significant variability in buffering for individual events. Some events can be seen to have shown good retention of pollutants (ie reduction in concentration from inlet to outlet), while others show an export of pollutants taking place. It seems that such variability is common in wetlands and most likely arises as pulses of pollutants pass through the wetland cause. This is thought to be quite common for many natural wetlands receiving storm flows from catchments (Sullivan etal, 2004).

It is apparent from Figure 6.4 that the buffering capacity of the Kericho Dionosoyiet wetland through storm events is extremely variable. This is widely found to be the case in various studies of natural wetland response to rainfall events and it is apparent that a large number of storm events need to be analysed in order to develop an understanding of this behaviour.

6.3 Outcomes of Water Quality Monitoring

Sufficient data was captured through the water quality monitoring through both wet and dry periods to allow characterisation of inflow and outflow loads at both wetlands. With such characterisation, relationships were determined between inflow loads for TSS, TP, TN and daily rainfall such that modelling of the wetlands performance could be performed and compared with outflow loads. This is presented in Section 8 below, from which the buffering capacity of the two wetlands is able to be assessed over a more meaningful range of conditions than applied at the times and on the days when measurements were taken.

The intensive event monitoring showed that the pilot wetlands can become nett exporters of sediments and nutrients during storm events; however the effect is limited and does not take place in all storm events. A pattern emerged then of the wetlands performing buffering under low flow and moderate flow conditions, but potentially exporting the retained parameters during large storm events. Nevertheless, the nett impact incorporating both low and high flow periods is of a nett removal of pollutants.

7. Wetlands Buffering Mechanisms and Processes

7. WETLANDS BUFFERING MECHANISMS AND PROCESSES

While buffering can be understood simply as a nett decrease in pollutant loads between inlet and outlet of a wetland, examination of the mechanisms and processes responsible for buffering can be instructive so that appropriate management procedures can be adopted.

Wetlands have the capacity to deplete or enrich nutrient concentrations in the water flowing through them depending on the type of plants dominating the wetland, the rate of throughflow, and the particular nutrient element being studied (phosphorus or nitrogen). Wetlands are particularly effective at sediment removal and while this may enhance downstream water quality, high accretion rates will promote successional changes in the vegetation of the wetland.

In this section, the mechanisms and processes that bring about buffering in natural surface flow wetlands are discussed. Finally, conclusions regarding buffering processes within the two pilot wetlands are made.

Buffering mechanisms and processes in wetlands range across a number of complex physical, chemical and biological areas (Bavor and Mitchell, 1994). For this study a particular focus has been adopted on the processes and mechanisms of significance for sediment and nutrient buffering in surface flow natural wetlands. Waters (2004a) described mechanisms and processes that may be significant for the buffering effectiveness of a wetland including:

- gravity driven settling of sediments and sediment attached pollutants;
- resuspension/scour of sediments and sediment attached pollutants under high velocity conditions;
- physical interception by plant matter;
- attachment/detachment of pollutants on bottom sediments;
- nitrification/denitrification processes;
- plant and biofilm uptake of nutrients and other pollutants; and
- consumption of plant materials through grazing, harvesting and burning.

Each of these processes is discussed separately below. Furthermore, these processes have been incorporated as appropriate into the model (LAVINKS-WEB) as described in Section 8.

7.1 Gravity Driven Settling and Resuspension of Sediments and Sediment Attached Pollutants

Mineral derived sediments generally have a density much greater than that of water and therefore have a tendency to sink to the bed of a water body through the process of settlement or sedimentation (Chin 2000). This effect is especially notable in wetlands where velocities are generally low because of the high resistance to flow provided by the vegetation within the water column.

Sedimentation is generally a process that happens continuously over time within a wetland. It is generally related most strongly to the residence time of the wetland, the longer the residence time, the more effective the settlement. The density, size and shape of the particles involved also play important roles in effectiveness of settling. Vegetation density and type do have a secondary influence on sedimentation as they provide flow resistance, thereby reducing velocities and increasing residence times both of which will make settlement more effective.

Resuspension may occur under high velocity conditions due to an increase in flow associated with extreme rainfall/runoff events. This is generally an extreme or rare event phenomenon in wetlands. The primary factors influencing resuspension are the local bed velocity in the area where resuspension occurs as well as sediment density, size and shape. As for sedimentation, vegetation density and type can play a role by providing flow resistance thereby reducing velocities which will make scour less effective.

At the Kericho Dionosoyiet wetland, the unusually dense plant morphology which causes flows to be highly channelised means sedimentation is less effective as a buffering mechanism than it could potentially be. With the central stream carrying most of the water flowing through the wetland at high velocity through the wetland, opportunities for settlement here are limited.

By contrast in the Eldoret Chepkoilel wetland, the very large size of the wetland, its consequent long residence times and the moderate level of vegetation present mean that sedimentation takes place quite effectively and the potential for scour is limited.

7.2 Physical Interception by Plant Matter

Analogous to filtration or screening, the presence of plant matter within a wetland provides a physical barrier that prevents sediment and sediment attached pollutants from being swept downstream by the flow (Waters 2004).

As a low flux rate process, plant matter interception is to be distinguished from filtration and screening which are high flux rate processes. Low flux rate processes such as plant interception allow suspended solids to be removed across a very broad range of particle sizes. This arises because the physical shear of water passing the plant matter is too low to re-entrain particles that become lodged against the plants, regardless of the size of the particle, the size of the plant material or the size of the interplant spacing.

Filtration and screening on the other hand are only effective in preventing particles larger than the spaces between the filter/screening media from passing. This arises because the shear created as water passes the media is high enough to re-entrain small particles, so that only particles larger than the interpore spacing can be retained.

Given the high biomass present in both wetlands, physical interception will be a significant buffering mechanism in both the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands.

7.3 Attachment/Detachment of Pollutants on Bottom Sediments

Attachment and detachment processes with bottom sediments take place where some physico-chemical or chemical condition within the sediments exerts a demand on a dissolved constituent in the sediment pore water and the overlying water column. The most common of these mechanisms are sorption-desorption and chemical precipitation.

Sorption-desorption processes arise when there is some attractive force operating between the surfaces of a solid object that is in contact with a fluid, and some constituent entrained in the fluid. Sorption may become effective due to a combination of properties of the solid surface (in this case the surfaces of the bottom sediment particles) and the constituent. Sorption processes can be described as adsorption, chemisorption and adsorption (Chin 2000).

Ion/electron exchange, the electrostatic nature of the surface and the polarity of the constituent are all potentially important factors in the uptake of the constituent on the surface of the sediment particles. Consequently, sorption is an important process for constituents that display electron exchange or are highly polar, such as heavy metals, phosphorus and long chain polyaromatic hydrocarbons (PAHs) including many pesticides and herbicides.

Sorption is generally a reversible process: if the concentration of the constituent in the water column is high, the constituent will become sorbed to the sediment particle surfaces; however, if the concentration of the constituent drops, then desorption may occur, that is the constituent may be released from the sediment particle surfaces. These processes occur most strongly in sediments that have a high Cation Adsoprtion Capacity (CAC).

CAC was measured and found to be quite low for both the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands, so it is apparent that sorption is not an important buffering mechanism for either wetland.

Chemical precipitation is a non reversible process whereby an ionic exchange takes place between two ions, resulting in the formation of a non-soluble salt so that the ions involved become permanently bound in the sediment. This process may occur in wetlands where the bed contains mineral deposits that will support such reactions. Precipitation can be an important process supporting the removal of heavy metals and phosphorus; however, the mineralisation of sediments for the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands do not support precipitation processes so precipitation is not an important process for either wetland.

From the above, it is apparent that mechanisms for attachment of pollutants to bottom sediments were found to be low in both the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands so these are not considered to be important mechanisms which would promote pollutant buffering processes in these wetlands.

7.4 Nitrification/Denitrification Processes

Nitrogen loss from wetlands can occur through nitrification/denitrification processes. Viner (1982) measured rates of denitrification in a papyrus swamp at Lake Naivasha between 1.5 and 6.4 mg N m^{-2} day^{-1} compared with mean rates of nitrogen fixation in only 0.0234 mg N $m^{-2}day^{-1}$.

Nutrient dynamics in wetlands are heavily influenced by the vegetation structure (Howard-Williams and Gaudet, 1985). In Africa, floating papyrus swamps (such as the central portion of the Eldoret-Chepkoilel wetland) are structurally and functionally quite different from bottom-rooted swamps (such as those dominated by Typha, Phragmites and rooted sedges, e.g., Kericho-Dionosoyiet).

In the Kericho Dionosoyiet wetland, the high degree of channelisation, high velocities and short residence time rule out nitrification/denitrification as a significant process. Nitrogen entering the wetland will simply travel through the wetland too rapidly for significant nitrification/denitrification to take place. For the Eldoret Chepkoilel wetland, nitrification/denitrification cycles are most likely quite significant mechanisms for removal of nitrogen.

7.5 Plant and Biofilm Uptake of Nutrients and Other Pollutants

Given the high amount of biomass and biofilm covered surface area that may be present in wetlands, there is potential for these plants and associated biofilms to store significant quantities of nutrients in their cellular structure (Bavor et al, 1998), particularly in macrophytic rhizomes. *Typha* spp. and *Cyperus papyrus* in particular usually have massive rhizomes. In *Typha* over 50% of plant biomass may be in the rhizome (Howard-Williams 1973) and in *C. papyrus*, Thompson (1975) found 30-40% of the biomass was root and rhizome material.

Tropical floating swamps are much more productive than rooted swamps. Net average production in *Cyperus papyrus,* a C4 plant, is 48-143 t ha^{-1} y^{-1} (Thompson et al, 1979). Total net productivity of *Typha* in tropical wetlands probably lies between 25-30 t ha^{-1} y^{-1} (Howard-

Williams and Gaudet, 1985). It should be noted that these high rates of primary production, which are comparable to those of fertilized crops such as maize and sugar cane, can be sustained in low nutrient conditions.

This high productivity under low nutrient conditions is achieved through very efficient nutrient cycling (see Thompson et al 1976 and Bavor et al, 1988) and is thought related to the high surface areas and efficiency of constructed wetland systems in removing nutrients from water even at very low concentrations. This can be understood conceptually with reference to Figures 7.1 and 7.2, since for floating papyrus vegetation, the position of the floating matt in the water column means:

- a much higher proportion of vegetation is present within the water column meaning that plant interception of sediments and nutrients is higher; and
- the rhizomes in the floating mat are able to directly draw nutrients from the water column, rather than extracting nutrients through the soil pore water.

If of the order of 20% of plant biomass P is permanently sequestered, the net removal of phosphorus into rhizome is of the order of 0.1 - 4 g $P/m^2 \bullet yr$ (Kadlec, 2003). This amount may be of great importance for lightly loaded wetlands, but of little importance for heavily loaded systems.

Consequently, plant uptake and surface biofilm mediated removal of nutrients is most likely a significant mechanism for removal of nutrients both for the Kericho Dionosoyiet and the Eldoret Chepkoilel wetland; however, this will be much more apparent in Chepkoilel than Dionosoyiet.

Nevertheless, from Figures 6.1 and 6.2, for both the Dionosoyiet and Chepkoilel wetlands it is apparent that Phosphorus is the limiting nutrient as N:P ratios are generally much higher than 7:1. Therefore in performing uptake, the plants will seek to extract phosphorus from the water to the greatest possible extent, whereas nitrogen is more readily available. Plant uptake is therefore likely to be quite effective for phosphorus removal, less so for nitrogen removal.

7.6 Consumption of Plant Materials

Through grazing, harvesting and burning, plant materials are removed from the wetland, and thereby the nutrients contained within the plant matter are also removed. Furthermore, all of these processes stimulate new growth and plants in their growth phase have a higher demand for nutrients than mature plants.

If material is not burnt or grazed, it can (1) decompose *in situ*, (2) accumulate as peat in the sediment or (3) it can be removed via the wetland outflow. The buffering capacity of wetland plants is determined by the relative rates of (1) and (2) versus (3).

Harvesting above ground papyrus biomass could be used as a management strategy to remove significant quantities of biomass and nutrients. Muthuri and Jones (1997) calculated that harvesting papyrus from Lake Naivasha (2,000 ha) would remove 72,000 t with 836 t of nitrogen and 115 t of phosphorus. However, it is thought that repeated removal of large quantities of papyrus (and the nutrients contained therein) may lead to reduced production rates of subsequent regrowth (see Muthuri and Jones 1997). Traditional use, as opposed to commercial-scale harvesting, should be encouraged (see Gichuki *et al*. 2001).

However, these buffering mechanisms are all absent or ineffective in both the Chepkoilel and Dionosoyiet wetlands. Neither wetland has significant populations of large indigenous herbivores, there is no harvesting or burning performed in Dionosoyiet and while harvesting and burning are performed in Chepkoilel, they are not done with the strategic intention of removing nutrients so they are most likely not effective as buffering mechanisms.

7.7 Implications for Buffering Effectiveness on the Pilot Wetlands

Considering the nett impact of these processes in the two pilot wetlands, it is apparent that for the Kericho Dionosoyiet wetland sedimentation, sediment attachment and nitrification/denitrification and plant uptake are largely ineffective as buffering mechanisms.

The only mechanism that appears feasible for removing sediments and nutrients at present in the wetland is physical interception by plants.

By contrast for the Eldoret Chepkoilel wetland, a number of buffering mechanisms were evidently feasible including:

- Sedimentation and plant interception are most likely the mechanisms primarily responsible for most of the removal of suspended sediments and phosphorus.
- Plant uptake is most likely also responsible for some phosphorus removal and nitrification/denitrification by which nitrogen is able to be removed.

Attachment of nutrients to sediments however is evidently almost completely absent from the Chepkoilel wetland as the CAC for sediments is low here, as it is also in Dionosoyiet.

With these considerations, the buffering capacity model was able to be assembled so as to take account of the dominant processes occurring in the two wetlands, as reported in the following section.

8. Preliminary Prediction Model of Wetlands Buffering capacity

8. PRELIMINARY PREDICTION MODEL OF WETLANDS BUFFERING CAPACITY

Modelling of water quality processes is increasingly recognised as an important aspect of management of natural resources such as wetlands. Among the potential uses of buffering capacity models in wetlands management, the following are particularly noteworthy:

- understanding buffering processes taking place in wetlands;
- determining buffering effectiveness over periods when or for locations where monitored data is not available; and
- forecasting impacts on buffering effectiveness of changes that may occur in a wetland, such as changes in management strategy, flows, pollutant loads, wetland area, plant types present and so on;

The modelling of hydrologic and water quality processes is a technically advanced discipline. In order to be effective modelling must take into account:

- the aims and objectives of performing modelling
- the background of model users and other stakeholders
- hardware availability
- the significant mechanisms and processes that will affect the phenomena being modelled and
- the time and length scales of interest.

Modelling of buffering capacity for wetlands is an important activity under the ToR. This section reports on the modelling approach adopted, the software selected for preliminary modelling and the modelling results.

The terms of reference specify that the buffering capacity model should describe "how wetlands buffer floods and low flows and suspended and dissolved solids". Outputs "are to include probability estimates of expected flows and dissolved solids concentrations out of a wetland given input discharge, type of soil and vegetation, vegetation cover and area of wetland etc". The buffering capacity model goes beyond this by modeling nutrient cycling processes as well as flows, suspended and dissolved solids. Furthermore, the incorporation of catchment hydrology and water quality components allows for ease of operation, as inputs required are simplified to rainfall, catchment area, wetland area, vegetation type and soil type within the wetland.

The following sections describe the base software adapted for use (POND), the customizations made to make the model suitable for the project's goals and form the final customised model product (LAVINKS-WEB), processes incorporated in the model, modeling methodology and results obtained.

8.1 Base Software Selected For Modelling

The base modelling framework adopted here is the hydrology-water quality model developed by the Cooperative Research Centre for Freshwater Ecology (CRCFE) dubbed "POND" (**PO**llutant **N**utrient **D**ynamics). This model has been most widely used in Australia, but is written generally enough so that other applications internationally across a range of climatic and landscape conditions are possible. The model has also been used successfully in countries with tropical climates such as Thailand. The background and details for the model are given in Lawrence and Breen (1998). The user manual for the model in its original form is given in Appendix A3.

Wetlands comprise a number of compartments, with transfers of water quality constituents between compartments as a result of physical, chemical, biological and microbial processes. The model describes in detail the dominant pollutant interception processes of nitrogen and phosphorus cycles in wetlands, for a range of inflow conditions. From Lawrence and Breen (1998), particular capabilities that the model displays with regard to these processes are: ·

- routing inflows to outflows thereby modelling the buffering of flows through the wetland taking into account the size and shape of the wetland;
- accounting for removal of sediments and sediment attached pollutants through stokes sedimentation;
- accounting for chemical and biological uptake of nitrogen and phosphorus by plants, the principal pollutants of interest for wetlands buffering;
- an extended detention computation capability to account for conservative buffering processes (dispersion and dilution);
- a 'washout' algorithm that describes re-release of pollutants under high flow events with an alternative solution which provides convergence in situations of high inflow;

- a sophisticated reduction-oxidation ("redox") sub-model that can account for surface re-aeration, photosynthesis generation and sediment oxygen demand;
- a nitrogen feedback link from the sediment redox sub-model to the water column washout & algal growth sub-model, including N_2(g) losses & NH_4 release;
- accounts for the effects of vegetation cover in nutrient processes

The model is coded in excel spreadsheet format, which gives it flexibility and makes it easy to use, even for modelling novices. The original spreadsheet model as developed by CRCFE comprised six sheets labelled A to F as described below.

