Solute Balance Modeling of Lake Naivasha (Kenya)
: Application of DMS

Chaweepan Suangkiattikun
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By

Chaweepan Suangkiattikun

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Degree Assessment Board

Prof. A.M.J. Meijerink (Chairman) WRS Department, ITC
Dr. Ir. H.W.T. Depeweg (External Examiner) IHE, Delft
Dr. Ir. Chris Mannaerts (First Supervisor) WRS Department, ITC
Drs. Robert Becht (Member) WRS Department, ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

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Abstract

The spatial and temporal variation and control of water quality of lake Naivasha is of high interest because the lake body represents the main fresh water resource of economic and environmental importance in the region. In order to study its solute behaviour and to be able to predict the impact of water inflows, outflows and abstraction on the lake water quality, a simple dynamic water quality model was built using DMS[1]. The model was designed using a simple conceptual mass balance structure in both quantity and quality constituents. Historical time series of lake levels, river inflows, meteorological data and solute (electrical conductivity) observations, were used to calibrate the modelling system. The lake water balance could be simulated at a monthly time interval with 92% prediction efficiency. The solute balance based on a non-conservative substance concept concerning internal processes of sediment exchange gave a good fit to the observed values. The solute behaviour was further evaluated using different scenarios of man-made water abstractions of the lake.

During the field survey campaign, the number of water samples required to monitor water quality of Naivasha lake (e.g. approx. 120 km^2 surface area), was also determined using a spatial sampling design, optimised using simulated annealing, and subsequent own laboratory analysis and statistical interpretation. Depending on the water quality variable, from 6 to 30 sample points are required for basic parameters to obtain a sound picture of the distribution of the constituent in the lake.

Key words: solute balance; water balance; water quality; Duflow

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[1] DMS: Duflow Modelling Studio v.3.5. (MX-Systems, The Netherlands & STOWA, 2002)

Table of Contents

List of Figures

List of Tables

List of Appendices

1. Outline of the Study

1.1. Introduction

Fresh water resources are an essential component of the earth's hydrosphere and an indispensable part of all terrestrial ecosystems. Water is needed in all aspects of life. An adequate supply of water of suitable quality makes a major contribution to economic and social development. However, many parts of the world are facing the problems of fast growing populations, rapid urbanization, rising costs of providing water, and pollution of fresh water. Humans have been polluting their water supplies since civilization began leading to the problems of scarcity and contaminations are becoming severe.

Lake Naivasha is distinctive among the lakes lying in the rift valley of central Ethiopia, Kenya and Tanzania. It represents one of the most important natural resources for the people living close to its shores, farmers, visitors and the Kenyan people in general, due to its biodiversity and economic potential as a source of water for horticultural production and tourism development. Some studies have been conducted to assess its quality in term of chemical composition and quantity in term of water budget of inflow-river and also the lake itself but it is also necessary to understand and evaluate its characteristics and behaviour. Those studies have been carried out both fieldwork investigation and models development using different software that serve different purpose of the studies.

The Duflow Modelling Studio (DMS) is a computer package developed by the STOWA (Stichting Toegepast Onderzoek Waterbeheer) that allows performing unsteady flow computations in networks of open watercourses and is also useful in simulating the transportation of substances in free surface flow with this property it can be implemental to this study.

This study aim to quantify the solute concentration, and attempt to provide an explanation for its variation in Lake Naivasha and to assess the feasibility of using DMS as a modeling tool in the simulation of solute balance.

1.2. Problem Statement

The lake Naivasha is located in the Kenya rift valley and is the only fresh water lake in a semi arid region. The inhabitants of the region depend on it for drinking water, fishery, recreation and irrigation water, because of that the demand on the resource is increasing dramatically with the associated consequences of pollution over the exploited resource.

Although there are some previous researches about water quality consequently during past years by ITC students. The result showed the spatial variation of solute concentration, however the temporal analysis hasn't done yet. Furthermore, the information regarding chemical transport in the lake is lacking. This information is needed to more effectively manage the lake and its watershed and to predict water quality responses to changes in constituent loading or hydrologic regime. Such change may re-

sult from increased agricultural activity and urban expansion within the watershed. Therefore is important to fulfil the lack and try to count with some tools to better understand how changes in hydrology and water quality in basin affects water quality in the lake.

1.3. Research Objective

1.3.1. General objective

The objective of the research is to study the chemical variation of inflow-river and to evaluate the use of DMS as a modeling tool for the assessment of the water quality of the lake. The model of the lake has to be able to describe the chemical balance.

1.3.2. Specific objective

- To assess the present water quality of input rivers and their spatial and temporal variation
- To develop the model to describe hydrologic and water quality condition in Lake Naivasha
- Simulate the DMS model to describe the solute balance of the lake in long term and short term periods
- Predict the solute behaviour to changes in constituent loading and hydrologic regime

1.4. Research Questions

- Are there any spatial and temporal variations of water quality of input river and if so what is its trend?
- How is the relationship between solute concentration and the discharge in Malewa River?
- What can be the methodology used to model the solute balance of Lake Naivasha?
- What could be happened to solute concentration if water level in the lake was changed?

1.5. Scope of The Study

According to the objective as mention above and the limiting time of study, the scope of this study has to be defined.

- The quality survey is emphasize on two main input rivers; Malewa and Gilgil.
- The input river for development of model use Malewa and Gilgil River due to their accounts for 90% of river discharge into lake. Other ephemeral flow does not take in to account.
- Water quality analysis includes the major cation and anion and the basic parameters that can be done in the field and some parameters need to carry out in ITC laboratory.
- The temporal variation of water quality in river will be done by comparison with the result of previous ITC research.
- The solute concentration is expressed in term of electrical conductivity (EC) in µS/cm.

1.6. Research Design

The development of the work is distributed in four areas: preparation of the fieldwork or pre-fieldwork, fieldwork, and post-fieldwork that include data analysis, modeling and final assessment. Figure 1.1 presents the research design in a flow chart.

1.6.1. Pre-fieldwork (3 weeks in August and September 2002)

Data Collection: This stage includes the writing of the proposal, review of the conducted research on the area also the M.Sc. thesis from the previous year, analysis of available and required data such as topographic map, time series of rainfall, evaporation, water levels of lake, discharge and chemical property of river.

Model Observation: This step consists of analysis of the software program to observe the required input for the model and to design the physical structure of model.

Fieldwork Preparation: Based on the objective and scope of study, the preliminary water quality survey is planned to monitor the quality of the river. The sample points are selected in the same location as previous studies in order to be able to do the temporal analysis and to ensure about the accessibility. This step uses various type of map e.g. the topographic map and thematic maps (GIS, ILWIS). The selection of variables is governed by knowledge of major ion from literature review. The preparation of the required equipment to measure the water quality variables is also part of this stage.

1.6.2. Fieldwork (3 weeks during 10th September – 2nd October 2002)

This phase include a program to retrieve data from automatic instrument (data logger) that have been installed in the study area and measure water quality of Malewa and Gilgil Rivers. Some parameters will be measure on the field and some others will be collected and taken back for further analysis in ITC laboratory.

Figure 1.1 Research Design Flowchart

1.7.   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.

Chapter 1 gives an outline of the study that includes introduction, problem statement, research objective, research questions, scope of the study, conceptual model, research design, and the structure of the thesis.

Chapter 2 informs a general description of the study area and Lake Naivasha and its drainage basin in term of geology, hydrology, meteorology, and water quality.

Chapter 3 explains the detail of methodology and its theory, beginning with the water quality analysis method, the statistical methods used in water sampling scheme and data analysis, the GIS methods used for spatial design of the model, and finally the DUFLOW model used for water and solute balance simulation.

Chapter 4 describes the water quality survey and assessments carried out in the main rivers and the lake. Statistical analysis of quality data and the conclusions has been conducted on overall present water quality. The spatial and temporal analysis also include in this chapter.

Chapter 5 gives all of description of model development and the methods used to prepare input for the model. The development of model consists of the conceptual model, Physical construction, boundary and initial condition, all variables required for running "DUFLOW" and the description of scenarios.

Chapter 6, the results of model are given. This chapter provide the result of water balance which include the calculated vs. observed lake level, calibration and sensitivity analysis, the result from quality part of DUFLOW in term of solute balance and the result obtained from different scenarios. The discussion for those results also included.

Chapter 7 provide the conclusions and recommendations deducted from the findings of the study.

2. Study Area Description and Relevance Research

2.1.   Background Information

The Republic of Kenya is located in the East of the continent of Africa, of area about 582,646 square kilometres. Its borders are with Tanzania, Uganda, Sudan, Ethiopia and Somalia. The coastline is bordered by the Indian Ocean. Much of Kenya is plateaux with highland areas. It rises from a low coastal plain on the Indian Ocean in a series of mountain ridges and plateaus, which stand above 3,000 meters (9,000 ft.) in the center of the country. The Great Rift Valley runs the length of the country and bisects the country above Nairobi opening up to a broad arid plain in the north. Mountain plains cover the south before descending to the shores of Lake Victoria in the west.

The study area is concentrated in the central rift valley of Kenya is an area of moderate altitude that result from formation of the rift, which was formed by violent subterranean forces that tore apart the earth's crust. These forces caused huge chunks of the crust to sink between parallel fault lines and force up molten rock in volcanic eruptions. The area forms a catchment for the drainage from two extensive forests 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 3000 m.

2.2.   Lake Naivasha and Its Basin

The Naivasha basin is situated in the Kenyan Rift Valley, about 80 km north west of Nairobi. The basin is located approximately between 0° 08' to 0° 55' S and 36° 00' to 36° 45' E. This part of the Rift Valley covers the three lakes of Nakuru, Elementeita and Naivasha to the south. The highest of the Rift Valley lakes, Naivasha (Figure 1) lies at about 1880 meter (6168 feet) above sea level, the lake level varies quite considerably - in 1926 it was reported to be 6 m higher. Eons ago it was higher than that and its waters gushed through Njorowa gorge, which is located now above the lake and forms the entrance to Hell's Gate National Park. Lakes in the Rift Valley are normally saline unless water can escape through an outlet, however there is now no visible outlet to the Naivasha Lake. The supposition is that there is underground seepage maintaining the movement of fresh water brought into the lake by the Gilgil and Malewa rivers in the north.

The Lake consists of the main lake, a small separated lake Oloidien and a smaller Crater Lake Sonachi. (Figure2) The total catchment of the lake is approximately 3200 km^2 (Morgan, 1998). The main lake (water surface) is approximately 120-150 km^2 plus 12 - 18 km^2 of swamp. LNROA (1996) reported that the lake has a mean depth of 4.7 m, with the deepest part at the Oloidien Bay (9 m) and around Crescent Island (17 m). In 1997 the mean depth of the lake was calculated at 3.8 m (Donia, ITC 1998). Rupasingha (ITC, 2002) have done the bathymetric survey during October 2001 and the result of calculated mean depth was 3.41 m at the level of 1886.38 masl.

Figure 2.1 Location of the study area.

Figure 2.2 Lake Naivasha Study Areas

Figure 2.3 Lake Naivasha and Land use in riparian zone

Figure 2.4 Physiography of the Central Rift Valley (Clarke et al., 1990)

2.2.1. Climate

The climate is warm and semi arid (East African Meteorological Dept. 1964). Air temperatures are moderate with monthly means from 15.9 to 18.5°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 warm temperature, low relative humidity and low rainfall make January, February the months with highest evaporation.

The April-May rainy season is the main rainy period, known as the long rains, while the short rains occur during October-November. Average rainfall and evaporation are 610 mm/yr and 1800-1900 mm/yr respectively (Åse, et al. 1986). The highlands surrounding the drainage basin receive more rain than the lakes and valley floor and provide most of the water that maintains the lake.

Breezes are common in the morning but afternoon winds are typical (11-15 km/h). Violent storms are also a common phenomenon and often lead to serious water movement in the lake. The wind direction is mainly from the southeast and the northwest depending on the season.

2.2.2. Hydrology

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 closed lake. Much of the rainfall designated for the Rift valley is intercepted by the surrounding highlands.

The main basin of Lake Naivasha is maintained primarily by the Malewa River (1730 km^2 watershed), which obtains its water from the Aberdare range, and Kinangop Plateau contributes about 90% of the discharge into the lake. Most of the remainder is provided by the Gilgil River (420 km^2 watershed), which drains the Bahati highlands to the north of the Elementeita – Nakuru basin. Consumption of water and irrigation and natural losses, often eliminate flow in the Gilgil before the lake is reached. The two rivers enter the northern side of the lake after passing North Swamp for several kilometres. The major portion of the northern swamp consists of a floating mat of *Cyperus papyrus*.

Water input by seepage occurs in the northeast and northwest sections, and seepage out in the south and southeast sections of the main lake.

2.2.3. Geology

The lakebeds mainly consist of volcanic materials or sub-aqueously deposited pyroclastics and organic matter. The structure of the area comprises faulting on the flanks and in the floor of the Rift Valley and slight folding in the Njorowa Gorge. The soils occupying the floor are light grey or brown to pinkish non-calcareous (Gaudet and Melack, 1981 from Ongweny, 1973). The soils in the Aberdare Mountains and the Kinangop plateau where the Malewa River originates are predominantly montmorillonite clay. Large tracts of alluvial and lacustrine deposits are found in the lower riverine systems and lakeshore. (Rachilo, 1978)

The general condition of lakeshore soil are predominantly alkaline, sodic and lacking organic matter, high ratio of silt and clay that make these soils more susceptible to surface sealing. With the exception

of hydrophidic soils closer to the lake, soil series in this area have moderate to rapid permeability in the substratum (Donohue and Thenya, 1998). The soils along the north shore above the lake are generally high in exchangeable Na^+ and K^+. The upper layers leach quickly, with an accumulation of $CaCO_3$ typical of the soils in semi-arid regions of Kenya. Soils of south eastern shore are composed of diatomite, while those at the lake edge is less alkaline and more liable to crack during drying (Gaudet and Melack, 1981).

The soils around the lake have been developed on sediments from volcanic ashes. They are deep, dark greyish brown to dark brown, firm, saline, sodic and little calcareous, fine gravelly, sandy clay loam to sandy clay with humic topsoil. These soils have a low agricultural fertility and poor workability but give, nevertheless, very high yields due to the irrigation possibilities and good farming management. (Hamududu, 1998)

2.2.4. Ecology

Lake Naivasha was declared as Kenya's second Ramsar site (a wetland of international importance) in 1995. Since it is a largest freshwater reservoir in the Rift Valley, it is of special ecological value to the region, and as such a refuge for wildlife in an otherwise dry area. The wetland supports the largest number of water bird species of any wetland in Kenya. It regularly supports more than 20,000 water birds. The lake has fringing shoreline vegetation, with emergent plants like papyrus, and floating and submerged species. The edges have a complex vegetation of terrestrial, water tolerant and wetland plants, due to frequent changes in water level. The river floodplains are dominated by papyrus. The entire wetland system is surrounded by woodland of Acacia. There are several hundreds of hippos, buffalo, monkeys, waterbuck and more than 350 bird species. (Ramsar, 1990)

2.2.5. Land use

Forests and agriculture dominate the area. The forest dominated mainly by the whistling thorn tree (*Acacia seyal*) and near the lake the "yellow fever tree" (*Acacia xantophloea*) is common. Lake Naivasha and its riparian lands are entirely state-owned. Surrounding lands are privately owned. The lake is used for tourism and recreation by the people from Nairobi, and for water sports, fisheries, cutting of vegetation, and subsistence hunting. The surrounding lands (Figure 2.3) dominate by horticultural industry, cultivation of vegetables, fruit and cereals, some pastoralism, and tourism. Agriculture is a growing practice around the lake mainly like horticultural farms that have increased in terms of irrigated area from 981.8 ha in 1988 to 7353 ha in 1998 (Tang, 1999)

According to the LNROA[1] management plan, there are 250000 people living around Lake Naivasha (often in inadequate housing and unsanitary living conditions) who can be considered as a potential threaten for the lake water quality; this number includes the Naivasha town with 45.000 inhabitants approximately and a 40% sewage covering (Beltran, 2001)

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[1] Lake Naivasha Riparian Owners Association

2.3. Lake Level Fluctuation

From the last 70 years the lake level fluctuates between 1884-1891 masl in response to net inflow. Litterick et al. (1979) reported that the daily recording of the main lake level showed repeated fluctuations with an 8 m decline between 1931 and 1952 followed by a 5 m increase during the next 10 years. The level of Lake Naivasha has shown a long-term downward trend over most of this century that responded dramatically to the abnormally heavy and widespread rains of September-December 1961 and it has not yet receded to its pre-1961 levels (Beresford et al., 1981). Lake Naivasha's water levels have fluctuated widely in recent years as El Niño rains in 1997 were followed by drought brought by La Niña. (Ramsa, 1990) According to the study of Åse et al., (1986), the annual level change normally drops during the beginning of the year, until the long rain start in April. Further they mentioned that the water level normally continues to rise even during June, July and August and the maximum occurs in September. Åse (1987) noticed that the drought during the middle of the year is not evident in the water level variations of the lake and the evaporation is not the main reason, they are great extent influenced by the flow of groundwater.

Beresford et al. (1981) mentioned their previous study to use the fluctuations as indicators of changing climate by relate the variations to sunspot numbers using spectral analysis. The result shows significant periodicities in Naivasha's levels at 7-year cycle.

2.4. Water Balance

The hydrological equilibrium of a drainage basin is maintained by the dynamic balance between sources of water and water losses. Principal sources, which bring water into a lake basin, are affluent rivers, seepage-in and precipitation while water may be lost through effluent rivers, seepage-out and evaporation.

Water inputs to the lake include rainfall, inflow from surrounding rivers, runoff and underground water from the catchment. Outputs include direct evaporation, water abstraction and groundwater outflow. The water balance of Lake Naivasha is predominantly controlled by river discharge, rainfall and evaporation. Compared to river discharge and rainfall, seepage plays a minor role in the main lake water balance and the lake level fluctuation. Gaudet and Melack (1981) found that the rate of seepage-in seem to be related to the amount of rainfall on the catchment.

Since the lake has no visible outflow, many researchers have the same conclusion that the lake has a subsurface outflow. Gaudet and Melack (1981) using mass-balance techniques calculated the water loss via seepage outflow in the southern portion of the lake as the residual in the hydrologic budget during the period of 1973, 1974 and 1975 the estimated outflow respectively was 5, 11 and 20% of total water loss.

According to the review by Ojiambo and Lyons (1993), the lake Naivasha water budget is difficult to calculate due to the monthly and annual variations of the climatological factors and the postulated subsurface outflow. Use of mean annual values does not take into account these subtle changes. They have analysed the data of many researchers and summarised the water balance that calculated by those researchers as show in Table 2.1. McCann's (1974) data cover the period when the lake level was generally rising after a long low-level period. Åse et al. (1986) intentionally took data from both falling

(dry) and rising (wet) periods of the lake level with eliminated water lost through seepage by the assumption that lakebed filled with thick layer of impermeable sediment. The basic equation used in the Table 2.1 may be written as:

$$INPUT = P + R + S_r + S_i$$
$$OUTPUT = E_o + ET + S_o + I_r \pm \Delta S$$
$$\pm \Delta S = INPUT - OUTPUT = P + R + S_r + S_i - E_o - ET - S_o - I_r$$

Where P is precipitation; R is inflow from river; S_r is surface runoff from surroundings (includes some of the yet unquantified return water from irrigation); S_i is seepage inflow, which also includes some of the irrigation water that reaches back to the lake via subsurface flow; E_o is open water evaporation from the lake; ET is Evapotranspiration from the swamps and lake algae and other vegetation; S_o is seepage outflow, which may reach groundwater or recirculate back to the lake in shallow levels; I_r is irrigation and industrial water; $\pm \Delta S$ denotes changes in water storage.

Ojiambo and Lyons (1993) used longer period from 1957-1980 to computed mean parameters of the hydrologic budget and found that evaporation loss to be 77%, irrigation 3% and seepage loss 20%. Using mass balance approaches, his data suggest that about 55% of the annual inflow is evaporated, while another 15% is utilized for irrigation, about 30% of total loss must be via seepage outflow.

Gitonga (1999) has done a long-term water balance studies on lake Naivasha and modelled on monthly time steps for the period of 1932-1997. The spreadsheet model's result shows a very good correlation between water balance components and the observed lake levels and also concluded that the ground water plays a crucial role in the water budget of the lake with the average ground water outflow from the lake about 4.6 mcm per month and since mid 1980s abstractions from the lake have increased progressively. His model predicted a current average abstraction of 57 mcm/year without this abstractions, the current lake level due to the storage change would be at least 2 meters higher.

Table 2.1 Comparison of Lake Naivasha hydrologic water balance calculations from different sources (Adapted from Ojiambo, 1996 and Gitonga, 1999)

	McCann (1974)	Gaudet and Melack (1981)	Åse et al. (1986)		Ojiambo (1996)	Gitonga (1999)	Abdulahi (1999)
Calculated year	1957-67	1973-75	1972-74	1978-80	1957-80	1932-97	1958-90
INPUT							
Precipitation	132	103	115	142	121	97	108
River discharge	248	185	187	254	212	223	229
Surface runoff	nd	0.6	nd	nd	0.6	nd	0.6
Seepage-in	nd	49	nd	nd	49	0.07	1.8
Total input	380	338	302	396	382.6	320.07	339.4
OUTPUT							
Evapotranspiration	346	313	308	301	294	271	278
Seepage-out	34	44	nd	nd	39	55	55
Irrigation+Industrial	nd	12	nd	nd	12	(57)	
Total output	380	369	308	301	345	326 (383)	333
Storage change	nd	-31	0.4	95	37.6	-5.9 (-62.9)	6.4

nd = not determined   Unit: million m³/year

Abdulahi (ITC, 1999) studied the change in groundwater storage and their interaction with lake level on the long-term periods. The simulated result using groundwater flow model (MODFLOW) showed similar result to Gitonga since they based on the same data and variables, the lake loss water via aquifer about 55 mcm/y over the period 1958-1970. But the change in groundwater storage in response to the change of lake level was insignificant.

2.5.   Solute Balance

The only available literature about chemical balance study in Lake Naivasha has done by Gaudet and Melack (1981) together with the estimation of water balance as previous description. The various component mass were calculated each month during the year 1973 and 1974 (insufficient analyses were available for 1975), the chemical balance presented by all mass-inputs minus all mass-outputs that calculated from the multiplication of water budget and chemical concentration of each component analysed during the calculated years. The five mass-inputs were from rainfall, surface runoff, river discharge, seepage-in, and mass released from sediment while two mass-outputs were seepage-out and use for irrigation, and mass taken up by sediment. Their results show in Table 2.2 and they summary that seepage and river discharge are of secondary importance as inputs. The major route of solute input and output for the lake both in the pelagic and littoral regions is sediment exchange, i.e. uptake, exchange and reaction with solids, detritus, biota and interstitial water of the sediments.

The actual mechanisms of removal by the sediments depend on the local microenvironment. They assumed that the major uptake of silica in this case is via diatoms. Bicarbonate uptake, CO_2 exchange, calcite precipitation in certain part of main lake, macrophyte uptake and ion exchange could all affect bicarbonate balance. Sulphate shows a small sediment release, which could represent a loss of H_2S from sediment. The most conservative ions, sodium and chloride, show a small net sediment uptake. The calcium and magnesium uptake could occur because of incorporation in plant cell walls and hard parts of mollusks, crayfish and fish and deposition as calcite. They also gave the consideration about potassium uptake which was not considered the recycling rate in their calculations that macrophyte incorporation may not be the most plausible sink, older sediments and sorption by organic matter and biota could also be a factor in potassium uptake.

Ojiambo and Lyons (1993) calculated the residence times for the major elements in the lake water and fell in the range of 3-6 years. Chloride was assumed to be a conservative element. The "chloride age" of lake was computed to be 5.4 years. This is very young age can be compared to chloride ages for other lakes in the region. The residence times of Na^+, K^+, Ca^{2+}, Mg^+ and HCO_3^- are all within 1 year of that of Cl^-, while those of SO_4^{2-} and SiO_2 are even less. The extremely short residence time of chloride is a strong proof of the hydraulic connection between the lake and the shallow groundwater system.

Table 2.2 Estimation mean annual solute budget, annual sediment uptake and release, and residence times of each solute for Lake Naivasha (Adapted from Gaudet and Melack, 1981 and Ojiambo and Lyons, 1993)

	Na	K	Ca	Mg	HCO$_3$	SO$_4$	Cl	F	SiO$_2$
Annual solute budget									
Inputs (% of total inputs)									
River discharge	11	7	12	21	25	11	10	5	14
Rainfall	0.5	0.9	0.3	0.5	0	1.2	1.4	-	-
Seepage	17	30	13	26	24	7	24	8	12
Sediment exchange*	72	61	79	52	51	81	73	86	74
Outputs (% of total outputs)									
Seepage	15	11	8	11	16	2	10	9	3
Sediment exchange*	85	89	92	89	84	98	90	91	97
Annual sediment uptake and release (tones x 10^3)									
Sediment release	7.6	5.1	7.5	1.0	19.1	5.2	4.0	0.8	11.4
Sediment uptake	8.2	7.3	12.8	2.0	48.4	5.1	4.7	0.5	22.1
Net change	-0.6	-2.2	-5.3	-1.0	-29.3	+1.0	-0.7	+0.3	-10.7
Ionic residence times (years)	6.4	6.2	5.7	4.4	5.9	3.4	5.4	3.9	3.5

* Residual term calculated by difference after accounting for change in storage in the lake.

2.6. Previous DMS Application

Donia (ITC, 1998) used DMS for modeling the transported of matter along Malewa, Gilgil River and Lake Naivasha, the three submodels for each compartment were combined to an integrated model. The comparison between measured and modelled lake level for the periods of 31 days during January and February 1985 showed approximately the same. The running within the periods of 12 days of different scenarios on the actual state and effect of organic wastewater from diaries discharge to river downstream using the dissolved oxygen model gave the result of temporary and potential increase of BOD content of lake water. The effect of water use at upstream was also analysed by DMS model, the result showed the fluctuation of downstream and lake level.

Mclean (ITC, 2001) built the dynamic system of Lake Naivasha's water balance based on one box model using DMS and for testing the hypothesis on whether phosphorus was more limiting than nitrogen in controlling tropic status of the lake and simulated the effect of the change of light, lake level and nutrients loading to the trophic status which characterized by trophic state indicators (secchi depth, nitrogen and phosphorus). The result from water balance simulation from year 1932 to 1990 showed the closed correlation in the first 30 years. The result from quality simulation showed that the increase in magnitude of those indicators caused the more eutrophic status of the lake.

Beltran (ITC, 2001) modelled the water balance of lake Naivasha in term of dynamic lake level fluctuation using DMS. Simple grid-type network with 20 nodes covering the lake area combined with runoff precipitation model was designed. Time series of water budget include discharge from town and farms are the input. The model showed correlation factor of 72% with observed lake level based for long period of 32 year (1968-1990) with monthly basis and 99% for a short period of 10 months (1999-2000) with daily basis. The various scenarios were developed for study the effect of hydrological regime e.g. runoff discharge from surrounding farm, rainfall, evaporation and wind. The impact of non-point sources over the lake were analysed for total dissolved solids and dissolved oxygen.

2.7. Concentration-Discharge Relationships Analysis

Plots of solute concentration against discharge result in the hysteresis loop have been used to relate stream hydrochemical variations to processes of flow generation. Walling and Webb (1980) studied the hysteresis phenomena and interpreted primarily in term of such processes as solute accumulation and flushing and groundwater recharge and outflow. They noted that distortions and modifications to the basic pattern of response would occur in large and varied basins, where increment of runoff from headwaters and tributaries draining different geological formations influenced the water quality characteristics of downstream sampling station. The nature of hysteretic loop associated with a particular event strongly depends on the origins of storm runoff and the "history" of flow contributions.

Evans and Davies (1998) provide a review of the literature on relationships between solute concentration and stream discharge, and suggest taxonomy for the simpler loops based on the ranking of three-component mixing models. The concentration of conservative solute in streamwater at a given time is described by the following mass balance equation:

$$C_T Q_T = C_G Q_G + C_{SO} Q_{SO} + C_{SE} Q_{SE}$$

Where C is concentration, Q is discharge, and the subscripts T, G, SO and SE represent total streamflow, groundwater, soil water and surface event water respectively. The developed method requires only C_T and Q_T be measured. The distinct patterns of loop were produced depending on the combination of the different ranking of those three components. From above equation, C_T at a given time will tend towards the flow component, which dominates at that time. At base flow, C_T is by definition equal C_G; on the rising limb it tends towards C_{SE}, and on the falling limb it tends towards C_{SO}. Three basic criteria are needed to characterize the various hysteresis types.

1. **Rotation pattern**. In a "clockwise" loop C_T is higher on the rising limb. C_{SE} must therefore exceed C_{SO}. With an "anticlockwise" loop C_{SO} must exceed C_{SE}.
2. **Curvature**. A "convex" loop implies that on one limb, C_T must tends towards a value greater that C_G and on the other value less than C_G. A "concave" is one in which all or a significant part of one limb is concave, this implies that C_G must have either the highest or lowest concentration.
3. **Trend**. This needs to be considered where a loop is concave. A "positive" trend implies that C_T is consistently higher during the event than it is at base flow, and hence that C_G has the lowest concentration. A "negative" trend implies the opposite that C_G has the highest concentration.

From these criteria, a synthetic template hydrograph with fix volume, timing and concentration has been used and their result gave six type of different loop depending on the components ranking.

However, Chanat el al. (2002) studied the consistency of patterns in concentration-discharge plots and explained that the trajectory of the C-Q trace over the course of a storm is determined by

1. The relative component volumes or size of the component hydrograph
2. The shape and timing of the component hydrographs
3. The solute concentration in the end-members

They applied the model to explore the range of possible C-Q plot patterns that might arise when the hydrograph volume, hydrograph timing and end-member concentration are allowed to vary. The result indicate that under some circumstances the pattern of a C-Q loop is not unambiguously determined by the rank order of concentrations of end-members, even when the simple mixing assumptions are met.

3. Materials and Methods

3.1. Sampling Design

The design of sampling scheme consists of defining the number, location and sampling pattern of the sampling site. When temporal variations in the parameters being measured are relevant, the sampling scheme must also specify the sampling frequency. Therefore in its most general form a sampling scheme determines where and how often to sampling. The sampling scheme is designed depending on the objective of the study, which is commonly to characterize the quality of water body in many limnological surveys.

According to the nature of Lake Naivasha that is shallow and well vertical mixing, therefore the occurrence of significant horizontal heterogeneity is the major problem in designing a water-sampling scheme. The sampling points should cover the surface area of the lake as evenly as possible, in order to capture the main features of the spatial variations.

The optimal spatial sampling scheme was designed using spatial simulated annealing (SSA) algorithm, which take into account sampling constraints and boundaries with the user-selected criteria. The minimization of the mean of the shortest distances criteria (MMSD) optimises for the distance to an observation in Euclidean sense has been selected in this study. The SSA algorithm was implemented using the software SANOS 1 for windows (Van Groeningen, 2000).

3.2. Water quality analysis and methods

The chemical analysis of surface water comprises temperature, pH, conductivity, total dissolved solids (TDS), alkalinity, total hardness, chloride, sulfate, nitrate, ammonia, phosphate, total suspended solids (TSS) and major cations determinations which followed the methods described in each test manual. A summary of the procedures is presented next in section 3.2.2. Major cations were analysed by inductivity-coupled plasma – atomic emission spectroscopy (ICP-ASE). The calibration curves for confirmation of the accuracy of spectrophotometer are presented in Appendix E (E-2).

3.2.1. Sample collection

Grab samples were taken at the various locations in flowing water surface. The samples taken within the riverine systems were assumed to be representative of the stream due to the natural element of mixing within the systems, the same assumption also applied for lake samples that have been spread sampling points over the area.

Sample were collected in acid washed polyethylene bottles that were rinsed three times with deionised water in the laboratory and then rinsed in the field with water samples before collection with carefully caped to reduce the air bubble as much s possible to prevent the post reaction with carbon dioxide. The samples for major cations, which will be analysed by ICP, and for sulphate determination were filtered through 0.45 µm filter paper to remove suspended solids then the filtrate were acidified with

nitric acid to pH 2. The samples for nitrogen and phosphorus analysis were acidified to pH 2 with sulfuric acid. The last set of samples was collected without adding any preservative for total suspended solids analysis. Temperature, pH, conductivity, TDS, alkalinity, total hardness and chloride were analysed in the field. Instrument was calibrated in either lab or the field on the same day of collecting samples to ensured levels of accuracy.

Collected samples were brought back to the hotel to stored in refrigerator and they were transported back to the laboratory at the end of fieldwork periods. Laboratory analysis involved testing for the presence of nitrate, phosphorus, ammonia, suspended solids, sulfate and major cations.

3.2.2. Chemical Analysis Procedure

pH

Apparatus: Portable multi-parameter meter, HACH sens*ion*156 with pH probe.

Procedure: The pH electrode is plugged into the black 5-pin connector of the sens*ion*. The electrode is placed in the water sample then the pH key has to be pressed for select pH mode, and after agitate the sample for 5-10 second to mixed well press the enter button to the reading, the electrode measures the pH electrochemically.

Conductivity, TDS and Temperature

Apparatus: Portable multi-parameter meter, HACH sens*ion*156 with conductivity probe.

Procedure: The conductivity electrode is plugged into the blue 5-pin connector of the sens*ion*. The electrode is placed in the water sample then the con/TDS/sal key has to be pressed for select the conductivity mode or TDS mode, after agitate the electrode for 5-10 second to dislodge air bubbles then press the enter button to the reading. The electrode measures the conductivity at 25°C or TDS and temperature electrochemically.

Alkalinity

Method: Phenolphthalein and Total Method, range 10 – 4000 mg/l as $CaCO_3$

Apparatus: Digital Titrator HACH16900, Graduated cylinder 25 & 100 ml, Erlenmeyer flask 250 ml.

Reagent: Phenolphthalein indicator (Cat. no. 942-99), Bromcresol Green-Methyl Red indicator (Cat. no. 943-99), H_2SO_4 titration cartridge (Cat. no. 14388-01 and 14389-01)

Procedure: Sample is titrated with sulfuric acid to a colorimetric end point corresponding to indicator used. Phenolphthalein alkalinity is determined by titration to a pH of 8.3 and indicates the total hydroxide and one half the carbonate present. Total alkalinity is determined by titration to a pH 3.7-5.1 and includes all carbonate, bicarbonate and hydroxide.

Total hardness

Method: EDTA method, range 10 – 4000 mg/l as $CaCO_3$

Apparatus: Digital Titrator HACH 16900, Graduated cylinder 25 & 100 ml, Erlenmeyer flask 250 ml.

Reagent: Hardness1 buffer solution (Cat. no. 424-32), ManVer2 indicator (Cat. no. 851-99), EDTA titration cartridge (Cat. no. 14364-01 and 14399-01)

Procedure: After the sample is buffered to pH 10.1, manVer2 indicator is added and forms a red complex with a portion of the calcium and magnesium in the sample. EDTA titrant reacts first with the free calcium and magnesium ions, then with those bound to the indicator, causing it to change to blue colour at the end point.

Chloride

Method: Mercuric Nitrate Method, range 10 – 8000 mg/l as Cl^-

Apparatus: Digital Titrator HACH 16900, Graduated cylinder 100 ml, Erlenmeyer flask 250 ml.

Reagent: Diphenylcarbazone indicator (Cat. no. 836-99), $Hg(NO_3)_2$ titration cartridge (Cat. no. 14393-01)

Procedure: Sample is titrated with mercuric nitrate under acid conditions in the presence of diphenyl-carbazone indicator that formed a pink-purple complex signalling the end point when a slight excess of mercuric ion is added.

Sulfate

Method: Method, range 0 - 70 mg/l as SO_4^{2-}

Apparatus: Spectrophotometer HACH DR/2010, Volumetric pipette 25 ml.

Reagent: SulfaVer 4 reagent (Cat. no.12065-99)

Procedure: Sulfate ions react with barium in the SulfaVer 4 Sulfate Reagent and form insoluble barium sulphate turbidity. The amount of turbidity formed detected at 450 nm is proportional to the sulfate concentration.

Nitrate

Method: Cadmium Reduction Method, range 0 - 4.5 mg/l NO_3^--N

Apparatus: Spectrophotometer HACH DR/2010, Volumetric pipette 25 ml.

Reagent: NitraVer 5 reagent (Cat. no.14034-99)

Procedure: Cadmium metal reduces nitrate in 25 ml sample to nitrite that reacts in an acidic medium with sulfanititic acid to form an intermediate diazonium salt, which couples to gentisic acid to form an amber-coloured product. The concentration is determined from absorbance at 400 nm.

Ammonia

Method: Salicylate Method, range 0 - 50 mg/l NH_3-N

Apparatus: Spectrophotometer HACH DR/2010, Tensette pipette HACH 0.1-1 ml.

Reagent: AmVer diluent reagent (Cat. no.26069-45), Ammonia Salicylate (Cat. no.23952-66), Ammonia Cyanurate (Cat. no.23954-66)

Procedure: Ammonia compounds in 0.1 ml sample combine with chlorine to form monochloramine, which then reacts with salicylate to form 5-aminosalicylate that is oxidized in the presence of a sodium nitroprusside catalyst to form a blue coloured compound. The blue colour is masked by the yellow colour from the excess reagent present to give a green solution. The concentration is determined from absorbance at 655 nm.

