Integration of GIS and Computer Modelling to Study the Water Quality of Lake Naivasha, Central Rift Valley, Kenya.

By
Noha Samir Donia

Supervised by:

Ir. Gabriel Parodi.
Dr. Ir. Chris Mannaerts.

Thesis submitted to the international Institute of Aerospace Survey and Earth Sciences in partial fulfillment of the requirements for the degree of Master of Sciences in Environmental Systems Analysis and Monitoring

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the international Institute of Aerospace Survey and Earth Sciences
Enschede, The Netherlands

If the sea were ink

For the words of my Lord,

the sea would be spent

before the Words of my Lord are spent.

Qur'an. The Cave 18:109.

To my loving parents
with gratitude.
To my Fiancée
whose love and support
have never failed.

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Abstract

Lake Naivasha is a highly significant national freshwater resource of Kenya. Its riparian area also supports large and vitally important socio economic activities, such as intensive horticulture, flower growing and geothermal power generation.

Due to the intense use of land and water resources, the lake became vulnerable to pollution from farmlands, settlements and industries. Rivers from the upstream basin especially Malewa and Gilgil rivers also contribute to potential pollutant input.

Since both rivers and their catchement areas are vital for the lake and its surrounding human activities, they must be conserved at all costs.

The objective of this research is to study the water quality of lake Naivasha and matter input from its drainage basin by integrating established monitoring data with GIS based methods and computer simulations of water flow and quality.

This was achieved by a general water quality and quantity survey of the study area followed by a detailed analysis of the gathered data .The analysis results are used as input to the DUFLOW water flow and quality model.

GIS-ILWIS techniques were used for the spatial design of the model. A digital elevation model (DEM) of the study area was constructed and was used to derive the physical characteristics of the river network (river profile and river length). The derived data from the DEM was checked and preprocessed before being used in the model.

Mathematical flow and water quality submodels had been designed for Malewa river, Gilgil river and lake Naivasha. Then an integrated model has been designed combining the three submodels. All these models were evaluated and verified based on field data.
Finally the integrated model was applied in running some scenarios and a sensitivity analysis of the results will be conducted.

This study is expected to help the decision maker to take the appropriate actions to improve the quality of water entering the lake and therefore the conservation of the lake ecosystem.

Table of Contents

List of Tables

List of Figures

List of Graphs

List of Photos

Chapter 1

Outline of the study

1.1 INTRODUCTION

Surface waters from rivers and lakes are important sources of public water supplies because of the high withdrawal rates they can normally sustain. One disadvantage of using surface water is that it is open to pollution of all kinds. Contaminants are distributed to lakes and rivers from diverse and intermittent sources, such as industrial and municipal wastes, runoff from urban and agricultural areas, and erosion of soil.

In regions with scarce water resources, this high pollutant loads induce the supplemental problem of high concentrations due to the limited dilution capacity of water (e.g. rainfall, runoff). Therefore, protection of water quality represents one of the most important goals for environmentalists.

Different models have been developed in order to analyze environmental impacts of pollution on water resources and to be able to evaluate different management practices to reduce them and to protect the water quality.

Up to now, most of the input data for water quality models were obtained based on fieldwork studies and manual cartographic work. With the development of GIS and Remote Sensing, the situation has changed. Although the fieldwork remains as an essential component in data acquisition, the majority of data can be obtained through automated procedures. Integration of GIS and the computer model seemed a very useful approach to address water quality & pollution assessment in river basins.

This research aims at applying this integration technique in water quality assessment of Lake Naivasha, the Kenya's second largest freshwater lake.

1.3 PROBLEM FORMULATION

Lake Naivasha, the only freshwater lake in Kenya rift valley, is continuously under threat of cultural eutrophication from the urban and agricultural activities from the catchement. So the current trend of utilisation of the resources of Lake Naivasha poses serious threats to the fragile lake ecosystem and its biodiversity. It is essential then to assess how many pollutants coming from the catchement and how it influences the lake water quality.

1.3 RELEVANCE OF THE RESEARCH

Many researches had been conducted to assess lake Naivasha water quality and the quality of its input rivers (Malewa and Gilgil) entering the north of the lake.

As example, (Gaudet, 1979) finds that the majority of the water entering the contiguous waters of the Naivasha basin that comes from the inflow rivers are richer in total nutrients than lake water, but similar in soluble concentrations. Total nutrients are carried predominant on silts and colloids which usually sediment or are filtered out by the papyrus swamp.

Also, (Harper, 1996) admits that the matter inputs or pollutants to the lake come originally from the river inputs. So Lake Naivasha ecology is so influenced by the matter inputs from rivers Malewa, Gilgil. But until now the lake remains fresh because the water coming from Malewa River is very dilute so that the salt input is low. This salt balance may be shifted if the nutrient load of the incoming water is increased.

All the previous studies admit an increase in nutrients loading into the lake especially from the input rivers and that the amount of nutrients that depend principally on the lake level of the lake and fluctuates with the amount of water inputs to the lake. But no research tries to establish a model to quantify and qualify this amount of nutrients. Also all the previous studies focuses on assessing the present water quality of the lake but no researches have focused on water quality management.

Since the relationship between quality and flow is very relevant in case of water quality management of lake Naivasha, a program suitable for modeling both aspects makes DUFLOW (Dutch Flow) a useful tool to be used in this research.
This model will be used to predict the change in water quality due to any changes in inputs to the lake which will help a lot to make a good water quality management plan of the lake to ensure its sustainability.

But why is it important to assess the lake water quality? This question can best be answered by looking at Lake Naivasha as a natural resource and at its socio-economic aspects.
Lake Water is used for irrigation by horticulture farms. Horticulture is of national importance as a source of foreign exchange and employment.
Also a large volume of water is pumped from the lake by the Kenya Power Company (KPC). This geothermal power generation company provides roughly 15% of national electric power requirements.
The lake provides domestic water supplies to Naivasha town either directly or from wells or bore holes around the lake.
The lake supports as a wide variety of animal and plant lives and is routinely include on bird watchers itineraries.
A small commercial fishery also depends on the lake water.
Because the tourist industry is the most important foreign exchange earner in Kenya today, the value of this lake cannot be overstated. For the tourist the lake offers bird watching as its best, sports fishing for black bass, camping, and game viewing.

1.4 RESEARCH OBJECTIVES

The main objective of the research is to study the water quality of Lake Naivasha and the pollutant inputs from its drainage basin by integrating established monitoring data with GIS based methods and computer simulation of water quality and flow.

The main objective of the study can be divided into the following specific objectives:

- To assess the present water quality of lake Naivasha and its input rivers and to identify the major pollution sources for rivers (Malewa, Gilgil) and for Lake.

- To model the transport of matter along Malewa and Gilgil rivers using DUFLOW by running different scenarios on the actual state, and another scenario with changing the amount of pollutants and prediction of what will happen.

1.5 RESEARCH METHODOLOGY

The methodology is subdivided into the following stages:

1.5.1 Model spatial & Temporal Design

For the simulation task, the model requires spatial data sets describing the river geometry .The GIS-basemethods were used to pre-process spatial input data of the water quantity & quality model.

The model requires also temporal data sets for the initial and boundary conditions concerning the water flow and water quality. These data were assembled during fieldwork survey and historical measurements. Analysis of gathered data has been conducted before being used as input to the model

1.5.2 DUFLOW Model Development

The DUFLOW program developed jointly by the IHE-Delft, TU-Delft and Wageningen Agriculture University, is a microcomputer package for the simulation of 0ne-dimensional unsteady flow and water quality in open channel systems.

The DUFLOW model was developed then evaluated and calibrated using the measured data. Both water flow and water quality parameters in the stream network and the lake were simulated using this model.

1.5.3 Scenario Analysis-Application

Different scenarios were applied to the model and sensitivity analysis of their results was undertaken in response to a range of artificial changes introduced to the input data. The aim of this sensitivity analysis is to measure and analyze the changes in water quality of the lake, and to quantify the effects of these changes.

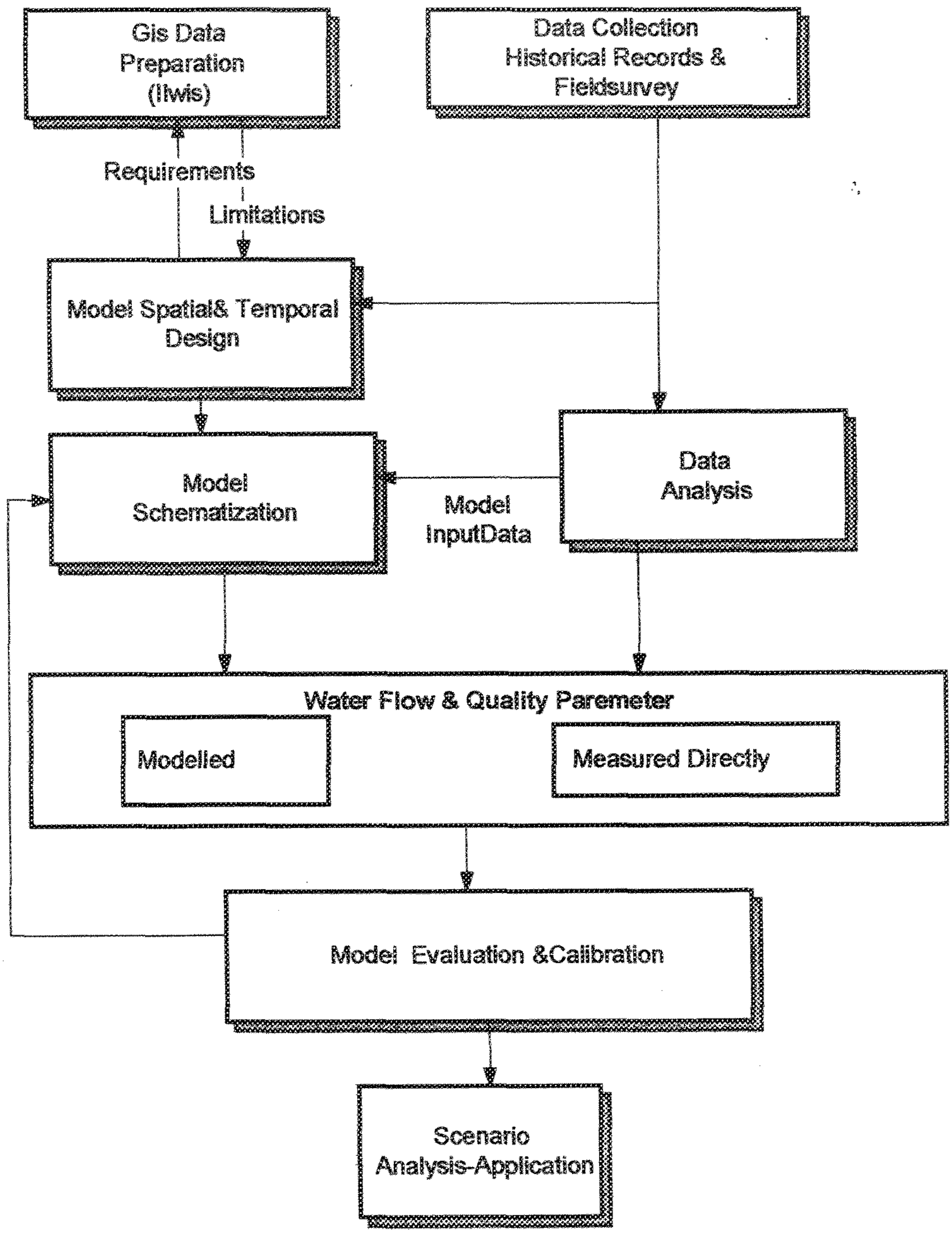


Figure 1-1 Flowchart illustrating the Research Methodology

1.6 THESIS STRUCTURE AND ORGANIZATION

The thesis consists of seven chapters. Its structure and sequence of the chapters represent the steps followed to solve the research problem

In chapter 1 an outline of the study is given. This chapter includes introduction, relevance of the research, problem formulation, research objectives, research methodology, and organization of the thesis.

Chapter 2 gives a general description of lake Naivasha and its drainage basin in terms of geology, hydrology, and water balance.
Also it describes lake Naivasha water quality problems and its environmental management activities.

In chapter 3, the methods of analysis used are explained in detail, beginning with the statistical methods used in data analysis, the GIS methods used for spatial design of the model, and finally the DUFLOW model used for flow and quality simulations.

Chapter 4 describes the water quality survey and assessments carried in the lake, the input rivers and the major pollution sources in the specific study area.
Statistical Analysis of gathered field data and conclusions have been conducted on major problems affecting the Lake Naivasha water quality.
Finally the compliance with water quality guidelines and standards was checked.

Chapter 5 deals with spatial and temporal Design of the model. First all parameters required to run "DUFLOW" program are identified, then it describes how the GIS methods are used to prepare the spatial parameters required through constructing of a DEM of the area in order to delineate the stream network.
Finally an accuracy check is carried on the output from the GIS.

Chapter 6 includes the implementation of the model through model schematization, evaluation and calibration. It describes also the different scenarios carried using the calibrated model.
As example the dissolved oxygen model showing the influence of dairy spill on river Malewa quality and Lake Naivasha. Then sensitivity Analysis is conducted by changing the spill load to assess its effect on Lake Water quality.

Chapter 7 provides the general discussion, limitations of the study, conclusions and recommendations deducted from the findings of the study.

Chapter 2

The Study area Description

The purpose of this chapter is to give a general background information about Kenya with special emphasis on the central rift valley that includes the studied lake Naivasha basin. The main aspects that have been dealt with in this chapter are the lake water balance and the water quality problems.

2.1 BACKGROUND INFORMATION ABOUT KENYA

Republic of Kenya is located in East Africa, of area about 580,370 square kilometers. Sudan and Ethiopia border the country on the north, on the east the country is bordered by Somalia and the Indian Ocean, on the south by Tanzania and on the west by Lake Victoria and Uganda (see figure 2-1).

2.2 KENYA RIFT VALLEY

The study area is concentrated in the Kenyan Rift Valley, 70 km north-west of Nairobi located between latitudes 0°09' to 0° 55' S and longitudes 35° 50' to 36° 42' E.
The central rift valley of Kenya, shown in figure (2-2), is an area of moderate altitude that resulted from formation of the rift. The area forms a catchement for the drainage from two extensive forest stands on both margins of the rift; the Nyandarua Mountains on the east rise to about 3960 m and Mau Escarpment on the west to above 3000m. The catchement presently includes three lakes: Naivasha, Nakuru, and Elmenteita and is beyond the authority of Nakuru district one of famous districts of Kenya.

The floor of the rift valley around Lakes Naivasha and Nakuru belongs to a Tertiary - Quarternary volcanic suite with associated alkaline sediments. It is characterised by exceptionally long and intense volcanic activity from middle Pleisocene to the last few hundred years.

This volcanic activity coupled with other types of tectonic movements has resulted in the formation of several lakes along the rift valley from Israel to the Okavango delta in Botswana. In Kenya among the seven major rift valley lakes Naivasha serves as a good example .To the south of Lake Naivasha, Longnot (3000 m) and several smaller volcanoes form a barrier which is breached by the Nijorowa Gorge (Hell's gate), a former outlet of the lake. To the north, the Naivasha basin is partially separated from the Elemeteita-Nakuru Basin by the Eburu mountain (2668 m).

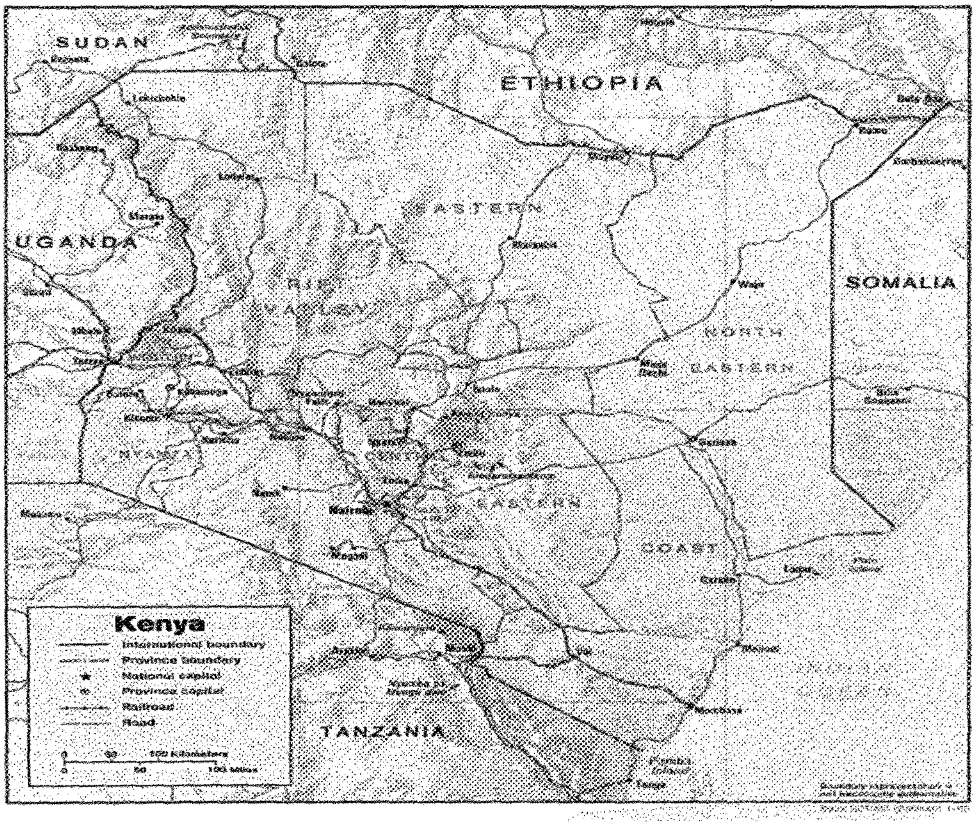


Figure 2-1 General overview of the country location

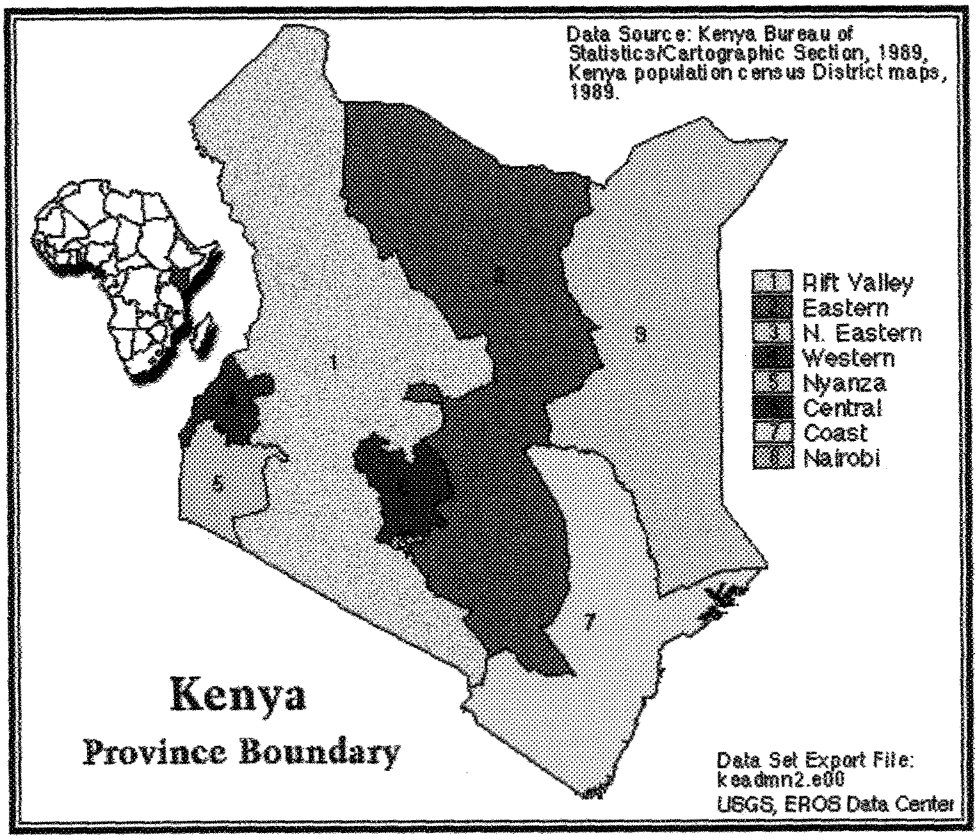


Figure 2-2 Location Map of the Kenya Rift Valley

2.3 LAKE NAIVASHA BASIN

The Naivasha basin is bounded by the Aberdares Mountains to the East and the Mau escarpment to the west, The total area of the catchement is 3200 sq.km and is shown on Figure (2-3). This Figure also shows the existing drainage network in the area.

The main sub-divisions in the catchement are:-(Mavuti 1983)

(i) The Malewa River Basin, including the Turasha River Basin (1,730 sq.km).
Drainage into the Malewa starts among the steep forested eastern slopes from the Kinangop plateau (2,483 m) and the Aberdares (3960+m) where the average annual rainfall is 1087.5 mm. Initial flow takes place in a westerly direction via a number of steeply graded tributaries that, at the lower slopes of the range, develop into four main tributaries, the Mugutyu, Turasha, Kitiri, and Makngi.

(ii) The Gilgil river basin (420 sq.km).
The Gilgil drains a long narrow basin (the Bahati Highlands to the north of the Elementeita-Nakuru basin) in the western part of the Naivasha catchement.
It has few tributaries and rises at an altitude of approximately 2,772 m, in an area where the average rainfall is 1300 mm. The two important tributaries of it are Marundati and Little Gilgil rivers.

(iii) The Karati Catchement; the lake itself; and the areas around the lake to the east, south and west (1,238 sq.Km).
Karati is the other river that flows occasionally into the lake, it drains about 134.7 (sq.Km) and is normally dry for long periods. It rises at altitude 2,6488 m. where annual rainfall is remarkably constant at about 775 mm, and well distributed throughout the year.

2.3.1 Geology of lake Naivasha Basin

The volcanic rocks of the Naivasha area consist of a mixed assemblage of acid and basic lava. In the Southeast and Southwest of the basin fumaroles, Hot Springs and steam vents are found and in the Njorowa Gorge these are being harvested for geothermal power generation. Several of the craters within the basin can be seen along the western side of the lake, one of which contains standing water (Crater Lake).

(Kilham, 1971) described the soils occupying the floor of the rift as grey or brown to pinkish non-calcareous soils. Soils surrounding the origin of the River Malewa, Lake Naivasha's major inflowing river, are young consisting predominantly of montmorillonie clays.

The soils along the northern shore of the lake are generally high in exchangeable Na + and K+ (Makin 1967) while silts, clays and recent lacustrie deposits are found along the northern Eastern Shore of the main lake.

Soils of the south eastern shore are composed of diatomite, while those of the lake littoral zone are less alkaline and more liable to craking (Gaudet 1977).

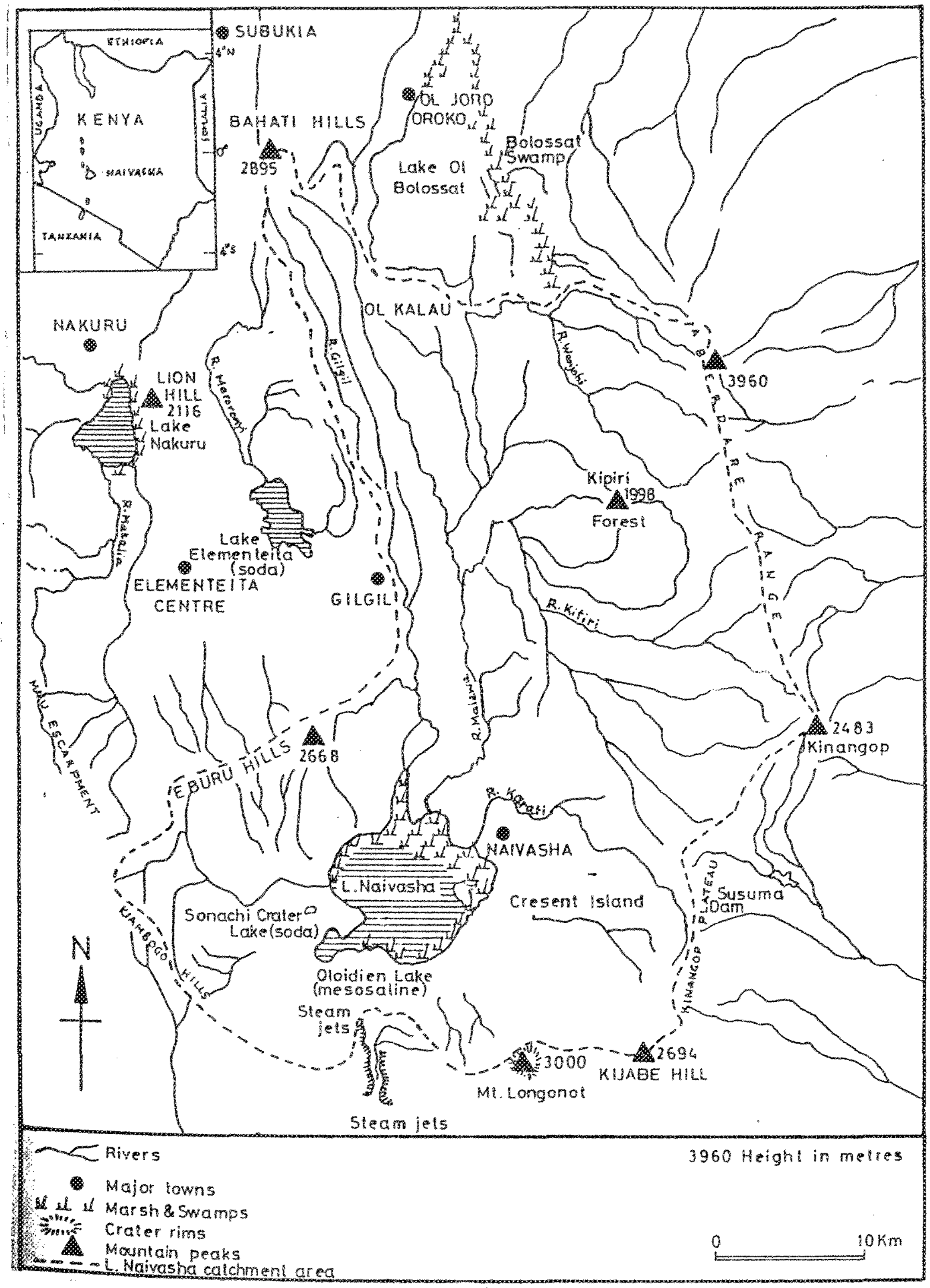


Figure 2-3 A map showing the lake Naivasha drainage basin (Mavuti 1983)

The three rivers enter the lake from the north through a swamp area (11.7 sq.km in area) that spreads out across the north end of the lake. Prior to entering the lake the river diverges into dendritic pattern and disappears under the floating mat of the swamp, no channel could be detected from the air.

The rainfall trend is bimodal, there are two wet seasons with a major peak in April-May and a minor one in October, November and two dry seasons with minimum rainfall in January. The higher rainfall in the elevated regions of the catchement (i.e. Aberdares Ranges and Kinangop plateau) than on the lake.

The catchement is highly modified by human activity, being used for cattle ranching, vegetable growing and dairy farming. These ranches keep beef cattle, and goats and sheep. The water used is generally abstracted from the rivers or from boreholes.

2.3.2 The hydrology of Lake Naivasha basin

The Naivasha Basin, whether or not it is technically a closed basin, behaves hydrologically as if it were one and fluctuates in the manner of a closed lake (Richardson &Richardson 1972). Lake level changes occur continuously. Although these changes in level generally reflect periods of drought versus excessive rainfall there is no simple correlation between any one of input vector on a monthly basis. In other words a mouth with High River discharge may result in Lake Levels other than those which would be predicted on the basis of discharge alone. This may be due to differences in climatic factors, as well as seepage effects which caused a delayed response to changes in the balance, and are of considerable importance in this basin (Gaudet & Melack 1979)

2.4 DESCRIPTION OF LAKE NAIVASHA

2.4.1 Location

Lake Naivasha is located in the eastern arm of the Rift valley, at 80 km south of the equator, at longitude and latitude 0 45' S& 36 20'E at mean altitude 1885 a.m.s.l. It is located within the boundaries of Naivasha division, part of Nakuru District.
The lake has four distinct components as shown in figure (2.4): (Mavuti 1983)

The Main Lake (150 sq. Km) is of maximum depth 6-8 m, mean depth 4m;

Crescent island Bay that forms the deepest part of the lake is presently of maximum depth 15m, mean depth 11m, and is chemically distinct from the main lake, it is the rim of an old volcanic cone and is composed of compact agglomerate containing pumice, tuff and obsidian;

Oloidien Bay (5.5 sq. km) is of maximum depth 7m and mean depth 6m that at low water levels is a separate lake and has considerably high pH.

And Lake Sonachi (0.2 sq. .Km), a small crater lake, 3 Km from the main lake of maximum depth 4 m and mean depth 3 m. is also a part of lake Naivasha system.

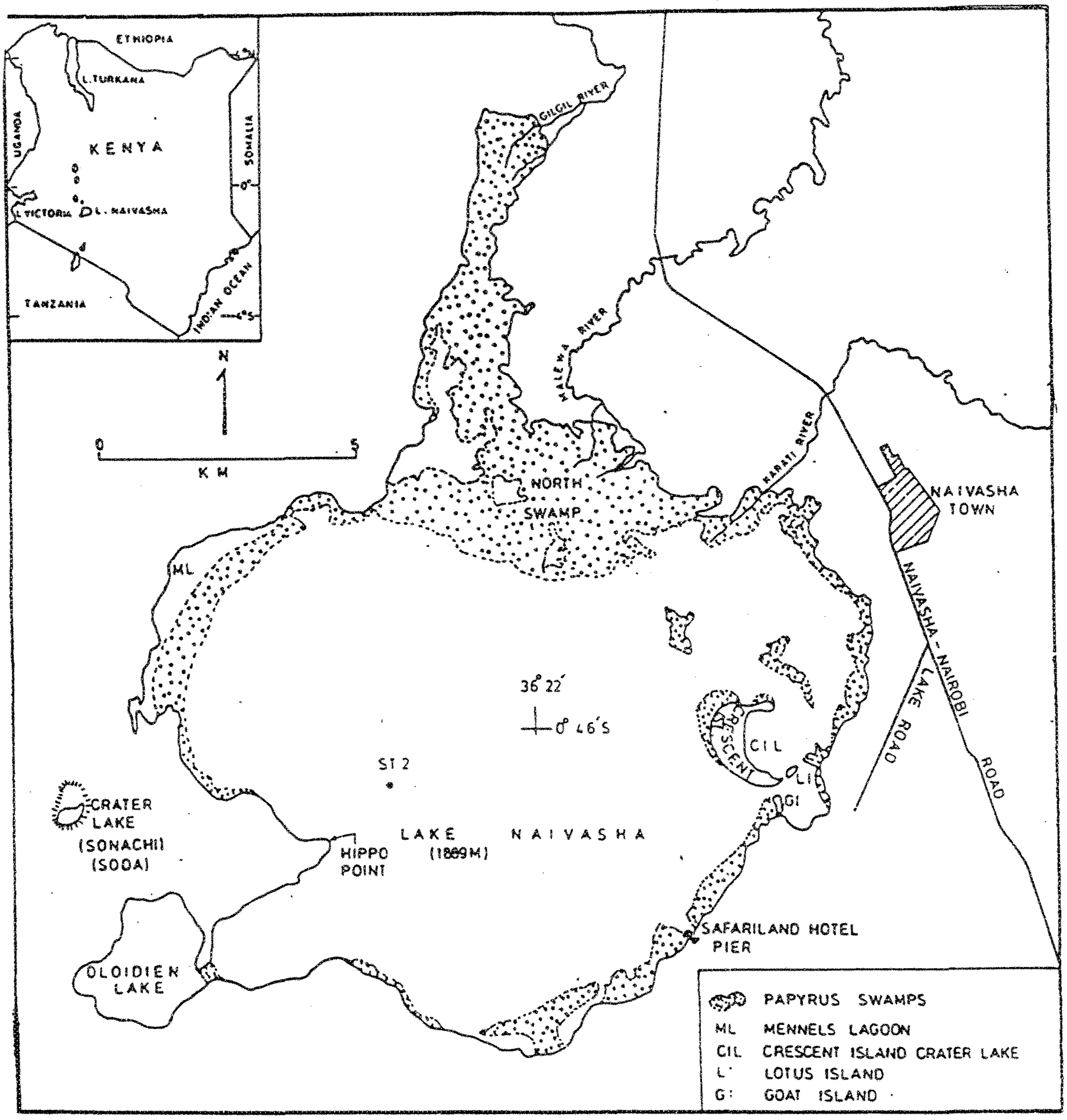


Figure 2-4 Lake Naivasha map (adopted from Mavuti 1983).

2.4.2 Lake History

The lake has only a short written history, though known to Massai and other original inhabitants of the rift valley for centuries. The name Naivasha comes from the Massai "e-naiposha", meaning approximately which is leaving, that which flows to and from". In 1885, Thompson described it as "a papyrus -fringed lake"..."there is no fish though Hippos are numerous. One remarkable characteristic is that it is the habit of enormous numbers of wild. They literally cover considerable area at certain seasons of the year"(Thompson 1985). Its earliest record is that, according to Massai oral history, there was a period immediately before the arrival of first Europeans when the lake was completely dry (Sikes 1935, Edmunson 1977).

2.4.3 Lake Climate

The climate of the area is warm and semi arid (East African Meteorological Dept., 1964). Air temperatures are moderate with monthly means varying little from 5.9 to 18.5 ^{0}C. Seasonal variations in water temperature are also light ranging from 19.5 to 23° C at the surface and from 19.2 to 21.5 ° C near the bottom. The combination of moderate temperature, low relative humidity and low rainfall make January ad February the months with highest evaporation.

Only light breezes are common in the morning but stronger afternoon winds (11 to 15 km /h) are typical, and often produce violent storms on the lake. Winds usually come from the south with the importance of easterly and westerly components depend on season. The stronger afternoon winds in conjunction with night-time cooling usually cause complete mixing in the main lake almost every day and well oxygenated water (5 mg/l) is present from top to bottom (Anon 1978, Melack 1979).

2.4.4 Lake Geology

The geological history of the lake basin determined from core samples records substantial changes in climate during the past 30000 years. From 12000 BP a large (62 sq. km) lake overflowed southward cutting the Nijorora Gorge. By 9200 BP the gorge was downcut to its present day level (2089.4 m) and a 400 (sq.km) lake occupied the Naivasha basin until 5700 BP. Decreasing rainfall reduced the size of the lake and closed the basin. In 3000 BP the lake dried out completely and remained dry for 100 years.

Naivasha is the highest of the rift valley lakes. The older lake sediments are composed of a mixture of volcanic ash, reworked volcanic strata and autochthonous organic matter. More recent deposits lack the volcanic component and form semi-liquidooze (gyttya) substratum (Richardson &Richardson 1972).

2.4.5 Lake Ecology

The lake has always been an important ecological site to Kenya, because of the diversity of flora and fauna in the range of vegetation-zones associated with the lake and the hinterland, which is greater than the rift valley lakes (Lincer et. al.1981).

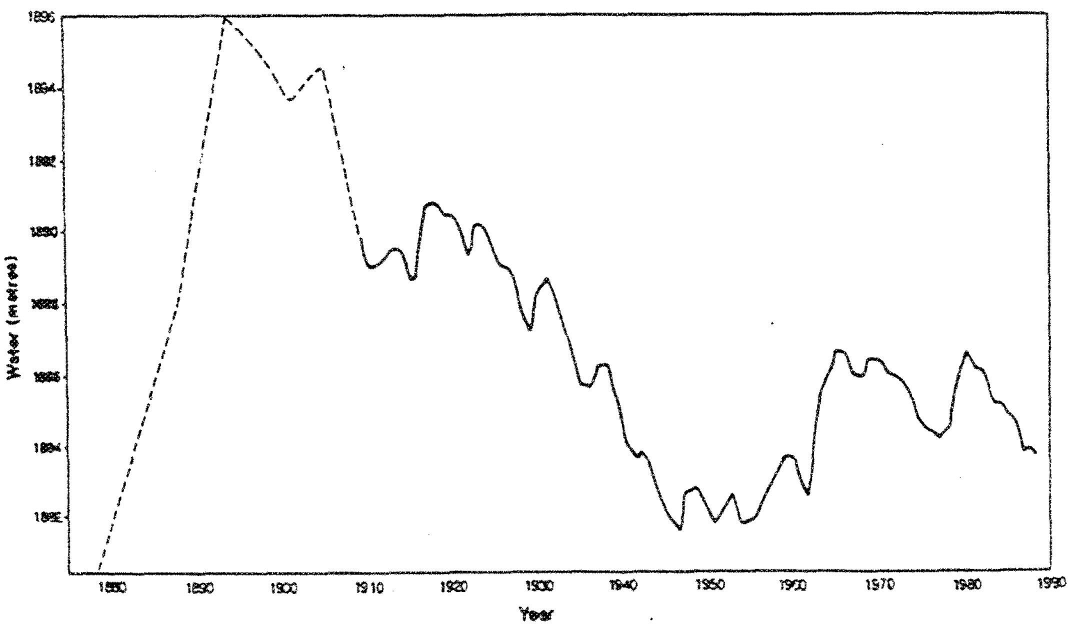
The vegetation particularly the papyrus swamps is the key to the ecological health of the Naivasha lake-system. The buffering effect of the papyrus is well documented, both for the former north swamp area (Gaudet 1979).