On Sheet A the user enters the basic parameterisation and calibration data for the wetland including size, shape and outlet details, initial conditions for water quality in the wetland and basic information about the soils, climate and vegetation cover.

On Sheet B the user enters time series of input data for the wetland – the flow rates, concentrations of total suspended solids, total nitrogen, total phosphorus and so on entering the wetland as well as environmental descriptors such as air temperature, wind speed and so on.

In Sheet C, mass balance modelling is performed whereby water quality and flow data are routed through the wetland by considering the combined effects of input data from sheet B and the water quality and flows from the previous day.

Sheet D performs sediment related physico chemical buffering processes such as interception and sedimentation of suspended sediments and adsorption-desorption processes for nitrogen and phosphorus.

Sheet E performs Reduction – Oxidation related buffering processes in the sediments and plant uptake.

Sheet F reports the model outputs, with columns arranged for easy comparison of model results against field monitoring data.

For further details on the model in its original condition the reader is referred to Lawrence and Breen (1998).

8.2 Model Customisation

While POND in itself is perfectly satisfactory at a technical level for modelling wetland buffering capacity, for the purposes of this project, a number of customisations have been made to the model to make its application more effective to the needs of the LVEMP wetlands component and to make it more applicable to the modelling tasks at hand. To distinguish the customised model from the original, from here in the report the original model will be referred to as POND and the customised model will be referred to as LAVINKS-WEB for **La**ke **Vi**ctoria **N**EMA **K**enya **S**MEC **We**tlands **B**uffering model.

Modifications enacted within LAVINKS-WEB that distinguish it from POND include:

- Addition of a number of graph sheets, G1 to G8 that show ingoing and outgoing flows, suspended solids, nitrogen, phosphorus;
- Relocating all required input parameters to sheet A to ensure ease of calibration/model manipulation;
- Addition of a wetland vegetation characterisation module on sheet A to simplify inputs by allowing specification of percentage plant cover in the event that direct estimates of uptake rates are not available;
- Addition of a non reactive TDS module on sheet C with inputs given on sheet A;
- Replacement of BOD compartments with an "organic store" compartment. The term BOD was misleading for this parameter as it represents the nett capacity for organics and other elements to bring about reducing conditions, rather than representing BOD as measured through laboratory analyses;
- Addition of a parameter describing the ratio between organic store and nitrogen. If the source of nitrogen is purely from organics, this ratio would be constant; however in situations where nitrogen may be derived from other sources such as agrochemical inputs and atmospheric transfers, this ratio varies;
- Addition of catchment hydrology and water quality submodels, as described below in the detailed modelling section. These submodels allow daily rainfall in the catchment of the wetland to serve as the basic input data for the model. Rainfall is input into column B of Sheet B (time series inputs) with inflow rates and water quality parameters (TSS, TP, TN,

DO, TDS) estimated from the data obtained in the pilot wetland studies reported in Sections 5 and 6. Given the stochastic nature of catchment water quality processes, these submodels are implemented with a "monte carlo" feature to reflect the variability in water quality conditions observed in the pilot wetland studies. The implementation of the monte carlo aspects are discussed in Appendix 3;

- Addition of a hydraulic estimate of outflow rate from wetland based on theory of flow through vegetation using Mannings equation. This supplements the estimate of flow based on the outlet conditions assumed by the model to obey the weir equation. This second outflow estimate is implemented on sheet C with the Mannings n parameter determined from the wetland vegetation characteristication module on sheet A;
- Calculation of TN/TP ratios and an assessment of whether the wetland vegetation is in a nitrogen limited or phosphorus limited condition, performed on sheet C and reported on sheet F;
- Addition of explicit buffering capacity - plant nutrient uptake modules in sheet D. These are drive by an explicit set of buffering capacity removal rate estimates on sheet A.
- Reporting of all modelling results and monitoring data on sheet F to facilitate ease of interpretation of model input and outputs;
- Addition of depletion prevention commands to prevent the concentration of constituents dropping below zero in the inflow in pond or in the outflow;
- Addition of graphics sheets G1, G2, G3 and G4 to give a visual interpretation of flow rates and nutrient concentrations at inlet and outlet; and
- Addition of an output summary sheet H1, and an interactive statistics module on sheet H2 to allow calculation of probabilities of buffering processes and events.

With these modifications, the sheets of the LAVINKS-WEB model fall into three classes as shown in Figure 8.1:

- input sheets A and B where the user enters the basic parameters describing the wetland (sheet A) and the time series inputs (sheet B);
- calculations sheets C, D and E, where the processes taking place are modelled, and which the user does not generally need to interact with; and
- output sheets F, G1 to G5, H1 and H2, which present the model results.

The form in which data is presented across the sheets is shown in Figure 8.2.

8.3 Processes Modelled

As described above, the pond model incorporates a number of buffering processes within wetlands that were previously described in Section 7. The way these are considered is described below.

Effective modelling of suspended solids is especially important because sediments are not only pollutants in their own right, but they also act as the carriers of particulate attached pollutants, especially phosphorus. Sedimentation and resuspension of suspended solids therefore are the primary factor in sediment water exchange of particulate pollutants.

Sedimentation is described by a simple fall velocity calculated according to Stokes law (see for example Chapra, 1997) and takes place continuously regardless of the flow rates through the wetland Factors important in determining the fall velocity according to Stokes Law are particle and fluid density, fluid viscosity, particle size (equivalent diameter), and a shape factor.

The fluid properties of inland waters are generally consistent across most environmental conditions, so it is only particle density, particle size and shape that generally need to be changed to account for different modelling situations. These three parameters can all be determined through standard laboratory tests available in most soils laboratories; however performing soils laboratory tests is not strictly necessary and in many situations it is quite feasible to run the model using the sediment properties as calibration parameters. Given that most soils display some heterogeneity, especially with particle size, the model allows up to four sediment fractions to be modelled.

Phosphorus and Nitrogen in filterable form are each associated across the four sediment fractions that are modelled. This is enabled through P Absorbance and N absorbance coefficients that specify the amount of P and N associated with each sediment fraction. This then allows phosphorus and Nitrogen to be removed from the wetland through sedimentation.

Sediment water exchange is often a dominant process that contributes to the buffering capacity of a wetland, especially for nutrients and heavy metals. After sedimentation has transported the suspended solids to the wetland bed, diffusion across the sediment water interface may occur for sediment attached pollutants. Similarly, dissolved constituents can diffuse between pore water in the bed and the overlying water column. Furthermore, removal processes mainly occur in the sediments, especially for bottom rooted emergent vegetation.

For example denitrification requires anoxic conditions so it is most likely to occur in the anoxic sediment layers than in the well oxygenated overlying water column.

An important assumption within the model is that the rhizome biomass is constant. This is a common assumption used for many wetlands buffering models such as the Tanzanian DUFLOW model (ARCADIS 2001). Care is therefore required if extensive harvesting, burning or grazing activities take place in the wetland, as model parameters will need to be reset accordingly if such events take place.

In the model distinction is made between inorganic and organic P and N. Inorganic P can occur in dissolved form in the water column as ortho phosphorus (PO_4^{3-}) or it can be adsorbed on sediments at the bed. Inorganic N occurs as dissolved ammonium (NH_4^-), or Nitrate (NO_3^{2-})or Nitrite (NO_2^-) depending on the redox state in sediments at the bed or in the water column. The organic P and N in the model represents the phosphorus and nitrogen available in dead organic material (detritus). Again these processes are modelled quite consistently with the Tanzanian DUFLOW model (ARCADIS, 2001)

While not a primary parameter of interest, the model accounts for dissolved oxygen so that nitrification, and sediment consumption can be accounted for. The dissolved oxygen component interacts with the bed organic load to determine the REDOX state of the bed. The model is also able to account for Iron and Sulphate deposits within the bed as these are often important factors in determining the REDOX state of the bed and thereby the capability of the bed to retain nutrients.

Data Requirements

To use the model several types of input data are needed. Some of these data will have to be collected from field surveys and sampling programs. For other data (for example the model parameters) one can rely reported values in literature or their values have to be identified by calibration of the model.

A semi one- dimensional schematisation of the real system has to be made. This requires geographical and morphological data (bathymetry). It is most convenient to have a digital topographical map as a background.

At the upstream and downstream boundaries of the systems boundary conditions for the POND model are normally entered for both flow and concentrations of the state variables used in the model. Commonly however, insufficient data is available for time series flow and concentrations to be specified on a daily basis.

Modifications introducted by SMEC in LAVINKS-WEB allow the model to run simply by entering daily rainfall for the site. The model can take such rainfall data on daily or monthly bases as required. It is recommended that at least monthly time steps are used for modelling as annual average rainfall will not give any sense of the dynamics of such a system. To further simplify data input, rainfall data are provided in Appendix A2 and in soft copy format for model input from the following sources:

- 1994 to 2004 rainfall for Kericho from James Finlay Kenya
- 1994 to 2004 rainfall for Eldoret from Moi University
- 1983 to 1990 rainfall for the following nine meteorology stations
    - Bungoma Water Supply (Station 8934134)
    - Kisii Water Supply (Station 9034092)
    - Miwani, European quarters (Station 9134009)
    - Narok Keekorok Game Lodge (Station 9135013)
    - Eldoret Expreimental Farm (Station 8935133)
    - Turbo Forest Nursery (Station 8935170)
    - Kibos Cotton Experiment Station(Station 9034081)
    - Ahero Kano Irrigation station (Station 9034086)
    - Kericho Tumbilil (Station 9035244)
- 1983 to 1990 basin average rainfall compiled from the above nine meteorology stations

Models using the rainfall for Kericho, Eldoret and the basin averaged rainfall are supplied in soft copy format. The 1983 to 1990 data from the nine individual stations and the basin wide average rainfall are provided in excel spreadsheet for easy "copy and paste" transfer to the LAVINKS-WEB model in case further modelling is proposed in locations where rainfall from these gauges would be appropriate for modelling.

From the rainfall data, a simple daily timestep deterministic rainfall-runoff model is applied to determine flow rate. Concentrations are determined by a stochastic descrption of the concentrations observed in the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands with the monte carlo feature (refer Appendix 3). Concentrations then vary on a daily time step in accordance with the statistics of the observed data, thereby giving a dynamic modelling environment that is found to better correspond to wetland behaviour than a strictly deterministic model.

The initial conditions reflect the state of the system at the starting time of the simulation. For water levels, flow and the concentration of all state variables the initial state has to be estimated. In practice this often is done by making a few initial runs with the model and using the model results as an estimate for the next simulation run. Initial values for the concentration of both water column and bottom (sediment) variables have to be set. For water column variables also measured values can be used, observed in a period representative for the starting time of the simulation.

Model Outputs

The output are presented in several ways. A summary table of removal rates, loads and other relevant parameters is given in sheet H1. This table or sub components of it can then be copied and paste to other Window application, using copy and paste. Result are also presented graphically as time series of flow in and out on sheet G1 and concentrations in and out on sheets G2 (TSS), G3 (TP) and G4 (TN). A further sheet is also available to give the probability distributions of events as required under the terms of reference.

8.4 Modelling Methodology

For the investigations undertaken here, the LAVINKS-WEB model was used in the following four stages:

1. preliminary modelling of the Kericho Dionosoyiet wetland;
2. detailed modelling of the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands;

3. establishment of a "typical" Lake Victoria basin wetland; and
4. Modelling of the buffering effectiveness of wetlands across the Kenyan portion of the Lake Victoria Basin.

The first three of these modelling stage are described below. Modelling of the buffering effectiveness of wetlands across the basin is described in Section 11.

Preliminary Modelling at the Kericho Dionosoyiet Wetland

Preliminary modelling to determine model suitability was performed for the period June to September for the Kericho Dionosoyiet wetland with inputs for each month taken from the extended duration monitoring results for hydrology and water quality at the inflow of each wetland as reported in Sections 5 and 6.

For the preliminary model, inputs vary on a monthly time scale. Calculations were performed at a daily time step, although it is expected that the results will be only broadly indicative of trends over time scales of months.

The preliminary modelling results for the Kericho Dionosoyiet wetland was successful in proving that the model would perform effectively for lake basin wetlands and hence could be adapted for more detailed use.

Hydrological flow rates produced by the model were found to give a more or less one to one match with the field data. This is to be expected for the Kericho Dionosoyiet wetland flow rates, as the water balance between inflows and outflows here is straightforward.

Results of the preliminary modelling are reported in the mid term report, but are not repeated here as further detailed modelling performed subsequent to the mid term report gave rise to a significantly different approach as described below.

Detailed Modelling of the Kericho Dionosoyiet and Eldoret Chepkoilel Wetlands

The preliminary modelling provided justification for the choice of the POND model and development of the LAVINKS-WEB model for the project; however the extent of modelling performed meant the model could only be used for the Kericho Dionosoyiet wetland, and only for the period over which data had been collected. A more sophisticated approach was desired in order to allow the model to be adapted for use in the Kericho Dionosoyiet Eldoret Chepkoilel wetland and other wetlands across the basin regardless of whether or not data was available for those periods.

Emphasis therefore was placed on developing means of determining input parameters to the model without the need for daily monitoring results. Therefore, in order to allow wide applicability of the model across the basin, a catchment simulation submodel was added to the model, allowing daily rainfall to be used as the basic input data. The catchment simulation submodel comprises two components a rainfall runoff component to predict inflows to the wetland and a runoff – water quality component to predict water quality concentrations from the inflow rate. Development of these two components is described below.

Rainfall - Runoff Component: Modified Isochronal Histogram Technique

A modified isochronal histogram technique is used to determine inflow to the wetland from the daily read rainfall records. The isochronal histogram technique as described in Chin (2000) is used widely in hydrology to model rainfall runoff processes. In the isochronal histogram technique, inflow to the wetland is determined from rainfall by a multiple linear regression relationship against the rainfall over the previous five days with a base flow component also added. Best results for the Kericho Dionosoyiet wetland were obtained when the multiple linear regression was applied to the hydrology monitoring results from Section 5 and extended for five days or longer. For the Eldoret Chepkoilel wetland, best results were obtained when the regression extended over ten days or longer.

Despite the success of the modified isochronal technique, when applied over a period of more than six months for both the Chepkoilel and Dionosoyiet wetlands, it was found that compared with the data from the hydrology monitoring reported in Section 5, results were variable over a monthly time scale. This arose as the streams feeding into the wetland are heavily influenced by groundwater flows in the upper part of the catchment. The variation of groundwater flows in response to rainfall is moderated over longer time periods than the daily rainfall that was used. The technique was therefore modified by allowing the baseflow component to vary in response to the previous month's rainfall. This greatly improved the operation for both wetlands.

Inflow - Water Quality Component: Monte Carlo Enhanced Polynomial Regression

Second order polynomial regression relationships were used to determine relationships between water quality concentrations from the inflow calculated by the modified isochronal histogram technique described above for both pilot wetlands. Distinct polynomial relationships were derived relating each of TSS, TP, TN and TDS, determined from the extended duration monitoring in Section 6, to the calculated inflow for the two pilot wetlands. These relationships generally showed trends of increasing concentrations of constituents with increase in flow rate, as shown in Figure 8.3.

While the second order polynomial relationships were a suitable means of predicting trends in water quality constituents with inflow, it was found that when applied in the model the concentrations predicted by the model at both inlet and outlet did not display the dynamic range of values in the monitored data.

It is well recognised that a number of factors limit the ability of deterministic modelling to reproduce natural environmental processes, some of these being:

- limitations in spatial and temporal resolution able to be reproduced by a model;
- the inherently stochastic nature of many natural environmental processes;
- effects of human activities which generally are extremely difficult to model;
- non linear dynamic effects (commonly referred to as *Chaos Theory*) that apply in most natural environmental systems;
- limitations in sampling for calibration and verification; and
- numerical diffusion and other factors imposed by representing the continuous processes that occur in the environment with discretised calculations in a numerical model.

Due to these limitations, an important emerging aspect of modelling is the growing acceptability of “fuzzy” modelling. In fuzzy modelling, some attempt is made to describe processes occurring through non deterministic means.

Applications of random number generators in representing stochastic processes is generally known as “monte carlo” simulation. The application is made by performing deterministic modelling as usual (in this case applying the polynomial regression relationships to determine water quality constituent concentrations at the inlet from the inflow), then adding a stochastic element consisting of the standard deviation describing the variable in question multiplied by the random number. This process is further explained in Appendix A3. In water quality modelling, monte carlo simulation is an important and long standing aspect of fuzzy modelling (see for example Fischer etal, 1979). Applications of stochastic approaches in modelling pollution contained in catchment runoff is well developed (Grum and Aalderink, 1997).

With the addition of the catchment simulation module, it was possible to model the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands for the years over which reliable rainfall data was available, 1994 to 2004; however, caution must be used in applying the model for times and at locations where monitoring in unavailable.