Phosphate

Method: Persulfate Method, range 0 – 3.5 mg/l PO_4^{3-}

Apparatus: Spectrophotometer HACH DR/2010, COD Reactor, Volumetric pipette 2 and 5 ml.,

Reagent: Test vial (Cat. no.27426-45), Potassium persulfate (Cat. no.20847-66), PhosVer 3 Phosphate Reagent Powder (Cat. no.21060-46)

Procedure: Phosphate in 5 ml sample is converted to orthophosphate by heating with acid and persulfate then reacts with molybdate in an acid medium to produce phosphomolybdate complex. Ascorbic acid then reduces the complex, giving an intense molybdenum blue colour. The concentration is determined from absorbance at 890 nm.

TSS

Method: Centrifuge Method

Apparatus: Electrical balance Metter Toledo AC100, Centrifuge Kokusan H-103N 50 ml tubes, Hot air oven Heraeus, Ultrasonic water bath QH Kerry, Desiccators, Volumetric pipette 50 ml.

Procedure: 50 ml of water sample is centrifuged 15 minute at 4000 rpm. After carefully remove super-natant, the tube with solids is dried at 105 °C then cool down in desiccators and weigh. TSS presents as the weight of dried residue per volume of sample.

3.2.3.   Inductively Coupled Plasma (ICP) method

ICP-AES, stands for Inductivity-Coupled Plasma – Atomic Emission Spectroscopy, is a multi-element analysis technique that will dissociate a sample into its constituent atoms and ions and cause them to emit light at a characteristic wavelength by exciting them to a higher energy level. This is accomplished by the use of an inductively coupled plasma source, usually argon. A monochromator can separate specific wavelengths of interest, and a detector is used to measures the intensity of the emitted light.

The plasma is used as a sample cell that will excite atoms. When these excited atoms return to the ground state, they will emit energy of a characteristic wavelength. The monochromator can direct these wavelengths to a detector. A typical plasma source is shown below in Figure 3.10. Initially, argon gas will pass through the quartz tube and exit from the tip. The tip of the quartz tube is surrounded by induction coils that create a magnetic field. The accurrent that flows through the coils is at a frequency of about 30 MHz and a power level around 2kW. The stream of argon gas that passes the coil has been previously seeded with free electrons from a Tesla discharge coil. The magnetic field excites these electrons, and they then have sufficient energy to ionize the argon atoms by colliding with them. The cations and anions present from the initial Tesla spark accelerate due to the magnetic field in a circular pattern that is perpendicular to the stream exiting from the top of the quartz tube. By reversing the direction of the current in the induction coils, the magnetic field is also reversed. This changes the direction of the excited cations and anions, which causes more collisions with argon atoms. This results in further ionization of the argon atoms and intense thermal energy. As a result, a flame shaped plasma forms on top of the torch.

Figure 3.1 Schematic diagram of a typical ICP-AES instrument

A second stream of gas is usually needed to cool down the inside of the quartz tube. This provide by a stream of argon that provides a vortex flow. The flow also provides a way of centering and stabilizing the plasma. When the sample flows into the plasma (in an aerosol form), the atoms present excite by the extreme temperatures. These excited atoms will emit energy at a characteristic wavelength.

In an ICP analysis, the plasma will reach a temperature in the range of 6,000 – 10,000 °C, which will efficiently atomize most elements. The resulting detection limits are very low, and they usually range from 1-10 ppb.

There is no electrode contact in the plasma source, which results in spatially separated excitation and emission zones. This creates a simple background spectra and a high signal to noise ratio. The sample is introduced as an aerosol by use of a nebulizer or atomizer. Pneumatic nebulation is the most often used method. A simultaneous ICP instrument can easily analyse up to 60 different elements at the same time without compromising the precision of the analysis or the detection limits.

Interferences

Interferences may be categorized as follows:

1. Spectral interferences: Light emission from spectral sources other than the element of interest may contribute to apparent net signal intensity. Sources of spectral interference include direct spectral line overlaps, broadened wings of intense spectral lines, ion-atom recombination continuum emission, molecular band emission, and stray (scattered) light from the emission of elements at high concentrations.

2. Non spectral interferences

   a. Physical interferences are effects associated with sample nebulization and transport processes. Changes in the physical properties of samples, such as viscosity and surface tension, can cause significant error.

   b. Molecular compound formation, ionization effects, and thermochemical effects associated with sample vaporization and atomization in the plasma cause chemical interferences.

3.3. GIS-ILWIS (DEM)

The software integrated land and water information system (ILWIS) developed and marked by International Institute for earth Observation and Earth Sciences (ITC, 1985). It is a geographic Information System (GIS) with image processing capabilities. The ILWIS software allows user to input, manage, analyse and output geographical data. The information on the spatial and temporal patterns on the earth surface can be generated. Therefore the questions such as what features, where and when can be answer.

Digital Elevation Models (DEM) is digital representations of continuously varying variables such as elevation, groundwater depth. Contour interpolation is one of the methods to create DEM; the first step is rasterizes contour lines in the segment map. This results in values for all pixels that are located on the segments while all other pixels in the map remain undefined. The second step is to interpolate the altitude value between the pixels to obtain the elevation of the undefined values. The output of contour interpolation is a raster map in which every pixel has a value. The linear interpolation between two contour lines is calculated as:

$$H_p = H_2 + \left(\left(\frac{d_2}{d_1 + d_2} \right) * (H_1 - H_2) \right) \qquad \text{Eq. 3.6}$$

Where: H_p is the calculated height value for an output pixel, H_1 and H_2 are the height value of the higher and lower contour lines and d_1 and d_2 are the distances from the pixel to the higher and lower contour lines

Figure 3.2 Schematic diagram of contour interpolation

3.4. Duflow Modeling Studio (DMS)

DUFLOW is the joint ownership of Rijkswaterstraat, IHE, the Delft University of Technology, STO-WA and the Agricultural University of Wageningen. The computational core of this model is based on the FORTRAN computer code IMPLIC which was originally developed by the Rijkswaterstraat. The summary of DMS were obtained from Duflow for Window v.3.3 – Reference Guide Duflow (STO-WA/EDS, 2000).

3.4.1. Purpose of the model

DUFLOW is designed to cover a large range of applications, such as propagation of tidal waves in estuaries, flood waves in rivers, operation of irrigation and drainage system, etc. Basically, free flow in open channel systems is simulated, where control structures like weirs, pumps, culverts and siphons can be included. The selected numerical scheme allows for a rather large time step in the computation and for choosing different lengths of the elementary sections.

Water quality is an increasing concern in water management, e.g. problems of algal bloom, contaminated silt, salt intrusion, etc. More often than not, water quality has to be described by a sometimes large number of parameters, therefore DUFLOW allows for a number of quality constituents, and it is able to model the interactions between these constituents. It is also flexibity for user to add or write his own quality model description file (a text-file containing the descriptions of the quality process) in the part of DUPROL included in DUFLOW package.

The major advantage in education is the short learning time which is due to its program structure and user-oriented input and output.

3.4.2. Options and elements

Duflow Modelling Studio consists of the following components:
- Duflow water quantity and quality: with this program one can perform unsteady flow computations in networks of open watercourses and simulate the transportation of substances in free surface flow
- RAM precipitation runoff module: with RAM one can calculate the contribution of rainfall to the surface flow from specified area.
- MoDuflow: this program simulates an integrated ground water and surface water problem.

3.4.3. Network Editor

The Network editor of DMS offers the user a tool for creating a model in a user friendly way. The network editor is a graphical editor that enables you to interactively draw the network schematization. The desired object (e.g. a node) can easily be selected from the Palette toolbar. The mouse is used to place the object in the network window. This network editor is based on the Standard Exchange Format (Dutch: Standaard Uitwisselings Formaat – SUF), which has consequences for the way in which the network is set up.

In the standard exchange format, a schematization is built up of nodes, sections and objects defined on these sections:

- Nodes are points at which one or more sections arise or end.
- A section connects two nodes.
- The schematization is set up and adjusted by selecting and dragging the objects.
- By selecting objects from the Network Window, one can activate the Object Properties dialog box, where the properties of these objects can be modified.
- Cross Sections can be applied on miscellaneous places on the section. The cross sectional profile over the entire section is interpolated between the different cross sections given by the user.

3.4.4. Scenario Manager

With the Scenario Manager the user can easily define different scenarios, which are based on the first created model. As default the data of each scenario is equivalent to the base scenario. The user however can easily alter the data for each scenario without affecting the data of the base scenario. By calculating the different scenarios and comparing the results the user can evaluate the effects of the scenarios on the model. The Scenario Manager window displays a project-tree of the open projects and scenarios.

In DUFLOW a model, representing a specific application, can be put together form a range of elements. Boundary conditions can be specified as:

- Water levels and discharges, either constant or in the form of time series or Fourier series;
- Additional or external flow into the network can be specified as a (time dependent) discharge or can be computed from a given rainfall;
- Discharge-level relations (rating curves) in tabular form;
- Concentrations and loads of all the transported materials in the quality model, either constant or in the form of time series or Fourier series.

In the network window, the network schematization can be created and interactively adjusted. Simple shaped cross-sections can be specified with only a few data. Two types of resistance formula can be used, viz. Manning and De Chezy. For more complex cross-sections (natural rivers) the width (both width of flow and width of storage) and the friction factor and the hydraulic radius can be specified as a function of the water level.

3.4.5. Presentation of the results

The Duflow interface is supplied with an elaborate presentation module. The presentation model is designed to give the user optimal support for interpretation of the results. Some possibilities of the presentation module with respect to plotting are:

- Boundary conditions can be plotted in the same graph as the results.
- Output facility to tables, makes it possible to import the results into a spreadsheet for further post processing.
- Local values can be read by a so-called hairline. Selecting a point on the graph with the mouse activates a vertical line in the graph window. The values of the active graphs in the graph window are printed in the legend.
- Aside from plotting the quantities with respect to time, one can also plot graphs with respect to space. For space related output the user can define the route by using the sections as defined in the network editor.
- Results of the Duflow calculation can be spatially visualised in the Network using Presentation scripts.

3.4.6. Physical and mathematical background

3.4.6.1. Flow

The unsteady flow equations

DUFLOW is based on the one-dimensional partial differential equation that describes non-stationary flow in open channels. These equations, which are the mathematical translation of the laws of conservation of mass and of momentum read:

$$\frac{\partial B}{\partial t} + \frac{\partial Q}{\partial x} = 0$$ Eq. 3.7

and

$$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{\partial(\alpha Qv)}{\partial x} + \frac{g|Q|Q}{C^2 AR} = a\gamma w^2 \cos(\Phi - \phi)$$ Eq. 3.8

while the relation:

$$Q = v \cdot A$$ Eq. 3.9

holds and where,

t = the time [m];
x = the distance measured along the channel axis [m];
$H(x,t)$ = the water level with respect to reference level [m];
$v(x,t)$ = the mean velocity (averaged over the cross-sectional area) [m/s];
$Q(x,t)$ = the discharge at location x and at time [m^3/s];
$R(x,H)$ = the hydraulic radius of cross-section [m];
$a(x,H)$ = the cross-sectional flow width [m];
$A(x,H)$ = the cross-sectional flow area [m^2];
$b(x,H)$ = the cross-sectional storage width [m];
$B(x,H)$ = the cross-sectional storage area [m^2];

g = the aceleration due to gravity [m/s^2];

$C(x,H)$ = the coefficient of De Chezy [m$^{1/2}$/s];

$w(t)$ = the wind velocity [m/s];

$\Phi(t)$ = the wind direction in degrees [degree];

$\phi(x)$ = the direction of channel axis in degrees, measured clockwise from the north [degrees];

$\gamma(x)$ = the wind conversión coefficient [-];

α = the correction factor for non uniformity of the velocity distribution in the advection term, defined as:

$$\alpha = \frac{A}{Q^2} \int v(y,z)^2 \, dydz \qquad \text{Eq. 3.10}$$

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

This mass equation (3.2) states that if the water level changes at some location this will be the net result of local inflow minus outflow. The momentum equation (3.3) expresses that the net change of momentum is the result of interior and exterior forces like friction, wind and gravity.

A mass conservation scheme for water movement is essential for proper water quality simulation. If the continuity equation is not properly taken into account, the calculated concentration will not match the actual concentration.

Boundary and initial conditions

For a unique solution of the set of equations, additional conditions have to be specified at the physical boundaries of the network and at the sections defined as hydraulic structures.

The user-defined conditions at the physical boundaries may be specified as levels, discharges or a relation between both.

At internal junctions the implicit condition states that the water level is continuous over such a junction node, and that the flows towards the junction are in balance since continuity requires:

$$\sum_{J=1}^{JJ} Q_{j,i} + q_i = 0 \qquad \text{Eq. 3.11}$$

where,

i = the indication for the junction mode;

$Q_{j,i}$ = the discharge from node j to node i;

q_i = the additional or lateral flow to node i.

The above equations are solved at each time step. They are transformed into a system of linear equations for the water levels by substitution of the equations 3.12 and 3.13. These two equation, which have Q and H as unknowns on the new time level t^{n+1} are formed for all sections in the network. After the water levels are computed using a standard solution method for systems of linear equations, the discharges are found by substituting the computed water levels into equations 3.12 and 3.13.

$$Q_i^{n+1} = N_{11} H_i^{n+1} + N_{12} H_{i+1}^{n+1} + N_{13} \qquad \text{Eq. 3.12}$$

$$Q_{i+1}^{n+1} = N_{21} H_i^{n+1} + N_{22} H_{i+1}^{n+1} + N_{23} \qquad \text{Eq. 3.13}$$

To start the computations, initial values for H and Q are required.

Structures

Various types of control structures can be defined such as weirs, culverts, siphons and pumping stations, which cover most of the control structures existing in real-life systems.

3.4.6.2. Quality

The mass transport equation

The quality part of the DUFLOW is based upon the one dimensional transport equation. The partial differential equation 3.9 describes the concentration of a constituent in a one-dimensional system as function of time and place.

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

Eq. 3.14

where;

C = the constituent concentration [g/m^3];
Q = the flow [m^3/s];
A = the cross sectional flow area [m^2];
D = the dispersion coefficient [m^2/s];
B = the cross sectional storage area [m^2];
x = the x coordinate [m];
t = the time [s];
P = the production of the constituent per unit length of the section [g/m.s].

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

Equation 3.9 has to be solved numerically. The solution technique selected is the method used in model flows. In order to apply this method equation 3.9 is rewritten as:

$$\frac{\partial S}{\partial x} + \frac{\partial(BC)}{\partial(t)} - P = 0$$

Eq. 3.15

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

$$S = QC - AD\frac{\partial C}{\partial x}$$

Eq. 3.16

Equation 3.11 describes the transport by advection and dispersion. Equation 3.10 is the mathematical formulation of the mass conservation law, which states that the accumulation at a certain location x is equal to the net production rate minus the transport gradient.

In this form the transport equation closely resembles the equations for the flow so that similar numerical approximations may be applied.

The dispersion coefficient either can be supplied by the user or can be calculated from the characteristics of the flow.

Initial conditions

Initial values for all state variables (concentrations) are required. These initial concentrations must be applied for each node. They can be based on historical measurements, obtained from former computations or from a first reasonable guess.

Boundary conditions

The way boundary conditions are treated in the quality part of DUFLOW is more complicated than for the flow part. It is necessary to distinguish between two types:

1. The physical boundaries of the system
2. The internal nodes in the system

At the beginning or end nodes in the network, in the flow part, a water level or discharge boundary can be applied. In the quality part at these locations a concentration boundary can be used.

Loads

At all nodes in the network an additional load can be applied, which means that this load is added to the mass balance equation of the node. A load is expressed as a mass unit per second.

3.4.7. Calibration

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. Evaluating the calibration results qualitatively and quantitatively can do this.

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 scatter plot 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.

3.4.8. Limitations

There are number of inherent limitations in the equations and methods used in DUFLOW and the important ones are summarised as follows.

The equations are for 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. Therefore it is not suitable for performing calculations of flows in which an extra spatial dimension is of interest. Water bodies with significantly different velocities in the vertical can therefore not be modelled. For instance, the model is not suitable for stratified waters. Also the flow must be directed roughly parallel to the channel axis.

As mentioned, vertical density differences are not taken into account; also horizontal density differences are not modelled because the density is assumed to be constant throughout. This is of interest in estuary, where a large concentration gradient has consequences for the water movement.

Although the equations underlying the model are valid in case of supercritical flow, the numerical solution method does not support supercritical flow. In structures the calculation of supercritical flow is not a problem. Because subcritical flow is assumed there must be one boundary condition at each of the boundaries of the network.

4. Water Quality Assessment

4.1. Water Quality Monitoring Plan

The water quality-monitoring plan has been set during fieldwork preparation. The survey was carried out during 11th September to 3rd October 2002 in the main research area of Malewa and Gilgil Basin and Lake Naivasha. Water quality data and water sample was taken from the main two rivers and its tributary in order to evaluated their contribution. The reconnaissance survey for Malewa upper catchment was done together with the flow measurement by Lukman (ITC, 2003). Since the limiting in time, 3 weeks of fieldwork were allocated, the first week for general survey to get the impression of the surrounding area and for upper catchment survey, the second for Malewa and Gilgil survey which was planed to collect the samples for each river in the same day and repeat field measurement in the next day, the last week for the lake. During that time data from automatic instruments that ITC have been installed were download, and collected some data from local officer, some riparian and farm owners.

In order to find the way to approach the sampling sites the following material was used; topographic maps, satellite images overlay with the selected sampling points, GPS with 15 meters average accuracy, compass.

4.1.1. Sampling points selection

The sampling points had already assigned during fieldwork preparation. According to the objective to assessment the present situation of water quality for this area and also to perform the analysis of spatial and temporal variation of river quality. The later need to select the same sampling points or the sites that is closed to the previous study as much as possible. The sites at stream flow gauge stations were also selected to allow the computation of loading. Furthermore, there are additional sampling points covering the tributary before joining with the main river in order to assess their contribution.

In the Malewa River, there was an attempt to study the background solute concentration and the contribution of subsurface flow in the upstream then the Turasha River that contributes with 50% of the discharge in the Malewa River was selected (Figure 2.4). Since the Turasha River consists of many tributaries and due to the time limitation therefore it has to select one of them. The Nandrasi River, one of the main tributaries originates from Aberdare Range has been chosen. It joins with Kitiri River before meet the Turasha. Some of spring water also investigated.

The different criteria were applied for selection sampling points in the lake. It had attempted to get the good representative of water quality throughout the hold area of lake by using statistical approach. The SANOS 1 statistical software has been used for construction the sampling scheme. The result from the criteria that the points should be well distributed and tried to minimize the mean of distances between pair of points, shows the scheme of 2 km^2 square grids with known coordinate (Figure 4.1). The result

from statistics gave the approximated total amount of sampling point is 25 to 30 with the minimum requirement 20 points. The question marks show the doubt points whether they can access since they are very closed the shoreline. It might be the shallow depth that the boat cannot pass or the marshy area since the used lake boundary was obtained from the past survey and also it might be dangerous due to present of wild animals.

Figure 4.1   Proposed lake sampling scheme result from SANOS 1

4.1.2. Parameter selection

The quality of surface water is determined by interactions with soil, transported solids (organics, sediments), rocks, groundwater and the atmosphere. It may also be significantly affected by agricultural, industrial, mineral and energy extraction, urban and other human actions, as well as by atmospheric inputs. The bulk of the solutes in surface waters, however, are derived from soils and groundwater baseflow where the influence of water-rock interactions is important.

The primary parameters for measuring the water quality focus on a combination of physical and chemical components. Selected parameters should reflect the underline characteristics of surface water. These parameters are arranged into two parts, the direct field measurement parameters comprise of temperature, conductivity, total dissolved solids, pH, alkalinity, chloride, hardness and the major ion constituents, which have been done later at ITC laboratory, included calcium, sodium, magnesium, potassium, aluminium, iron, manganese, sulphate, phosphate, nitrate and ammonia.

Since the electrical conductivity (EC) is the reliable parameter to measure the magnitude of dissolved mineral in water. EC routing comprises the measurement of EC in the main stream at a number of points, and in all-visible seepage zones, springs and contributing stream. It represents a powerful tool in reconnaissance studies and under favourable circumstances can be used for the estimation of partial area contributions to total flow (Appelo et al., 1983). For this reason EC routing technique was applied for the upstream reconnaissance.

4.2. Water Quality Survey and Samples Collection

The survey for the upper catchment was done on 12th to 15th September 2002. Nandrasi River original from Aberdare Mountain lines about 2400-3000 masl. Its upstream passes forest and undisturbed area with contribution from small channels and springs. Some parts of Nandrasi go through the small village. The shape is regular with the width from upstream to downstream around 2 to 5 m and depth 0.2 to 0.6 m. Quality determination for EC was done and recorded every 5-minute interval at the same time of flow measurement. Except for the site without flow measurement, the grab sample was measured. The 15 sampling points of upstream (○) and 11 points of spring or seepage water (Δ) are shown in Figure 4.2. It should be noted that not all point can be seen in the map, some points are overlap when they are presented in small-scale map and some points (e.g. S5 to S7) have the same coordinate because GPS accuracy became lower (4 m in open area to about 15 m under tree) due to the lower signal in the forest. Moreover, the survey has to stop at N14 before Kitiri River because of very steep valley. The details of locations are in Table 4.1.

The survey for Malewa and Gilgil River carried out in 3 days of 20th–22nd September 2002. Malewa and Gilgil are meandering rivers. The Malewa is a turbulent and well-mixed stream, characterized by sand bars, deltas, irregular bed shapes, high velocities and heterogeneous flows and discharges influenced by gradients and anthropogenic factors. Width and depth, from upstream at 2GB5 gauging station (M1) to downstream (M8), vary from 12-6 m and 5-0.2 m respectively. On the other hand, the Gilgil River is defined regular shapes, small velocities and discharges compared to Malewa. Gilgil at G3 has width about 5 m and depth 0.7 m and at 2GA1 gauging station (G5) has approximately width 5 m and depth 0.3 m.

The water level of Malewa observed during the sample collection at 2GB1 gauging station was 15 cm (reading on the stuff gauge) on 21st September 2002. The stuff gauge level of Gilgil on 22nd September 2002 at 2GA1 gauging station was 66 cm, at 2GA3 gauging station in Murindati River was 47 cm while the level at 2GA6 gauging station in Little Gilgil River may not be accurate since during the time of collecting sample from Little Gilgil it has to be noted that there is some kind of ceremony organized by the local people whose blocked the water flow by temporary dam at downstream of 2GA6 which cause the water level read from stuff gauge to be at 21 cm but after removing this obstruction the level became 18 cm.

Lake Naivasha survey carried out on 25th-27th September 2002. The water quality by visual investigation is brownish, slightly turbid especially in the northeast of Crescent Island since this part is very shallow, the observed depth is less than 20 cm with muddy bed. Water inside the crater is clearer. The condition of wind and the shallow depth make the water in the main lake mixed well and it is more calm wind than at the crater part. The lake is surrounded by agricultural farms, which abstract water from river and lake for irrigation. Some of them constructed pipe or dug canal to transport water to the cultivated area.

21 water samples from 11 sites were collected from Malewa River, 6 samples from Gilgil River and 25 samples from the lake as shown in Figure 4.3. The details of sampling points are in Table 4.2 and 4.3. Samples from the first survey of Malewa were brought back for further analysis. Each sample was taken using 250-ml and 150-ml polyethylene bottles, the former for nitrogen and phosphorus analysis was preserved with sulphuric acid to prevent the microbial activity that can alter the chemical compo-

sition of water sample, the later for major cation and sulphate analysis was filtered and then preserved with nitric acid to avoid the precipitation of carbonate and bicarbonate which affect the content of dissolved cation. The procedure and method for sample collection and chemical analysis are described in chapter 3.

On-site measurement was done in the same time with collecting water except for lake water samples that is impracticable to make a titration in boat due to the wavy condition. Therefore lake water samples were collected into the 1 litre plastic bottle after come back to hotel each sample was agitated and transferred into 3 bottles; two are the same as mentioned above and one more additional 250-ml bottle without any preservative is for total suspended solids (TSS) analysis. Unfortunately, the lake samples for major cation analysis were not filtered by the reason of not enough filter papers. It is importance to highlight that the filtering equipment; 50 ml plastic syringe used to draw water and filtered through filter disc 0.45 μm pore size (diameter 2 cm) is not suitable since its diameter is too small and became clog very easy then a lot of them have spent in prior survey of river. It strongly recommends using filter funnel apparatus with vacuum pump for future work.

During fieldwork it have found that there are some practical limitations to approach the assigned points: it is impossible to access because some tracts became an impasse by a jungle; some due to lack of permission from new landowner. Some points that last year MSc. student could approach by boat but this time cannot be done since the trip went to that place by car and no rout available; the water from some tributaries cannot be collected because of very low flow or almost dry.

In some sampling point inside the lake cannot access the exactly locations as in the proposed scheme especially in the first day (point L1 to L5) because it was not only the very shallow depth from the sedimentation of river discharge and also the work started late due to the boat preparation then the sampling became inconvenient by afternoon wind. The experience from the first day improved the task for the others two days. The navigation or waypoints function in GPS cannot be used, it has found that the download coordinated into GPS has been changed therefore both GPS and compass were used together to identify the directions and locations and try to keep the radius in 300 meter from the proposed coordinates.

Figure 4.2 Sampling Point Map for Upper Catchment

Figure 4.3 Sampling Point Map for Lake Naivasha and Its inflow

Table 4.1 Locations of Sampling Points in Upper catchment (N = Nandrasi, S = spring or seepage)

Sample ID	X-coordinate	Y-coordinate	Sample ID	X-coordinate	Y-coordinate	Sample ID	X-coordinate	Y-coordinate
N1	232803	9941446	N10	229994	9939821	S4	236745	9945334
N2	233186	9941400	N11	228457	9939129	S5	237003	9944360
N3	233188	9941398	N12	228530	9938955	S6	237003	9944360
N4	232851	9941394	N13	228371	9939070	S7	237003	9944360
N5	232816	9941368	N14	226210	9939727	S8	236133	9945808
N6	234389	9943332	N15	226179	9939827	S9	236189	9945694
N7	234673	9945822	S1	236134	9948314	S10	236180	9945698
N8	234676	9945834	S2	236736	9946450	S11	235057	9944904
N9	234569	9945709	S3	236661	9946014			

Table 4.2 Locations of Sampling Points in Malewa (M) and Gilgil (G)

Sample ID	X-coordinate	Y-coordinate	Place
G1	204532	9945721	2GA3 gauging station in Murindati river
G2	206543	9944790	2GA6 gauging station in Little Gilgil river
G3	205289	9941924	Gilgil (after Murindati meet Little Gilgil)
G4	206421	9935195	Gilgil at bridge
G5	206369	9933242	2GA1 gauging station
G6	205820	9931044	2GA5 gauging station
M1	210232	9945264	2GB5 gauging station
M2	210811	9945570	Turasha river before meet Malewa
M3	210741	9941750	Malewa after meet Turasha
M4	211972	9938990	Kasuki river before meet Malewa
M5	210985	9937642	2GB1 gauging station
M6	213038	9936490	Biazi river before meet Malewa
M7	213729	9932136	Malewa's tributary
M8	211889	9927768	Malewa in village
M9	210800	9926456	Malewa at pumping station in Morandat farm
M10	209113	9926374	Malewa at bridge (main road)
M11	206125	9921051	Malewa before reach the lake

Table 4.3 Locations of Sampling Points in Lake Naivasha (L)

Sample ID	X-coordinate	Y-coordinate	Sample ID	X-coordinate	Y-coordinate	Sample ID	X-coordinate	Y-coordinate
L1	211807	9916532	L10	202035	9915956	L19	202030	9912204
L2	210108	9918038	L11	203974	9915978	L20	203972	9911908
L3	210920	9918320	L12	205941	9915976	L21	205990	9911962
L4	208016	9917786	L13	207956	9915968	L22	208027	9912054
L5	205937	9918606	L14	209985	9913985	L23	206009	9910046
L6	203949	9918242	L15	208034	9913950	L24	204029	9910010
L7	202037	9918076	L16	206001	9913934	L25	199997	9910034
L8	200019	9918134	L17	204025	9914022			
L9	199995	9916002	L18	202009	9914076			

4.3. Result of Water Quality Analysis

4.3.1. Upper Catchment

From the survey of visible seepage in the Aberdare's, it have obviously found that it can be used the EC value to distinguish those two origins. The EC of points S1 to S3 and S8 to S11 range from 109.2 to 148.7 µS/cm that should be originated from spring and the others set is from 38.5 to 44.5 µS/cm

which expected to be recharge. Table 4.4 shows the value of EC and temperature. All of these S-series water are from the uphill in the area of forest. The higher EC in spring water are normal since the water dissolved the mineral from subsurface that in the Aberdare consists mainly of Basalts (Pesantez, ITC 2001)

Table 4.4 EC and Temperature of Sampling Points in Upper catchment

Sample ID	EC (μS/cm)	T (°C)	Sample ID	EC (μS/cm)	T (°C)	Sample ID	EC (μS/cm)	T (°C)
N1	98.0	12.0	N10	96.9	13.3	S4	44.5	12.0
N2	61.9	11.6	N11	96.7	13.1	S5	395	14.8
N3	54.5	11.6	N12	87.8	15.7	S6	60.3	10.2
N4	62.7	10.7	N13	89.5	13.8	S7	38.5	9.2
N5	102.3	nd	N14	98.3	15.7	S8	109.2	11.7
N6	109.5	15.8	N15	106.6	17.7	S9	148.7	12.7
N7	117.0	14.9	S1	121.6	13.8	S10	112.8	14.8
N8	72.6	nd	S2	122.3	13.3	S11	125.9	13.0
N9	111.7	nd	S3	110.5	12.0			

Remark: data for N-series are average value.
nd = no data available

Figure 4.4 EC-value along the Nandrasi River and its tributary on different day

The EC profiles on the different site and day of investigation along Nandrasi River from upstream to downstream is presented in Figure 4.4. It can be seen that EC decreased from upstream toward downstream. The N10 site was selected to be the main observed site and installed the temporary stuff gauge. General characteristics of stream at this site are a strength, rectangular-bed channel with some gravel. The width is 2.4 m and depth is between 0.44 – 0.55 m. Water flow was about 0.2 m^3/s. On the first day (12th Sep 02) EC of this site was at 98.7 μS/cm, the water was quite clear as it can see the riverbed. EC decreased in the next two days (14th Sep 02) because there was rainfall in the Aberdare during the unvisited day that can notice a trace of water level on the stuff gauge increase from 0.4 m to 0.48 m sometime after rain and go down to 0.4 m again and also from the colour of water become brown and turbid. In the last day EC increased again which shows that the surface runoff has ceased, the water at this time came from the baseflow. The level on this day slightly decreased to 0.395 m. The circle points with arrows show the contribution of tributary to the main stream. It can say that the diluted tributaries affect to the decreasing of EC along the main stream.

4.3.2. Lake Naivasha and Riverine system

Water quality and univariate statistics of both rivers and the lake were presented in Table 4.5 to 4.9. Gilgil has only few observations then the quartile, percentile and skewness have not reported. From the statistics result, It have shown that the distribution of almost all quality parameters indicate nearly symmetrical about their mean value as illustrated by the closeness of the mean and median. There are few outliers with high value due to their different natural e.g. the tributaries of main rivers and the shallow part of lake.

The mean value for various parameters of the main stream of Malewa River are as following; temperature 19.6°C, pH 7.48, EC 110.8 µS/cm, TDS 52.5 mg/l, chloride 7.6 mg/l, total alkalinity 51.6 mg/l, hardness 37.5 mg/l, nitrate 0.64 mg/l, ammonia 0.30 mg/l, sulfate 2.4 mg/l, phosphate 0.28 mg/l. The mean concentrations for major cation are Ca^{+2} 8.17, Na^+ 11.09, K^+ 3.97, Mg^{+2} 2.18, Fe^{+2} 0.19, Al^{+3} 0.27 and Mn^{+2} 0.02 mg/l.

The main stream of Gilgil River quality in average value are as following; temperature 18.2°C, pH 6.94, EC 83.2 µS/cm, TDS 39.3 mg/l, chloride 4.8 mg/l, total alkalinity 38.6 mg/l, hardness 22.1 mg/l, nitrate 2.26 mg/l, ammonia 0.68 mg/l, sulfate 2.2 mg/l, phosphate 0.36 mg/l. The mean concentrations for major cation are Ca^{+2} 3.58, Na^+ 11.30, K^+ 4.96, Mg^{+2} 0.73, Fe^{+2} 0.50, Al^{+3} 0.11 and Mn^{+2} 0.04 mg/l.

Quality parameters of Lake Naivasha reported in mean values are as following; temperature 21.0°C, pH 8.96, EC 301 µS/cm, TDS 144.7 mg/l, chloride 14.4 mg/l, total alkalinity 133.0 mg/l with carbonate alkalinity 32.9 mg/l and bicarbonate alkalinity 100.1 mg/l, hardness 56.8 mg/l, nitrate 1.77 mg/l, ammonia 0.40 mg/l, sulfate 4.9 mg/l, phosphate 0.39 mg/l and total suspended solids 43.08 mg/l. The mean concentrations for major cation are Ca^{+2} 14.54, Na^+ 38.17, K^+ 22.25, Mg^{+2} 6.54, Fe^{+2} 0.49, Al^{+3} 0.51, Mn^{+2} 0.14 and Li^+ 0.004 mg/l.

According to the result of analysis, it confirms the investigation by many previous that Malewa water contains a predominance of bicarbonate. Sodium and calcium are the major cations, while in Gilgil sodium is the major cation. Since the Malewa river drains predominantly trachytes, tuffs and welded tuffs but its headwaters begin in the strongly alkaline lavas and olivine basalts that from the Aberdare and Kipipiri ranges (Gaudet and Melack, 1981). In general, water quality of both two rivers is in the range of normal level of surface water (Appendix E, E-3) even though the tributaries have higher concentration in almost all parameters.

 It has seen that Malewa River during the period of dry season with low flow many tributaries were dry then only 3 samples from them were collected. The result of tributary's water analysis show that almost all parameters are high value i.e. EC of M4, M6 and M7 are very high means that tributaries contained more solute than the main river. The same situation is occurred in Little Gilgil, which is the tributary of Gilgil contains high solute concentration that not only because of the nature of itself in dry season but also influence by the surrounding community.

Temperature results indicated that the river systems are consistently cooler than the lake for the period sampled. This can be directly related to the source of the river as well as higher level of solar radiation input on the surface.

The pH levels in the lake are more slightly basic condition than the rivers but still in the range of surface water standards (Appendix E, E-3), which ranges of pH, is 5-9. The rising of pH can be influenced by temperature, which affects the H^+ activity and also the rapidly removing of CO_2 by algal photosynthesis during the daytime.

The EC (& TDS) of lake are also higher than rivers that can be associated with the import of dissolved nutrients and sediments from the swamps in the northern part also the turbulent to the bottom sediments since the water level is low.

The presence of carbonate and bicarbonate alkalinity in lake water is mainly come from the weathering process of lacustrine deposit although bicarbonate is actually derived largely from gaseous CO_2. The hardness of water in this basin can be defined as mainly carbonate hardness (since sulfate is low) determined by concentrations of calcium and magnesium bicarbonates. It was found calcium concentrations higher than magnesium in the overall locations. According to the US.GS.[1] Scale (soft 0-60 mg/l, moderately hard 61-120 mg/l, hard 121-180 mg/l and very hard 300-up mg/l), hardness of lake water can be classified as slightly to moderately hard water whereas Malewa and Gilgil are in the range of soft water.

The levels of nutrients during this period in lake are relatively higher than in river. This might due to the leaching from swamps as well as the decay of plant and animal detritus. Since pH of lake is above 8, at this pH levels phosphorus release from sediments is also increasingly .The phosphate level of the lake indicated the eutrophic status; it ranges from 0.28 - 0.64 mg/l, which is higher than the guideline value by US.EPA that recommended the concentration of phosphate should below 0.1 mg/l to prevent Eutrophication.

The major cation analysis shows the high content of sodium, calcium and potassium in all sources of water, which is mainly come from rock weathering. The amount of each is depending on the rock mineralogy. Pesantez (ITC, 2001) reviewed from Kilham & Hecky (1973) who emphasized the importance of chemical weathering of the rock as the source of major solutes in Lake Naivasha. Harper et al. (1993) mentioned about the preliminary analysis of Naivasha sediments using X-ray fluorescence analysis in the Centre for Nuclear Sciences of Nairobi University indicate that these sediments are calcium-rich.

Water quality of lake comparing with rivers in all parameter is higher concentration. The mainly factor effecting this circumstance is the high evaporation of lake water as shown in table 2.1 that the evaporation (or evapotranspiration) is highest among all hydrologic components. The water lost by evaporation leads to the concentrate of remaining water. The other factor controlling the quality or the freshness is flushing process, which indicates the resident time of solute stay in the lake. The longer resident time, the higher internal lake processes occur especially the process of exchanging solute between water and the lake sediment which is also control its quality together with the discharge from river mouth via swamps and effluent from human activity and waste from livestock leading to the increasing of solute concentration.