2.4.6 Lake Hydrogeology

The Naivasha catchement is in a hydrogeologically complex environment. Borehole record examinations by (Clark, 1990) show that the piezometric surface generally follows the surface contours, i.e. underground movement of water is occurring both axially along the rift (discharge), and laterally from the bounding highlands into the rift (recharge). The data support discharge flow from north and south from Naivasha, with a steeper fall to the south.

2.4.7 Lake Water-Level Variations

Recordings of the water level have been made at three different places around the lake. The details of these gauging locations, correction for datum height and discussion on the collection and presentation of the water level variations (shown in graph 2-1) are given in Ase (1987). For the construction of the part of the graph that covers 1880-1908 the data are uncertain, and consequently are shown with a broken line.
The range of water levels during the past century can be seen to span 15 m.



Graph 2-1 Historical Lake Levels (Ase 1987).

2.5 WATER BALANCE OF LAKE NAIVASHA BASIN

The water balance of the area is complicated; the principal sources that bring water to the lake are inflowing rivers, seepage in and precipitation.

For river discharges, most of the surface water input to the lake comes from the Malewa River (90%). The other streams (Gilgil & karati) are either dry or flow intermittently during low rainfall periods. Maximum discharge normally occurs in September-October.

For seepage in, ground water seepage along the NE and NW shores provided 13-16% of the inflow in 1973-75. For Precipitation, maximum rainfall in the immediate vicinity of the lake occurs in April and allows a slight amount of recharge but is insufficient to offset losses by utilisation (irrigation) and evaporation. The resulting annual deficit is offset by river discharge originated in the elevated regions of the catchement (Aberdares ranges and Kinangop plateau), where there is substantial annual surplus.

The water losses from Lake Naivasha is through evapotranspirration, seepage out and utilisation or abstraction
Evapotranspiration is divided into evaporation from the water body and transpiration from the swamp area and aquatic vegetation.
For evaporation, The climate of Naivasha section of the Gregory Rift is hot, dry and windy. After the April rains, Evaporation increases each month and results in an annual evaporation loss almost twice that of local rainfall. The evaporation output is about 80% of the total output through all pathways.

For seepage-out and utilisation -Between 1973 and 1975 approximately 20% of the total water was lost from the lake as seepage or abstracted from lakeside irrigation.
For Abstraction from the lake, it includes direct and indirect abstraction from the lake.

The Lake Naivasha Riparian Association within the lake management plan (August 1995) estimated preliminary water budget for the area. The results of this study are shown in the following tables (2-1,2-2).

Variables	**Wet Conditions**	**Mean conditions**	**Dry Conditions**
Direct Rainfall on the lake	**939 mm**	**608 mm**	**442 mm**
Open Water Evaporation	**1529 mm**	**1529 mm**	**1743 mm**
Transpiration from swamps	**2141 mm**	**2141 mm**	**2440 mm**
Area of swamps	**18 sq km**	**12 sq.km**	**9 sq.km**
Area of lake	**150 sq.km**	**120 sq.km**	**102 sq.km**
Lake Storage (10^6m^3)	**600**	**320**	**50**
Average lake level(a.m.s.l)	**1888.3**	**1885**	**1882.3**

Table 2-1 Variables used in the water budget (Lake Management plan 1995).

Inputs	Wet Conditions	Mean Conditions	Dry Conditions
Direct Rainfall on the lake	140.8	72.9	45
Malewa River	378	153	53
Gilgil River	74	24	3.2
Karati River	6.5	2.1	0.28
Watershed Unguaged area	117.8	77.9	34.2
Seepage-in	54	54	32
Total Inputs	771.1	383.9	167.7
Outputs	**Wet Conditions**	**Mean Conditions**	**Dry Conditions**
Loss due to transpiration	38.5	26.7	21.9
Evaporation loss	229	183.5	177.8
Seepage out	54	54	32
Abstraction(estimated)	33.8	44.6	53.2
Total Outputs	355.3	308.8	284.9
Balance	+415.8	+75.1	-117.2

Table 2-2 Preliminary Annual water Budget in ($10^6 m^3$) (Lake Management plan 1995).

2-6 WATER QUALITY PROBLEMS OF LAKE NAIVASHA

The lake environment and its natural resources face a number of threats as result of socio-economic activities within the lake and its catchement. Landuse has evolved from pastoralism to sedentary farming and ranching.

Arise in human population density has resulted in intensive irrigated farming, and subdivision, intensive use of agro-chemicals, deforestation and the growth of the Naivasha township. Consequently more runoff, silt and nutrients have been discharged into the lake via inflow rivers.

Also the intensive horticultural activity around the lake has many effects on the water quality of the lake due to possible pollution by fertilisers and chemicals.
Of chemicals applied to crops 30-90% terminates in the soil, some of which drain to the lake during heavy rainfall, Some farmers are suspected of using unacceptable chemicals. Organ-Chloride pesticides, through biomagnification, could affect bird species at the top of the food chain.

The tendency by some Riparian farmers to reclaim more land for cultivation as the lake recedes results in the destruction of fringing marshland and papyrus zones; this subsequently increases siltation and reduces the buffering effects of agrochemical and nutrients on surface run-off.
Additionally, the trend by illegal fishermen to burn fringing papyrus from fear of hiding hippos and buffaloes results in the re-release of bioaccumulated toxins into the lake in the form of ash.

Finally, the rapid expansion of the tourist industry around Naivasha may outstrip the provisions of infrastructure facilities such as sewage disposal and also cause disturbance to natural breeding places and the fragile ecosystem itself.

Chapter 3

Methods of analysis

This chapter describes the methods used for analysis:

(1) The GEO-EAS & SPSS as statistical analysis tool for data.
(2) The GIS-ILWIS, version 2.1 (ITC 1997).
(3) The DUFLOW model, version 2.05 (ICIM 1995).

3.1 GEO-EAS & SPSS STATISTICS PROGRAMS

Before modeling the water quality of rivers and lake, we need to know the following:
- Familiarity with the data by the description of important features of the gathered data using the GEO-EAS program as tool of Analysis.
- The proof that lake Naivasha lake is well mixed lake in order to model it using DUFLOW, this can be checked using T statistic method and SPSS program.

3.1.1 Description of the important data features

GEO-EAS (a geostatistical environmental Assessment Software) is a collection of interactive software tools for performing two dimensional geostatistical analyses of spatially distributed data. This program is used as analysis tool to determine the important data features:

- **Data errors**

Check Data in order to the determination of the possible errors or outliers by:
- Sorting the data and examine the extreme values and try to investigate their origin.
- Locating the extreme values on a map.
- Checking coordinate errors by sorting and examining coordinate extremes.
- Examining the posting of data.

- **Univariate Description**

The univariate tools can be used to describe the distributions of individual variables One of the most common and useful presentations of data sets is the histogram. A histogram records how often observed values fall within certain intervals or classes, It is common to use a constant class width for the histogram so that the height of each bar is proportional to the number of values within that class.

Also the important features of histograms can be captured by a few summary statistics. The summary statistics fall into three categories: Measures of location, Measures of spread and Measures of shape.
The statistics of first group give us information about where various parts of the distribution lie. The mean, the median and the mode give us idea where the center of distribution lies.

The second group includes the variance, the standard deviation. These are used to describe the variability of data values.
The shape of the distribution is described by the coefficient of skewness and the coefficient of variation; the coefficient of skeweness provides information on the symmetry while the coefficient of variation provides information on the length of the tail of certain types of distributions.

- **Measures of location**

The Mean is the arithmetic average of the data values.

Mean $=\frac{1}{n}\sum_{i=1}^{n} x_i$ where n is the number of data, $x_i....x_n$ are the data values.

The Median is the midpoint of the observed values if they are arranged in increasing order. Half of the values are below the median and half are above the median.
Median = $x_{(n+1)/2}$ if n is odd, $(x_{n/2}+ x_{(n/2+1)})$ if n is even where n is the number of data, $x_i....x_n$ are the data values.

The mode is the value that occurs most frequently. The class with the tallest bar on the histogram gives a quick idea where the mode is.

- **Measures of Spread**

Variance is the average squared difference of the observed values from their mean.

Variance $(\sigma^2)= \frac{1}{n}\sum_{i=1}^{n}(x_i - mean)^2$

Standard Deviation is the square root of variance

- **Measures of Shape**

Coefficient of Skewness is a quantity describing the symmetry of the histogram.
If the median is less than the mean this means a positively skewed histogram which has a long tail of high values to the right. In geochemical datasets, positive skewness is typical when the variable being described is the concentration of minor element. If there is a long tail of small values to the left and the median is greater than the mean, as is typical for major element concentrations, the histogram is negatively skewed. If the skewness is close to zero, the histogram is approximately symmetric and the median is close to the mean.

$$\text{Coefficient of skewness} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - mean)^3}{\sigma^3}$$

Coefficient of Variation (CV) is a statistic used to describe the shape of distribution.

CV = ratio between the standard deviation and the mean.

If CV >1 it indicates the presence of some high sample values which causes high variability, if CV=0.33 it means that the data is approximately normal distributed.

- **Bivariate Description**

The bivariate tools are used to describe the relationships between different variables. The most common display of bivariate data is the scatterplot, which is an x-y graph of the data on which the x-coordinate corresponds to the value of one variable and the y-coordinate to the value of other variable.

There are three patterns one can observe on a scatterplot: the variables are positively correlated, negatively correlated or uncorrelated.

Correlation coefficient is the statistic most used to summarize the relationships between two variables .It can be calculated from:

$$\text{Correlation coefficient} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - m_x)(y_i - m_y)}{\sigma_x \sigma_y}$$

Where m is the mean, (x, y) are the two variables and n is the number of samples.

- **Spatial Description**

Spatial features of the data set such as location of extreme values, the overall trend, or the degree of continuity are of considerable interest.

- **Data Postings**

The simplest display of spatial data is a data posting, a map on which each data location is plotted along with its corresponding data value.

- **Variograms**

Variogram is a way to describe the spatial correlation of the sample data set.

3.1.2 Variability Analysis of lake data

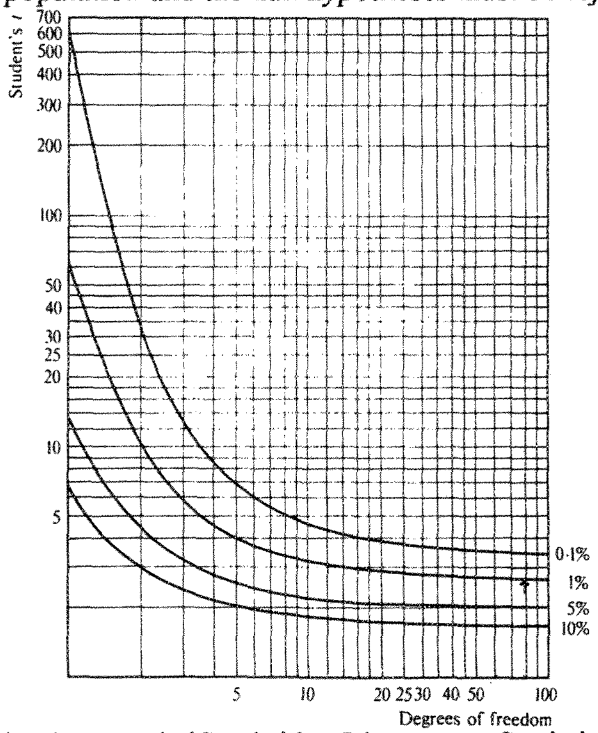
T statistics method is used to determine the variability of lake data with depth especially to check thermal stratification of the lake, i.e. to check the variability of temperature data with depth. This method is used after describing the subpopulation differences in SPSS Statistical Program.

To define different subpopulation, we define different groups of data of same depth as representative of subpopulation, and the procedure Means was run to display the means, standard deviations, and the number of cases for subgroups.

Since T test is a parametric test, it is based on the assumption that the population data are normally distributed. So before applying the T test, the variability within the subpopulation must be assessed first to ensure that the coefficient of variation within the subpopulation doesn't exceed 35% i.e. the data are normally distributed. Then T test is applied between every two successive subpopulation to test the variability between different successive subpopulation i.e. different successive depths. T test provides an index, t, to represent the difference between the means and the standard error of this difference. This index can then be referred to prepared tables or a graph, from which the degree of significance of the difference can be assessed.
Student's t, the index concerned, is readily calculated as follows:

$$t = \frac{difference between the mean}{standard error of the difference} \text{ i.e. } = \frac{|\bar{a} - \bar{b}|}{\sqrt{\frac{\sigma_a^2}{n_a} + \frac{\sigma_b^2}{n_b}}}$$

Where $\bar{a}, \bar{b}$ are the means of two different subpopulation, σ_a, σ_b are the standard deviations and n_a, n_b are the degree of freedom. After calculation of the t index, the degree of freedom must be calculated. The degree of freedom is a measure of sample size that equals $n_a + n_b - 2$. By referring to graph (3-1) using the calculated t index and degree of freedom we can get the corresponding significance percentage of the difference. The percentage value shows the percentage probability of being wrong when one rejects the null hypothesis, which assumes no real difference, exists between the data. If the significant percentage falls into the 5% probability range, so the null hypothesis would have to be accepted and it is therefore possible also to accept the inverse hypothesis and there is difference with no more than a 5% chance of being in error. On the other hand if it falls in the range of 1%, it would be necessary to accept the null hypothesis, i.e.; one had failed to establish a difference. If the significance increases to above 5%, it means one must accept that there is a clear difference between the subpopulation and the null hypotheses must be rejected.



Graph 3-1 Student's t graph (Cambridge Elementary Statistical tables, Table 3)

3.2 ILWIS-GIS SOFTWARE

The software integrated land and water information systems (ILWIS) developed and marketed by international institute for Aerospace Survey and earth Sciences (ITC, 1985) .It is a Geographic information System (GIS) with Image processing capabilities.

The ILWIS software allows you to input, manage, analyze and output geographical data. From the data you can generate information on the spatial and temporal patterns on the earth surface. You therefore can answer such questions as what features, where and when.

ILWIS in this research is used as a tool for construction a GIS the study area. Also ILWIS is used to prepare the spatial parameters used by the water quality model. Finally it is used for the presentation of data and an interpolation between variables because it is a helpful qualitative display (point estimation).

The integration or linkage of the spatial data handling capabilities of a GIS with the model offers the advantage associated with utilizing the full information content of the data to analyze the hydrologic processes.

3.2.1 Construction of GIS of the study area

Geographic Information Systems (GISs) are highly specialized database management systems for spatially distributed data. Geographic information system (GIS) is designed to store, manipulate and display geographic information such as maps of soils, topography, landuse and land cover.

GISs can be classified into two distinct categories, vector or raster, characterized by the way in which analysis is performed on the spatial information. GIS analysis must begin by converting points, vectors and polygons into digital form.
This step is called digitizing. Once in digital form, analysis is either performed on the original polygons, points or vectors comprising the map, or on a raster of pixels (picture elements) replacing the digitized vectors or polygons.

In our research case, topographic maps with all features (rivers, contours, roads), soil, geology maps, sample points, pollution points, lakes, discharge stations points were digitized and attribute tables have been linked to each map containing all possible information in the form of attribute values. Digitized maps have been used for spatial presentation of the area and for qualitatively description of all different parameters.

Also GIS has been used for displaying all water quality variables on a geographically registered map and in colour to correspond with varying water quality levels. This visualising technique is helpful for rapid understanding of water quality conditions.

Some digitized maps have been used in a raster format in order to be able to perform some spatial operations like DEM construction and interpolation techniques that will be described in the following sections and for more details see ILWIS reference guide.

3.2.2 Preparation of spatial input for DUFLOW model

ILWIS was used to prepare some spatial parameters for DUFLOW model like the rivers profile through construction of the digital elevation model (DEM).
The digital elevation model (DEM) is the digital representation of altitude. This can be the absolute altitude in meter a.m.s.l of the terrain surface. It is constructed by performing line interpolation: the estimation of unknown altitude values between digitized, known contour lines.

In line interpolation various steps are recognized. First, a digital contour line map is created. This involves the manual digitizing of contour lines from an analogue topographic map. Once a vector map with the digitized contour lines is obtained, the next step is to convert this information into raster format. The resulting raster map contains both pixels, which have a value corresponding to the elevation of known contour lines, and pixels, which represent the unknown elevations in between contour lines.
So the line interpolation operation in ILWIS integrates the two steps of rasterizing and interpolation. It first rasterizes a segment map representing contour lines and then proceeds with the estimation of values for all unknown pixels by means of linear interpolation. The distances are calculated forwards and backwards, with no more changes occur. Then a linear interpolation is performed using the two distance values.This returns the value for the undefined pixel.

The linear interpolation algorithm in ILWIS defines for each pixel the shortest distance to the nearest higher contour line (d1), and the nearest lower contour line (d2). When the distance values for all pixels are calculated the program will start the process of linear interpolation applying the formula:

$h_{unknown} = H_2 + ((d_2/d_1 + d_2) * (H_1 - H_2))$.Where H1 and H2 are the height values of the higher and lower contour lines.
As example pixel no 1 in figure (3-1) is determined by contour lines with values 0m and value 10m.The distance to these contour lines is respectively 1 and 3 and therefore the pixel value will be ((3*10))+(1*0))/4=7.5 m. This interpolation matches reality.

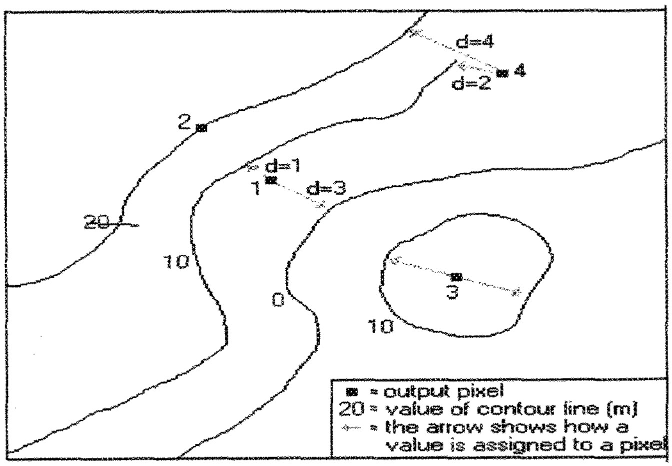


Figure 3-1: Linear interpolation between contour lines.

3.2.3 Point estimation techniques

ILWIS point estimations methods were used instead of ordinary kriging inspite of its advantages because of its time consuming and also the results ordinary kriging depend heavily about our assumptions of the model which are difficult to verify.
This deterministic method of interpolation was chosen also because our final goal of estimation is contouring and representing the gathered data in qualitatively demonstrative way.

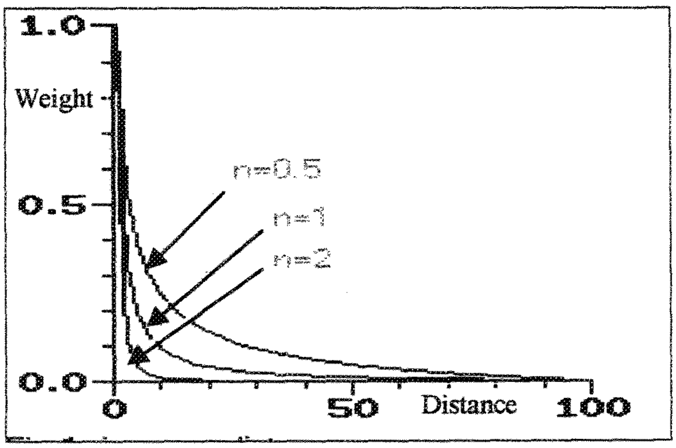
- **Moving average method for lake data**

To estimate unknown values, we use weighted linear combinations where the weights account for the distance to the nearby samples by using the inverse distance method.
This method relies on the idea that that data are more likely to be useful if they are measured near the point of interpolation. Thus more weight is given to the closest samples and less to those who are farthest away.

The value of intermediate point is thus calculated from the summation of the product of the observation values v_i and weights, divided by the summation of weights. The inversely distance algorithm used is by making the weights inversely proportional to any power of the distance.

$$v_1 = \frac{\sum_{i=1}^{p} \frac{1}{d_i^n} v_i}{\sum_{i=1}^{p} \frac{1}{d_i^n}}$$ Where v are the sample values, d are the distances from the p samples.

As we decrease n, the weights given to the samples become more similar .For progressively larger values of n the closest sample would receive a progressively larger percentage of the total weight. Graph (3-2) shows the manner in which weight values decrease when distance increases, for different values of n.



Graph 3-2 the weight at different n values for different distances

3-3 DUFLOW MODEL

DUFLOW model is a deterministic distributed numerical model. The computational core of this model is based on the Fortran computer code that was originally developed by Rijkswaterstaat.

It was chosen in this research due to short learning time and because it includes both simulations of rivers and reservoirs, less input parameters required.

The model is divided into two distinct parts but closely linked (the water flow and quality simulation).

With this program one can perform unsteady flow computations in networks of open watercourses. The model simulates the flow behavior in channel networks. It has shown to provide accurate results for a variety of applications such as: propagation of tidal waves in estuaries, flood waves in rivers, operation of irrigation networks and systems of drainage canals, oscillations and wind driven circulation in harbors, lakes and lagoons.

In the water quality part of DUFLOW, This program is useful in simulating the transportation of substances in free surface flow and can simulate more complex water quality processes specified by the user like eutrophication of streams and etc.

The user can supply the process descriptions. This special concept enables the user to create different types of water quality models; For example non -conservative constituents such as dispersion and transport of sediment and salt, chemical processes of toxic substance (e.g. heavy metals).

Two predefined eutrophication models are included in the package, which is based on the US EPA model EUTRO4.They can simulate the major interactions of the nutrient cycles, algae production, benthic and carbonaceous oxygen demand, atmospheric reactions, and their effect on the dissolved oxygen (DO) balance. The nitrogen cycle is divided into four compartments: organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen.

In a similar manner, the phosphorus cycle is modeled by using two compartments .The primary internal sink of DO in the model is biochemical oxygen demand (BOD). The major sources of DO are surface reaction, algae photosynthesis, and atmospheric rearation.

DUFLOW is a predictive model, especially suited for the simulation of changes in existing systems. It can be used to simulate the behavior of a system due to operational measure such as opening or closing of sluices, switching on pumping stations, reduction of pollutant loads etc., and thus to optimize the day to day management decisions and to evaluate management strategies.

3.3.1 Physical and mathematical background of the model

- The basic equations of water movement are

Continuity: $$\frac{\partial B}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

And

Motion: $$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{\partial(\alpha Q v)}{\partial x} + \frac{g|Q|Q}{C^2 AR} = a\gamma w^2 \cos(\Phi - \phi)$$

Where

T time[s].
x distance as measured along the channel axis[m].
H(x, t) water level with respect to reference level[m].
v (x, t) mean velocity (averaged over the cross sectional area)[m/s].
Q (x, t) discharge at location x and at time t [m^3/s].
R (x, H) hydraulic radius of cross-section [m].
∝ (x, H) cross-sectional flow width[m].
A (x, H) cross-sectional flow area [m^2].
b (x, H) cross sectional storage width [m].
B (x, H) cross sectional storage area [m^2].
g acceleration due to gravity [m/s^2].
C (x, H) coefficient of De Chezy [m^2/s] where Chezy equation is given by:
$q = CS^{1/2} h^{3/2}$ where q is the discharge, S is channel slope and h flow depth.
w (t) wind velocity [m/s].
ϕ(x) direction of channel axis in degrees, measured clockwise from the north[degrees].
Φ(t) wind direction in degrees[degrees].
γ(x) wind conversion coefficient[-].
α correction factor for non-uniformity of the velocity distribution in the advection term ,defined as:

$$\alpha = \frac{A}{Q^2}\int v(y,z)^2 dydz$$

Where the integral is taken over the cross-section A [m^2].

Since for the derivation of this equation, it has been assumed that the fluid is well mixed and hence the density may be considered to be constant, so the advective term in the momentum equation can be written as follows:

The advective term $\frac{\partial(\alpha Q v)}{\partial x}$ can be broken into:

$$\alpha\left(2\frac{Q}{A}\frac{\partial Q}{\partial x} - \frac{Q^2}{A^2}\frac{\partial A}{\partial x}\right)$$

The first term represents the impact of the change in discharge. The second term which expresses the effect of change in cross-sectional flow area, is called the Froude Term.

- **For matter transport equation**

Continuity: $\frac{\partial S}{\partial x}+\frac{\partial (BC)}{\partial t}=P$

Where

S: the transport (quantity of the constituent passing a cross section per unit time).

x: x-coordinate[m].

B: cross sectional storage area [m^2].

C: constituent concentration [g/m^3].

t: time[s].

P: production of the constituent per unit length of the section (g/m.s).

The production term includes all physical, chemical and biological processes to which a specific constituent is subject to.

Several transportation mechanisms can be considered:

- Transportation with the average velocity, the advective or convective transport.
- Diffusion, molecular and turbulent transport.
- Dispersion transport, due to the uneven velocity distribution, wind, mixing in tidal flow, etc.

Diffusion and Dispersion are combined into the dispersive transport. Usually dispersion dominates the diffusion, so the molecular diffusion can be neglected.

S= Sc + Sd

$$= Q\,C - A\,D\frac{\partial C}{\partial x}$$

Sc: Convective Transport.

Sd: Dispersive transport (negative sign because of a positive $\partial C/\partial x$; C is increasing in the positive direction; which gives a transport in the negative x direction.

By substituting the value of S, the mass transport equation becomes:

$$\frac{\partial (BC)}{\partial t}=-\frac{\partial (QC)}{\partial x}+\frac{\partial}{\partial x}(AD\frac{\partial C}{\partial x})+P$$

Q: flow [m3/s].

A: cross-sectional flow area [m^2].

D: dispersion coefficient [m^2/s].

- **Methods of solving equations**

These equations are solved in a numerical way by a so-called finite difference method, which is described in details in DUFLOW manual.

- **Computational assumptions**

The model works only well in case of subcritical flow, this is determined by Froude number which represents the ratio between inertial forces and gravity forces.

$F=\frac{v}{\sqrt{gL}}$ Where v is the mean velocity of flow in m/s, g is the acceleration of gravity in m/sec^2, L characteristic depth in m.

In open channel flow the characteristic depth is equal to the hydraulic depth D, which is defined as the cross sectional area of the water normal to the direction of flow in the channel divided by the width of the free surface.
For rectangular channels this is equal to the depth of the flow section.

When F is equal to unity, $V=\sqrt{gD}$ and the flow is said to be in a critical state.
If F is less than unity, or $F<\sqrt{gD}$, the flow is subcritical as been assumed by the DUFLOW model. In this state the inertial forces become dominant; so the flow has a high velocity and is often described as tranquil and streaming.
If F is greater than unity, or $V=\sqrt{gD}$, the flow is supercritical. In this state the inertial forces become dominant; so the flow has a high velocity and is usually described as raid, shooting, and torrential.

This is why it is advised to take the time step in the model to be:
$\Delta t < \frac{\Delta x}{V}$ Where V is the critical velocity ($V=\sqrt{gD}$) and D is the hydraulic depth of the river. This will avoid the instability in numerical calculations that arise when time step chosen becomes large.

3.3.2 Steps in implementation of the DUFLOW model

- **Model Schematization**

To design the conceptual model for DUFLOW is necessary to examine its data requirements that correspond to:

- Extent of the computational region, in space and time: It corresponds to the name of the region, project, or river, and the period of simulation. This data will be part of the control file.

- Network: The river is devised into sections, or space steps, such as changes in cross sections are reasonable well followed. Neighboring river sections with different length must not exceed the ratio 1:3. Also nodes are selected at the boundaries of the network, junctions. The space step must be a small fraction (1/40th,or less) the wavelength, if any. The time step must also be a fraction of the wave period as described above.

- Once the river has been schematized, the data requirements for simulation are:

Network: It comprises:

1. **Network Definition**: For each river's section is required the section number, the <begin>and the <end> node numbers.
2. **Nodes**: For each node is required: node number, X-Coord, Y-Coord, catchement (the fraction of the total precipitation that discharges to the node).

3. **Sections:** For each section is required: section number, length, aspect, bottom level (height above reference level at the begin and end of the section),resistance in the positive and negative direction (i.e., the channel friction),and the wind conversion coefficient ($*10^{-6}$)

4. **Cross Sections**: For each section is required the cross section profile which is specified by the width-of-flow profile and width-of -storage profile at the <begin node> and the <end node> together with the corresponding depth to bottom for each change in the geometry.

5. **Structures**: It compromises: Weirs, Pumps, Siphons, Culverts, etc.

- Initial Conditions: There are given terms of: initial levels at each node and initial discharges at the beginning and at the end of each section. These initial values can be based on historical measurements, obtained from former computations or from a first reasonable guess.

- Boundary Conditions: These are given in terms of conditions at the physical boundaries of the system and compromise: water level, flow boundary condition or discharge. Conditions can be specified at each node such as: level, discharge and level, rain, wind velocity and wind direction.

- Structure Control: It includes the different operational modes for the structures (as they were not used, no further information will be given).

- Control File:It compromises the calculation definition in terms of:
  - Start of Computation: start date and time of the simulation.
  - Start of Output: start date and time of writing data to the result file.
  - End of Computation :end data and time of the simulation
  - Time step Flow: Time interval used for calculation in the hydraulic part.
  - Time step Quality: Time interval for the quality part of the model.
  - Output interval: Interval for writing data to the result files, starting at <start of <output>. It is rounded to the nearest multiple of<time step quality>.
  - Resistance formula: To indicate the formula to be used for calculating the channel friction.
  - Calculation of Advection Term: To indicate the way in which the advection is to be computed: T (total), D (damped), N (not computed).
  - Extra Iteration: To indicate if the level dependent parameters are calculated from the situation at the previous time.
  - Theta (Hydraulic calculation): It is the factor controlling numerical damping.
  - Decouple: It only takes place at these nodes where a discharge is located. Option N (No) considers dispersion at both sides of a node. Option Y (Yes) considers dispersion only in the forward direction.
  - Theta (Quality Calculation):It is the factor controlling the numerical solution of the advection and dispersion equation.

- **Evaluation of the model**

It is very important to check the results of the very first calculation for a new canal system. The first model of a new network system will contain one or more mistakes concerning the cross-sections, the storage area or the boundary conditions.
The very first results of a new model have to be analyzed in details, to be sure that mistakes are detected immediately. A PC program ECDUFLOW was used for systematic evaluation calculations that are based on DUFLOW output files. Several methods are used to evaluate the model based on the following assumptions:
An arbitrary section as an element of a network system is considered.
The differential equations describing one-dimensional unsteady flow in open channel systems neglecting the wind term and with $\alpha = 1$, are written in the form:

$$B\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (1)$$

$$\frac{1}{gA}\left(\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)\right) + \frac{\partial h}{\partial x} + \frac{|Q|Q}{C^2A^2R} = 0 \qquad (2)$$

Integration of equations (1) and (2) in x direction over the section length gives:

$$\int_1^2 B\frac{\partial h}{\partial t} + \int_1^2 \frac{\partial Q}{\partial x}dx = 0$$

$$\int_1^2 \frac{1}{gA}\left(\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)\right)dx + \int_1^2 \frac{\partial h}{\partial x}dx + \int_1^2 \frac{|Q|Q}{C^2A^2R}dx = 0$$

The results of the integration using average values over the section length (Δx):

$$Q(x_2)-Q(x_1) = -B_{av}\Delta x\frac{dh}{dt} = \Delta F\frac{dh_{av}}{dt} \qquad (3)$$

$$h(x_2)-h(x_1) = -\frac{1}{gA}\left(\frac{dQ_{av}}{\partial t}\Delta x + \frac{Q_1^2}{A} - \frac{Q_2^2}{A}\right) + \frac{\Delta x}{C^2A^2R_{av}}Q_{av}|Q_{av}| \qquad (4)$$

Where $\frac{dh}{dt} = \frac{H_{av}^{n+1} - H^{n-1}{}_{av}}{2\Delta t}$ and $\frac{dQ_{av}}{dt} = \frac{Q_{av}^{n+1} - Q^{n-1}{}_{av}}{2\Delta t}$

ΔF = $B*\Delta x$= SW*L (the average storage width where($L=\Delta x$).
A av = A (the average cross-section area).
R av = R (the average hydraulic radius).
C av = C (The average Chezy coefficient).
Δt = the output interval rounded to the nearest multiple of time step.
Hav, Qav: The average of water level and discharge over a section.

Equation (3) gives the possibility to check the difference between the discharge at point "2" and discharge at point "1" at any time level t for any element, that difference equals the internal storage (mass balance without additional inflow or outflow).
Equation (4) gives the balance between the water level difference over the section Δx and the sum of (local acceleration, advective acceleration and friction terms). These two equations (3) and (4) together give the possibility to check the results of calculations and also the results of measurements.

There are two methods applied to evaluate the model

- **Details of Calculation method** where for a series of output steps all data concerning the two equations (3), (4) are given. So these two equations can be validated for several time levels as defined in output file.

- **Table method** where all terms of momentum equations are presented in a table and a graph is drawn showing the behavior of these terms for different time steps.

- **Calibration of the model**

Calibration means comparing with the measured data and changing the different assumed parameters to reduce the difference between simulated values and real measured values. When the calibration results are satisfactory, it can be concluded that the model parameters are representative for the existing situation. This can be done by evaluating the calibration results qualitatively and quantitatively.

- Comparison between measured and simulated values provides a visual, qualitative measure of the similarity between patterns, thereby giving some idea of the spatial distribution of error in the calibration.

- A scatterplot between the measured against the simulated heads is another way of showing the calibrated fit. Deviation of points from the straight line should be randomly distributed.

- A listing of measured and simulated heads together with their differences and some type of average of the differences are a common way of reporting the calibration results. The average of the differences is then being used to quantify the average error in the calibration.

- **Scenario & Sensitivity Analysis**

So after calibration, the model can be used accurately to run many scenarios, to simulate future conditions. The calibrated model can be used to predict the response of the system to future events.

The object of sensitivity analysis is to measure the effect on the outputs of a controlled perturbation in the inputs of the model. Sensitivity analysis also tests the capacity of the model to reproduce non-linearity of the physical system.
It means that if we increase or decrease by a factor of two, for example, one input condition (internal or external) the model response is not increased or decreased by the same factor. Internal factor like space step, time of simulation, froud number.
External factor like input time series of discharge or rainfall, etc…

3.3.3 Limitations of DUFLOW model

Also the DUFLOW model has some known limitations as follows:

1- The DUFLOW equations are of one-dimensional flow. This means that the flow of the water in a section will be averaged over the width and depth of that section. DUFLOW is therefore not suitable for performing calculations of flows in which extra spatial dimension is of interest.

2- Water bodies with significantly different velocities in the vertical can therefore not be modeled. For instance the model is not valid for stratified water.

3- Although the equations underlying the model are valid in case of supercritical flow, the numerical solution method does not support supercritical flow.

Chapter 4
Water quality Survey and Assessments

This chapter describes the field survey done on water quality of lake Naivasha and inflowing rivers during the intensive program in the field work and includes also a statistical analysis of the data and discussion of the results. Finally the chapter includes an evaluation of the compliance of data with the water quality guidelines.

4-1 WATER QUALITY SURVEY IN GENERAL

A water quality survey has been done in the period (6 Oct. 97 to 26 Oct. 97) to examine the existing water quality of the lake Naivasha, Malewa, Gilgil and Karati rivers. Water Quality and quantity data for the study were analysed from the main lake itself and the downstream part of the main rivers. Also it includes a survey of potential pollution sources affecting the field study area.

Before the analysis of a water-quality data collected, information about the sampling locations, sampling parameters and methods that were used is given.

4.1.1 Sample locations

On the rivers, sample locations were selected near a gauging flow station, so that both stream discharge and water quality data can be collected and analysed simultaneously.

- **Reconnaissance fieldtrips**

This was done by conducting reconnaissance trips to the area, especially the discharge stations; to identify exactly the boundaries of the specific field study; to identify existing pollution sources and pathways of pollutants and conducting discussions and meeting with specialists.

- **Sampling**

In order to have a comprehensive assessment of the lake water quality, input rivers, point and diffuse sources of industrial, urban, agricultural and natural materials must be analyzed in order to determine the complete impacts of all human activities on water quality. Then a qualitative survey of the general condition of the rivers was conducted by collecting samples for Malewa, Gilgil, karati rivers, also a transect survey for lake Naivasha were conducted. Finally samples from different pollution sources were collected. Figure (4-1) shows water quality sample locations visited during fieldwork

These surveys provide the scientific basis for the development of the lake in order to meet the most specific requirements and sensitive uses to which it is subjected.

4.1.2 Sample collection

All samples were taken after identification of their exact locations using a Global positioning system (GPS) and the help of aerial photographs and toposheets.

4.1.3 Sample parameters

Some quality parameters were measured directly on spot in the field like temperature, conductivity, and dissolved oxygen (if possible). Other parameters are measured in the lab on the same day (evening).