Once the input data had been established through the modified isochronal histogram technique and the monte carlo water quality simulator, it was found that calibration of the model itself was actually quite straightforward and results obtained were quite good, as described in Section 8.5 below.

Typical Lake Victoria Basin Wetland Model Development

Following the successful development of the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands, a variation on the LAVINKS-WEB model was developed that is better suited to application for other wetland sites where calibration/verification data is not available.

Not surprisingly, the rainfall - runoff and water quality - runoff relationships developed for the pilot wetland sites were unique to each site.

A number of factors would be likely to cause these relationships to be specific to the pilot wetland sites including differences in land use, topography, soils, rainfall, atmospheric conditions, vegetation cover, and catchment area. It was therefore not possible to generalise these relationships in order to develop basin wide “average” isochrononal histogram and polynomial regression relationships relating inflows to the wetland to rainfall and water quality coming into the wetland to inflow rates.

Furthermore, there was a risk that adopting complex relationships between incoming water quality constituent concentrations and inflow rate would lead to a non robust model in which it might be difficult to understand buffering processes taking place. Consequently the “rational” method (see Chin 2000) was used to determine inflow rates on a daily interval and the water quality to inflow relationships were based on the mean of each of the water quality constituents separately (TSS, TP, TN and TDS), obtained from the extended duration monitoring, with the monte carlo simulation retained, and based on the standard deviation of the relevant constituent.

Importantly, these developments also allowed water quality to be disaggregated from hydrology, thereby improving the robustness of the model. With these developments it was found that the model generally worked well and produced results that seemed sensible and reasonable.

8.5 Modelling Results

Modelling results for the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands have been quite successful and SMEC are confident that the wetlands buffering model developed will prove to be a robust tool for analysing and predicting wetlands performance for the Lake Victoria Basin.

Kericho Dionosoyiet Modelling Results

Over the 10 year period of modelling at Kericho, good removal rates were observed for suspended solids and total phosphorus, while nitrogen removal rates were modest. These results are summarised in Table 8.1, while Figures 8.4 a to e show typical time series of incoming and outgoing flow rates, TSS, TP, TN and TDS values over the whole 11 year period from January 1994 to December 2004.

Phosphorus and nitrogen removals should be considered with the recognition that the ratio of nitrogen to phosphorus in the wetland is generally greater than 7:1, thus suggesting that growth in the wetland would be phosphorus limited. The vegetation would, therefore, be expected to have a much greater demand for phosphorus, whereas nitrogen would be readily available within the wetland to the extent that it could be recycled from decaying detritus and would not need to be “extracted” or sourced from the water column.

This would be expected, as the residence time of the wetland is too short and conditions are generally too oxidised for nitrogen cycling (resulting in removal via denitrification) to be significant, hence nitrogen removal is problematic. These findings are consistent with the studies of Gichuki etal (2003) who, through stable isotope tracer investigations for carbon and nitrogen cycling in a wetland within the lake basin, showed that N and C cycles were tightly bound within the wetland.

Eldoret Chepkoilel Modelling Results

For the Eldoret Chepkoilel wetland, removal rates were significant for the three parameters of primary interest: TSS, TP and TN as shown in Table 8.2. Figure 8.4 f to j show typical time series of incoming and outgoing flow rates, TSS, TP, TN and TDS values over the whole 11 year period from January 1994 to December 2004.

Presumably the high residence time is the main reason why all three parameters show high removal rate, particularly nitrogen, as the residence time for the Eldoret Chepkoilel wetland is quite long (one to two months), allowing ample time for nitrogen cycling to take place.

Table 8.1 Summary of Buffering Capacity Effectiveness for Dionosoyiet Wetland, Kericho, KENYA

	Inlet Water Quality						Outlet Water Quality					
		TSS	TP	TN	TDS			TSS	TP	TN	TDS	N/P ratio
Maximum		35.7	0.064	8.368	0.089			16.37	0.027	5.60	0.089	6158
Average		14.0	0.028	0.979	0.029			7.28	0.015	0.83	0.029	78
Mininimum		1.0	0.002	0.111	0.013			1.81	0.001	0.12	0.019	6.0
		mg/l	mg/l	mg/l	mg/l			mg/l	mg/l	mg/l	mg/l	
	Load In						**Load Out**					
	discharge	**TSS**	**TP**	**TN**	**TDS**		**Discharge**	**TSS**	**TP**	**TN**	**TDS**	
Average	29.4	382.0	0.7	39.7	0.9		29	217	0.43	31.7	0.84	
	Ml/d	kg/day	kg/day	kg/day	kg/day		Ml/d	kg/day	kg/day	kg/day	kg/day	
	Loading Rates on Input						**Load removed (kg/day)**					
	discharge	**TSS**	**TP**	**TN**	**TDS**			**TSS**	**TP**	**TN**	**TDS**	
Average	0.38	49	0.09	5.13	0.11			165	0.2952	8	0.015	
	m/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day			kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day	
	Areal Removal Rate (kg/ha/day)						**Relative Reduction % (load removed/incoming load)**					
		TSS	**TP**	**TN**	**TDS**			**TSS**	**TP**	**TN**	**TDS**	
Average		**21.3**	**0.038**	**1.03**	**0.00**			**43%**	**41%**	**20%**	**1.9%**	

Table 8.2: Summary of Buffering Capacity Effectiveness Chepkoilel wetland, Eldoret KENYA

	Inlet Water Quality						**Outlet Water Quality**					
		SS	**TP**	**TN**	**TDS**			**SS**	**TP**	**TN**	**TDS**	**N/P ratio**
Maximum		90.0	0.649	2.877	0.177			28.77	0.213	1.07	0.09	108
Average		10.6	0.077	0.414	0.051			5.65	0.028	0.12	0.05	5
Mininimum		0.0	0.002	0.008	0.006			0.00	0.001	0.00	0.02	0.024
		mg/l	mg/l	mg/l	mg/l			mg/l	mg/l	mg/l	mg/l	
	Load In						**Load Out**					
	discharge	**TSS**	**TP**	**TN**	**TDS**		**Discharge**	**TSS**	**TP**	**TN**	**TDS**	
Average	115.4	2533.4	18.9	92.1	6.2		115	997	5.94	27.0	5.69	
	Ml/d	kg/day	kg/day	kg/day	kg/day		Ml/d	kg/day	kg/day	kg/day	kg/day	
	Loading Rates						**Load removed (kg/day)**					
	discharge	**TSS**	**TP**	**TN**	**TDS**			**TSS**	**TP**	**TN**	**TDS**	
Average	0.20	44	0.33	1.60	0.11			1536	12.9690	65	0.486	
	m/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day			kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day	
	Areal Removal Rate (kg/ha/day)						**Relative Reduction % (load removed/incoming load)**					
		TSS	**TP**	**TN**	**TDS**			**TSS**	**TP**	**TN**	**TDS**	
Average		**26.74**	**0.23**	**1.13**	**0.01**			**61%**	**69%**	**71%**	**8%**	

While overall removal rates are generally good at both wetlands (with the exception of nitrogen at Kericho Dionosoyiet wetland), removal rates fluctuate very widely on a day to day basis. Indeed on a day to day time scale it is not uncommon for removal rates to be negative, implying that at short time scales the wetland is exporting rather than removing a particular parameter. This arises because both wetlands have residence times long enough that delay effects take place, with temporally offset peaks. If large pulse of a pollutant enters the wetland as a “spike” on one day, then drops the next, not all of the pollutant entering the wetland on the first day will exit the wetland that day. For several days following the pollutant spike event, the pollutant levels will be elevated above the inflow values so that statistically the wetland was very efficient in removing the pollutant on the first day but was exporting pollutants for the next few days.

8.6 Scenario Modelling

In order to demonstrate the capabilities of the model, and to make some more generalised statements about the effectiveness of buffering capacity of the wetlands, scenario modelling was performed for the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands to determine their performance if a variety of scenarios involving changes to the wetland or its environmental conditions should take place.

Scenario modelling is a particular strength of the LAVINKS-WEB model, as the model can quite quickly and easily be adjusted to allow scenario assessment to take place because it has been implemented in MS Excel.

Scenario Assessments performed looked at the impacts of changing wetland area, hydraulic loading and loadings of TSS, TP and TN against the time series inputs for the period 1994 to 2004 for Kericho Dionosoyiet wetland and Eldoret Chepkoilel, and for the period 1983 to 1990 for the typical basin wetland. Behaviour of the wetland with changes in each of these parameters was assessed over the comparing the removal rates of TSS, TP and TN (that is reduction in parameter load divided by incoming load) for each different scenario.

Scenario analyses were run for changes in area, changes in inflow rate and changes in inflow loading for the Kericho Dionosoyiet, Eldoret Chepkoilel and typical Basin wetland by multiplying the relevant parameter value by a multiplier coefficient ranging between 0.1 (10%) and 5 (500%). For the wetland area, this was straightforward as the area only appears in one place on sheet A. For the inflow rate and loadings, these values were calculated as usual, then the multiplier coefficient was applied over the range of values for the whole input time series, so that the input series was scaled by between 0.1 and 5, but the relative variability of the values remained the same. While it is unlikely that such drastic changes in area would take place in the near future for these wetlands, it is nevertheless instructive to consider these possible changes in order to determine the robustness of the systems to change.

Note that changes in incoming pollutant loads were found to be only relevant for the particular parameter being assessed and no cross pollutant load impacts were noted. For example, a change in TSS input generally resulted a change in TSS removal rate, but not in TP or TN. As such results presented are only for impact of changing TSS on TSS removal, changing TP on TP removal and changing TN on TN removal.

So for example, at the Kericho Dionosoyiet wetland this approached allowed assessment to be done of what would have happened over the period 1994 to 2004 if the area of wetland had been as low as 10% of what it actually is, or as much as 5 times what it actually is. Similarly if inflow rates had been as low as 10% of what they were, or as much as 5 times as they were and so on. Such an approach is common for assessing scenarios using water quality models.

Results from the scenario analysis should be treated with caution. They are indicative only and merely give an indication of the type of behaviour that is to be expected should changes in the wetland occur. With the collection of more data under different conditions in the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands and hopefully in other wetlands in the basin area as well, scenario analysis will be able to be performed with a much higher degree of confidence.

Given that calibration data was available for the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands, the different scenarios that were run extended over a reasonably wide range of parameter values. This is justified as the calibration provides sensible base data that can be extended from and the results of scenario analysis therefore have some degree of credibility.

Kericho Dionosoyiet Wetland Scenario Assessment

Results for the Kericho Dionosoyiet wetland scenario assessment are shown in Figure 8.5 for cases of changing wetland area, changing inflow rate and changing pollutant loads entering the wetland.

Changing Wetland Area at Kericho Dionosoyiet

For the Kericho Dionosoyiet wetland, moderate changes in wetland area were found to have little effect on TSS or TP removal rates; however, change in wetland area had a marked impact on effectiveness in TN buffering. If the wetland area was increased, TN buffering rates remained constant, but if the wetland area was reduced below 50%, the ability of the wetland to remove nitrogen was severely compromised as shown in Figure 8.5.

This was the most extreme change that was noticed in wetland performance through all of the scenarios analysed for all of the wetlands. The extreme level of change in behaviour seen at when the wetland area was reduced to 20% of its actual area means the model is operating well out of its calibration conditions and the reliability of model estimates here is questionable. Nevertheless, indications are that the wetland would be under severe stress should its area be reduced to such an extent.

It is apparent then that if the area of the Dionosoyiet wetland is reduced, there is a risk of significant loss of buffering capacity for Nitrogen if a reduction in area were to occur. Preservation of the current wetland should therefore be adopted as an important aspect of the Dionosoyiet wetland management plan. By contrast, if an increase in wetland area occurs, it is not expected that this will lead to greatly improved buffering capacity.

Changing Inflow Rates at Kericho Dionosoyiet

Changing inflow rate also drastically affected buffering capacity of the model. Reductions in inflow rate resulted in markedly improved buffering and increase in inflow rate meant buffering capacity was compromised, as shown in Figure 8.5. All three parameters, TSS, TP and TN showed similar trends in buffering across the range of flow rates assessed.

It is therefore clear that improved buffering performance can be achieved by attention to catchment management actions that will reduce runoff, and thereby reduce flows entering the wetland; however should increases in runoff occur, the buffering capacity of the wetland will be compromised across all three parameters. This verifies that activities such as tree planting and native vegetation restoration on the upstream catchment can therefore be seen to be very important to wetlands buffering capacity. By contrast if activities such as further urbanisation or clearing of vegetation should occur on the catchment, these are likely to lead to increased runoff, which would therefore lead to diminished buffering capacity. Care shuld be taken to control the impacts of such activities on runoff.

Changing Incoming Pollutant Loads at Kericho Dionosoyiet

For incoming pollutant loads at the Kericho Dionosoyiet wetland, Figure 8.5 shows that improved removal occurred for TP when TP removal rates were lowered; however increasing TP load did not affect the removal rate. For TSS and TN, change in pollutant load was not seen to affect removal rates.

The wetland will therefore be resilient to changes in pollutant loadings; however reducing TP loading will drastically improve the buffering capacity of the wetland with respect to TP. Any steps taken through catchment management to reduce phosphorus loads will therefore be most beneficial to the wetland.

Scenario Assessment for the Eldoret Chepkoilel Wetland

Results for the Eldoret Chepkoilel wetland are shown in Figure 8.6, which shows that generally the wetland is even more resilient to change than the Kericho Dionosoyiet wetland, as discussed below.

Changing Wetland Area at Eldoret Chepkoilel

Decreases in wetland area will slightly reduce removal rates in the wetland for TSS and TP as would be expected, but, somewhat surprisingly, may increase TN removal. This most likely arises as Nitrogen transfer from the atmosphere to the wetland will be dependant on wetland residence time, so it is possible that this effect will be reduced if the area of the wetland and therefore the residence time of the wetland are reduced.

Minor increases in removal rates for TSS and TP are observed if the wetland area is increased; however there is little or no change in the TN removal rate. It can therefore be seen that preserving the wetland's current area is important in ensuring reductions in TSS and TP removal rates do not take place; however there is not likely to be any improvement in buffering capacity if the area of the wetland is increased.

The finding that reduction in wetland size will improve TN removal is promising in that it indicates that the wetland can be manipulated to increase nitrogen removal; however given that reduction in area would compromise TSS and TP removal, it certainly cannot be recommended as strategy for improving TN removal. This shows however that performing other management strategies for TN removal may be successful. Trials on harvesting and other wetland management strategies to improve TN removal would be worth undertaking.

Changing Flow Rate at Eldoret Chepkoilel

As for the Kericho Dionosoyiet wetland, reducing flow rates improved buffering performance while increasing flow rates diminished buffering performance, particularly for TSS and TP. Catchment activities that are likely to increase the amount of runoff entering the wetland such as increased urbanisation or vegetation clearing should be avoided, while activities that would reduce runoff such as tree planting and vegetation restoration should be encouraged.

Changing Incoming Pollutant Loads at Eldoret Chepkoilel

Trends for changing pollutant loads at the Eldoret Chepkoilel wetland were similar to those for the Kericho Dionosoyiet wetland; however these trends were even stronger than in Kericho Dionosoyiet wetland. Reducing pollutant loads entering the wetland will result in markedly improved buffering performance, while increasing loads will slightly diminish the reduction rates for TSS and TP, while TN removal will be markedly diminished. Catchment management strategies aimed at lowering pollutant exports from land surfaces should therefore be strongly encouraged.

8.7 Recommendations for Future Model Use

It is important in undertaking a modelling activity that the processes are well understood. It must be recognised that water quality modelling is a highly complex discipline. Water quality models are among the most complex computer software packages developed in terms of the sophistication of algorithms invoked to perform numerical simulations of water quality processes. While the complexity of representing the distributed features of a landscape in a Geographical Information System (GIS) are readily apparent to novice users, it is more difficult to develop an appreciation of the complexity of processes involved in resolving water quality issues. Successful future model use is therefore highly dependant on the abilities, expertise and training of the users.

It must be stressed quite strongly that the future successful application of the LAVINKS-WEB model in understanding wetland buffering capacity processes and using the model as a management tool is highly dependant on the support, opportunities and incentives offered to staff who will undertake modelling. In particular, it is highly recommended that a training program be developed for the ongoing advancement of modelling expertise for officers who will undertake modelling.

In addition to the development of modelling expertise in officers, further technical steps that should be undertaken to advance the capability of the models are calibration refinements, and expanding the number of wetlands modelled as described below.

Kericho Dionosoyiet wetland and Eldoret Chepkoilel Wetland Calibration Refinement

For the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetland, gathering of more data is required to confirm extended duration trends and to ensure model calibration is reliable. It is recommended that monthly monitoring is carried out through the rest of 2005 and until July 2006 so that data over two full seasonal cycles is available. Daily rainfall records will also need to be updated from Moi University and James Finlay Kenya for calibration of input data.

With monthly data collected through until July 2006, updating the model calibration will be possible. This should be done by:

- adjusting the regression relationships between (a) inflow rate and rainfall and (b) water quality; and by
- comparing the model output time series graphs (sheets G1 to G5) with the monitored data. Should any significant differences be apparent, then parameters on sheet A can be modified, particularly the plant uptake rates and the sediment properties.