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[1]The United States Geological Survey

Table 4.5 Malewa River Water Quality during 20th – 22nd September 2002

Sample ID	Temp. (C)	pH	EC (μS/cm)	TDS (mg/l)	Chloride (mg/l as Cl-)	P Alk (mg/l CaCO₃)	Total Alk (mg/l CaCO₃)	Hardness (mg/l CaCO₃)	NO₃⁻-N (mg/l)	NO₃⁻ (mg/l)	NH₃-N (mg/l)	NH₃ (mg/l)	SO₄²⁻ (mg/l)	PO₄³⁻ (mg/l)	Ca⁺² (mg/l)	Mg⁺² (mg/l)	K⁺ (mg/l)	Na⁺ (mg/l)	Fe⁺² (mg/l)	Al⁺³ (mg/l)	Mn⁺² (mg/l)
M1	18.3	6.72	99.2	47.2	9.4	0.0	54.4	28.0	0.20	0.70	0.40	0.50	2	0.27	7.17	1.83	3.88	11.92	0.26	0.15	0.02
M2	18.3	7.20	107.8	51.3	7.4	0.0	59.6	53.6	0.10	0.40	0.00	0.00	2	0.28	9.29	2.77	3.45	9.22	0.11	0.01	0.01
M3	18.3	7.20	107.7	49.4	6.9	0.0	58.4	50.0	0.10	0.60	0.10	0.10	3	0.17	8.16	2.16	3.81	10.44	0.19	1.67	0.02
M4	16.4	8.17	377.0	182.2	7.2	0.0	192.4	56.8	0.20	0.80	0.10	0.10	2	0.35	15.08	2.13	18.72	73.06	0.04	0.03	0.06
M5	19.5	7.91	105.5	50.2	9.8	0.0	54.4	35.2	0.10	0.50	0.20	0.30	2	0.37	7.96	2.09	3.90	10.62	0.24	0.09	0.04
M6	17.6	8.41	487.0	235.0	9.4	0.0	237.6	54.4	0.10	0.50	0.20	0.20	13	0.31	14.41	2.04	20.44	105.21	0.00	0.00	0.01
M7	19.8	8.38	463.0	224.0	10.4	0.0	233.2	39.6	0.20	0.81	0.00	0.00	14	1.24	14.69	1.13	19.59	102.22	0.08	0.05	0.01
M8	20.8	7.96	111.5	52.9	9.8	0.0	55.8	42.4	0.20	0.71	0.20	0.30	3	0.26	8.26	2.1	4.10	11.21	0.19	0.09	0.01
M9	20.5	7.55	114.4	54.0	8.3	0.0	49.6	28.0	0.30	1.21	0.10	0.10	2	0.29	8.16	2.13	4.13	11.70	0.18	0.06	0.01
M10	19.8	7.57	118.6	56.3	5.9	0.0	51.2	22.8	0.10	0.50	0.40	0.50	2	0.37	8.16	2.21	4.14	11.93	0.15	0.02	0.02
M1	18.2	7.60	113.8	54.1																	
M2	16.7	7.67	108.8	51.7																	
M3	18.3	7.71	106.5	50.6		0.0	45.2														
M4	17.6	8.15	382.0	185.2		0.0	197.0														
M5	18.8	7.57	108.0	51.3		0.0	50.0														
M6	18.8	8.28	486.0	237.0		0.0	268.0														
M7	18.2	8.40	459.0	222.0		0.0	243.0														
M8	21.2	7.91	110.5	52.6		0.0	50.0														
M9	21.0	7.36	112.5	53.4		0.0	48.8														
M10	20.4	7.27	115.8	55.1		0.0	41.0														
M11	24.6	6.98	121.0	57.4	3.5	0.0	52.0	39.6	0.10	0.50	0.50	0.60	3.0	0.25	8.19	2.12	4.31	11.66	0.19	0.1	0.03

Remark: The first set measured on 20th Sep 02 and the second measured on 21st Sep 02. Blank cells show no repeat measurements have been done.

Table 4.6 Statistical summary of mainstream of Malewa River

Sample ID	Temp. (C)	pH	EC (µS/cm)	TDS (mg/l)	Chloride (mg/l as Cl-)	P Alk (mg/l CaCO₃)	Total Alk (mg/l CaCO₃)	Hardness (mg/l CaCO₃)	NO₃⁻-N (mg/l)	NO₃⁻ (mg/l)	NH₃-N (mg/l)	NH₃ (mg/l)	SO₄²⁻ (mg/l)	PO₄³⁻ (mg/l)	Ca⁺² (mg/l)	Mg⁺² (mg/l)	K⁺ (mg/l)	Na⁺ (mg/l)	Fe⁺² (mg/l)	Al⁺³ (mg/l)	Mn⁺² (mg/l)
Average	19.6	7.48	110.8	52.5	7.6	0.0	51.6	37.5	0.15	0.64	0.24	0.30	2.4	0.28	8.17	2.18	3.97	11.09	0.19	0.27	0.02
Minimum	16.7	6.72	99.2	47.2	3.5	0.0	41.0	22.8	0.10	0.40	0.00	0.00	2.0	0.17	7.17	1.83	3.45	9.22	0.11	0.01	0.01
Maximum	24.6	7.96	121.0	57.4	9.8	0.0	59.6	53.6	0.30	1.21	0.50	0.60	3.0	0.37	9.29	2.77	4.31	11.93	0.26	1.67	0.04
Median	19.5	7.57	110.5	52.6	7.9	0.0	51.2	37.4	0.10	0.55	0.20	0.30	2.0	0.28	8.16	2.13	4.00	11.44	0.19	0.09	0.02
SD	1.9	0.36	5.5	2.7	2.2	0.0	5.1	11.0	0.08	0.25	0.18	0.22	0.52	0.07	0.57	0.27	0.27	0.94	0.05	0.57	0.01
1st quartile	18.3	7.24	107.8	51.0	6.7	0.0	49.6	28.0	0.10	0.50	0.10	0.10	2.0	0.26	8.11	2.10	3.86	10.58	0.17	0.05	0.01
3rd quartile	20.7	7.69	114.1	54.1	9.5	0.0	54.4	44.3	0.20	0.70	0.40	0.50	3.0	0.31	8.21	2.17	4.13	11.76	0.20	0.11	0.02
1st percentile	18.2	7.07	105.9	49.7	5.2	0.0	45.9	26.4	0.10	0.47	0.07	0.07	2.0	0.23	7.72	2.01	3.70	10.07	0.14	0.02	0.01
90th percentile	21.1	7.91	117.5	55.8	9.8	0.0	57.9	51.1	0.23	0.86	0.43	0.53	3.0	0.37	8.57	2.38	4.19	11.92	0.25	0.61	0.03
Skewness	1.1	-0.59	-0.1	0.0	-0.9	-	-0.4	0.2	1.32	1.91	0.28	0.00	0.6	-0.10	0.41	1.70	-0.89	-1.20	-0.09	2.79	0.94

Table 4.7 Gilgil River Water Quality on 22nd September 2002

Sample ID	Temp. (C)	pH	EC (µS/cm)	TDS (mg/l)	Chloride (mg/l as Cl-)	P Alk (mg/l CaCO₃)	Total Alk (mg/l CaCO₃)	Hardness (mg/l CaCO₃)	NO₃⁻-N (mg/l)	NO₃⁻ (mg/l)	NH₃-N (mg/l)	NH₃ (mg/l)	SO₄²⁻ (mg/l)	PO₄³⁻ (mg/l)	Ca⁺² (mg/l)	Mg⁺² (mg/l)	K⁺ (mg/l)	Na⁺ (mg/l)	Fe⁺² (mg/l)	Al⁺³ (mg/l)	Mn⁺² (mg/l)
G1	18.0	6.38	83.4	39.6	6.9	0.0	26.8	10.4	0.30	1.41	0.20	0.20	1	0.25	3.24	0.69	4.61	11.17	0.60	0.16	0.05
G2	15.0	7.47	191.6	91.3	2.8	0.0	90.0	16.8	0.30	1.51	0.61	0.71	5	1.12	7.25	1.03	11.29	32.34	0.22	0.19	0.01
G3	18.6	7.16	82.9	39.2	2.6	0.0	50.0	26.8	0.30	1.51	0.91	1.11	2	0.38	3.41	0.72	4.68	11.59	0.45	0.08	0.04
G4	19.0	6.98	84.4	39.9	5.4	0.0	44.8	30.0	0.50	2.11	0.60	0.70	2	0.35	3.64	0.74	4.82	11.50	0.45	0.07	0.02
G5	17.9	7.02	81.2	38.4	5.2	0.0	32.0	16.4	0.81	3.32	0.60	0.70	3	0.40	3.64	0.73	4.65	11.17	0.44	0.08	0.02
G6	17.3	7.15	83.9	39.5	3.7	0.0	39.2	26.8	0.71	2.95	0.61	0.71	3	0.40	3.95	0.76	4.70	11.06	0.55	0.16	0.05

Table 4.8 Statistical summary of mainstream of Gilgil River

Sample ID	Temp. (C)	pH	EC (µS/cm)	TDS (mg/l)	Chloride (mg/l as Cl-)	P Alk (mg/l CaCO₃)	Total Alk (mg/l CaCO₃)	Hardness (mg/l CaCO₃)	NO₃⁻-N (mg/l)	NO₃⁻ (mg/l)	NH₃-N (mg/l)	NH₃ (mg/l)	SO₄²⁻ (mg/l)	PO₄³⁻ (mg/l)	Ca⁺² (mg/l)	Mg⁺² (mg/l)	K⁺ (mg/l)	Na⁺ (mg/l)	Fe⁺² (mg/l)	Al⁺³ (mg/l)	Mn⁺² (mg/l)
Average	18.2	6.94	83.2	39.3	4.8	0.0	38.6	22.1	0.52	2.26	0.58	0.68	2.2	0.36	3.58	0.73	4.69	11.30	0.50	0.11	0.04
Minimum	17.3	6.38	81.2	38.4	2.6	0.0	26.8	10.4	0.30	1.41	0.20	0.20	1.0	0.25	3.24	0.69	4.61	11.06	0.44	0.07	0.02
Maximum	19.0	7.16	84.4	39.9	6.9	0.0	50.0	30.0	0.81	3.32	0.91	1.11	3.0	0.40	3.95	0.76	4.82	11.59	0.60	0.16	0.05
Median	18.0	7.02	83.4	39.5	5.2	0.0	39.2	26.8	0.50	2.11	0.60	0.70	2.0	0.38	3.64	0.73	4.68	11.17	0.45	0.08	0.04
SD	0.7	0.32	1.2	0.6	1.7	0.0	9.4	8.3	0.23	0.85	0.25	0.32	0.84	0.06	0.27	0.03	0.08	0.23	0.07	0.05	0.02

Table 4.9 Lake Naivasha Water Quality during $25^{th} - 27^{th}$ September 2002

Sample ID	Temp. (C)	pH	EC (µS/cm)	TDS (mg/l)	Chloride (mg/l Cl-)	CO_3^{2-} Alk (mg/l CaCO₃)	HCO_3^- Alk (mg/l CaCO₃)	Total Alk (mg/l CaCO₃)	Hardness (mg/l CaCO₃)	NO_3^--N (mg/l)	NO_3^- (mg/l)	NH_3-N (mg/l)	NH_3 (mg/l)	SO_4^{2-} (mg/l)	PO_4^{3-} (mg/l)	TSS (mg/l)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	Fe^{+2} (mg/l)	Al^{+3} (mg/l)	Mn^{+2} (mg/l)
L1	21.3	8.79	326	156.7	14.4	29.6	118.4	148.0	70.4	0.40	2.01	0.91	1.11	0	0.56	79.0	16.83	7.02	25.45	41.23	0.99	1.22	0.18
L2	22.2	8.72	324	155.9	15.2	31.2	116.8	148.0	82.0	0.40	1.82	0.30	0.40	1	0.51	70.0	16.82	7.09	25.19	42.44	0.69	0.96	0.16
L3	22.6	8.73	332	159.6	21.1	24.8	134.4	159.2	65.2	0.30	1.41	0.30	0.30	1	0.64	91.0	17.55	7.01	26.38	44.13	0.84	1.53	0.20
L4	22.6	8.92	297	142.7	14.7	57.6	91.4	149.0	50.0	0.40	1.71	0.60	0.70	0	0.29	36.0	14.94	6.65	22.29	37.73	0.48	0.43	0.11
L5	22.9	9.07	296	142.2	14.2	70.4	81.2	151.6	52.0	0.30	1.42	0.10	0.10	0	0.35	46.0	14.86	6.63	22.38	38.08	0.32	0.36	0.11
L6	20.3	9.02	301	144.9	15.2	48.0	93.6	141.6	57.2	0.60	2.62	0.40	0.50	0	0.47	57.0	14.52	6.51	22.24	37.53	0.53	0.53	0.13
L7	20.5	9.08	298	143.0	15.1	73.6	75.6	149.2	56.0	0.40	1.81	0.50	0.60	8	0.33	38.0	14.60	6.59	22.28	38.51	0.32	0.35	0.12
L8	20.9	9.06	297	142.5	14.3	34.4	111.6	146.0	52.8	0.40	1.61	0.40	0.50	0	0.38	40.0	14.64	6.57	22.02	37.48	0.57	0.44	0.12
L9	21.5	9.02	294	141.5	13.0	24.0	124.0	148.0	51.6	0.50	2.32	0.40	0.50	8	0.35	31.0	13.83	6.54	22.01	37.04	0.48	0.56	0.13
L10	20.7	9.01	299	143.7	13.9	22.0	107.0	129.0	52.0	0.50	2.22	0.30	0.30	4	0.28	22.0	14.57	6.60	21.89	37.02	0.37	0.43	0.14
L11	20.3	8.96	299	143.7	14.5	20.0	129.0	149.0	55.2	0.51	2.22	0.20	0.20	4	0.36	20.0	14.46	6.40	21.84	36.69	0.44	0.43	0.14
L12	20.2	8.95	299	143.8	14.8	24.0	102.0	126.0	50.8	0.40	1.61	0.30	0.30	7	0.36	17.0	15.06	6.64	21.78	37.10	0.42	0.40	0.13
L13	20.0	8.96	297	142.6	13.0	26.0	102.0	128.0	53.2	0.30	1.51	0.50	0.60	7	0.53	28.0	14.36	6.45	21.85	38.80	0.54	0.46	0.13
L14	20.3	8.98	297	142.6	15.7	36.0	93.0	129.0	55.6	0.40	1.62	0.30	0.30	8	0.57	28.0	14.36	6.37	21.66	38.12	0.48	0.47	0.16
L15	20.4	8.97	302	145.0	12.4	24.0	96.0	120.0	55.6	0.40	1.72	0.50	0.60	6	0.36	44.0	14.34	6.48	21.98	37.85	0.37	0.40	0.13
L16	20.8	8.98	296	142.2	16.0	22.0	93.0	115.0	61.2	0.40	1.82	0.10	0.10	7	0.34	36.0	14.22	6.53	21.61	37.56	0.34	0.32	0.13
L17	21.0	9.01	295	141.8	14.1	18.0	90.0	108.0	65.2	0.30	1.51	0.40	0.50	7	0.31	42.0	14.41	6.41	21.53	37.12	0.30	0.31	0.13
L18	21.4	8.99	293	140.7	12.9	26.0	87.0	113.0	58.0	0.51	2.22	0.20	0.30	8	0.32	49.0	13.27	6.39	21.37	37.85	0.37	0.39	0.12
L19	21.4	8.97	292	140.4	13.2	30.0	86.0	116.0	61.2	0.30	1.32	0.40	0.40	7	0.36	44.0	13.28	6.34	21.61	37.47	0.42	0.42	0.13
L20	21.1	8.97	294	141.3	13.7	30.0	92.0	122.0	56.0	0.30	1.51	0.40	0.50	8	0.38	32.0	13.29	6.42	21.37	36.94	0.37	0.28	0.12
L21	20.8	8.95	301	144.5	14.7	26.0	102.0	128.0	54.0	0.51	2.32	0.20	0.20	6	0.30	42.0	13.76	6.38	21.72	37.15	0.38	0.39	0.13
L22	20.4	8.94	301	144.8	12.9	20.0	96.0	116.0	52.8	0.40	1.62	0.10	0.10	8	0.29	37.0	14.11	6.42	21.35	37.19	1.21	0.50	0.17
L23	20.0	8.95	302	144.5	13.4	32.0	90.0	122.0	54.0	0.30	1.21	0.10	0.20	4	0.34	50.0	13.94	6.30	21.44	38.13	0.31	0.30	0.12
L24	20.4	8.96	299	143.8	13.2	32.0	96.0	128.0	49.6	0.40	1.90	0.10	0.10	7	0.30	50.0	13.64	6.44	21.48	37.75	0.37	0.36	0.12
L25	21.4	9.04	298	143.5	14.1	42.0	94.0	136.0	48.0	0.30	1.31	0.50	0.60	7	0.43	48.0	13.77	6.29	21.54	37.40	0.38	0.42	0.12
Average	21.0	8.96	301	144.7	14.4	32.9	100.1	133.0	56.8	0.40	1.77	0.34	0.40	4.9	0.39	43.08	14.54	6.54	22.25	38.17	0.49	0.51	0.14
Minimum	20.0	8.72	292	140.4	12.4	18.0	75.6	108.0	48.0	0.30	1.21	0.10	0.10	0.0	0.28	17.00	13.27	6.29	21.35	36.69	0.30	0.28	0.11
Maximum	22.9	9.08	332	159.6	21.1	73.6	134.4	159.2	82.0	0.60	2.62	0.91	1.11	8.0	0.64	91.00	17.55	7.09	26.38	44.13	1.21	1.53	0.20
Median	20.8	8.97	298	143.5	14.2	29.6	96	129.0	55.2	0.40	1.71	0.30	0.40	7.0	0.36	42.00	14.36	6.48	21.84	37.56	0.42	0.42	0.13
SD	0.83	0.09	10.3	5.0	1.7	14.8	14.8	14.8	7.5	0.08	0.37	0.19	0.24	3.19	0.10	17.35	1.08	0.22	1.34	1.79	0.22	0.30	0.02
Variance	0.69	0.01	106.0	24.7	2.9	219.4	220.5	217.8	56.4	0.01	0.14	0.04	0.06	10.16	0.01	301.08	1.17	0.05	1.79	3.21	0.05	0.09	0.0005
1st quartile	20.4	8.95	296.0	142.2	13.2	24.0	91.4	122.0	52.0	0.30	1.51	0.20	0.20	1.0	0.32	32.00	13.83	6.40	21.54	37.15	0.37	0.36	0.12
3rd quartile	21.4	9.01	301.0	144.5	14.8	34.4	107.0	148.0	58.0	0.40	2.01	0.40	0.50	7.0	0.43	49.00	14.64	6.60	22.24	38.12	0.53	0.47	0.14
1st percentile	20.2	8.84	294.0	141.4	12.9	20.8	86.4	115.4	50.3	0.30	1.36	0.10	0.10	0.0	0.30	24.40	13.43	6.35	21.40	37.03	0.32	0.31	0.12
90th percentile	22.4	9.05	315.2	151.5	15.5	53.8	121.8	149.1	65.2	0.51	2.28	0.50	0.60	8.0	0.55	64.80	16.12	6.87	24.07	40.26	0.78	0.80	0.17
Skewness	0.9	-1.54	2.2	2.2	2.7	1.7	0.8	0.1	1.9	0.54	0.59	0.89	0.95	-0.7	1.15	1.12	1.55	1.48	2.34	2.39	2.05	2.60	1.56

4.3.3. Correctness of analysis

The Cation -to- Anion Balance method have been used for checking the reliability of the analysis, The principle of this method is based on the electroneutrality of all water when the concentration of anion and cation are express as milli-equivalents per litre the summation of each must balance because all waters are electrically neutral. The test is based on the percentage difference defined as follows:

$$\%difference = 100 * \left(\frac{\sum cations - \sum anions}{\sum cations + \sum anions} \right)$$ Eq.4.1

The accept/reject criterion usually is taken around ±10% difference ionic balance and depends on water types. High bicarbonate waters tempt to be unstable (CO_2 exchanges) due to interactions with colloidal and suspended mater (alkalinity changes). The differences over the acceptance criteria are related to several factors. The falling out of data from acceptable range might be due to use of different kind of equipments (i.e. ICP-AES, Spectrophotometer and titration method), which have different accuracy and sensitivity leading to imbalance of anion and cation. The samples were not analysed for all the parameters in the same day and some change in ionic balance maybe occurred during transport outside refrigerator (It took 24 hours from Naivasha to ITC) so the water properties could have changed. The analysis were not included other compartments which could have contribution. Figure 4.5, 4.6 and 4.7 are the electro neutrality results for Malewa, Gilgil Rivers and the lake Naivasha respectively. 3 samples of M2, G3 and L17 are a slightly deviating from acceptable range. The details are given in Appendix E

Figure 4.5 Result of Ion Balance for Malewa River Water Samples

Figure 4.6 Result of Ion Balance for Gilgil River Water Samples

Figure 4.7 Result of Ion Balance for Lake Naivasha Water Samples

4.4. Spatial analysis

The chemical quantity have been analysed for different quality parameters along the Malewa, Gilgil and over the entire surface area of Lake Naivasha. The profile of spatial variation for each resources are discussed below in term of their relation the each other and their change in concentration over space. The distance between observation points and lake water body were calculated by exported sampling points map in shape file format from ILWIS into ArcView and calculated the distances by the Network Analysis option.

4.4.1. Malewa River

The Malewa hydrochemical profile for the main channel included point M1, M3, M5, M8 to M11 are shown in Figure 4.8. It is observed that an increasing concentration from upstream until the mouth happened visibly for EC, which increased from 99.2 μS/cm to 121.0 μS/cm (Figure 4.8 A). Whereas the increase in concentration of other parameters in the same figure are not obviously and the slightly fluctuation happened such as in hardness. However, the concentration at river's mouth is still higher than the headwater. The increased in conductivity after M5 (2GB1 station) can caused by the join of Biazi River and another tributary, which have high EC value at 487 and 463 μS/cm respectively. But they are not too much affect the value of main river since they were very low flow.

The alkalinity, hardness as well as pH are obviously decreased at points M8 to M10 probably due to the influence from untreated domestic waste when the river pass through village and industrial waste from vine factory that located upper stream of point M10. The Malewa hardness can be defined as mainly carbonate hardness determined by the high bicarbonate than sulfate. It was found that concentration of calcium higher than magnesium in all locations.

Sodium, the most conservative ion, shows good correlation with EC and sodium also is the major cation in Malewa with the highest concentration amount among all cations (Figure 4.8 B). While the minor cation like calcium, potassium and magnesium have lesser correlation with EC.

Leaching process from organic soil and the decay of living organism are the main associated sources of nitrate. The decrease of nitrate have been observed in the upstream and it gradually increased after 2GB1 station and then rapidly go up to the peak of 1.2 mg/l at M9 (Figure 4.8 C) which is the con-

structed dam for pumping station of private orchard located after the worker's village that might have the polluted water from fertilizer used. Ammonia and phosphate show the similar trend with pH after M1 (2GB5 station) and they again raised up to higher concentration after pass the residential area. The untreated wastewater from household and agricultural activities probably the main causes for this circumstance. This can be proved by the decline trend of phosphate at the last point before reach the lake which is the undisturbed by human since it is a living place of wild animal.

The profiles of trace elements in Figure 4.8 D show that iron and manganese have a similar trend, they decreased after 2GB1 station and increased again near the river's mount. On the other hand, aluminium is consistent except for the concentration of aluminium at point M3 was abnormally high. Unfortunately that it cannot recheck since the repeat collection for ions measurement has not been carried out.

4.4.2. Gilgil River

The profiles along the distance for Gilgil River are depicted in Figure 4.9. Alkalinity and hardness show the same pattern according to the predominance of bicarbonate predominant. They are increased rapidly from first point (G1) in Murindati River to the second point (G3) because of the contribution of the high bicarbonate from Little Gilgil. It is also observed the increase of pH at G3 confirming the present of bicarbonate increasing. From G3 to G4 which stay apart for about 9 km, there is no significance different in EC and bicarbonate as well as others parameter (Figure 4.9A). The only one location at G5 (2GA1 gauging station) shows suddenly drop of alkalinity, hardness and EC as well. This might be the effect from wastewater with acidic condition.

It is noticed that the hydrochemical condition of major cation of Gilgil is quite consistent (Figure 4.9 B). There is no upward or downward trend in many ions such as sodium, calcium, potassium, and magnesium. They look to follow EC trend except for the sodium ion at downstream is a little bit declines.

Figure 4.9 C delineated the profile of nitrate, ammonia, and phosphate together with pH. It is distinct that nitrate increased with distance and it is peak at 2GA1 (G5) and inclines after this point. The increased of nitrate may be come from the leaching of irrigated soil since the surrounding land use is mainly for agriculture. The peak of nitrate at G5 might be due to the leaching from suspended solids, which is high deposit in this site. It was observed that Gilgil became very shallow from the sediment deposition. The presence of ammonia shows the correlation with pH. Water with high pH level from Little Gilgil (pH at G2 is 7.47) has influenced to the equilibrium of nitrate and ammonia. The rise in ammonia concentration explained that water was polluted by human waste and also waste from uncontrolled livestock.

In Figure 4.9 D, it has shown the similar trend for iron, aluminium and manganese that decreased over the distance from upstream to downstream and they have increased at location G6.

A

B

C

D

Figure 4.8 Concentration profile of water quality along Malewa River toward the lake

Figure 4.9 Concentration profile of water quality along Gilgil River toward the lake

4.4.3. Lake Naivasha

By the application of GIS-ILWIS software, the spatial distribution of example parameters has presented in point maps in Figure 4.10 and 4.11. Each point represent the individual sample and the size of point have been stretched (stretch size 10 to 20 pt) following its value therefore the bigger size the higher value. The figures depict some example amount all parameters. It is obviously noticed that all parameters have extreme value or highest concentration at the northeastern (sampling point no. L1, L2 and L3) as the result of the shallow part of the water body which has a lot of sediment deposit that can be trap most of ions on the particles, the pattern for this area also occurred for cations. And since the water samples were not filtered then some cations that was absorbed on sediment can be released.

The EC values show the regular trend over the entire lake except for those shallow locations. The value range from 292 μS/cm near the Hippo point and a little bit increase to around the middle of the lake. It can see that the points near shoreline are higher value both in the north, which closed to river's mouth, and in the south. This pattern is typically found for others parameter that correlated to EC such as sodium, chloride and total suspended solids. The regular pattern is also occurred for pH, sodium, potassium, chloride and sulphate (the last was not shown).

Alkalinity shows distinct pattern with other parameters. The variation of alkalinity is easily perceived the high concentration along the northern part which range from 142 mg/l to 152 mg/l at the Malewa discharge point and it gradually decrease and have lowest value at the middle, the southern part of the lake has moderate alkalinity compared with another part. Since the bicarbonate is dominant characteristic of lake water and the presence of carbonate, it can be seen that the distribution form of calcium and magnesium are alike as alkalinity. In contrast, hardness is highest at the center of lake and near Hippo point and it become lower when it is far from these locations.

Total suspended solids variation is as expected that the locations near shoreline have greater amount of suspended particles (> 40 mg/l) than the location which located inside the lake that have less influence from scouring effect near the bank.

The variation of nutrients is seem to be erratic, the whole type (nitrate, ammonia and phosphate) do not have clear trend. However, it can notice that the northwest, south and the area around Crescent Island have higher nutrients.

The spatial variation for trace elements, e.g. iron, aluminium and manganese, is regularly distributed over the entire area except the location near southeast shore that has high concentration of iron at 1.21 mg/l and manganese at 1.7 mg/l.

Figure 4.10 Spatial variation of water quality in Lake Naivasha (1)

Figure 4.11 Spatial variation of water quality in Lake Naivasha (2)

4.4.4. Estimation of samples size

In the planning of sample survey, a question that is always frequently asked is at which a decision must be made about the size of the sample in order to be a good representation of quality of water-body. Too large a sample implies a waste of resources, and too small a sample diminishes the utility of the results (Cochran, 1963). This question cannot be discussed without first receiving an answer to another question. How accurately does the researcher wish to obtain? Or how much does the limitation of error can be accepted? The statement of precision desired depends on the user's work and may be made by giving the amount of error, which is willing to tolerate in the sample estimates.

Wood (1987) applied the formula of Stein (1945) to calculate the required sample size for a given precision level as following:

$$N = \frac{(t^2)(s^2)}{d^2}$$
Eq. 4.1

where: N is the computed sample size, t is the tabulated value for the desired confidence level and the degree of freedom of the initial sample, d is the desired precision and s^2 in the variance of the initial sample. The 95, 90 and 80% probability levels were used to calculate sample sizes or the number of plots require. Calculations were rounded to the nearest whole number.

An initial sample size of 25 points and their variance from this survey (Table 4.9) were used to calculate the sample size requirements based on the above equation. Since the quality parameters are variety in characteristics, the consideration of the precision level given to each parameter is flexible depending on the magnitude of mean and variance and the precision of instrument used in measurement. It is also depending on the result after the iteration. If the result became perturbation or pit by giving the error sign, the precision level for that parameter has to be adjusted otherwise it will result in only 1 sample required which is not logically estimation. Therefore, the 5 or 10% of the mean, the instrument's precision or the reasonable value depending on the mean and variance were assigned to get an impression of sample size for those parameters.

The initial estimate of the number of samples that should be collected for each water quality parameter respect to desired precision and probability level is given in Table 4.10. It can be seen that number requirements generally increased with a tighter confidence interval and higher probability level for example the sample sizes for temperature at precision of $\pm0.5°C$ are increased from 10, 14 to 17 points when the probability increase from 80, 90 to 95% respectively since the more accuracy need, the more samples require. Sample size is directly proportional to the variance of the initial sample, as calculated in Stein's equation. It is clearly seen for Fe^{+2} and Al^{+3}, which have almost equalled mean but Al^{+3} has higher variance. The required sample for Al^{+3} is also higher than Fe^{+2} since it need more point to capture and describe its variation in the nature.

The precision is also directly related to the estimated size such as total alkalinity and hardness. Although they have high variance, however, these two parameters do not need very precise measurement since they are always fluctuated by their nature. Therefore only 6 to 12 points are required for $\pm10\%$ precision, as well as EC needs only 5 to 9 points for the same percentage of precision. Whereas sulfate and TSS, which variances are more than twice times of mean but both of them need to be assigned high precision because of their low level in lake water, require great amount of sample. Nevertheless,

it has to be noted that high variance of sulfate and TSS also strongly influence by the detection limit of instrument and accuracy of analytical method.

Even though it is very useful to estimate the sample size by this method but the initial value assigned to start calculation should be obtained from the trustable observation with good representative for the overall population. In case that it does not need the very high precision as well as high probability resulting in the small sample size, the user has to give the consideration for the distribution of sampling points over the entire study area in order to get the good accuracy for interested quality parameter.

Table 4.10 Number of samples for desired precision and probability level

Parameter	Unit	Mean	Variance	Precision ($\pm$ unit)	Number of sample for probability		
					95%	90%	80%
Temperature	°C	21.0	0.69	0.5	17	14	10
				1.0	7	6	6
pH	-	8.96	0.01	0.05	24	18	13
				0.1	9	7	5
EC	µS/cm	301	106	5.0	25	19	14
				10.0	9	8	5
Chloride	mg/l Cl$^-$	14.4	2.9	0.7	32	24	18
				1.4	11	8	6
Total Alkalinity	mg/l CaCO$_3$	133.0	217.8	6.7	28	22	16
				13.3	10	8	6
Hardness	mg/l CaCO$_3$	56.8	56.4	2.8	39	30	21
				5.7	12	10	7
NO$_3^-$	mg/l NO$_3^-$	1.77	0.14	0.09	93	72	51
				0.18	26	20	15
NH$_3$	mg/l NH$_3$	0.40	0.06	0.05	124	95	67
				0.10	34	26	19
SO$_4^{2-}$	mg/l SO$_4^{2-}$	4.9	10.16	0.50	208	159	112
				1.00	55	42	30
PO$_4^{3-}$	mg/l PO$_4^{3-}$	0.39	0.01	0.02	136	104	74
				0.04	37	28	20
TSS	mg/l	43.08	301.08	2.2	330	252	178
				4.3	85	65	46
Ca^{+2}	mg/l	14.54	1.17	0.50	27	21	15
				1.00	9	8	6
Mg^{+2}	mg/l	6.54	0.05	0.05	104	80	56
				0.10	29	22	16
K$^+$	mg/l	22.25	1.79	0.50	39	30	22
				1.00	13	10	7
Na$^+$	mg/l	38.17	3.21	0.50	68	52	37
				1.00	20	15	11
Fe^{+2}	mg/l	0.49	0.05	0.05	104	80	56
				0.10	29	22	16
Al^{+3}	mg/l	0.51	0.09	0.05	184	141	100
				0.10	49	38	27
Mn^{+2}	mg/l	0.14	0.0005	0.007	55	42	30
				0.014	16	13	9

4.5.   Temporal analysis

In order to assess the change of water quality in Naivasha Basin with respect to time variation, the temporal analysis have been done by comparison of the data set of this study with those of the previous investigation by ITC's MSc students. The data of Malewa River and Gilgil River from Muñoz (ITC, 2002) are used by selecting the nearest point with this study since some point are not exactly the same place but it can be assumed to be a representative of nearby areas. The comparison errors due to the difference of quality of analysis are expected to be low and acceptable because the analysis was done by the same method which is supposed to be similar accuracy and precision such as using portable multi-parameter meter, HACH sension156 for determine pH, conductivity, TDS and temperature, using Spectrophotometer HACH DR/2010 and the same chemicals for determine nitrate, ammonia, phosphate and sulfate, using ICP-AES for measure major cations. Except for alkalinity and hardness analysis used different kind of test kit for titration method and chloride determination that using mercuric nitrate titration method for this study instead of mercuric thiocyanate method with spectrophotometer HACH DR/2010 then these three parameters might have different accuracy.

The observation for Malewa and Gilgil water quality in year 2001 was done during 1st – 3rd October 2001. The sampling started from 2GB1 gauging station for Malewa River and from the location after Muridati combine with Little Gilgil for Gilgil River (Figure 4.12). The comparison of Malewa River has divided it into 3 locations; at 2GB1 gauging station with code M1 of 2001 and M5 of 2002, location after passing Marula Estate with code M2 of 2001 and M8 of 2002, and the bridge across main road around 11 kilometres far from the lake identified with code M3 of 2001 and M10 of 2002. Gilgil River's sampling points for year 2001 have only 2 points that can be used, the first point is upstream after Murindati combine with Little Gilgil (G1 of 2001 and G3 of 2002) and the second is downstream at 2GA1 gauging station (G2 of 2001 and G5 of 2002).

Sampling points 2001   Sampling points 2002

Figure 4.12 Comparison of sampling points location between 2001 and 2002

The temporal variation of water quality at the adjacent locations between year 2001 and 2002 observations are shown in Table 4.11 and 4.12. The changes in concentration of quality parameters are presented by the plus sign (+) if its value increased and by minus sign (-) if its value decreased comparing with the previous year.

The variations of Malewa River have illustrated in Table 4.11, most of them show increased trend. Parameters that decreased in concentration at all locations are chloride, nitrate, ammonia, iron, aluminium and manganese while temperature, conductivity, TDS, calcium, magnesium, potassium, sodium and sulfate increased in all locations except for sulfate at bridge is no change. The pH at last point before reach the lake is a little bit decreased, phosphate concentration also decreased after passing Marula Estate. In general, the changes were not too much deviation within ±10 units in almost all parameters excluded EC and TDS which are normally fluctuation day by day.

Gilgil River shows the contrast result (Table 4.12), most of quality parameters have reduced in concentration at both two locations but ammonia and sodium are increased. At 2GA1 station, temperature and chloride are higher in this year whereas sulfate and potassium are lower. Alkalinity and hardness exhibit the huge fluctuation especially the hardness at 2GA1 gauging station in 2001 is extremely increased to 250.23 mg/l as $CaCO_3$, unfortunately that there is not any remark about this unusual concentration in the previous report.

It can be noticed that the magnitude of deviation in Gilgil are less than in Malewa, this could be due to the characteristics of the river itself that Gilgil is smaller and lower velocity then the effect from its turbulence is less and there is not too much affect by human activity at downstream since during dry period the water level is low and cannot provide enough water for irrigation.

The difference of concentration caused by many factors. It is not only affect by the change in the flow characteristic of water which include velocity and volume related to water input into channel system and its denudation capability to flush or dissolve mineral from soil or its capacity to carry the organic sediment along the stream as well as the dilution effect but also by the chemical reaction of those chemicals that occurred during the transportation under the different conditions. According to the rating curve at 2GB1 gauging station developed by Podder (ITC, 1998); $Q_{2GB1} = 27.29(H + 0.024)^{1.76}$, where Q is discharge (m³/s), H is the stage height (m), 27.29 and 1.76 are constant and 0.024 is the stage correction); it can calculate the discharge on the day of samples collection in 2002 that the water level in Malewa was 0.15 m, which is equal to 1.26 m³/s whereas the discharge measured in 2001 by velocity-area method (Muñoz, 2002) was 5.5 m³/s. Although the value from different method might give an error for comparison but it can be used for rough estimation that the discharge in 2002 is lower than in 2001 then the increase in concentration due to the decrease in discharge is reasonable.

Discharge of Gilgil at 2GA1 gauging station in 2001 measured by the same method and person is about 0.56 m³/s and in 2002 the recorded level at staff gauge is 0.66 m, which is equal to 1.04 m³/s calculated by the rating equation $Q_{2GA1} = 4.336(H - 0.124)^{2.295}$. The raise of discharge in the recent year could explain the drop of overall concentration.