4.1.4 Methods of Chemical Analysis

- Nitrate, phosphate, sulfate, turbidity, alkalinity, pH, chloride, hardness analysis were conducted on gathered samples using an aqualytic MP-Fotomer AL 25 and a reflectolab instrument. A Horiba (water quality checker U10 multi electrode instrument) was used in the lake survey. All analysis methods are described in annex B, table (B-1).

- Grab samples were obtained by collecting a quantity of water in a sample bottle (250ml) and a bucket was also used to collect the samples.

- Sample bottles are closed carefully until being analysed.

- All equipment that makes contact with a water-quality sample was carefully cleaned before reuse by rinsing it with a distilled water, filters (0.45 μ) were used when the sample is turbid and filters were discarded after use.

- Field equipment was calibrated before water-quality samples were analysed. We refer to the manual of each equipment that describes the calibration procedures for each parameter measured.

4.1.5 Units of Analysis

The analysis of water samples were expressed in mg/l (milligrams per litre sample) or PPM (parts per million by weight of sample) or mmol/l (millimols per litre sample) or meq/l (milligram equivalents /l).

4.2 WATER QUALITY SURVEY OF WATER BODIES

4.2.1 Water quality survey of lake Naivasha

The water quality survey of lake Naivasha has been done at 50 different point locations and multiple water depths. It was done using a boat on lake Naivasha. This sampling didn't include both lake Oloidien and Crescent island because these locations were not accessible.
Depth, temperature, electrical conductivity, salinity, dissolved oxygen, pH and turbidity were measured at each sampling site at multiple depths (surface, -50cm, -100cm until bottom).

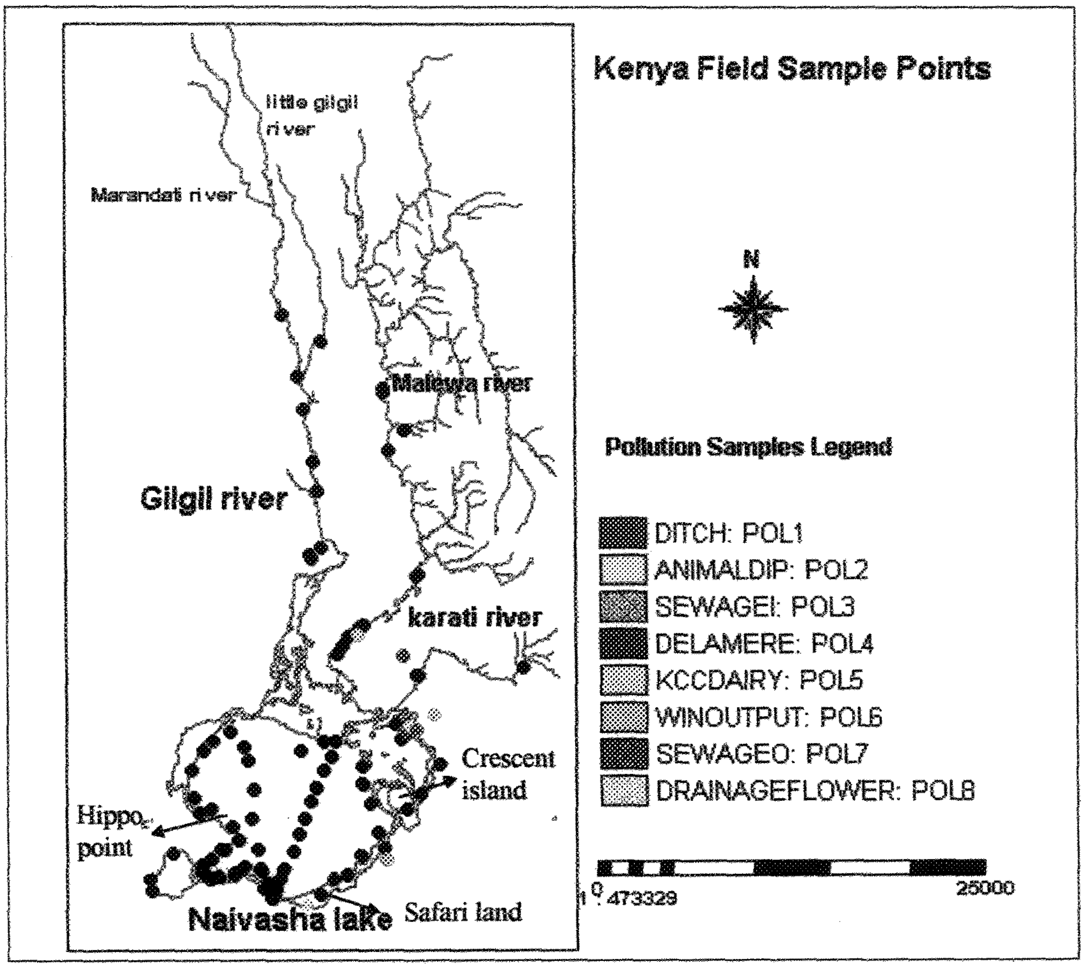


Figure 4-1 Water Quality Sample locations visited during fieldwork (Oct. 97).

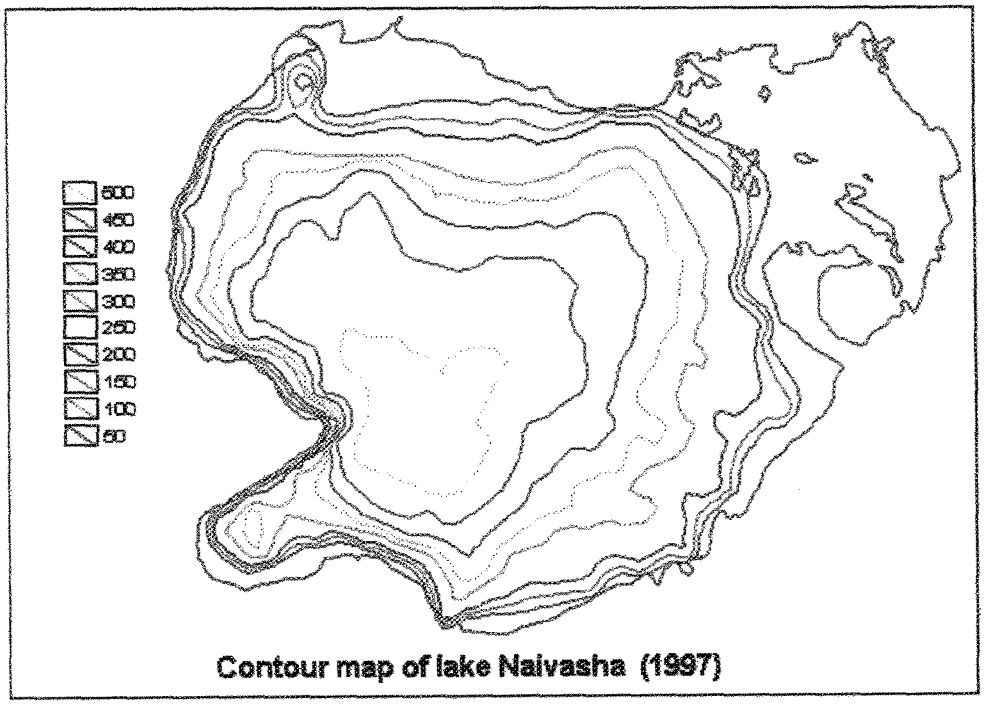


Figure 4-2 Rough bathymetric contour map of lake Naivasha (fieldwork Oct. 97).

- **Bathymetry of the lake**

  - **Depth Survey 1997**

Depth was measured roughly at each sampling site using a bamboo's pole, the above figure (4-2) shows the variations in lake depth from very shallow areas (50cm) to relatively deep areas more than 5m depth and average depth is around 3.8m.

  - **Comparison with previous depth surveys of the lake**

Thompson and Dodson (1963) did the first depth survey of lake Naivasha, but they had no echo sounder so interpreted their results from point readings. Ase (1983) did the first echo sounding survey and produced a very accurate depth contour. Hickely (1991) improved upon the Ase data using an echo sounder and chart recorder. He produced the contour map seen in figure (4-3).

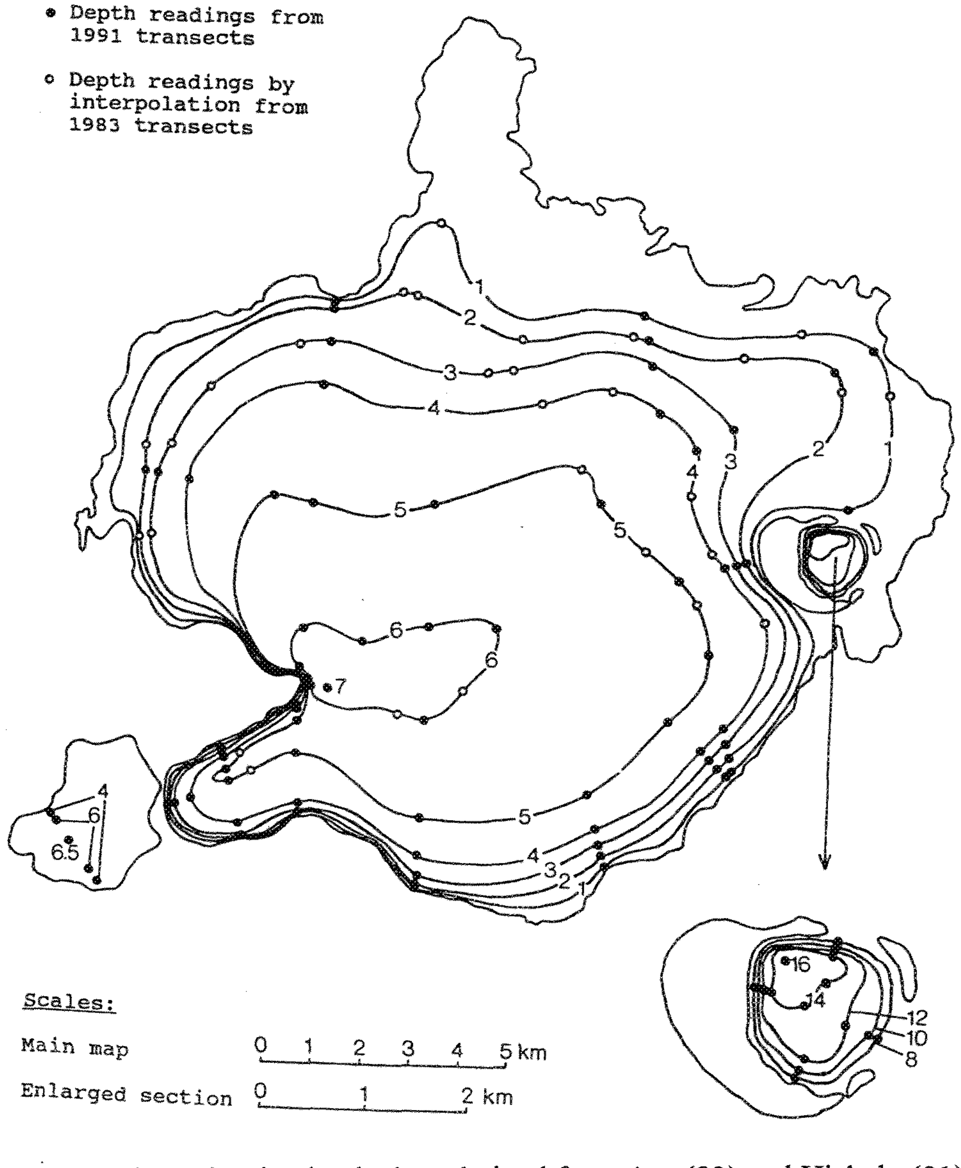


Figure 4-3 Lake Naivasha depth chart derived from Ase (83) and Hickely (91).

- **Thermal classification of the lake**

Thermal classification of the lake provides the basis upon which water quality assessment and interpretation are based.
To classify the thermal status of the lake, the variability of temperature throughout the water column must be assessed. If there is high variation of temperature throughout the water column, this will cause big change in water density. The highest density of water occurs at the bottom of the lake and this can be overlain by colder (0°C-4°C) or warmer (4°C-30°C) waters present in the lake. A clear physical separation of the water mass of different density occurs and when in this condition, the lake is described as being stratified (Chapman, 92).

But when the surface waters cools or warms towards 4°c the density separation is either eliminated or reaches a level where wind can easily induce vertical circulation and mixing of the water masses producing a constant temperature throughout the water column. In this condition the lake is termed homothermal and the process is defined as vertical circulation, mixing and overturn (Chapman, 92).

Since stratification in shallow lakes is rare as they have water mixing throughout their water column due to wind energy input, lake Naivasha can be considered as a well mixed lake. This appears clearly after analyzing the measured temperature data of the lake using the T statistical test described in section (3.1.2).
Data were divided into groups of same depth, four groups were chosen of depths =(20, 100, 200, 300) cm as shown in Table (4-1).
The variability between these groups and the surface layer group was assessed, the output result is given in Table (4-2).

Group#	Group	Group Mean	Standard Deviation	variance coeff %	Cases
1	Temp20	23.39	0.9727	4	43
2	Temp 100	22.43	1.27	5.6	35
3	Temp200	21.59	0.8273	3.8	35
4	Temp300	21.1	0.4908	2.3	22

Table 4-1 The temperature spatial variability of the lake water.

Group	(2, 1)	(3, 2)	(4, 3)
T test	3.683	3.27	2.8
Degree of freedom	76	68	55
Significance %	1%	1%	3%

Table 4-2 The temperature variability over the lake water column.

By looking at table (4-1), we deduce that the coefficient of variance in every group is low which means low spatial variability and also table (4-2) shows that the variability over the water column is very low. The same T test was conducted on the other measured lake parameters. The result ensures that the lake is well mixed and no vertical stratification occurs.

- **Measuring lake's water temperature using remote sensing techniques.**

Surface water temperature can, of course be measured directly by conventional thermometer as was done during fieldwork. However it is not always possible to visit the lake at regular intervals throughout the season especially if some locations in the lake are relatively inaccessible much more efficient and powerful method is the use of an airborne infrared radiometer. In our case, a Landsat 5 TM image (thermal band) taken in January 95, has been used to measure the lake surface temperature using the following procedure:

- In order to extract physical parameters from the satellite it was necessary to convert the raw digital numbers in the different channels to radiance values. The raw digital data is usually delivered on so-called CCT tape where measured radiance are stored in re-scaled digital numbers in a full range. The conversion of these digital numbers back to spectral radiance again was done by using the following equation and by knowing the upper and lower limit of the so-called dynamic ranges for any band:

$$L_i = L_{min,i} + \frac{L_{max,i} - L_{min,i}}{DN_{max}} DN \qquad \textbf{(1)}$$

Where L_i =spectral radiance in band i [mW/cm^2/str/µm].
$L_{min,i}$ =spectral radiance at DN= 0 [mW/cm^2/str/µm].
$L_{max,i}$ =spectral radiance at DN= DN_{max} [mW/cm^2/str/µm].
DN =digital number from the original tape.
DN_{max}=the range of digital numbers from original tape data.

- Because the data is provided in 8-bit format, the maximum digital number is always equal to 255. The minimum and maximum spectral radiance are provided by the Earth Observation Satellite company. For Band 6 of TM, $L_{min,6}$= 0.1238 and $L_{max,6}$= 1.438 in mW/cm^2/str/µm.

- Then the spectral radiance of band 6 was converted to an at-satellite temperature of the scanned earth-atmosphere system. This was done assuming that emissivity equals to one and using equation (1).

$$T = \frac{K_2}{LN\left(\frac{k_1}{L_i} + 1\right)} \qquad \textbf{(2)}$$

Where T = at-satellite temperature in Kelvin [°k].
k_1, k_2 = calibration Constants [mW/cm^2/str/µm].
L_i = spectral radiance in band 6 [mW/cm^2/str/µm].

For TM6 thermal calibration constants are k_1= 60.776 and k_2=1260.5 in mW/cm^2/str/µm.

- The previous two equations were applied on the satellite image band 6 using the map calculation utility of ILWIS and the result was converted from Kelvin to degrees Celsius. Finally a classification was done on the output map using the density slicing option in the image-processing module of ILWIS and the map shown in figure (4-4) was obtained.

- Notice that the atmospheric correction was not done due to lack of data about the atmospheric temperature during the satellite period.

- **Comparison between lake temperature measured using remote sensing techniques and real measurements**

First a comparison is done between the temperature derived from satellite image with the previous temperature data recorded 22.5-24 in Jan 1990 by Harper, we can deduce that the atmospheric error is around 2.5 °c but the pattern found in this year was the same. The lower temperature is in the main lake and the higher is in Crescent island and in Hippo point.

To compare the result with the measured data (Oct.97), a temperature map (figure 4-5) was constructed using the moving average interpolation in ILWIS described in section (3.2.2).
A difference in temperature values ranges from 19°C-23° C in case of temperature data driven from satellite image and ranges from 22°C to 26°C in case of measured temperature data. This difference can be due to difference in season of observation, the satellite image was taken in January 95 and the measured data are for October 97. Also it can be errors from the atmosphere which has a significant effect on the magnitude of the temperature extracted from satellite data.

But as we are not really interested in the exact temperature value so a spatial comparison can be made between the two maps. We can notice by looking at the two figures that the temperature pattern is almost similar. In relatively deep areas, in the middle of the lake, the temperature is relatively lower, and in the Hippo points in the western side of the lake and in the northern side near the river inputs and the northwestern part of the lake the temperature is higher.
This warmer temperature may probably be due to a wind-driven water movement (wind direction in the measurement day was from SE to NW). So shallow surface water was driven towards the western part of the lake. We notice also that in both maps, the crescent island is warmer than the main lake by about 1.4°C.
In the satellite map, it appears some red spots in the main lake which are of colder temperature referring to water hyacinths existing in the lake (see photo 4-1, 4-2).

From the above discussion, it is advisable to use remote sensing techniques as a tool for monitoring the surface lake temperature.

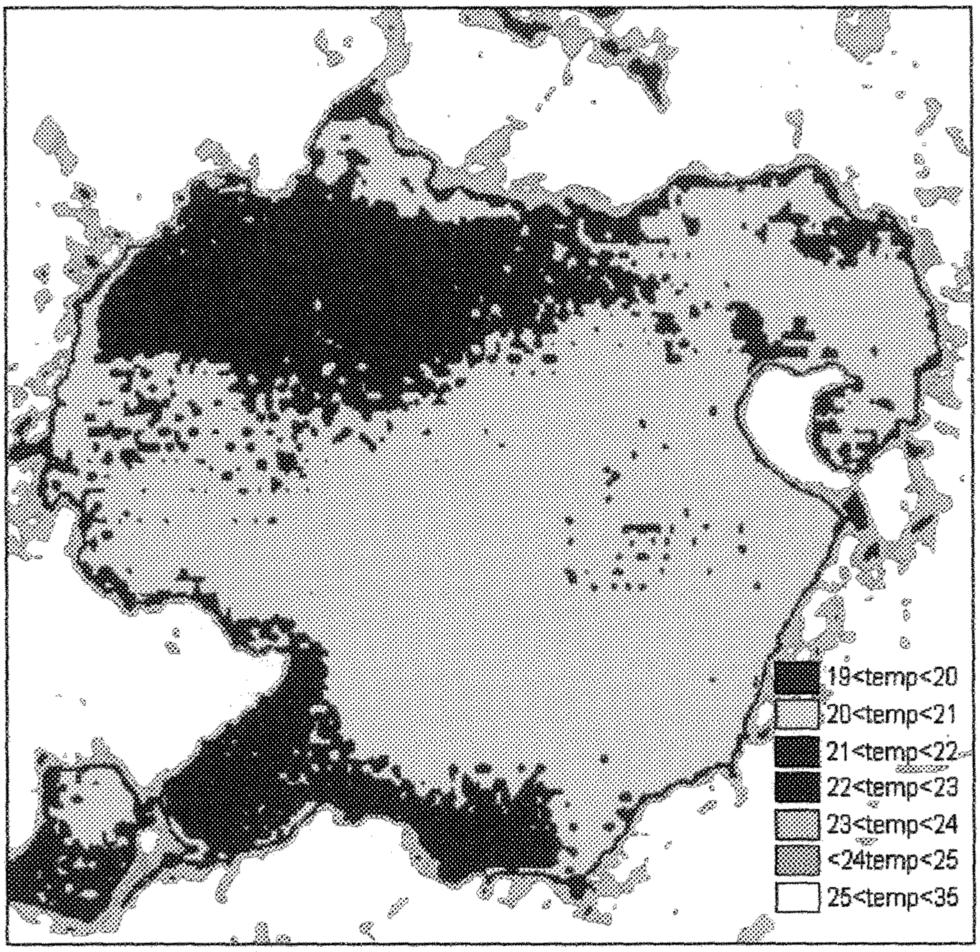


Figure 4-4 Temperature map of lake Naivasha derived from TM 6 (Jan.95)

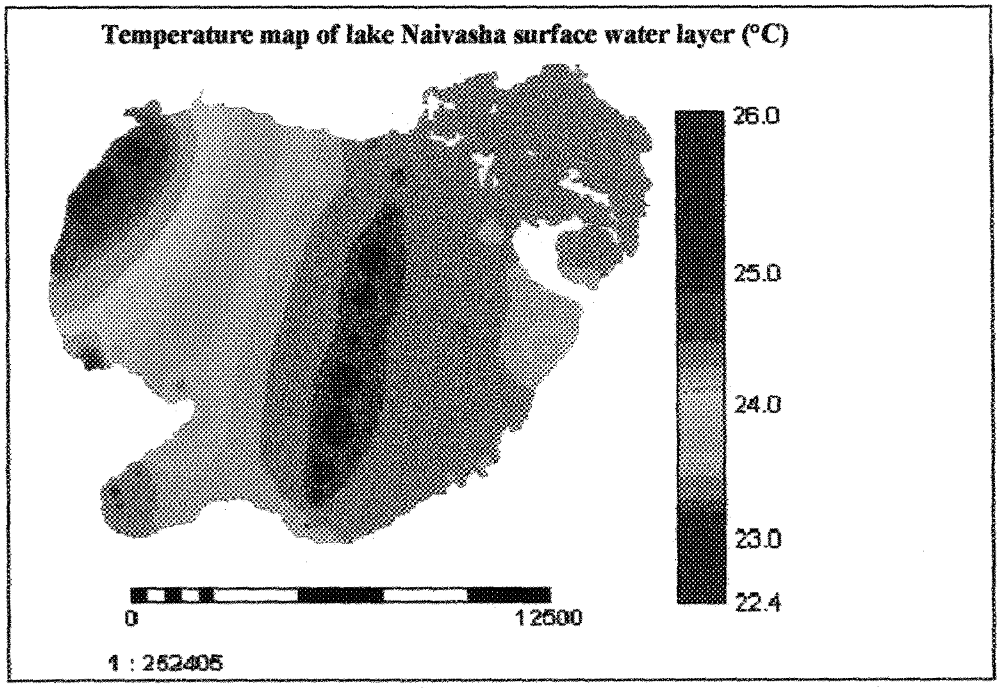


Figure 4-5 Temperature map of lake Naivasha derived from field data (Oct. 97)

Photo 4-1 Water hyacinths in the lake

Photo 4-2 View of the lakeshore

- **Eutrophic Status of the lake**

The word eutrophication is used to describe a serious degradation of water quality, this degradation results from the accumulation of plant nutrients, sediments, silt and organic matter in the lake from surrounding watershed.

One way to inspect the eutrophic status of the lake is to study the dissolved oxygen concentrations in the lake as the amount of oxygen in the water is an important indicator of overall health of the lake. It is essential for aquatic life. Without oxygen, a lake would be an aquatic desert devoid of fish, plants and insects. There are also many chemical reactions that occur depending on whether or not oxygen is in the water.
For this reason, many experts consider the dissolved oxygen to be an important parameter to characterize lake water quality.

Two maps showing the oxygen distribution in the lake were constructed, one map for the upper layer (figure 4-6) and the other for the bottom layer of the lake (figure 4-7). These maps were made using moving average point interpolation technique in ILWIS as described in section (3.2.2), This technique was applied on gathered field data.

We notice that the values of DO range from 7.1 mg/l to 11.5 mg/l in lake upper layer. The Do increases in some regions due to existence of algae and aquatic plants, which causes the increase of oxygen production. This can be indication that the lake is susceptible to eutrophication. These areas are almost nearby the river inputs.
DO decreases in relatively deep areas in the middle of the lake.

We notice also that the values of DO ranges from very low 0 to 7.8 in the lake bottom layer. The oxygen depletion on the lower layer is because of active population of decomposers like bacteria, fungi and other organisms living on the lake bottom which need oxygen to break down organic matter that originate from the watershed and lake itself. DO concentration at the bottom layer increases in relatively shallow areas where there is more diffusion of oxygen, which is aided by turbulence (e.g., wind), to be distributed in the lake water.

By comparing the two maps, we notice that at the areas where the concentration of oxygen in the bottom layer is almost zero, this corresponds to very high DO in the upper layer (11.5 mg/l) and big algae blooms. As example the Hippo point at the western side of the lake.
This correspondence can be explained that as algae populations die and sink to the bottom of the lake. Their decay by bacteria can reduce oxygen concentrations in bottom waters to levels, which are too low to support fish life, resulting in fish kills.

Also when oxygen is reduced to less than one mg/l on the lake bottom, several chemical reactions and also anaerobic biochemical reactions occur within the sediments. Notably, the essential plant nutrient, phosphorus can be released from its association with sediment-bound iron and moves freely into the overlying waters.
Due to wind energy and vertical mixing process, this phosphorus may be transported into the upper layer where it can be used by algae and aquatic plants. This internal pulse of phosphorus often termed (internal loading) can thus accelerate algae and aquatic plant problems associated with cultural eutrophication.

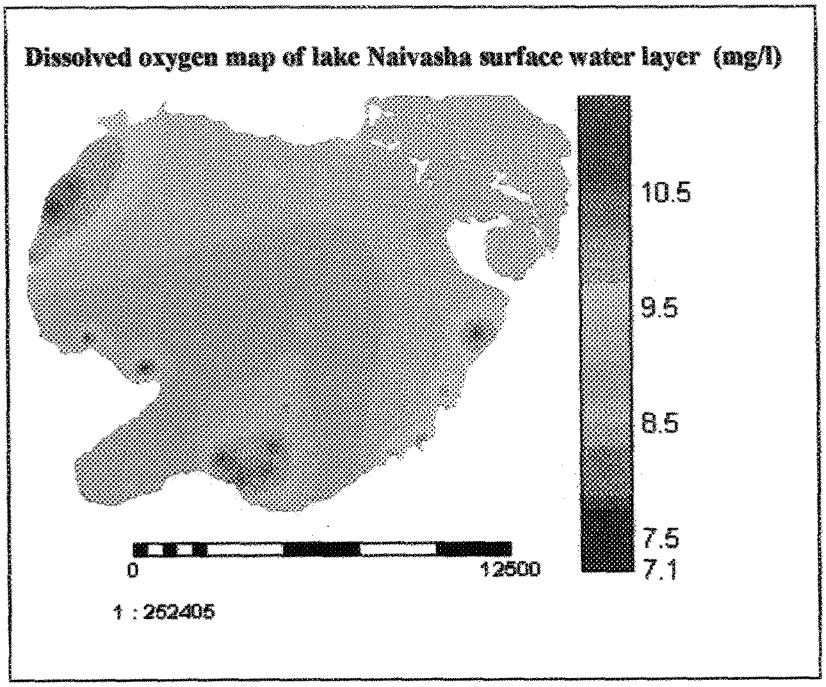


Figure 4-6 Dissolved oxygen map of the surface water layer of lake Naivasha.

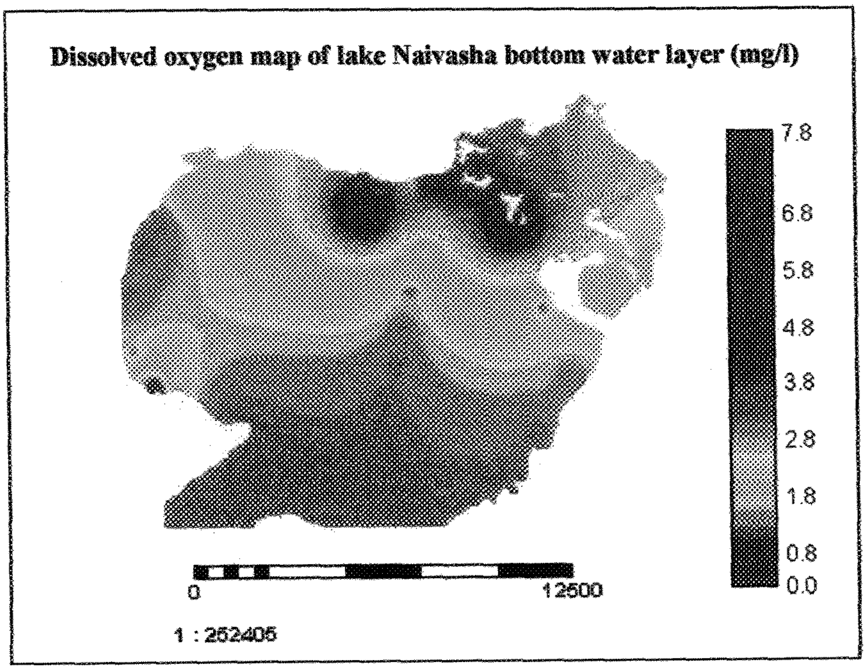


Figure 4-7 Dissolved oxygen map of the bottom water layer of lake Naivasha.

- **Acidific Status of the lake**

Sampling for pH has been conducted to provide an indication of the acid/base status and the buffering capacity of water. A map for pH was made using moving average interpolation technique in ILWIS on the gathered sample data for the upper lake layer.

By looking at the pH map (figure 4-8), pH ranges from the max value 7.9 at the Crescent island and at the Hippo point and the lowest value of pH is in the middle of the lake. Because pH was measured during daytime, the photosynthetic reaction also may influence pH and may explain also partly observed variations.

- **Salinity Status of the lake**

Electrical Conductivity of lake water is a measure of the total concentration of ions and gives an indication of total dissolved salts and a measure of water quality.
Conductivity was measured at different locations of the lake and a map for conductivity was made using moving average interpolation technique in ILWIS on the gathered sample data for the upper lake layer.

By looking at the conductivity map (figure 4-9), conductivity was highest at the eastern side of the lake at Hippo point with value 464 us/cm.
Conductivity at Crescent island is lower approximately 456 us/cm whereas conductivity in the middle of the lake in front of Safari land is lower 449 us/cm.

- **Suspended Matter Status of the lake**

Some of the silt and organic matter that enter the lake does not settle to the lake bottom. Instead it remains suspended in the water. These suspended matter, also the algae population in lake water, decrease water transparency and can affect the suitability of the lake habitat for some species.

So turbidity was measured at different locations, it is a measure of total suspended matter in the lake and an indication of amount of suspended matter going into the lake and the algae concentration. A map was made for turbidity distribution around the lake.

From the turbidity map (figure 4-10), we can notice that the turbidity is highest at the western side near the crescent island and is minimum in the middle of the lake and in the eastern side of the lake near the Hippo point. The increase of turbidity at the western side because it is nearby the Karati river outlet that can carry many suspended sediments.

Also by inspecting turbidity data towards the bottom of the lake, it increases to max at the bottom layer due to sediments particles which quickly settle on the bottom, this is called (sediment turbidity) .

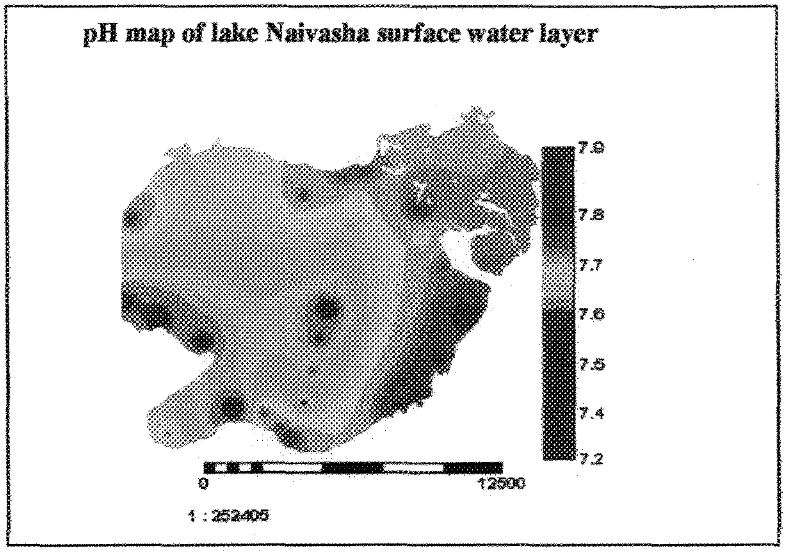


Figure 4-8 pH map of lake Naivasha.

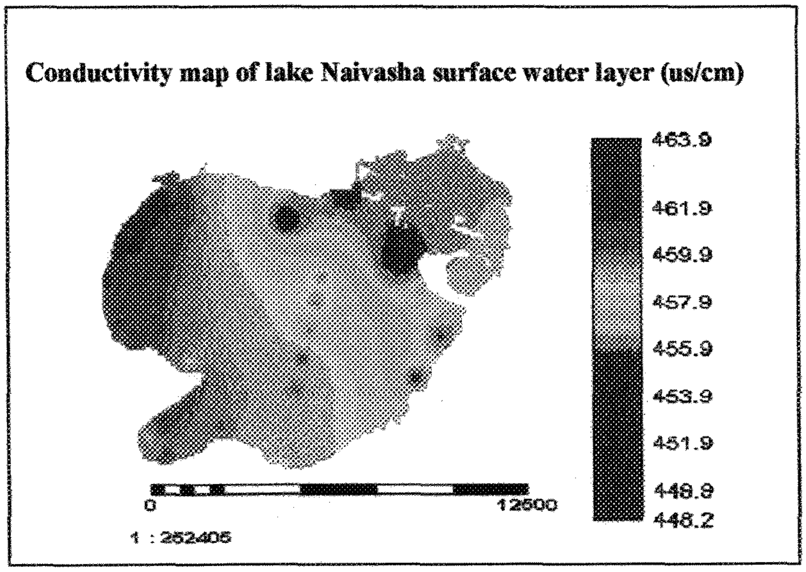


Figure 4-9 Conductivity map of lake Naivasha.

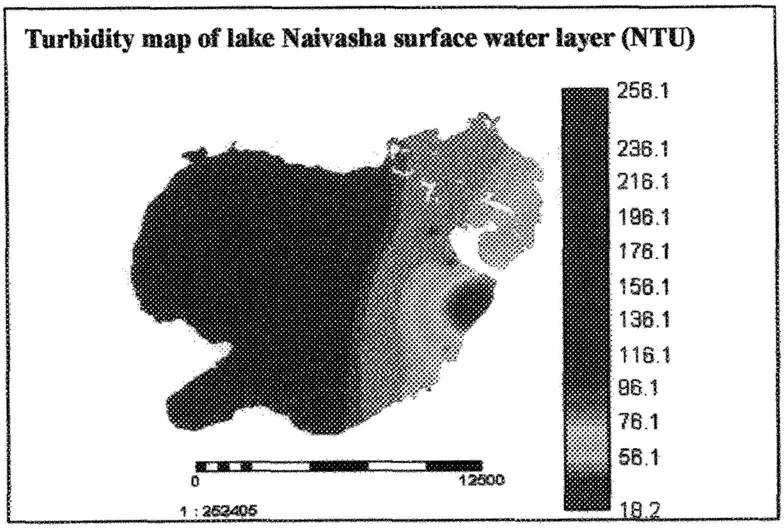


Figure 4.10 Turbidity map of lake Naivasha

4.2.2 Water quality survey of input rivers, lake shore and Oloidian lake

Sampling of the rivers water were carried at one depth assuming that the rivers were well mixed and homogeneous with respect to water quality at each sample point.

- For Malewa river upstream up to a distance of 25.5 km from the lake, samples were taken to investigate the change of water quality along the river towards the lake. Samples were taken especially in the areas where Malewa river passes nearby different farms i.e. (Homegrown, Marandati, and Marula) which cultivate summer beans, Macadami, lucerne and strawberries. Also samples were taken nearby different dairy farms and dairy factories like the dairy training center and the KCC factory. A sample was taken at the discharge station (GB1), and a sample was taken in Kasuki river, a tributary of Malewa river joining it before the discharge station GB1. Finally samples were taken from Malewa river upstream in order to compare the water quality of Malewa river downstream and upstream, all these samples were taken approximately the same day so that all hydrological conditions were similar. Photos 4-3, 4-4 show the various use of river Malewa at the sampling sites.
- For Gilgil river the upstream up to a distance of 27 Km from lake shore, samples were taken to investigate the change of water quality along the river towards the lake. Also samples were taken from Marandati river at discharge station (GA3), also from little Gilgil river at discharge station (GA5).
- For karati river, the third river entering the lake, few samples were taken downstream and upstream because it was dry during fieldwork period.