The recalibrated models should then be used again for the assessment of buffering performance, particularly removal rates and if results of show significant differences from the initial results provided here, then scenario modelling should also be repeated.

From July 2006 onwards, monitoring conducted on a quarterly basis through one week intensive monitoring periods using the automated monitoring equipment at each site would be a more effective use of resources. It would be most valuable if such monitoring were to continue for at least a further two to three year period under the LVEMP wetlands component.

Over such a time frame, it should then be possible to perform community/stakeholder education with the aim of handing over water quality monitoring and modelling responsibilities for these two wetlands to the management committees for the respective wetlands. This then will allow water quality monitoring and modelling to become permanent ongoing activities under these committees and will allow monitoring and modelling to be used by the committees as means of assessing the effectiveness of their management activities.

Modelling of Other Wetlands in the Lake Victoria Basin

For other wetlands, initial comparative assessments of buffering potential can be performed easily and quickly by modifying the Typical Lake Basin Wetland to reflect the conditions applying in various wetlands across the basin. For such initial assessments, the only parameters that need to be changed are the wetland area and percentage vegetation covers on sheet A. The daily rainfall series for the period 1983 to 1990 should also be pasted into sheet B from the database provided depending on the location of the wetland. Apart from these parameters, the model parameters should not be further modified unless at least four months of data is obtained covering both wet and dry periods.

It is recommended that such initial comparative assessments be done for at least eight to ten wetlands in different locations across the basin in order to develop an understanding of the likely performance of the wetlands under different conditions. This will allow decisions to be made on a rational basis about which wetlands in the basin are best suited to, or in most need of further investigations. Decisions about which wetlands should be subjected to more detailed modelling and how such modelling should develop would depend on the outcomes of the modelling.

9. Technology Transfer: Train and Work With a Select Team of Scientists

9. TECHNOLOGY TRANSFER: TRAIN AND WORK WITH A SELECT TEAM OF SCIENTISTS

From the inception of this project, technology transfer has been seen as a highly important component. A particular reason for the significance of technology transfer is the time limits of the project. A twelve month time frame is sufficient to establish the buffering capacity of the two pilot wetlands and to determine broadly the overall buffering capacity of wetlands in the lake basin; however many aspects of wetlands buffering capacity will require further ongoing investigations over many years such as:

- extending the investigations to cover a wider range of wetlands across the basin to confirm that buffering capacity trends for the two pilot wetlands are valid at basin scale;
- determining if changes in buffering capacity are taking place with time; and
- examining the impacts of management activities, particularly long termimpacts.

The establishment of a long term capacity to effectively perform buffering capacity studies is therefore important in ensuring that the investigations reported here are able to be extended to cover these aspects. To succeed in achieving these long term objectives, it is critical that relevant personnel have an understanding of the techniques involved in all aspects of buffering capacity determination. The technology transfer component therefore sought to impart knowledge to the relevant personnel.

Technology transfer on the project was performed through three major means:

i. Workshop based training given by experts in the form of technology transfer seminars.
ii. Field based training through the involvement of a selected group of officers during flow monitoring, sampling and analysis sessions that will go on throughout the study.
iii. a visit to the LVEMP Uganda wetlands component to ensure that the experience of this group could be incorporated into the knowledge base of Kenyan Component and so the SMEC team could develop an understanding of the process by which a successful wetlands investigative group was able to be developed in an African context.

These aspects are discussed separately below, followed by an assessment of the effectiveness of technology transfer and recommendations for future training.

9.1 Technology Transfer Workshops

Technology transfer workshops were held on an approximately monthly basis between August 2004 and April 2005. The schedule of workshops held is given in Table 9.1 below.

Table 9.1: Wetlands Buffering Capacity Technology Transfer Workshop Schedule August 2004 to April 2005

Session	Timing	Location	Theme	Presenters
1	August 2004	Kericho	Introduction: Best practices in wetland monitoring	Mr Stanley Ambasa, LVEMP Wetlands Dr Michael Waters SMEC Mr Harrison Ngirigacha SMEC
2	September 2004	Eldoret	Wetland functions and values	Dr Stephen Njoka LVEMP secretariat Mr Stanley Ambasa, LVEMP Wetlands Dr Michael Waters SMEC Mr Harrison Ngirigacha SMEC Dr Okeyo Owour Moi University
3	October 2004	Busia	Hydrology and water quality processes in wetlands	Mr Stanley Ambasa LVEMP Wetlands Dr Michael Waters SMEC Mr Harrison Ngirigacha SMEC Mrs Margarent Abira LVEMP Water Quality Dr Gichuki LVEMP Fisheries
4	January 2005	Kericho	Automated wet weather sampling procedures in wetlands	Dr Michael Waters SMEC Mr Harrison Ngirigacha SMEC
5	March 2005	Busia	Mapping of Environmentally Sensitive Wetlands and Pilot Wetlands	Dr Tesfae Korme, RCMRD Mr Lawrence Okello, RCMRD Mr Antony Ndubi Dr Michael Waters
6	April 2005	Busia	Wetlands Buffering Capacity Modelling	Dr Michael Waters

The workshops were organised in a participatory approach: the selected training resource persons present on topics identified to match with the theme, followed by a discussions and reactions from the participants. This approach facilitated interactive participation leading to dissemination of knowledge existing among the participants, and allowing the experts fill in the gaps.

A group activity of a practical nature related to the workshop theme was also included in the programme for each workshop. This allowed participants to undertake further learning through peer interaction. Modern approaches to technology transfer stress the need for trainees to be "active learners" in order to gain the most benefit from such training programmes.

Participants were drawn from the following organisations;

(i) The client including the main officers based in Busia and NEMA Officers from the basin,

(ii) Selected KARI officers, mainly from the LVEMP Secretariat in Kisumu, in particular the information officers, to ensure uptake of the concepts will be spread widely through LVEMP,

(iii) Other LVEMP components including Water Quality, Fisheries and Agriculture. Moi University was also involved being the capacity building unit of the LVEMP,

(iv) Local Authorities, specifically Kericho and Eldoret Municipal Authorities since the pilot wetland sites are located within their jurisdiction,

(v) Community stakeholders for the pilot wetland sites including the chair of the Nyagacho spring committee at Kericho and a represesentative of management from the Equator Flower Company in Eldoret,

(vi) Relevant ministry officials drawn from a diversity of Departments including Water, Agriculture, Health, Lands and Housing and others as appropriate.

A summary of the proceedings of each workshop is included in Appendix 4 and the LVEMP wetlands component kept records of all attendances at each of the workshops.

9.2. Field Training

A select team of officers and scientists from the client were involved as closely as possible in all aspects of the pilot studies, especially in monitoring, sample collection and analysis. This was important in enabling the data monitoring program to continue beyond the study period.

The key personnel involved in the field training sessions were;

(i) Mr. Stephen Katua (The Component Coordinator – Wetlands Management),

(ii) Mr. Stanley Ambasa (Task Leader – Wetlands Buffering Capacity Project),

(iii) Mr. Charles Kanyugo (Water Quality Management Component, also carrying out water quality measurements),

(iv) Mr Reuben Ngesa (Hydrology Officer, Kisumu District Water Office)

(v) Mr. Zephaniah Ouma, replaced by Ms Joan Nyarombe in October (NEMA District Environment Officer based in Kericho)

(vi) Ms Joan Nyarombe in October (NEMA District Environment Officer based in Kericho)

(vii) Ms. Nancy Muui (NEMA District Environment Officer, Uasin Gishu based in Eldoret)

(viii) Mr Clement Wangai (NEMA Officer based in Busia)

(ix) Mr Wawiru (NEMA District Environment Officer, Iten)

Other participants were also being involved in these activities as appropriate from time to time.

9.3. Consultation with the Uganda LVEMP Wetlands Component

As part of the capacity building activity, the SMEC team took part in a visit to the LVEMP wetlands component Uganda under the leadership of the Kenyan Wetlands Component Coordinator, Mr. Stephen Katua and also accopmained by the Wetlands Buffering Capacity Task Leader, Mr. Stanley Ambasa. The trip took place from the 11^{th} – 13^{th} October 2004. The main aim of the trip was to determine how the results of the Ugandan wetland component and the expertise could be used to enhance the deliverables from the Kenyan wetland buffering study. The objectives of the trip were;

- To establish the approaches and methodologies applied in Uganda in regard to successes and achievements from wetland studies. Areas of focus included mapping, monitoring and capacity building. This would provide an opportunity to enrich the findings from the Kenyan studies and an basis for harmonisation of the monitoring procedures,

- To familiarise with the Ugandan wetland site and their similarities and/or differences with the Kenyan sites, considering tha most are within the same climatic zones,
- To identify available knowledge and knowledge gaps arising from the work already undertaken in Uganda through a review of the literature and information resources, and
- to establish means of harmonising procedures across the region.

The trip provided a number of useful insights into the approach that the Ugandan component have undertaken in performing buffering capacity studies for wetlands in the Ugandan portion of the basin. These insights will greatly assist SMEC in ensuring that the Kenyan buffering capacity study can be best harmonised with the previous and ongoing works in Uganda. Points that are particularly noteworthy to come out of the study include the following:

- It was found that there is quite a degree of consistency between the definitions of buffering capacity adopted by the Ugandan component and SMEC;
- The wetlands mapping aspects undertaken by the Ugandan component have a high degree of consistency with the approach being adopted by SMEC;
- Studies undertaken by the Ugandan component have mostly focussed on large wetlands directly fronting onto Lake Victoria where the principle source of pollution is municipal wastewater. There is a significant knowledge gap for wetlands receiving urban stormwater in upland areas. SMECs approach for studying the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetland matches well against this, allowing this knowledge gap to be filled;
- The focus on lakeside littoral wetlands has forced the Ugandan component to a non-load based approach whereby buffering is parameterised as the ratio of nutrients to salinity. This parameterisation is not appropriate for uplands wetlands where parameterisation needs to focus on ration of input to output load;
- The modelling that has been done by the Ugandan component is extremely limited, while the modelling capacity of the Tanzanian component has been dissipated since the Tanzanian study was completed in 2001. SMEC’s modelling approach is therefore critical in building a new capability for buffering modelling of wetlands of the Lake Victoria basin that can be drawn on by all three groups;

- Data collection time frames previously adopted have been geared towards long term investigations similar to SMECs extended duration investigation approach. The time scales of SMECs extended duration monitoring approach is therefore well justified; and

Intensive investigations of storm events has not previously been attempted within the Lake Victoria basin area, but is considered an important aspect of determining the buffering capacity of wetlands in the basin.

9.4: Technology Transfer Effectiveness

Effectiveness of technology transfer is largely a function of the willingness of participants to learn from technology transfer opportunities, which was seen to be almost universally extremely high. Initially in each session, participants were found to be most attentive and eager to learn. As participants became more familiar with the topics, it was found that they offered important insights into the local application of a number of the concepts that were presented on.

Participants were found to expect and indeed to want and appreciate opportunities to listen to experts; however, this passive aspect of technology transfer was less effective than when participants were given practical activities to undertake, especially when given the opportunity to work in groups. This follows the usual pattern observed in modern approaches to education where a “trainer centred” approach leads to a “trainee centred” approach to technology transfer.

Reflecting this pattern of development, the initial workshops held were made to appeal to a wide audience on generalised topics suited for presentation to a large audience, then were made more focussed on more specialised topics better suited for presentation to a more selected audience.

Participants relished the opportunity to provide feedback on the sessions, which was generally positive.

9.5.Observations on Technology Transfer Related Issues

Technology transfer related issues that were observed over the period of the project as specific to the contexts of the officers involved included the following:

- A number of officers were seen to have high levels of knowledge in niche specialty areas such as remote sensing for wetlands identification and community consultation;
- It was found that most officers appreciated highly the opportunity to attend technology transfer sessions, but they found difficulty in drawing links between aspects covered in sessions and practical implementations they could make in their own work environment;
- Due to the poor Information Technology (IT) infrastructure present in Kenya generally, and in the Lake Basin area in particular, IT resources are generally not well used;
- Officers were often found to have highly sophisticated theoretical understanding of particular knowledge areas but limited resources or opportunities for putting these into effect in real world situations and therefore little practical experience in implementations;
- There was a widespread appreciation for the use of simple, practical, robust techniques that have a history of longstanding local use; and
- The focus of officers is strongly on people and communication related rather than task and technology related issues. For example, in developing wetland management plans there was a strong appreciation of the importance of stakeholder and community consultations which were seen as over-riding the significance of automated monitoring and modelling of water quality in a wetland;

Given these observations, a number of recommendations for future technology transfer arise, as discussed in Section 9.6 following.

9.6: Recommendations for Future Technology Transfer

While the issues that were observed to arise were specific to the local context, influences at a global level are also significant. Internationally, rapid rates of technological change are now the norm for most scientific and professional areas. This means that maintaining an awareness of the latest developments in a technical discipline is increasingly difficult. Consequently, technology transfer is increasingly recognised as an ongoing long term activity in most professions, rather than as an activity that is performed at one off intervals.

Given both the local and global issues, the following are recommended to address these issues:

- There is an urgent need to upgrade access to IT related facilities and provide high level IT support to officers in the lake basin area;
- Specific buffering capacity related technology transfer needs to develop an ongoing aspect, particularly GIS, remote sensing, modelling and automated equipment use. It is important to ensure that officers who have received technology transfer through this project are given the opportunity and encouragement to strengthen their skills in this area;
- Related to the previous point, postdoctoral scholarship places should be made that will allow officers to undertake postgraduate study to doctoral level in niche areas of interest to themselves and of strategic value to LVEMP and NEMA;
- A range of broad based technology transfer activities focussing on developing more rounded technical analytical capabilities is also required. Topics of particular value would include advanced spreadsheet techniques (including lookup and logical functions, macro writing, visual basic and so on), and database management (including SQL).
- Opportunities should be made for regular attendances at international workshops and conferences of relevance, especially where officers have contributions of value they can make to such functions through presentations of papers, posters and so on;
- Opportunities for the hosting of regional and international workshops and conferences in the Lake Basin area should be encouraged so that a broad range of officers are able to get exposure to wide ranging international expertise;
- Opportunities for more technology transfer opportunities at an institutional level should be encouraged, such as placements of local staff in institutions from other countries and vice versa. This is especially to be encouraged at the regional level with support for exchanges of officers with the Ugandan and Tanzanian components;
- Officers should be encouraged to develop stronger involvements with Universities. Such involvements could include presenting guest lectures, supervising final year and graduate research theses and offering vocational placements within the component; and
- Finally, training opportunities should be integrated closely with work plans

10. Wetlands Mapping

10. WETLANDS MAPPING

In wetlands, the way landscape elements are spatially arranged can significantly influence water quality buffering as well as a variety of other wetland functions (Spellenberg 1992, Keifler 1996). This section reports on the components of the project related to mapping. Two aspects of mapping are important under the project, firstly mapping of the land use at the two pilot wetlands studied, and secondly, mapping of the most important Environmentally Sensitive Wetland Areas (ESWA) in the Kenya portion of the Lake Victoria coastal zone.

Wetlands are generally large complex features of a landscape, so mapping is an important aspect of any study on wetlands. Mapping aspects undertaken for the Buffering Capacity study fall under two categories into which this section is divided as:

1. Preparation of land use/land capability maps of the pilot wetlands and
2. The identification, description and mapping of important Environmentally Sensitive Wetland Areas (ESWA) in the Kenyan portion of the Lake Victoria Basin

SMEC International sub-contracted the Regional Centre for Mapping of Resources for Development (RCMRD) to undertake the mapping of the two pilot wetland sites in Kericho (Dionosoyiet wetland) and Eldoret (Chepkoilel wetland) using QuickBird satellite imagery and mapping of wetlands distribution in the Lake Victoria Basin in Kenya using high resolution Landsat satellite imagery at a basin-wide level.

Specific objectives of the mapping tasks then were to:

i. Use high resolution QuickBird satellite imagery to perform land use / land cover mapping of the two wetland sites in Kericho and Eldoret
ii. Use high resolution Landsat satellite imagery to carryout basin-wide mapping of wetlands in the Lake Victoria Basin in Kenya based on three classes (papyrus vegetation, non-papyrus vegetation, open water)
iii. To convert the Rapid Assessment data into a GIS layer for use as ancillary data for the image interpretation
iv. To create other thematic databases for the project such as international boundaries, roads, rivers, AFRICOVER land cover, soil types, land suitability,

environmentally sensitive areas of the Kericho Dionosoyiet wetland and Eldoret Chepkoilel wetlands and any other important features

10.1 Land Use/Land Capability maps of the Pilot Wetlands

As the existing maps for the pilot wetlands (1:50000 for Eldoret and 1: 10000 for Kericho) are not adequate for mapping, Quickbird satellite images were obtained for the two sites and have been converted into GIS format in ARC MAP. CDs containing the quickbird images for the Kericho and Eldoret sites have been incorporated into ARC MAP maps with areas of vegetation marked in as separate layers/shape files.

The supporting ecw, tif, jpg and other files necessary to view the maps through ARC MAP have been supplied to the wetlands component.