Change in water temperature can cause by the different of ambient air temperature, which is the result from climate, time of the day, sunshine or cloud over the area at certain time. The change in chemical

composition of stream is mainly from the variation of the input of water and chemicals from its environment. Diluted rain is one of the effecting factors that can diminish the concentration since after the rainfall over the upper catchment the stream discharge is increased and mixed with the baseflow water result in the decline of solute concentration. In addition the acid rain can influence the buffering capacity of stream water result in the change in chemical reaction. Bootsma et al. (1996) reported the pH of rain over the area of Lake Malawi in Mozambique during 1990-1991 was about 6 whereas the rain of the Central Amazon Basin during 1983-1985 had mean pH value at 4.9 (Lesack & Melack, 1991).

During the period of long dry-season, groundwater, which generated baseflow plays an importance role to the temporal variations in stream water chemistry because of the water table movement. The flow velocity of water from underground going out to the stream channel can be more or less effect on the dissolution of chemicals that it pass through. The low flow velocity bring about the longer contact time between water and surface of soil particles leading to the higher dissolved solute whereas the greater velocity is in opposite way.

Furthermore, the importance factor that directly affects the overall water quality is the change of run-off composition by human activities leading to the change of land use and land cover. Uncontrolled livestock and wild animals are another effecting factor that can be the source of ammonia and chloride, which it have found their trace and footprint in every visited place during the period of sample collection.

Table 4.11 Temporal variation of Malewa River quality

Parameters	Unit	2GB1 gauging station			After passing Marula Estate			At bridge (main road)		
		2001 (M1)	2002 (M5)	Change	2001 (M2)	2002 (M8)	Change	2001 (M3)	2002 (M10)	Change
Temp.	($^{\circ}$C)	16.1	19.5	+3.4	17.4	20.8	+3.4	17.8	19.8	+2
pH		7.5	7.91	+0.41	7.60	7.96	+0.36	8.0	7.57	-0.43
EC	(μS/cm)	71	105.5	+34.5	80.7	111.5	+30.8	81.0	118.6	+37.6
TDS	(mg/l)	34	50.2	+16.2	38.7	52.9	+14.2	38.8	56.3	+17.5
Chloride	(mg/l as Cl-)	21.2	9.8	-11.4	12.9	9.8	-3.1	14.6	5.9	-8.7
Total Alk	(mg/l CaCO$_3$)	54.92	54.4	-0.52	54.92	55.8	+0.88	61.02	51.2	-9.82
Hardness	(mg/l CaCO$_3$)	30.03	35.2	+5.17	25.02	42.4	+17.38	28.03	22.8	-5.23
NO$_3$-N	(mg/l)	1	0.10	-0.90	0.80	0.20	-0.60	1.0	0.10	-0.90
NH$_3$-N	(mg/l)	1	0.20	-0.80	6.10	0.20	-5.90	1.1	0.40	-0.70
SO$_4^{2-}$	(mg/l)	1	2	+1	<LOD*	3	+3	2	2	0
PO$_4^{3-}$	(mg/l)	0.27	0.37	+0.1	0.40	0.26	-0.14	0.41	0.37	-0.04
Ca^{+2}	(mg/l)	5.22	7.96	+2.74	5.8	8.26	+2.46	6.03	8.16	+2.13
Mg^{+2}	(mg/l)	1.92	2.09	+0.17	2.04	2.1	+0.06	2.18	2.21	+0.03
K$^+$	(mg/l)	1.39	3.90	+2.51	3.94	4.10	+0.16	3.34	4.14	+0.8
Na$^+$	(mg/l)	6.29	10.62	+4.33	7.75	11.21	+3.46	6.68	11.93	+5.25
Fe^{+2}	(mg/l)	1.92	0.24	-1.68	2.32	0.19	-2.13	1.97	0.15	-1.82
Al^{+3}	(mg/l)	1.39	0.09	-1.3	1.75	0.09	-1.66	1.54	0.02	-1.52
Mn^{+2}	(mg/l)	0.33	0.04	-0.29	0.43	0.01	-0.42	0.38	0.02	-0.36

Remark: *value lower than limit of detection is assumed to be zero

Table 4.12 Temporal variation of Gilgil River quality

Parameters	Unit	After Murindati meet Little Gilgil			2GA1 gauging station		
		2001	2002	Change	2001	2002	Change
Temp.	($^\circ$C)	18.9	18.6	-0.3	17.5	17.9	+0.4
pH		7.7	7.16	-0.54	7.4	7.02	-0.38
EC	(μS/cm)	88	82.9	-5.1	92.1	81.2	-10.9
TDS	(mg/l)	42.2	39.2	-3	44.2	38.4	-5.8
Chloride	(mg/l as Cl-)	7.5	2.6	-4.9	2.2	5.2	+3
Total Alk	(mg/l CaCO3)	61.02	50.0	-11.02	54.92	32.0	-22.92
Hardness	(mg/l CaCO3)	22.02	26.8	+4.78	250.23	16.4	-233.83
NO_3^--N	(mg/l)	0.7	0.30	-0.40	0.9	0.81	-0.09
NH_3-N	(mg/l)	0.9	0.91	+0.01	0.4	0.60	+0.2
SO_4^{2-}	(mg/l)	<LOD*	2	+2	2	3	-1
PO_4^{3-}	(mg/l)	0.49	0.38	-0.11	0.6	0.40	-0.2
Ca^{+2}	(mg/l)	4.04	3.41	-0.63	5.39	3.64	-1.75
Mg^{+2}	(mg/l)	1.18	0.72	-0.46	1.17	0.73	-0.44
K^+	(mg/l)	4.65	4.68	+0.03	4.7	4.65	-0.05
Na^+	(mg/l)	11.47	11.59	+0.12	11.13	11.17	+0.04
Fe^{+2}	(mg/l)	1.71	0.45	-1.26	2.16	0.44	-1.72
Al^{+3}	(mg/l)	0.84	0.08	-0.76	0.97	0.08	-0.89
Mn^{+2}	(mg/l)	0.31	0.04	-0.27	0.24	0.02	-0.22

Remark: * value lower than limit of detection is assumed to be zero

5. Model Development

5.1. Conceptual Model

The approach for the model development proposed for this research is shown in Figure 5.1. The box model will be applied representing the lake as a unique area with inputs and outputs in quality and quantity terms to calibrate the model based on the known budget. Three main inflows are rainfall precipitation, surface runoff and ground water; also three main outflows are evaporation, groundwater seepage and abstraction.

The input variables used to build up the model are long-term data obtain from previous studies, ITC database and literature reviews that include the meteorological and hydrological data, quality and quantity data. The result from concentration and discharge relationships analysis is combined to produce a simple conceptual model of hydrological processes thought to generate the long term of solute concentration in discharge. The solute model uses mass conservation equation for the above various components.

Figure 5.1 Conceptual model of water balance for the lake

The model working based on the mass balance techniques in monthly basis calculated the water level change from the net result of inflow minus outflow at each month. Inflow calculated from summation of surface water, rainfall and groundwater inflow (this term was assumed to be zero in this study) whereas outflow is summation of evaporation, abstraction and groundwater outflow. All of outflow was assigned the negative sign and all component input in unit of flow (m^3/s). Therefore, the DUFLOW calculation based on unsteady flow equation (Eq. 3.2) can be express in a simpler form as:

$$\Delta Q_S = Q_P + Q_R + Q_{Gin} - Q_E - Q_A - Q_{Gout} \qquad \text{Eq. 5.1}$$

where:
ΔQ_S	=	monthly net flow (m^3/s)
Q_P	=	the month i's direct rainfall over the lake surface area (m^3/s)
Q_R	=	the month i's inflow river discharge from Malewa and Gilgil River (m^3/s)
Q_{Gin}	=	inflow from groundwater come into the lake (m^3/s)
Q_E	=	the month i's evaporation of lake surface water (m^3/s)
Q_A	=	water abstraction (m^3/s)
Q_{Gout}	=	groundwater outflow (m^3/s)

The monthly net flow will be used together with the cross section area and the section length to calculate the water level for each month.

The conceptual model of chemical balance is shown in Figure 5.2. The solid arrow indicates the loss or gain of solute of the lake system whereas the white arrow indicates the loss of water by evaporation process, which affects the concentration of solute. The lake system itself also has an internal process of solute exchange between water and sediment that is another importance factor effecting solute balance.

Figure 5.2 Conceptual model of solute balance for the lake

The working of solute model is based on the one-dimensional transport equation (Eq. 3.9), which explains the change of concentration in space and time due to the advection, dispersion and reaction. Since the application of the model is for the conceptual or idealized lake as one box with uniformity characteristics, therefore the change of concentration in space are not taken in to account. The expression of calculation can be written as:

$$\Delta C_S = (C_P Q_P + C_R Q_R + C_{Gin} Q_{Gin} - C_E Q_E - C_A Q_A - C_{Gout} Q_{Gout} \pm \Delta Ex)/Q_S \qquad \text{Eq. 5.2}$$

where: ΔC_S = monthly net concentration (μS/cm)

C_P = the month i's concentration of direct rainfall over the lake surface area (μS/cm)

C_R = the month i's concentration of river discharge (μS/cm)

C_{Gin} = concentration of groundwater come into the lake (μS/cm)

C_E = the month i's concentration of evaporation of lake surface water (μS/cm)

C_A = concentration of water abstraction (μS/cm)

C_{Gout} = concentration of groundwater outflow (μS/cm)

ΔEx = Net exchange solute load via sediment (μS/cm. m^3/s)

Since the concentration of solute in water loss by evaporation is expected to be zero, the abstraction and groundwater outflow are the same water as lake water and the groundwater inflow assumed to be zero, then equation 5.2 can be rewritten as:

$$\Delta C_S = (C_P Q_P + C_R Q_R - C_L Q_A - C_L Q_{Gout} \pm \Delta Ex)/Q_S \qquad \text{Eq. 5.3}$$

where: C_L = concentration of lake water in month i-1 (μS/cm)

5.2.   Physical Construction

The physical scheme for DMS model was constructed after defines a project for lake model with the base scenario that automatically created by DMS in the project directory. The georeferenced map contains lake's water body which exported from ILWIS in shape file format was imported into DMS and serving like a geographical background layer including real UTM coordinates. The simple network based on the conceptual model was build to represent the lake as a section with two nodes of inflow and outflow.

The nodes are points from which one or more sections arise or end whereas the section represents the horizontal length of water body and the direction of water flow. The depth and profile of channel or lake are defined by cross-section that contain cross sectional data. The discharge in or out is connected to the network via the discharge points.

Figure 5.3 shows the constructed model of lake with NODE1 defined as the inflow and NODE2 represents the outflow; SEC is the connected section between two nodes with the approximated length of the lake at 10,000 m and flow direction is from north to south. CSC is the cross section, which was assigned line type channel with 4 m height based on the mean depth of Lake Naivasha calculated by Donia (ITC, 1998) and 15,000 m flow width therefore the approximated volume of the lake is 600 million cubic meter.

Five discharge points were connected onto the network at schematisation points, they included three inflow of rainfall, evaporation and groundwater inflow and two outflow of abstraction and groundwater outflow. The surface runoff was neglected owing to the semi-arid nature of the area and the fact that surrounding soil is composed chiefly of volcanic material, with high infiltration rate. The constructed model was used in the simulation of both hydrology and solute components.

Figure 5.3 Constructed model of Lake Naivasha in DMS

5.3. Boundary Condition

Boundary condition refers to the data as a constant value or a set of data in a form of time series that need to be given as a property of the objects on the network boundary with positive value for incoming water and negative value for outflowing water. The boundary condition have been assigned to nodes and discharge points in the above constructed model; river discharges into the lake were given into NODE1 whereas no scheme was selected at NODE2 which supposed to be dead end so no water or substance are leaving the system at this point since the lake does not have surface outlet. The time series for rainfall and evaporation were put in the discharge points with the unit of flow (m^3/s) that resulted from multiply the rainfall or evaporation with surface area of lake.

5.4. Time Series and Model Variables

In order to construct the water balance model, the complete set time series for all the inputs to the model were obtained from Gitonga (ITC, 1999) who studied and worked with the long-term data. The description of all time series are as following. Data in tabular format are in Appendix A and B.

5.4.1. Lake Level and surface area

The water levels of Lake Naivasha have been recorded since 1908. Level from January 1932 to July 2002 shows in Figure 5.4. Three stations have been operational at various times. Station 2GD4 located on Oloidien Lake, which is separated from main lake during low water levels then it was not take into account. Station 2GD1 has data from 1908 to April 1982 by the Ministry of Water Development. The hardcopy hydrograph recorded from 1908 to 1968 was digitised and combined with maximum monthly levels in tabular format from 1951 to 1982 to form the series from 1932 to April 1982. Station 2GD6 has data from 1967 to 1987 which were corrected the shift due to different datum used to change observed level to height above sea level. Data from this station was used to extend data of 2GD1 until 1987. Other sources of data were from Sulmac Farm situated in the south of the lake and from Vaughan who is a lake riparian. The weekly recorded by Sulmac farm was used to extend data to 1993, Vaughan's record was used to stretch data series to 1998, the data gaps were filled and completed to present by data from the Ministry of Water Development who restored monitoring again since 1997 through Water Resources Assessment and Planning Project. The time series of observed lake level have not used for model input but they have used for calibration of the calculated level.

Figure 5.4 Observed water level of Lake Naivasha during 1932 – 2002

Surface area is a crucial parameter for calculated the volume of rainfall and evaporation over the lake. The physical relationships can be summarized in area-depth curve (so called rating curve). The relationship is developed by using the DEM, which was obtained from interpolation of contour map with spatial resolution of 50 m. Then the calculation of surface area related to certain water level in every interval of 0.20 m was done using ILWIS software. The rating equations were obtained from the series of level and their related area as shown in Figure 5.5 (detail in Appendix A, A-2).

Figure 5.5 Lake level – Area rating curve

5.4.2. Discharge Flow

Station 2GB1 has been used for Malewa River. The original data commenced from 1931 to present with many data gaps. Podder (ITC, 1997) filled the gaps from 1960 to 1990 using linear interpolation, simple and multilinear regression with neighbouring stations. The same technique was used and station 2GC4 was chosen to fill the gaps from 1950 to 1960 by Gitonga (ITC, 1999) and he also filled the data for period 1932 to 1950 using linear interpolation since no data from neighbouring station are available. Discharge of Malewa River from January 1932 to August 2000 presents in Figure 5.6.

Figure 5.6 Discharge of Malewa River during 1932 - 2000

Discharge for Gilgil River was obtained from 2GA5 gauging station, which located downstream proximity to Lake Naivasha. This station has data from December 1959 to 1997. Gitonga (ITC, 1999) who worked with this series filled the data gaps using data from upstream and nearby station; 2GA3, 2GA6 and 2GB1. The regression was done using log transformed data to ensure homoscedasticity. Figure 5.7 shows the data series of this station from January 1932 to December 1997.

Figure 5.7 Discharge of Gilgil River during 1932 – 1997

5.4.3. Rainfall

The Naivasha District Office (D.O.) rainfall station (ID no. 9036002) was selected to be representative of rainfall over the lake since this station located near the lake on the east and has continuous record from 1910 to 1997. The data gaps in 1977 were filled using a neighbouring station from the Kenya Meteorological Department (ID no. 9036179) located at Korongo Farm on the western shore (Gitonga, ITC 1999). Data from 1998 to present were also obtained from Naivasha D.O. station. Monthly rainfall series from January 1932 to August 2002 is shown in Figure 5.8.

Figure 5.8 Monthly rainfalls over the lake from 1932 – 2002

5.4.4. Evaporation

The most importance single factor in the evaporative loss of water is the incoming solar radiation. The vapour pressure is also a primary variable and depends on the water temperature. Wind, air temperature, and water quality also contribute to the evaporative flux (Thomann & Mueller, 1987). The most simple and direct approach is measurement of water loss in evaporation pan.

Previous estimation of water evaporation of Lake Naivasha was based on Class-A pan evaporation data from Naivasha Water Development Department (W.D.D) station (ID no. 9036281). Abdulahi (ITC, 1999) who worked with the same data set with Gitonga (ITC, 1999) mentioned that a pan coefficient of 0.94 was used to convert pan evaporation to free water surface evaporation. Data from this station was available from 1959 to 1990, Gitonga have screened them for typing error and outliers using scatter plots, filled data gaps for the year 1958, 1972, 1978 and missing data during weekend using linear regression and computed long-term monthly average. In order to decrease the error cause by estimated long-term evaporation in the model, both available recorded data were used together with the long-term. Figure 5.9 shows the long-term average monthly evaporation and Figure 5.10 depicts the monthly evaporation from January 1959 to December 1990.

Figure 5.9 Long-term monthly average evaporation of Lake Naivasha

Figure 5.10 Monthly evaporation of Lake Naivasha from 1959 – 1990

5.4.5. Abstraction

The abstraction refer to the water flow out of the lake system by the industries, agricultural farms and riparian around the lake which was significantly increased during the year 1980. From the water budget calculation by Gaudet & Melack (1987), they estimated the water abstraction during 1973-1975 ranged from 7 – 15 mcm/y with the average abstraction rate at 12 mcm/y, the same result of average value with the calculated year from 1957 – 1980 was calculated by Ojiambo (1996). Whereas Gitonga (ITC, 1999) worked with long-term data from 1932 – 1997 estimated the abstraction at 57 mcm/y since year 1985. Beltran (ITC, 2001) gave the abstraction rate at 1.5 m^3/s ($\approx$ 47.3 mcm/y) in his DMS model for lake level during 1999-2000.

Since the river discharges input to the model have considered only 2 main rivers, Malewa and Gilgil, while the others sources of water incoming such as Karati River, which is ephemeral and ungauged discharge, were neglect. Therefore it can be expected the under estimated of outflow. The abstraction was considered to be minimal before 1985 and it has been given at lower level of 0.39 m^3/s ($\approx$ 12 mcm/y) since January 1985. And from the fact that the horticulture industries have increased very much during the last 4 years of simulated period then the value of 1.9 m^3/s ($\approx$ 60 mcm/y) has been used since year 1994.

5.4.6. Groundwater

In order to simplify the model parameter of groundwater inflow, which is hardly to determine the real value and based on the fact that the lake level is mainly controlled by groundwater outflow then the groundwater inflow was assumed to be zero. This assumption is also supported by the previous work of Gitonga (ITC, 1999) that the calculated groundwater inflow is very low at 1.8 mcm/y ($\approx$ 0.05 m^3/s)

The same researchers and period of calculated time estimated groundwater outflow as abstraction. Gaudet & Melack (1987) estimation during 1973-1975 ranged from 17 – 78 mcm/y with the average at 44 mcm/y. Ojiambo (1996) evaluated the mean value at 39 mcm/y from the range between 18 – 50 mcm/y. The spreadsheet model of Gitonga (ITC, 1999) gave the result of estimated groundwater outflow at 55 mcm/y without abstraction. Beltran (ITC, 2001) used adjusted constant value based on Gitonga's study at 1.2 m^3/s ($\approx$ 38 mcm/y), which was also the assigned value into the model of this study.

5.5. Calculation Settings

5.5.1. Time step

Since the calculation is based on monthly basis then the calculation setting was set time step for every 30 day and 11 hours in order to minimize the shifting of value due to the different number of day in a month. According to the limitation of calculation period in DUFLOW that allows user set the maximum period at 57 years therefore the running of model has to be divided into 2 sub-periods. The first sub-period was from January 1932 to December 1988 and the second sub-period was from December 1988 to December 1997.

5.5.2. Resistance Formula

The channel friction was calculated using De Chézy resistance formula with the coefficient of 40 as the default of DUFLOW. If Manning coefficient (n) 0.04 (for channel clean, winding, some pool and shoals) has been used, then the calculation of Chézy coefficient, $C = R^{1/6}/n$ where R is hydraulic radius which is equal to the cross-sectional area divided by the perimeter; is equal to 31.5 which did not give any different result from the default value in model simulation.

5.6. Initial Condition

The initial condition of discharge has obtained from the time series as mentioned above. The first sub-period used value of January 1932 and the second sub-period used value of December 1988.

The initial condition of lake water level for the first sub-period also used observed level of January 1932 at 1890.98 masl. The result from the running of first sub-period conduced the initial value for the second sub-period. The level put in the model was expressed in S.I. unit (meter) by subtract the absolute level with 1881.20 masl, which is the bed level of main lake derived from DEM and this bed level was plus back to the result from the simulation to get the absolute level.

5.7. Model Calibration for Flow

After assign the known inflow and outflow into the model, the quantity (flow) model for water balance (scenario 1) was run. The calibration has been carried out by fitting the peak of evaporation and adjusting unknown parameters e.g. abstraction rate and groundwater outflow based on the fact or assumption from literature review. Until the long term overall matching of the calculated and observed level in term of accepted efficiency has been met. The model efficiency (R^2) as defined by Nash and Sutcliffe (1970) was used to judge the model's prediction capability. The R^2 statistic indicates how close the plot of the simulated versus observed value come to the 1:1 line. The R^2 is calculated as:

$$R^2 = \frac{\sum_{i=1}^{n}(O_i - \overline{O})^2 - \sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \qquad \text{Eq 5.5}$$

Where O_i and P_i are the observed and predicted (simulated) values, O is the mean of the observed value, and i is the number of data. The R^2 can range from $-\infty$ to 1, with 1 indicating a perfect fit.

Once the hydrology component of the model was properly calibrated, the next step was to define the relationship between solute concentration and discharge and to simulate the quality model.

5.8. Quality Model of Solute Balance

This study used the electrical conductivity (EC) or electrical conductance as main parameter to calculate the balance of solute in the lake. The EC is treated as a whole as a single element, which is measured by the unit of EC (µS/cm at 25˚C). The EC has been used in many studies since it is well known that EC shows almost the same variation pattern as the concentration of many of the ions does except in the case of strong volcanic influences or contamination by mining or other exceptional conditions, most river show a similar variation pattern of concentration of ions and conductance during flood (Nakamura, 1971).

5.8.1. EC-Discharge Analysis

According to the EC data is available only 1 year then the needed pre-process before assign them in the quality model is to analyse the relation of EC variations subject to the change of discharge in time in order to use the relation from available dataset to estimate EC in discharge over the period of simulation.

Discharge and EC at 2GB1 gauging station in Malewa River were recorded by the CTD-diver (concentration-temperature-depth) every 2 hours from October 2000 to September 2001. The discharge were converted from the diver recording in the height of water level to the rate of flow in m³/s using the rating curve developed by Podder (ITC, 1998). The raw data was screened for the outliers and discard the anomalous EC during the period of the 23 February 2001 to 24 March 2001, which was the appearance of malfunction of the diver or it probably plugged with mud during low flow. Unfortunately, the interpolation technique for fill the data gaps cannot applied due to the lack of any other data therefore this period was not included in the analysis. Figure 5.11 shows the temporal variation of discharge and EC on daily basis. The interpolation for gaps was applied only for the better visualization. Whereas, the scatter plot between these two variables is in Figure 5.12.

Figure 5.11 Daily discharge and EC of Malewa River at 2GB1 station during October 2000-2001

Figure 5.12 Scatter plots of daily discharge against EC

In general, the concentration of substance decreases as the quantity of discharge increases and become higher when discharge decreases which express the inverse relationships, the general explanation for this relation is the cause of dilution effect from water quantity at particular time. Hem (1985) described the dissolved solids and discharge relation that one of the more direct and important factors is the variable volume of liquid water from rainfall available for dilution and transport of weathering product therefore the dissolved solids should be an inverse function of the rate of discharge over all or at least most of the record range. In this data set, it can see that only short period of wet season from April to May and some range during flood or high peak discharge from June to September show the inverse relationships influenced by dilution effect between EC and discharge.

It is clearly shown that most of the records are not following the dilution concept, as it can perceive in the same figure that during dry season from October to March there is no specific pattern. The concentration fluctuates very much whereas the discharge remains constant or has a small change. The possible reason for this is the effect from the flow component (the contribution of source of water that buildups the river flow), which consist of surface runoff, subsurface flow or groundwater. During the long dry period, the baseflow is mainly contributed by groundwater. The most of the groundwater contribution from Malewa catchment comes from the eastern area of the catchment, primarily the Kinangop Plateau area. The majority of the baseflow contribution comes from the ungauged areas of the catchment with approximately 56%; the 44% of the remaining baseflow contribution come from the upper Malewa catchment (Graham, 1998). The different origins of groundwater, which maybe composed of different geochemical characteristics and varying in hydrological patterns also affect the pattern of solute and discharge relationships. Whereas during wet season; April to May and August to September; the surface component is much grater than the groundwater component. The total river flow increases owing to surface runoff, the relative influence of groundwater component becomes less; i.e. the groundwater component also increases but not as quickly as the surface runoff (O'Connor, 1976). Both the dilution effect and flow component played a role as well as time lag between peak concentration and peak discharge which probably produced by continuous rainfall or many storm occurred in different places over the drainage basin.

The opposite situation that the concentration remained constant as discharge changed also happened during 11th-20th January 2001. This situation has been investigated by Gaudet and Melack (1981) and they gave the explanation of two mechanisms occurring with the solute that can produce this situation that are (a) the rapid equilibration between the water and soil through which the water is percolating and (b) the concentration of the solute in the river is at saturation.

In order to get an idea of the relationships between EC and the generated discharge due to particular storm-runoff event, the EC and discharge for selected peak runoff were plotted. The plots typically exhibit loops patterns so called "Hysteresis" loop, which range from simple, readily identifiable loops to more complex indeterminate shapes. These patterns can be used to infer runoff processes and pathways. Hysteresis occurs where the solute concentration at a given discharge on the rising limb of the hydrograph differs from that at an equivalent discharge on the falling limb. In most early studies, hysteresis was attributed to the flushing of soluble material during the early part of storm flow, leading to elevated concentration on the rising limb (Evan et al., 1999).

From Figure 5.13 and 5.14, it can be seen that the clockwise loop are the major form and they vary from simple to complex loops. The clockwise form is dominated by the effect of high concentrations of EC in the early runoff from the land surface; in term of component mixing the concentration of total streamflow (C_T) is higher on rising limb than on the falling limb. Concentration of surface water (C_{SE}) must therefore exceed soil water (C_{SO}) whereas counterclockwise is in contrast. From the chemograph, the flood cycle can be divided into three phases. During the first stage, discharge increases rapidly but EC changes little and may even increase, as a result of the flushing of soluble material. In the second phase, discharge reaches a maximum and begins to decrease and EC fall rapidly due to the fresh character of storm runoff and the high stream stages, which prevent groundwater seepage from entering the stream. The third phase representing the falling limb is marked by gradually increasing concentrations, as a result of a reduction in the proportion of storm runoff and an increase in baseflow. If the concentration returned to the baseflow level, the closed loop will be formed as in Figure 5.13 C and E. Whereas Figure 5.13 A and B show the pronounced loop that the concentration did not return to baseflow concentration, it might due to the continuous runoff supply by remote subcatchment. The high fluctuation in the early stage of Figure 5.13A was found when EC increase very rapidly, even before the steepest increase in discharge occurs. It seems to be related to early supply by the runoff of tributaries due to short rain just upstream of the measurement location. While the event after long dry period in March 2001 (Figure 5.13B) with rapidly increase in discharge shows the constant EC indicated C_{SE} is as equal as C_G, which might be explained that it due to the flushing of accumulated solute at soil surface and after this flush wave, the concentration became lower.

The series of three continuously single events in April 2001 are shown from Figure 5.13C, D and E. It can be seen that although the same pattern of hysteresis are form in Figure C and E. However, they are different in the magnitude of convexity which influences by the difference in total runoff volume with different composition of those three components as well as the different time lag of peak discharge and peak concentration. It is easily noticed that the middle event shows the difference circumstance since the EC was increased in rising limb and it still continued increasing in falling limb before decreasing to baseflow at the end of hydrograph producing the cross-over or eight-shape loop with rotation of the anticlockwise-to-clockwise. It was also observed this pattern in April and June (Figure 5.14 B and D) but they are not close loop since the hydrograph still influenced by runoff due to unevenly rainfall distribution and new storm therefore the concentration was not yet returned to baseflow.

The opposite direction, clockwise-to-anticlockwise, was found in October and May (Figure 5.14 A and C). The EC tended to decrease in the rising limb and in the early of falling limb and then become substantially increase again before return to baseflow concentration. The decrease in the rising limb might be due to the contribution from surface water (C_{SE}), which is less concentration than baseflow while the increase of EC after the cease of surface runoff could cause from the going out of soil water (C_E). The similar rotation is also found in September event but the loop is very flat because of the constant EC. This figure might reflect the specific substance that is dominant and reach the saturated concentration leading to stable EC.

The eight-shape loop may be attributed to unsynchronized inputs of substantial runoff contributions from several upstream source areas. More complicated hysteresis loops also may occur in a large and heterogeneous drainage basin as a result of the aggregation process (Walling and Webb, 1980).

Figure 5.13 Different types of hysteresis observed in Malewa River at 2GB1 station

Figure 5.14 Various form of eight-shape hysteresis loop observed in Malewa River at 2GB1 station

Furthermore, Chanat et al. (2002) characterized the variability in C-Q plot patterns resulting from variation in end-members volume, timing and solute concentration and concluded that variability in these three factors can result in more than one C-Q loop shape for a given rank order of end-member solute concentrations. The prominence of the event water versus soil water, which is defined as a capacity to influence the total streamflow concentration may result from a combination of end-member volume, timing, or concentration. The plausible hydrological variability in field situation can confound the interpretation of C-Q plots, even when the fundamental end-member mixing assumptions are satisfied.

Since the interrelationship of chemical composition subject to the difference magnitude of discharge depend on many factors as above mention. The scatter plot in Figure 5.12 also shows that there is no significant direct correlation between these two parameters. The traditional and popular way to analyse their relationships is to model with properly assumption and method of derivation of equation to physical and chemical factors subject to the temporal variations, which need more data of the measured concentration and volume of each components. According to the objective of this study, it aims to simplify the method and the DUFLOW itself with friendly user interface allow putting the chemicals both in the unit of concentration or in mass load. Therefore the attempt to adapt the method of Nakamura (1971) for estimation of conductance loading by the relation between CQ and Q was done.

Figure 5.15 shows that the EC load (multiplication between EC and discharge) have the same trend with discharge. When plotting EC load against discharge (Figure 5.16), there is good correlation with R^2 0.8245 explained by polynomial function; $y = 2.1036x^2 + 75.2106x + 152.4808$ where y is EC load (μS/cm* m^3/s) and x is discharge (m^3/s). This approach gives the better relation than C-Q plot since it include the discharge itself in dependent variable, y. In order to validate this relation, the observed load has plotted against calculated load derived from above polynomial equation in Figure 5.17 and it shows the same correlation whereas the different correlation with poorer R^2 were obtained if the power function was used. The equation in Figure 5.16 was used with the time series of Malewa discharge (Figure 5.6) to calculate the EC load and imported to DUFLOW as load scheme.

Figure 5.15 Discharge and EC load of Malewa River at 2GB1 station during October 2000-2001

Figure 5.16 Discharge and EC load relationships

Figure 5.17 Correlation between observed and calculated EC load

5.8.2. Quality Model Formulation and Assumption

The model is developed under the following assumptions.

- The lake water is well mixing; no stratification in vertical depth; supported by the statistical analysis of vertical samples at every 1 meter depth for EC by Mclean (ITC, 2001) The result showed that no significant relation between depth and EC, temperature. The lake is vertically well mixed.

- The EC of Gilgil River and rainfall assume to be fixed value since there are no available data series of continuous records.

- The first step was applied the conservative substance model to prove that whether it can be used for this lake otherwise the non-conservative substance model was selected.

5.8.3. Boundary Condition

The constant boundary condition of EC concentration was assigned to Gilgil River at 130 μS/cm that obtained from the approximate average from historical record collected from various studies. The EC in rainwater was set at 20 μS/cm, which was measured the short rain in Naivasha town occurred during fieldwork on 2nd October 2002. The only one set of time series of EC was for Malewa River, which was derived from C-Q analysis in section 5.8.1.

5.8.4. Initial Condition

According to the lack of EC data of lake water during the simulation period, and from the historical record collected by Verschuren (1996) the nearest data of EC at 330 μS/cm in August 1931 has been used.

5.8.5. Calculation Time Step

The calculation time-step based on monthly basis. In order to decrease the error of number of the calculation result due to different number of the day in each month, therefore the time step size was set at every 30 days and 11 hours. The calculation period started from January 1932 to December 1997 since most of the available time series end at 1997 (see also section 5.5)

5.8.6. Dispersion Coefficient

Although the well vertical mixing was assumed but the DUFLOW need to input the coefficient of the horizontal mixing since the lake model was treated as the channel of river. In any real situation, there is some mixing that occurs along the length due principally to the horizontal gradient of velocity. The phenomenon is called longitudinal dispersion (Thomann & Mueller, 1987). The dispersion coefficient was given at 100 based on the calculation of Beltran (ITC, 2002).

5.8.7. Sink Rate Constant

Due to the nature of shallow lake with spacious surface area of Lake Naivasha and its location in semi-arid zone, the evaporation is not only the predominance process controlling the water balance but it is also a major mechanism governing the lake water become concentrate. As it can be seen that the EC of lake water is higher than river discharge because the concentrate of solute take place when the water evaporate. However, evaporation is not only one factor influences the solute concentration.

According to the fact that release and uptake of solute due to the chemical and biochemical reaction in natural environment is not a minor process also the exchange of solute between particulate matter and water should be taken in to account. As stated by the literature review the sediment exchange is the major process of solute movement where all most all of major solute present the same behaviour that uptake rate is higher than release. Gaudet & Melack (1981) calculated the mean annual sediment uptake and release for each solute in tons*10^3 based on the data during 1973-1974 as shown in table 5.1.

Table 5.1 Calculated mean annual uptake and release of solutes in the main lake (tons*10^3)

	Na	*K*	*Ca*	*Mg*	*HCO₃*	*SO₄*	*Cl*	*F*	*SiO₂*
Sediment release	7.6	5.1	7.5	1	19.1	5.2	4	0.8	11.4
Sediment uptake	8.2	7.3	12.8	2	48.4	5.1	4.7	0.5	22.1
Net change	*0.6*	*2.2*	*5.3*	*1*	*29.3*	*-0.1*	*0.7*	*-0.3*	*10.7*

The net uptake in the above table were converted into sink rate as following steps:
- First, the unit of "tons*10^3 per year" converted to "g/m^3 per day" with the correction factor.

$$\frac{ton*10^3}{year} * \frac{10^6 g}{ton} * \frac{year}{365 day} \div (600*10^6 \, m^3) = 4.5*10^{-3} \text{ g m}^{-3}\text{day}^{-1}$$

where: $600 * 10^6$ m^3 is estimated volume of lake (width*length*depth =10000*15000*4)
- Then the total dissolved solids (TDS) is calculated from the formula (Clesceri et al., 1998):

$$\text{TDScal} = (0.6*\text{Alk}) + \text{Na} + \text{K} + \text{Ca} + \text{Mg} + \text{Cl} + \text{SO}_4 + \text{SiO}_2 + \text{NO}_3 + \text{F} \qquad \text{Eq. 5.5}$$

The unavailable data for some solute were given zero. The result TDScal is 0.155 g m^{-3}day^{-1}.

- The relation between EC and TDS is "EC*0.6 = TDS" (Morgan, 1998). Then the uptake rate in term of EC is equal to

$$\frac{TDScal}{0.6} = \frac{0.155}{0.6} = 0.258 \ \mu S/cm.day^{-1}$$

The sink rate constant at 0.258 μS/cm.day^{-1} was added into the quality model as external parameter.

5.9. Model Calibration for Quality

When the properly quality model has developed, the next step was to simulate the EC values of lake and compare them with the observed data. Availability of observed water quality data was very limited, making it difficult to do a reasonable calibration. However, the model was tested to observe how well the model could represent the dynamics of the EC. The historical EC of Lake Naivasha collected from many sources since 1929 have shown in Appendix D.

5.10. Sensitivity Analysis

Sensitivity analysis determines the sensitivity of model outputs to changes in model parameters, or, how much variation in the output is attributed to a particular input parameter. The sensitivity analysis has performed to the by changing the value of one parameter while the rest were keeping constant. The model has been 'run' using different parameter values, which were changed over a range of ±25% and ±50% and the results have been compared with the initial result. The relative sensitivity in term of the deviation between the initial and sensitivity result curve calculated as:

$$\%\Delta = 100 * \frac{(Result_{sensitivity} - Result_{initial})}{Result_{initial}}$$ Eq. 5.6

Since the model was calibrated for the hydrology, only the parameters that affect the water quality model were selected for sensitivity analysis i.e. dispersion coefficient (D) and sink rate constant (Sd).

5.11. Scenarios Running

According to the objectives of this study, the following scenarios have been developed.

Scenario 1: lake level simulation (water balance)
The water level change according to the change of incoming and outgoing water in form of time series has simulated, the balance of water budget depict the fluctuation of lake level in compare with the observed level. The abstraction and groundwater outflow have been adjusted to match those levels.

Scenario 2: solute balance based on conservative mass with constant EC value
The simplest quality model was developed and the constant EC for all components was assigned in the concentration scheme to show that whether this model could explain the fate of solute comparing with the observed data. EC of Gilgil River was 130 μS/cm, Malewa River was 110 μS/cm and rainfall was 20 μS/cm.