The average water velocity and average depth were measured for all sampled rivers using a current meter. Aeration rate was calculated using Isaacs formula (1969).

$$K_2(20°C)=2.833 \frac{V}{H^{\frac{3}{2}}}$$

,Where K_2 is aeration rate in day^{-1}, V mean stream velocity (ft/sec), H mean depth (ft). The calculated aeration rates for rivers are in table (4-3).

River	Velocity(ft/sec)	Average depth(ft)	Aeration (day^{-1})
Malewa	2.6	0.733	11.7
Gilgil	1.7	0.425	17.38
Little Gilgil	0.7	0.2	22.17
Marandati	0.324	0.65	1.75

Table 4-3 Aeration rates calculated for rivers included in the study.

- For the lake shore, several samples were taken especially in the southern lake shore and in easily accessed areas because it was difficult to reach the lake shore from the boat due to presence of Hippos at almost all the lake shore points.
  But some samples has been successfully taken from farms shore lines like Kjabe far, Aberdare farm, Sulmac farm, lake flower farm, win factory, Gold Smith, Fish Eagle, Elsamere and Yaght club shores. Also few samples were taken to investigate the water 'quality of Oloidian lake, and to compare it with the lake Naivasha water quality.

Photo 4-3 Human Use of river Malewa

Photo 4-4 Use of river Malewa for Agriculture

4.3 WATER QUALITY SURVEY OF POLLUTION SOURCES

A detailed survey of pollution sources affecting the area of study was made and the following is an inventory of existing point sources.

The industrial (leading business) in Naivasha Division

(a) Pan African Vegetables and Foods (Production of dehydrated vegetables, mainly for the export market);
(b) Economic Housing group (Production of prefabricated houses);
(c) Kenya Co-operative Creameries (Handles all aspects of milk production);
(d) Kenya commercial Bank;
(e) Pharmaceutical & Horticultural Inputs Ltd. (manufacturers);
(f) Njowang'a Motors garage;
(g) Naivasha Farm inputs Ltd. (animal feeds);
(h) Donleah ltd. (Hardware supplies);
(i) Njonge Glass Mart;
(j) Ng'anga General Hardware;
(k) Alert Agencies (Hardware);
(l) Win factory.

Also the non-functioning municipal sewage treatment plant of Naivasha town (Oct.97) is an important source of pollution, the flower farms drainage output, the animal dip locations, ditches from agricultural farms.
Samples were collected from some accessible pollution sources:

- **Naivasha sewage treatment works(NSTW)**

The NSTW plant, which was constructed in 1984, stopped its operation in 1992 because of vandalism of essential accessories in the main power switchboard, which deprived the main pumps of power. The electrical fittings for the industrial area extension were also vandalised. As a result the two main pumps, the four aerators and an additional sludge pump lack electrical power and cannot be operated.
Absence of aeration causes a very stench to emanate from the plant. Impaired through flow causes frequent flooding by sludge of the surrounding areas during and after rain, causing a heath risk to neighbours and Naivasha town residents.

Samples were taken from input to the plant and from the ponds of the plant itself and at the effluent out from the plant.
The result of analysis of sample shows that the sample of input and the outfall is about the same, very high chloride, ammonium and nitrate which shows the non-functioning of the sewage treatment plant.

Fortunately this outfall is not directly to the lake but it is through a ditch in the Kignoto area but it can influence severely the ground water in this area especially that this area gets the drinking water from a private well nearby the sewage outlet.
So leaching of the contaminated water can easily pollute the ground water and will cause serious health diseases in the surrounding areas. Photos 4-5 and 4-6 show clearly the sewage plant and the sewage outlet in Kignoto area.

Photo 4-5 The sewage treatment plant inlet.

Photo 4-6 The sewage treatment plant outlet.

- **Sample taken from wine factory output**

Wineyards is as factory for producing wines from cultivated grapes. Wastewater is discharged in the soil without any treatment. By making analysis of the wastewater from the factory we notice that the sulfate content is extremely high about 475 mg/l, the chloride content is very high (250 mg/l) also the ammonium content is relatively high (26 mg/l).

- **Sample taken from the dairy outputs.**

KCC and Delamere dairies are the most famous dairy farms existing in Naivasha area. A sample from the wastewater output has been taken from each to analyse, the output shows a high content of chloride in both, also a very high content of sulphate especially in case of Delamere farm. Ammonium and nitrate contents are very high in both samples.

- **Sample taken from drainage line in Shah flower farm**

Shah flower farm was shone to represent the water quality in the drainage lines of flower farms which are many in Naivasha area and on which depends most of the economy of the area. The main type of flowers cultivated in Shah farm is rose for which many fertilisers and pesticides are used.

The main fertiliser used is Urea and calcium nitrate about 30 tons/month each; the main pesticide used is Sulphur powder about 3000 kg/month.

From the analysis of the sample in the drainage line near the flower farm, it shows a very high chloride content and also a relatively high Ammonium and nitrate content.

- **Sample from non point source (a ditch from agriculture field)**

A sample was taken from a ditch in Pelican Farm (see photo 4-7). This farm is used to cultivate maize as a main crop, the sample analysis shows a relatively high amount of chlorides 86 mg/l and a relatively moderate nitrate and ammonium about 5 mg/l. The sulphate value is very high 25.5 mg/l.

- **Sample take from animal dip near Pelican farm**

Manure of animals is a major pollutant in Naivasha area (see photo 4-8).
From the sample analysis, we notice extremely high salt content (chlorides =1250 mg/l) also a very high sulfate (175 mg/l), very high Ammonium (50mg/l) and a relatively high nitrate (8 mg/l).

Photo 4-7 A sample from a ditch on a farm.

Photo 4-8 A sample from animal dip.

4.4 DATA ANALYSIS AND INTERPRETATION

4.4.1 Check data validity and outliers

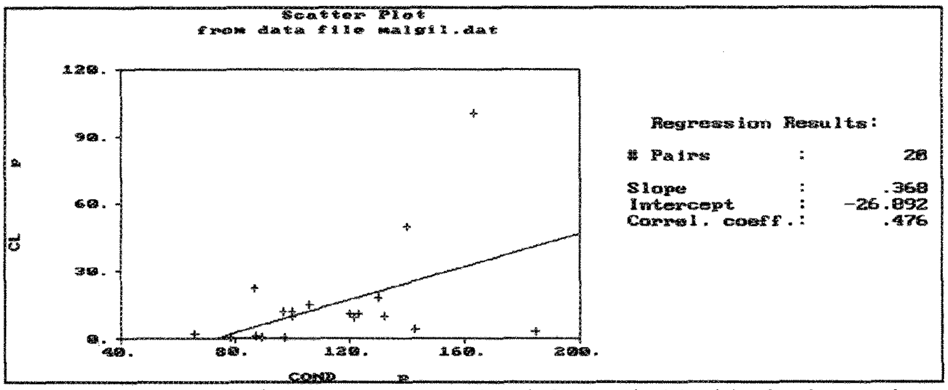
All data has been checked by drawing postplots of all data to verify if there were some outliers in the data and the data were also revised for any error in typing before entering the data in a GIS database.

4.4.2 Univariate analysis

An univariate analysis on all parameters was conducted as described in section (3.1.1), the output results are shown in Annex B, table B2.

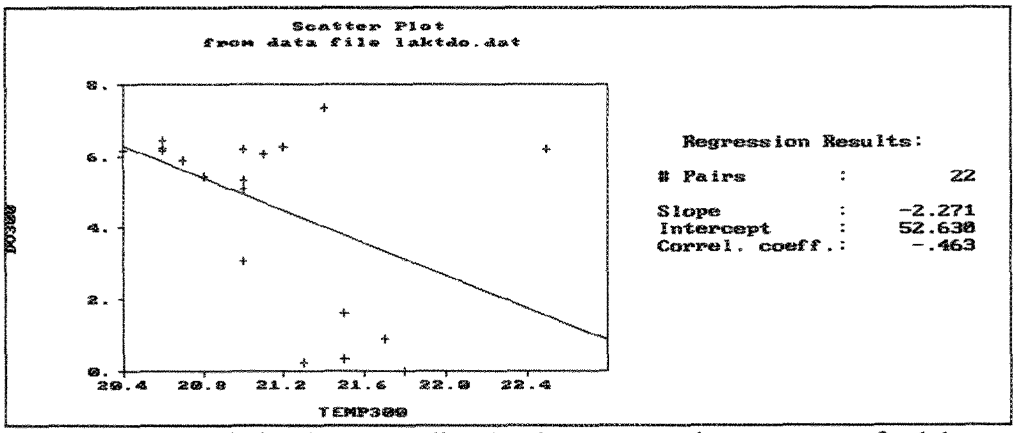
4.4.3 Bivariate Analysis of data

Some bivariate analysis examples have been done for the data. By drawing a graph for correlation study between conductivity and chlorides in rivers, we deduce that the correlation coefficient is about 0.5 which can be expected because the conductivity is a measure of total salts.



Graph 4-1 Correlation between conductivity and chloride for input rivers.

Also a bivariate analysis has been done for lake data between dissolved oxygen and temperature at the upper layer of the lake, the correlation was about -0.5.



Graph 4-2 Correlation between dissolved oxygen and temperature for lake Naivasha.

4.4.4 Spatial Analysis

A spatial analysis of water quality was made for rivers Malewa and Gilgil and also for the lake Naivasha transect sample results.

- **Rivers profiles**

By drawing the profiles of different water quality parameters against distance, we can analyze the trend of changes in water quality towards the lake.

- Malewa river

After inspecting the profiles of different parameters shown in graphs (4-3, 4-5, 4-7 and 4-9), we notice that:
The overall trend of conductivity increases gradually from about 80 to 130 us/cm when the river enters the swamp towards the lake. Also there is a quite abrupt increase in conductivity at the GB2 discharge station.
The turbidity is fluctuating, increasing trend at GB2 station, decreasing afterwards, and finally increasing towards the lake, this fluctuation can be due to the different characteristics of river bed and associated water turbulence at different sampling points.
pH values are relatively constant 6.5-7, this value is close to the natural value in case of rivers draining volcanic rocks.
DO values range from 6-8 mg/l, especially high values of DO at discharge stations (GB1, GB2), due to the hydrological structures which increases the river water aeration rate.
Phosphate values are relatively low but they increases in parts of rivers crossing the different farms , the value of phosphates in water reaches 1mg/l in Malewa river nearby Olmogogo, Homegrown farms and also nearby the dairy training center.
Nitrate values range from 1 to 7 mg/l, it reaches its max value in the river near KCC factory for milk processing. Also nitrate is relatively high nearby the dairy training center.
Ammonia ranges from (8 mg/l) nearby KCC factory and Marandati farm and increases to max (26 mg/l) nearby Homegrown farm.
Sulfate values are relatively high in the area nearby the eastern rift margin due to the composition of nearby rocks (kinangop tuff).
Chloride values differ so much between dry period and rainy period, the average value of dissolved chlorides in the first week of the field was 7 mg/l but in the beginning of rainy period it reaches an average of 15 mg/l.

- **Gilgil River**

After inspecting the profiles of different parameters from graphs (4-4,4-6, 4-8 and 4-10), we observe that the overall trend of conductivity increases gradually from about 87 to 163 us/cm when the river enters the swamp towards the lake. Also there is abrupt increase in conductivity at the diversion of the river.

pH values are relatively constant about 7. DO values range from 5-11 mg/l, especially high values of DO were measured downstream near the lake swamp.
Phosphate values are relatively low but they increase in parts of rivers crossing the different farms , the value of phosphates in water reaches 5mg/l in Gilgil river nearby Suswa farm . Nitrate values range from 1 to 3mg/l. Ammonia ranges from (8 mg/l) and increases to max (18 mg/l) nearby Suswa farm. Also it has a relatively high value in the irrigation canal. Sulfate values are moderate about 17.7 mg/l. There is an overall trend of increase in chloride value towards the lake.

By comparing the results of Gilgil river with both Marandati and little Gilgil rivers, we notice that the conductivity of little Gilgil is the highest about 180 us/cm, also the dissolved oxygen is higher in little Gilgil than in Gilgil river due to higher aeration rate.

Karati river

Samples from Karati river show a high conductivity and chloride content, this is because that it was almost dry and there is seepage and accumulation of salts. Also the sulfate content is extremely high reaches 600 mg/l. The nitrate and ammonium values are relatively high especially downstream at Manera farm.

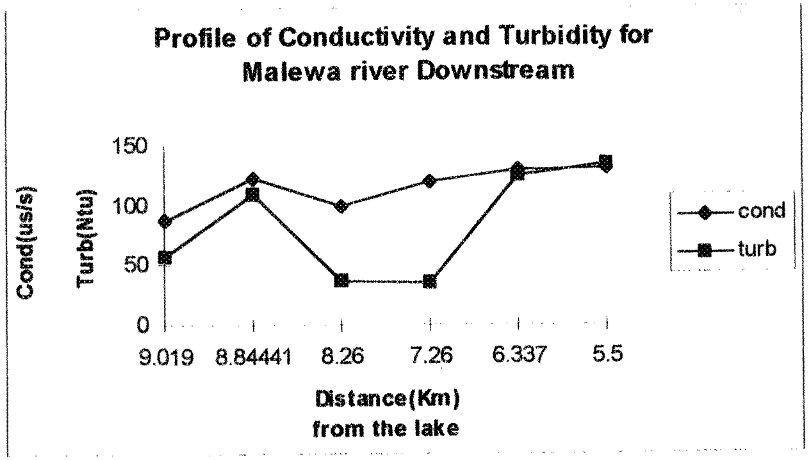
Lake Shore line

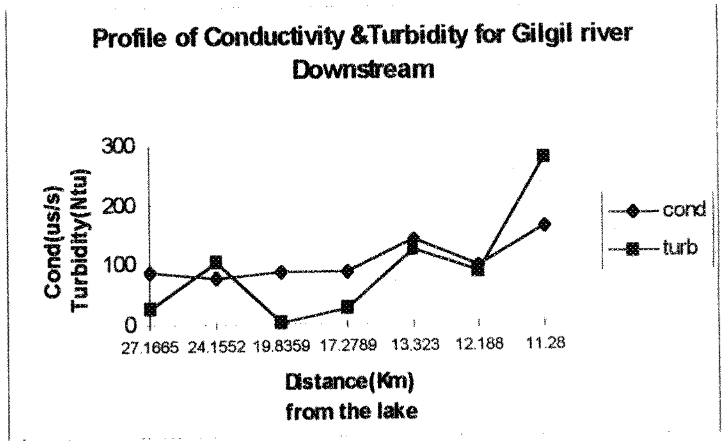
By inspecting the results of the analysis of the lake shore line water, we notice that the chloride value is higher at some farm lake shores (average =250 mg/l) compared with the main lake itself (average =35 mg/l). Also that the sulfate value at the lake shore is higher (average=50mg/l) compared to main lake (avereage=20mg/l).

Oloidien Lake

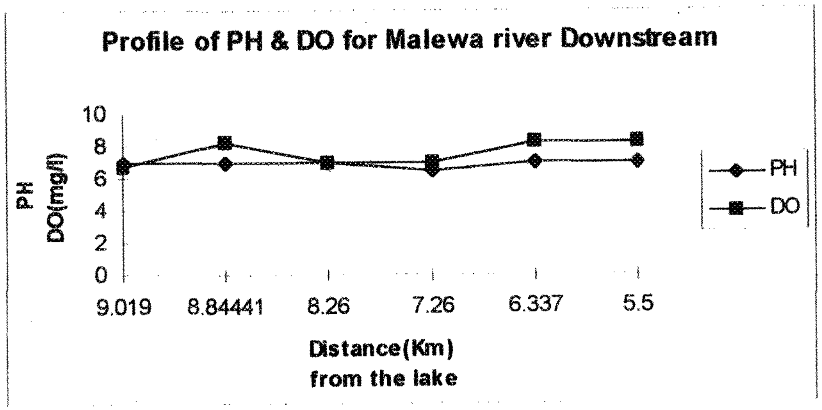
Oloidien lake lies only 0.5-1 kilometer to the south of lake Naivasha. Some bucket samples were taken from Oloidien lake. The result analysis shows a large difference between the water composition of Oloidien lake and Naivasha lake.
Oloidien is much more saline with a electrical conductivity lake of 3400 us/cm about 7 times the conductivity of lake Naivasha. The chloride concentration is high about 250 mg/l. Oloidien lake is an alkaline lake as its pH value is about 10 .The alkalinity is about 34 mmol/liter. This is totally different from the nearest point in lake Naivasha whose pH value is 7. This might indicate that there is almost no interaction between the two lakes.

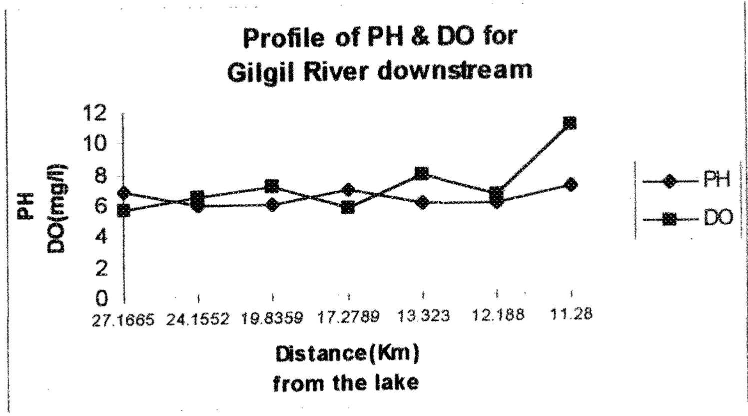
Oloidien lake as compared to lake Naivasha, presents quite dismal picture with only few species of very mall fish, several species of salt-tolerant aquatic plants, and dense growth of blue-green algae. In general very few species are supported by such a simple system, compared to the species supported by the system complex of Lake Naivasha.



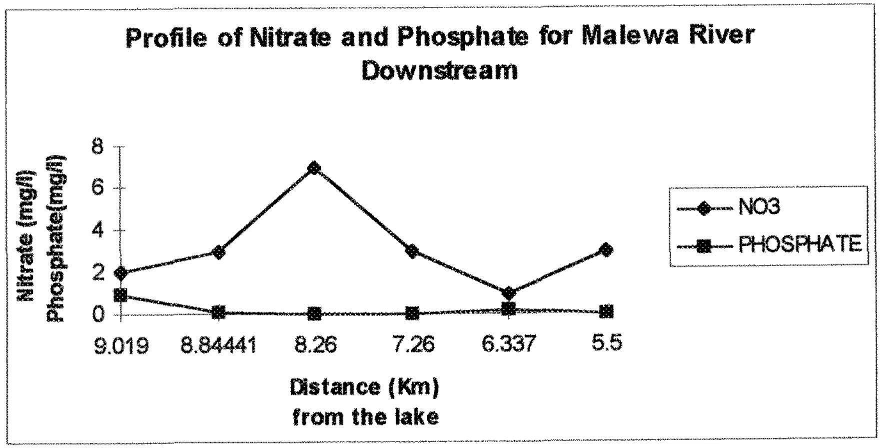


Graph 4-3 Profile of Conductivity & Turbidity for Malewa river. **Graph 4.4** Profile of Conductivity & Turbidity for Gilgil river.

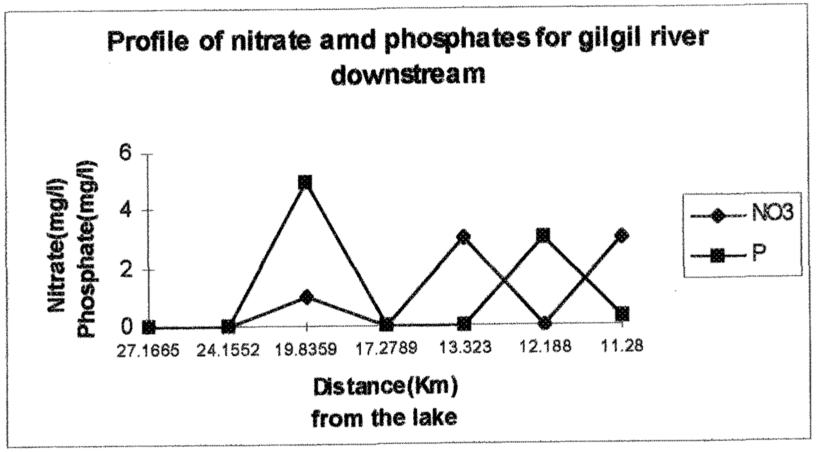




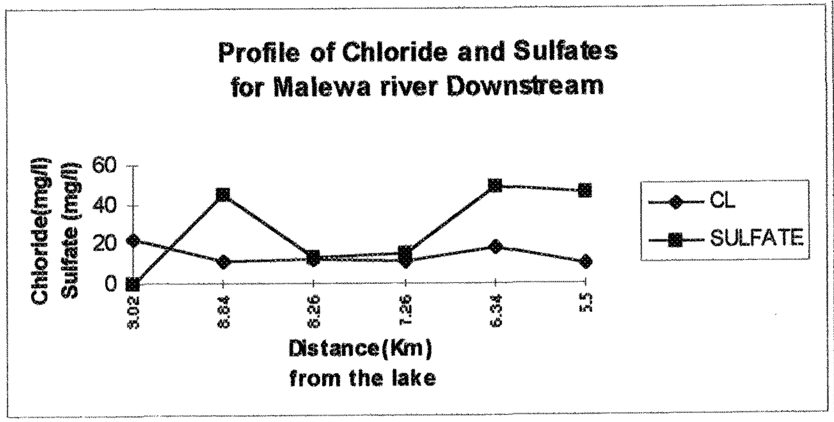
Graph 4.5 Profile of pH & DO for Malewa river Downstream. **Graph 4.6** Profile of pH & DO for Gilgil river Downstream



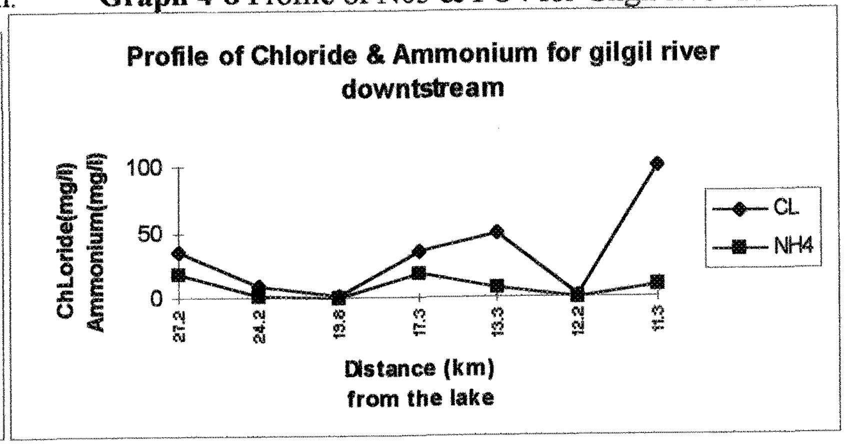
Graph 4-7 Profile of N03 & PO4 for Malewa river Downstream.



Graph 4-8 Profile of N03 & PO4 for Gilgil river downstream.



Graph 4-9 Profile of Chloride & Sulfates for Malewa river

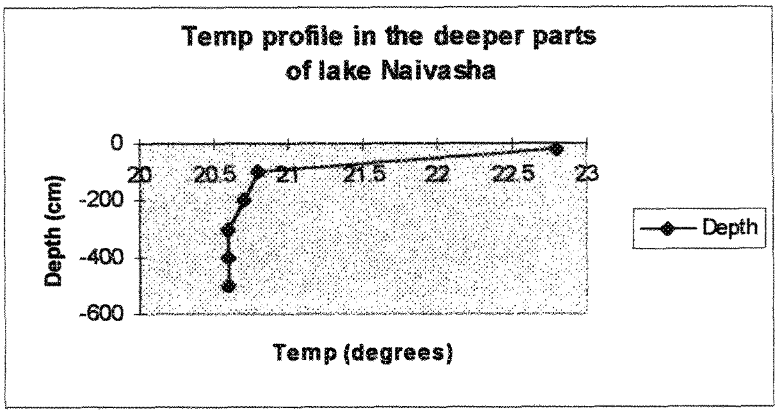


Graph 4-10 Profile of Chloride & Ammonium for Gilgil river

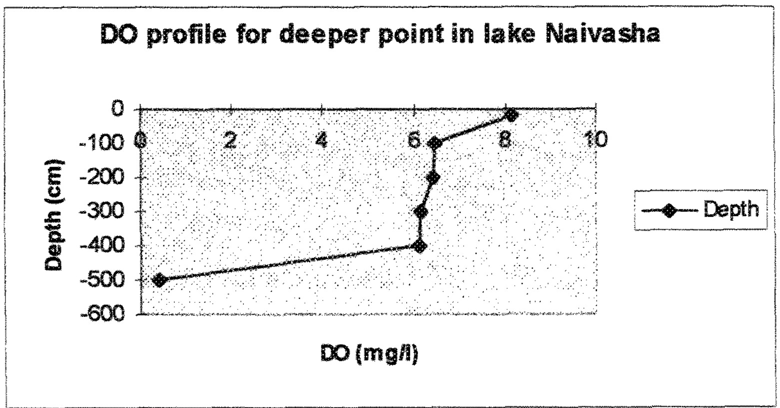
- **Naivasha lake Profiles**

  - **Dissolved oxygen and temperature profiles**

To characterize the oxygen condition in the lake, it is useful to make a depth profile of oxygen measurements taken from top to bottom which may provide insight on the relative populations of oxygen producing plants and bottom dwelling decomposers. Also temperature profiles were drawn at the sample site. The sampling site was chosen directly over the deepest portion of the lake basin as shown in graphs (4-11, 4-12).



Graph 4-11 Temperature profile in deeper parts of lake Naivasha.



Graph 4-12 Oxygen profile in deeper parts of lake Naivasha.

By looking at above graphs, we notice that the temperature is almost constant throughout the water column at the exception of the surface layer.
Also oxygen concentration is almost constant except at the bottom water layer of the lake due to depletion of oxygen at the bottom layer natural process described before.

Similar oxygen-depth and temperature-depth profiles were measured at almost all observations (61 points).

4.4.5 Discussion

From above analysis, we can conclude that the major problem of the lake is that it is susceptible to eutrophication due to important algae growth.
Also the excessive growth of algae may interfere with different water uses like recreational activities and for swimming and fishing.
This important algae growth can be due to increased supply of nutrients to the lake.

Another problem of the lake is an increase in bottom sediment layer, which may cause a decrease in water level .The gradual filling-in of a lake, is a natural process however.
Streams carry sand, silt, clay, organic matter and other chemicals into the lake from the surrounding watershed. These materials settle out once they reach quieter waters which cause an increase of bottom sediment layer.

Since the major source of nutrients and sediments are the input rivers, and as these nutrients and sediments can be greatly accelerated by human development in the watershed as appeared in the rivers data analysis.
As example the increase in agricultural practices will increase the nutrients in the river waters and also will contribute to the sediment pollution of the lake.

We can assume that a large fraction of nutrients and other chemicals are transported to the lake as sediment sorbed matter. We analyzed here only the soluble fractions. Chemical mass input budgets are therefore higher than the river water quality analysis may indicate.

So it is necessary to quantify and qualify the input from this rivers by establishing a model, which simulate their behavior and predicting the future influence of any activity in the watershed on lake water quality.

4-5 COMPLIANCE WITH WATER QUALITY STANDARDS

4.5.1 Assessing the water quality of lake and river for drinking water purpose

A comparison is made with WHO guidelines for drinking water. The comparison was done for Malewa, Gilgil rivers and lake water as shown in table (4-4).

Variable	Guideline Value	Number of Non -Compliant values rivers	median of non-compliant values rivers	Number of Non-Compliant values lake	median of non-compliant values lake
Chlorides (Cl^-)	<150 mg/l	-	-	3	336.7
Sulphates (SO_4^{2-})	<250 mg/l	-	-	-	-
Phosphate	<7 mg/l P	-	-	1	9
Nitrates	<100mg/l N	-	-	-	-
pH	6.5-9	-	-	-	-
NH_4^+	<0.6 mg/l	9	14.5	4	5

Table 4-4 Comparison between gathered water quality data and WHO guidelines.

For the rivers data, only the concentration of ammonium exceeds the limit for the use of rivers and lake water in drinking purpose. Also for the lake data, chloride concentrations exceed the limit to use the water for drinking.

4.5.2 Assessing the water quality of effluent discharges with Kenyan government guidelines

A comparison was made with Kenya Guidelines since the legislative control acts are based upon these guidelines. Details about these guidelines are in annex A.

Variable	Guideline Value	Number of Non -Compliant values	median of non-compliant values
PH	6-9	-	-
Sulfates	500	1	680
Ammonia	0.2	8	730
Phosphate	1	3	18.6
Temperature	+-2 °C of ambient Temp	-	-
Chloride	1000	1	1250

Table 4-5 Comparison between effluent discharge data and Kenya guidelines.

From table (4-5), it is obvious that the ammonia concentration exceeds the limit with about 3000 times, then the phosphate value, which exceeds the limit about 20 times. Chlorides and sulfates exceed also the limit but only with about 1.3 times.

Chapter 5

Temporal and Spatial Design of the Model

As the last chapter included the determination of water quality status of rivers to be modeled; so at this step the DUFLOW model can be developed.
This chapter deals with the first step in DUFLOW model development, which includes the temporal and spatial design of the model.
The required steps for temporal and spatial design are:

1- Identification of different kinds of temporal and spatial data needed.
2- Preparation of spatial data using GIS-ILWIS techniques followed by a check of the accuracy pre-processing of some of these data before being used in the model.

5-1 TEMPORAL & SPATIAL DATA REQUIRED

Prior to the application of the model, all available data was analyzed in detail. Depending upon the length, continuity and reliability of historical data, the specific time periods for model calibration and validation were identified. The procedure adopted and the results achieved for different kinds of required data were illustrated below.

5-1.1 Topographic data

The topographic maps listed in table (5-1) provides a complete coverage of the specific study area of the research and were obtained for general use as well as providing the data source for the catchement and lake boundaries, contours and context features. These maps were generated from UK Ordnance Survey Overseas Survey Department maps, which have been updated in Kenya.

Sheet	Title	Year
133/4	Longnot	1974
133/2	Naivasha	1974
119/4	Gilgil	1974

Table 5-1 Map Sheets used in the research work.

5-1.2 Temporal data

River staff gauge data (daily basis) was obtained from the Kenya Water Department for several gauges in the study area. Rating equations were also given, this data was used for calibration of water flow model. GB1 station was chosen to be the boundary input of the Malewa model. GA3 station was chosen to be the upper boundary of Marandati river, also GA6 for input of little Gilgil river. Monthly flow of non-exceedance tables for these river gauge stations are found in annex B (tables B3, B4 and B5). Lake level series was also obtained from the Kenya Water Department.

5.1.3 Spatial Data

By analyzing the inputs required by the DUFLOW model, especially all the elements that have spatial expression, they were identified like network orientation, nodes locations, river length, river profile and cross sections. Also the lake area and volume.
Schematic cross sections were plotted from the field notes and previous measurements. Node locations, river length, river profile were prepared using GIS-ILWIS as will be described later in section (5-2).

- **River Cross section**

Figures (5-1, 5-2, 5-3 and 5-4) show the cross sections of the rivers simulated in the model. Malewa and Gilgil river cross sections were assumed from field investigations. Little Gilgil and Marandati rivers cross sections were taken from previous measurements.

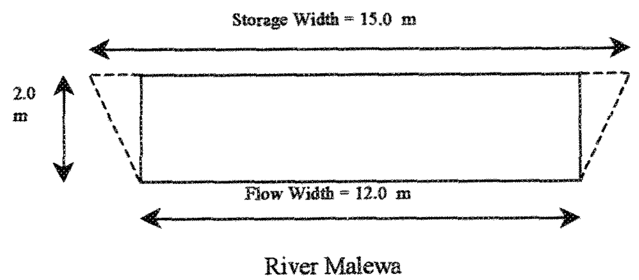


Figure 5-1 Malewa river cross section.

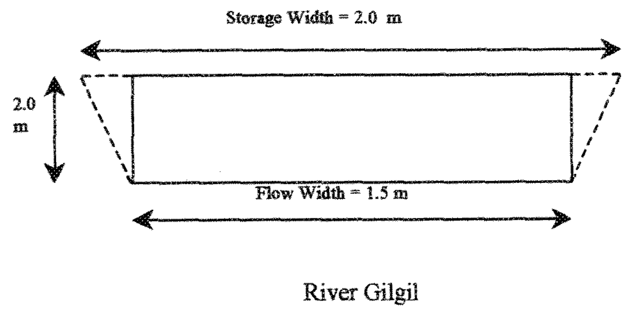


Figure 5-2 Gilgil river cross section.

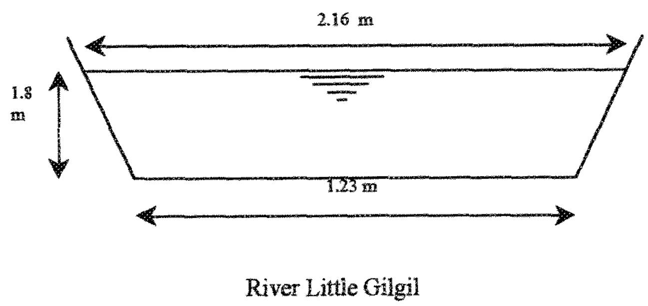


Figure 5-3 Little Gilgil river cross section.

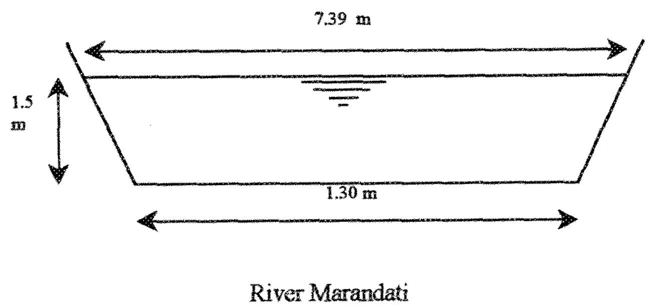


Figure 5-4 Marandati river cross section

Photo (5-1) gives a clear view of Malewa river cross section as seen during fieldwork
Also photo (5-2) and photo (5-3) show clearly the cross sections of Gilgil and Marandati rivers.

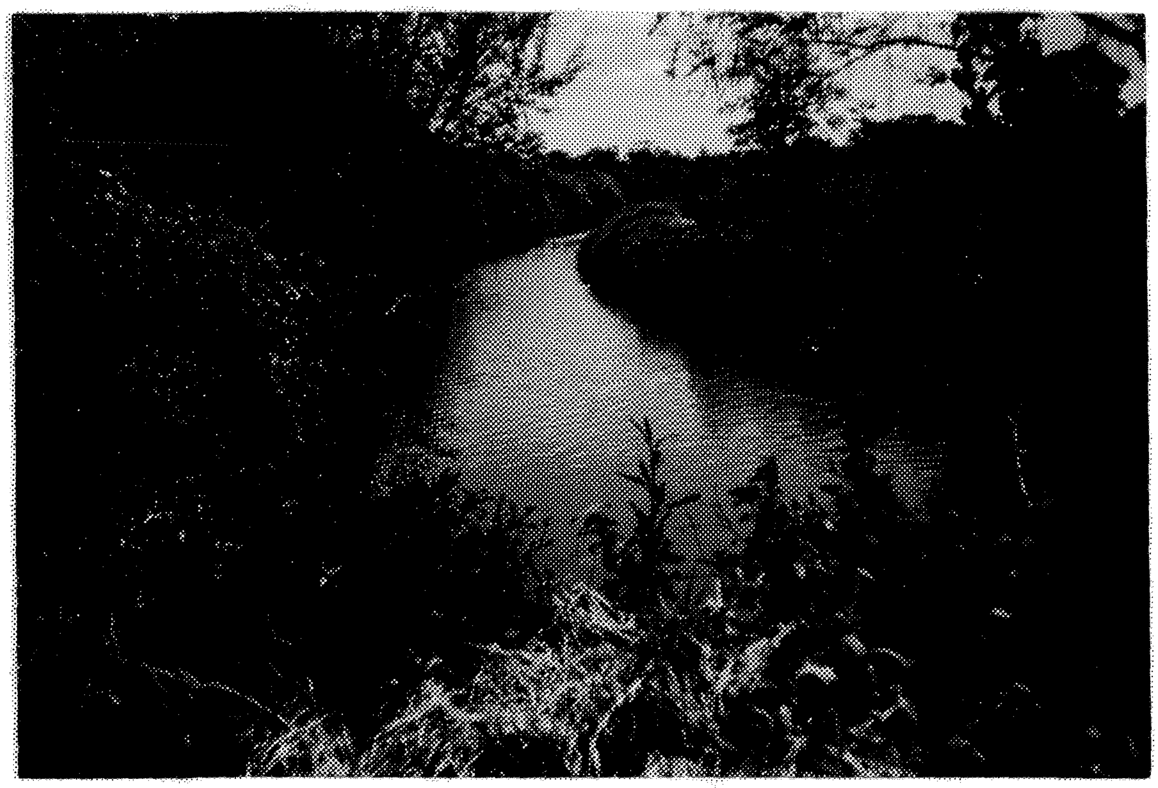


Photo 5-1 Malewa river cross section at GB1 Discharge Station.

Photo 5-2 Gilgil river cross section at the lower bridge.