The detailed mapping for the two wetland sites at Kericho and Eldoret was a relatively straightforward mapping activity. Mapping began by georeferencing the QuickBird images to WGS 84 UTM ZONE 36 N followed by enhancement using linear stretching. Heads up on-screen digitization interpretation using GEOVIS Software was then done to delineate and map the land use / land cover within and around each of the wetlands based on the available QuickBird image extent.

A number of land use / land cover classes were defined across both wetlands, although not all classes were necessary present at both sites, these being:

- Papyrus wetland vegetation
- Non-papyrus wetland vegetation
- Agriculture
- Agriculture/built-up
- Arboretum/informal grazing
- Built-up/Urban Areas
- Indigeneous forest
- Industrial reserve
- Minor drain
- Open water
- Recreational/urban reserve
- Roads and paths
- Water pan
- Roads and paths
- Intensive horticulture
- Roads
- Rivers
- Sediment Deposition zone
- Spring
- Cemetery

Soils layers, current and potential land use features and areas significant for buffering were also included as layers for each wetland in the GIS products provided.

Kericho Dionosoyiet Wetland

The Kericho Dionsoyiet wetland is located approximately 1 km North East of the Kericho town centre. A full description of the wetland site is provided in Section 4. The wetland is situated in a protected reserve, within which recreational, washing and bathing activities are permitted. It is almost entirely surrounded by areas of urban land use, with the Nyagacho housing area to the East, township primary school to the North and the industrial estate of the Kericho town to the South and West. The topography of the area is highly undulating between altitudes of 1,950 to 2,050 m. As indicated in Section 4, the Dionosoyiet wetland consists solely of non papyrus vegetation and open water.

Figure 10.1 shows the quickbird image for the Dionosoyiet wetland in its raw state. The interpretations on the image are shown in Figure 10.2

Eldoret Chepkoilel Wetland

The Chepkoilel wetland is located North East of Eldoret. The section of the wetland studied extends from approximately 5 km North of the Eldoret town centre to approximately 15 km North of the town. A full description of the wetland site is provided in Section 4.

As for the Kericho Dionsoyiet wetland, the Chepkoilel wetland has a very high length to width ratio. It is a permanent riverine wetland that lies in a wide bottom valley separated with gently undulating topography on both sides.

Figure 10.3 shows the quickbird image for the Chepkoilel in its raw state. The interpretations on the image are shown in Figure 10.4.

10.2 Basin Wide Distribution and Mapping of Environmentally Sensitive Wetlands

Wetlands cover about 2-3% of the land area in Kenya (Republic of Kenya, 2002) but their total area has been declining by approximately 7% per year, largely through drainage for agriculture (Gichuki, 1995).

The main aim of the mapping activity was to produce a map of Lake Victoria Basin Environmentally Sensitive Wetland Areas (ESWA). ESWA's are considered to be those with the following values:

a. Breeding of fish and bird species;
b. Habitats of animals, birds and fish species;
c. Habitats of rare species
d. Migratory areas of birds, animals and fish; and
e. Any other factor of environmental concern;

In order to map ESWAs, it was necessary first to define what was meant by an ESWA, consider previous work on broad scale wetlands mapping in the basin, then proceed with the mapping tasks as described below.

Identifying and Defining ESWAs

Prior to the commencement of this study, A number of ESWA's have already been identified by the rapid assessment of wetlands exercise that was carried out by LVEMP Wetlands Component. To facilitate ESWA identification, SMEC dispatched a world renowned tropical wetlands ecologist, Professor Patrick Osborne, Director of the Centre for Tropical Ecology, University of Missouri, USA to the field as part of the team for this study. From Professor Osborne's visit it became apparent that all permanent wetlands in the Kenyan portion of the Lake Victoria Basin should be regarded as environmentally sensitive.

This finding was reached given that the Lake Victoria catchment area is generally very densely populated and contains extensive human land-use. These human use factors in the catchment exert significant stress on wetlands within the region. It was evident that all wetlands observed were significant at least because of bird breeding and habitat factors, thereby making them ESWA's with reference to values a. and b. listed above.

Previous studies on the Distribution of Wetlands in the Kenyan Portion of the Lake Victoria Basin

Surveys and inventories carried out within the basin have identified most wetlands to be linked to the lakeshore (beaches, estuaries, bays and inlets), floodplains and the deltas of rivers and streams entering the lake. The channels of main rivers are fringed by a narrow belt of macrophytes and small patches of riverine forests while those in the river catchments consist of springs, water storage dams, fish farms or ponds and valley bottom marshes (Katua and Mmayi 2001; *Gichuki et al.,2001;* Raburu, 2002).

River discharge has profound influence on the size and stability of the floodplain and deltaic wetlands which predominate the Lake Victoria Basin. River Yala has the largest deltaic wetland (30,000 ha), followed by Nyando (14,400 ha), Nzoia (7,500 ha), Kuja (4,062 ha) and Sondu-Miriu (3,500 ha). In addition to these, there are numerous isolated wetlands that depend on seasonal floods of rivers and subsurface water flow. These wetlands include the Kamandi floodplain (480ha), Gucha-Migori floodplain (726 ha), Homa Bay swamp on Nogusi River (55 ha) and Kisumu Swamp (623 ha). There are approximately 483 small ponds wetlands of water on the Kano plain. The rice paddy fields of west Kano (436 ha) constitute a significant wetland (Katua and Mmayi 2001). All these rivers have catchments in high rainfall zones with prolonged wet seasons thus forming extensive swamps on the lakeshore.

The Yala Swamps (0°07'N-0°01'S/33°58'-34°15'E) encompass the Nzoia Delta and all the lakeshore south to Ugowe Bay, and all the land east to Lake Kanyaboli. They also extend back up the Yala River in the south. In total they comprise 38,000 – 52,000 ha of wetland, including

Lake Kanyaboli (1500 ha), and stretch 25 km from W-E and 15 km from N-S at the lakeshore. They also include several minor lakes. Another swamp is situated at the mouth of the Nyando River at Nyakach Bay, extending back onto the Kano Plains (0°11-0°19'S/34°47'-34°57'E) while another occurs at the mouth of the Sondu River (0°18'-0°21'S/34°45'-34°48'E). The Nyando Swamp measures 15 km from W-E and some 6 km from N-S. Together the swamps on the Kano Plains occupy about 10 000 ha. South of the Gucha Delta is a swamp (0°54'-0°-58'S/34°08'-34°11'E), while small swamps occur immediately south of the town of Kisumu and at the mouth of the Mogusi River near Homa Bay (0°28'S/34°31'E).

Other small wetlands, including seasonally flooded areas and permanent swamps, occur on the upper courses of these rivers and their tributaries. The most important of these are found at the foot of the dip slopes on the west side of the Rift Valley, from the Cherangany Hills south to the equator. One such wetland, which includes both floodplain and permanent swamp, occurs on the Nozia River immediately north and east of Kitale (1°00'-1°09'N/34°57'-35°05'E). This wetland is 20 km long from NW-SE and 1-5 km wide and used to extend to about 6000 ha. A small permanent swamp approximately 1000 ha is situated north of the Little Nzoia River (0°52'N/35°13'E). A seasonal floodplain occurs on the Kimandi River, a tributary of the Yala River which measures 12x6 km and covers 4800 ha (0°12'-0°16'N/35°10'-35°16'E).

The major river systems wholly contained in the Kenyan portion are the Sio, Nzoia, Yala and Sondu Miriu. The Kuja –Migori and Malaba rivers rise in far Western Kenya but discharge to the lake through Uganda and the Mara rises in Southern Kenya but discharges through Tanzania. All of these rivers generally flow in an Easterly direction, rising in the highlands that separate the Rift Valley from the Lake Victoria Basin then flowing into the North Eastern Portion of the lake. The Sio river discharges directly into the lake, Nzoia and Yala rivers discharge into the Lake through the Yala swamp, the Nyando discharges into the Winam gulf via the Nyando wetlands.

Given the significance of the major river systems to wetlands of the Kenyan Portion of the Lake Victoria Basin, river courses are shown on the wetlands maps as can be seen in Figure 10.5.

Yala Swamp Classification

Ten vegetation classes were generated and labeled by Otieno (2004) using the supervised and unsupervised classification methods on Landsat TM images to determine the detailed composition of vegetation types in Yala swamp. The results from Otieno (2004) showed that

LANDSAT TM images are well suited to mapping the landscape characteristics of wetlands which are difficult to map by conventional ground methods.

Basin Wide ESWA Mapping Methodology

Major components of the approach for implementing the basin wide wetlands mapping aspects were:

- Development of a mapping implementation strategy
- Mapping of basin-wide wetlands using Landsat imagery
- Fieldwork
- Cartographic design and printing of final maps

Steps taken in implementing the mapping of basin wide ESWAs were as follows:

(i) Data compiled by the LVEMP wetlands component through the rapid assessment reporting was incorporated into a GIS format,

(ii) Data from existing databases were considered including the Africover Landuse Database System developed in 2002. The Africover landuse system classifies the landuse in Kenya into 18 different classes, of which wetlands form one class.

(iii) Remote sensed data from Landsat was mosaiced over the Kenyan lake basin area;

(iv) Landsat imagery was subjectied to supervised classification according to the techniques developed by Otieno (2004) to classify the characteristics of the Yala swamp to develop a primary estimate of ESWA distribution.

(v) LANDSAT imagery was subjected to onscreen digitisation to develop a final ESWA distribution.

(vi) Image verification was done by field work and by cross checking between supervised classification and on screen digitisation results.

Incorporation of Rapid Assessment Data

The mapping activity aims to produce a map of Lake Victoria Basin wetlands and especially Environmentally Sensitive Wetland Areas (ESWA).

The LVEMP Wetlands Component attempted to identify ESWAs throughout the basin area through a series of investigations dubbed “rapid assessments”. Rapid assessment reports have been generated and are available for the Nyando, Sondu-Miriu and Kuja, Migori river basins and for part of the Sio river basin. Rapid assessment has also been performed for the Yala and Nzoia basins, but the results are scattered and have not yet been compiled as reports.

For the Sio basin, part of the basin was covered in the first rapid assessment report (Sio part 1), with the remainder of the basin covered at a later stage (Sio part 2). Unfortunately the Sio part 1 report is no longer held by the wetlands component and all attempts to trace another copy were unsuccessful.

Incorporation of the Rapid assessment results into the mapping was a valuable first step in defining the wetlands of the lake basin; however, this source of information does not cover the whole lake basin, and is not as rigorous, comprehensive or as objective as a remote sensing technique such as Landsat based classification.

From the Rapid Assessment reports, a table of wetland locations was developed as shown in Table 10.1.

The Rapid Assessment sites table was initially compiled in MS Excel, then converted to Dbase format and imported into Arcview GIS as a shape file. The shape file was then projected to WGS 84 UTM ZONE 36 N so as to overlay with the satellite image layers and other map databases.

To include wetlands identified by the rapid assessment into the mapping, a geo-reference table of the wetland sites was compiled. Many of the wetlands had already been geo-referenced by GPS or other means. For the remaining wetlands, the locations of the wetland sites were identified on the 1:50,000 and 1:250,000 topographical maps for the basin and geo-reference coordinates were taken from these maps. The locations of the rapid assessment sites are shown in Figure 10.6.

Table 10.1: Summary of Published Rapid Assessment Wetland Sites

Name	Latitude (North +)	Longitude	permanent/ ephemeral	Type	Issues	Comments
Symboyon	-0.091	35.550	permanent	Man made	Encroachment	Highly eutrophic
Eastleigh	-0.073	35.577	permanent	Man made	Encroachment	Eucalyptus trees/agriculture
Bartion wetland	-0.144	35.575	permanent	Man made	Siltation	Surrounding well conserved
Kamngorion	0.046	35.591	permanent	Riverine	Encroachment	Agriculture
Kibrong	0.052	35.011	permanent	Palustrine	Encroachment	High in biodiversity
Awach Rae	-0.206	34.945	permanent	Palustrine	Encroachment	High in biodiversity
Kusa (Nyando delta)	-0.302	34.855	permanent	Palustrine	Encroachment	High in biodiversity
Nyando delta	-0.279	34.868	permanent	Palustrine	Encroachment	High in biodiversity
Sironga	-0.596	34.911	permanent	Palustrine	Reclaimed	Brick making activity
Kiabonyoru	-0.577	34.918	permanent	Riverine	Drained	Eucalyptus/agriculture
Kegati	-0.716	34.824	permanent	Palustrine	Encroachment	Brick making/agriculture
Kianginda	-0.653	34.928	permanent	Riverine	Drained	Eucalyptus trees
Eronge	-0.667	34.918	permanent	Riverine	Reclaimed	Brick making
Bunyunyu	-0.700	34.882	permanent	Riverine	Drained	Brick making/Eucalytus trees
Awendo	-0.900	34.531	permanent	Riverine	Encroachment	Agriculture/Urbanization
Angaseet	-0.971	35.058	ephemeral	Riverine	Drained	Agriculture/deforestation
Oyani	-0.986	34.541	permanent	Riverine	Encroachment	Eucalyptus/agriculture
Gogo dam	-0.900	34.355	permanent	Man made	Siltation	Deforestation in the catchment
Gucha delta	-0.944	34.121	permanent	Palustrine	Encroachment	Agriculture/macrophyte harvesting
Serwer	-0.330	35.205	permanent	Riverine	Encroachment	Eucalyptus/grazing
Kabianga	-0.423	35.168	permanent	Riverine	Encroachment	Eucalyptus trees
Kapsewa	-0.400	35.123	permanent	Riverine	Encroachment	Eucalyptus trees/agriculture
Motata	-0.109	35.428	permanent	Riverine	Encroachment	Eucalyptus/agriculture
Chagware	-0.086	35.446	permanent	Riverine	Encroachment	Eucalyptus/grazing
Chemawoi	-0.500	35.134	permanent	Riverine	Encroachment	Eucalyptus/Brick making
Bargiro	-0.541	35.155	permanent	Riverine	Encroachment	Eucalyptus/Brick making
Kororet	-0.621	35.221	permanent	Riverine	Encroachment	Eucalyptus/grazing
Deurat	-0.641	35.228	permanent	Riverine	Encroachment	Eucalyptus/Brick making
Daraja Mbili	-0.614	35.193	permanent	Riverine	Encroachment	Ecalyptus/grazing
Chepkolon	-0.650	35.189	permanent	Riverine	Encroachment	Eucalyptus/grazing
Osodo (Sondu delta)	-0.305	34.761	permanent	Palustrine	Encroachment	Agriculture/macrophyte harvesting
Siteko	0.423	34.125	permanent	Riverine	Encroachment	Agriculture/macrophyte harvesting
Munongo	0.364	34.147	permanent	Riverine	Burning	Vegetation intact
Sigalame	0.284	34.057	ephemeral	Riverine	Encroachment	Agriculture/grazing
Sio Port (Sio delta)	0.228	34.011	permanent	Palustrine	Overfishing	Fish breeding area
Munana dam	0.266	34.086	permanent	Man made	Siltation	Poor management
Namaderema	0.405	34.330	ephemeral	Riverine	Encroachment	Needs restoration
Eshibembe	0.448	34.332	ephemeral	Riverine	Encroachment	Agriculture
Nambale bridge	0.432	34.250	permanent	Riverine	Encroachment	Agriculture
Namulungu	0.455	34.393	ephemeral	Riverine	Encroachment	Agriculture
Muremia	0.437	34.289	ephemeral	Riverine	Encroachment	High in biodiversity
Bunduluku	0.407	34.109	permanent	Riverine	Encroachment	Kenya-Uganda border
Sango	0.359	34.107	permanent	Riverine	Encroachment	Kenya-Uganda border
Nawolo (Hainga)	0.336	34.150	permanent	Riverine	Encroachment	Kenya-Uganda border
Ludacho	0.359	34.111	permanent	Riverine	Encroachment	Kenya-Uganda border
Muluanda	0.318	34.073	permanent	Riverine	Encroachment	Kenya-Uganda border
Mirere	0.432	34.414	ephemeral	Riverine	Encroachment	Reference points to be confirmed
Namalasira	0.414	34.416	ephemeral	Riverine	Encroachment	Reference points to be confirmed
Khayo	0.493	34.368	ephemeral	Riverine	Encroachment	Reference points to be confirmed
Kemera	-0.667	34.834	permanent	Riverine	Drained	Eucalyptus/agriculture
Kapsoit	-0.648	35.216	permanent	Riverine	Encroachment	Eucalyptus/grazing

Landsat Image Interpretation and Classification

Broad scale mapping of wetlands in the lake basin from LANDSAT TM imagery has previously been performed by Otieno (2004) for the Yala wetland within the Kenyan portion of the Lake Victoria basin as described above. Further, wetlands of the Tanzanian portion of the basin were mapped under the Tanzanian LVEMP wetlands component buffering capacity study (ARCADIS, 2001).

Mapping of the basin-wide wetlands was done using six Landsat-ETM scenes:

1. P169 / R059

2. P169 / R 060

3. P169 / R061

4. P170 / R059

5. P170 / R060

6. P170 / R061

The individual bands of the five images were georeferenced to WGS 84 UTM ZONE 36 N, mosaiced, composed (bands 2, 3, and 4 in Blue, Green and Red order) and enhanced using the linear stretch option as shown in Figure 10.6. The primary mapping products derived were delineated using the FAO AFRICOVER-developed GEOVIS Software. Mapping of the wetlands across the entire basin was based on three classes defined as: papyrus vegetation, non-papyrus vegetation and open water. Two techniques were used: supervised classification and the heads up on-screen digitization interpretation method.