Scenario 3: solute balance based on conservative mass with time series of Malewa EC-load

The EC-load for Malewa derived from the EC and discharge relationships was substituted to the concentration scheme in scenario2 and simulated in the same condition to examine the fate of solute when the source is vary in time an whether the conservative concept could be accepted.

Scenario 4: solute balance with sink rate

According to the result from scenario3 and the fact that solute in the nature is not conservative even the most conservative such as sodium ion which is low exchange rate by the sediment, therefore the attempt to include sink rate was done. The total uptake rate by sediment for all kind of major solute was converted into the unit of sink rate (see section 5.8.7) and added into the quality model.

Scenario 5: Effect of lake exploitation

Many arguments among the stakeholders in the effect of exploitation of Lake Naivasha to its water quality have occurred with the question that if the horticultural industries still continue exploit the huge quantity, either the lower of lake level or the worse water quality of lake will be. Therefore the attempt to simulate this situation was implemented in this scenario.

Scenario 6: Effect of Malewa River exploitation

The other exploitation is of river water by the farms located along Malewa River. Some of them constructed the dike to store water for irrigation, some pumped out water directly from the river channel. This scenario aims to simulate the fate of solute in the lake under the lower inflow condition.

Scenario 7: Effect of exploitation of both lake and Malewa River

The combination of exploitations between direct abstraction from Lake Naivasha and abstraction from Malewa River before it reaches the lake was performed. The assigned rate of direct abstraction is the same as in scenario 5 whereas the percentage of reduction of Malewa discharge was assigned at 25%. This scenario reflects some of the real situation that the exploitation occurs in both resources.

6. Model Result and Discussion

The developed scenarios were run using the same physical network with different condition as described in chapter 5. The first scenario is result from the water balance simulation, scenario 2 to 4 show the development of solute balance model and sensitivity analysis whereas the remaining scenarios purpose to simulate the effect of constituent loading and hydrologic regime. The results from each scenarios are as following.

6.1. Water Balance

Scenario 1: lake level simulation

Lake level or water balance simulation is the first scenario that needs to be developed in order to achieve the flow of water inside the lake presented by the fluctuation of lake level which was calibrated to follow the historical behaviour of the lake.

The initial simulation was done in order to proof that whether it can use only Malewa River to model lake level and to investigate the effect of rainfall and evaporation to lake level. The result and the comparison of variables are shown in Figure 6.1. During the proposal, it has decided to use only Malewa River since it contributed more than 90% of river discharge. The first trial used only this river but the result is not so good that it could expected the lower level than the observed level as it can be seen in curve number 1 and 2, the level became very low after January 1976 and also give the poor r^2 (coefficient of determination to determine trend) and high sum square difference. Therefore both Malewa and Gilgil were used and because the data for Gilgil are available until December 1997 so that the simulation is limited at this year. The simulated level is better than using only Malewa during the initial period but after January 1960 that the rainfall was abnormally high from climatic factor whereas the evaporation calculated from long-term estimation (Gitonga, 1999) did not take into account this situation then the outcome shows increasing of level of curve number 3 and also number 4 which tried to increase groundwater outflow but they are not much enhancing. Due to the effect of long-term evaporation as mentioned above so that it has to mix the real observed value of pan evaporation with long-term estimation which is used in the period of no available data, the result is much more better in term of trend (r^2) and model efficiency (R^2) as in curve number 5.

The next step was to try to fit the calculated level with the observed level by adjusting the abstraction. The results show in Figure 6.2. The abstraction before the period of 1985 expected to be very low (Beltran, 2002) then the curve number 1 present the same setting with number 2 except the abstraction start from 1985. It doesn't enhance the overall result but the level during 1985 – 1991 becomes closed to observed level. According to the estimated abstraction by Gitonga (1999), the abstraction about 60 mcm/y was assigned from year 1994 at 1.9 m^3/s, the result shows in curve number 3 which gave the better values both r^2 and sum square different.

Number	1	2	3	4	5
r^2	0.659	0.766	0.826	0.856	0.857
R^2	-0.515	0.003	0.446	0.659	0.815
SumSqDiff. (m^2)	3039	2001	1112	683	371
River	malewa	malewa	malewa+gilgil	malewa+gilgil	malewa+gilgil
Gwin (m^3/s)	0	0	0	0	0
Gwout (m^3/s)	1.2	1.2	1.2	1.25	1.2
Abstraction (m^3/s)	0.39	0	0.39	0.39	0.39
Evaporation	long-term monthly average				mix real data

Remark : abstraction started from year 1980.

Figure 6.1 Initial simulation of lake level

Number	1	2	3
r^2	0.857	0.858	0.884
R^2	0.815	0.812	0.850
SumSqDiff. (m^2)	371	377	302
River	malewa+gilgil	malewa+gilgil	malewa+gilgil
Gwin (m^3/s)	0	0	0
Gwout (m^3/s)	1.2	1.2	1.2
Abstraction (m^3/s)	0.39	0.39(1985)	0.39(1985)&1.9(1994)
Evaporation	mix real data	mix real data	mix real data

Figure 6.2 Calibration of model by adjusting the abstraction

Result from Figure 6.2 (curve number 3) is acceptable but it still has the wide gaps between observed and simulated level during year 1967 to 1986 (the simulated level is higher during 1967-1980 and become lower from 1981-1986). When the evaporation was overlaid on the level curve, it has seen that during 1967-1986 the real evaporation data are extremely and continuously drop (lower than the long-term average) whereas in 1981-1986 are vice versa, result in the difference. In order to improve this situation, those periods were substituted with long-term average evaporation and the result curve is as final result

It might have the question that why the groundwater-outflow has not been adjusted. This is because if groundwater-outflow was gradually increased, the hold curve from 1932 to 1966 and the period after 1988 become lower and the lake becomes totally dry after around 20 years of simulation when it reaches the estimation value of Gitonga (1999).

The final result of simulation comparing with the observed level in the unit of absolute level (masl) has shown in Figure 6.3. It shows the very good correlation between observed and simulated level with R^2 (Nash-Sutcliffe model efficiency) 0.923. In the other words, the model can explain about 92% of the real situation of lake level with sum of square difference 155 m^2 (Figure 6.4).

Figure 6.3 Comparison between observed and simulated lake level from 1932-1997

Figure 6.4 Correlation between observed and simulated lake level from 1932-1997

The lake level model showed that it was influence by the each of flow component. The change in flow component such as including or excluding the discharge from Karati River, which is ephemeral and un-gauge discharge (surface runoff or antecedent flow during rainstorm) result in the significantly change of simulated result and also affected the adjusted value of groundwater outflow and abstraction that have to be increased.

The model also highly depended on the actual data as during model development the long-term average evaporation have been used through out the 66 years of simulation, the result from the trial run showed the high peak of lake level in January 1962 which result from the abnormally high rainfall due to the climatic factor in the previous month whereas the long-term estimated evaporation did not take in to account this situation, therefore the model need to be provided with real value and/or carefully treated data in order to get the good balance.

In addition, since the designed lake based on the box shape, some error might be occurred due to the calculation over the rectangular cross-sectional area. The experimental model with bowl shape adapted from the lake profile (from southwest to northeast) have been tried, the result shows no major improvement in term of lake level and there is also no significance difference of simulated EC between these two shape of cross-section.

6.2. Solute Balance

Scenario 2: solute balance based on conservative mass with constant EC value

This scenario aims to prove that whether the conservative mass basis, which assume no lost of substances in the system with all constant value for EC input to the model can be match with the observed data. The EC values assigned to each component were obtained from the average of historical data. The EC for Malewa River was at 110 μS/cm; the higher value at 130 μS/cm for Gilgil River and the measured EC in rainfall during fieldwork was about 20 μS/cm.

The result graph in Figure 6.5 shows that the simulated EC are higher than the observed EC through out the hold period but both of them shows the similar trend. By the assumption of conservative mass, the model can be fit with observed data if the inputs EC of Malewa are lower than 110 μS/cm. When the EC at 70 μS/cm was used, it gave the satisfactory result in some period but most of the result the simulated EC is still higher than observed EC. This scenario shows that the conservative mass concept probably give a roughly explanation for the trend of EC in the lake with certain amount of error depending on the mass input setting.

Figure 6.5 Simulated EC based on conservative mass with constant EC input

Scenario 3: solute balance based on conservative mass with time series of Malewa EC-load

The time series for EC of Malewa River were assigned in the model in term of EC-load instead of constant value of EC concentration in scenario 2. EC-load was calculated from the EC-load and discharge relationships, which was developed from data series recorded by CTD-diver from October 2000 to September 2001 as explained in section 5.8.1. The result is in Figure 6.6. It can be seen that the simulated EC show the higher value than observed EC for the hold 66 years. This proves that the conservative mass is not enough to explain the solute behaviour of the lake. It suggests applying non-conservative concept by adding the parameter of controlling the fate of solute.

Figure 6.6 Simulated EC based on conservative mass with time series of Malewa EC-load

The failure of conservative mass concept in this case might due to the fact that bicarbonate and carbonate are the major cation contributed to lake quality. Since in river discharge, bicarbonate is lower than in lake and carbonate is absent. The increasing of them in lake is from internal processes of biological respiration. They are non-conservative substance and trend to precipitate into calcite in water rich in calcium and high pH from algal productivity. The decrease in dissolved substance also causes from the adsorption onto the particulate matter.

Scenario 4: solute balance with sink rate

Due to the characteristics of semi-closed lake without open-channel outlet, water flow out via ground-water. The settle of sediment are more substantial than lake or reservoir with outflowing stream. Therefore the internal lake processes is the importance factor influencing lake water quality. The exchange of solute between sediment and water plays an important role in controlling of solute balance. Since the sediment uptake rate of solute is higher than released rate according to the study of Gaudet and Melack (1981), then the sink rate was applied into the quality model.

The sink rate was calculated based on the sediment net uptake studied by Gaudet and Melack (1981) and assigned to the quality model as the zero order decay. The simulated result as in Figure 6.7 shows that simulated EC were fit well with the observed data. Only some points are not match since the measurement error can vary in high range. And it also causes from the error of EC input for Gilgil River that has assigned constant value. The observed points that are higher or lower than simulated curve are affected by high or low discharge from Gilgil, which may be varied in concentration of dissolved solute but the assigned value for Gilgil is constant.

The comparison between EC and lake level shows that EC was increased when water level decreased and it was decreased when water level increased. The inverse relation causes from the dilution of solute by volume of water.

Figure 6.7 Simulated EC with sink rate

Sensitivity Analysis

The sensitivity analysis was performed for two parameters, dispersion coefficient (D) and sink rate (Sd) in order to determine their effect to the model calculation. The values of both parameters were varied from ±25% and ±50% of default values, which were given at 100 for dispersion coefficient and at 0.258 $\mu S.cm^{-1}.day^{-1}$ for sink rate. The result of sensitivity analysis for dispersion coefficient shows in Figure 6.8. The percentage of change in simulated EC are very low, the maximum change is less than 0.06%. This is due to the default value was set at very quick rate since the model is based on the assumption of well mixing. Furthermore, the dispersion coefficient at this level reflects the fast mixing rate, which occur faster than time scale (monthly time-step size), then it cannot see the variation. However, when the dispersion coefficient was low at 50, the percentage of changes in EC are higher than at 75 and its change does not proportionally with the change of dispersion coefficient.

Figure 6.8 Sensitivity analysis for dispersion coefficient

Figure 6.9 shows the result of sensitivity analysis for sink rate. It is clearly that when sink rate was increased, the EC value was decreased due to the more uptake of dissolved solute by sediment or particulate matter. And the water becomes less concentration. The percentage of change in EC is proportional to the change of sink rate as it can be seen that the change of EC for +25% of sink rate (0.1935 μS.cm^{-1}.day^{-1}) is equal to that for –25% of sink rate (0.3225 μS.cm^{-1}.day^{-1}).

It is also noticed that there are sharp peak of change in year 1962 response to the steeply increase of peak discharge of Malewa river (Figure 5.5) due to the heavy rainfall.

Figure 6.9 Sensitivity analysis for sink rate

6.3. Simulation of Effect

According to the objective of the study in prediction of the solute behavior to change due to the change of water level in the lake. Three situations were modelled. The first is the change of lake level because of the increase in demand of water by direct abstraction from lake. The second is the change of lake level result from the decrease of Malewa discharge which causes from the exploitation at upatream before it reach the lake. The third is the combination of exploitation of lake and river. The simulation of these effects were performed in period of 10 years from 1988 to 1997.

Scenario 5: Effect of lake exploitation

Scenario 4 was set as default and run again in the period of last 10 years. The value of abstraction rate, the same as the final result of water balance (scenario 1), was at 12 mcm/y (0.39 m^3/s) from year 1985 and increase to 60 mcm/y (1.9 m^3/s) from year 1994. The simulation for study effect of lake exploitation was set the abstraction rate since year 1988 at 90 mcm/y (2.85 m^3/s). The comparison of these two situations both in water level and EC is shown in Figure 6.10. It has found that if the exploitation occurred at 90 mcm/y, the lake level will gradually drop until at the end of year 1997, it will be about 4 meters lower than the reality. The simulated EC with increasing abstraction also decrease by 64 µS/cm (decrease from 262 to 198 µS/cm) at the end of simulation.

The exploitation of lake water reduce the solute concentration by shortening the resident time of water stay inside the lake, in the other word, it accelerate the flushing process. Then the proportion of new diluted water from river is rising, lake water quality become more similar to river water, which has lower EC. This situation keeps water fresh. Another reason that might not reflect by the model is the decrease of evaporation due to the decrease of surface area of lake in response to decline of lake level. When the amount of evaporation is less, the water will be less concentrate leading to drop of EC. It has to keep in mind that calculated evaporation rate assigned to the model is based on the surface area of observed level and it did not depend on the simulated level itself. Then both situations have the same rate of evaporation. If the evaporation was calculated subject to the change of simulated lake level, the simulated EC of this scenario could be expected to be lower than 198 µS/cm.

Figure 6.10 Effect of exploitation of lake water to EC

Scenario 6: Effect of Malewa River exploitation

This scenario aims to predict the fate of solute if the lake level was decreased due to the lack of inflow from river discharge. The Malewa discharge was assigned to decrease at 25% and 50% of the measured value. The 10 years of simulation started from year 1988 to 1997 that is the same as scenario 4 and its result is shown in figure 6.11. It has no doubt that the inflow is decreased then the lake level become lower. At the end of year 1997, lake levels are 3.5 and 6.3 m lower than the normal situation for the decrease of discharge at 25% and 50% respectively. The 50% decreasing of discharge result in the totally dry of lake at the middle of year 1997. The change in water quality shows the opposite trend that EC increase while the level decrease. Since the EC of Malewa River is lower than lake water then the decreasing in discharge diminish the diluted water coming to the lake, moreover the old water inside lake still be concentrated by evaporation resulting in raising of EC.

The effect of exploitation of river becomes significantly increased when 50% decreasing of discharge occur. EC was higher than EC of 25% decreasing discharge. It was substantially increased during 1996 and steeply decreased from the middle up to the end of this year due to the low and high peak discharge respectively. These peaks significantly influence to the volume of lake water and the dilution effect at very low water level. Before the period that lake is dry, EC is rapidly raised to 984 µS/cm. When the lake is dry, it is suddenly stop calculation (DUFLOW gave the warning message and reported zero EC).

Figure 6.11 Effect of exploitation of Malewa to EC of lake Naivasha

Scenario 7: Effect of exploitation of both lake and Malewa River

This scenario was performed in order to predict the change in EC of lake, if the exploitation occurred both at the river which result in reduction of inflowing water and abstraction for irrigation around lake. The exploitation of lake by increasing of direct abstraction at 90 mcm/y since 1988 as in scenario 5 was combined with the exploitation of Malewa River leading to decrease its discharge for 25% as in scenario 6. The result of this scenario comparing with normal situation, scenario 5 and 6 is shown in Figure 6.12. This scenario shows that at the end of year 1997, lake level will be lowest comparing with others and it is lower than normal situation by 4.7 meters while the level change due to the decrease of inflow (scenario 6) will be lower than normal situation by 3 meters and the level change due to the increase of abstraction will be lower than normal situation by 4 meters.

Both cases that include the decline of discharge result in increase of EC and their magnitude of change of EC are bigger than the case that only abstraction is increased. Since the effect from the decline of discharge is more influence to solute than the effect from abstraction. It means that at the given rates of discharge and abstraction will encourage the deterioration of water quality, e.g. the high peak in year 1994 and 1995. However, the fluctuation of EC implies that in the period with low discharge, e.g. the low peak in year 1995 and after 1996, the influence from abstraction become more significant especially at the end of simulation. The EC goes down and almost reach the same concentration as the EC of abstraction alone.

Figure 6.12 Effect of exploitation of both lake and Malewa to EC of lake Naivasha

Conclusions and Recommendations

Conclusions

The research aims to assess the variations of solute fluxes and water quality of main rivers and lake in the Naivasha area. The fieldwork was carried out for spatial assessment, which included the area observation, chemical analysis and interpretation of water quality. The temporal analysis was performed for the rivers by comparison with previous ITC's observation and modelling. The DMS software was used to simulate the long-term temporal variation of Lake Naivasha in both quantity and quality. The model was designed in a simple conceptual structure for a straightforward solution in both flow and quality aspects, as the DMS can be applicable for the user who is not hydrologist or hydraulic engineer.

According to the research objectives and questions, the conclusions can be given as follows:

- **Water quality**

Based on the quality monitoring of September 2002, water of Lake Naivasha and two main rivers, Malewa and Gilgil, are generally in the normal range of surface water with predominance of bicarbonate, sodium and calcium. They are commonly alkaline with pH between 7 to 9. The hardness of rivers can be categorised as soft water while the lake is moderately hard. Chemicals content of lake water is higher than those of rivers in all parameter due to the influences from sunlight, evaporation and its internal processes, which normally occur in those lakes.

Malewa and Gilgil show a spatial variation along the streams. EC, alkalinity, hardness, major cation e.g. sodium, calcium, potassium and magnesium trend to increase from upstream to downstream with some fluctuation in both rivers. Nutrients (nitrate, ammonia and phosphate) and trace elements (iron, aluminium and manganese) in Malewa have an irregular pattern. Nutrient in Gilgil are higher than Malewa and trend to increase toward the river's mount while the trace elements at upstream and downstream are higher than at the points between them since both upstream and downstream are affected by human activity.

Water quality of Malewa's upper catchment in Nandrasi River also included in the survey. It is still fresh with EC between 90-120 μS/cm due to the origin from undisturbed area and it shows the temporal variation in 3 days of observation by the influence of local rain presented at the Aberdare Ranges. The lake quality is fairly homogeneous across the waterbody except for the shallow part at the northeast, which almost all parameters are high due to the effect from sediment inflow and alkalinity is high at the area near the river's mount. The water quality monitoring sample sizes estimation by statistical approach concerning about the variation and desired precision of quality parameters as well as the required confidence level shows that as high as those three factors are needed, as big as the size is required.

- **Model simulation**

The model for water and solute balance of the lake based on conceptual box model was designed with both quantity and quality constituents as inflows and outflows. Since Duflow provides various types of object that suit the user's need, the lake was represented as a section with defined cross-sectional area and length. The discharge points represented inflows and outflows, which were given as time series of rainfall, evaporation and river discharges. These time series were obtained from historical measurement. For the abstractions and groundwater outflow evidence and data from earlier research (Gitonga, 1999) was used and adjusted in order to calibrate the water balance, which was expressed as the correlation between simulated and observed lake level. The final result of long-term simulation on monthly basis from year 1932 to 1997 indicated the good fit between them with Nash and Sutcliffe R^2 of 0.92. The water balance model highly depend on the actual data of each component therefore it needs to be provided with carefully treated data from trustable sources.

After the water balance was accepted, the solute balance model was written in Duflow quality model. The solute concentration represented as electrical conductivity (EC), which can be treated as a single constituent. A one-year recording of EC of Malewa River was analysed before applying into the model. The EC-discharge relationships revealed various types of hysteresis loops due to the influence from different combination of concentration and relative volume of flow components (surface water, groundwater and soil water) and time lag between each component. All of these factors reflected the complexity of basin characteristics, which made it difficult to construct a simple mathematical relation.

The method of EC-load and discharge relationships adapted from Nakamura (1971) was selected. It shows that EC-load trends to follow the discharge, which was explained by second order polynomial equation. This relation was applied to the time series of Malewa discharge whereas the other model components were given the observed value. The result from series of developed model implied that the non-conservative concept was appropriate. The solute balance is not only controlled by the evaporation but also by sediment exchange. The net uptake (sink rate) at 0.258 μS/cm.day^{-1} calculated from solutes study by Gaudet and Melack (1981) was assigned and the result shows that the simulated EC fit well with the historical observed data.

Three scenarios were performed to predict the fate of solutes in accordance with the decline of lake level due to the increase of water demand. The model was simulated for year 1988-1997. The increase of direct abstraction leads to the less concentration of solute because of the acceleration of flushing process. An increase of Malewa exploitation, which causes the drop of inflows and lake level results in the raising of concentration because of the lack of diluted water and the old water still be concentrated by evaporation. The effect of exploitation by direct abstraction at 90 mcm/y and 25% decrease of Malewa discharge show that the EC will increase in the overall period but the magnitude of increase depends on the combination of effect by those two components that positively or negatively effect each other.

Recommendations

- Water quality monitoring should be done more periodically and over extended periods or ITC's fieldwork should be carried out in different period of the year (normally on October and September) because of the ability of quality parameters to fluctuate as a result of different conditions.
- The temporal analysis of lake behaviour should be carried out since the seasonal change could effect the spatial variation of water quality as well as the sample size estimation.
- In order to better understand the concentration-discharge relationships, all of flow components could be investigated further and a model developed to describe their relationships (e.g. isotope studies)
- In the lake model should be incorporated a time series with a relation to the groundwater flows or it could be linked with Modflow using the Moduflow interface.
- In a next step, it is recommended to model the selective ion species and/or the chemicals from surrounding farm as well as to study more detail of internal processes controlling those ions.

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Appendices

Appendix A – Lake Level

A-1 Observed lake level from January 1932 to July 2002

Jan-32	1890.98	Jan-37	1888.31	Jan-42	1886.54	Jan-47	1884.97	Jan-52	1885.98
Feb-32	1890.98	Feb-37	1888.15	Feb-42	1886.78	Feb-47	1885.58	Feb-52	1885.85
Mar-32	1890.98	Mar-37	1888.31	Mar-42	1887.03	Mar-47	1886.29	Mar-52	1885.94
Apr-32	1890.98	Apr-37	1888.79	Apr-42	1887.26	Apr-47	1886.48	Apr-52	1886.01
May-32	1890.98	May-37	1889.15	May-42	1887.16	May-47	1886.58	May-52	1885.93
Jun-32	1890.89	Jun-37	1889.55	Jun-42	1887.20	Jun-47	1886.66	Jun-52	1885.87
Jul-32	1890.86	Jul-37	1889.95	Jul-42	1887.07	Jul-47	1886.55	Jul-52	1885.87
Aug-32	1890.83	Aug-37	1889.91	Aug-42	1886.87	Aug-47	1886.48	Aug-52	1885.86
Sep-32	1890.86	Sep-37	1889.78	Sep-42	1886.70	Sep-47	1886.47	Sep-52	1885.81
Oct-32	1890.83	Oct-37	1889.80	Oct-42	1886.63	Oct-47	1886.37	Oct-52	1885.71
Nov-32	1890.77	Nov-37	1889.81	Nov-42	1886.56	Nov-47	1886.18	Nov-52	1885.58
Dec-32	1890.67	Dec-37	1889.70	Dec-42	1886.47	Dec-47	1886.11	Dec-52	1885.40
Jan-33	1890.55	Jan-38	1889.57	Jan-43	1886.34	Jan-48	1886.02	Jan-53	1885.23
Feb-33	1890.49	Feb-38	1889.46	Feb-43	1886.24	Feb-48	1885.85	Feb-53	1885.14
Mar-33	1890.37	Mar-38	1889.34	Mar-43	1886.17	Mar-48	1885.83	Mar-53	1885.08
Apr-33	1890.22	Apr-38	1889.24	Apr-43	1886.09	Apr-48	1885.81	Apr-53	1885.01
May-33	1890.16	May-38	1889.14	May-43	1886.12	May-48	1885.88	May-53	1884.99
Jun-33	1890.06	Jun-38	1889.04	Jun-43	1886.15	Jun-48	1885.99	Jun-53	1884.94
Jul-33	1890.06	Jul-38	1888.96	Jul-43	1886.12	Jul-48	1886.04	Jul-53	1884.84
Aug-33	1890.06	Aug-38	1888.92	Aug-43	1886.05	Aug-48	1885.92	Aug-53	1884.74
Sep-33	1890.06	Sep-38	1888.88	Sep-43	1885.94	Sep-48	1885.85	Sep-53	1884.70
Oct-33	1890.06	Oct-38	1888.82	Oct-43	1885.82	Oct-48	1885.76	Oct-53	1884.69
Nov-33	1890.10	Nov-38	1888.69	Nov-43	1885.64	Nov-48	1885.63	Nov-53	1884.58
Dec-33	1890.10	Dec-38	1888.55	Dec-43	1885.53	Dec-48	1885.50	Dec-53	1884.42
Jan-34	1889.82	Jan-39	1888.43	Jan-44	1885.43	Jan-49	1885.39	Jan-54	1884.25
Feb-34	1889.59	Feb-39	1888.35	Feb-44	1885.35	Feb-49	1885.31	Feb-54	1884.25
Mar-34	1889.52	Mar-39	1888.28	Mar-44	1885.30	Mar-49	1885.27	Mar-54	1884.50
Apr-34	1889.44	Apr-39	1888.15	Apr-44	1885.25	Apr-49	1885.19	Apr-54	1884.83
May-34	1889.36	May-39	1888.01	May-44	1885.20	May-49	1885.19	May-54	1885.19
Jun-34	1889.29	Jun-39	1887.92	Jun-44	1885.20	Jun-49	1885.31	Jun-54	1885.32
Jul-34	1889.21	Jul-39	1887.85	Jul-44	1885.19	Jul-49	1885.34	Jul-54	1885.42
Aug-34	1889.13	Aug-39	1887.72	Aug-44	1885.18	Aug-49	1885.25	Aug-54	1885.48
Sep-34	1889.06	Sep-39	1887.60	Sep-44	1885.02	Sep-49	1885.16	Sep-54	1885.43
Oct-34	1888.98	Oct-39	1887.45	Oct-44	1884.81	Oct-49	1885.10	Oct-54	1885.37
Nov-34	1888.91	Nov-39	1887.25	Nov-44	1884.70	Nov-49	1884.94	Nov-54	1885.27
Dec-34	1888.84	Dec-39	1887.12	Dec-44	1884.62	Dec-49	1884.74	Dec-54	1885.17
Jan-35	1888.78	Jan-40	1887.06	Jan-45	1884.59	Jan-50	1884.79	Jan-55	1885.12
Feb-35	1888.72	Feb-40	1887.02	Feb-45	1884.61	Feb-50	1884.77	Feb-55	1885.01
Mar-35	1888.65	Mar-40	1887.26	Mar-45	1884.61	Mar-50	1884.68	Mar-55	1884.94
Apr-35	1888.57	Apr-40	1887.47	Apr-45	1884.63	Apr-50	1884.64	Apr-55	1884.90
May-35	1888.50	May-40	1887.38	May-45	1884.83	May-50	1884.69	May-55	1884.82
Jun-35	1888.44	Jun-40	1887.25	Jun-45	1885.07	Jun-50	1884.82	Jun-55	1884.75
Jul-35	1888.38	Jul-40	1887.14	Jul-45	1885.03	Jul-50	1884.95	Jul-55	1884.92
Aug-35	1888.32	Aug-40	1886.99	Aug-45	1884.97	Aug-50	1884.93	Aug-55	1885.12
Sep-35	1888.28	Sep-40	1886.79	Sep-45	1884.90	Sep-50	1884.85	Sep-55	1885.23
Oct-35	1888.25	Oct-40	1886.69	Oct-45	1884.84	Oct-50	1884.72	Oct-55	1885.18
Nov-35	1888.21	Nov-40	1886.56	Nov-45	1884.72	Nov-50	1884.62	Nov-55	1885.21
Dec-35	1888.19	Dec-40	1886.43	Dec-45	1884.57	Dec-50	1884.50	Dec-55	1885.29
Jan-36	1888.18	Jan-41	1886.64	Jan-46	1884.39	Jan-51	1884.56	Jan-56	1885.31
Feb-36	1888.18	Feb-41	1886.89	Feb-46	1884.26	Feb-51	1885.05	Feb-56	1885.27
Mar-36	1888.27	Mar-41	1886.88	Mar-46	1884.43	Mar-51	1885.28	Mar-56	1885.28
Apr-36	1888.67	Apr-41	1886.83	Apr-46	1884.44	Apr-51	1885.47	Apr-56	1885.45
May-36	1888.75	May-41	1886.82	May-46	1884.46	May-51	1885.51	May-56	1885.53
Jun-36	1888.74	Jun-41	1886.79	Jun-46	1884.62	Jun-51	1885.66	Jun-56	1885.61
Jul-36	1888.73	Jul-41	1886.75	Jul-46	1884.86	Jul-51	1885.82	Jul-56	1885.82
Aug-36	1888.69	Aug-41	1886.71	Aug-46	1884.89	Aug-51	1885.88	Aug-56	1886.13
Sep-36	1888.65	Sep-41	1886.66	Sep-46	1884.91	Sep-51	1885.99	Sep-56	1886.24
Oct-36	1888.60	Oct-41	1886.60	Oct-46	1884.85	Oct-51	1886.15	Oct-56	1886.23
Nov-36	1888.51	Nov-41	1886.55	Nov-46	1884.79	Nov-51	1886.19	Nov-56	1886.13
Dec-36	1888.42	Dec-41	1886.50	Dec-46	1884.78	Dec-51	1886.09	Dec-56	1886.03

A-1 Observed lake level from January 1932 to July 2002 *(Continued)*

Jan-57	1885.92	Jan-62	1887.82	Jan-67	1888.92	Jan-72	1889.04	Jan-77	1886.50
Feb-57	1885.86	Feb-62	1888.17	Feb-67	1888.83	Feb-72	1888.98	Feb-77	1886.34
Mar-57	1885.95	Mar-62	1888.05	Mar-67	1888.70	Mar-72	1888.90	Mar-77	1886.37
Apr-57	1886.13	Apr-62	1887.89	Apr-67	1888.57	Apr-72	1888.75	Apr-77	1886.53
May-57	1886.37	May-62	1887.84	May-67	1888.43	May-72	1888.66	May-77	1887.41
Jun-57	1886.50	Jun-62	1888.15	Jun-67	1888.54	Jun-72	1888.59	Jun-77	1887.62
Jul-57	1886.63	Jul-62	1888.17	Jul-67	1888.75	Jul-72	1888.57	Jul-77	1887.81
Aug-57	1886.73	Aug-62	1888.15	Aug-67	1888.85	Aug-72	1888.52	Aug-77	1888.02
Sep-57	1886.68	Sep-62	1888.21	Sep-67	1888.92	Sep-72	1888.51	Sep-77	1888.06
Oct-57	1886.59	Oct-62	1888.42	Oct-67	1888.94	Oct-72	1888.44	Oct-77	1887.95
Nov-57	1886.51	Nov-62	1888.59	Nov-67	1888.92	Nov-72	1888.50	Nov-77	1888.03
Dec-57	1886.49	Dec-62	1888.59	Dec-67	1888.89	Dec-72	1888.47	Dec-77	1888.26
Jan-58	1886.47	Jan-63	1888.52	Jan-68	1888.87	Jan-73	1888.38	Jan-78	1888.31
Feb-58	1886.46	Feb-63	1888.45	Feb-68	1888.81	Feb-73	1888.27	Feb-78	1888.29
Mar-58	1886.45	Mar-63	1888.40	Mar-68	1888.72	Mar-73	1888.16	Mar-78	1888.45
Apr-58	1886.53	Apr-63	1888.38	Apr-68	1888.59	Apr-73	1888.03	Apr-78	1888.96
May-58	1886.73	May-63	1888.59	May-68	1889.75	May-73	1887.95	May-78	1889.28
Jun-58	1887.07	Jun-63	1889.00	Jun-68	1889.80	Jun-73	1887.93	Jun-78	1889.16
Jul-58	1887.33	Jul-63	1889.36	Jul-68	1889.82	Jul-73	1887.85	Jul-78	1889.15
Aug-58	1887.40	Aug-63	1889.31	Aug-68	1889.75	Aug-73	1887.80	Aug-78	1889.20
Sep-58	1887.39	Sep-63	1889.19	Sep-68	1889.81	Sep-73	1887.80	Sep-78	1889.25
Oct-58	1887.36	Oct-63	1889.20	Oct-68	1889.79	Oct-73	1887.77	Oct-78	1889.42
Nov-58	1887.28	Nov-63	1889.12	Nov-68	1889.75	Nov-73	1887.73	Nov-78	1889.47
Dec-58	1887.25	Dec-63	1889.07	Dec-68	1889.75	Dec-73	1887.63	Dec-78	1889.44
Jan-59	1887.14	Jan-64	1889.43	Jan-69	1889.69	Jan-74	1887.50	Jan-79	1889.36
Feb-59	1887.02	Feb-64	1889.52	Feb-69	1889.61	Feb-74	1887.33	Feb-79	1889.52
Mar-59	1886.95	Mar-64	1889.39	Mar-69	1889.56	Mar-74	1887.21	Mar-79	1889.51
Apr-59	1886.88	Apr-64	1889.33	Apr-69	1889.48	Apr-74	1887.25	Apr-79	1889.57
May-59	1886.86	May-64	1889.52	May-69	1889.50	May-74	1887.33	May-79	1889.64
Jun-59	1886.85	Jun-64	1889.62	Jun-69	1889.45	Jun-74	1887.32	Jun-79	1889.73
Jul-59	1886.73	Jul-64	1889.61	Jul-69	1889.32	Jul-74	1887.47	Jul-79	1889.79
Aug-59	1886.73	Aug-64	1889.61	Aug-69	1889.12	Aug-74	1887.55	Aug-79	1889.79
Sep-59	1886.74	Sep-64	1889.72	Sep-69	1889.11	Sep-74	1887.72	Sep-79	1889.73
Oct-59	1886.72	Oct-64	1889.88	Oct-69	1889.01	Oct-74	1887.82	Oct-79	1889.61
Nov-59	1886.66	Nov-64	1890.07	Nov-69	1888.91	Nov-74	1887.83	Nov-79	1889.55
Dec-59	1886.63	Dec-64	1890.22	Dec-69	1888.86	Dec-74	1887.78	Dec-79	1889.46
Jan-60	1886.55	Jan-65	1890.16	Jan-70	1888.79	Jan-75	1887.62	Jan-80	1889.32
Feb-60	1886.25	Feb-65	1890.08	Feb-70	1888.74	Feb-75	1887.47	Feb-80	1889.20
Mar-60	1886.05	Mar-65	1890.01	Mar-70	1888.63	Mar-75	1887.34	Mar-80	1889.09
Apr-60	1885.99	Apr-65	1889.91	Apr-70	1888.72	Apr-75	1887.20	Apr-80	1888.98
May-60	1885.92	May-65	1889.77	May-70	1888.90	May-75	1886.99	May-80	1889.13
Jun-60	1885.84	Jun-65	1889.71	Jun-70	1888.99	Jun-75	1887.03	Jun-80	1889.28
Jul-60	1885.92	Jul-65	1889.76	Jul-70	1889.03	Jul-75	1887.08	Jul-80	1889.33
Aug-60	1885.87	Aug-65	1889.68	Aug-70	1888.99	Aug-75	1887.27	Aug-80	1889.20
Sep-60	1885.91	Sep-65	1889.60	Sep-70	1889.07	Sep-75	1887.66	Sep-80	1889.08
Oct-60	1885.92	Oct-65	1889.53	Oct-70	1889.15	Oct-75	1887.86	Oct-80	1888.93
Nov-60	1885.95	Nov-65	1889.44	Nov-70	1889.12	Nov-75	1887.89	Nov-80	1888.88
Dec-60	1885.96	Dec-65	1889.34	Dec-70	1889.03	Dec-75	1887.79	Dec-80	1888.82
Jan-61	1885.85	Jan-66	1889.24	Jan-71	1888.89	Jan-76	1887.64	Jan-81	1888.67
Feb-61	1885.73	Feb-66	1889.14	Feb-71	1888.78	Feb-76	1887.49	Feb-81	1888.53
Mar-61	1885.60	Mar-66	1889.04	Mar-71	1888.61	Mar-76	1887.32	Mar-81	1888.37
Apr-61	1885.47	Apr-66	1888.94	Apr-71	1888.50	Apr-76	1887.16	Apr-81	1888.63
May-61	1885.38	May-66	1888.86	May-71	1888.50	May-76	1887.06	May-81	1889.04
Jun-61	1885.37	Jun-66	1888.94	Jun-71	1888.61	Jun-76	1887.00	Jun-81	1889.23
Jul-61	1885.29	Jul-66	1888.96	Jul-71	1888.72	Jul-76	1886.93	Jul-81	1889.25
Aug-61	1885.18	Aug-66	1888.90	Aug-71	1888.89	Aug-76	1886.82	Aug-81	1889.56
Sep-61	1885.15	Sep-66	1888.82	Sep-71	1889.23	Sep-76	1887.06	Sep-81	1889.64
Oct-61	1885.27	Oct-66	1888.83	Oct-71	1889.21	Oct-76	1886.87	Oct-81	1889.65
Nov-61	1885.86	Nov-66	1888.90	Nov-71	1889.21	Nov-76	1886.60	Nov-81	1889.59
Dec-61	1887.16	Dec-66	1888.89	Dec-71	1889.11	Dec-76	1886.73	Dec-81	1889.54