Photo 5-3 Marandati river cross section at GA3 Discharge Station.

5.1.4 Flow & Quality estimated parameters

The Manning Roughness coefficient and Dispersion Coefficient are the mainly estimated parameters in case of DUFLOW model.

- **Manning roughness coefficient**

The water as it flows is in contact with the channel bed and banks. The roughness of the beds and banks exert a friction against the flow of the water. The measure of the channel roughness is known as Manning's n that characterize the roughness in the Manning formula in open channels.
Several authors (GRAY, 1970;CHOW, 1959;FOSTER et al.1980) present different tables with coefficients for different types of channels and surfaces (crops, grasslands,..). (CHOW, 1959) table for roughness is included in annex C (table C1).

By looking at table C1 and the photos (5-1,5-2 and 5-3) of the rivers in the study area, the Manning coefficient for the rivers were selected as described in table (5-2).

River name	**River Bed**	**Vegetation**		**Selected Manning Roughness coefficient**
		Type	Density	
Malewa	Gravel	bushes	Little	0.035-0.05
Gilgil	Clay, soil and sand	bushes	Little	0.03-0.04
Marandati	Soil &Rock	weed	High	0.045-0.08
Little Gilgil	Soil &Rock	weed	High	0.045-0.08

Table 5-2 Manning coefficients selected for different rivers in the study area.

- **Dispersion Coefficient**

Dispersion is the mixing of the river water in the longitudinal direction due to horizontal and vertical gradients of velocity (Thomman & Muller, 1987).
The Value of dispersion coefficient varies from small streams, rivers, lakes and reservoirs. Also the value of dispersion depends on the roughness which is usually affected by vegetation such as the cleaning of water body affects a lot the dispersion.
For dispersion coefficient of small streams, the literature shows very few values. As example, dispersion values were given by de Heer (1979) in table C2, annex C.
In case of lakes and reservoirs, the dispersion is controlled mostly by the wind, so in a well mixed lake the dispersion coefficient is very high.
For rivers, a variety of theoretical and empirical relationships have been proposed. An example of these equations is given by (Fisher); a very frequently used relationship

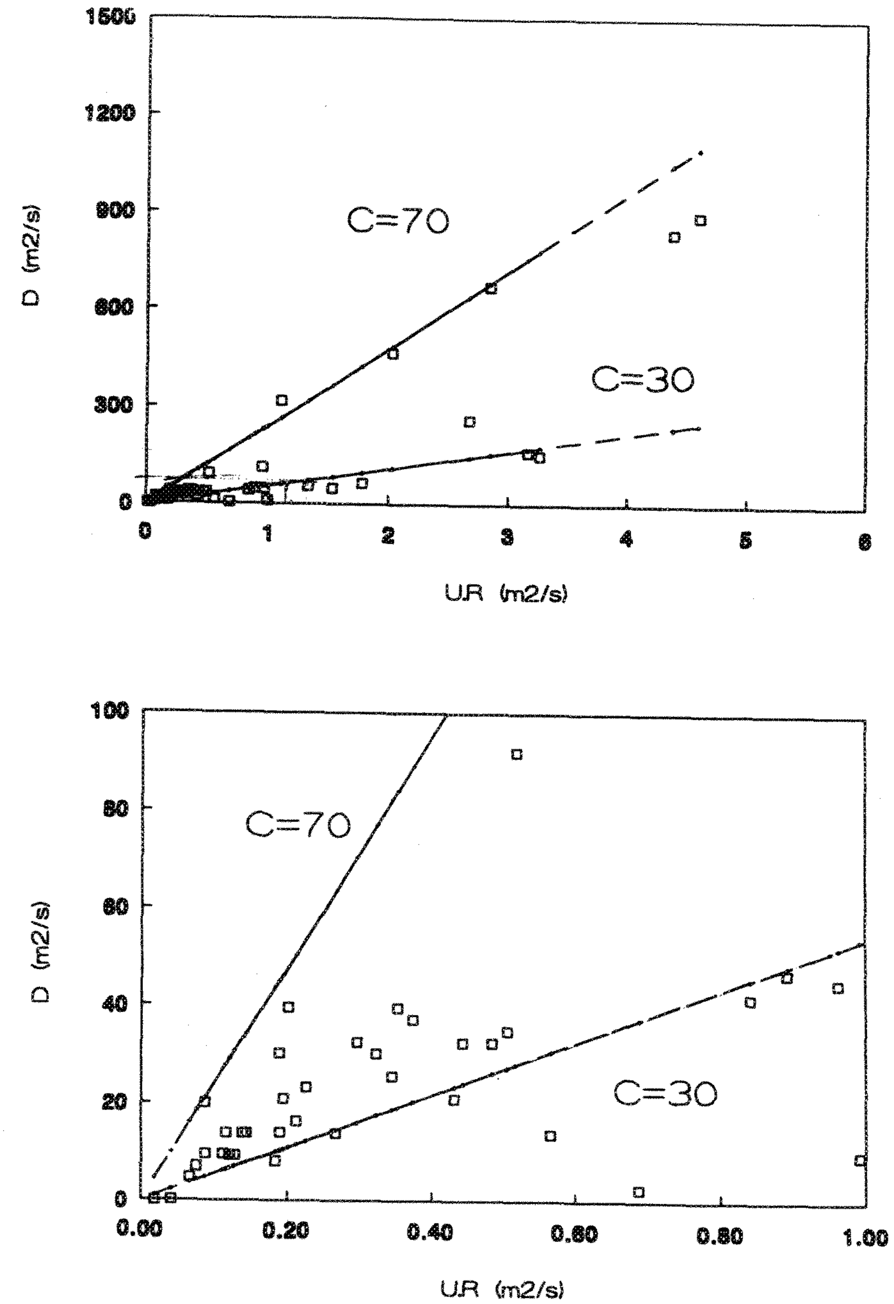
$D = C_e \, nu \, R^{5/6} \sqrt{g}$

where D: Dispersion Coefficient (m^2/s)
C_e: Proportional Constant ($m^{1/6}$)
g : Acceleration (m/s^2)
n : Manning Constant ($s/m^{1/3}$)
R : Hydraulic Radius (m)

The value of C_e is about 1910 if SI units are used, if Chezy equation is used

$D = C_e \, nu \, \frac{R}{C}\sqrt{g}$ Where C Chezy Constant ($C = R^{1/6}/N$)($m^{1/2}/s$)

Graph 5-1shows the value of D against UR. In principal the relation between both variables is linear but it depends on the Chezy constant value.
Since the Chezy constant is not easy known so the lines in graph (5-1) only presented extreme situations for very rough channels (C=30) and for smooth channels (C=70).
The dispersion coefficient was calculated using the above equation and the graph and was used as external variable for DUFLOW quality model.
The dispersion coefficient for Malewa river was assumed to be from 9.6 to 10 m2/s.



Graph 5-1 Dispersion Coefficient as a function of UR for several streams

5.2 PREPARATION & PREPROCESSING OF SPATIAL DATA USING GIS-ILWIS

River topographic maps were digitized using GIS-ILWIS and the nodes and sections of the river model were divided depending on bed slope difference and river shape.

5.2.1 River length

The rivers length were calculated using GIS- ILWIS as follows:

- Identify the model nodes locations by editing the river segment map.
- Calculating the histogram of the segment map.
- Determination of the required sections length of the rivers from the calculated histogram.

Also the length of the sections were calculated using the DUFLOW program in the input module part of the model responsible of network schematization.

A substantial error in the physical network is introduced by DUFLOW when using simple (long section lengths) representations for meandering rivers. This error was not observed in the section length calculated using GIS-ILWIS. This is due to that DUFLOW assumes a straight line connecting the different nodes but GIS-ILWIS measures the actual length of the section taking into consideration their different shapes.

So to assess the effect of this error in length calculation on the model of Malewa river (width=12m, discharge=2m^3/s, depth=2m); table (5-3) was constructed as an example.
For each section of Malewa model, the following values were calculated:
Sinuosity ratio = (ratio between ILWIS length and model length).
Slope difference ratio (Δ s%) = (Slope model-slope ILWIS).
Froude number difference (ΔF) = (Froude model - Froude ILWIS).
Head difference in meters (Δ H) = (Head model - Head ILWIS).

From table (5-3), we notice that the difference in length calculation method between DUFLOW and GIS-ILWIS causes a change in slope, Froude number and head calculated. This change increases in case the section shape is meander and not straight.
Looking at section 6 whose sinuosity ratio is almost unity i.e. almost straight section, the increase in slope is 0.4%, very small change in Froude number and no change in level.
But in section 12 where the sinuosity ratio is so high 4.4, this causes a high increase in slope 26.4%, a decrease in depth 0.14m and an increase in Froude number until it becomes close to unity that causes the flow to be critical. This type of flow cannot be simulated in DUFLOW.

From the above discussion, we conclude that the length is calculated more accurately in case of using GIS-ILWIS techniques than using DUFLOW program and the use of ILWIS is preferred due to independence of number of nodes on section length accuracy.

But if GIS-ILWIS was not available so the user can use the length calculated by DUFLOW program taking into consideration the shape of the river reaches to be simulated.
In case of meander river reaches (sinuosity ratio more or equal to 1.5) more nodes have to be selected to represent this reach of river. But in case of straight river reaches (sinuosity equals to 1.1), less nodes are required to represent the straight reach.

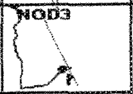
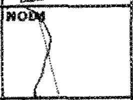
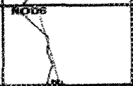
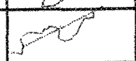
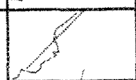
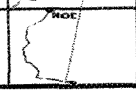
Section	Shape	Sinuosity	ΔS%	ΔF	ΔH (m)
V		1.377119	14.5	0.07	-0.03
2		1.111111	4.3	0.03	-0.01
3		1.862464	33.2	0.15	-0.05
4		1.268293	10.3	0.05	-0.02
5		1.105442	2.4	0.02	-0.01
6		1.017214	0.4	0.01	0
7		1.264591	6.1	0.04	-0.01
8		1.798064	18.4	0.11	-0.04
9		1.39485	9.1	0.06	-0.02
10		1.759134	8.8	0.08	-0.05
11		2.311111	10	0.1	-0.08
12		4.43686	26.4	0.2	-0.14
13		1.937407	7.2	0.07	-0.07
14		1.413812	3.2	0.02	-0.03
15		1.277641	2.1	0.46	-0.2
16		1.830986	6.4	0.06	-0.06

Table 5-3 Comparison between length calculated using GIS and DUFLOW for Malewa river.

5.2.2 River profile

The river profile was obtained by constructing a digital elevation model of the area of study. The digital elevation model (DEM) is a numerical presentation of the topographic surface. It consists of a set of elevation measurements for location distributed over the land surface (Aronoff, 1991). The source of the elevation Data for the digital elevation model (DEM) was the 1:50000 topographic map sheets. All the contours, at 40m height interval, for all the catchement area were digitized and stored as a vector contour map.

The DEM was created by applying the contour interpolation function of pixel size "20m" and of accuracy "1m" as described in section (3.2.2).

Since the selection of a proper pixel size is crucial in the vector to raster conversion operation; the pixel size was determined by three facts:

1. A maximum of detail was required to get accurate relief data for the model input.
2. With bigger pixel size than 10m resolution, some contour lines (e.g. steep slopes) would overlap.
3. The 10 m pixel size was the smallest possible taking into account that the accuracy of 1:50000 maps is about 0.2 mm or 10 m. It meant that using a scale of a pixel size smaller than 10 m would give redundant information.

Some problems appeared in the generated DEM shown in figure (5-5):

1. A digitizing error was assumed to be 0.5 mm which corresponding to 5 m. So there is error of 5 m for altitudes also the error difference in digitizing the river map and the contour causes that there are places that the river doesn't cross in the middle of two contours. So the river map was edited to coincide with the contour map.
2. The second problem that appeared is the large amount of pixels that rasterization of lake Naivasha catchement took approximately 200 MBYTES on a very advanced computer of a 66 Mbytes RAM and taking almost 8 hours of processing. So in order to make the process faster and less space on the hard disk, only the contour map was divided into small map only covering the interested area of study.

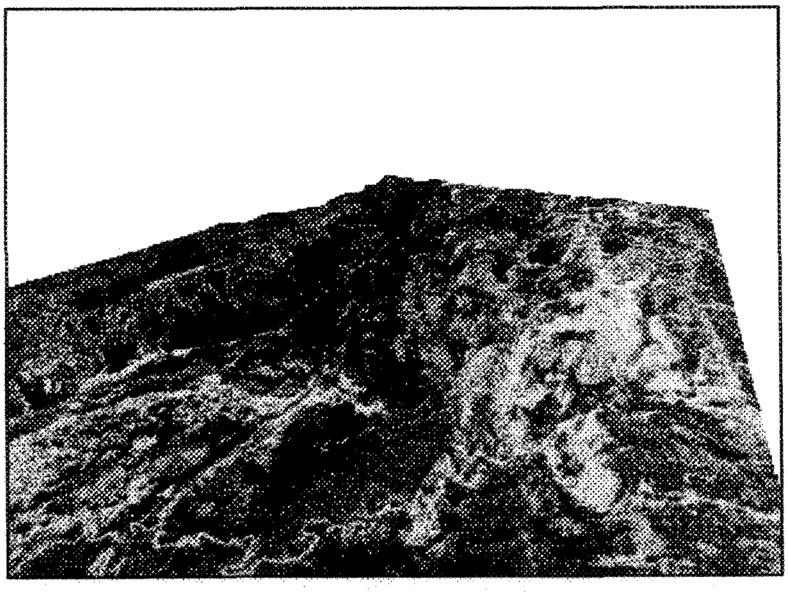


Figure 5-5 DEM generated for the specific study area.

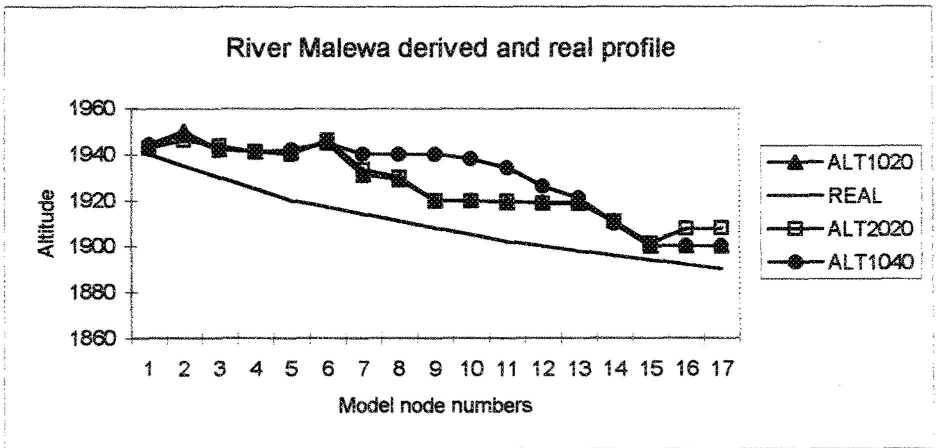
Before using the output data from the generated DEM as an input data in the model DUFLOW, its accuracy have been tested. The output from generated DEM have been compared visually with the real data from topographic maps (graph 5-2 and 5-3).

The absolute difference between the generated DEM and the real data from the topographic maps have been used as an indication of possible errors in the data. The accuracy of the data has been tested in the two streams: Malewa river and Gilgil river.
By comparing the generated DEM and the real data from the topographic maps in the two rivers, it clear that the possible errors are bigger in the case of Malewa (+30m) at section 6 of length =1300m than in the case of Gilgil (+10m) at section 11 of 1300m length.

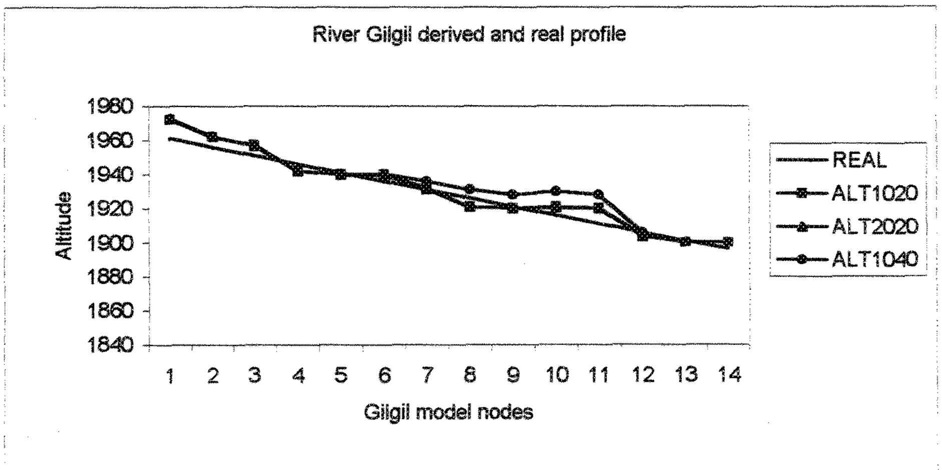
These maximum errors in altitude influence a lot the DUFLOW model, an error of 30 m in altitude for Malewa river (rectangular cross section 13m width, 2m depth, flow =2 m3/s,n =0.035)causes an error of 1% in slope and an error of 0.08m in water depth.
Also an error of 10 m in altitude for Gilgil river (rectangular cross section 2.5 m width and 2 m depth, flow = 2 m3/s, n= 0.035) causes an error of 0.03% in slope and an error of 0.14m in water depth. The difference in DEM values influences the DUFLOW model as it can change the type of flow from subcritical to supercritical.

In order to reduce this error in the DEM, pixel size and the contour interval were decreased individually to assess the influence of each factor on the DEM accuracy.
The effect of these changes was shown in graphs (5-2, 5-3). ALT 2020 means the altitude calculated at pixel size 20m and contour interval 20m, ALT1020 means the altitude calculated at pixel size 10m and contour interval 20m and ALT2040 means the altitude calculated at pixel size 20m and contour interval 40m.

By looking at the graph, it is obvious that the decrease in pixel size has no effect on the output DEM accuracy in our case. In contrary the decrease in contour interval improves a lot the accuracy of the output DEM. So it is advisable not to use DEM in river profile generation in case of incised meander rivers as Malewa river unless very detailed contour map and ground truth altitude points are available.



Graph 5-2 DEM accuracy analysis for Malewa river.



Graph 5-3 DEM accuracy analysis for Gilgil river

5.2.3 Lake Naivasha volume calculation

To represent the lake in the DUFLOW model, its accurate volume was calculated as follows:

1. Calculation the area of the lake area from the digitized map

- Mask the water bodies polygon map for only lake Naivasha.
- Calculation of histogram of lake Naivasha polygon map.
- From the histogram, the area of lake Naivasha is calculated.

2. Calculation the area of the lake from the satellite image (95).

- Make NDVI of TM bands.
- Make color composite of TM bands 5,7, NDVI.
- Screen digitizing of lake Naivasha from the color composite map.
- Calculation histogram of the output segment map of the lake.
- Get the area of lake Naivasha from the histogram.

3. Comparison between the results from digitized maps and satellite image

Method	Perimeter(m)	Area(km^2)
Digitized map	88905.52	126.534180
Satellite image	58353.42	122.649822

Table 5-2 Area & Perimeter calculated from digitized maps and satellite image

This difference in area and perimeter were due to different time periods, satellite image was of 1995 and digitized maps were of 1974.

5.2.4 Automated link between ILWIS and DUFLOW

After the identification of nodes in ILWIS, the nodes can be read directly in DUFLOW model by running a script written to link ILWIS output with DUFLOW input in order to make the process relatively automated.

The script calls a C program (see annex E) which constructs the input network files for DUFLOW including the network schematization (network orientation, nodes coordinates).

This program is very useful in case of high number of nodes as it saves the time consumed in nodes input.

Chapter 6
Model Implementation

As the required input parameters were prepared in chapter (5), this chapter describes the use of these parameters for implementation of different models.
DUFLOW Mathematical modeling of water and salt concentrations in the hydraulic system of the study area has been used for next situations:
- The simplified mathematical modeling of the downstream Malewa river.
- The simplified mathematical modeling of the downstream Gilgil river.
- The simplified mathematical modeling for downstream Malewa and Gilgil rivers and the lake.

Each mathematical model includes the schematization, evaluation, and calibration, verification of water quantity and quality if possible and finally checking of its accuracy.

After implementation of different models, the scenario and sensitivity analysis were applied on the precalibrated models.
The first scenario was the simulation of the actual spill from a dairy factory and assuming hypothetical accident spill from the same factory in order to assess the sensitivity of the model to this increase in load and its influence on the lake water quality.
The second scenario is simulating permitted abstraction scenario and assuming real abstraction rate and assess its effect on lake water level.
Each different scenario is followed by a detailed discussion of the results.

6-1 CONSIDERATIONS FOR ALL MODELS

Some basic considerations had been followed in model implementation:

- The layout of a channel network must be specified in a convenient form based on the following factors:
    - -Purpose of the computation
    - -Geometry of the canal system
    - -Numerical factors
    - -Boundary conditions

- For each section, The length input is the calculated length using ILWIS in section 5.2.1 and the longitudinal profile is the adjusted DEM derived profile in section 5-2.2. A reference level was taken for all nodes equals 1900m a.m.s.l.

- For schematization, the cross-section of all rivers was approximated from field investigation and historical data as shown in section (5.1.3).

- The simulation period is chosen based upon the availability of real data for validation.

- For Estimated Parameters (Roughness & Dispersion Coefficients)
  The roughness coefficient and dispersion coefficient were assumed from the figures and The literature as explained in section (5.1.4).

- For the start of numerical computations initial values have to be given for all nodes and branches. Horizontal water levels, small discharges and measured concentrations are used as initial conditions for the river model.
  For some cases where no initial values are available, the initial conditions were taken from the results of some initial simulations using the option "new initials" in the main menu of the program.

- Three types of boundary conditions are needed for the calculations of water movements and salt concentration in the system.
  1.Rating curves (when available).
  2.Discharges.
  3-Concentration.

- All simulations were carried assuming zero withdrawals. Since available data does not specify the exact amount of withdrawal during the simulation periods, it was not possible to accurately estimate the decrease of monthly flow in every river section. Thus the monthly flows simulated are natural flows without considering the withdrawals. Also the withdrawals from the lake are neglected compared to high loss of lake water by evaporation.

- The dry season is chosen especially because low discharge conditions are used as the basis for the design of treatment facilities and the control of the maximum permissible effluent to rivers. Also at a higher river discharge rates, the ecological effects of a polluted effluents in a river are less harmful. Finally drought conditions are critical for rivers serving as a water source for urban water supply.

- Runoff from subcatchement areas was not included in rivers model implementation. To assess the lake, we focus on input from rivers because surface runoff around the lake is rare because of low rainfall and high porosity of the local volcanic soil, so runoff is not considered.

- In case of evaluation of all models , these steps must be followed:
  - Select a section from the river network.
  - Select certain time level of analysis which is equal to time step or factor of time step

- The model is compared against independent data for all the rivers and the lake together and also on individual river basin which demonstrate a correspondence between its behavior and reality. Then the model is calibrated by changing some estimated parameters used in its development.

6.2 MATHEMATICAL MODELING FOR DOWNSTREAM MALEWA

6.2.1 Malewa Model Schematization

- **Network Layout**

The Malewa river downstream was represented by a network of 17 nodes and 16 sections. Also a more detailed (discretised) model has been done for Malewa river downstream consisting of 287 nodes and 286 sections with space step of 100 m between nodes.

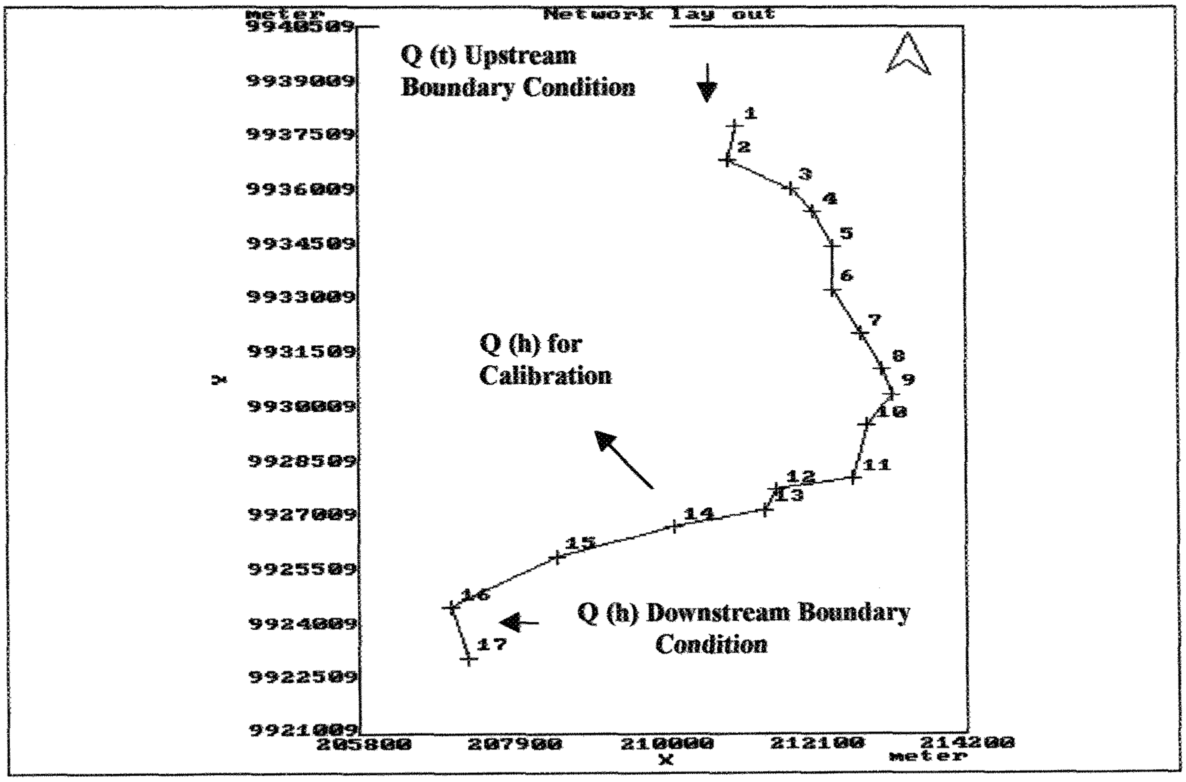


Figure 6-1 Malewa simplified network designed in DUFLOW Program.

- **Control Data**

The period of simulation to calibrate the model was chosen to be 1960 and the simulation was made in the dry season (Jan 1960). This year was chosen specially due to availability of data downstream to validate the model.

Time step	Froud number	Min water level
120 sec	Option (total) taking Froude number into consideration.	0.1 m

Table 6-1 Malewa network control data used as input in DUFLOW model.

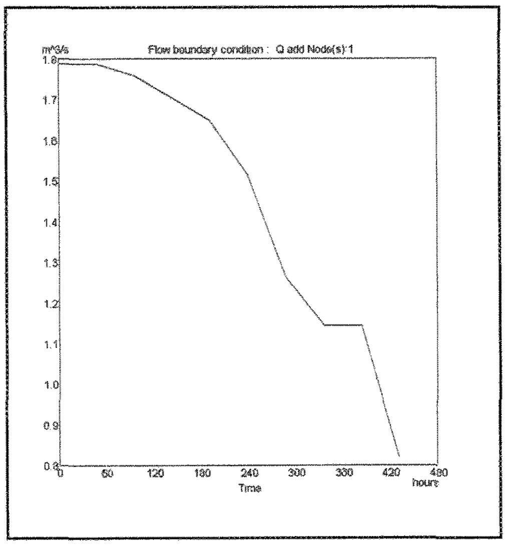
- **Boundary conditions**

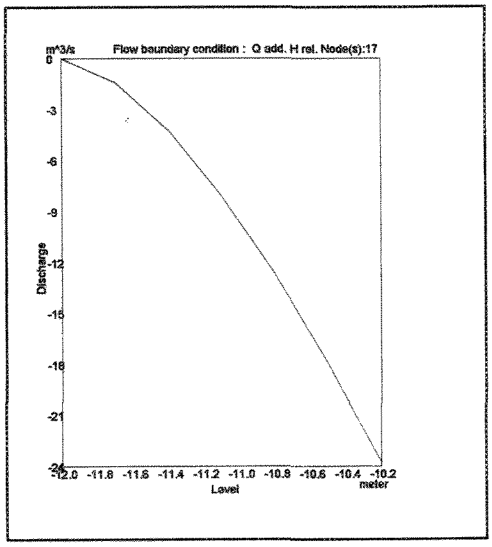
- Water flow Boundary Conditions:

The input boundary condition at node "1" is the hydrograph (station GB1) from the historical data as shown in graph (6-1).
At node 17 downstream, the steady state rating curve is selected graph (6-2).

-Water Quality Upstream Boundary Condition:

The measured chloride concentrations in the field at the discharge station GB1 is given (=12 mg/l). The chloride concentrations at node 17 is given constant (= 12 mg/l) as chloride is conservative substance.





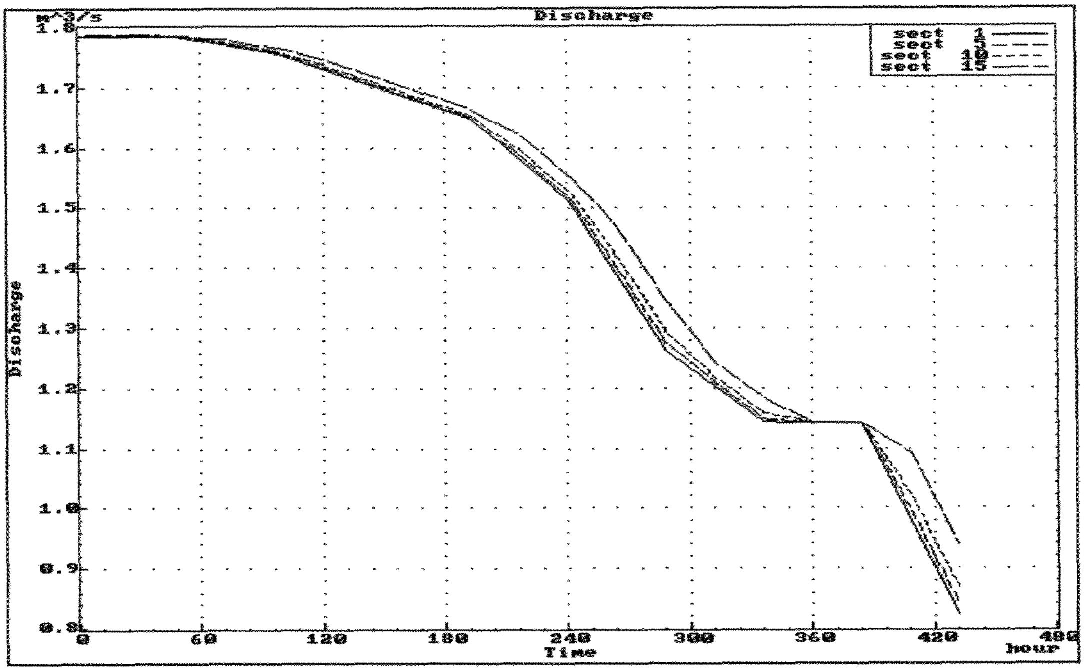
Graph 6-1 Discharge input at node "1". **Graph 6-2** Q & H relation at node 17

- **Calculations & output**

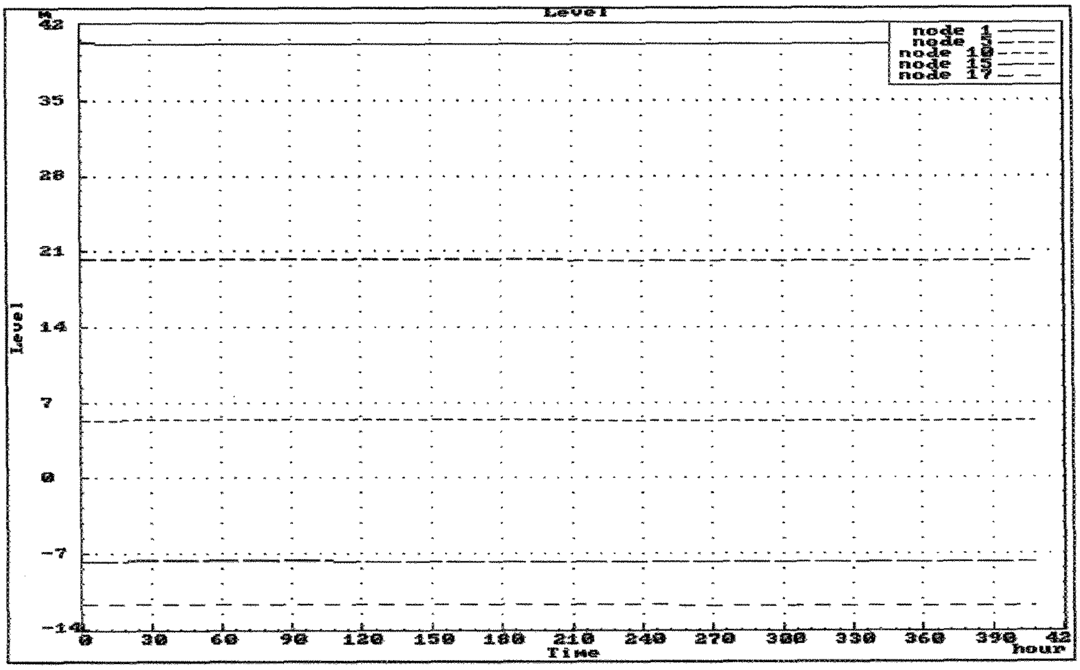
Flow, water level and salt concentrations were calculated for all sections in the river at different time levels. The time levels are given in hours and are measured from the start of the calculations (t=0).

Graph (6-3) gives the flow rate through each of the cross-sections at the sections 1,5,10,15 of the Malewa network as function of time.
It shows a phase shift in the function Q (t), caused by friction and inertia influences along the network sections. The water travels with a velocity equals 0.63 m/s, i.e. the water needs 13 hours approximately to reach the lake section.

Graph (6-4) gives the water levels at the nodes 1,5,10,15,17 as function of time.
It shows almost constant level in x-direction at different times.



Graph 6-3 Discharge in sections 1,5,10,15 of Malewa network.



Graph 6-4 Water levels at nodes 1,5,10,15,17 of Malewa network.

Also for using the simplified model (16 sections) in quality simulation, it gives a lot of instabilities and negative salt concentration due to the big length of sections. So its advisable to use the more detailed model in quality simulations as will be described later in section (6.1.4).

6-1.2 Evaluation of the Malewa model

The model is evaluated using the ECDUFLOW module described in section (3.3.3).

- For Flow part

The Flow part of the analysis of details module was run for Section 1 is selected and at time level of 0.73 hours where the time level of output equals 240 seconds.

```
 DUFLOW  2.10                                 Analysis - Details

CALCULATION TIME LEVEL      0.73 hours          SECTION    1

L    length            =     1300.00 m            Friction term:
H1   level begin       =   40.223000 m                 -Q*|Q|*L
H2   level end         =   35.249001 m                 ---------         = -4.982817 m
Hav. prev timestep     =   37.736000 m                 C²*A²*R
Hav. next timestep     =   37.736000 m
Q1   discharge begin   =     1.78700 m3/s
Q2   discharge end     =     1.78700 m3/s         Acceleration term:
Q    average disch.    =     1.78700 m3/s              -L    dQ
Qav. prev timestep     =     1.78710 m3/s              --- * ---         =  0.000010 m
Qav. next timestep     =     1.78700 m3/s              gA    dt
A1   area begin        =     2.67599 m²
A2   area end          =     2.98801 m²
A    average area      =     2.83200 m²           Advective term:
R    hydr. radius      =    0.227044 m                 Q1²/A1-Q2²/A2
SW   Storage width     =    15.00000 m                 -------------     =  0.004485 m
C    de Chezy coeff.   =      21.390 m½/s                   gA
dt   time interval     =         240 sec

SW*L*dH/dt             =      0.0000 m3/s         SUM of the 3 terms     = -4.978322 m
Q1 - Q2                =      0.0000 m3/s         H2 - H1                = -4.973999 m
   Esc = exit                 PgUp = Previous              PgDn or ←┘ =  next
```

From the above results of analysis, we deduce that both the differential equations (continuity and motion) governing the water movements are satisfied.
Also the contribution of acceleration term is almost zero and the friction and convection terms have negative contribution.

-For Water Quality

In order to check that convective and dispersive transport, the model has been run without the dispersive transport by assuming dispersion constant to be zero but unfortunately a numerical diffusion is still present.
The Numerical diffusion introduced by discretization of the mass transport equation leads to an additional smoothing of concentration gradients. The numerical dispersion for the solution method used can be approximated by:

$$E_{num} = \frac{u}{2}(1-2\theta)u\Delta t$$

For θ =0.5 this results into a numerical dispersion equal to 0.a value of θ<0.5 however may lead to a non positive solution, which may cause instabilities. A value of 0.55 is recommended.

To analyze the effect of numerical diffusion, a simple comparison can be done between the result of the model and the result of a simple mass balance computation after assuming the following scenario as shown in figure (6-2).