Supervised classification applied to wetlands of the Lake Basin Region

In order to adopt the techniques reported by Otieno (2004) to the Kenyan portion of the lake basin region, it was necessary to simplify the scheme somewhat to make it consistent with the Africover classification scheme and the Ugandan Biomass study, which is reported on in the Harmonisation section below.

The single most wide spread wetland vegetation species in the lake region is Cyperus papyrus. Other significant emergent wetland species in the lake basin include *Cyperus immensus, Typha domingensis* and *Phragmites mauritianus*. These have all been studied in detail, as reported in recent literature.

As stated earlier, with the dominance of *Cyperus papyrus* throughout the lake basin, and to be consistent with africover, this study has adopted wetlands classes as:

- Cyperus papyrus (floating and emergent)
- Emergent species and
- Open water

Image Classification

Image classification refers to the computer-assisted interpretation of remotely sensed images. Although automated procedures are able to incorporate information about such image characteristics as texture and context, the major image classifications are based solely on the detection of the spectral signatures (i.e., spectral response patterns) of land cover classes. The success with which this can be done is dependent on the presence of distinctive signatures for the land cover classes of interest in the band sets in use and the ability to reliably distinguish these signatures from other spectral response patterns that may be present.

Supervised Classification - The first step in supervised classification is to identify examples of the information classes (i.e., land cover types) of interest in the image called training sites.

The software system is then used to develop a statistical characterization of the reflectances for each information class. This stage is often called signature analysis and may involve developing a characterization as simple as the mean or the range of reflectances on each band, or as complex as detailed analyses of the mean, variances and covariances over all bands. Once a statistical characterization has been achieved for each information class, the image is then classified by examining the reflectances for each pixel and making a decision about which of the signatures it resembles most.

Each pixel in the study area has a value in each of the seven bands of imagery, these are respectively: Blue, Green, Red, Near Infrared, Middle Infrared, Thermal Infrared and another Middle Infrared bands. These values form a unique signature which can be compared to each of the signature files. The pixel is then assigned to the cover type that has the most similar signature. There are several different statistical techniques that can be used to evaluate how similar signatures are to each other. These statistical techniques are called classifiers.

Classifiers Used - Maximum Likelihood Classifier - the distribution of reflectance values in a training site is described by a probability density function, developed on the basis of Bayesian statistics. This classifier evaluates the probability that a given pixel will belong to a category and classifies the pixel to the category with the highest probability of membership. It is the most accurate if training site selection and GPS Truthing is well done. The procedure is based on Bayesian probability theory. Using information from a set of training sites, MAXLIKE uses the mean and variance/covariance data of the signatures to estimate the posterior probability that a pixel belongs to a particular class. By incorporating information about the covariance between bands as well as their inherent variance, MAXLIKE produces what can be conceptualized as an elliptical zone of characterization of the signature. In actuality, it calculates the posterior probability of belonging to each class, where the probability is highest at the mean position of the class, and falls off in an elliptical pattern away from the mean.

Liner Discriminant Analysis (Fisher Classifier) - The FISHER classifier conducts a linear discriminant analysis of the training site data to form a set of linear functions that express the degree of support for each class. The assigned class for each pixel is then that class which receives the highest support after evaluation of all functions. These functions have a form similar to that of a multivariate linear regression equation, where the independent variables are the image bands, and the dependent variable is the measure of support. In fact, the equations are calculated such that they maximize the variance between classes and minimize the variance within classes. The number of equations will be equal to the number of bands, each describing a hyper-plane of support. The intersections of these planes then form the boundaries between classes in band space.

Of the hard supervised classifiers, MAXLIKE and FISHER are clearly the most powerful. With high-quality (i.e., homogenous) training sites, they are both capable of producing excellent results.

Onscreen digitisation

Mapping of the wetlands at basin wide scale by onscreen digitisation from the Landsat TM imagery was performed using the GEO-VIS software. An example of the results is shown in Figure 10.7 at the Chepkoilel Eldoret wetland. Scanned and georeferenced 1:50,000 scale topographic maps of the project area were used as ancillary data to support the image interpretation as shown in Figure 10.8. This is a straightforward technique to implement, yet it is also time consuming and can under some circumstances be quite subjective. Nevertheless, onscreen digitisation remains the most reliable technique for interpretation of spatial features from remote sensed images

Comparison of Onscreen Digitisation and Automated Classification Results

From the documented distribution of wetlands within the Lake Victoria Basin (see above), one expects to see a wetland map which depicts most of the major wetland types like the riverine wetlands, and the large swamps that occur within the major river basins. In this regard, onscreen digitisation showed a much more reliable distribution of wetlands. The wetlands distribution clearly fell into geographic areas in which wetlands would be expected to occur – valley bottoms and following river/stream courses.

Comparison of maps produced by the onscreen digitisation and automated classification techniques revealed the following:

- classification results were most reliable from the maximum likelihood method;
- distribution of wetlands near the Yala swamp where classification truthing data was obtained from was most reliable.
- Distribution of wetlands in coastal regions of the basin was also more reliable than in upland areas. This is most probably because the truthing site is a coastal wetland
- Distribution of wetlands was more reliable in the Landsat image in which the Yala wetland appeared
- Forested areas were often mistakenly classified as papyrus dominated wetland areas as shown by the large area classified as wetland in the Kakamega region, which is actually part of the Kakamega forest.
- Large wetlands in areas of flat terrain were more reliably mapped than small wetlands in areas with rugged terrain. This appears to be so even in upland areas as the large wetland in Ruma national park was well mapped by the classification
- Large shallow open water areas could be mistakenly classified as non papyrus wetland, such as the area at the head of Winam gulf.

From the above, findings, while onscreen digitisation is undoubtedly the most rigorous technique for wetland mapping, supervised classification appears to be a promising as a future means of mapping wetland distribution. Area estimates from classification and digitisation are within the same order of magnitude. Proximity to the truthing site, similarity of physical geographic setting to the truthing site and being on the same satellite image or not all appear to be factors in determining how successful mapping is. Further research is required in order to make classification more reliable, but with further work that should be possible in the near future.

Mapping Outcomes

Through the mapping component, the extent of wetlands within the Kenyan portion of the Lake Victoria Basin has been assessed as:

Papyrus dominated wetland areas	662 km^2
Non-papyrus vegetation dominated wetland areas	1,490 km^2
Open water wetland areas	16.6 km^2
TOTAL WETLAND AREA	**2,168 km^2**

These wetland areas were developed from the onscreen digitisation technique. They should be considered against the area of the basin which was determined to be 37,860 km^2 and the area of the lake within Kenyan territory of 3,967 km^2.

In considering these areas of wetland, the following points should also be noted:

- Landsat image resolution is 30 m by 30 m which limits the minimum size of wetlands included in this mapping; however this resolution issue is unlikely to be significant in areal determination as each wetland below the resolution of the image will be less than 0.0009 km^2. There would need to be 24,000 such wetlands in the basin area to introduce a 1% error into the total wetland area estimate, or an average of one such wetland for every 1.4 km^2 across the whole basin, which is most unlikely.
- River banks are often fringed with wetland vegetation and due to the partly subjective nature of digitisation. It is possible that some mis-classification has taken place; whereby some areas determined to be river but should have been shown as water and vice versa. The total area of rivers was determined to be 252 km^2, which is 90% smaller than the total wetlands area, so error in possible mis-classification must be much lower than 10%.

Products produced and delivered to the LVEMP wetlands component were:

i. Digital eight band single images covering the Lake Victoria Basin in Kenya (georeferenced in WGS 84 UTM ZONE 36 N)

ii. Digital false colour composit Landsat mosaic images of the Lake Victoria Basin in Kenya (georeferenced in WGS 84 UTM ZONE 36 N)

iii. Digital true colour QuickBird image composits of the Kericho and Eldoret sites (georeferenced in WGS 84 UTM ZONE 36 N)

iv. Five A1 hardcopies of basin-wide wetland maps whose sample is shown in *Figure 10.9.*

v. Five A3 hardcopies of land use/land cover maps of the Kericho Dionosoyiet wetland site whose sample is shown in *Figure 10.9*.

vi. Five A3 hardcopies of land use/land cover maps of the Eldoret Chepkoilel Wetland site whose sample is shown in *Figure 10.10*.

vii. A three CD set of the final digital databases of the project

Further supplementary data includes the provision of the FAO Africover land use / land cover data of Kenya were georeferenced to WGS 84 UTM ZONE 36 N and clipped using the project area boundary that was provided by SMEC International. The data was then added into the project database.

From the study, the SMEC team have seen that human land use factors create such problems for wetlands that recommendations from this study are that significant further mapping work should be undertaken, particularly:

- A program for updating wetland distribution status should be developed whereby LANDSAT Mosaic images are obtained and mapping performed at 5 to 10 year intervals in order to assess changes in wetland distribution;
- the maps produced through this project should be compared with maps developed from remotely sensed data collected over the last 30-40 years. This will enable an analysis of change in wetland area and major vegetation type over this critical time period. Analysis of these maps will require careful interpretation to ensure comparability between years (e.g., consideration of seasonal changes and inter-annual variations in rainfall). This analysis will provide an indication of the long-term history of the wetlands and their ecological sustainability under increasing environmental stress. This activity would be a suitable future research topic and is amenable to be undertaken as a PhD dissertation.
- While onscreen digitisation is clearly the more reliable technique for wetlands mapping from remote sensed images, the time, expense, level of detailed remote sensing expertise

involved in performing onscreen digitisation as well as its subjective nature severely restricts the ability to undertake the above two recommendations. Further research should be performed into the use of supervised classification for wetlands delineation in the basin area in order to improve its reliability. This will ensure that the above two recommendations are able to be implemented sustainably.

11. Basin Wide Wetlands Buffering Capacity

11. BASIN WIDE WETLANDS BUFFERING CAPACITY

It has long been considered that wetlands play a significant role in reducing the loads of pollutants entering Lake Victoria, however the extent to which this takes place has until now been very poorly understood. No attempts are known to have been made to quantify the buffering capacity of the Kenyan part of the Lake Victoria Watershed. The term “buffering capacity” of wetlands refers to the net improvement in water quality from inflows to outflow that takes place as water flows through a wetland. This is most apparent as reductions in suspended solid and nutrient loads transmitted through the wetland.

Given the extent of data collection for the pilot wetlands, the mapping activities that have taken place, and the development of a model for wetland buffering determination, it is now possible to give some preliminary estimation of the extent of buffering capacity that takes place in wetlands in the basin. This is done by firstly considering briefly some issues associated with scaling, then by describing the data available to assist in scaling, followed by a description of the estimation methodology and finally by presenting the results.

11.1 Scaling Issues

Scaling from site based measurements to a catchment wide understanding of hydrology and water quality issues is generally considered a difficult task. While some hydrology and water quality processes do scale linearly from pilot scale to catchment scale others do not. For example, suspended sediments removal in wetlands is generally dominated by particle settling and plant interception. These phenomena are well described by linear processes: settlement in water generally taking place at a constant velocity (stokes settlement) dependant only on the sediment properties while plant interception can be described mostly in terms of sediment size, plant stem size and plant stem areal density.

By contrast, long term nitrogen removal is generally dominated by biologically driven nitrification-denitrification cycles which rely on cycling between anaerobic and aerobic states within the sediments and water column and by plant uptake processes. Nitrification-denitrification is generally much more efficient in wetlands at medium scale and large scale than at small scale due to residence time considerations and the ability of large colonies of nitrifying and denitrifying micro-organisms to become established, but the extent to which the efficiency increases with scale has never been examined in detail.

Measurement representation and error issues are also problematic, particularly the unpredictability of small and medium scale heterogeneity on the catchment, see for example Grayson and Bloschl (2000).

In upscaling from pilot scale to catchment scale for the present study, factors accounted for were:

- The nett long term average runoff rate, SS, TP and TN loads entering Lake Victoria from the Kenyan portion of the basin.
- Differences in rainfall between the two pilot wetland sites and the whole basin area. Rainfall data was obtained from the access database maintained by the LVEMP Water Quality Component in Kisumu.
- Differences in water quality between the pilot wetland sites and across the whole lake basin.

The LAVINKS model was used as the primary tool to assess the buffering capacity of wetlands in the Kenyan portion of the Lake Victoria Basin.

SMEC are fully confident that the scientific rigour used to upscale in order to estimate the buffering capacity of wetlands across the Kenyan portion of the basin are commensurate with current international best practice. However, it should be noted that such estimates are subject to a high degree of uncertainty and much more work will be required over many years to verify the results presented here.

11.2 Basin Wide Rainfall, Flow Rate and Water Quality Data

Daily Rainfall data was obtained from the LVEMP Water Quality Component rainfall and climate database. For rainfall data on record, the period from 1 January 1983 to 31 December 1990 was the longest contiguous period over which rainfall data was available with a minimum number of data gaps at a reasonable number of stations that covered the major part of the Kenyan portion of the Lake Basin.

Stations from which rainfall data was used were Bungoma Water Supply, Kisii Water Supply, Miwani, European quarters, Narok Keekorok Game Lodge, Eldoret Expreimental Farm, Turbo Forest Nursery, Kibos Cotton Experiment Statio, Ahero Kano Irrigation station and Kericho Tumbilil. Uniform weighting was applied to the rainfall from each station in order to estimate the basin wide average rainfall. A summary of average annual rainfall from these stations is presented in Table 11.1, while the data itself is presented in Figure 11.1.

Table 11.1: Rainfall Summary Across the Lake Victoria Basin, 1983 to 1990

Station	Average yearly rainfall (mm)
Bungoma Water Supply	1564
Kisii Water Supply	1796
Miwani, European quarters	943
Narok Keekorok Game Lodge	1038
Eldoret Experimental Farm	982
Turbot Forest Nursery	1238
Kibos Cotton Experiment Station	1231
Ahero Kano Irrigation station	1200
Kericho Tumbilil	2042
Basin average rainfall estimate	**1345**

Long term average river discharges into the Lake were determined by COWI (2002). These estimates are based on rainfall runoff modelling using the NAM and SMAP models for gauged rivers and from the modified rational method for ungauged catchments. Results from that study are summarised in Table 11.2 and show a total average discharge of 292 m^3/s.

Table 11.2: Kenyan River Average Discharges into Lake Victoria

River Basin	Long Term Average Discharge Estimate (m³/s)	TP load (t/yr)	TN load (t/yr)
Sio	11.4	47	248
Nzoia	115.3	946	3,340
Yala	37.6	102	999
Nyando	18.0	175	520
North Awach	3.7	15	112
South Awach	5.9	39	322
Sondu	42.2	318	1,374
Gucha-Migori	58.0	283	2,849
Total	**292.1**	**1,925**	**9,764**

11.3. Buffering Capacity Estimation Methodology

Buffering capacity estimation was performed using the basin default LAVINKS-WEB model with the entire wetlands in the Kenyan portion of the basin by accounting for the total area of wetlands in the basin from Section 10 as 2,168 km^2. The basin wide averages/totals of rainfall, runoff and water quality data were also required as discussed below.

With the estimate of the long term average discharge from Table 11.2 and knowing the average rainfall on the catchment from Table 11.1, inflow rates in the model were able to be determined by assuming a simple rational method rainfall runoff relationship and simply changing the runoff coefficient until the nett average outflow from the wetland matched the discharge estimate entering the lake. With this approach, a runoff coefficient of 0.177 was adopted which gave a suitable result and is a quite reasonable value for the runoff coefficient for an area such as the Lake Victoria Basin.

Concentrations coming into the wetlands from the catchment for TSS, TP and TN were determined by taking the average concentrations at the inlet of the two pilot wetlands for each of these parameters as reported in Section 6, then applying a scaling parameter to account for the much larger catchment size over the whole basin compared to the two wetlands individually.

Factors taken into account in applying scaling parameters for each constituent were:

- The erosive potential of streams: increase in flow occurs with distance downstream from the headwaters, given that both the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands are in upland areas, lower sediment loads would be expected to be coming off the catchments in these areas than further downstream where the erosive potential of streams entering wetlands would be expected to be much higher.
- Impacts of spatial and temporal scales on constituent sediment interactions: given that the spatial extent of the catchment is quite large, it can be expected that constituent-suspended sediment interactions will generally reach equilibrium. Phosphorus-sediment interactions generally tend to move to an equilibrium point where most of the phosphorus becomes bound on the suspended sediments, therefore upscaling for sediments and phosphorus should be done consistently. Nitrogen equilbria points tend to differ quite radically, as nitrogen associated with sediments is usually in an organic form. As the organics break down over time, the nitrogen then becomes released so nitrogen upscaling should be relatively independent of suspended sediment upscaling.

Consequently a scaling parameter of 10 was applied to TSS and TP, but there was no apparent reason to upscale nitrogen, so the upscaling factor applied to TN was 1 (neutral – no scaling).

The other major effect taken into account in upscaling was the sediment size distributions. Sediment size distributions were changed to give more particles in the smaller sediment fractions. This is justified as the Kericho Dionosoyiet wetland and Eldoret Chepkoilel sites are located in upland areas where larger, denser sediment particles tend to be entrained into the flow. Further downstream particles will tend to be smaller and lighter due to increased organic content.