A-1 Observed lake level from January 1932 to July 2002 *(Continued)*

Jan-82	1889.53	Jan-87	1887.19	Jan-92	1887.28	Jan-97	1886.50	Jan-02	1886.42
Feb-82	1889.31	Feb-87	1887.11	Feb-92	1887.16	Feb-97	1886.40	Feb-02	1886.27
Mar-82	1889.04	Mar-87	1887.03	Mar-92	1887.03	Mar-97	1886.30	Mar-02	1886.16
Apr-82	1888.98	Apr-87	1886.94	Apr-92	1886.90	Apr-97	1886.20	Apr-02	1886.04
May-82	1889.01	May-87	1886.81	May-92	1886.77	May-97	1886.21	May-02	1886.53
Jun-82	1889.01	Jun-87	1886.63	Jun-92	1886.64	Jun-97	1886.09	Jun-02	1886.53
Jul-82	1888.95	Jul-87	1886.70	Jul-92	1886.77	Jul-97	1886.06	Jul-02	1886.40
Aug-82	1888.95	Aug-87	1886.75	Aug-92	1886.91	Aug-97	1886.07		
Sep-82	1888.89	Sep-87	1886.66	Sep-92	1887.04	Sep-97	1885.97		
Oct-82	1888.85	Oct-87	1886.57	Oct-92	1887.18	Oct-97	1885.85		
Nov-82	1888.89	Nov-87	1886.49	Nov-92	1887.32	Nov-97	1885.80		
Dec-82	1889.41	Dec-87	1886.40	Dec-92	1887.45	Dec-97	1886.84		
Jan-83	1889.35	Jan-88	1886.31	Jan-93	1887.56	Jan-98	1887.88		
Feb-83	1889.25	Feb-88	1886.23	Feb-93	1887.48	Feb-98	1887.96		
Mar-83	1889.18	Mar-88	1886.22	Mar-93	1887.40	Mar-98	1887.91		
Apr-83	1889.09	Apr-88	1886.38	Apr-93	1887.32	Apr-98	1887.85		
May-83	1889.00	May-88	1886.23	May-93	1887.24	May-98	1888.31		
Jun-83	1888.93	Jun-88	1886.21	Jun-93	1887.16	Jun-98	1888.75		
Jul-83	1888.92	Jul-88	1886.50	Jul-93	1887.08	Jul-98	1888.84		
Aug-83	1888.92	Aug-88	1886.75	Aug-93	1887.00	Aug-98	1888.89		
Sep-83	1888.97	Sep-88	1886.97	Sep-93	1886.92	Sep-98	1888.91		
Oct-83	1889.08	Oct-88	1887.19	Oct-93	1886.84	Oct-98	1888.92		
Nov-83	1889.19	Nov-88	1887.18	Nov-93	1886.76	Nov-98	1888.92		
Dec-83	1889.15	Dec-88	1887.17	Dec-93	1886.54	Dec-98	1888.82		
Jan-84	1889.09	Jan-89	1887.17	Jan-94	1886.50	Jan-99	1888.79		
Feb-84	1888.97	Feb-89	1887.16	Feb-94	1886.40	Feb-99	1888.44		
Mar-84	1888.79	Mar-89	1887.15	Mar-94	1886.23	Mar-99	1888.31		
Apr-84	1888.69	Apr-89	1886.89	Apr-94	1886.10	Apr-99	1888.24		
May-84	1888.37	May-89	1886.87	May-94	1886.10	May-99	1888.10		
Jun-84	1888.26	Jun-89	1886.84	Jun-94	1886.16	Jun-99	1887.94		
Jul-84	1888.14	Jul-89	1886.82	Jul-94	1886.40	Jul-99	1887.80		
Aug-84	1888.02	Aug-89	1886.80	Aug-94	1886.50	Aug-99	1887.70		
Sep-84	1887.91	Sep-89	1886.77	Sep-94	1886.60	Sep-99	1887.68		
Oct-84	1887.90	Oct-89	1886.75	Oct-94	1886.50	Oct-99	1887.57		
Nov-84	1887.88	Nov-89	1886.93	Nov-94	1886.50	Nov-99	1887.49		
Dec-84	1887.87	Dec-89	1887.13	Dec-94	1886.92	Dec-99	1887.49		
Jan-85	1887.86	Jan-90	1887.32	Jan-95	1886.80	Jan-00	1887.34		
Feb-85	1887.81	Feb-90	1887.48	Feb-95	1886.64	Feb-00	1887.13		
Mar-85	1887.57	Mar-90	1887.49	Mar-95	1886.40	Mar-00	1886.93		
Apr-85	1887.56	Apr-90	1887.60	Apr-95	1886.40	Apr-00	1886.79		
May-85	1887.61	May-90	1888.02	May-95	1886.47	May-00	1886.69		
Jun-85	1887.67	Jun-90	1888.43	Jun-95	1886.50	Jun-00	1886.47		
Jul-85	1887.72	Jul-90	1888.40	Jul-95	1886.51	Jul-00	1886.35		
Aug-85	1887.78	Aug-90	1888.35	Aug-95	1886.30	Aug-00	1886.27		
Sep-85	1887.83	Sep-90	1888.30	Sep-95	1886.30	Sep-00	1886.20		
Oct-85	1887.81	Oct-90	1888.25	Oct-95	1886.40	Oct-00	1886.09		
Nov-85	1887.72	Nov-90	1888.19	Nov-95	1886.45	Nov-00	1886.08		
Dec-85	1887.64	Dec-90	1888.14	Dec-95	1886.56	Dec-00	1886.02		
Jan-86	1887.55	Jan-91	1888.09	Jan-96	1886.50	Jan-01	1886.01		
Feb-86	1887.46	Feb-91	1888.04	Feb-96	1886.40	Feb-01	1886.02		
Mar-86	1887.38	Mar-91	1887.85	Mar-96	1886.30	Mar-01	1885.87		
Apr-86	1887.29	Apr-91	1887.66	Apr-96	1886.20	Apr-01	1885.94		
May-86	1887.20	May-91	1887.52	May-96	1886.07	May-01	1886.15		
Jun-86	1887.38	Jun-91	1887.44	Jun-96	1886.00	Jun-01	1886.13		
Jul-86	1887.40	Jul-91	1887.48	Jul-96	1886.10	Jul-01	1886.15		
Aug-86	1887.38	Aug-91	1887.53	Aug-96	1886.24	Aug-01	1886.33		
Sep-86	1887.36	Sep-91	1887.48	Sep-96	1886.30	Sep-01	1886.39		
Oct-86	1887.34	Oct-91	1887.43	Oct-96	1886.50	Oct-01	1886.41		
Nov-86	1887.32	Nov-91	1887.39	Nov-96	1886.50	Nov-01	1886.50		
Dec-86	1887.28	Dec-91	1887.34	Dec-96	1886.56	Dec-01	1886.52		

A-2 Relation between lake level and surface area derived from DEM

Lake level (masl)	Surface area (m^2)	Lake level (masl)	Surface area (m^2)
1884.00	94482772	1887.60	140179199
1884.20	96267366	1887.80	142864746
1884.40	98220140	1888.00	145369629
1884.60	100311441	1888.20	147736816
1884.80	102511613	1888.40	150009277
1885.00	104790998	1888.60	152213379
1885.20	107119947	1888.80	154376465
1885.40	109468800	1889.00	156520020
1885.60	111807905	1889.20	158655762
1885.80	114107609	1889.40	160790527
1886.00	116338253	1889.60	162923340
1886.20	118470182	1889.80	165050293
1886.40	120473749	1890.00	167158691
1886.60	122319293	1890.20	169228027
1886.80	126501465	1890.40	171237793
1887.00	130487793	1890.60	173149902
1887.20	134050293	1890.80	174931152
1887.40	137260254	1891.00	176535645

Equations for level ≤ 1886.60 masl

$$Y = -0.617806672495\ X^3 + 3494.31624625919\ X^2 - 6587942.36122145\ X + 4140143136.23547$$

$R^2 = 0.99997$

Equations for level > 1886.60 masl

$$Y = -0.165364090206367\ X^4 + 1249.69703887057\ X^3 - 3541600.27561621\ X^2 - 4460790498.33767\ X - 2106955583385.73$$

$R^2 = 0.9987$

Total $R^2 = 0.9997$

Appendix B Time Series Input Data

B-1 Rainfall (mm/month) from January 1932 to August 2002

Jan-32	3.60	Jan-37	16.30	Jan-42	16.80	Jan-47	56.90	Jan-52	4.80
Feb-32	35.60	Feb-37	11.20	Feb-42	15.50	Feb-47	45.00	Feb-52	32.80
Mar-32	30.50	Mar-37	77.70	Mar-42	64.30	Mar-47	120.10	Mar-52	22.60
Apr-32	99.10	Apr-37	161.80	Apr-42	107.40	Apr-47	199.60	Apr-52	125.70
May-32	71.10	May-37	142.70	May-42	58.90	May-47	124.20	May-52	119.10
Jun-32	16.30	Jun-37	161.50	Jun-42	47.00	Jun-47	13.20	Jun-52	1.00
Jul-32	22.60	Jul-37	101.10	Jul-42	7.90	Jul-47	81.30	Jul-52	13.20
Aug-32	14.00	Aug-37	36.80	Aug-42	70.40	Aug-47	11.20	Aug-52	31.20
Sep-32	124.00	Sep-37	16.80	Sep-42	7.10	Sep-47	34.50	Sep-52	60.20
Oct-32	54.40	Oct-37	65.80	Oct-42	20.30	Oct-47	24.40	Oct-52	52.80
Nov-32	32.80	Nov-37	96.00	Nov-42	23.40	Nov-47	51.80	Nov-52	55.90
Dec-32	42.90	Dec-37	51.60	Dec-42	4.60	Dec-47	25.70	Dec-52	14.20
Jan-33	38.60	Jan-38	20.60	Jan-43	17.30	Jan-48	6.10	Jan-53	7.90
Feb-33	7.40	Feb-38	9.70	Feb-43	32.80	Feb-48	8.90	Feb-53	12.20
Mar-33	17.80	Mar-38	60.20	Mar-43	1.00	Mar-48	47.20	Mar-53	21.30
Apr-33	56.90	Apr-38	75.70	Apr-43	67.10	Apr-48	73.70	Apr-53	112.50
May-33	44.70	May-38	42.90	May-43	83.10	May-48	47.00	May-53	125.00
Jun-33	26.20	Jun-38	18.80	Jun-43	41.40	Jun-48	32.30	Jun-53	58.20
Jul-33	18.00	Jul-38	16.30	Jul-43	62.70	Jul-48	13.20	Jul-53	7.10
Aug-33	93.00	Aug-38	40.40	Aug-43	53.30	Aug-48	30.70	Aug-53	52.60
Sep-33	47.00	Sep-38	29.00	Sep-43	74.70	Sep-48	91.20	Sep-53	23.90
Oct-33	38.90	Oct-38	62.20	Oct-43	10.90	Oct-48	50.50	Oct-53	81.80
Nov-33	52.60	Nov-38	62.00	Nov-43	36.80	Nov-48	51.30	Nov-53	73.40
Dec-33	43.20	Dec-38	19.10	Dec-43	19.10	Dec-48	21.30	Dec-53	18.00
Jan-34	2.50	Jan-39	12.40	Jan-44	40.40	Jan-49	1.80	Jan-54	32.00
Feb-34	1.30	Feb-39	33.80	Feb-44	17.30	Feb-49	18.80	Feb-54	3.60
Mar-34	39.10	Mar-39	24.40	Mar-44	36.80	Mar-49	33.00	Mar-54	24.40
Apr-34	58.70	Apr-39	104.10	Apr-44	82.80	Apr-49	118.40	Apr-54	149.40
May-34	40.10	May-39	9.10	May-44	31.20	May-49	88.10	May-54	159.80
Jun-34	90.40	Jun-39	17.50	Jun-44	38.60	Jun-49	40.90	Jun-54	76.20
Jul-34	72.90	Jul-39	41.90	Jul-44	49.00	Jul-49	14.20	Jul-54	41.40
Aug-34	44.70	Aug-39	94.20	Aug-44	44.50	Aug-49	42.70	Aug-54	27.70
Sep-34	19.30	Sep-39	24.40	Sep-44	67.60	Sep-49	13.70	Sep-54	91.40
Oct-34	57.20	Oct-39	15.00	Oct-44	71.90	Oct-49	31.50	Oct-54	25.40
Nov-34	21.60	Nov-39	34.80	Nov-44	93.70	Nov-49	17.50	Nov-54	44.70
Dec-34	14.00	Dec-39	5.60	Dec-44	36.10	Dec-49	36.10	Dec-54	45.00
Jan-35	1.50	Jan-40	36.30	Jan-45	19.30	Jan-50	8.90	Jan-55	35.30
Feb-35	55.40	Feb-40	65.50	Feb-45	36.80	Feb-50	31.80	Feb-55	78.70
Mar-35	44.70	Mar-40	93.70	Mar-45	28.20	Mar-50	74.20	Mar-55	16.00
Apr-35	135.90	Apr-40	236.20	Apr-45	23.40	Apr-50	106.70	Apr-55	137.40
May-35	47.20	May-40	67.60	May-45	93.20	May-50	31.00	May-55	27.40
Jun-35	130.30	Jun-40	10.40	Jun-45	62.00	Jun-50	29.70	Jun-55	30.00
Jul-35	0.00	Jul-40	8.40	Jul-45	20.10	Jul-50	29.50	Jul-55	57.20
Aug-35	17.80	Aug-40	27.90	Aug-45	78.70	Aug-50	64.50	Aug-55	82.60
Sep-35	38.10	Sep-40	8.90	Sep-45	111.80	Sep-50	109.00	Sep-55	60.70
Oct-35	62.00	Oct-40	51.80	Oct-45	22.90	Oct-50	43.20	Oct-55	77.00
Nov-35	56.40	Nov-40	37.60	Nov-45	75.70	Nov-50	28.70	Nov-55	32.30
Dec-35	46.50	Dec-40	21.60	Dec-45	9.40	Dec-50	11.40	Dec-55	78.00
Jan-36	55.40	Jan-41	18.50	Jan-46	13.20	Jan-51	14.70	Jan-56	57.20
Feb-36	139.40	Feb-41	15.00	Feb-46	0.00	Feb-51	23.40	Feb-56	103.90
Mar-36	71.90	Mar-41	92.70	Mar-46	7.60	Mar-51	95.80	Mar-56	55.60
Apr-36	165.40	Apr-41	98.30	Apr-46	97.80	Apr-51	269.20	Apr-56	73.20
May-36	32.30	May-41	176.50	May-46	100.30	May-51	77.00	May-56	80.80
Jun-36	39.60	Jun-41	22.60	Jun-46	34.00	Jun-51	21.10	Jun-56	30.20
Jul-36	24.60	Jul-41	7.40	Jul-46	11.70	Jul-51	56.60	Jul-56	34.30
Aug-36	30.20	Aug-41	7.10	Aug-46	54.40	Aug-51	45.00	Aug-56	50.00
Sep-36	31.80	Sep-41	20.10	Sep-46	79.80	Sep-51	64.80	Sep-56	79.20
Oct-36	53.10	Oct-41	39.60	Oct-46	91.70	Oct-51	52.30	Oct-56	26.90
Nov-36	55.40	Nov-41	80.30	Nov-46	65.00	Nov-51	60.20	Nov-56	40.40
Dec-36	25.40	Dec-41	55.10	Dec-46	31.00	Dec-51	57.70	Dec-56	24.60

B-1 Rainfall (mm/month) from January 1932 to August 2002 *(Continue)*

Jan-57	49.80	Jan-62	94.50	Jan-67	14.60	Jan-72	18.60	Jan-77	30.90
Feb-57	13.50	Feb-62	15.00	Feb-67	7.50	Feb-72	106.60	Feb-77	24.50
Mar-57	80.30	Mar-62	54.40	Mar-67	50.60	Mar-72	17.60	Mar-77	30.60
Apr-57	190.20	Apr-62	127.00	Apr-67	108.90	Apr-72	18.60	Apr-77	205.00
May-57	155.40	May-62	151.90	May-67	119.40	May-72	46.30	May-77	130.60
Jun-57	77.70	Jun-62	24.60	Jun-67	46.10	Jun-72	92.30	Jun-77	20.10
Jul-57	69.10	Jul-62	3.60	Jul-67	84.40	Jul-72	20.70	Jul-77	67.10
Aug-57	50.30	Aug-62	43.20	Aug-67	52.10	Aug-72	42.30	Aug-77	41.80
Sep-57	19.10	Sep-62	38.60	Sep-67	34.40	Sep-72	32.10	Sep-77	18.80
Oct-57	41.10	Oct-62	61.20	Oct-67	99.10	Oct-72	92.50	Oct-77	78.50
Nov-57	40.60	Nov-62	33.50	Nov-67	57.00	Nov-72	63.90	Nov-77	109.50
Dec-57	23.90	Dec-62	55.40	Dec-67	24.90	Dec-72	10.10	Dec-77	72.60
Jan-58	50.50	Jan-63	33.80	Jan-68	1.80	Jan-73	57.20	Jan-78	76.30
Feb-58	134.90	Feb-63	37.80	Feb-68	113.70	Feb-73	58.20	Feb-78	54.20
Mar-58	74.40	Mar-63	39.40	Mar-68	85.50	Mar-73	8.00	Mar-78	222.40
Apr-58	36.80	Apr-63	212.60	Apr-68	251.40	Apr-73	127.10	Apr-78	125.10
May-58	128.00	May-63	131.80	May-68	13.80	May-73	84.20	May-78	73.70
Jun-58	26.70	Jun-63	39.60	Jun-68	59.10	Jun-73	33.50	Jun-78	15.00
Jul-58	86.10	Jul-63	2.50	Jul-68	3.60	Jul-73	20.50	Jul-78	10.90
Aug-58	11.90	Aug-63	25.10	Aug-68	2.50	Aug-73	29.90	Aug-78	77.10
Sep-58	19.80	Sep-63	10.40	Sep-68	38.90	Sep-73	55.90	Sep-78	79.40
Oct-58	36.80	Oct-63	29.00	Oct-68	55.50	Oct-73	35.00	Oct-78	44.60
Nov-58	66.80	Nov-63	87.40	Nov-68	84.10	Nov-73	52.10	Nov-78	32.50
Dec-58	93.20	Dec-63	152.70	Dec-68	55.40	Dec-73	13.60	Dec-78	98.20
Jan-59	16.00	Jan-64	9.10	Jan-69	42.80	Jan-74	13.40	Jan-79	77.70
Feb-59	15.70	Feb-64	52.30	Feb-69	33.90	Feb-74	16.90	Feb-79	121.20
Mar-59	54.10	Mar-64	105.90	Mar-69	61.70	Mar-74	32.10	Mar-79	58.80
Apr-59	75.90	Apr-64	165.90	Apr-69	30.40	Apr-74	223.10	Apr-79	70.70
May-59	117.90	May-64	10.90	May-69	115.10	May-74	67.00	May-79	63.20
Jun-59	49.80	Jun-64	18.50	Jun-69	19.90	Jun-74	75.00	Jun-79	63.40
Jul-59	15.70	Jul-64	101.30	Jul-69	13.00	Jul-74	70.30	Jul-79	28.20
Aug-59	62.00	Aug-64	8.10	Aug-69	16.50	Aug-74	44.50	Aug-79	49.60
Sep-59	50.80	Sep-64	37.60	Sep-69	29.50	Sep-74	46.00	Sep-79	47.60
Oct-59	27.70	Oct-64	89.40	Oct-69	23.40	Oct-74	30.20	Oct-79	21.10
Nov-59	84.10	Nov-64	55.10	Nov-69	62.60	Nov-74	40.80	Nov-79	74.60
Dec-59	14.70	Dec-64	53.80	Dec-69	39.00	Dec-74	49.40	Dec-79	35.40
Jan-60	55.40	Jan-65	34.80	Jan-70	83.50	Jan-75	1.70	Jan-80	39.10
Feb-60	28.20	Feb-65	14.90	Feb-70	35.80	Feb-75	21.40	Feb-80	6.50
Mar-60	140.00	Mar-65	24.10	Mar-70	110.90	Mar-75	25.80	Mar-80	53.60
Apr-60	106.20	Apr-65	110.60	Apr-70	100.10	Apr-75	127.20	Apr-80	125.60
May-60	39.60	May-65	56.00	May-70	83.50	May-75	54.80	May-80	155.80
Jun-60	7.90	Jun-65	32.10	Jun-70	58.60	Jun-75	20.40	Jun-80	67.50
Jul-60	3.80	Jul-65	36.60	Jul-70	37.40	Jul-75	80.30	Jul-80	2.20
Aug-60	89.70	Aug-65	34.00	Aug-70	12.00	Aug-75	50.60	Aug-80	7.90
Sep-60	56.10	Sep-65	18.10	Sep-70	83.10	Sep-75	61.80	Sep-80	32.20
Oct-60	30.50	Oct-65	54.20	Oct-70	27.40	Oct-75	81.40	Oct-80	20.00
Nov-60	65.50	Nov-65	66.00	Nov-70	41.80	Nov-75	15.70	Nov-80	93.40
Dec-60	45.50	Dec-65	39.50	Dec-70	9.60	Dec-75	24.50	Dec-80	9.70
Jan-61	0.00	Jan-66	20.50	Jan-71	41.70	Jan-76	7.80	Jan-81	0.30
Feb-61	26.20	Feb-66	45.00	Feb-71	2.30	Feb-76	29.80	Feb-81	24.20
Mar-61	26.20	Mar-66	73.60	Mar-71	6.30	Mar-76	16.90	Mar-81	178.70
Apr-61	96.50	Apr-66	206.20	Apr-71	64.00	Apr-76	69.00	Apr-81	142.00
May-61	130.00	May-66	28.20	May-71	173.80	May-76	46.10	May-81	65.70
Jun-61	8.60	Jun-66	12.80	Jun-71	11.70	Jun-76	67.80	Jun-81	31.50
Jul-61	0.00	Jul-66	5.60	Jul-71	39.30	Jul-76	48.40	Jul-81	54.80
Aug-61	49.50	Aug-66	98.80	Aug-71	112.80	Aug-76	75.80	Aug-81	44.80
Sep-61	50.50	Sep-66	87.90	Sep-71	21.80	Sep-76	47.60	Sep-81	29.60
Oct-61	102.60	Oct-66	51.10	Oct-71	137.70	Oct-76	7.50	Oct-81	41.30
Nov-61	334.50	Nov-66	112.90	Nov-71	32.70	Nov-76	23.20	Nov-81	59.50
Dec-61	117.30	Dec-66	5.40	Dec-71	49.40	Dec-76	46.00	Dec-81	35.60

B-1 Rainfall (mm/month) from January 1932 to August 2002 *(Continue)*

Jan-82	24.70	Jan-87	8.20	Jan-92	23.30	Jan-97	57.10	Jan-02	67.80
Feb-82	20.80	Feb-87	19.30	Feb-92	13.10	Feb-97	6.70	Feb-02	0.00
Mar-82	6.20	Mar-87	45.80	Mar-92	13.20	Mar-97	72.11	Mar-02	121.60
Apr-82	118.30	Apr-87	67.80	Apr-92	164.40	Apr-97	28.20	Apr-02	168.90
May-82	111.30	May-87	118.20	May-92	85.40	May-97	0.00	May-02	145.20
Jun-82	20.70	Jun-87	158.80	Jun-92	89.00	Jun-97	30.60	Jun-02	21.40
Jul-82	8.20	Jul-87	54.60	Jul-92	94.50	Jul-97	161.90	Jul-02	15.80
Aug-82	57.40	Aug-87	42.00	Aug-92	22.40	Aug-97	39.80	Aug-02	39.20
Sep-82	45.90	Sep-87	11.50	Sep-92	101.40	Sep-97	105.40		
Oct-82	92.60	Oct-87	18.40	Oct-92	70.60	Oct-97	29.40		
Nov-82	170.70	Nov-87	57.80	Nov-92	30.10	Nov-97	45.70		
Dec-82	65.10	Dec-87	11.40	Dec-92	59.20	Dec-97	7.40		
Jan-83	35.50	Jan-88	38.70	Jan-93	182.00	Jan-98	110.40		
Feb-83	33.80	Feb-88	9.80	Feb-93	16.50	Feb-98	155.70		
Mar-83	8.30	Mar-88	80.60	Mar-93	10.20	Mar-98	98.90		
Apr-83	84.30	Apr-88	121.40	Apr-93	20.10	Apr-98	81.34		
May-83	38.20	May-88	90.60	May-93	39.30	May-98	21.88		
Jun-83	99.70	Jun-88	16.00	Jun-93	60.60	Jun-98	66.40		
Jul-83	39.60	Jul-88	37.90	Jul-93	0.10	Jul-98	31.50		
Aug-83	46.20	Aug-88	62.30	Aug-93	13.70	Aug-98	74.50		
Sep-83	58.40	Sep-88	27.00	Sep-93	44.60	Sep-98	0.90		
Oct-83	92.00	Oct-88	17.20	Oct-93	23.10	Oct-98	1.10		
Nov-83	59.30	Nov-88	39.60	Nov-93	41.10	Nov-98	8.80		
Dec-83	38.90	Dec-88	15.50	Dec-93	22.50	Dec-98	1.50		
Jan-84	3.20	Jan-89	77.80	Jan-94	7.90	Jan-99	18.70		
Feb-84	4.50	Feb-89	23.80	Feb-94	32.40	Feb-99	1.80		
Mar-84	3.00	Mar-89	38.90	Mar-94	56.10	Mar-99	93.00		
Apr-84	64.20	Apr-89	91.00	Apr-94	124.00	Apr-99	52.00		
May-84	8.30	May-89	116.60	May-94	60.00	May-99	1.80		
Jun-84	0.00	Jun-89	37.50	Jun-94	53.60	Jun-99	32.10		
Jul-84	51.10	Jul-89	80.10	Jul-94	70.80	Jul-99	7.10		
Aug-84	42.10	Aug-89	86.40	Aug-94	27.80	Aug-99	15.50		
Sep-84	6.90	Sep-89	55.40	Sep-94	11.90	Sep-99	33.20		
Oct-84	52.00	Oct-89	79.40	Oct-94	65.80	Oct-99	21.70		
Nov-84	100.30	Nov-89	47.10	Nov-94	22.70	Nov-99	67.20		
Dec-84	101.90	Dec-89	119.40	Dec-94	18.40	Dec-99	26.20		
Jan-85	17.80	Jan-90	38.90	Jan-95	55.14	Jan-00	1.95		
Feb-85	63.80	Feb-90	99.70	Feb-95	0.00	Feb-00	3.45		
Mar-85	66.70	Mar-90	135.50	Mar-95	56.20	Mar-00	2.36		
Apr-85	147.10	Apr-90	185.30	Apr-95	93.70	Apr-00	50.23		
May-85	84.80	May-90	75.90	May-95	107.40	May-00	12.86		
Jun-85	22.40	Jun-90	14.50	Jun-95	80.10	Jun-00	8.98		
Jul-85	29.10	Jul-90	19.00	Jul-95	42.00	Jul-00	18.76		
Aug-85	11.20	Aug-90	67.50	Aug-95	46.20	Aug-00	2.02		
Sep-85	51.00	Sep-90	46.60	Sep-95	25.40	Sep-00	20.34		
Oct-85	16.60	Oct-90	99.20	Oct-95	71.40	Oct-00	24.08		
Nov-85	21.20	Nov-90	63.50	Nov-95	80.10	Nov-00	99.46		
Dec-85	26.70	Dec-90	23.90	Dec-95	52.70	Dec-00	24.60		
Jan-86	40.80	Jan-91	7.20	Jan-96	38.70	Jan-01	137.96		
Feb-86	39.90	Feb-91	3.10	Feb-96	69.39	Feb-01	18.06		
Mar-86	40.60	Mar-91	79.80	Mar-96	17.60	Mar-01	136.74		
Apr-86	161.00	Apr-91	68.20	Apr-96	27.70	Apr-01	83.78		
May-86	40.10	May-91	62.70	May-96	93.00	May-01	14.38		
Jun-86	36.70	Jun-91	76.20	Jun-96	59.20	Jun-01	21.12		
Jul-86	7.60	Jul-91	11.20	Jul-96	39.50	Jul-01	17.02		
Aug-86	48.60	Aug-91	15.80	Aug-96	92.60	Aug-01	44.42		
Sep-86	27.00	Sep-91	22.20	Sep-96	126.30	Sep-01	76.90		
Oct-86	41.90	Oct-91	65.20	Oct-96	40.70	Oct-01	48.00		
Nov-86	70.00	Nov-91	70.60	Nov-96	84.70	Nov-01	75.30		
Dec-86	55.80	Dec-91	15.70	Dec-96	76.00	Dec-01	22.40		

B-2 Evaporation (mm/month) from January 1959 to December 1990 (Naivasha D.O.)

Jan-59	212.05	Jan-63	150.80	Jan-67	183.70	Jan-71	155.00	Jan-75	173.90
Feb-59	189.40	Feb-63	147.20	Feb-67	175.85	Feb-71	151.80	Feb-75	156.70
Mar-59	199.10	Mar-63	148.60	Mar-67	184.30	Mar-71	187.00	Mar-75	181.60
Apr-59	182.10	Apr-63	145.70	Apr-67	117.60	Apr-71	132.70	Apr-75	156.90
May-59	163.50	May-63	218.10	May-67	115.60	May-71	121.00	May-75	142.40
Jun-59	174.20	Jun-63	130.05	Jun-67	113.55	Jun-71	126.10	Jun-75	123.90
Jul-59	163.80	Jul-63	152.40	Jul-67	86.90	Jul-71	111.90	Jul-75	118.70
Aug-59	182.75	Aug-63	152.75	Aug-67	132.40	Aug-71	118.10	Aug-75	107.50
Sep-59	203.65	Sep-63	178.65	Sep-67	156.10	Sep-71	149.90	Sep-75	134.10
Oct-59	225.00	Oct-63	197.10	Oct-67	169.20	Oct-71	162.60	Oct-75	134.30
Nov-59	164.80	Nov-63	128.35	Nov-67	126.60	Nov-71	139.60	Nov-75	140.90
Dec-59	178.15	Dec-63	113.00	Dec-67	153.90	Dec-71	129.40	Dec-75	156.70
Jan-60	181.85	Jan-64	170.30	Jan-68	175.60	Jan-72	117.80	Jan-76	180.30
Feb-60	208.45	Feb-64	161.30	Feb-68	129.60	Feb-72	115.40	Feb-76	163.40
Mar-60	189.85	Mar-64	155.85	Mar-68	105.70	Mar-72	179.80	Mar-76	190.90
Apr-60	183.50	Apr-64	145.25	Apr-68	106.80	Apr-72	199.50	Apr-76	134.60
May-60	202.75	May-64	182.40	May-68	133.40	May-72	124.20	May-76	172.80
Jun-60	200.90	Jun-64	150.30	Jun-68	123.20	Jun-72	112.00	Jun-76	126.30
Jul-60	194.27	Jul-64	149.65	Jul-68	122.20	Jul-72	140.00	Jul-76	133.30
Aug-60	227.63	Aug-64	157.55	Aug-68	134.40	Aug-72	144.50	Aug-76	142.10
Sep-60	189.50	Sep-64	149.70	Sep-68	161.80	Sep-72	166.10	Sep-76	152.50
Oct-60	178.20	Oct-64	138.20	Oct-68	139.10	Oct-72	126.70	Oct-76	168.60
Nov-60	147.25	Nov-64	156.85	Nov-68	113.90	Nov-72	121.90	Nov-76	137.00
Dec-60	170.75	Dec-64	146.25	Dec-68	133.70	Dec-72	208.50	Dec-76	148.40
Jan-61	216.00	Jan-65	177.00	Jan-69	151.80	Jan-73	148.10	Jan-77	135.10
Feb-61	218.60	Feb-65	196.10	Feb-69	116.60	Feb-73	129.60	Feb-77	147.70
Mar-61	241.50	Mar-65	226.90	Mar-69	141.35	Mar-73	214.60	Mar-77	168.70
Apr-61	155.50	Apr-65	186.70	Apr-69	151.20	Apr-73	151.40	Apr-77	117.90
May-61	184.30	May-65	187.90	May-69	145.90	May-73	151.40	May-77	127.30
Jun-61	180.10	Jun-65	153.80	Jun-69	131.90	Jun-73	120.30	Jun-77	117.50
Jul-61	192.80	Jul-65	163.15	Jul-69	138.90	Jul-73	139.10	Jul-77	99.50
Aug-61	148.20	Aug-65	175.70	Aug-69	157.30	Aug-73	142.40	Aug-77	126.50
Sep-61	195.50	Sep-65	164.90	Sep-69	151.40	Sep-73	112.60	Sep-77	145.00
Oct-61	227.40	Oct-65	186.00	Oct-69	161.40	Oct-73	139.70	Oct-77	171.90
Nov-61	94.55	Nov-65	127.25	Nov-69	123.80	Nov-73	111.10	Nov-77	107.50
Dec-61	143.85	Dec-65	158.70	Dec-69	143.20	Dec-73	139.70	Dec-77	132.50
Jan-62	121.50	Jan-66	173.60	Jan-70	117.20	Jan-74	191.00	Jan-78	149.10
Feb-62	152.50	Feb-66	166.35	Feb-70	137.30	Feb-74	170.50	Feb-78	136.90
Mar-62	172.10	Mar-66	149.35	Mar-70	154.60	Mar-74	162.00	Mar-78	122.40
Apr-62	158.55	Apr-66	128.60	Apr-70	122.20	Apr-74	98.60	Apr-78	116.80
May-62	144.90	May-66	150.25	May-70	117.30	May-74	136.30	May-78	128.70
Jun-62	150.05	Jun-66	130.30	Jun-70	118.90	Jun-74	127.50	Jun-78	119.40
Jul-62	161.80	Jul-66	139.60	Jul-70	133.40	Jul-74	109.10	Jul-78	196.70
Aug-62	178.90	Aug-66	135.10	Aug-70	136.80	Aug-74	115.70	Aug-78	147.10
Sep-62	173.80	Sep-66	130.80	Sep-70	150.30	Sep-74	125.60	Sep-78	147.70
Oct-62	166.40	Oct-66	157.30	Oct-70	148.30	Oct-74	143.80	Oct-78	162.75
Nov-62	162.80	Nov-66	112.00	Nov-70	115.40	Nov-74	102.30	Nov-78	120.20
Dec-62	155.30	Dec-66	166.60	Dec-70	149.50	Dec-74	149.40	Dec-78	147.25

B-2 Evaporation (mm/month) from January 1959 to December 1990 (Naivasha D.O.)
(Continued)

Jan-79	172.30	Jun-81	141.20	Nov-83	163.30	Apr-86	127.00	Sep-88	118.50
Feb-79	150.00	Jul-81	145.70	Dec-83	123.90	May-86	120.10	Oct-88	144.90
Mar-79	223.45	Aug-81	150.30	Jan-84	176.70	Jun-86	96.10	Nov-88	107.20
Apr-79	210.00	Sep-81	158.70	Feb-84	179.80	Jul-86	105.20	Dec-88	125.70
May-79	192.00	Oct-81	163.20	Mar-84	205.70	Aug-86	145.63	Jan-89	133.50
Jun-79	185.55	Nov-81	171.80	Apr-84	163.80	Sep-86	140.10	Feb-89	134.90
Jul-79	231.00	Dec-81	176.00	May-84	197.30	Oct-86	153.00	Mar-89	158.80
Aug-79	212.90	Jan-82	198.40	Jun-84	196.00	Nov-86	129.70	Apr-89	115.60
Sep-79	228.80	Feb-82	176.40	Jul-84	149.30	Dec-86	142.90	May-89	101.90
Oct-79	184.00	Mar-82	212.30	Aug-84	144.00	Jan-87	135.60	Jun-89	87.10
Nov-79	153.40	Apr-82	164.50	Sep-84	147.30	Feb-87	163.00	Jul-89	87.90
Dec-79	181.40	May-82	152.10	Oct-84	120.70	Mar-87	179.10	Aug-89	96.30
Jan-80	200.70	Jun-82	133.95	Nov-84	115.50	Apr-87	133.00	Sep-89	104.20
Feb-80	175.40	Jul-82	160.70	Dec-84	124.40	May-87	121.30	Oct-89	126.40
Mar-80	197.30	Aug-82	163.40	Jan-85	159.50	Jun-87	86.80	Nov-89	119.50
Apr-80	148.30	Sep-82	171.10	Feb-85	121.00	Jul-87	108.20	Dec-89	120.80
May-80	149.30	Oct-82	145.40	Mar-85	155.80	Aug-87	127.10	Jan-90	135.10
Jun-80	162.60	Nov-82	120.40	Apr-85	100.90	Sep-87	150.30	Feb-90	121.20
Jul-80	147.70	Dec-82	153.00	May-85	114.50	Oct-87	182.30	Mar-90	125.30
Aug-80	176.00	Jan-83	187.10	Jun-85	110.40	Nov-87	109.20	Apr-90	111.80
Sep-80	165.60	Feb-83	148.20	Jul-85	97.30	Dec-87	145.60	May-90	112.00
Oct-80	171.40	Mar-83	205.20	Aug-85	119.60	Jan-88	143.70	Jun-90	110.40
Nov-80	133.20	Apr-83	174.40	Sep-85	134.75	Feb-88	158.70	Jul-90	116.00
Dec-80	179.20	May-83	197.60	Oct-85	138.50	Mar-88	141.50	Aug-90	117.30
Jan-81	197.70	Jun-83	155.70	Nov-85	122.90	Apr-88	110.50	Sep-90	143.80
Feb-81	176.20	Jul-83	167.25	Dec-85	143.60	May-88	91.30	Oct-90	121.40
Mar-81	209.90	Aug-83	165.90	Jan-86	149.90	Jun-88	81.90	Nov-90	107.50
Apr-81	121.30	Sep-83	154.90	Feb-86	158.90	Jul-88	89.80	Dec-90	123.70
May-81	133.60	Oct-83	151.01	Mar-86	161.50	Aug-88	117.70		

B-3 Long-term average evaporation (mm/month)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
166.64	159.75	176.77	139.555	147.88	133.14	133.98	144.66	152.24	159.75	128.01	145.79

B-4 Evaporation (mm/month) from January 1999 to August 2002 (Naivasha W.D.D.)