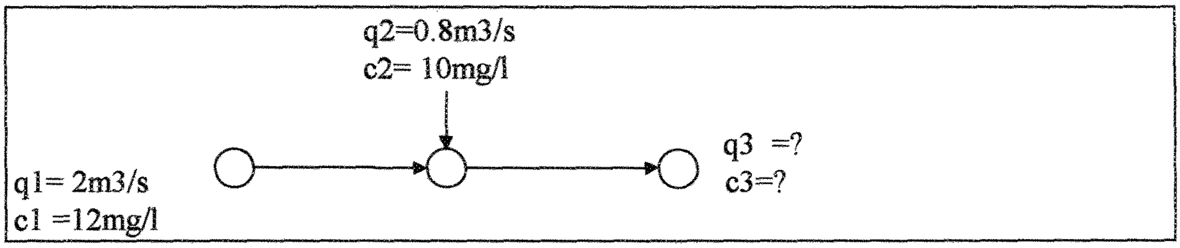


Figure 6-2 Schematic of the river system to illustrate the numerical diffusion influence

- The maximum average concentration equals 3.5 mg/l using the simplified Malewa model.

-The result from steady mass balance computation (without dispersion) for dissolved matter:

$$c3= \frac{c1 * q1 + c2 * q2}{q1 + q2} = 11.3 \text{ mg/l}$$

Where: c1: concentration of the salt water = 10mg/l
Q1: Discharge of the salt water = 0.8 m3/s
c2: concentration of the Malewa river = 12mg/l
q2: discharge from the Malewa river = 2 m3/s

From this comparison, it can be concluded that the numerical diffusion influences very much in the model and the physical dispersive transport gives only a very minor effect. So, it can be concluded that the convective transport is dominant.

6-1.3 Calibration of the model

In preparing the model, not all parameters are known especially the bottom roughness and lateral storage areas for the water flow and the dispersion coefficients for concentration computations have to be estimated. So to check and improve the estimations, the model has to be calibrated.
Calibration means comparing the computed results with the measured data.
For Malewa model, the roughness and storage areas were tried and changed during this process, A comparison has been done between the rating curve obtained by the model in GB2 station downstream (section 14) and real rating curve measured at this station.
The results of this calibration are presented in graphs (6-5,6-6).

The salt concentrations calculated from the detailed model must be compared with the computed results. But due to lack of measurements, we only calculate the average concentration in the channel. As Chloride is a conservative substance, the average concentration must be 12 mg/l which is satisfied by the quality model (average concentration =12.01 mg/l).

When the calibration results are satisfactory, it can be concluded that the model parameters are representative for the existing situation
Owing to the incompleteness of data about reference level of discharge stations, so the water level calculated by the model differs from the real level measurements. But it is obvious that the rating curve generated from the model matches the real rating curve and the relation between the model levels and the real levels is linear equation with slope approximately equals unity.

6-1.4 Accuracy check of the Malewa model

An accuracy check was made using the simplified model; The outputs from this detailed model is compared with the outputs of the simplified at the GB2 node (see graph 6-7).

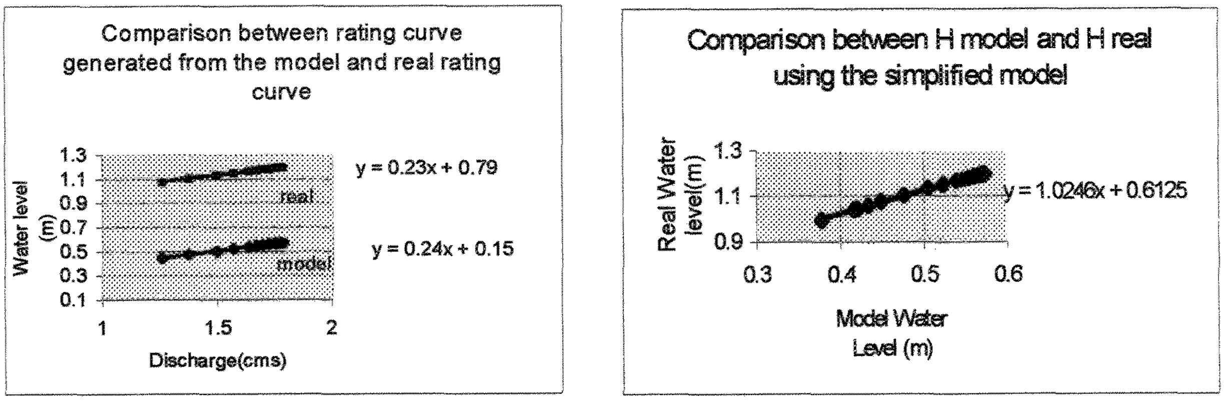
Table (6-2) shows a comparison is done between the simplified model and the detailed model by calculating the execution time and storage space of the result file for each model.

Model	**Simplified**	**Detailed**
Execution time	4 min 52sec	8 min 5 sec
Output Accuracy	same	same
Storage Space	16 Kbytes	16 Kbytes

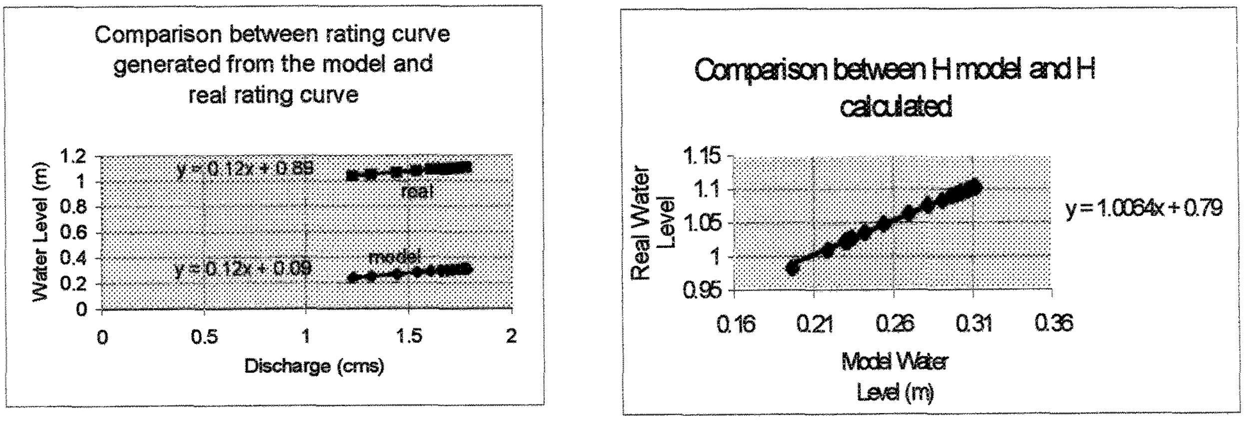
Table 6-2 Comparison between the simplified and detailed Malewa model

So from the above discussion about the accuracy check of the simplified model versus he detailed model, we deduce that in case of this particular case, the detailed models doesn't influence the accuracy of flow simulation but it takes more processing time.

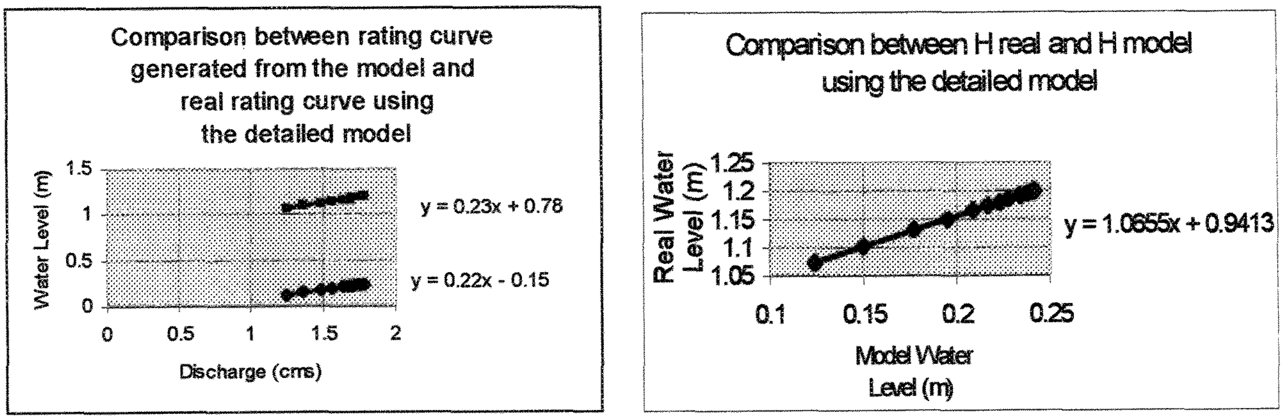
So in case of using the detailed model, the chloride concentration is preserved constant to be 12 mg/l all over the channel sections, no fluctuation in chloride concentration occurs.
This means that the detailed model is more accurate than the simplified one in case of water quality simulations.



Graph 6-5 Comparison between Malewa model output and real data (n=0.035)



Graph 6-6 Calibration of Malewa model by using the roughness coefficient (n=0.05)



Graph 6-7 Accuracy check of Malewa model.

6-3 MATHEMATICAL MODELING OF DOWNSTREAM GILGIL

6.3.1 Gilgil Model Schematization

- **Network Layout**

The Gilgil River, the Marandati and little Gilgil are represented in the model network. Marandati river beginning from GA3 station is schematized into a network, consisting of 5 nodes, 4 sections, (from node "1" to node "4'). Little Gilgil river bordered by GA6 station is schematized into a network (from node "19" to "22"). Gilgil River is schematized into a network from node "5" to node "18" (figure 6-3).
A detailed model has been done for Gilgil downstream consisting of 244 nodes and 243 sections with space step of 100 m between each node.
In this model, only the water flow is computed. The water quality part is not considered in the model, as no water quality scenarios will be done on Gilgil River.

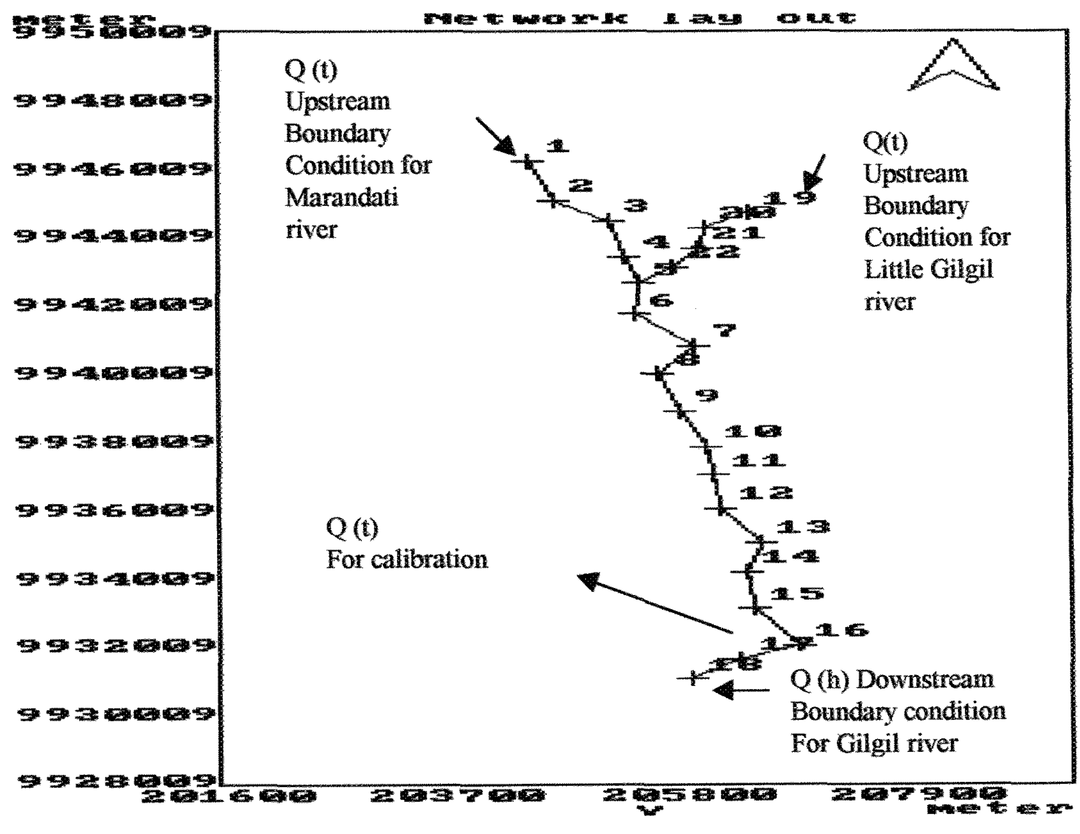


Figure 6-3 Gilgil network designed in DUFLOW Program

- **Control Data**

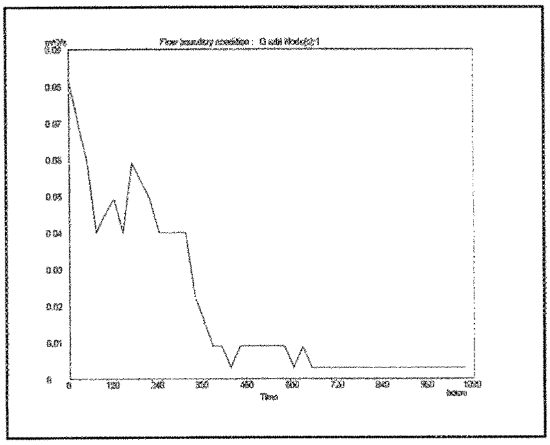
The period of simulation to calibrate the model was chosen to be 1970, and the simulation was made in dry season (17 Jan. 1970 to 17 Feb.1970).

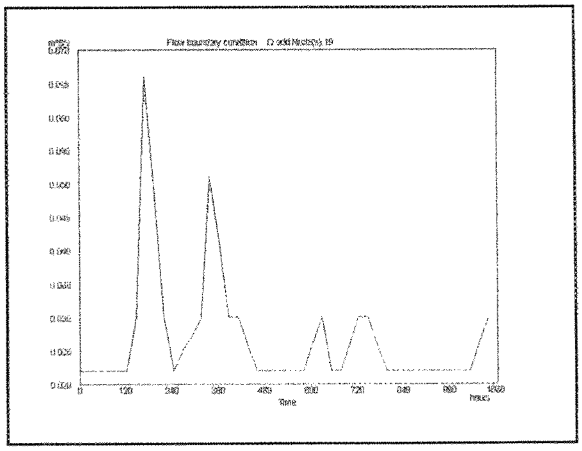
Time step	Froud number	Min water level
120 sec	Option neglected Froud number	0.1 m

Table 6-3 Gilgil model control data

- **Boundary conditions**

The input boundary conditions are the discharge series measured at the discharge station GA3 on Marandati river from the historical data, and also upstream at GA6 on little Gilgil river from historical data, the boundary conditions downstream at node 17 is the Q&H rating curve (graph 6-8, 6-9).

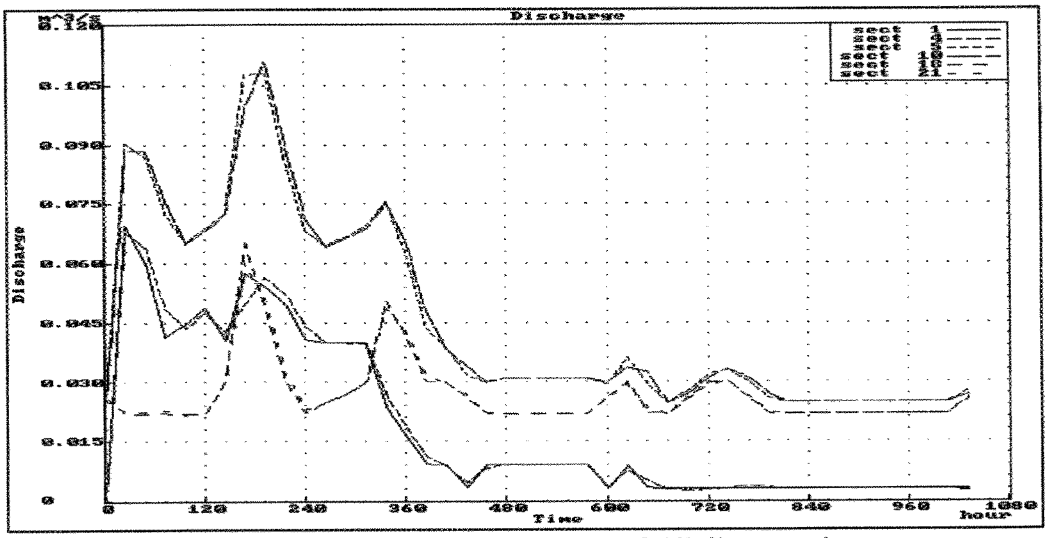




Graph 6-8 Input Discharge for GA3 **Graph 6-9** Input Discharge for GA6

- **Calculations**

The output at certain sections is shown in graph (6-10) for flow calculations.



Graph 6-10 Discharges at sections 1,4,5,21,10 of Gilgil network

Graph 6-10 shows the discharge calculated at the junction point ((section 5) where the two rivers Marandati and Gilgil are connected to river Gilgil, Also it shows the discharge calculated in Marandati river (section 4) and Little Gilgil river (section 21).
From the graph it is obvious that the discharge calculated at section 5 equals the summation of discharges calculated at section 4 and section 21.

6.3.2 Evaluation of the model

- **Analysis details of calculation**

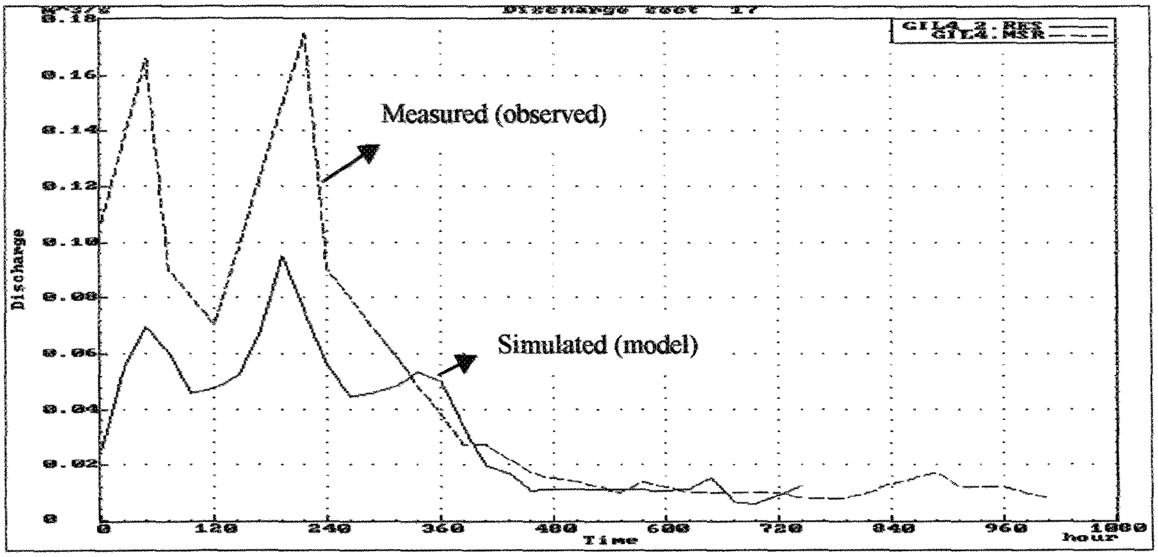
The analysis of details module was run for Gilgil model. Section 10 is selected and at time level of 3.27 hours where the time level of output equals 240 seconds.

```
  DUFLOW   2.10                                     Analysis - Details

 CALCULATION TIME LEVEL      3.27 hours          SECTION   10

 L   length            =      1300.00 m           Friction term:
 H1  level begin       =    36.202999 m                  -Q*|Q|*L
 H2  level end         =    31.184999 m                  --------      = -5.019142 r
 Hav. prev timestep    =    33.693501 m                  C^2*A^2*R
 Hav. next timestep    =    33.695000 m
 Q1  discharge begin   =      0.09436 m3/s
 Q2  discharge end     =      0.08734 m3/s        Acceleration term:
 Q   average disch.    =      0.09085 m3/s               -L    dQ
 Qav. prev timestep    =      0.09037 m3/s               -- *  --      = -0.001108 r
 Qav. next timestep    =      0.09154 m3/s               gA    dt
 A1  area begin        =      0.30450 m^2
 A2  area end          =      0.27750 m^2
 A   average area      =      0.29100 m^2         Advective term:
 R   hydr. radius      =     0.154077 m                  Q1^2/A1-Q2^2/A2
 SW  Storage width     =      2.00000 m                  ---------------  =  0.000613 r
 C   de Chezy coeff.   =       12.800 m^½/s                  gA
 dt  time interval     =          240 sec

 SW*L*dH/dt            =       0.0081 m3/s        SUM of the 3 terms  = -5.019637 r
 Q1 - Q2               =       0.0070 m3/s        H2 - H1             = -5.018000 r
    Esc = exit                       PgUp = Previous          PgDn or <-' =  next
```

From the above results of analysis, we deduce that both the differential equations (continuity and motion) governing the water movements are satisfied. Also the contribution of acceleration and advective term is almost zero and the friction has high negative contribution.

6.3.3 Verification of Gilgil model

To calibrate the model, graph (6-11) is drawn to compare between the discharge Series calculated by the model in GA5 station downstream (sect 17) and the real data.



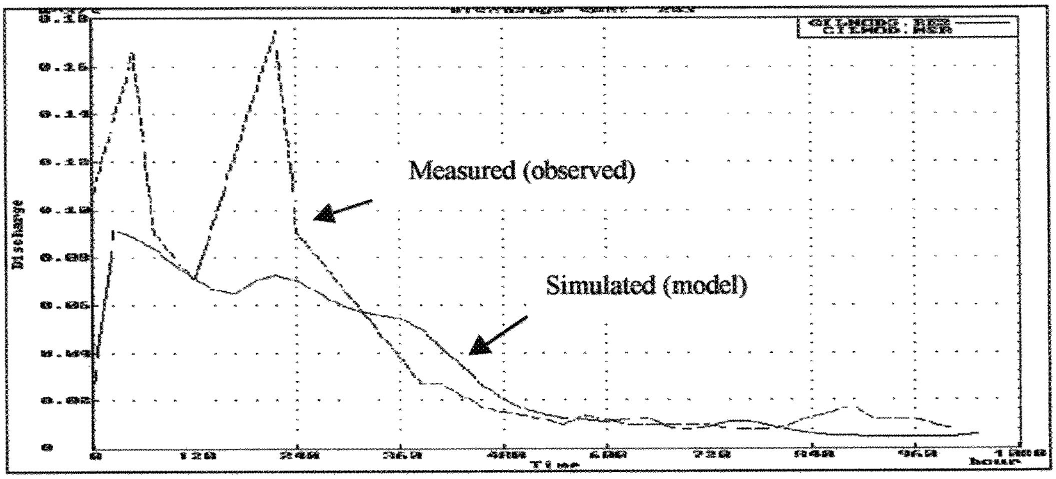
Graph 6-11 Comparison between measured and calculated discharge at GA5 for Gilgil

In the above graph, there is difference between real and measured discharge data especially in the first simulation period because runoff was not taken into consideration into model simulation. But in the dry period, the model is more accurate and the measured and real discharges are matching. The model could not be calibrated during the rainy period due to lack of rainfall information.

6.3.4 Accuracy check of the model

The output from the detailed and simplified models was compared at GA5 node. Also due to non-consideration of rainfall input and runoffs from surrounding areas in model simulation, the real measurements are different from the calculated ones especially during the rainfall events in the beginning of simulation.
The model is more accurate in dry period simulations as shown in graph (6-12)

With respect to accuracy check of the detailed model, no advantages in using the detailed model rather than the simplified one as the output accuracy is approximately same, the detailed model in contrary needs more processing time and more time in building the network.



Graph 6-12 Accuracy check of Gilgil model.

6.4 *MATHEMATICAL MODELING OF DOWNSTREAM (MALEWA,GILGIL) AND LAKE NAIVASHA.*

6.4.1 Model Schematization

- **Network Layout**

  Both Malewa and Gilgil rivers are represented as above and the lake Naivasha is represented as a rectangular cross section of 2500m width and 4m depth and a segment of length 40km preserving the calculated volume of the lake section (5.2.3).

- **Control Data**

  The period of simulation of the model is chosen to be year 1985 from Jan 19 to Feb 19 in the dry period. Other control data are in table (6-4).

Time step	**Froud number**	**Min water level**
120 sec	option negecled froud number	0.1 m

Table 6-4 Malewa, Gilgil and Lake Model control data

- **Estimated Parameters**

  - **Roughness coefficient**

    The lake roughness was assumed to be very low, Manning's n=0.01.

  - **Dispersion Coefficient**

    The lake dispersion coefficient is assumed to be higher or 100 m2/s (Aalderink 96).

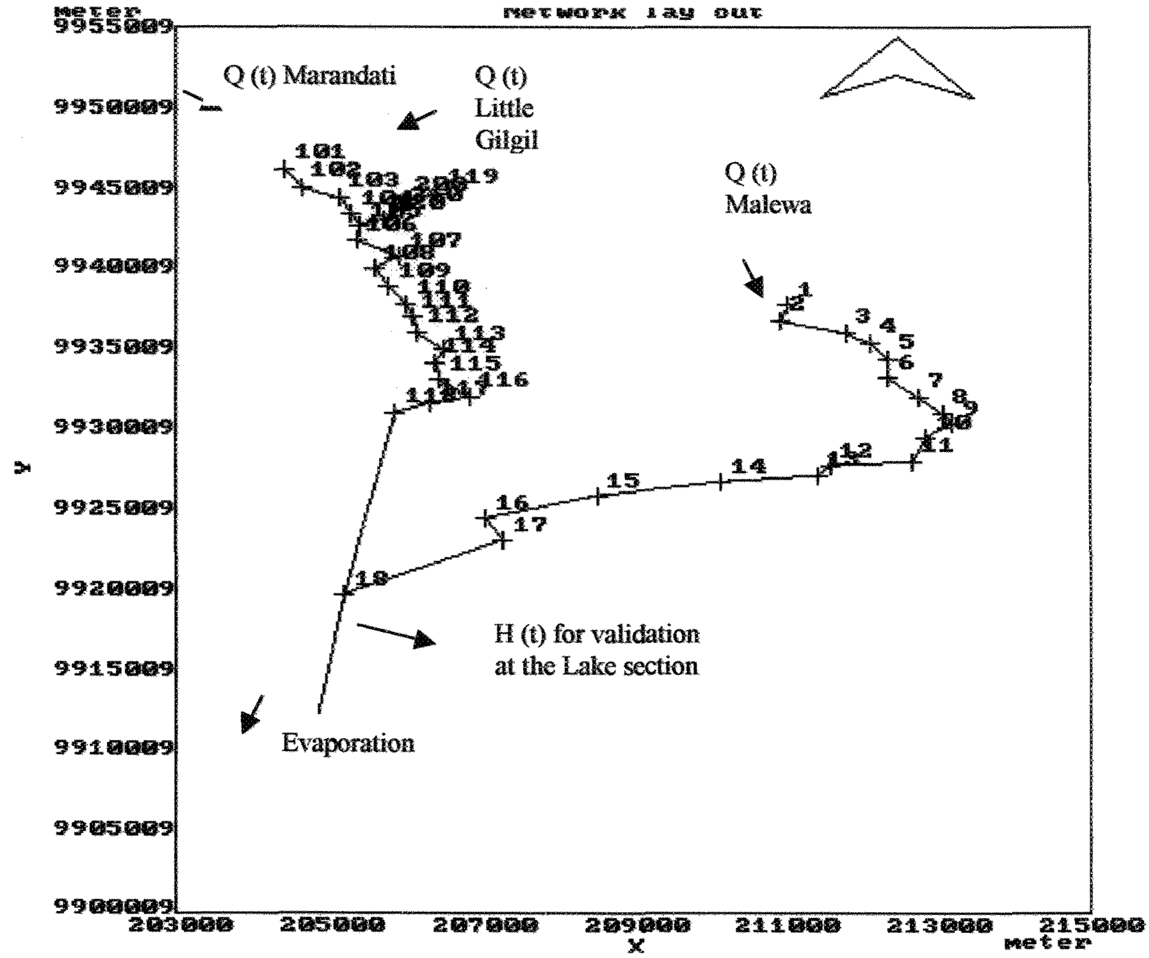


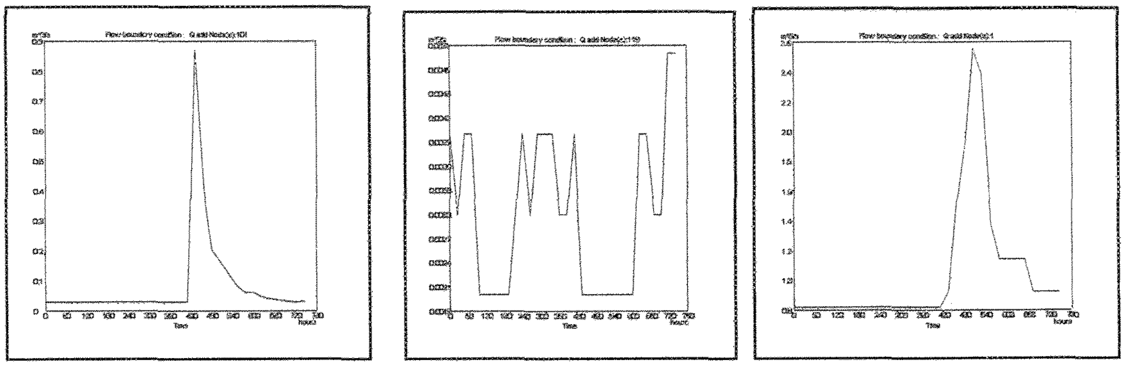
Figure 6-4 Representation of Malewa, Gilgil and lake Naivasha in DUFLOW.

- **Initial conditions**

For the start of numerical computations initial values have to be given for all nodes and branches. These conditions were set for each simulation period.
Horizontal water levels, small discharges and zero concentrations were used as initial conditions for the model.

- **Boundary conditions**

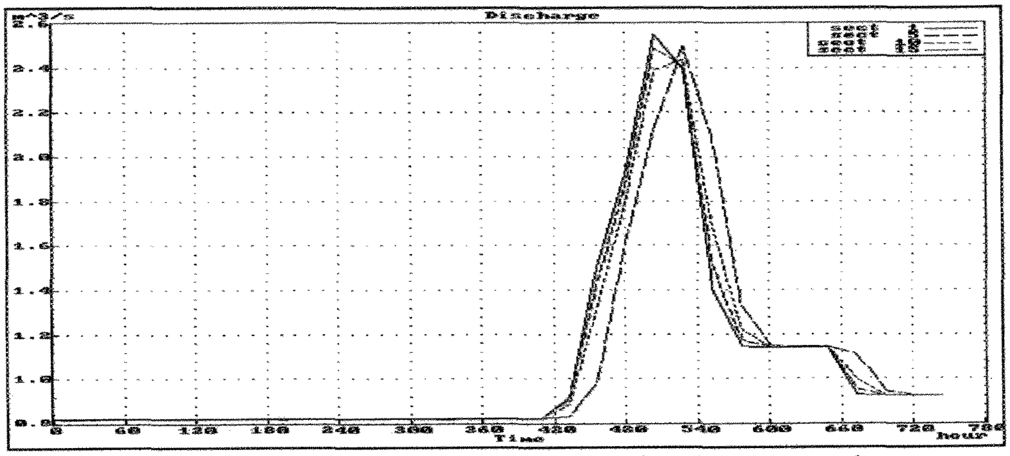
The inputs of the DUFLOW model is the historical data sets containing a time series for the discharge for the gauged river flow sections and gathered lake level data are used for validation of the model. The boundary conditions at the end node of the lake are the average estimated lake evaporation during dry period from literature.(see graph 6-13).



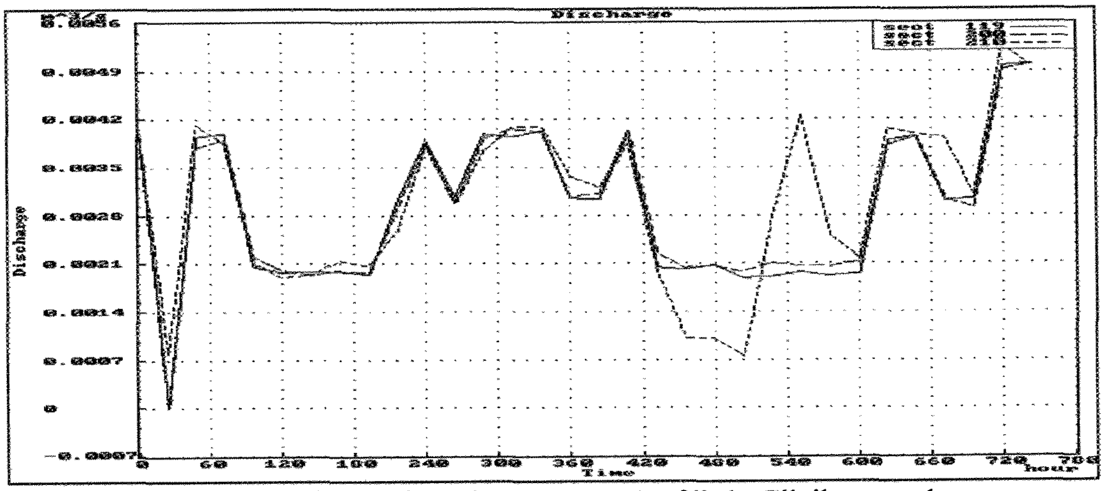
Graph 6-13 Input discharge for Marandati, little Gilgil and Malewa rivers.

- **Calculations**

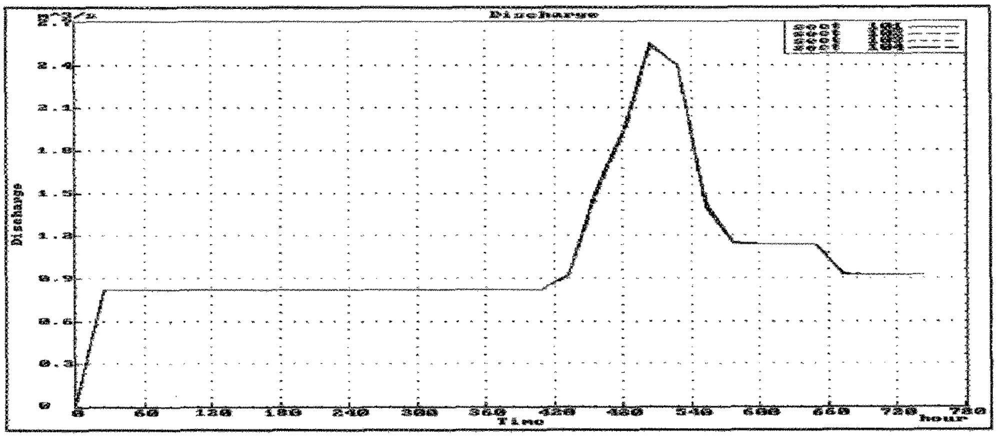
The Flow and water level were calculated for all sections in the river.The output discharge at certain sections are shown in graphs (6-14, 6-15, 6-16, 6-17)



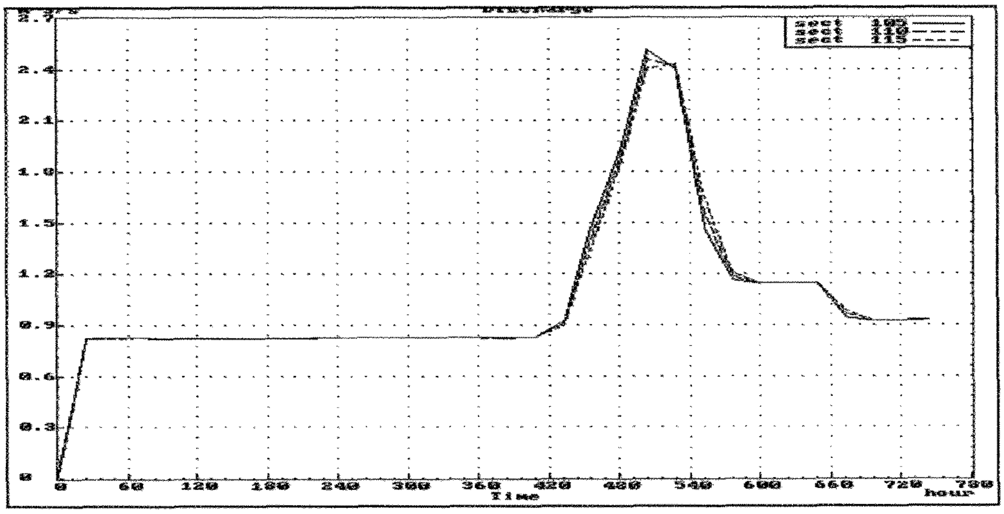
Graph 6-14 Discharge for sections (1,5,10,15) of Malewa network.



Graph 6-15 Discharge for sections (119,200,210) of little Gilgil network



Graph 6-16 Discharge for sections (101,102,103,104) of Marandati network



Graph 6-17 Discharge for sections (105,110,115) of Gilgil network.