Adjusting plant uptake rates and relative cover factors only had a very minor effect on the basin wide nett wetland model, so these rates were left at default values.

11.4. Buffering Capacity Estimates for the Whole Lake Victoria Basin, Kenyan Area

After adjusting the model in the ways described in Section 11.3, the average outgoing phosphorus and nitrogen loads from the basin wide equivalent model to Lake Victoria were able to be estimated. Results for the entire period from 1983 to 1990 were not included in the analysis as it was found that the spatial extent of the model meant that the time required for model warm up was quite long – approximately 12 months. To ensure the warm up phase did not contaminate results, only model outputs from July 1984 to December 1990 were analysed. For this period, model loads were found to match the loads estimated as entering the Lake by COWI (2002). The model was therefore considered to be running under acceptable conditions.

Under the conditions described above, load reduction rates of 47% for TSS, 48% for TP and 27% for TN were determined from the modelling results run for July 1984 to December 1990.

The lower removal rate for nitrogen is to be expected as:

- Generally the wetlands in the basin would be expected to be phosphorus limited, and therefore plants will tend to uptake phoshorus very efficiently but nitrogen less so;
- As discussed earlier, phosphorus is usually much more strongly associated with sediments especially at long time scales and is therefore more effectively removed by sedimentation processes than nitrogen; and
- Time scales for nitrogen cycling mean there are significant delays in breakdown and removal of nitrogen from the water column.

Summary statistics for the basin wide buffering capacity estimation are contained in Table 11.3 below.

Table 11.3: Summary of Buffering Capacity Effectivess for Wetlands of the Kenyan Portion of the Lake Victoria Basin

Summary of Buffering Capacity Effectiveness

Lake Victoria Basin wide Wetland equivalent Kenya

	Inlet Water Quality				Outlet Water Quality				N/P
	TSS	TP	TN	TDS	TSS	TP	TN	TDS	ratio
Maximum	346.79	1.11	4.86	0.08	78.14	0.28	1.20	0.04	7.94
Average	112.16	0.39	1.38	0.03	58.81	0.20	0.99	0.04	5.10
Minimum	0.98	0.00	0.11	-0.01	30.14	0.10	0.70	0.03	3.47
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	

	Load In					Load Out				
	discharge	TSS	TP	TN	TDS	Discharge	TSS	TP	TN	TDS
Average	25,140	2,799,162	9,721	34,442	888	25,249	1,517,103	5,154	25,220	891
	Ml/d	kg/day	kg/day	kg/day	kg/day	Ml/d	kg/day	kg/day	kg/day	kg/day

	Loading Rates					Load removed (kg/day)			
	discharge	TSS	TP	TN	TDS	TSS	TP	TN	TDS
Average	0.0116	12.9	0.0448	0.1588	0.0041	1,292,138	4,566	9,482	18
	m/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day	kg/ha/day

	Areal Removal Rate (kg/ha/day)				Relative Reduction % (load removed/incoming load)			
	TSS	TP	TN	TDS	TSS	TP	TN	TDS
Average	5.96	0.02	0.04	5.96	47%	47%	27%	5%

From this section it can be seen that wetlands are therefore a highly significant component of water quality control for the Kenyan portion of the Lake Victoria Basin. Wetlands preservation, restoration management and rehabilitation are very necessary activities in maintaining a healthy ecosystem in the Lake Victoria basin. Furthermore, it is vitally necessary that water quality monitoring for the basin address the issue of wetlands buffering capacity. Simply measuring the loads of pollutants entering the lake and modelling in lake processes is insufficient to truly develop effective management strategies for the lake and its basin.

12. Recommendations for Improved Use or Non-Use of the Pilot Wetlands

12. RECOMMENDATIONS FOR IMPROVED USE OR NON-USE OF THE PILOT WETLANDS

According to the SMEC proposal in response to the Terms of Reference specified for the study, management plans were to be drawn up for each of the pilot wetlands within the time frame of the project. After consultation with the wetlands component, there was agreement that it would not be possible for SMEC to provide full management plans able to be implemented within a 12 month time frame because of the need to gain community involvement and acceptance of such management plans.

Management plans with community involvement and acceptance generally require a two to three year time frame to be drawn up, often longer – as shown by the Lake Naivasha Management Plan (Lake Naivasha Management Committee, 2005), which took 9-10 years to be developed.

Furthermore, a management plan needs to offer a flexible framework within which actions can be taken to ensure that the wetland's values and functions are sustainable over a long period of time. The management plan therefore needs to involve review aspects in an ongoing manner.

The draft management plans developed here are based on SMEC's wide experience of management plan preparation internationally. Additionally, particular attention was paid to ensuring consistency with the Lake Naivasha Management Plan, which is an exemplary model for management plans. Where ever possible, the management plans presented here seek to be consistent with the Lake Naivasha Management Plan.

Following below is a description of factors involved in the development of draft management plans for the Kericho Dionosoyiet wetland and the Eldoret Chepkoilel wetland. The draft plans themselves appear as Appendices A6 and A7.

12.1 Management of the Kericho Dionosoyiet Wetland

The Kericho Dionosoyiet wetland has a prominent position close to the town centre at Kericho. Indeed the wetland divides the town itself from Nyagacho, the main residential area for Kericho.

Through undertaking site activities at the Dionosoyiet wetland, it became clear that the local community values the Kericho-Dionosoyiet wetland and through the office of the District Environment Officer, there is potential for a management system to be developed that will incorporate a suitable level of collaboration between relevant local communities, stakeholders and local authorities. This local concern for the wetland makes it additionally attractive as a site for intensive, long-term monitoring.

Prominent aspects that were taken into account in the development of a management plan for the wetland were:

- Stakeholder and Community Consultation
- Water Use
- Habitat Management and Nature Conservation
- Waste Disposal
- Public Access
- Research Use
- Education, awareness and Information
- Monitoring and Evaluation
- Management Committee Framework
- Measures of Success and
- Structural Integrity of the wetland

Of these, stakeholder and community consultation is discussed. Details of all other aspects are contained in Appendix A6, the draft Management Plan for the Kericho Dionosoyiet wetland.

Stakeholder and Community Consultation Aspects

In conjunction with Ms Joanna Nyarombe, the District Environment Officer for Kericho, a stakeholder and community consultation process to gain stakeholder and community support for developing the wetlands management plan for the Dionosoyiet wetland from the draft provided by SMEC to a final form suitable to the community was initiated including the following steps:

1. Perform initial investigations to identify issues;

2. Identify stakeholders;
3. Organise a stakeholder meeting;
4. Establish a Dionosoyiet Wetland taskforce;
5. Provide the committee with a working draft of the management plan developed by SMEC for the buffering capacity project;
6. Receive comments from the committee on the working draft management plan;
7. Amend the working draft management plan to incorporate committee comments and comments from any other stakeholders who respond;
8. Review of the management plan through the review process for the buffering capacity project;
9. Incorporate the reviewers comments in order to finalise the draft management plan;
10. Hand over the management plan to the committee for further refinement in order to take ownership of the management plan; and
11. Committee to develop an action plan to implement the management plan.

Primary stakeholders for the Kericho Dionosoyiet wetland are represented by:

- NEMA through the district environment officer for Kericho district;
- The LVEMP wetlands component;
- The township primary school immediately to the North of the site;
- Kericho Municipal Council who have jurisdiction over the wetland;
- The cemetery on the western side of the wetland;
- The chief for the town area;
- Community groups such as the committee for the spring protection project within the wetland;
- The district water officer and water quality officer;
- The LVEMP soil and water component;
- The district public health officer; and
- The district forestry officer.

The initial meeting for the stakeholders was held on 13 April 2005. The agenda for the meeting was:

- To inform the stakeholders that SMEC is drawing up a draft management plan and seeks stakeholder inputs;

- To determine stakeholder issues in the effective management and functioning of the wetland; and
- To form a committee for wetland management and set in place a time frame for the committee to begin functioning.

At this brief meeting it was decided there was a need to further involve the community so a second meeting was scheduled for 26 April 2005.

For the meeting on 26 April, 29 stakeholder and community representatives attended. The attendees were asked to state what issues they saw as significant for the wetland. A large number of issues were raised, which are tabulated in the management plan.

Following this discussion, it was agreed that there was a strong desire to form a committee. Nominations were called for a chairman, secretary and treasurer of the committee. Captain Reuben Chebeleon was appointed chair, Mr Samson Mukumdi was appointed secretary and Ms Joyce Thuo was appointed treasurer.

12.2 Management of the Eldoret Chepkoilel Wetland

The Eldoret-Chepkoilel wetland is utilized by local communities for water, as grazing and for the harvesting plant products. The wetland also provides water for the Equator Flower Farm and receives effluent from the flower farm and from the Moi University sewage treatment ponds.

All management plans for wetlands in western Kenya should include sections on monitoring and controlling invasive weeds such as *Mimosa pigra, Eichhornia crassipes* and *Salvinia molesta*. This is a particularly important issue for the Chepkoilel wetland as *Mimosa* has been observed to be present in the wetland and its spread in a rural area such as Eldoret Chepkoilel could be devastating.

Management Plan aspects that have been particularly addressed for the Chepkoilel wetland include:

- Stakeholder/Community Consultation

- Water Use
- Habitat Management and Nature Conservation
- Tourism, Education and Research
- Horticulture and Agriculture
- Waste Disposal
- Public Access
- Local Community Awareness and Information
- Monitoring and Evaluation
- Review Process
- Management Committee, Institutional Framework and Terms of Reference
- Measures of Success

Staeholder consultation is discussed below, the remaining aspects are covered in the management plan in Appendix A7.

Stakeholder Community consultation aspects

In conjunction with Ms Nancy Muui, the District Environment Officer for Uasin Gishu, a stakeholder and community consultation process was initiated involving the following steps:

1. Perform initial investigations to identify issues;
2. Identify stakeholders;
3. Organise a stakeholder meeting;
4. Establish a Chepkoilel Wetland taskforce;
5. Provide the committee with a working draft of the management plan developed by SMEC for the buffering capacity project;
6. Receive comments from the committee on the working draft management plan;
7. Amend the working draft management plan to incorporate committee comments and comments from any other stakeholders who respond;
8. Review of the management plan through the review process for the buffering capacity project;
9. Incorporate the reviewers comments in order to finalise the draft management plan;
10. Hand over the management plan to the committee for further refinement in order to take ownership of the management plan; and
11. Committee to develop an action plan to implement the management plan.

Important stakeholders for the wetland include:

- NEMA represented through the district environment officer for Uasin Gishu
- Eldoret Municipal Council
- Wareng County Council
- Ministry of Water through the district water officer
- Ministry of Agriculture
- Moi University Chepkoilel campus through the Chepkoilel Campus Nature Conservation Committee
- The Equator Flower Farms

A half day workshop was held on 15 April at Chepkoilel. The meeting was attended by 12 stakeholders representing Eldoret Municipal Council, the Office of the Chief, Chepkoilel area, Ministry of Water, NEMA, LVEMP Wetlands Component (through SMEC), Ministry of Forestry and the local community. At the workshop, invitations were issued for interested parties to become involved in the committee for management of the wetland. The immediate role of the committee is to determine its own terms of reference and establish operating principles. In the long term, the role of the committee will be ensure suitability of the management plan for stakeholders and the local community and to facilitate implementation of the management plan.

The agenda for the meeting was:

- To inform the stakeholders that SMEC is drawing up a draft management plan and seeks stakeholder inputs;
- To determine stakeholder issues in the effective management and functioning of the wetland; and
- To form a committee for wetland management and set in place a time frame for the committee to begin functioning.

From the meeting, a number of issues that were identified as significant to stakeholders. These are presented as an addendum to the management plan.

13. Preliminary Guidelines For Use/Non-Use of Wetlands

13. PRELIMINARY GUIDELINES FOR USE/NON-USE OF LAKE VICTORIA BASIN WETLANDS

As has been elaborated in earlier sections, the tropical wetlands of the basin of Lake Victoria are extremely important to the functioning of the lake system as well as to the welfare of local communities. They perform buffering services to the lake inflows, trapping suspended sediments and nutrients, reducing inflows, especially when located strategically at the major inflow points. They also form a rich resource base for the communities living around them.

By contrast, it must also be acknowledged that there are numerous negative values associated with wetlands – they may harbour disease vectors, are associated with flood risks and may harbour pest and weed species. Wetlands are also fragile ecosystems; their positive functions can easily be lost through mismanagement or neglect. So a variety of complex functions and values are associated with wetlands, some of which are not well understood even by international experts. It is apparent then that clear guidelines for wetlands use and non use will greatly assist in successful wetland management.

Furthermore, it must be acknowledged that wetlands are "open ecosystems" (Sainty, 1994), that is, flows of water, pollutants and constituents, as well as movements of animal species, pollen and seeds into and out of the system are virtually unrestricted and generally dominate over the nett standing amounts of these quantities in the wetland. In such systems, preventive techniques are difficult to apply and successful management is heavily reliant on a vigilant and responsive management approach (adaptive management), that regularly assesses the status of the system for a range of indicators and formulates actions in response to these.

Management actions are also required to be wholistic, integrating across a range of areas in order to ensure a resilient system develops that is able to cope with change itself in the event that . There are no "silver bullets" in such settings.

Appendix A8 contains a draft management plan framework (MPF) for Lake Victoria Basin wetlands that has been compiled by SMEC according to the requirement of the terms of reference to develop preliminary guidelines for use/non use of wetlands. The MPF is based on international best practice procedures

In consideration of the nature of wetlands as open systems. The MPF consists of the following sections:

- Wetlands definition and description;
- Maintenance and plant replacement guidelines
- Sedimentation management
- Water level control and drainage advice
- Weed management
- Pest management
- Maintenance procedures
- Monitoring guidelines
- Checklists of operations and maintenance

Community and stakeholder consultation and involvement should be invoked as fully as possible to ensure optimal acceptance of management activities leading to successful wetland management.

Management Plan Framework Purpose

The purpose of this MPF is to educate and advise both experienced and inexperienced personnel in understanding and managing wetlands.

Three major management outcomes are highlighted in this MPF:

- the assessment of sediment/debris deposition – to determine if sediment/debris removal is required to sustain buffering function, habitat value and amenity of the wetland system.
- the early detection of aquatic plant damage or short-circuiting pathways that may be establish within the system so that remediation can be carried out to prevent compromising buffering processes.
- the ongoing assessment of the health of the wetland as an ecosystem

The MPF shuld be applied as an adaptive management tool, whereby management goals remain consistent but objectives and techniques may be amended with time in response to feedback from the system.

Implementation Aspects

Successful implementation will require wide promotion of the management plan framework in conjunction with the development of wetland management plans based on those developed for the Kericho and Eldoret wetlands, adapted to suit the particular wetland in question as appropriate.

It must be recognised that management planning for wetlands must be done on a case by case basis as individual differences between wetlands and their environmental settings are usually large. A "one size fits all" approach is not possible, so the MPF should not be seen as a recipe for success in wetland management, rather as an examplar from which variations should be made as appropriate for the individual wetland being considered with due reference to current best practices in wetland management at any particular point in time, and for any given location.

14. Recommendations

14. RECOMMENDATIONS

This study has established that through their buffering capacity, wetlands in the Kenyan portion of the Lake Victoria Basin are highly important in ensuring water quality in downstream environments is preserved. This is especially so for suspended sediments, nitrogen and phosphorus given the roles they play as agents of eutrophication. Consequently, the recommendations of this report focus on the importance of preserving wetland areas, further improving understanding of wetland buffering processes, and ensuring wetland management for the Lake Basin is able to be sustainable in the long term socially, economically and environmentally.

A wide range of recommendations are given in the specific sections of the report. Here these are summarised and supplemented under the broad areas of:

1. recommendations regarding the pilot wetland sites;
2. recommendations for wetland management generally across the lake basin

14.1 Recommendations Regarding the Pilot Wetland Sites

For the pilot wetland sites, draft management plans have been drawn up and management committees have been formed. It is important that the management committee is fully supported in developing further the management plans for the two sites. Actions required to be performed at the two pilot wetlands that will preserve their buffering capacity and ensure they are maintained as significant community and environmental resources are provided in these management plans.

Furthermore, given the significant effort that has been performed through studying the pilot wetland sites through this study, it would be highly valuable for ongoing work to be continued at these sites.

The ideal monitoring conditions present at the Dionosoyiet Kericho site mean it is an ideal site for further monitoring. Ecological studies of tropical wetlands have rarely included mass balances of sediment and nutrients over prolonged periods with consistent, continuous monitoring including through storm events because so often conditions for compiling water balances are not suitable. The Kericho Dionosoyiet wetland site infrastructure and the equipment made available through LVEMP provide an excellent opportunity to fill this gap in the current understanding of tropical wetland ecology.

This opportunity should be utilised and would be ideal for a graduate student working through the LVEMP wetlands component to undertake research if facilities from this study can be made available. Care should be taken to ensure that such research is performed in conjunction with the management planning process and should fully involve the wetlands management committee as appropriate.