Jan-99	152.80	Jan-00	138.00	Jan-01	88.70	Jan-02	86.36
Feb-99	172.50	Feb-00	153.60	Feb-01	120.50	Feb-02	93.98
Mar-99	129.60	Mar-00	189.70	Mar-01	126.40	Mar-02	101.60
Apr-99	117.90	Apr-00	122.40	Apr-01	88.30	Apr-02	104.65
May-99	128.70	May-00	149.70	May-01	106.00	May-02	89.66
Jun-99	103.80	Jun-00	105.10	Jun-01	98.60	Jun-02	59.94
Jul-99	106.10	Jul-00	101.70	Jul-01	102.10	Jul-02	71.88
Aug-99	105.70	Aug-00	139.30	Aug-01	107.20	Aug-02	83.31
Sep-99	134.70	Sep-00	136.00	Sep-01	104.06		
Oct-99	138.60	Oct-00	124.10	Oct-01	71.88		
Nov-99	93.30	Nov-00	114.00	Nov-01	72.64		
Dec-99	106.60	Dec-00	104.50	Dec-01	75.18		

B-5 Malewa River Discharge (m³/sec) from January 1932 to August 2000

Jan-32	1.278	Jan-37	1.083	Jan-42	1.304	Jan-47	1.215	Jan-52	3.220
Feb-32	1.080	Feb-37	0.834	Feb-42	0.708	Feb-47	0.710	Feb-52	1.198
Mar-32	1.869	Mar-37	0.941	Mar-42	1.602	Mar-47	1.925	Mar-52	0.922
Apr-32	3.801	Apr-37	8.367	Apr-42	3.960	Apr-47	5.255	Apr-52	1.723
May-32	7.045	May-37	11.284	May-42	11.686	May-47	15.727	May-52	13.100
Jun-32	4.498	Jun-37	26.779	Jun-42	9.164	Jun-47	10.895	Jun-52	2.582
Jul-32	6.971	Jul-37	16.233	Jul-42	8.792	Jul-47	22.697	Jul-52	1.861
Aug-32	5.743	Aug-37	19.194	Aug-42	8.219	Aug-47	10.988	Aug-52	7.682
Sep-32	16.629	Sep-37	4.108	Sep-42	11.373	Sep-47	13.022	Sep-52	5.512
Oct-32	9.568	Oct-37	4.248	Oct-42	1.934	Oct-47	6.360	Oct-52	6.918
Nov-32	3.812	Nov-37	5.730	Nov-42	1.420	Nov-47	3.420	Nov-52	3.161
Dec-32	2.553	Dec-37	6.303	Dec-42	1.239	Dec-47	2.553	Dec-52	1.646
Jan-33	3.137	Jan-38	1.947	Jan-43	0.893	Jan-48	1.129	Jan-53	0.932
Feb-33	1.330	Feb-38	1.137	Feb-43	0.695	Feb-48	0.724	Feb-53	0.708
Mar-33	1.013	Mar-38	1.433	Mar-43	0.694	Mar-48	0.961	Mar-53	0.859
Apr-33	1.010	Apr-38	1.297	Apr-43	1.069	Apr-48	1.320	Apr-53	1.350
May-33	2.260	May-38	1.744	May-43	1.621	May-48	3.400	May-53	2.255
Jun-33	3.892	Jun-38	1.443	Jun-43	1.820	Jun-48	6.285	Jun-53	2.517
Jul-33	5.783	Jul-38	2.975	Jul-43	4.386	Jul-48	5.839	Jul-53	1.514
Aug-33	8.541	Aug-38	5.440	Aug-43	7.480	Aug-48	10.954	Aug-53	2.515
Sep-33	21.661	Sep-38	5.928	Sep-43	8.031	Sep-48	12.230	Sep-53	1.479
Oct-33	5.941	Oct-38	4.012	Oct-43	1.876	Oct-48	2.932	Oct-53	2.086
Nov-33	3.535	Nov-38	3.531	Nov-43	1.253	Nov-48	3.186	Nov-53	2.692
Dec-33	3.055	Dec-38	2.217	Dec-43	1.019	Dec-48	1.848	Dec-53	1.665
Jan-34	0.830	Jan-39	1.215	Jan-44	0.634	Jan-49	0.941	Jan-54	0.810
Feb-34	0.542	Feb-39	0.869	Feb-44	0.431	Feb-49	0.657	Feb-54	0.546
Mar-34	0.830	Mar-39	0.889	Mar-44	0.551	Mar-49	0.655	Mar-54	0.605
Apr-34	3.632	Apr-39	1.852	Apr-44	0.906	Apr-49	2.168	Apr-54	1.937
May-34	9.400	May-39	1.127	May-44	1.037	May-49	1.811	May-54	16.576
Jun-34	6.569	Jun-39	1.111	Jun-44	0.843	Jun-49	4.908	Jun-54	32.044
Jul-34	2.486	Jul-39	2.667	Jul-44	4.844	Jul-49	5.710	Jul-54	9.787
Aug-34	4.196	Aug-39	4.409	Aug-44	5.208	Aug-49	12.299	Aug-54	11.257
Sep-34	0.661	Sep-39	2.484	Sep-44	6.316	Sep-49	11.501	Sep-54	10.541
Oct-34	1.538	Oct-39	1.243	Oct-44	3.611	Oct-49	3.863	Oct-54	6.010
Nov-34	1.684	Nov-39	1.427	Nov-44	2.410	Nov-49	3.038	Nov-54	2.886
Dec-34	2.972	Dec-39	0.950	Dec-44	4.492	Dec-49	1.898	Dec-54	2.782
Jan-35	2.823	Jan-40	1.346	Jan-45	0.893	Jan-50	1.555	Jan-55	1.209
Feb-35	2.237	Feb-40	0.957	Feb-45	0.725	Feb-50	0.901	Feb-55	1.428
Mar-35	1.524	Mar-40	3.264	Mar-45	0.784	Mar-50	1.222	Mar-55	1.009
Apr-35	1.385	Apr-40	6.028	Apr-45	0.849	Apr-50	2.434	Apr-55	2.218
May-35	2.596	May-40	18.122	May-45	1.374	May-50	2.136	May-55	2.552
Jun-35	5.231	Jun-40	2.955	Jun-45	3.577	Jun-50	2.508	Jun-55	1.278
Jul-35	6.326	Jul-40	4.301	Jul-45	5.404	Jul-50	8.086	Jul-55	2.730
Aug-35	4.529	Aug-40	3.928	Aug-45	15.131	Aug-50	13.469	Aug-55	12.687
Sep-35	8.430	Sep-40	2.984	Sep-45	9.530	Sep-50	11.071	Sep-55	14.443
Oct-35	5.463	Oct-40	1.545	Oct-45	4.168	Oct-50	3.631	Oct-55	11.242
Nov-35	3.522	Nov-40	1.088	Nov-45	3.157	Nov-50	2.067	Nov-55	5.669
Dec-35	2.222	Dec-40	1.073	Dec-45	1.725	Dec-50	1.466	Dec-55	4.141
Jan-36	2.509	Jan-41	0.888	Jan-46	1.018	Jan-51	0.899	Jan-56	11.038
Feb-36	6.198	Feb-41	0.831	Feb-46	0.586	Feb-51	0.710	Feb-56	4.243
Mar-36	6.865	Mar-41	1.710	Mar-46	0.613	Mar-51	1.134	Mar-56	1.713
Apr-36	12.104	Apr-41	4.816	Apr-46	1.136	Apr-51	10.595	Apr-56	5.019
May-36	11.561	May-41	13.156	May-46	2.959	May-51	10.248	May-56	14.759
Jun-36	3.206	Jun-41	7.671	Jun-46	5.404	Jun-51	10.503	Jun-56	6.574
Jul-36	4.057	Jul-41	5.739	Jul-46	3.984	Jul-51	4.830	Jul-56	11.147
Aug-36	8.804	Aug-41	7.124	Aug-46	14.927	Aug-51	25.446	Aug-56	18.322
Sep-36	5.691	Sep-41	4.626	Sep-46	12.536	Sep-51	6.776	Sep-56	18.645
Oct-36	3.915	Oct-41	2.678	Oct-46	4.042	Oct-51	9.408	Oct-56	15.766
Nov-36	2.383	Nov-41	3.701	Nov-46	5.447	Nov-51	11.501	Nov-56	5.813
Dec-36	1.686	Dec-41	6.129	Dec-46	1.963	Dec-51	10.424	Dec-56	2.660

B-5 Malewa River Discharge (m³/sec) from January 1932 to August 2000 *(Continue)*

Jan-57	1.476	Jan-62	15.791	Jan-67	0.974	Jan-72	2.066	Jan-77	0.909
Feb-57	1.776	Feb-62	1.555	Feb-67	0.758	Feb-72	3.633	Feb-77	0.396
Mar-57	2.035	Mar-62	1.682	Mar-67	0.820	Mar-72	1.746	Mar-77	0.677
Apr-57	5.492	Apr-62	3.176	Apr-67	1.488	Apr-72	1.081	Apr-77	6.603
May-57	19.103	May-62	31.919	May-67	18.106	May-72	1.472	May-77	22.192
Jun-57	13.629	Jun-62	8.517	Jun-67	8.664	Jun-72	4.672	Jun-77	6.307
Jul-57	9.220	Jul-62	8.050	Jul-67	16.260	Jul-72	3.001	Jul-77	18.029
Aug-57	12.931	Aug-62	7.051	Aug-67	12.156	Aug-72	9.845	Aug-77	14.341
Sep-57	9.979	Sep-62	24.200	Sep-67	4.121	Sep-72	2.659	Sep-77	7.214
Oct-57	3.652	Oct-62	17.868	Oct-67	6.193	Oct-72	3.569	Oct-77	3.433
Nov-57	3.682	Nov-62	5.849	Nov-67	7.215	Nov-72	8.693	Nov-77	12.828
Dec-57	2.621	Dec-62	3.613	Dec-67	3.953	Dec-72	2.275	Dec-77	9.693
Jan-58	1.493	Jan-63	4.403	Jan-68	1.090	Jan-73	1.599	Jan-78	4.046
Feb-58	6.157	Feb-63	1.736	Feb-68	2.121	Feb-73	1.215	Feb-78	1.574
Mar-58	4.839	Mar-63	2.147	Mar-68	12.245	Mar-73	0.783	Mar-78	12.059
Apr-58	2.184	Apr-63	18.663	Apr-68	39.788	Apr-73	1.269	Apr-78	17.193
May-58	30.823	May-63	33.926	May-68	20.993	May-73	1.460	May-78	19.799
Jun-58	6.282	Jun-63	10.298	Jun-68	11.774	Jun-73	2.756	Jun-78	2.999
Jul-58	19.307	Jul-63	2.953	Jul-68	8.993	Jul-73	2.917	Jul-78	8.145
Aug-58	14.035	Aug-63	9.080	Aug-68	12.841	Aug-73	8.047	Aug-78	7.739
Sep-58	6.316	Sep-63	5.122	Sep-68	3.231	Sep-73	4.547	Sep-78	12.484
Oct-58	8.078	Oct-63	2.412	Oct-68	2.722	Oct-73	3.917	Oct-78	11.881
Nov-58	3.020	Nov-63	2.719	Nov-68	6.160	Nov-73	3.655	Nov-78	8.246
Dec-58	7.993	Dec-63	29.325	Dec-68	6.182	Dec-73	1.178	Dec-78	3.600
Jan-59	2.311	Jan-64	4.388	Jan-69	1.365	Jan-74	0.657	Jan-79	1.804
Feb-59	1.404	Feb-64	1.426	Feb-69	1.780	Feb-74	0.519	Feb-79	19.168
Mar-59	1.580	Mar-64	2.884	Mar-69	1.546	Mar-74	0.781	Mar-79	2.813
Apr-59	1.839	Apr-64	13.979	Apr-69	1.415	Apr-74	5.562	Apr-79	7.478
May-59	5.533	May-64	14.056	May-69	6.620	May-74	2.276	May-79	11.864
Jun-59	4.163	Jun-64	3.836	Jun-69	1.184	Jun-74	4.415	Jun-79	9.923
Jul-59	4.414	Jul-64	13.557	Jul-69	1.317	Jul-74	14.990	Jul-79	7.713
Aug-59	10.218	Aug-64	23.083	Aug-69	2.002	Aug-74	7.430	Aug-79	5.490
Sep-59	8.456	Sep-64	15.364	Sep-69	4.245	Sep-74	16.164	Sep-79	3.601
Oct-59	5.337	Oct-64	25.648	Oct-69	1.505	Oct-74	11.151	Oct-79	3.580
Nov-59	4.144	Nov-64	4.982	Nov-69	1.668	Nov-74	5.502	Nov-79	2.935
Dec-59	2.555	Dec-64	2.796	Dec-69	1.236	Dec-74	1.694	Dec-79	1.184
Jan-60	1.524	Jan-65	3.068	Jan-70	2.194	Jan-75	0.888	Jan-80	0.747
Feb-60	1.017	Feb-65	1.124	Feb-70	1.390	Feb-75	0.615	Feb-80	0.682
Mar-60	1.589	Mar-65	1.045	Mar-70	2.350	Mar-75	0.731	Mar-80	0.936
Apr-60	2.430	Apr-65	2.103	Apr-70	14.965	Apr-75	1.457	Apr-80	2.852
May-60	2.544	May-65	8.521	May-70	11.098	May-75	2.200	May-80	8.522
Jun-60	1.852	Jun-65	1.627	Jun-70	9.241	Jun-75	3.146	Jun-80	12.883
Jul-60	1.987	Jul-65	3.126	Jul-70	6.766	Jul-75	7.205	Jul-80	8.589
Aug-60	5.023	Aug-65	2.593	Aug-70	10.008	Aug-75	23.113	Aug-80	2.136
Sep-60	10.270	Sep-65	2.310	Sep-70	12.374	Sep-75	19.148	Sep-80	1.887
Oct-60	5.257	Oct-65	1.945	Oct-70	10.905	Oct-75	16.961	Oct-80	1.493
Nov-60	6.291	Nov-65	4.246	Nov-70	3.655	Nov-75	3.834	Nov-80	2.614
Dec-60	1.836	Dec-65	2.124	Dec-70	1.698	Dec-75	1.520	Dec-80	1.238
Jan-61	0.957	Jan-66	1.045	Jan-71	1.255	Jan-76	0.861	Jan-81	0.842
Feb-61	0.686	Feb-66	0.867	Feb-71	0.922	Feb-76	0.678	Feb-81	0.598
Mar-61	0.791	Mar-66	1.165	Mar-71	0.743	Mar-76	0.751	Mar-81	0.924
Apr-61	1.461	Apr-66	9.586	Apr-71	1.873	Apr-76	1.350	Apr-81	23.132
May-61	2.436	May-66	6.317	May-71	10.930	May-76	2.009	May-81	24.378
Jun-61	1.483	Jun-66	2.725	Jun-71	8.345	Jun-76	1.354	Jun-81	4.964
Jul-61	2.004	Jul-66	2.162	Jul-71	10.423	Jul-76	5.265	Jul-81	11.964
Aug-61	8.011	Aug-66	8.646	Aug-71	30.953	Aug-76	8.387	Aug-81	22.814
Sep-61	6.693	Sep-66	14.093	Sep-71	13.630	Sep-76	9.463	Sep-81	9.146
Oct-61	14.385	Oct-66	4.299	Oct-71	6.391	Oct-76	2.629	Oct-81	5.882
Nov-61	79.430	Nov-66	12.987	Nov-71	2.665	Nov-76	1.250	Nov-81	3.991
Dec-61	29.114	Dec-66	1.989	Dec-71	3.051	Dec-76	1.640	Dec-81	2.060

B-5 Malewa River Discharge (m³/sec) from January 1932 to August 2000 *(Continue)*

Jan-82	1.064	Jan-87	1.243	Jan-92	0.150	Jan-97	0.713
Feb-82	0.997	Feb-87	1.226	Feb-92	0.168	Feb-97	0.480
Mar-82	0.759	Mar-87	2.167	Mar-92	3.759	Mar-97	0.843
Apr-82	2.304	Apr-87	1.999	Apr-92	8.731	Apr-97	10.795
May-82	6.772	May-87	4.358	May-92	8.371	May-97	2.592
Jun-82	4.939	Jun-87	7.545	Jun-92	10.063	Jun-97	4.267
Jul-82	2.644	Jul-87	3.983	Jul-92	14.908	Jul-97	5.048
Aug-82	8.832	Aug-87	0.765	Aug-92	15.113	Aug-97	8.115
Sep-82	4.973	Sep-87	0.917	Sep-92	13.986	Sep-97	1.100
Oct-82	3.920	Oct-87	0.792	Oct-92	11.137	Oct-97	8.740
Nov-82	11.913	Nov-87	2.888	Nov-92	8.279	Nov-97	30.414
Dec-82	6.304	Dec-87	1.439	Dec-92	6.109	Dec-97	14.945
Jan-83	1.961	Jan-88	1.096	Jan-93	4.785	Jan-98	61.561
Feb-83	1.468	Feb-88	1.131	Feb-93	5.067	Feb-98	17.421
Mar-83	1.902	Mar-88	1.279	Mar-93	0.644	Mar-98	2.338
Apr-83	6.212	Apr-88	13.959	Apr-93	1.440	Apr-98	9.100
May-83	8.406	May-88	11.139	May-93	2.849	May-98	32.953
Jun-83	3.739	Jun-88	5.013	Jun-93	3.920	Jun-98	18.300
Jul-83	5.468	Jul-88	2.608	Jul-93	2.365	Jul-98	15.740
Aug-83	11.815	Aug-88	6.986	Aug-93	2.472	Aug-98	10.823
Sep-83	11.840	Sep-88	9.317	Sep-93	3.008	Sep-98	8.063
Oct-83	17.615	Oct-88	4.600	Oct-93	0.960	Oct-98	9.884
Nov-83	11.954	Nov-88	2.215	Nov-93	0.480	Nov-98	6.829
Dec-83	6.224	Dec-88	1.189	Dec-93	0.869	Dec-98	1.431
Jan-84	2.135	Jan-89	1.086	Jan-94	0.127	Jan-99	1.028
Feb-84	1.099	Feb-89	0.700	Feb-94	3.079	Feb-99	0.619
Mar-84	1.064	Mar-89	2.746	Mar-94	2.258	Mar-99	1.249
Apr-84	0.955	Apr-89	4.759	Apr-94	14.360	Apr-99	1.292
May-84	1.035	May-89	1.085	May-94	10.719	May-99	3.519
Jun-84	0.902	Jun-89	1.573	Jun-94	6.174	Jun-99	0.574
Jul-84	1.141	Jul-89	3.938	Jul-94	6.260	Jul-99	3.129
Aug-84	1.555	Aug-89	6.030	Aug-94	8.724	Aug-99	4.522
Sep-84	1.384	Sep-89	8.977	Sep-94	8.584	Sep-99	7.819
Oct-84	3.647	Oct-89	9.774	Oct-94	7.176	Oct-99	3.873
Nov-84	2.238	Nov-89	5.900	Nov-94	15.198	Nov-99	3.375
Dec-84	3.274	Dec-89	7.522	Dec-94	1.637	Dec-99	2.386
Jan-85	1.331	Jan-90	1.609	Jan-95	0.308	Jan-00	0.984
Feb-85	0.999	Feb-90	1.163	Feb-95	3.005	Feb-00	1.788
Mar-85	1.206	Mar-90	2.755	Mar-95	4.580	Mar-00	0.386
Apr-85	10.329	Apr-90	18.216	Apr-95	10.396	Apr-00	0.413
May-85	12.857	May-90	14.386	May-95	6.557	May-00	0.423
Jun-85	7.628	Jun-90	2.286	Jun-95	4.865	Jun-00	0.772
Jul-85	9.180	Jul-90	3.609	Jul-95	6.529	Jul-00	3.321
Aug-85	8.508	Aug-90	4.905	Aug-95	6.030	Aug-00	5.082
Sep-85	6.677	Sep-90	1.651	Sep-95	9.207		
Oct-85	7.673	Oct-90	7.776	Oct-95	15.512		
Nov-85	4.549	Nov-90	4.833	Nov-95	16.629		
Dec-85	1.910	Dec-90	1.436	Dec-95	5.125		
Jan-86	1.226	Jan-91	0.640	Jan-96	1.584		
Feb-86	0.968	Feb-91	0.293	Feb-96	2.362		
Mar-86	1.098	Mar-91	3.158	Mar-96	2.460		
Apr-86	1.056	Apr-91	6.970	Apr-96	3.820		
May-86	16.259	May-91	6.518	May-96	2.582		
Jun-86	4.241	Jun-91	6.010	Jun-96	4.241		
Jul-86	5.811	Jul-91	4.906	Jul-96	10.115		
Aug-86	4.711	Aug-91	6.298	Aug-96	15.981		
Sep-86	5.829	Sep-91	5.712	Sep-96	15.282		
Oct-86	4.535	Oct-91	6.059	Oct-96	11.407		
Nov-86	3.998	Nov-91	0.110	Nov-96	10.809		
Dec-86	3.003	Dec-91	0.581	Dec-96	1.920		

B-6 Gilgil River Discharge (m^3/sec) from January 1932 to December 1997

Jan-32	0.028	Jan-37	0.022	Jan-42	0.029	Jan-47	0.026	Jan-52	0.103
Feb-32	0.022	Feb-37	0.016	Feb-42	0.012	Feb-47	0.012	Feb-52	0.026
Mar-32	0.048	Mar-37	0.018	Mar-42	0.039	Mar-47	0.050	Mar-52	0.018
Apr-32	0.130	Apr-37	0.393	Apr-42	0.138	Apr-47	0.205	Apr-52	0.043
May-32	0.308	May-37	0.597	May-42	0.627	May-47	0.950	May-52	0.736
Jun-32	0.164	Jun-37	2.003	Jun-42	0.446	Jun-47	0.568	Jun-52	0.076
Jul-32	0.304	Jul-37	0.993	Jul-42	0.421	Jul-47	1.589	Jul-52	0.048
Aug-32	0.232	Aug-37	1.256	Aug-42	0.383	Aug-47	0.575	Aug-52	0.348
Sep-32	1.027	Sep-37	0.145	Sep-42	0.603	Sep-47	0.729	Sep-52	0.219
Oct-32	0.474	Oct-37	0.152	Oct-42	0.050	Oct-47	0.267	Oct-52	0.301
Nov-32	0.130	Nov-37	0.231	Nov-42	0.033	Nov-47	0.112	Nov-52	0.100
Dec-32	0.074	Dec-37	0.264	Dec-42	0.027	Dec-47	0.074	Dec-52	0.040
Jan-33	0.099	Jan-38	0.051	Jan-43	0.017	Jan-48	0.024	Jan-53	0.018
Feb-33	0.030	Feb-38	0.024	Feb-43	0.012	Feb-48	0.013	Feb-53	0.012
Mar-33	0.020	Mar-38	0.033	Mar-43	0.012	Mar-48	0.019	Mar-53	0.016
Apr-33	0.020	Apr-38	0.029	Apr-43	0.022	Apr-48	0.030	Apr-53	0.030
May-33	0.063	May-38	0.044	May-43	0.039	May-48	0.111	May-53	0.063
Jun-33	0.134	Jun-38	0.033	Jun-43	0.046	Jun-48	0.263	Jun-53	0.073
Jul-33	0.234	Jul-38	0.092	Jul-43	0.159	Jul-48	0.237	Jul-53	0.036
Aug-33	0.404	Aug-38	0.215	Aug-43	0.335	Aug-48	0.572	Aug-53	0.073
Sep-33	1.488	Sep-38	0.242	Sep-43	0.371	Sep-48	0.668	Sep-53	0.035
Oct-33	0.243	Oct-38	0.140	Oct-43	0.048	Oct-48	0.090	Oct-53	0.056
Nov-33	0.117	Nov-38	0.117	Nov-43	0.027	Nov-48	0.101	Nov-53	0.080
Dec-33	0.096	Dec-38	0.061	Dec-43	0.021	Dec-48	0.047	Dec-53	0.041
Jan-34	0.015	Jan-39	0.026	Jan-44	0.011	Jan-49	0.018	Jan-54	0.015
Feb-34	0.008	Feb-39	0.016	Feb-44	0.006	Feb-49	0.011	Feb-54	0.009
Mar-34	0.015	Mar-39	0.017	Mar-44	0.009	Mar-49	0.011	Mar-54	0.010
Apr-34	0.561	Apr-39	0.047	Apr-44	0.017	Apr-49	0.059	Apr-54	0.051
May-34	4.075	May-39	0.024	May-44	0.021	May-49	0.046	May-54	1.023
Jun-34	0.709	Jun-39	0.023	Jun-44	0.016	Jun-49	0.186	Jun-54	2.576
Jul-34	0.072	Jul-39	0.079	Jul-44	0.183	Jul-49	0.230	Jul-54	0.489
Aug-34	0.149	Aug-39	0.160	Aug-44	0.202	Aug-49	0.673	Aug-54	0.595
Sep-34	0.011	Sep-39	0.072	Sep-44	0.265	Sep-49	0.613	Sep-54	0.543
Oct-34	0.037	Oct-39	0.027	Oct-44	0.121	Oct-49	0.133	Oct-54	0.247
Nov-34	0.042	Nov-39	0.033	Nov-44	0.069	Nov-49	0.095	Nov-54	0.088
Dec-34	0.092	Dec-39	0.019	Dec-44	0.164	Dec-49	0.049	Dec-54	0.084
Jan-35	0.086	Jan-40	0.030	Jan-45	0.017	Jan-50	0.037	Jan-55	0.026
Feb-35	0.062	Feb-40	0.019	Feb-45	0.013	Feb-50	0.017	Feb-55	0.033
Mar-35	0.036	Mar-40	0.105	Mar-45	0.014	Mar-50	0.027	Mar-55	0.020
Apr-35	0.032	Apr-40	0.248	Apr-45	0.016	Apr-50	0.070	Apr-55	0.061
May-35	0.076	May-40	1.159	May-45	0.031	May-50	0.058	May-55	0.074
Jun-35	0.203	Jun-40	0.091	Jun-45	0.119	Jun-50	0.073	Jun-55	0.028
Jul-35	0.265	Jul-40	0.155	Jul-45	0.213	Jul-50	0.374	Jul-55	0.082
Aug-35	0.166	Aug-40	0.136	Aug-45	0.900	Aug-50	0.765	Aug-55	0.703
Sep-35	0.397	Sep-40	0.093	Sep-45	0.471	Sep-50	0.581	Sep-55	0.843
Oct-35	0.216	Oct-40	0.037	Oct-45	0.148	Oct-50	0.122	Oct-55	0.594
Nov-35	0.117	Nov-40	0.023	Nov-45	0.100	Nov-50	0.055	Nov-55	0.227
Dec-35	0.061	Dec-40	0.022	Dec-45	0.043	Dec-50	0.034	Dec-55	0.147
Jan-36	0.073	Jan-41	0.017	Jan-46	0.021	Jan-51	0.017	Jan-56	0.579
Feb-36	0.258	Feb-41	0.015	Feb-46	0.009	Feb-51	0.012	Feb-56	0.152
Mar-36	0.297	Mar-41	0.042	Mar-46	0.010	Mar-51	0.024	Mar-56	0.043
Apr-36	0.658	Apr-41	0.181	Apr-46	0.024	Apr-51	0.546	Apr-56	0.192
May-36	0.617	May-41	0.740	May-46	0.092	May-51	0.521	May-56	0.869
Jun-36	0.102	Jun-41	0.348	Jun-46	0.213	Jun-51	0.540	Jun-56	0.280
Jul-36	0.142	Jul-41	0.231	Jul-46	0.139	Jul-51	0.182	Jul-56	0.587
Aug-36	0.422	Aug-41	0.313	Aug-46	0.883	Aug-51	1.865	Aug-56	1.177
Sep-36	0.229	Sep-41	0.171	Sep-46	0.692	Sep-51	0.292	Sep-56	1.206
Oct-36	0.135	Oct-41	0.080	Oct-46	0.142	Oct-51	0.463	Oct-56	0.954
Nov-36	0.068	Nov-41	0.125	Nov-46	0.215	Nov-51	0.613	Nov-56	0.236
Dec-36	0.042	Dec-41	0.254	Dec-46	0.051	Dec-51	0.534	Dec-56	0.079

B-6 Gilgil River Discharge (m³/sec) from January 1932 to December 1997 *(Continued)*

Jan-57	0.035	Jan-62	0.942	Jan-67	0.011	Jan-72	0.074	Jan-77	0.002
Feb-57	0.045	Feb-62	0.079	Feb-67	0.008	Feb-72	0.085	Feb-77	0.001
Mar-57	0.054	Mar-62	0.065	Mar-67	0.016	Mar-72	0.044	Mar-77	0.002
Apr-57	0.218	Apr-62	0.109	Apr-67	0.027	Apr-72	0.032	Apr-77	0.031
May-57	1.248	May-62	0.686	May-67	0.641	May-72	0.038	May-77	0.794
Jun-57	0.778	Jun-62	0.306	Jun-67	0.289	Jun-72	0.141	Jun-77	0.460
Jul-57	0.450	Jul-62	0.534	Jul-67	0.947	Jul-72	0.247	Jul-77	2.463
Aug-57	0.722	Aug-62	1.056	Aug-67	0.999	Aug-72	0.724	Aug-77	2.059
Sep-57	0.502	Sep-62	1.705	Sep-67	0.376	Sep-72	0.290	Sep-77	0.311
Oct-57	0.123	Oct-62	0.783	Oct-67	0.203	Oct-72	0.056	Oct-77	0.202
Nov-57	0.124	Nov-62	0.267	Nov-67	0.691	Nov-72	0.130	Nov-77	2.356
Dec-57	0.077	Dec-62	0.164	Dec-67	0.362	Dec-72	0.065	Dec-77	0.389
Jan-58	0.035	Jan-63	0.119	Jan-68	0.088	Jan-73	0.043	Jan-78	0.056
Feb-58	0.255	Feb-63	0.056	Feb-68	0.030	Feb-73	0.039	Feb-78	0.030
Mar-58	0.182	Mar-63	0.060	Mar-68	0.114	Mar-73	0.035	Mar-78	0.198
Apr-58	0.060	Apr-63	0.661	Apr-68	1.291	Apr-73	0.042	Apr-78	0.313
May-58	2.439	May-63	2.790	May-68	1.391	May-73	0.052	May-78	0.362
Jun-58	0.263	Jun-63	1.190	Jun-68	1.212	Jun-73	0.067	Jun-78	0.176
Jul-58	1.267	Jul-63	0.476	Jul-68	0.809	Jul-73	0.077	Jul-78	1.467
Aug-58	0.810	Aug-63	0.434	Aug-68	1.150	Aug-73	0.209	Aug-78	0.272
Sep-58	0.265	Sep-63	0.328	Sep-68	0.203	Sep-73	0.181	Sep-78	1.138
Oct-58	0.374	Oct-63	0.103	Oct-68	0.085	Oct-73	0.235	Oct-78	0.511
Nov-58	0.094	Nov-63	0.169	Nov-68	0.138	Nov-73	0.187	Nov-78	0.588
Dec-58	0.070	Dec-63	1.054	Dec-68	0.406	Dec-73	0.003	Dec-78	0.113
Jan-59	0.010	Jan-64	0.202	Jan-69	0.028	Jan-74	0.032	Jan-79	0.037
Feb-59	0.002	Feb-64	0.025	Feb-69	0.027	Feb-74	0.032	Feb-79	0.475
Mar-59	0.009	Mar-64	0.032	Mar-69	0.046	Mar-74	0.047	Mar-79	0.010
Apr-59	0.009	Apr-64	0.689	Apr-69	0.020	Apr-74	0.062	Apr-79	0.140
May-59	0.075	May-64	0.123	May-69	0.657	May-74	0.002	May-79	0.056
Jun-59	0.060	Jun-64	0.069	Jun-69	0.059	Jun-74	0.033	Jun-79	0.136
Jul-59	0.088	Jul-64	1.065	Jul-69	0.094	Jul-74	0.375	Jul-79	0.369
Aug-59	0.512	Aug-64	1.514	Aug-69	0.207	Aug-74	1.211	Aug-79	0.324
Sep-59	0.353	Sep-64	1.544	Sep-69	0.440	Sep-74	1.689	Sep-79	0.170
Oct-59	0.622	Oct-64	1.834	Oct-69	0.152	Oct-74	0.048	Oct-79	0.037
Nov-59	0.251	Nov-64	0.553	Nov-69	0.078	Nov-74	0.004	Nov-79	0.025
Dec-59	0.176	Dec-64	0.260	Dec-69	0.058	Dec-74	0.002	Dec-79	0.004
Jan-60	0.001	Jan-65	0.111	Jan-70	0.064	Jan-75	0.012	Jan-80	0.002
Feb-60	0.001	Feb-65	0.016	Feb-70	0.013	Feb-75	0.006	Feb-80	0.001
Mar-60	0.001	Mar-65	0.013	Mar-70	0.071	Mar-75	0.007	Mar-80	0.004
Apr-60	0.003	Apr-65	0.042	Apr-70	0.630	Apr-75	0.009	Apr-80	0.003
May-60	0.002	May-65	0.033	May-70	1.442	May-75	0.009	May-80	0.226
Jun-60	0.011	Jun-65	0.030	Jun-70	1.018	Jun-75	0.056	Jun-80	0.096
Jul-60	0.137	Jul-65	0.059	Jul-70	0.424	Jul-75	0.618	Jul-80	0.189
Aug-60	0.311	Aug-65	0.194	Aug-70	0.494	Aug-75	2.008	Aug-80	0.068
Sep-60	1.475	Sep-65	0.229	Sep-70	1.570	Sep-75	2.629	Sep-80	0.106
Oct-60	0.173	Oct-65	0.312	Oct-70	1.017	Oct-75	0.516	Oct-80	0.019
Nov-60	0.207	Nov-65	0.867	Nov-70	0.324	Nov-75	0.156	Nov-80	0.017
Dec-60	0.007	Dec-65	0.199	Dec-70	0.032	Dec-75	0.021	Dec-80	0.008
Jan-61	0.002	Jan-66	0.018	Jan-71	0.013	Jan-76	0.003	Jan-81	0.005
Feb-61	0.002	Feb-66	0.028	Feb-71	0.059	Feb-76	0.002	Feb-81	0.006
Mar-61	0.004	Mar-66	0.034	Mar-71	0.074	Mar-76	0.002	Mar-81	0.016
Apr-61	0.011	Apr-66	0.078	Apr-71	0.075	Apr-76	0.003	Apr-81	0.536
May-61	0.026	May-66	0.269	May-71	0.086	May-76	0.001	May-81	0.784
Jun-61	0.008	Jun-66	0.324	Jun-71	0.243	Jun-76	0.002	Jun-81	0.165
Jul-61	0.012	Jul-66	0.488	Jul-71	1.143	Jul-76	0.083	Jul-81	0.752
Aug-61	0.303	Aug-66	1.366	Aug-71	1.849	Aug-76	0.258	Aug-81	3.323
Sep-61	0.600	Sep-66	1.800	Sep-71	0.880	Sep-76	0.314	Sep-81	1.807
Oct-61	0.460	Oct-66	0.438	Oct-71	0.254	Oct-76	0.028	Oct-81	0.758
Nov-61	1.383	Nov-66	0.767	Nov-71	0.228	Nov-76	0.002	Nov-81	0.210
Dec-61	1.676	Dec-66	0.090	Dec-71	0.145	Dec-76	0.002	Dec-81	0.176

B-6 Gilgil River Discharge (m³/sec) from January 1932 to December 1997 *(Continued)*