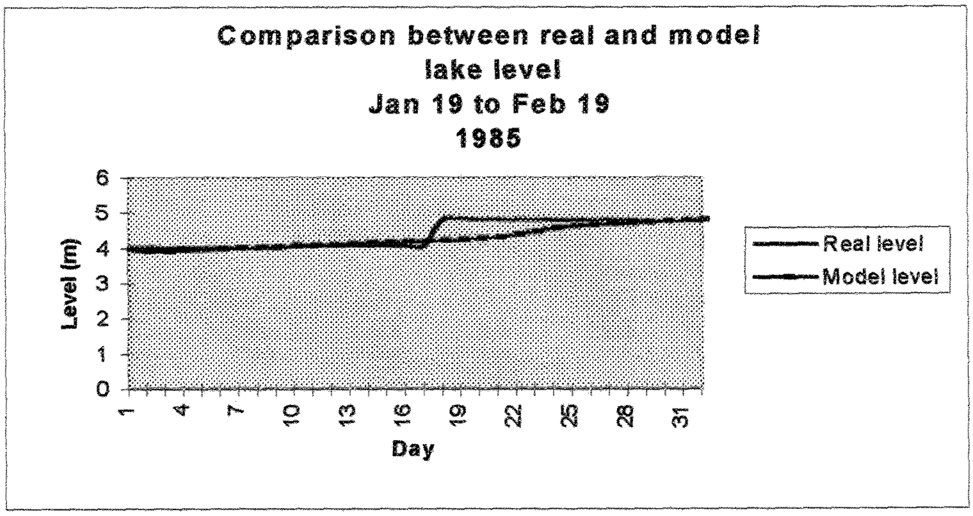
The used models are the simplified, evaluated rivers models.

6.4.2 Verification of the model

The Gilgil, Malewa and lake combined model is verified by the following ways:

1. Comparing the contribution of Malewa and Gilgil rivers in this year by the real data From the model output, the Malewa and Gilgil contribution is about 50mm/month That is matching with the average river contribution to the lake in dry period.

2. Comparing level of the lake calculated from the model and measured one (graph 6-18).



Graph 6-18 Calibration of Malewa, Gilgil and lake model.

Graph 6-18 shows that the overall increase in Lake Level in this period calculated from the model and from real measurements are approximately same.
Notice that the real level data obtained from Kenya water resources ministry however seemed doubtful to us.

6-5 SCENARIO ANALYSIS

Upstream use of water must only be undertaken in such a way that it does not effect water quantity or water quality, for downstream users. So we need to determine seasonal, short and long term trends in water quantity and quality in relation to demographic changes, water use changes and management interventions for the purpose of water quality protection. As an example for the use of the model as a tool for analyzing the effects of water use upstream, the following scenarios were considered.

- Human Activities in the catchement especially those having direct effluent on the rivers or the lake affect the water quality of the lake.
  As example a spill from a dairy factory (one of the largest dairy factories in the subwatershed) with capacity of 30.000 m3/year milk production was simulated.
  This dairy factory discharge daily wastewater to Malewa river downstream without treatment as shown in figure (6-5).

- Excessive water abstraction upstream from Malewa and Gilgil rivers could have a direct impact on the commercial fishery of the lake, and the important habitats associated with the fishery due to the increase in chloride concentration and salinity of the lake.
  Therefore abstraction scenarios were simulated using the simplified DUFLOW model.
  The first scenario assumed permitted abstraction rate and the second scenario assumed real abstraction rate.
  The major abstraction points for Malewa and Gilgil rivers are shown in figure (6-6).

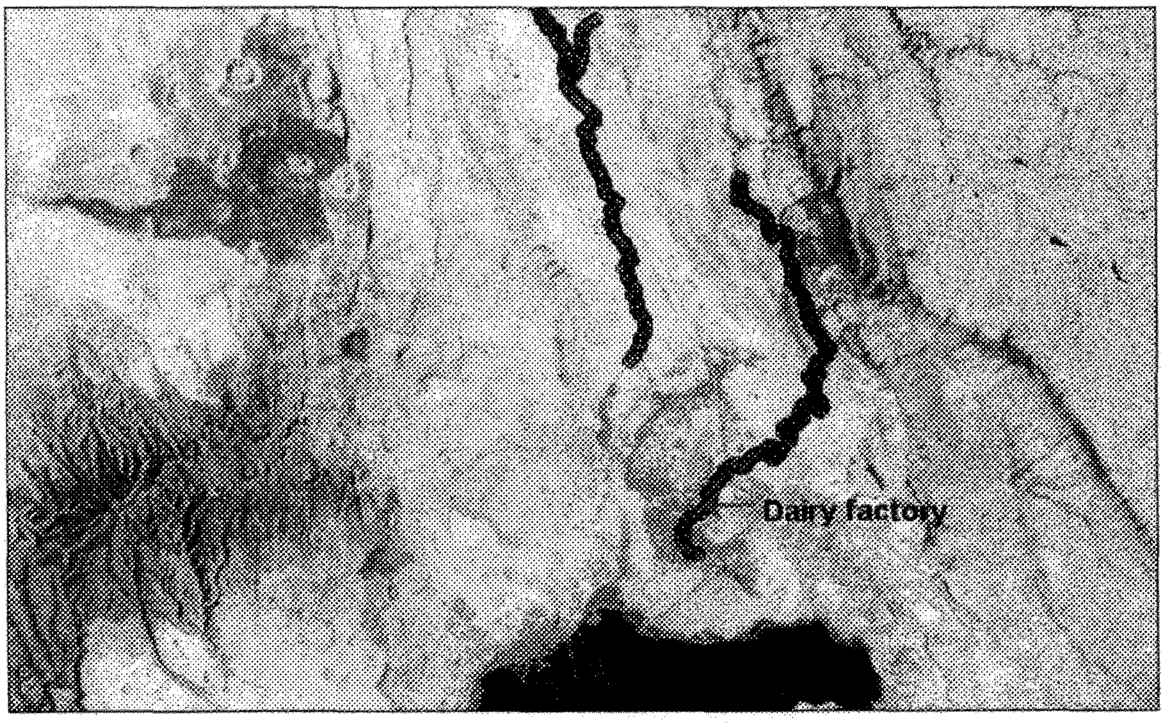


Figure 6-5 DUFLOW detailed model and dairy factory location.

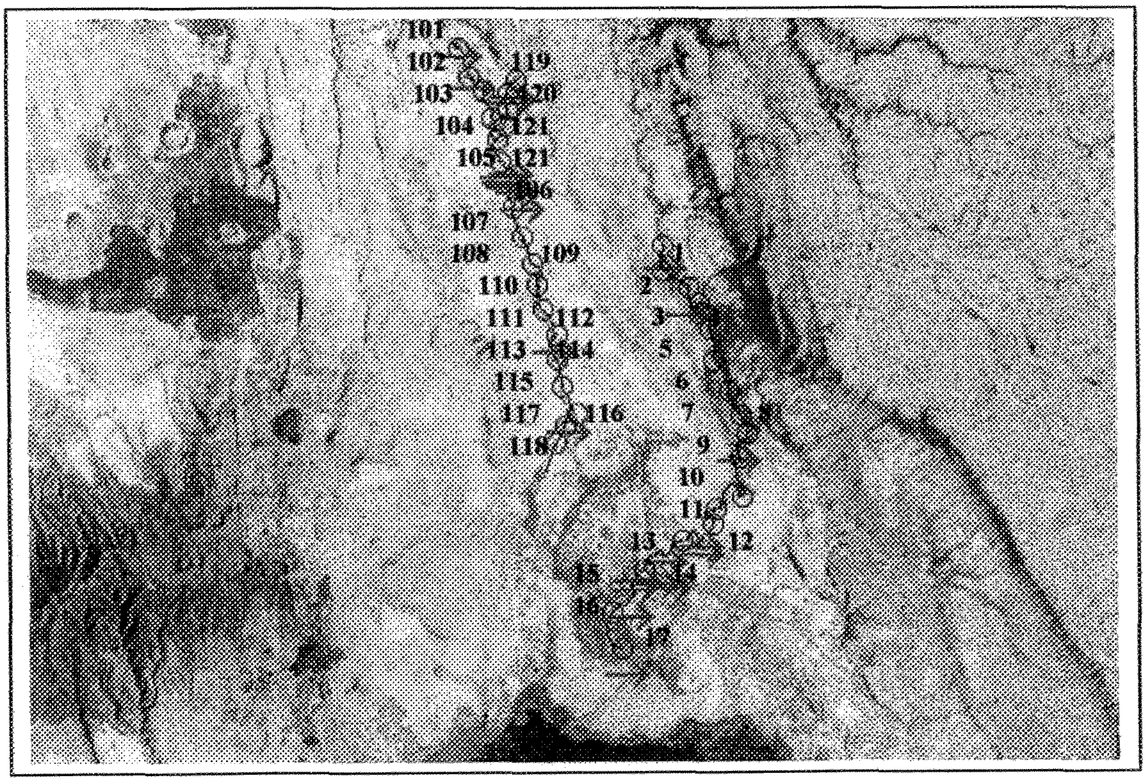


Figure 6-6 DUFLOW simplified model and abstraction points location.

6.5.1 Spill Scenario

It is quite interesting to see that the spill from this dairy could be easily located and the propagation of the spill can be easily simulated in the Malewa river water using the dissolved oxygen model described below.

- **Dissolved oxygen model**

This wastewater contains large amounts of organics which have to be biodegraded as the river continues its course. The result is the lowering in the oxygen level downstream of the outlet. This amount of oxygen consumed can be measured by the biological oxygen demand (BOD).

Dissolved oxygen model was developed as shown in annex 3 to simulate the BOD concentration in Malewa river and the lake section.

Figure 6-7 depicts schematically the reactions and processes in the developed dissolved oxygen model. It shows the addition of oxygen to water by reaeration from the atmosphere and by photosynthesis.
At the same time, oxygen is depleted from the water by aerobic biochemical reactions and by respiration. Further, if the water is supersaturated with oxygen, it will be lost to the atmosphere by the same exchange process which causes reaeration in oxygen-deficient waters.

This water quality model was used in conjunction with the hydrological Malewa detailed model described in section (6.2) to simulate the spill of the dairy factory.

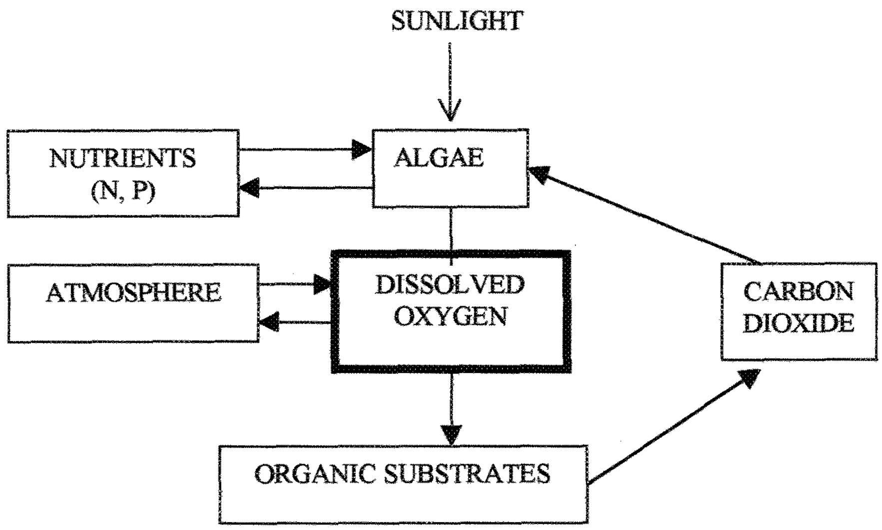
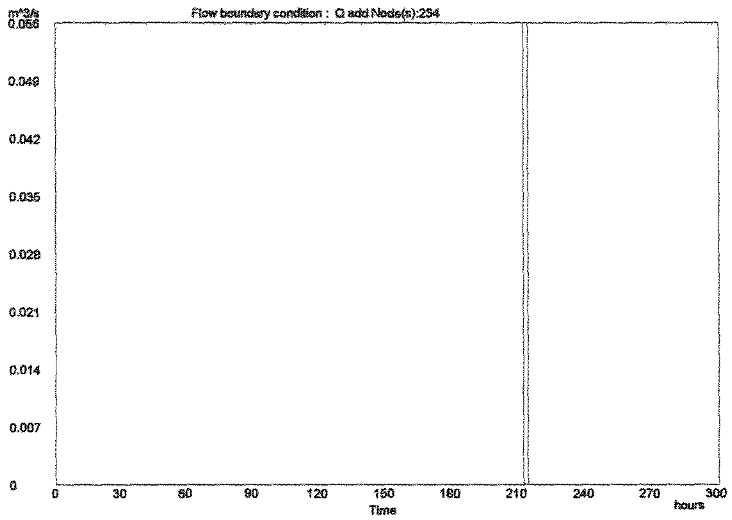


Figure 6-7 Partial representation of reactions and processes Affecting Dissolved Oxygen Level in a stream

- **Spill Simulation**

The period of simulation is for 12 days from 19 Jan 85 to 31 Jan 85 assuming that the spill occurs once in these days and the effect of this spill on the lake was analyzed.
The spill was assumed to start at 8.00 p.m. local time and to last until 10.00 p.m in 27 Jan 85. The BOD concentration of the wastewater of the dairy was assumed to be 900 mg/l at node 234 (dairy spill location) and the volume of the wastewater to be 0.056 m3/s (Graph 6-19) same as average wastewater and BOD concentration of similar dairy factories derived from literature (Verstraete, 1984).

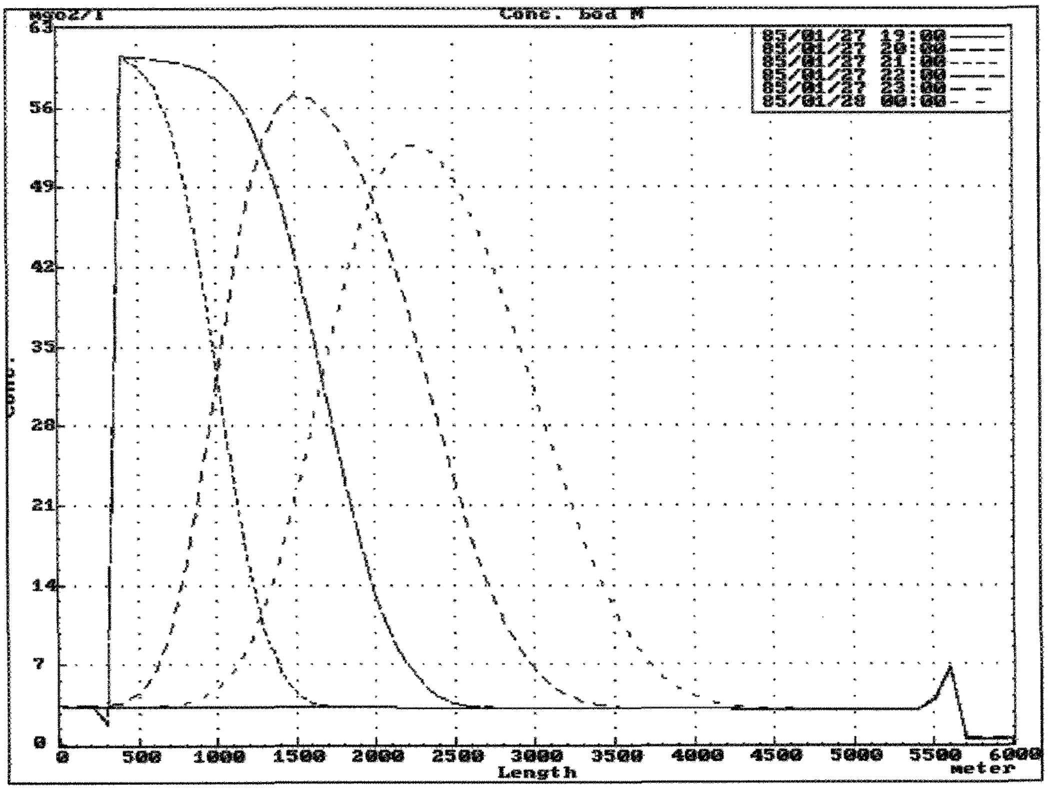


Graph 6-19 Dairy spill load

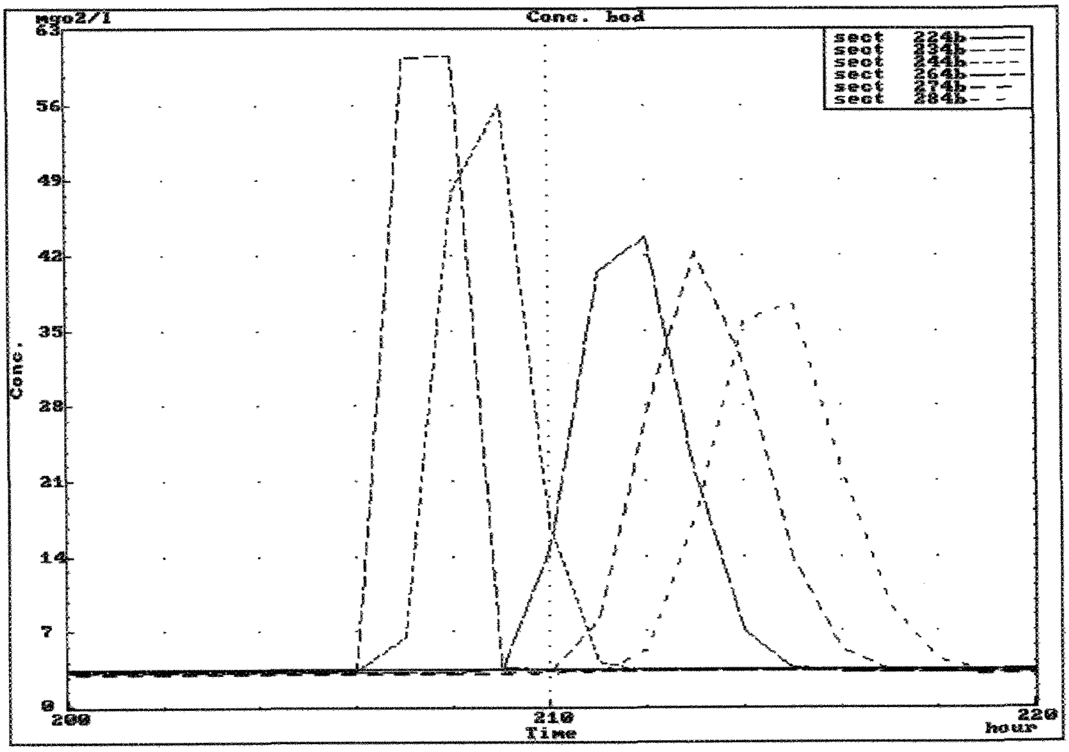
The simulation was done for two cases:

A. The change in the BOD concentration in the river sections in different time period (Simulation of the spill in time domain i.e. at specified locations as function of time). Initially the fluctuation of BOD was found to be high (62 mg/l) which gradually becomes constant after few hours (6 mg/l). The spill bloom takes almost 8 hours to reach the beginning of lake section with concentration (37 mg/l) and takes another 8 hours to diminish until the initial concentration is restored. (Graph 6-20).

b. The propagation of the spill in different sections at certain time period. (simulation of spill in space domain i.e. at specified time intervals along a defined longitudinal profile or route).At node 234 , the spill was assumed to enter Malewa river. From that point along the river ,the propagation of spill was assumed. This is shown in graph (6-21). The spill is propagated along the river until it reaches the lake section which is about 5.6 km away from the spill location. The graph shows a decrease in BOD concentration along the river until it reaches the lake section.



Graph 6-20 Spill propagation in different time periods.



Graph 6-21 Spill propagation at different locations.

6.5.2 Abstraction Scenario

All abstraction points from rivers were considered as shown in table 6-5.The simplified calibrated model of Malewa, Gilgil and the lake was considered in the simulation period (10 days from Jan 19 till Jan 26) in year 1985.

The abstraction rate considered is the average rate after taking into account the allowed operation hours and the permitted amount of abstraction for each point.
The change in lake level due to abstraction was monitored by considering the change in input river flows into the lake.

Node #	Abstraction Points (Malewa river)	Permitted Rate (m3/s)	Actual Rate (m^3/s)	Node #	Abstraction Points (Gilgil, little Gilgil, Marandati rivers)	Permitted Rate (m3/s)	Actual Rate (m^3/s)
1	Bislati	0.00005	0.0006	101	Dripland	0.0022	0.0127
15	Morendat	0.06267	0.004	106	Begg-Power Generation	0.0021	0.0023
15	Kcc factory	0.0014	0.003	120	Osiria	0.0021	0.0003
1	Kigio	0.0006	0.0003	120	Osiria	0.0002	0.0003
13	Homegrown	0.0023	0.01914	117	Marula	0.0126	0.02
9	Dairy training institute	0.0041	0.0011	114	Marula	0.0002	0.00072
14	Morendat north	0.0531	0.0123	106	Morris Githinji	0.0002	0.002
4	Ol-Morogi dairy	0.0002	0.0002	106	Geoffrey Mbuthia Kaviti	0.00006	0.001
17	Marula	0.042614	0.1576	106	Francis Kahura	0.0002	0.0007
15	Marula	0.0074	0.016	106	Daniel Mwago	0.0003	0.00047
15	Olaragwai	0.042	0.234	106	Wanderi	0.0002	0.0007

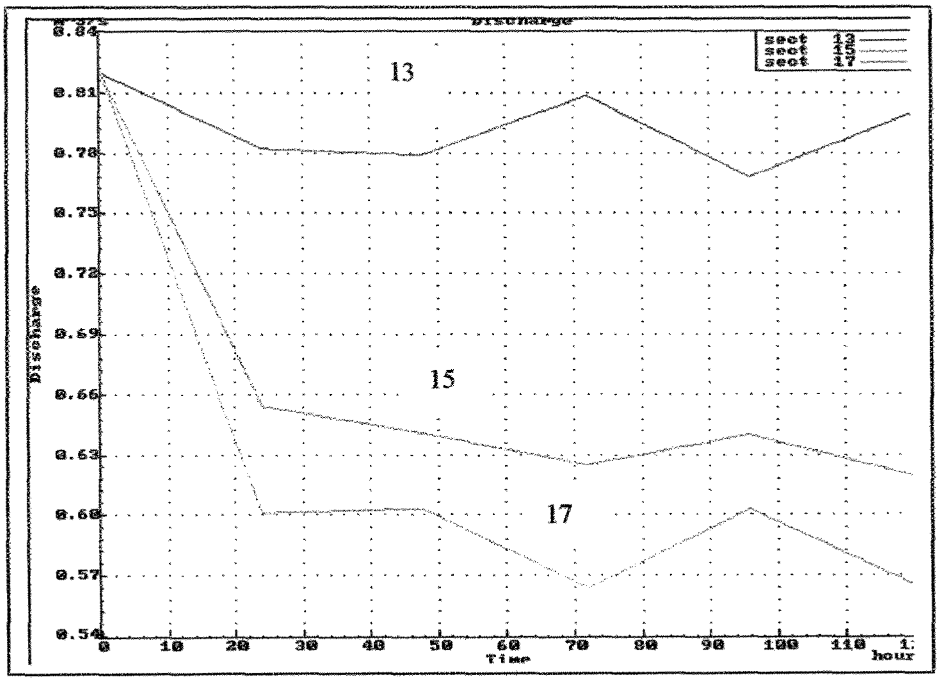
Table 6-5 Permitted & Actual abstraction rate from Malewa, Gilgil rivers.

- **Abstraction simulation**

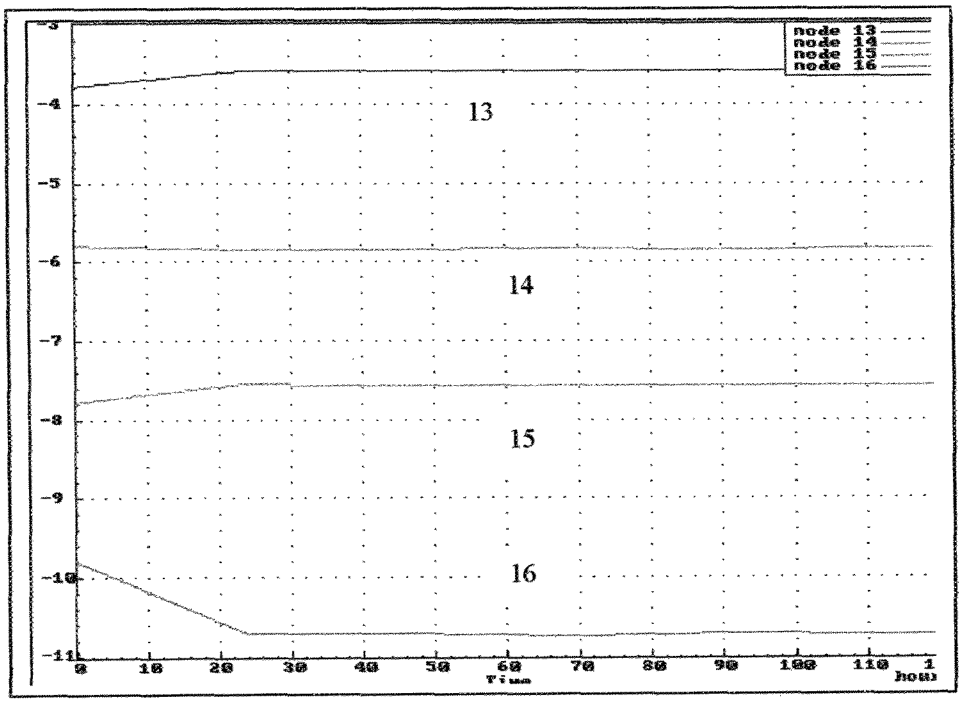
The simulation was done for two cases:

a. The change in the discharge in the river sections due to abstraction in different time periods (simulation of the spill in time domain), see graph (6-22).
As example, the effect of abstraction at node15 was monitored by drawing the discharge at section 13 and at section 17. A sudden decrease in discharge occurs.

b. The change in level in different sections (simulation of level in time domain).
Also the effect water level at node 15 was monitored by drawing the water level at nodes 13,14,16,17 as shown in graph (6-23).
A decrease in level occurs suddenly at node 16 due to the high abstraction rate at node 15.



Graph 6-22 Discharge Change in Malewa river due to abstraction in section 15



Graph 6-23 Level fluctuations in Malewa river due to abstraction in section 15

6-6 Sensitivity Analysis

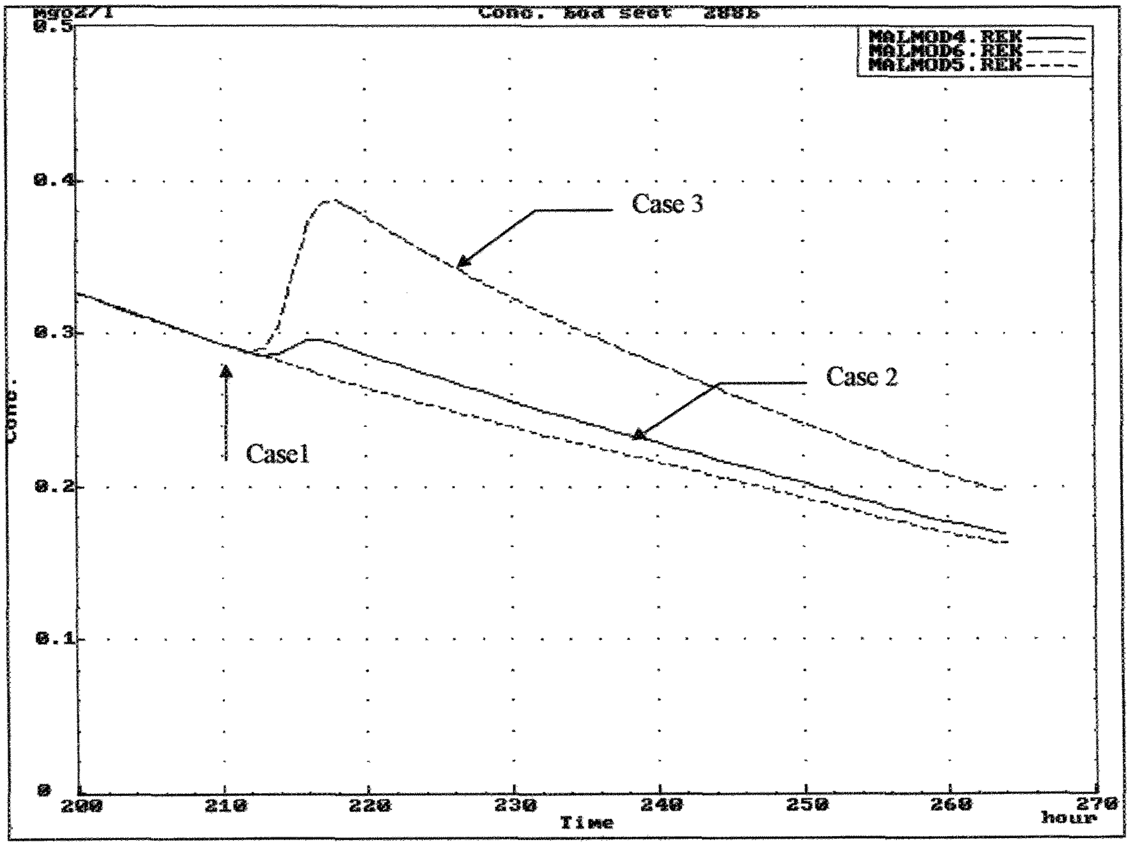
6.6.1 The Effect of spill on lake water quality

Assuming that there is accidental spill from the factory which reaches about 5 times its normal daily waste load, and the model was run to check its sensitivity to this change in spill load and the effect on lake water quality. Graph (6-24) shows the BOD concentrations in lake section (section 288 b) for the following cases:

Case1 : The lake quality without any spill upstream

Case2 : The lake quality with a normal waste load without treatment factory

Case3 : The lake quality with accidental spill at the dairy factory.



Graph 6-24 Model Sensitivity Analysis at the lake section for different spill cases

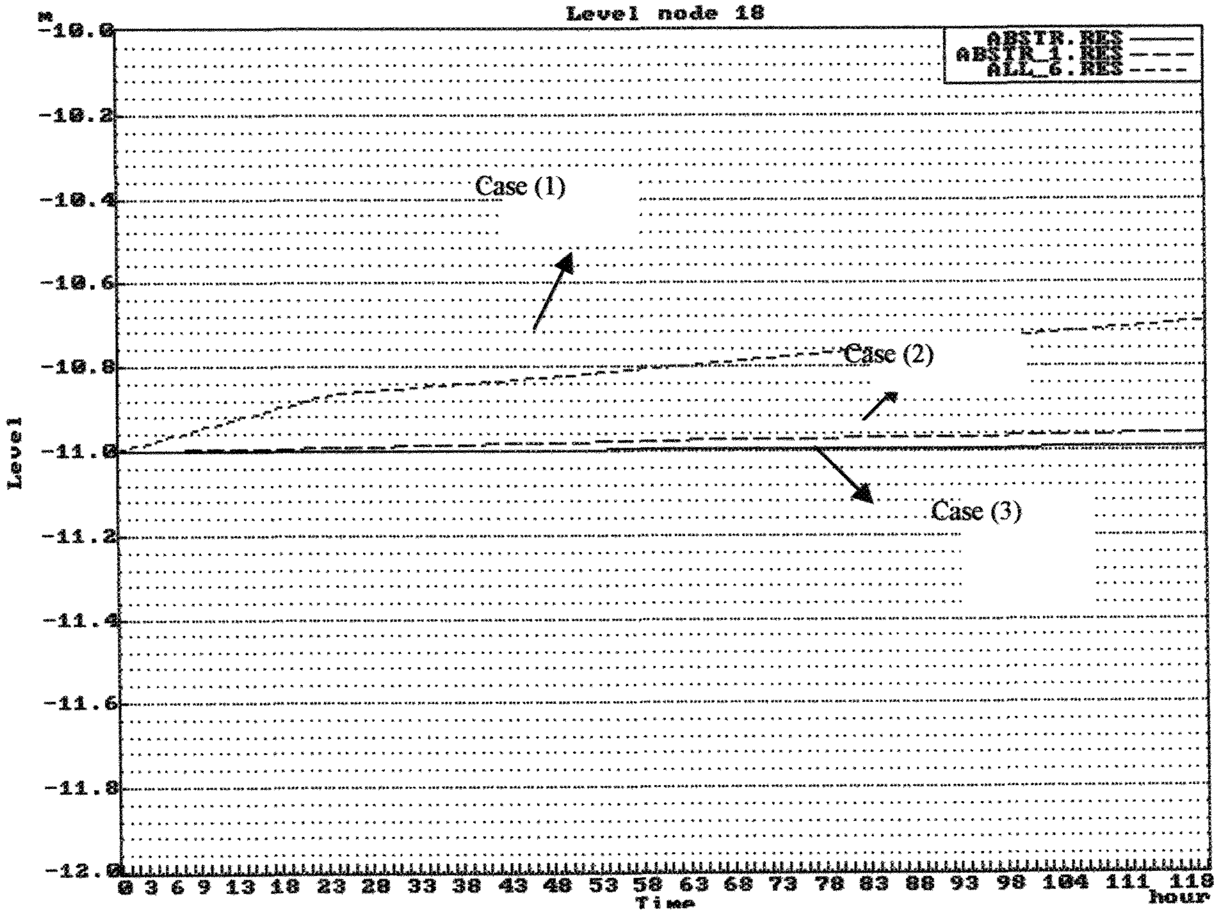
Graph (6-24) shows an increase of 0.01 mg/l of BOD concentration at the lake section in case (1) and an increase of 0.1 mg/l in case (2) .As unpolluted water typically have BOD values of 2 mg/l O_2 or less ,so an increase of 0.01 mg/l means an increase of 0.5 % from the permitted value which can be neglected. But an increase of 0.1 mg/l means an increase of 5% which is considerable but has no harmful effect on lake water quality.

Notice that the spill of the dairy was assumed to be once in the 12 days which is not the case in reality where the dairy spill is daily.

6-6.2 Effect of abstraction of water upstream on lake water level

Assuming that the abstraction rate is the actual rate measured at the field which is in major cases more than the allowed one, and the model was run to check its sensitivity to this change in abstraction rate and its effect on lake water level.

Graph (6-25) shows the sensitivity of the model to change in input conditions upstream and effect on lake water level downstream
Case (1): The lake water level without any abstraction upstream.
Case (2): The lake water level with a permitted abstraction rate.
Case (3): The lake water level with actual abstraction rate.



Graph 6-25 Model Sensitivity Analysis at the lake section for different abstraction rates.

Graph 6-25 shows an increase in water level of the lake if no abstraction occurs around 0.3m. This increase in water level becomes only 0.02 m when the abstraction was done with the permitted rate. Finally the increase of lake water level is negligible if real abstraction rates were used.

Chapter 7
Conclusions and Recommendations

In this chapter a general discussion about the research and limitations of the study concerning the data and model is described. Conclusions are drawn about the achievements of the research. Recommendations are proposed and future research issues are also indicated.

7.1 GENERAL DISCUSSION

This study was conducted aiming to design a model able to simulate the water flow and water quality of the major rivers (Malewa, Gilgil) flowing into lake Naivasha.
The potential of the "DUFLOW" model was tested and the parameters needed to drive the model were determined.

ILWIS-GIS was used for the spatial components (river network, etc..) of the model by constructing a DEM of the study area from a contour map. The river profiles and the river length were derived from the DEM and were used in the model schematization after being preprocessed and adjusted.

Water quality assessment of the lake was necessary to identify the initial and boundary values of the quality parameters for the model and to identify the pollution sources affecting the inflowing rivers.

ILWIS-GIS was also used in spatial presentation of water quality maps of Naivasha Lake and to construct a prototype environmental information system of the area of study.

The model was developed in several stages, beginning with a standalone model of each river alone and an integrated model including all the input rivers and the lake.
Each model was verified and calibrated using available observed flow data.
Some scenarios were simulated using the calibrated model as example a spill of a dairy factory discharging its effluent in Malewa river.
An accidental spill was assumed and its effect of river lake quality was analyzed through making sensitivity analysis of the model using changes in pollutant loads.

Although it is difficult to validate the water quality model due to lack of enough historical water quality monitoring data, the environmental information system and water quality model appears to have immediate potential for operational use as a decision support tool for water management in the area. It can be used as low-cost scenario engine to answer what if questions when meteorological condition or pollution sources change. Finally, the methodology seems sufficiently flexible to be applied to other lake basins in spite that some time and technical limitations were faced during the study.
A discussion about these limitations is given in the following section.

7.2 LIMITATIONS OF THE STUDY

7-2.1 Study area access

- Concerning suitability to measure the discharge of river and taking samples from the rivers and the lake:

- No easy access to the river system (the river existing within private boundaries or in a very difficult area to access) like the difficulty to get permission to go into some farms due to security purposes.

- The water levels were high for measuring the discharge using handheld current meter; especially during the heavy rainstorms in last two weeks of the field.

- When sampling in the lake, it was quite dangerous to go with the small boat near Hippo areas; also the boat got stuck in very shallow areas.

- Some roads within the study area were impassable even with 4-wheel drive vehicles.

- Data Availability

- The maps and aerial photographs were of diverse dates; also conflicting information was present in some sources.