A study of the Eldoret-Chepkoilel wetland would also produce additional understanding on the sustainable capacity of this wetland to handle external nutrient loadings. Careful monitoring of resource use (e.g., papyrus harvesting) and the presence of aquatic weeds needs to be initiated.

14.2 Recommendations Regarding Wetlands in the Lake Victoria Basin

Recommendations regarding wetlands generally across the Kenyan area of the Lake Victoria basin can be considered under short term and long term headings as described below.

Short-term recommendations

A number of recommendations can be made that will practically and more or less immediately improve the status of wetlands within the Lake Victoria basin including:

1. The Kericho-Dionosoyiet wetland study site with the modifications established by the LVEMP project provides an excellent opportunity for the long-term assessment of the buffering capacity of a Kenyan wetland. This site in particular should continue to be monitored for its buffering capacity and changes in vegetation.

2. Satellite imagery should be obtained for a small number of selected wetlands in the Lake Victoria basin extending back over four decades. Images at approximately ten-year intervals for each wetland may be used to detect changes in wetland vegetation and these may be related to changes in catchment management.
3. Wetlands should be monitored to ensure that infestations with *Eichhornia crassipes* (water hyacinth) *Mimosa pigra* and *Salvinia molesta* are quickly detected. Depending on the seriousness of infestations, early detection will allow control measures to be instituted;
4. Further investigations of wetland environmental sensitivity should be conducted that draw on and extend the Rapid Assessments that have been performed. From these, environmental and cultural values should be assessed and where appropriate, site should be designated for potential listing as RAMSAR sites.
5. Stakeholder groups and local communities should be encouraged to develop management plans at numerous sites across the basin for significant wetlands. This would form a "bottom-up" process that involves consultation with local communities, stakeholders, local government officials and wetland users from the outset.
6. Effective wetland management requires basic hydrological data. Monitoring capacity of rainfall and streamflows within the Lake Victoria catchment should be enhanced and the data collected made readily available to wetland ecologists.
7. Where harvesting of *Cyperus papyrus* and other wetland species occurs, care should be taken to include these activities under management plans. Harvesting should be monitored as part of the management plan to develop sustainable cropping strategies.
8. Community education programs should be undertaken to ensure that stakeholders are fully aware of the ecological services that are provided by wetlands.

Long Term Recommendations

Long term recommendations are mostly focussed at institutional level and will take some time to yield positive outcomes for wetlands in the basin. Nevertheless, these recommendations are necessary if wetlands are to be managed sustainably in the future:

- A wetlands sustainability framework needs to be developed in which the concepts of thinking globally and acting locally on environmental, economic and social sustainability are incorporated;

- Given its relative new standing within the Ministry of Environment and Natural Resources, the National Environment Management Authority, NEMA needs to fully develop into a well respected organisation through an institutional strengthening process. Such institutional strengthening must incorporate a strong sense in NEMA officers of core values of environmental, social and economic sustainability implemented through integrity. Without strength of leadership in the main environmental authority, appreciation of the values and functions of natural resources such as wetland may be weakened, wetlands will therefore be put at risk and wetland buffering capacity will be jeapoardised;
- Training programmes for officers from NEMA and other agencies must ensure the organisation builds cross disciplinary capacity in administrative, analytical, social, economic and environmental skills with officers to develop both broad ranging skills and specific technical niches. Within such a training framework, All NEMA officers should be given significant training in wetlands management and wetlands buffering processes, while a select group of officers should receive high level training in performing wetlands investigations, especially focussing on buffering capacity; and
- Cross institutional collaborations need to be encouraged between Ministries and between ministries and Local Government as wetlands fall across a number of different levels of responsibility;

15. Conclusions

15. CONCLUSIONS

Wetlands in the Kenyan portion of the Lake Victoria Basin are important assets serving various social, economic and environmental purposes. This report has examined the buffering capacity of wetlands of the basin. Aspects of the study included hydrology and water quality monitoring for two pilot wetlands in the basin, examination of the buffering processes taking place in wetlands, mapping of the pilot wetlands and Environmentally Sensitive Wetland Areas (ESWA's) across the Kenyan portion of the lake basin, modelling, estimation of the buffering capacity of wetlands in the Kenyan portion of the lake basin and technology transfer components.

Products associated with the report that have been delivered include:

- Hydrology and water quality data gathered at the two pilot wetlands: the Kericho Dionosoyiet and the Eldoret Chepkoilel wetlands, in microsoft excel format;
- Maps of the pilots wetlands were delivered to the LVEMP wetlands component on 23 April 2005;
- Maps of the distribution of ESWA's in the Kenyan portion of the Lake Victoria data, also delivered on 23 April 2005;
- GIS files for the pilot wetland and ESWA distribution maps;
- Models for the hydrology and water quality behaviour of the two pilot wetlands, a "typical" lake basin wetland and a model for the equivalent impact of wetlands basin wide, all coded in Microsoft Excel;
- Draft management plans for the Kericho Dionosoyiet and Eldoret Chepkoilel wetlands; and
- A management plan framework for wetlands within the Kenyan portion of the Lake Victoria basin.

Monitoring was performed in the two pilot wetlands by conducting long term monitoring over an eight month period from June 2004 to February 2005 and intensive monitoring in the short rains 2004 and the long rains 2005.

From the monitoring it was concluded that the most important buffering processes operating in the two wetlands are plant interception of suspended sediments and nutrients and plant uptake of nutrients. Sedimentation and nitrification-denitrification are also significant processes in the Eldoret Chepkoilel wetland; but the residence times of the Kericho Dionosoyiet wetland are too low for these processes to be of great significance. Sediment binding of nutrients for both wetlands is very low as the sediments at both sites are low in CAC. Nitrogen to phosphorus ratios are generally much higher than 7:1 so phosphorus is the limiting nutrient for plant growth, confirming that the pilot wetlands are more effective at retaining phosphorus than nitrogen. Strategic harvesting is seen as the most effective tool for improving buffering potential of the two wetlands as this will increase residence time, improve the flow distribution of water though the wetlands, will increase plant uptake through encouraging plant growth and will represent a nett removal of solids and nutrients from the wetlands.

Considering the buffering processes that operateand the results from the monitoring allowed models to be established to examine the buffering processes within the two pilot wetlands. These models were then run to simulate conditions in the two wetlands over the 11 year period from 1 January 1994 to 31 December 2004. The results of modelling showed significant removal of suspended solids, phosphorus and nitrogen to occur in both wetlands. Scenario modelling showed that both wetlands are generally robust and would be expected to cope well with any environmental changes that may occur such as changes in wetland area, inflow or pollutant loadings; however dramatic reduction in wetland area would be expected to seriously impair wetland buffering capacity, particularly for the Kericho Dionosoyiet wetland. Improved performance from both wetlands can be expected if wetland areas are at least maintained or increased and if inflow or pollutant loadings are kept at current levels or decreased.

Mapping of wetland areas was performed was performed by onscreen digitisation to delineate the two pilot wetland sites and to determine the extent and distribution of environmentally sensitive wetland areas across the basin area. Supervised classification was also used to determine the extent of wetland areas across the basin and was found to give promising results. Further work is required to make this technique more reliable; however the superior quaitification and more objective basis for classification clearly makes it a more powerful tool for the future.

Knowing the extent of wetlands across the basin from the mapping activities, modelling was then extended to a basin wide level to examine the buffering potential of wetlands across the Kenyan portion of the basin. At basin wide level it was found that wetlands are responsible for retaining approximately 70% of the suspended solids and phosphorus leaving the catchment and approximately 60% of nitrogen leaving the catchment.

Technology Transfer was performed through a series of workshops and by inclusion of NEMA and other officers in the field. Workshop topics included planning and logistics for wetlands investigations, values and functions of wetlands, water quality in wetlands, use of advanced automated equipment for wetland buffering capacity studies, mapping aspects and modelling. Workshops were all well attended and feedback about the sessions was generally positive.

Draft management plans were prepared for the two pilot wetlands and a draft management plan framework has been given for wetlands across the Kenyan portion of the lake basin. Committees have been established to coordinate the implementation for both the Dionosoyiet and Chepkoilel wetlands.

The project has been completed within a one year time frame as originally agreed upon in the terms of reference and all conditions of the terms of reference have been met satisfactorily.

16. References

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Appendices

A1. ANALYTICAL PROCEDURES USED AT THE KISUMU WATER QUALITY LABORATORY

Total nitrogen – Persulphate Method

Principle

Organic and inorganic nitrogen is converted to nitrate by alkaline oxidation at 100°C to 110°C. Total nitrogen is determined by analysing the nitrate in the digestate, where nitrate is reduced to nitrite by cadmium in ammonium chloride buffer at pH = 8.5. The nitrite is diazotized with sulphanilamide and coupled with N- (1-napthyl)-ethylenediamine di-hydrochloride forming a red azo-dye. The absorbance of the red colour is measured in a photometer at 540 nm

Treatment of sample, standard and blanks:

It is important, due to calculations, to keep track of samples according to order of reduction and column used for reduction.

(i) Transfer the solution from the digestion container to a measuring cylinder,
(ii) Fill to 60 ml with the ammonium chloride buffer and mix,
(iii) Transfer the 60 ml to a conic flask,
(iv) Pour the solution into Cd-column. and collect at a rate of 7 to 10 ml/min,
(v) Discard the first 25 ml.,
(vi) Collect the rest in a measuring cylinder,
(vii) Pour 25 ml into the conic flask (3),
(viii) As soon as possible, and not more than 15 min. after reduction, add 1 ml colour reagent,
(ix) Measuring the absorbance at 543 nm within 2 hours from addition of reagent,
(x) Use distilled water to zero the photometer,
(xi) If sample absorbance exceeds absorbance of control 2.464 mg/L, use result of the sample to make a right dilution and analyse again.

Nitrates and Nitrites – Cadmium Reduction Method

Principle

Nitrate is reduced to nitrite by cadmium in an ammonium chloride buffer at pH = 8.5. Nitrite is diazotized with sulphanilamide and coupled with N-(1-napthyl)-ethylenediamine di-hydrochloride forming a red azo dye at pH 1.5 -2. The absorbance of the red colour is measured in a photometer at 543 nm. Suspended matter in the column will restrict sample flow. Metals above several milligrams per litre lower reduction capacity. EDTA is added to the NH_4Cl buffer to eliminate interference from metals.

Reagents for NO_2+NO_3-N

Ammonium chloride buffer pH = 8.5: Dissolve 10.0 g NH4Cl in 1000 ml distilled water. Adjust pH 8.5 by adding three or four NaOH pellets as necessary. Check the pH = 8.5.

Colour reagent: Combine 375 ml distilled water, 50 ml conc. phosphoric acid, H3PO4, 5.0g sulfanilamide, and 0.25 g N- (1- naphthyl)- ethylenediamine dihydrochloride C10H7NHCH2CH2NH2-2 HCl. Dilute with distilled water to 500 ml.

Preparation of reduction column

Insert a glass wool plug into bottom of reduction column and fill with water. Add sufficient Cu-Cd granules to produce a column 18.5 cm long. Maintain water level above Cu-Cd granules to prevent entrapment of air. Wash column with 200 ml of dilute NH_4Cl-EDTA solution. Activate column by passing through it, at 7 to 10 ml/min., at least 100 ml of a solution composed of 25% 1.0 mg/L NO_3-N standard and 75% of NH_4CL-EDTA buffer solution.

Check reduction capacity by passing a standard NO_3-N followed by a standard NO_2-N at equal concentrations and compare the absorbance values, reduction must be at least 75%. If column is not to be used for several hours or longer, pour 50 ml of dilute NH_4CL-EDTA solution on to the top and let it pass through the system. Store Cu-Cd column in this solution and never let it dry.

Treatment of sample

(i) Turbidity removal: Filter turbid sample through 0.45 μm pore-diameter membrane filter. Test filters for nitrate contamination.

(ii) pH adjustment: Adjust pH to between 7 and 9, as necessary, using a pH-meter and dilute HCl or NaOH. This insures a pH of 8.5 after adding NH_4Cl-EDTA buffer.

Analysis

(i) Sample = untreated, treated or diluted sample

(ii) Treat blanks (distilled water) as sample but make 2 replicates for each column in use.

(iii) Treat standard as sample.

(iv) Treat control samples as samples but make 2 replicates on each column.

Reduction capacity check

Before reducing samples check reduction capacity of column(s) by treating standard 200 μg/L NO_3-N and standard 200 μg/L NO_2-N as samples and calculate reduction capacity as:

$$\frac{\text{Absorbance}_{\text{standard } NO_3\text{-N}} * 100}{\text{Absorbance}_{\text{standard } NO_2\text{-N}}} \%$$

For each column in use on the day of analysis check reduction capacity regularly during analysis for example after every 6 to 10 samples and always end analysis on columns with a reduction capacity check.

Sample Reduction

It is very important, due to calculations, to keep track of samples according to order of reduction and column used for reduction.

(i) Mix 15.0 ml of sample, standard, blank or control sample with 45 ml of NH_4Cl-EDTA buffer in a conic flask.

(ii) Pour mixed sample into column and collect at a rate of 7 to 10 ml/min.

(iii) Discard the first 25 ml.

(iv) Collect the rest in a measuring cylinder.

(v) Rinse the conic flask with distilled water and pour 25 ml of the reduced sample back to the conic flask.

(vi) Proceed from step 1 with next sample, standard, blank or control sample there is no need to wash column between samples.

(vii) As soon as possible, and not more than 15 minutes after reduction, add 1 ml colour reagent and mix.

(viii) Wait for 10 minutes.

(ix) Measure absorbance at 543 nm within 2 hours from addition of reagent.

(x) If sample absorbance exceeds absorbance of control sample 750 µg/, dilution and analyse again.

Calculations

(i) For each column: Calculate average $absorbance_{Blank}$

(ii) Subtract the average absorbance $_{Blank}$ from all standards, control samples, samples and samples diluted prior to reduction.

(iii) Calculate average blank corrected $absorbance_{Standard}$

(iv) Calculate the content of NO_2+NO_3-N in all samples and control samples using blank corrected

(v) Absorbance: Plot blank corrected standard absorbance against standard concentration to make a calibration curve. Using blank corrected sample absorbance to read the sample concentration from the standard curve and multiply it with the dilution factor to obtain the sample result.

Or

Use a calculator or a computer programme to perform a linear regression on blank corrected standard absorbance and standard concentrations. Calculate the sample result on blank corrected sample absorbance and multiply it with the dilution factor to obtain the sample result.

Orthophosphates (Ascorbic Acid Method)

Principle

Ammonium Molybdate and potassium Antimonyl tartrate react in acid medium (0.2 Mol/l) with orthophosphate to form a heteropoly acid-Phosphomolybdic acid- that is reduced to intensely coloured molybdenum blue by ascorbic acid. The absorbance of the blue colour is measured in a photometer at 880 nm.

Analysis

(i) Sample = untreated or diluted sample

(ii) Treat standards as samples

(iii) Treat control samples as a sample but make 2 replicates of each concentration.

(iv) Blank= Sulphuric acid 0.04 Mol/ l. Make 2 replicates.

(v) For highly coloured or turbid waters, prepare a blank by adding 1 ml of ascorbic acid and 1 ml of 0.04 Mol /l sulphuric acid.

(vi) Transfer 25 ml of the preserved sample, standard or control solution into a reaction bottle

(vii) Add 1 ml ascorbic acid, mix and wait for 30 sec.

(viii) Add 1 ml combined solution, mix and wait for 30 sec.

(ix) Wait for 10 min. Measure the absorbance at 880 nm in a photometer. Absorbance measurement between 10 and 30 minutes.

(x) Use distilled water to set the photometer to zero.

Calculations

(i) Calculate average of absorbance for the blank.

(ii) Subtract the average from all standards, control and samples.

(iii) Make a calibration curve.

(iv) Read the sample concentration from the standard curve and multiply it with the dilution factor if it has been diluted.

A2. RAW DATA FOR HYDROLOGY AND WATER QUALITY

A3. MODELLING IMPLEMENTATION ASPECTS

Monte carlo Implementation of Stochastic component of water quality

From elementary normal distribution statistics, a number y(i) that forms part of a sequence that follows the normal distribution can be described as consisting of the following components:

$y(i) = y_{ave} + y_{sd}.z(i)$

Where y_{ave} and y_{sd} are the average and standard deviation of the sequence y(i) for i = 1 to n. The distribution of numbers in the sequence z(i) from i = 1 to n has a probability described by the standardised Gaussian "bell curve" distribution. Probabilities p(i) associated with the z(i) sequence therefore follow the bell distribution given by the relationship

$p(i) = \exp[-z(i)^2]$

Excel's random numbers generator has a uniform distribution between 0 and 1, so inverting this equation shows us how to generate a random number sequence following the Gaussian distribution as:

$z(i) = \pm \mathrm{sqrt}\{-\log_n[p(i)]\}$

A4. USER MANUAL, POND MODEL

A5. TECHNOLOGY TRANSFER HANDOUTS

A6: DRAFT MANAGEMENT PLAN FOR THE KERICHO DIONOSOYIET WETLAND

A7. DRAFT MANAGEMENT PLAN FOR THE CHEPKOILEL WETLAND ELDORET

A8. DRAFT GUIDELINES FOR WETLAND USE IN THE BASIN