- Difficult in collecting data especially about sewage plant performance and other pollution effluents due to security or political reasons.

- Lack of recent data about cross sections of river Malewa, Gilgil. Also good reference levels of gauge stations are not available.

- Lack of historical water quality data to validate the model due to non-existence of a monitoring program for the study area of interest.

7-2.2 Validity of the Model

In using the DUFLOW model, the following limitations were faced:

- The river Malewa has a non uniform slope which implies the discretization of the river into a large number of small reaches or sections (300 nodes) especially in the case of quality part. This increases the processing time of calculation.

- Also it was necessary to neglect the Froude number, in case of Gilgil river which has varying cross sections in order to stabilise the model against instability in computations arising during calculation.

- Due to time limitation, only two factors influencing the water quality had been simulated by two different scenarios and postponing other factors for further research.

7.3 CONCLUSIONS

Based on the study the further conclusions could be furthermore made.

7.3.1 On DEM Generation

- When using the raster DEM of the area to get information about river profiles of incised rivers as Malewa and Gilgil, a detailed contour map is needed to have accurate DEM.

- When using raster DEM in case of meandering river as Malewa, some other reference and control points are needed to get details information about point altitudes.

- The pixel size had not a great effect on the accuracy of the output rivers profile generated from the DEM in our study case.

7.3.2 On GIS-ILWIS, RS integration in the study

Integrating GIS in the system seems to be a very useful in this kind of studies for:

- It improves the visual display and interpretation of monitoring and simulating results rather than using traditional numerical figures.

- It saves a lot of time for determination of physical river network characteristics. The length calculated is more accurate than DUFLOW model especially in case of meandering rivers as in case of Malewa River.

Where conventional field investigations of water quality takes a long time, particularly for pollution over a large area. To fill the gap when no samples are taken and to maintain a periodical real time water quality forecast, satellite imagery were proved to be efficient tool in the study by calculating e.g. the temperature distribution of lake Naivasha using thermal (TM band 6).

7.3.3 On Water quality assessment and modeling

Water quality assessment has been done in details for the area, it shows that lake Naivasha is susceptible to eutrophication due to the matter inputs from the input rivers.

The main sources of pollution in upper catchement are dairies whose wastewater effluent causes increase in organic matter in the water coming to the lake.
This organic matter is measured by the biological oxygen demand measurement of the water.

Using the dissolved oxygen model of DUFLOW, the effect of actual spill of one of the existing dairies was simulated. The results show a temporary and potential increase of BOD content of lake water due to this spill.

7.4 RECOMMENDATIONS

As the model result indicates that matter input from the rivers can threaten the lake water quality, several steps are proposed, the effects of which would be to develop the sustainable management of the lake for all its uses:

1- An overall management plan be drawn up paying attention to:
a) The balance between human water use and maintenance of the lake
b) The balance between agriculture and wildlife in the riparian zone around the lake; the overall pattern of landuse within the lake catchement.
c) The provision of an agricultural advice and intensive scheme to cover the above .
d) Continued careful management of the lake fishery.
e) The maintenance of a "buffer" of natural vegetation at the edge as eco-technological approach to preserve lake water quality by using existing wetland vegetation to purify urban effluents.

2- A full-time ecological and hydrological monitoring programme has to be implemented to provide accurate information necessary for implementation of the management plan. It must be some continuous liminological monitoring of the lake on which future management strategies can be based.

3- The third is the coordination between different institutions so no conflicting programs arise. Co-operative and collaborative among the ministries like the public works ministry (sewage plant), the tourism ministry (fisheries department), the commerce ministry (industry dep.), the ministry of energy (thermal power), ministry of education (awareness of people), the ministry of health (monitoring the quality of drinking water, are needed if ecosystem integrity is to be achieved and maintained.

4-The establishment of a programme of education on environmental and water conservation needs and their scientific basis for administrators, farmers, schools and the general public. Environmental education is necessary to provide the people with the necessary knowledge, values, altitudes and commitment to participate both individually and collectively to help solve the environmental problems of the lake.

5- The construction of data information centre to provide required information of decision maker and promoting awareness and a sense of participation in the catchement community.

6- And last not least, There is a need to enact consolidated environmental legislation in Kenya, which will enable the strengthening of environmental conservation and the protection of sustainable utilisation of natural resources. This is the role of environment and natural resources sector which is charged with the responsibility of co-ordinating the planning development and management of all environmental activities.

7.5 FUTURE RESEARCH

Several issues are identified which will need further research and development.

- Estimating runoff from all the subcatchement draining into lake Naivasha by precise subcatchement delineation and precise calculation of the rainfall-runoff component using a combination of RAM precipitation runoff module, DUFLOW and ILWIS-GIS techniques.

- Incorporating the flash floods from the town area in the study and its effect on lake water quality. Together with a photo-interpretation and field survey, the existing DUFLOW model files could be extended with the RAM module and the effects could be modeled.

- Estimating Base flow and seepage and including the estimations into the developed model by linking DUFLOW with a groundwater modeling program as example "MODFLOW" to evaluate the interactions.

- Modeling the effect of agricultural practices as the increase use of pesticides, fertilizers on water quality by developing new water quality modules within DUFLOW program.

- Use eutrophication model in DUFLOW to assess the water quality of Naivasha Lake after establishing a detailed model of the lake. This however will require more input and survey data at specific locations in order to calibrate the model.

- Use of some optimization techniques linked to the model to assess the effect of increase in water abstraction upstream due to diversion of inlet rivers due to agriculture and water supply to other urban areas on Lake water level and quality.

- Sampling and analysis of sediment in the lake bottom to assess the sediment discharge into the lake.

- Study the influence of soil erosion that increases due to the population growth on Lake siltation and delta formation at the river mouth.

- The use of remote sensing needs to be extended to assess other water quality parameters of Naivasha Lake as chlorophyll, turbidity and total suspended solids detection. These can be initial conditions for the water quality model.

- The integrated method between GIS and DUFLOW model needs to be completely automated. The spatial parameters prepared by GIS can be directly input to DUFLOW model also the model output cab be directly forwarded to GIS package to display all water quality variables from simulations on a geographically registered map and in colour to correspond with varying water quality levels.

References and Bibliography

Aalderink R.H., 1996, *Procesbeschrijvingen DUFLOW Conservatieve stof*, Landbouwuniversiteit Wageningen Vakgroep Waterkwaliteitsbeheer en Aquatishe Oecologie.

Abiya I.O., 1997, *Towards sustainable utilization of lake Naivasha, Kenya*, Naivasha Wildlife and Fisheries Training Institute, Naivasha, Kenya.

Aguilar P. B., 1996, *Editing of an automatic digital terrain model and quality assessment*, MSc. thesis, ITC the Netherlands.

Anderson M.P. and William W.Woessner, 1992, *Applied Groundwater Modeling Simulation of flow and advective transport*, Academic press.

Anonymus, 1978, *Limnological investigations of lakes in Kenya 1976-1977*, Tech Report No.6.Water Quality and Pollution Control section. MIN.of Water Dev.Kenya.71 pp.

Arig E.S. and R.W.Michieka, 1987, *The Infestation, Status and Control of Salvinia Molesta D.S.Mitchell in Lake Naivasha, Kenya.*

Ase L.e., 1982, Lake Naivasha – en sotvattenssjo I kenyas Rift Valley och dess vattenstandsvariationer. Svensk Geografisk Arsbok 59: 157-169.

Ase L.E., K. Serbono and P. Syren, (1986), *Studies of lake Naivasha, and its drainage area*, Naturgeografiska Institutionen Stockholms Universitet, Forsningsrapport 63,1-75.

Ase L. E., 1987, *A note on the water budget of lake Naivasha, Kenya-especially the role of Salvinia molesta Mitch and Cyperus papyrus L.*, Department of Physical Geography, University of Stockholm.

Barnard P.C. and Jeremy Biggs, 1988, *Macroinvertebrates in the catchement streams of lake Naivasha, Kenya*, National Geographic Society Research Reports, volume 12,pages 267-272.

Barnes H.H., 1967, *Roughness Characteristics of Natural Channels*, Geological survey water-supply paper.

Beven K.,Michael and J.kirkby, 1993,*Channel Network Hydrology*, John Wiley & Sons.

Brierly B., Harper D. and Thomas R., *Water chemistry and phytoplankton studies of lake Naivasha, short term spatial and temporal variations.*

CEC DG XII, STD-3 Program, 1995, *Monitoring lakes in Kenya: An Environmental Analysis Methodology for Developing Countries*. RCSSMRS (Kenya), Aquator Spa (Italy), Earth Observation Sciences Ltd. (UK)

Chapman D., 1992, *Water Quality Assessments, A guide to the use of biota, Sediments and Water in Environmental monitoring*, Chapman & Hall.

Chow V.T., 1959, *Hydrologic studies of floods in the united states*, in floods, vol.III of Symposia Darcy, International Association of Scientific Hydrology, Publication No 42, pp.134-170.

Clark, F., Alan Beeby and Peter Kirby, 1989, *a study of the macroinvertebrates of lakes Naivasha*, Oloidien and Sonachi, Kenya.

Clark, 1990, *Geological volcanological, and Hydrological controls on the occurrence of geothermal activities in the area surrounding lake Naivasha, Kenya*. Ministry of Energy, Nairobi, Kenya.

Edmunsen R.N., 1977, *Lake was dry land once*. Daily Nation, Nairobi.March 3rd 1977.

Engulund E, Allen Sparks, 1988, *GEO-EAS (Geostatistical Environmental Assessment Software) User's Guide*, EPA.

Ferrer, 1993, *Application of remote Sensing and GIS for Runoff Estimation: applied in Canas catchement, Spain*, MSc. Thesis, ITC.

Gaudet, J.J., 1977, *Natural Drawdown on Lake Naivasha, Kenya and the formation of papyrus swamps*, Department of Botany ,University of Nairobi, Kenya.

Gaudet, J.J., 1978, *Effect of tropical swamp on water quality*, Department of Botany, University of Nairobi, Kenya.

Gaudet J.J., 1979, *Seasonal changes in nutrients in a tropical swamp: north swamp, lake Naivasha Kenya.* Journal of Ecology (1979) 67.953-981.

Gaudet J.J. and M.R Litterick, 1979, *The limnology of an African lake: lake Naivasha*, Kenya, Department of Botany, University of Nairobi, Kenya.

Gaudet J.J.and Melack J.M., 1979, *Major ion chemistry and solute budget in a tropical African Lake basin*, Freshwater Biology.

Gregory S., 1989, *Statistical methods and the Geographer*, Longman Scientific &Technical.

Harper D., Muchiri S.M. and Mavuti K.M., 1988, *Ecology and management of lake Naivasha, Kenya in relation to climatic change, Aliens species introductions and agricultural development.*

Harper D, 1992, Publications on the ecology of *the lake Naivasha and Hell's Gate National Park (1984-92)*, Department of Adult Education and Zoology ,University of Leicester.

Harper D., 1992, *The ecology and distribution of the Zooplankton in lakes Naivasha and Oloidien.*

Harper D. and Mucai Muchiri, 1992, *The ecology of lake Naivasha, Kenya: introduction and historical review.*

Harper D., G.Phillips, A.Chilvers, N.Kitaka and K.Mavuti, 1992, *Eutriphication Prognosis for lake Naivasha, Kenya.*

Harper D., 1996, *The ecology of lake Naivasha and Hell's gate national park.*

Harper D., Adams C. and Mavuti K., 1995, *The aquatic plant communities of the lake Naivasha Wetland Kenya: Patterns, Dynamics and Conservation.*

Heer H.De., 1979, *Measurements and Computations on the behaviour of the insecticides azinnnnphos-methyl and dimethoate in ditches.* PUDOC, Wageningen.

Hickley P., 1991, *A revised depth and contour map for lake Naivasha Kenya.* Earthwatch/Univ of leicester.

ICIM, 1995, *DUFLOW-a micro computer package for the simulation of one dimensional unsteady flow and water quality in open channel systems,* Bureau ICIM, Rijswijk, The Netherlands

IHE DELFT, 1996, *Appraisal of the proposal for extension of the water resources assessment and planning (WRAP),* Project into phase V, Ministry of Land Reclamation, Regional and Water Development, Kenya

ITC, 1998, *Ilwis 2.1 for windows,* Reference guide, International institute for Aerospace Survey & Earth Sciences.

Isaaks E.H. and R.Mohan Srivastava, 1989, *Applied Geostatistics,* Oxford University Press.

Jorgensen S.E., 1994, *Fundamentals of Ecological Modeling, ELSEVIER.*

Jorgensen S.E and M.J.Gromiec, 1989, *Mathematical Submodels in Water Quality Systems, ELSEVIER.*

Kilham P., 1971, *Biochemistry of African lakes and rivers,* PHD thesis, Duke University, Durham.NC.199 pp.

Kingdom of The Netherlands, Ministry Of Foreign Affairs, 1996, *Water Resources Assessment And Planning Project (phase V),* Ministry of Land Reclamation, Regional and Water Development, Kenya.

King H.W., 1939, *Handbook of Hydraulics: for the solution of hydraulic problems.*

Lerman A., 1978, *Lakes Chemistry Geology Physics,* Springer-Verlag.

Liao H.H. and S.Tim Udoyara, 1994, *Interactive water quality modeling within a GIS environment, Comp, Environ, and Urban Systems,* Vol 18,No5, pp.343-363.

Lijuan, L., 1994, *A Study on Water Quantity-Quality Relationships in the Prasae River , Rayong Province, South-East Thailand.* MSc. thesis , ITC, Enschede ,The Netherlands.

Lincer J., L.Zalkind, D. Brown and Hopcraft J.B.D., 1981, *Organochlorine residues in Kenya's Rift Valley lakes.* J.Appld Ecology.18.157-191.

Litterick M.R., J.J.Gaudet, J.Kalff and J.Melack, 1989, *The limnology of an african lake, Lake Naivasha, Kenya.*

Makin J., 1976, *The soils and groundwaters of the animal husbandry Research Station (Naivasha) Soil Survey Unit,* Special report, Kenya Soil Survey Nairobi.

Maitima, J.M., 1991, *Vegetation Response to Climatic Change in Central Rift Valley ,Kenya,*Quaternary research 35,234-245

Mavuti K.M., 1983, *Wetlands and shallow water bodies in Kenya: Characteristics and general status of knowledge*, Promotion of science and tech.Kenya.5.pp-48-58.

Meijerink, De Brower, Mannaerts and Valenzuela, 1994, *Introduction to the use of Geographic Information Systems For Practical Hydrology*, UNESCO.

Meybeck M., Chapman D.V., and Helmer R., 1989, *Global Fresh Water Quality: A first assessment*: GEMS Global Environment Monitoring System.

Montserrat, J.F., 1993, *GIS and Remotely sensed Data Acquisition For Water Quality modeling* .A Study in Teba Catchement, Malaga, Spain, MSc. thesis ,ITC, Enschede, The Netherlands.

Nemerow N.L., 1974, *Scientific Stream Pollution Analysis*, McGraw Hill Book Company.

Norusis M.J./SPSS Inc., *SPSS/PC+ 4.0 Base Manual* for the IBM PC/XT/AT and PS/2.

Pandey B. R., 1996, *An integrated Approach For the Identification and The assessment of Waste Emission Impacts on Bagmiti River, Kathmandu Valley ,Nepal.* MSc. thesis, ITC, Enschede ,The Netherlands.

Rast W. and S.O.Ryding, 1989, *The control of eutrophication of lakes and reservoirs*, Paris:UNESCO, Parthenon.

Richardson J. and Richardson A., 1972, *History of an African lake and its climate implications*, Ecol. Monogr.42: 499-534.

Smith D.I., and Peter Stopp, 1978, *The river Basin an introduction to the study of hydrology*, Cambridge University press.

Study of the national water master plan, 1992, Vol III, Kenya water resources ministry.

Shen H.W., 1979, *Modeling of Rivers*, Wiley & Sons.

Sikes H.L., 1935, *Notes on the hydrology of lake Naivasha*. Journal of East Africa and Uganda Natural History Society.13.74-89.

Suryadi, Delft August 1987, *A Mathematical Modeling study for upgrading work of tidal Irrigation/Drainage System of the Bambai-Seluang-Belawang Muhur unit*, South Kalimantan, Indonesia.

Thompson, A.O. M.S.c. and R.G. Dodson M.S.c Geologists, 1963, *Geology of The Naivasha Area* , Explanation of Degree Sheet 43 S.W.

Thomann, R.V. and John A.Muller 1987, *Principles of Water Quality Modeling and Control*, HarperCollins Publishers, New York.

Ven Te Chow, 1981, *Open-Channel Hydraulics*,McGraw-Hill Kogakusha, Ltd.

Verschren D., *Paleo-Ecologica Study of Anthropogenic Disturbance On Lake Naivasha (Kenya)*,Serving the need for historically grounded management and Exploitation of tropical ecosystems, Laboratory of animal ecology ,state university of gent ,Belgium.

Verspuy C., July 1991, *ECDUFLOW Evaluation Check DUFLOW Research concerning PC-program ECDUFLOW*, IHE Delft, Delft university of technology-Faculty of civil engineering.

Verstraete, W., 1984, *Biotechnological Processes in Environmental Technology*- Lecture note laboratory general & applied microbial ecology, state university of gent, Belgium.

Vieux B.B., 1991, *Geographic Information Systems and Non-Point Source water quality and quantity Modeling*, Hydrological processes , Vol.5,101-113.

WHO, 1984, *Guidelines for drinking-Water Quality*, Vol 2,Health Criteria and other supporting Information, Geneva.

WHO, 1993, *Guidelines for drinking-water quality*, Second edition Vol.1, Recommendation.

Wim Timmermans 1995, *Remote Sensing Evapotranspiration*, ir theses Delft University of Technology, Faculty of Civil Engineering , Department Hydrology.

ANNEX

Annex A
The legislative environmental controls of Kenya
(Water Related Acts)

The Water Act

Water in Kenya is owned by the government, subject to any right of the user, legally acquired .The control and rights to use water is exercised by the minister administering the act, and such use can only be acquired under the provisions of the act. The minister is also vested with the duty to promote investigations, conserve ad properly use water throughout Kenya.

Water permits may be acquired for a range of purposes, including the provision and employment of water for the development of power. The permit for proposed abstraction and storage, or their purposes, is subject to the approval of the water Apportionment Board. The board may set the conditions of the permit, namely the quantity of water granted and the time for abstraction, and may vary the conditions of the permit. The conditions of the permit must be adhered to, and at the determination of the permit, the Board may require the permit holder to remove all works erected in connection with the license.

Easements can be granted over land for the purposes of water development and reticulation. Compensation for the use of the land, or for damages incurred due to the operation of the works within the easement, are determined by the water Apportionment Board. The construction of certain wells requires a permit and notice of intention of any well is required, as well as data on the quantity and level of water struck. Pollution of groundwater is required to be controlled by sealing off any contaminated water and other methods as prescribed. Miscellaneous sections of the act pertinent to environmental matters deal with striking of an aquifer in the course of mining operations, prohibit the release of water without a permit, and specify penalties for polluting water used for human consumption.

The factories Act

Environmental health and safety requirements within a functioning geothermal power facility are regulated by this act. The Act requires that work areas be of an appropriate standard, well ventilated, with suitable lighting. Sanitary areas and drinking and washing areas should be provided, and safety provisions are described in the act.

The Public Health Act

This act contains directives regarding regulation of activities that affect human health. There exist provisions within the act to deal, in a general way, with water, air and noise quality as they pertain to human health. An environmental nuisance is defined, and includes the emission from premises of wastewater, gases, and smoke, which could be regarded as injurious to health. The owner and/or occupier of premises responsible for such nuisances are liable to prosecution under the act.

Chief's Authority Act

It empowers chiefs to issue order in relation to the following matters, which may have some relevance to lake's problems

- To prevent the pollution of water in any stream, watercourse or water-hole, and prevent the obstruction of any stream or water course.
- Regulating the use of artificial water supplies constructed from pubic funds

The chief's Authority Act also provides or the Minister to authorize any chief to issue orders for work or services for the conservation of natural resources.

Local Government Act

The local government act is concerned with a wide range of matters that affect the day to day activities of individuals and organizations. The section which has direct relevance is section 163,Subsection (e) empowers municipal council, town councils and urban councils to control or prohibit all businesses, factories and workshops which by reason of smoke, fumes, chemicals, gases, dust, smell, noise or vibration or other cause may be a source of danger, discomfort or annoyance to the neighborhood and to prescribe the conditions subject to which business, factories and workshops shall be carried on.

Water Quality Guidelines

GUIDELINES FOR DISCHARGE INTO PUBLIC WATERCOURSE.

pH................................	6.0-9.0
BOD (5 days at 20°C) not to exceed..	20 mg/l
COD not to exceed..................	50 mg/l
Total Suspended Solids not to exceed	30 mg/l
n-Hexane extrcat not to exceed......	30 mg/l
Oils (Mineral Animal & Vegetable)...	5.0 mg/l
Total Phenol not to exceed..........	2.0 mg/l
Copper (Cu) not to exceed...........	0.05 mg/l
Zinc (Zn) not to exceed.............	0.5 mg/l
Lead (Pb) not to exceed.............	0.1 mg/l
Arsenic (As) not to exceed..........	0.002 mg/l
Total Mercury (Hg) not to exceed....	0.005 mg/l
Alkyl Mercury not to exceed.........	0.001 mg/l
PCB (Polchlorinated Biphenyl) not to exceed.............................	0.003 mg/l
Pesticides residues not to exceed...	0.05 mg/l
Sulphates not to exceed.............	500 mg/l
Dissolved Manganese (Mn)	1.0 mg/l
Chromium (total)....................	0.1 mg/l
Chloride not to exceed..............	1000 mg/l
Fluoride not to exceed..............	2.0 mg/l
Coliform bacteria...................	1000/100ml
Free Ammonia not to exceed..........	0.2 mg/l
Sulphides (S^-) not to exceed........	0.1 mg/l
Cadmium (Cd) not to exceed..........	0.05 mg/l
Cyanide (CN^-) total not to exceed...	0.1 mg/l
Organic Phosphorous not to exceed...	1.0 mg/l

Chromium (six) (Cr^{6+}) not to exceed	0.005 mg/l
Total Dissolved Solids not to exceed	1200 mg/l
Selenium (Se) not to exceed.........	0.05 mg/l
Nickel (Ni) not to exceed...........	1.0 mg/l
Barium (Ba) not to exceed...........	2.0 mg/l
Temperature not to exceed...........	+/- 2°C of ambient temperature of the water body.
Oil/grease..........................	Nil (no trace)
Toxic Substances....................	Nil
Odour...............................	Not objectionable to the nose.
Colour..............................	Not objectionable to the eyes OR not to exceed 5 mgPt/l

NB. No person shall discharge into any watercourse any of the following substances;

- Calcium Carbide
- Chloroform
- Condensing water
- Degreasing solvents
- Inflamable solvents

GUIDELINES FOR DISCHARGE INTO PUBLIC SEWERS.

pH..................................	6.0-9.0
BOD (5days at 20°C) not to exceed...	500 mgO_2/l
COD not to exceed...................	1000 mg O_2/l
Temperature not to exceed...........	27°C +/- 2°C
Total Suspended Solids not to exceed	500 mg/l
Total non-volatile Dissolved Solids not to exceed......................	2000 mg/l
Detergents not to exceed............	15 mg/l
Phenols not to exceed...............	10 mg/l
Oils/grease not to exceed...........	10 mg/l
Soaping Oils and Fats not to exceed.	50 mg/l
Hydrocarbons not to exceed..........	20 mg/l
Hydrocarbons (cyclic)...............	5 mg/l
Silver (Cyclic Ag) not to exceed....	2 mg/l
Arsenic (As)........................	0.2 mg/l
Barium (Ba) not to exceed...........	10 mg/l
Cadmium (Cd) not to exceed..........	0.5 mg/l
Chlorite not to exceed..............	2 mg/l
Cyanide (CN^-) not to exceed.........	0.5 mg/l
Total Cyanide not to exceed.........	2.0 mg/l
Cobalt (Co) not to exceed...........	1.0 mg/l
Chromium six (Cr^{6+}) not to exceed...	0.05 mg/l
Total Chromium (Cr) not to exceed...	1.0 mg/l
Copper (Cu) not to exceed...........	1.0 mg/l
Mercury (Hg) not to exceed..........	0.01 mg/l
Ammoniacal Nitrogen ($N-N_4/NH_3$)not to exceed.............................	20 mg/l
Nikel (Ni) not to exceed............	1.0 mg/l

Nitrates (NO_3) not to exceed........	20 mg/l
Lead (Pb) not to exceed.............	1.0 mg/l
Total Phosphorous not to exceed.....	30 mg/l
Sulphur (S) not to exceed...........	2.0 mg/l
Sulphide (S^2) not to exceed.........	2.0 mg/l
Selenium (Se) not to exceed.........	0.2 mg/l
Tin (Sn) not to exceed..............	5.0 mg/l
Sulphite (SO_3^{2-}) not to exceed......	50 mg/l
Sulphate (SO_4^{2-}) not to exceed......	1000 mg/l
Zinc (Zn) not to exceed.............	5.0 mg/l
Total non Ferous metals not to exceed	10 mg/l
Chlorides (Cl^{1-}) not to exceed......	1000 mg/l

NB. No person shall discharge into the sewers any of the following substances;

- Calcium Carbide
- Chloroform
- Condensing water
- Degreasing solvents
- Radioactive residues
- Inflamable solvents
- Substances likely to interfere with the sewers.

Annex B
Water flow & Quality Data

Parameter	Measuring Method	Equipment used
Alkalinity	Total alkalinity, bicarbonate and carbonate in water samples was determined using the titration method, which involves adding a standard solution of sulphuric acid to the sample with a burette and monitor the change in its pH using Methylorange or phenolptaleine indicator.	Reagent Bottles, titration solution, titration pipette, glass bottles.
pH	pH is measured using indicator paper for few seconds into the solution to be tested and compare it with the colour scale by a combination glass electrode.	pH indicator papers at the field for river samples and Horiba for lake samples.
Turbidity	Turbidity was tested in the field using the scattered/ transmitted light principle (turbidity cell).	Fotometer at the lab or Horiba in field.
Temperature	Using the temperature scale of the EC meter in the field. Or the thermistor of the Horiba instrument.	EC meter for river and lake samples.
DO	The DO measurement is based upon the membrane-electrode method using a membrane galvanic O_2 cell	Horiba U10 in field
Conductivity	Using the electrode cell in which the conductivity is an index of the flow of electrical current in the sample.	EC meter or Horiba in field
Phosphate	Using the reflectoquant test strips and the colorimetric method using Photometer AL 25.	Reflectometer and Photometer in the lab.
Nitrate	Nitrate is reduced to nitrite by a reduction agent. In the presence of an acidic buffer, this nitrite reacts with an aromatic amine to form a diazonium salt, which in turn reacts with N- (1-naphthyl)-ethylene-diamine to form a red-violet azo dye, the concentration of which is determined reflectometrically.	Refloctometer and Photometer in the lab.
Sulfate	Using Barium -Sulfate method in which the reagent Sulfate-01 contains hydrochloride acid, which acidifies the sample. Reagent Sulfate-02 contains Barium chloride, which combines with sulfate to form Barium Sulfate .The turbidity created thereby, is measured.	Fotometer in the lab
Hardness	Using complexometric titration method and attached reagents until the solution colour changes, then the reading of the titration tube indicates their hardness of the solution	Reagents, Titration solution, titration tube, glass bottles.
Ammonium	Using Nessler's method in which Potassium tetra-iodo-mercurate reacts with ammonium ions in alkaline medium to form a brown product (a derivative of Millon's base).	Fotometer in the lab
Chloride	Using Fe-III-thiocyanate method in which mercury thiocyanate reacts with choride ions to form $HgCL_2$ and $HgCL_4$.the thiocyanate released in this way combines with FE^{3+} to form an orange red Fe-III-thiocyanate.	Fotometer in the lab

Table B-1 Methods of Analysis and equipment used

Variable	Mean	Variance	Std. Dev	Coef. Var %	Skew	Kurt	Min	25% Tile	Median	75% Tile	Max
Cond											
input rivers	113.7	875.5	29.6	26	0.592	2.82	66	87.95	106	131.5	184.4
lake	457.1	12.4	3.5	0.77	-0.78	3.4	450	456	457	458	462
Turb											
input rivers	79.07	4110.58	64.1	81.08	1.266	5.01	4	28.87	57	117	275
lake	30.69	1317.3	36.29	118.24	6.295	41.4	17	22	25	27.75	266.5
PH											
input rivers	6.7	0.162	0.402	6.007	-0.83	1.95	6	6.175	6.9	7	7.1
lake	7.609	0.02	0.14	1.84	-0.36	3.13	7.2	7.5	7.6	7.7	7.9
Temp											
input rivers	19.88	1.202	1.096	5.516	-0.12	3.05	17.9	19.4	19.9	20.3	22
lake shore	23.39	0.946	0.973	4.15	1.365	4.5	21.9	22.8	23.2	23.6	26.2
DO											
input rivers	7.66	1.855	1.4	17.8	0.65	3.3	5.7	6.5	7.8	8.23	11
lake shore	8.84	1.2	1.08	12.2	0.37	2.8	7	8.1	8.8	9.4	11.63
ALKP											
input rivers	1.78	1.182	1.1	61	0.25	3.2	0	1.23	1.8	2.25	4.4
lake shore	5.05	7.175	2.68	52.95	3.33	13.1	3.5	3.7	4.5	4.9	15.1
CL											
input rivers	17.9	516.3	22.7	126.9	2.5	9.3	2	3.25	11	17.3	100
lake shore	74.5	18793.2	137.1	183.5	2.336	7.47	4	9.3	19	32.75	515
NH4											
input rivers	6.06	68.6	8.28	136.6	1.15	3.2	0	0	0.5	8	26
lake shore	2	2	1.4	70.7	0.27	2.5	0	1	2	3	5
NO3											
input rivers	1.91	3.2	1.79	93.78	0.96	4.1	0	0	2	3	7
lake shore	3.7	6.2	2.5	67.2	0.554	2.59	0	2	3.5	5	9
PO4											
input rivers	0.522	1.43	1.19	229.1	3.4	13.4	0	0	0.1	0.25	5.1
lake shore	0.89	4.9	2.2	249.9	3.3	12.6	0	0.700	0.156	5	9
SO4											
input rivers	28.26	1561.6	39.5	139.8	1.731	4.97	0	2.5	11	45	138
lake shore	5.06	7.2	2.7	52.95	3.34	13.143	3.5	3.7	4.5	4.9	15

Table B-2 The basic statistics results for input rivers and lake shore data

No.	Month	Sample Size	20% Flow (cms)	10% Flow (cms)
1	January	11	2.102	1.128
2	February	12	1.612	0.849
3	March	11	1.888	1.072
4	April	13	2.521	1.476
5	May	13	3.782	2.386
6	June	12	3.139	1.959
7	July	13	3.593	2.367
8	August	12	4.354	2.889
9	September	13	3.948	2.534
10	October	12	4.024	2.645
11	November	12	2.736	1.533
12	December	12	2.117	1.134

Table B-3 monthly flow of non-exceedance for RGS (2GB2).

No.	Month	Sample Size	20% Flow (cms)	10% Flow (cms)
1	January	19	0.011	0.007
2	February	19	0.012	0.007
3	March	19	0.013	0.009
4	April	20	0.014	0.010
5	May	21	0.015	0.009
6	June	20	0.015	0.010
7	July	21	0.015	0.009
8	August	21	0.013	0.007
9	September	19	0.012	0.006
10	October	17	0.011	0.005
11	November	18	0.012	0.007
12	December	19	0.013	0.008

Table B-4 monthly flow of non-exceedance for RGS (2GA6).

No.	Month	Sample Size	20% Flow (cms)	10% Flow (cms)
1	January	12	0.110	0.088
2	February	12	0.098	0.077
3	March	12	0.102	0.080
4	April	13	0.108	0.080
5	May	13	0.119	0.57
6	June	12	0.191	0.126
7	July	13	0.2534	0.161
8	August	13	0.339	0.208
9	September	10	0.386	0.226
10	October	11	0.196	0.116
11	November	11	0.180	0.109
12	December	12	0.128	0.086

Table B-5 monthly flow of non-exceedance for RGS (2GA3).

Annex C
Reference Tables

Type of channels and description	**Manning's value**		
Minor streams < 30m at bank full	**Minimum**	**Normal**	**Maximum**
Clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
Same as above but more stones and weeds	0.03	0.035	0.04
Clean, winding, some pools and shoals	0.033	0.04	0.045
Same as above, but some weeds and stones.	0.035	0.045	0.05
Same as above, lower stages more ineffective slopes and sections.	0.04	0.048	0.055
Same as 4 but more stones	0.045	0.05	0.06
Sluggish reaches, weedy, deep pools.	0.05	0.07	0.08
Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush.	0.075	0.1	0.15

Table C-1 Values of roughness coefficient n for natural streams (CHOW 59).

Speed U (m/s)	Depth (m)	Dispersion D (m^2/s)
0.046	0.16	0.19
0.048	0.21	0.05
0.050	1	0.083
0.053	0.18	0.21
0.055	0.5	0.04
0.065	0.15	0.07
0.069	4	1.66
0.2	0.3	0.16

Table C-2 Some values of Dispersion constant of small streams (de Heer 1979).

Annex D

```
/*Duflow a simple oxygen model for a stream*/
  WATER BOD  [5.000]  mg O2/l  ; biochemical oxygen demand
  WATER NH4  [10.00]  mg NH4/l ; Ammonium
  WATER O2   [6.500]  mg O2/l  ; Oxygen Concentration
  PARM  Kbod [0.330]  1/day    ;Decay constant bod
  PARM  KNh4 [0.396]  1/day    ;Decay constant ammonia
  PARM  Kl   [0.500]  m/day    ;mass transfer coefficient oxygen
  PARM  Os   [7.457]  mg O2/l  ;saturation concentration oxygen
  PARM  Aon  [4.570]  mg O2/mgN;mg O2/mg Nitrogen
  PARM  AlFA [0.030]  mg o2/(W/m2);Oxygen production constant
  PARM  SOD  [0.500]  g/m2,day    ;Sediment oxygen demand

  XT   iO [207] W/m2 ;Radiation
  Flow Z  [2.0000]m  ;water depth
  {
  K1(NH4)=-Knh4;
  K1(BOD)=-Kbod;
  K1(O2)=-kl/z;
  K0(O2)=kl*Os/z-Kbod*BOD -Aon*Knh4*NH4-SOD/Z +ALFA*IO;
  }
```

Annex E

```
/*C code to link Ilwis program to Duflow program */
#include "stdio.h"
#include "stdlib.h"
#include "string.h"
main(int argc,char *argv[])
{
  FILE *in, *out, *out1;
  char sr[10];
  char ss[10];
  char sp[10];
  int i,j;
  clrscr();
  if(argc!=4)
  {
    printf("you forgot to enter the file name or the class name\n");
    exit(1);
  }
  if((in=fopen(argv[1],"r"))==NULL)
  {
    printf("cannot open source file\n");
    exit(1);
  }
  if((out=fopen(argv[2],"w+"))==NULL)
  {
    printf("cannot open target file file\n");
    exit(1);
  }
  if((out1=fopen(argv[3],"w+"))==NULL)
  {
    printf("cannot open target file file\n");
    exit(1);
  }
  fscanf(in,"%s %s %s",ss,sr,sp);
  fprintf(out,"* DUFLOW data file :%s\n",argv[2]);
  fprintf(out,"*  Network data   program version:2.04\n");
  fprintf(out,"*\n");
  fprintf(out,"+FI       0.0\n");
  fprintf(out1,"* DUFLOW data file :%s\n",argv[3]);
  fprintf(out1,"*  Network data   program version:2.04\n");
  fprintf(out1,"*\n");
  i=0;
  do
  {
    fscanf(in,"%s %s %s\n",ss,sr,sp);
    i+=1;
    if(i<10)
    fprintf(out,"   %d    %s    %s     0E+00  1.00\n",i,ss,sr);
  else if(i<100)
     fprintf(out,"  %d    %s    %s     0E+00  1.00\n",i,ss,sr);
     else
     fprintf(out," %d    %s    %s     0E+00  1.00\n",i,ss,sr);
  }while(!feof(in));
  for(j=1;j<i;j++)
  {
   if(j<10){if(j==9)
        fprintf(out1,"SECT   %d          %d       %d     %d      0  0.00   0.00   0.00
        0.00\n",j,j,j,j+1);
     else
        fprintf(out1,"SECT   %d          %d       %d      %d      0  0.00   0.00   0.00
        0.00\n",j,j,j,j+1);
         }
     else if(j<100){if(j==99)
        fprintf(out1,"SECT  %d         %d      %d     %d      0  0.00  0.00
       0.00  0.00\n",j,j,j,j+1);
        else fprintf(out1,"SECT  %d         %d      %d     %d      0  0.00   0.00   0.00
        0.00\n",j,j,j,j+1);
     }
     else
        fprintf(out1,"SECT %d        %d     %d     %d      0  0.00   0.00   0.00
       0.00\n",j,j,j,j+1);
    fprintf(out1,"W              180.0     3.6\n");
    fprintf(out1,"\n");
  };
  return 0;
 }
```