Jan-82	0.083	Jan-87	0.027	Jan-92	0.018	Jan-97	0.091
Feb-82	0.035	Feb-87	0.000	Feb-92	0.020	Feb-97	0.060
Mar-82	0.020	Mar-87	0.024	Mar-92	0.505	Mar-97	0.108
Apr-82	0.064	Apr-87	0.012	Apr-92	1.205	Apr-97	1.501
May-82	0.317	May-87	0.039	May-92	1.154	May-97	0.344
Jun-82	0.428	Jun-87	0.635	Jun-92	1.396	Jun-97	0.575
Jul-82	0.384	Jul-87	0.287	Jul-92	2.095	Jul-97	0.684
Aug-82	0.961	Aug-87	0.170	Aug-92	2.125	Aug-97	1.118
Sep-82	0.920	Sep-87	0.174	Sep-92	1.961	Sep-97	0.142
Oct-82	0.599	Oct-87	0.029	Oct-92	1.550	Oct-97	1.207
Nov-82	0.857	Nov-87	0.068	Nov-92	1.141	Nov-97	4.375
Dec-82	1.744	Dec-87	2.156	Dec-92	0.834	Dec-97	2.100
Jan-83	0.062	Jan-88	0.064	Jan-93	0.648		
Feb-83	0.014	Feb-88	0.045	Feb-93	0.687		
Mar-83	0.010	Mar-88	0.075	Mar-93	0.082		
Apr-83	0.013	Apr-88	2.247	Apr-93	0.187		
May-83	0.033	May-88	1.147	May-93	0.379		
Jun-83	0.101	Jun-88	0.766	Jun-93	0.527		
Jul-83	0.412	Jul-88	1.017	Jul-93	0.313		
Aug-83	0.632	Aug-88	2.770	Aug-93	0.327		
Sep-83	1.096	Sep-88	3.901	Sep-93	0.401		
Oct-83	0.887	Oct-88	5.631	Oct-93	0.123		
Nov-83	0.523	Nov-88	3.015	Nov-93	0.060		
Dec-83	0.259	Dec-88	1.928	Dec-93	0.111		
Jan-84	0.058	Jan-89	0.063	Jan-94	0.015		
Feb-84	0.000	Feb-89	0.525	Feb-94	0.411		
Mar-84	0.000	Mar-89	0.230	Mar-94	0.298		
Apr-84	0.000	Apr-89	0.749	Apr-94	2.015		
May-84	0.000	May-89	1.873	May-94	1.490		
Jun-84	0.000	Jun-89	0.106	Jun-94	0.843		
Jul-84	0.000	Jul-89	1.031	Jul-94	0.855		
Aug-84	0.000	Aug-89	1.615	Aug-94	1.204		
Sep-84	0.000	Sep-89	1.211	Sep-94	1.184		
Oct-84	0.000	Oct-89	1.364	Oct-94	0.984		
Nov-84	0.256	Nov-89	0.909	Nov-94	2.137		
Dec-84	0.468	Dec-89	0.495	Dec-94	0.214		
Jan-85	0.030	Jan-90	0.109	Jan-95	0.038		
Feb-85	0.097	Feb-90	0.156	Feb-95	0.401		
Mar-85	0.018	Mar-90	0.480	Mar-95	0.619		
Apr-85	0.043	Apr-90	3.264	Apr-95	1.444		
May-85	1.556	May-90	2.345	May-95	0.897		
Jun-85	1.306	Jun-90	0.178	Jun-95	0.659		
Jul-85	1.770	Jul-90	0.338	Jul-95	0.893		
Aug-85	2.391	Aug-90	0.519	Aug-95	0.822		
Sep-85	2.093	Sep-90	0.113	Sep-95	1.273		
Oct-85	0.462	Oct-90	0.991	Oct-95	2.183		
Nov-85	0.208	Nov-90	0.509	Nov-95	2.345		
Dec-85	0.105	Dec-90	0.093	Dec-95	0.695		
Jan-86	0.027	Jan-91	0.081	Jan-96	0.207		
Feb-86	0.040	Feb-91	0.036	Feb-96	0.312		
Mar-86	0.031	Mar-91	0.422	Mar-96	0.326		
Apr-86	0.076	Apr-91	0.955	Apr-96	0.513		
May-86	0.308	May-91	0.891	May-96	0.342		
Jun-86	0.656	Jun-91	0.820	Jun-96	0.572		
Jul-86	1.644	Jul-91	0.664	Jul-96	1.403		
Aug-86	0.953	Aug-91	0.860	Aug-96	2.251		
Sep-86	0.432	Sep-91	0.778	Sep-96	2.149		
Oct-86	0.248	Oct-91	0.827	Oct-96	1.589		
Nov-86	0.132	Nov-91	0.013	Nov-96	1.503		
Dec-86	0.076	Dec-91	0.073	Dec-96	0.252		

Appendix C Time Series Output Data

C-1 Calculated lake level from January 1932 to December 1997

Jan-32	1890.98	Jan-37	1888.30	Jan-42	1886.34	Jan-47	1884.60	Jan-52	1885.42
Feb-32	1890.88	Feb-37	1888.15	Feb-42	1886.21	Feb-47	1884.51	Feb-52	1885.33
Mar-32	1890.72	Mar-37	1888.03	Mar-42	1886.11	Mar-47	1884.47	Mar-52	1885.22
Apr-32	1890.65	Apr-37	1888.08	Apr-42	1886.09	Apr-47	1884.55	Apr-52	1885.20
May-32	1890.66	May-37	1888.27	May-42	1886.17	May-47	1884.73	May-52	1885.29
Jun-32	1890.62	Jun-37	1888.63	Jun-42	1886.25	Jun-47	1884.90	Jun-52	1885.32
Jul-32	1890.57	Jul-37	1888.99	Jul-42	1886.30	Jul-47	1885.13	Jul-52	1885.25
Aug-32	1890.52	Aug-37	1889.21	Aug-42	1886.35	Aug-47	1885.32	Aug-52	1885.24
Sep-32	1890.63	Sep-37	1889.25	Sep-42	1886.41	Sep-47	1885.41	Sep-52	1885.26
Oct-32	1890.76	Oct-37	1889.18	Oct-42	1886.37	Oct-47	1885.45	Oct-52	1885.27
Nov-32	1890.73	Nov-37	1889.18	Nov-42	1886.28	Nov-47	1885.43	Nov-52	1885.26
Dec-32	1890.65	Dec-37	1889.20	Dec-42	1886.18	Dec-47	1885.37	Dec-52	1885.20
Jan-33	1890.55	Jan-38	1889.11	Jan-43	1886.06	Jan-48	1885.26	Jan-53	1885.09
Feb-33	1890.40	Feb-38	1888.95	Feb-43	1885.94	Feb-48	1885.14	Feb-53	1884.97
Mar-33	1890.22	Mar-38	1888.81	Mar-43	1885.82	Mar-48	1885.03	Mar-53	1884.87
Apr-33	1890.09	Apr-38	1888.72	Apr-43	1885.72	Apr-48	1884.96	Apr-53	1884.82
May-33	1889.99	May-38	1888.63	May-43	1885.67	May-48	1884.93	May-53	1884.81
Jun-33	1889.91	Jun-38	1888.52	Jun-43	1885.62	Jun-48	1884.92	Jun-53	1884.79
Jul-33	1889.85	Jul-38	1888.43	Jul-43	1885.60	Jul-48	1884.93	Jul-53	1884.73
Aug-33	1889.88	Aug-38	1888.37	Aug-43	1885.63	Aug-48	1884.98	Aug-53	1884.67
Sep-33	1890.06	Sep-38	1888.33	Sep-43	1885.68	Sep-48	1885.10	Sep-53	1884.61
Oct-33	1890.15	Oct-38	1888.28	Oct-43	1885.65	Oct-48	1885.14	Oct-53	1884.56
Nov-33	1890.10	Nov-38	1888.25	Nov-43	1885.56	Nov-48	1885.10	Nov-53	1884.53
Dec-33	1890.04	Dec-38	1888.17	Dec-43	1885.48	Dec-48	1885.04	Dec-53	1884.48
Jan-34	1889.90	Jan-39	1888.03	Jan-44	1885.37	Jan-49	1884.93	Jan-54	1884.39
Feb-34	1889.71	Feb-39	1887.89	Feb-44	1885.26	Feb-49	1884.81	Feb-54	1884.28
Mar-34	1889.54	Mar-39	1887.75	Mar-44	1885.15	Mar-49	1884.71	Mar-54	1884.19
Apr-34	1889.46	Apr-39	1887.67	Apr-44	1885.08	Apr-49	1884.67	Apr-54	1884.19
May-34	1889.50	May-39	1887.58	May-44	1885.01	May-49	1884.65	May-54	1884.42
Jun-34	1889.57	Jun-39	1887.46	Jun-44	1884.93	Jun-49	1884.64	Jun-54	1884.83
Jul-34	1889.57	Jul-39	1887.38	Jul-44	1884.90	Jul-49	1884.65	Jul-54	1885.08
Aug-34	1889.53	Aug-39	1887.35	Aug-44	1884.91	Aug-49	1884.73	Aug-54	1885.18
Sep-34	1889.42	Sep-39	1887.30	Sep-44	1884.93	Sep-49	1884.82	Sep-54	1885.28
Oct-34	1889.29	Oct-39	1887.18	Oct-44	1884.93	Oct-49	1884.83	Oct-54	1885.32
Nov-34	1889.19	Nov-39	1887.08	Nov-44	1884.92	Nov-49	1884.79	Nov-54	1885.30
Dec-34	1889.09	Dec-39	1886.97	Dec-44	1884.91	Dec-49	1884.73	Dec-54	1885.25
Jan-35	1888.96	Jan-40	1886.85	Jan-45	1884.84	Jan-50	1884.64	Jan-55	1885.18
Feb-35	1888.85	Feb-40	1886.75	Feb-45	1884.75	Feb-50	1884.55	Feb-55	1885.11
Mar-35	1888.74	Mar-40	1886.71	Mar-45	1884.65	Mar-50	1884.47	Mar-55	1885.03
Apr-35	1888.69	Apr-40	1886.80	Apr-45	1884.56	Apr-50	1884.44	Apr-55	1884.99
May-35	1888.65	May-40	1887.00	May-45	1884.50	May-50	1884.41	May-55	1884.96
Jun-35	1888.65	Jun-40	1887.05	Jun-45	1884.49	Jun-50	1884.36	Jun-55	1884.90
Jul-35	1888.66	Jul-40	1886.99	Jul-45	1884.50	Jul-50	1884.39	Jul-55	1884.88
Aug-35	1888.61	Aug-40	1886.93	Aug-45	1884.62	Aug-50	1884.52	Aug-55	1884.99
Sep-35	1888.59	Sep-40	1886.86	Sep-45	1884.77	Sep-50	1884.66	Sep-55	1885.16
Oct-35	1888.58	Oct-40	1886.77	Oct-45	1884.80	Oct-50	1884.70	Oct-55	1885.29
Nov-35	1888.56	Nov-40	1886.69	Nov-45	1884.78	Nov-50	1884.65	Nov-55	1885.34
Dec-35	1888.50	Dec-40	1886.60	Dec-45	1884.73	Dec-50	1884.57	Dec-55	1885.36
Jan-36	1888.42	Jan-41	1886.48	Jan-46	1884.63	Jan-51	1884.47	Jan-56	1885.42
Feb-36	1888.42	Feb-41	1886.35	Feb-46	1884.52	Feb-51	1884.37	Feb-56	1885.46
Mar-36	1888.46	Mar-41	1886.26	Mar-46	1884.41	Mar-51	1884.33	Mar-56	1885.42
Apr-36	1888.59	Apr-41	1886.27	Apr-46	1884.35	Apr-51	1884.47	Apr-56	1885.43
May-36	1888.72	May-41	1886.42	May-46	1884.34	May-51	1884.64	May-56	1885.55
Jun-36	1888.72	Jun-41	1886.53	Jun-46	1884.34	Jun-51	1884.73	Jun-56	1885.64
Jul-36	1888.66	Jul-41	1886.52	Jul-46	1884.34	Jul-51	1884.80	Jul-56	1885.74
Aug-36	1888.65	Aug-41	1886.51	Aug-46	1884.45	Aug-51	1885.01	Aug-56	1885.94
Sep-36	1888.63	Sep-41	1886.48	Sep-46	1884.61	Sep-51	1885.18	Sep-56	1886.18
Oct-36	1888.58	Oct-41	1886.42	Oct-46	1884.68	Oct-51	1885.24	Oct-56	1886.37
Nov-36	1888.52	Nov-41	1886.39	Nov-46	1884.70	Nov-51	1885.35	Nov-56	1886.43
Dec-36	1888.44	Dec-41	1886.40	Dec-46	1884.67	Dec-51	1885.44	Dec-56	1886.39

C-1 Calculated lake level from January 1932 to December 1997 *(Continued)*

Jan-57	1886.31	Jan-62	1887.98	Jan-67	1888.95	Jan-72	1889.45	Jan-77	1887.33
Feb-57	1886.22	Feb-62	1887.98	Feb-67	1888.79	Feb-72	1889.37	Feb-77	1887.21
Mar-57	1886.17	Mar-62	1887.88	Mar-67	1888.66	Mar-72	1889.26	Mar-77	1887.14
Apr-57	1886.25	Apr-62	1887.94	Apr-67	1888.65	Apr-72	1889.13	Apr-77	1887.26
May-57	1886.50	May-62	1888.23	May-67	1888.80	May-72	1889.05	May-77	1887.49
Jun-57	1886.73	Jun-62	1888.41	Jun-67	1888.95	Jun-72	1889.01	Jun-77	1887.64
Jul-57	1886.86	Jul-62	1888.40	Jul-67	1889.10	Jul-72	1888.99	Jul-77	1887.81
Aug-57	1886.97	Aug-62	1888.42	Aug-67	1889.22	Aug-72	1888.98	Aug-77	1887.97
Sep-57	1887.04	Sep-62	1888.60	Sep-67	1889.22	Sep-72	1888.95	Sep-77	1888.00
Oct-57	1887.03	Oct-62	1888.80	Oct-67	1889.22	Oct-72	1888.92	Oct-77	1888.02
Nov-57	1886.99	Nov-62	1888.83	Nov-67	1889.24	Nov-72	1888.92	Nov-77	1888.14
Dec-57	1886.93	Dec-62	1888.78	Dec-67	1889.19	Dec-72	1888.86	Dec-77	1888.24
Jan-58	1886.86	Jan-63	1888.71	Jan-68	1889.07	Jan-73	1888.76	Jan-78	1888.22
Feb-58	1886.87	Feb-63	1888.63	Feb-68	1889.01	Feb-73	1888.64	Feb-78	1888.21
Mar-58	1886.87	Mar-63	1888.61	Mar-68	1889.20	Mar-73	1888.52	Mar-78	1888.36
Apr-58	1886.91	Apr-63	1888.87	Apr-68	1889.69	Apr-73	1888.46	Apr-78	1888.62
May-58	1887.17	May-63	1889.28	May-68	1890.08	May-73	1888.41	May-78	1888.80
Jun-58	1887.39	Jun-63	1889.48	Jun-68	1890.22	Jun-73	1888.34	Jun-78	1888.82
Jul-58	1887.56	Jul-63	1889.44	Jul-68	1890.27	Jul-73	1888.29	Jul-78	1888.82
Aug-58	1887.72	Aug-63	1889.39	Aug-68	1890.29	Aug-73	1888.26	Aug-78	1888.88
Sep-58	1887.75	Sep-63	1889.31	Sep-68	1890.25	Sep-73	1888.24	Sep-78	1888.98
Oct-58	1887.74	Oct-63	1889.19	Oct-68	1890.18	Oct-73	1888.19	Oct-78	1889.06
Nov-58	1887.74	Nov-63	1889.22	Nov-68	1890.18	Nov-73	1888.13	Nov-78	1889.09
Dec-58	1887.75	Dec-63	1889.48	Dec-68	1890.16	Dec-73	1888.03	Dec-78	1889.08
Jan-59	1887.68	Jan-64	1889.59	Jan-69	1890.07	Jan-74	1887.89	Jan-79	1889.09
Feb-59	1887.53	Feb-64	1889.48	Feb-69	1889.94	Feb-74	1887.74	Feb-79	1889.18
Mar-59	1887.40	Mar-64	1889.47	Mar-69	1889.82	Mar-74	1887.66	Mar-79	1889.22
Apr-59	1887.32	Apr-64	1889.61	Apr-69	1889.74	Apr-74	1887.69	Apr-79	1889.23
May-59	1887.31	May-64	1889.70	May-69	1889.72	May-74	1887.71	May-79	1889.31
Jun-59	1887.28	Jun-64	1889.69	Jun-69	1889.65	Jun-74	1887.73	Jun-79	1889.37
Jul-59	1887.24	Jul-64	1889.79	Jul-69	1889.53	Jul-74	1887.84	Jul-79	1889.39
Aug-59	1887.25	Aug-64	1890.00	Aug-69	1889.41	Aug-74	1887.95	Aug-79	1889.36
Sep-59	1887.27	Sep-64	1890.22	Sep-69	1889.32	Sep-74	1888.07	Sep-79	1889.29
Oct-59	1887.22	Oct-64	1890.47	Oct-69	1889.22	Oct-74	1888.15	Oct-79	1889.21
Nov-59	1887.17	Nov-64	1890.58	Nov-69	1889.12	Nov-74	1888.14	Nov-79	1889.14
Dec-59	1887.10	Dec-64	1890.51	Dec-69	1889.04	Dec-74	1888.06	Dec-79	1889.04
Jan-60	1886.99	Jan-65	1890.39	Jan-70	1888.95	Jan-75	1887.93	Jan-80	1888.90
Feb-60	1886.88	Feb-65	1890.20	Feb-70	1888.85	Feb-75	1887.78	Feb-80	1888.74
Mar-60	1886.80	Mar-65	1890.01	Mar-70	1888.83	Mar-75	1887.66	Mar-80	1888.63
Apr-60	1886.76	Apr-65	1889.89	Apr-70	1888.95	Apr-75	1887.61	Apr-80	1888.63
May-60	1886.67	May-65	1889.84	May-70	1889.10	May-75	1887.56	May-80	1888.74
Jun-60	1886.54	Jun-65	1889.75	Jun-70	1889.18	Jun-75	1887.52	Jun-80	1888.84
Jul-60	1886.42	Jul-65	1889.64	Jul-70	1889.21	Jul-75	1887.61	Jul-80	1888.84
Aug-60	1886.37	Aug-65	1889.51	Aug-70	1889.25	Aug-75	1887.86	Aug-80	1888.75
Sep-60	1886.40	Sep-65	1889.38	Sep-70	1889.34	Sep-75	1888.14	Sep-80	1888.62
Oct-60	1886.41	Oct-65	1889.27	Oct-70	1889.40	Oct-75	1888.31	Oct-80	1888.52
Nov-60	1886.40	Nov-65	1889.21	Nov-70	1889.37	Nov-75	1888.32	Nov-80	1888.44
Dec-60	1886.34	Dec-65	1889.13	Dec-70	1889.26	Dec-75	1888.21	Dec-80	1888.33
Jan-61	1886.20	Jan-66	1888.99	Jan-71	1889.13	Jan-76	1888.07	Jan-81	1888.17
Feb-61	1886.04	Feb-66	1888.85	Feb-71	1888.97	Feb-76	1887.93	Feb-81	1888.04
Mar-61	1885.89	Mar-66	1888.81	Mar-71	1888.81	Mar-76	1887.80	Mar-81	1888.09
Apr-61	1885.81	Apr-66	1888.90	Apr-71	1888.77	Apr-76	1887.71	Apr-81	1888.37
May-61	1885.77	May-66	1888.93	May-71	1888.85	May-76	1887.64	May-81	1888.63
Jun-61	1885.68	Jun-66	1888.86	Jun-71	1888.93	Jun-76	1887.59	Jun-81	1888.73
Jul-61	1885.58	Jul-66	1888.79	Jul-71	1889.07	Jul-76	1887.59	Jul-81	1888.85
Aug-61	1885.57	Aug-66	1888.85	Aug-71	1889.39	Aug-76	1887.64	Aug-81	1889.06
Sep-61	1885.61	Sep-66	1888.99	Sep-71	1889.60	Sep-76	1887.67	Sep-81	1889.16
Oct-61	1885.90	Oct-66	1889.07	Oct-71	1889.66	Oct-76	1887.61	Oct-81	1889.14
Nov-61	1886.86	Nov-66	1889.14	Nov-71	1889.63	Nov-76	1887.52	Nov-81	1889.10
Dec-61	1887.69	Dec-66	1889.11	Dec-71	1889.54	Dec-76	1887.44	Dec-81	1889.01

C-1 Calculated lake level from January 1932 to December 1997 *(Continued)*

Jan-82	1888.86	Jan-87	1887.04	Jan-92	1886.87	Jan-97	1887.15
Feb-82	1888.70	Feb-87	1886.91	Feb-92	1886.73	Feb-97	1887.01
Mar-82	1888.57	Mar-87	1886.81	Mar-92	1886.69	Mar-97	1886.94
Apr-82	1888.54	Apr-87	1886.78	Apr-92	1886.78	Apr-97	1886.91
May-82	1888.56	May-87	1886.84	May-92	1886.90	May-97	1886.85
Jun-82	1888.53	Jun-87	1886.94	Jun-92	1887.05	Jun-97	1886.82
Jul-82	1888.48	Jul-87	1886.96	Jul-92	1887.24	Jul-97	1886.85
Aug-82	1888.48	Aug-87	1886.88	Aug-92	1887.44	Aug-97	1886.86
Sep-82	1888.47	Sep-87	1886.76	Sep-92	1887.61	Sep-97	1886.83
Oct-82	1888.52	Oct-87	1886.65	Oct-92	1887.73	Oct-97	1886.97
Nov-82	1888.65	Nov-87	1886.59	Nov-92	1887.78	Nov-97	1887.26
Dec-82	1888.70	Dec-87	1886.52	Dec-92	1887.82	Dec-97	1887.74
Jan-83	1888.61	Jan-88	1886.42	Jan-93	1887.85		
Feb-83	1888.47	Feb-88	1886.32	Feb-93	1887.79		
Mar-83	1888.37	Mar-88	1886.34	Mar-93	1887.67		
Apr-83	1888.34	Apr-88	1886.51	Apr-93	1887.56		
May-83	1888.36	May-88	1886.67	May-93	1887.49		
Jun-83	1888.36	Jun-88	1886.72	Jun-93	1887.44		
Jul-83	1888.38	Jul-88	1886.75	Jul-93	1887.36		
Aug-83	1888.45	Aug-88	1886.83	Aug-93	1887.27		
Sep-83	1888.58	Sep-88	1886.92	Sep-93	1887.19		
Oct-83	1888.76	Oct-88	1886.97	Oct-93	1887.08		
Nov-83	1888.87	Nov-88	1886.96	Nov-93	1886.98		
Dec-83	1888.86	Dec-88	1886.91	Dec-93	1886.85		
Jan-84	1888.73	Jan-89	1886.87	Jan-94	1886.71		
Feb-84	1888.56	Feb-89	1886.78	Feb-94	1886.59		
Mar-84	1888.41	Mar-89	1886.73	Mar-94	1886.58		
Apr-84	1888.29	Apr-89	1886.74	Apr-94	1886.70		
May-84	1888.16	May-89	1886.76	May-94	1886.79		
Jun-84	1888.03	Jun-89	1886.76	Jun-94	1886.81		
Jul-84	1887.93	Jul-89	1886.81	Jul-94	1886.83		
Aug-84	1887.83	Aug-89	1886.90	Aug-94	1886.85		
Sep-84	1887.72	Sep-89	1887.01	Sep-94	1886.86		
Oct-84	1887.65	Oct-89	1887.10	Oct-94	1886.91		
Nov-84	1887.63	Nov-89	1887.18	Nov-94	1886.95		
Dec-84	1887.60	Dec-89	1887.22	Dec-94	1886.88		
Jan-85	1887.50	Jan-90	1887.19	Jan-95	1886.75		
Feb-85	1887.38	Feb-90	1887.17	Feb-95	1886.63		
Mar-85	1887.35	Mar-90	1887.30	Mar-95	1886.61		
Apr-85	1887.44	Apr-90	1887.58	Apr-95	1886.67		
May-85	1887.57	May-90	1887.77	May-95	1886.72		
Jun-85	1887.64	Jun-90	1887.76	Jun-95	1886.72		
Jul-85	1887.68	Jul-90	1887.72	Jul-95	1886.72		
Aug-85	1887.72	Aug-90	1887.69	Aug-95	1886.72		
Sep-85	1887.74	Sep-90	1887.67	Sep-95	1886.79		
Oct-85	1887.72	Oct-90	1887.71	Oct-95	1886.95		
Nov-85	1887.67	Nov-90	1887.72	Nov-95	1887.10		
Dec-85	1887.57	Dec-90	1887.63	Dec-95	1887.10		
Jan-86	1887.45	Jan-91	1887.47	Jan-96	1887.01		
Feb-86	1887.33	Feb-91	1887.33	Feb-96	1886.90		
Mar-86	1887.24	Mar-91	1887.27	Mar-96	1886.80		
Apr-86	1887.25	Apr-91	1887.29	Apr-96	1886.72		
May-86	1887.33	May-91	1887.32	May-96	1886.68		
Jun-86	1887.35	Jun-91	1887.33	Jun-96	1886.67		
Jul-86	1887.33	Jul-91	1887.31	Jul-96	1886.77		
Aug-86	1887.31	Aug-91	1887.27	Aug-96	1886.96		
Sep-86	1887.28	Sep-91	1887.25	Sep-96	1887.15		
Oct-86	1887.24	Oct-91	1887.23	Oct-96	1887.27		
Nov-86	1887.21	Nov-91	1887.15	Nov-96	1887.33		
Dec-86	1887.15	Dec-91	1887.02	Dec-96	1887.28		

Appendix D - Historical EC of Lake Naivasha

This dataset comprise the surface-water conductivity from main water of Lake Naivasha collected from many sources between 1929 and 1991 by Verschuren (1996) and the data of previous ITC research has carried out since 1997.

Record	Date	Water-Surface Conductivity in various units, as reported	µS/cm at25°C
1	10-Jun-29	Alk.Res: 0.0037N	410
2	7-Jul-29	Alk.Res: 0.0039N	431
3	22-Nov-30	Alk: 0.00288N	320
4	3-Aug-31	Alk: 0.00303N	336
5	12-Dec-52	Cond: 400 µmhos/cm (20°C); Alk: 4.45 meq/l	448
6	8-Nov-60	Cond: 318 µmhos/cm (20°C); Alk: 3.30 meq/l	356
7	10-Feb-61	Cond: 335 µmhos/cm (20°C); Alk: 3.43 meq/l	375
8	5-Jun-61	Cond: 330 µmhos/cm (20°C); Alk: 3.31 meq/l	370
9	Dec-64	Cond: 250 µmhos/cm (20°C); Alk: 2.3 meq/l	280
10	11-Jul-69	Cond: 208 µmhos/cm (20°C); Alk: 2.19 meq/l	233
11	1970	Cond: 330 µmhos/cm (20°C); Alk: 2.84 meq/l	370
12	14-Jan-73	Cond: 314 µmhos/cm (20°C); Alk: 3.72 meq/l	352
13	18-Mar-73	Cond: 311 µmhos/cm (20°C); Alk: 2.94 meq/l	348
14	14-Apr-73	Cond: 321 µmhos/cm (20°C)	360
15	11-May-73	Cond: 321 µmhos/cm (20°C)	360
16	12-Jun-73	Cond: 321 µmhos/cm (20°C)	360
17	23-Jul-73	Cond: 327 µmhos/cm (20°C)	366
18	27-Oct-73	Cond: 327 µmhos/cm (20°C)	366
19	10-Dec-73	Cond: 335 µmhos/cm (20°C)	375
20	22-Dec-73	Cond: 370 µmhos/cm (20°C); Alk: 3.75 meq/l	415
21	10-Feb-74	Cond: 353 µmhos/cm (20°C); Alk: 3.76 meq/l	396
22	Jul-74	Cond: ca.365 µS/cm (25°C)	ca.365
23	Aug-74	Cond: ca.365 µS/cm (25°C)	ca.365
24	Sep-74	Cond: ca.365 µS/cm (25°C)	ca.365
25	Oct-74	Cond: ca.325 µS/cm (25°C)	ca.325
26	Oct-74	Cond: ca.345 µS/cm (25°C)	ca.345
27	Nov-74	Cond: ca.350 µS/cm (25°C)	ca.350
28	Dec-74	Cond: ca.335 µS/cm (25°C)	ca.335
29	Feb-75	Cond: ca.340 µS/cm (25°C)	ca.340
30	Apr-75	Cond: ca.395 µS/cm (25°C)	ca.395
31	Apr-75	Cond: ca.385 µS/cm (25°C)	ca.385
32	27-Dec-75	Cond: 445 µmhos/cm (20°C); Alk: 4.25 meq/l	499
33	1973-1975	Cond: 363 µS/cm (25°C); Alk: 3.42 meq/l; TDS: 329 mg/l	363
34	1978-1980	Cond: 311-353 µS/cm	311-353
35	Dec-82	Cond: 259 µS/cm; Alk: 1.95 meq/l	259
36	Jan-83	Cond. Read from graph	250
36	Jul-84	Cond: 350 µS/cm; Alk: 3.2 meq/l	350
37	Jul-87	Cond: ca.380 µS/cm	ca.380
38	Jul-88	Cond: ca.415 µS/cm	ca.415
39	Jan-89	Cond: 480 µS/cm	480
40	Apr-90	Cond: ca.280 µS/cm	ca.280
41	Jul-91	Cond: ca.320 µS/cm	ca.320
42	Oct-97	Cond. Average	457
43	Sep-00	Cond. Average	471
44	24-30 Sep 01	Cond. Average	330
45	25-27 Sep 02	Cond. Average	301

Appendix E – Chemical Analysis

E-1 Correctness of analysis (meq/L)

Sample	Ca^{+2}	Mg^{+2}	K^+	Na^+	Fe^{+2}	Al^{+3}	NH_4^+	Mn^{+2}	Cl^-	HCO_3^-	CO_3^{-2}	SO_4^{-2}	NO_3^-	PO_4^{-3}	∑cations	∑anions	%diff.	result
M1	0.36	0.15	0.10	0.52	0.009	0.017	0.028	0.001	0.27	1.09	0.00	0.04	0.01	0.01	1.18	1.41	-8.98	Acceptable
M2	0.46	0.23	0.09	0.40	0.004	0.001	0.000	0.000	0.21	1.19	0.00	0.04	0.01	0.01	1.19	1.46	-10.23	Not Acceptable
M3	0.41	0.18	0.10	0.45	0.007	0.186	0.006	0.001	0.19	1.17	0.00	0.06	0.01	0.01	1.34	1.44	-3.74	Acceptable
M4	0.75	0.18	0.48	3.18	0.001	0.003	0.006	0.002	0.20	3.84	0.00	0.04	0.01	0.01	4.60	4.11	5.55	Acceptable
M5	0.40	0.17	0.10	0.46	0.009	0.010	0.017	0.001	0.28	1.09	0.00	0.04	0.01	0.01	1.17	1.42	-9.93	Acceptable
M6	0.72	0.17	0.52	4.58	0.000	0.000	0.011	0.000	0.27	4.75	0.00	0.27	0.01	0.01	6.00	5.30	6.16	Acceptable
M7	0.73	0.09	0.50	4.45	0.003	0.006	0.000	0.000	0.29	4.66	0.00	0.29	0.01	0.04	5.78	5.30	4.38	Acceptable
M8	0.41	0.17	0.10	0.49	0.007	0.010	0.017	0.000	0.28	1.11	0.00	0.06	0.01	0.01	1.21	1.47	-9.77	Acceptable
M9	0.41	0.18	0.11	0.51	0.006	0.007	0.006	0.000	0.23	0.99	0.00	0.04	0.02	0.01	1.22	1.30	-3.17	Acceptable
M10	0.41	0.18	0.11	0.52	0.005	0.002	0.028	0.001	0.17	1.02	0.00	0.04	0.01	0.01	1.25	1.25	-0.04	Acceptable
M11	0.41	0.17	0.11	0.51	0.007	0.011	0.033	0.001	0.10	1.04	0.00	0.06	0.01	0.01	1.25	1.22	1.48	Acceptable
G1	0.16	0.06	0.12	0.49	0.021	0.018	0.011	0.002	0.19	0.54	0.00	0.02	0.02	0.01	0.87	0.78	5.61	Acceptable
G2	0.36	0.08	0.29	1.41	0.008	0.021	0.039	0.000	0.08	1.80	0.00	0.10	0.02	0.04	2.21	2.04	3.98	Acceptable
G3	0.17	0.06	0.12	0.50	0.016	0.009	0.061	0.001	0.07	1.00	0.00	0.04	0.02	0.01	0.94	1.15	-10.01	Not Acceptable
G4	0.18	0.06	0.12	0.50	0.016	0.008	0.039	0.001	0.15	0.90	0.00	0.04	0.03	0.01	0.93	1.13	-9.92	Acceptable
G5	0.18	0.06	0.12	0.49	0.016	0.009	0.039	0.001	0.15	0.64	0.00	0.06	0.05	0.01	0.91	0.91	-0.21	Acceptable
G6	0.20	0.06	0.12	0.48	0.020	0.018	0.039	0.002	0.10	0.78	0.00	0.06	0.05	0.01	0.94	1.01	-3.63	Acceptable
L1	0.84	0.58	0.65	1.79	0.04	0.14	0.06	0.007	0.41	2.37	0.59	0.00	0.03	0.02	4.10	3.41	9.14	Acceptable
L2	0.84	0.58	0.64	1.85	0.02	0.11	0.02	0.006	0.43	2.33	0.62	0.02	0.03	0.02	4.07	3.45	8.24	Acceptable
L3	0.88	0.58	0.67	1.92	0.03	0.17	0.02	0.007	0.60	2.69	0.50	0.02	0.02	0.02	4.27	3.84	5.31	Acceptable
L4	0.75	0.55	0.57	1.64	0.02	0.05	0.04	0.004	0.41	1.83	1.15	0.00	0.03	0.01	3.61	3.43	2.60	**Acceptable**
L5	0.74	0.55	0.57	1.66	0.01	0.04	0.01	0.004	0.40	1.62	1.41	0.00	0.02	0.01	3.58	3.46	1.61	Acceptable
L6	0.72	0.54	0.57	1.63	0.02	0.06	0.03	0.005	0.43	1.87	0.96	0.00	0.04	0.01	3.57	3.32	3.73	Acceptable
L7	0.73	0.54	0.57	1.68	0.01	0.04	0.03	0.004	0.43	1.51	1.47	0.17	0.03	0.01	3.60	3.61	-0.13	Acceptable
L8	0.73	0.54	0.56	1.63	0.02	0.05	0.03	0.004	0.40	2.23	0.69	0.00	0.03	0.01	3.57	3.36	2.99	Acceptable
L9	0.69	0.54	0.56	1.61	0.02	0.06	0.03	0.005	0.37	2.48	0.48	0.17	0.04	0.01	3.51	3.54	-0.35	Acceptable
L10	0.73	0.54	0.56	1.61	0.01	0.05	0.02	0.005	0.39	2.14	0.44	0.08	0.04	0.01	3.52	3.10	6.43	Acceptable
L11	0.72	0.53	0.56	1.60	0.02	0.05	0.01	0.005	0.41	2.58	0.40	0.08	0.04	0.01	3.48	3.52	-0.49	Acceptable
L12	0.75	0.55	0.56	1.61	0.02	0.04	0.02	0.005	0.42	2.04	0.48	0.15	0.03	0.01	3.55	3.12	6.47	Acceptable
L13	0.72	0.53	0.56	1.69	0.02	0.05	0.03	0.005	0.37	2.04	0.52	0.15	0.02	0.02	3.60	3.11	7.32	Acceptable
L14	0.72	0.52	0.55	1.66	0.02	0.05	0.02	0.006	0.44	1.86	0.72	0.17	0.03	0.02	3.54	3.23	4.63	Acceptable
L15	0.72	0.53	0.56	1.65	0.01	0.04	0.03	0.005	0.35	1.92	0.48	0.12	0.03	0.01	3.55	2.91	9.92	Acceptable
L16	0.71	0.54	0.55	1.63	0.01	0.04	0.01	0.005	0.45	1.86	0.44	0.15	0.03	0.01	3.49	2.94	8.66	Acceptable
L17	0.72	0.53	0.55	1.61	0.01	0.03	0.03	0.005	0.40	1.80	0.36	0.15	0.02	0.01	3.49	2.74	12.11	Not Acceptable
L18	0.66	0.53	0.55	1.65	0.01	0.04	0.02	0.004	0.36	1.74	0.52	0.17	0.04	0.01	3.46	2.83	9.92	Acceptable
L19	0.66	0.52	0.55	1.63	0.02	0.05	0.02	0.005	0.37	1.72	0.60	0.15	0.02	0.01	3.46	2.87	9.28	Acceptable
L20	0.66	0.53	0.55	1.61	0.01	0.03	0.03	0.004	0.39	1.84	0.60	0.17	0.02	0.01	3.42	3.03	6.11	Acceptable
L21	0.69	0.52	0.56	1.62	0.01	0.04	0.01	0.005	0.41	2.04	0.52	0.12	0.04	0.01	3.46	3.14	4.72	Acceptable
L22	0.70	0.53	0.55	1.62	0.04	0.06	0.01	0.006	0.36	1.92	0.40	0.17	0.03	0.01	3.51	2.88	9.75	Acceptable
L23	0.70	0.52	0.55	1.66	0.01	0.03	0.01	0.004	0.38	1.80	0.64	0.08	0.02	0.01	3.48	2.93	8.60	Acceptable
L24	0.68	0.53	0.55	1.64	0.01	0.04	0.01	0.004	0.37	1.92	0.64	0.15	0.03	0.01	3.47	3.12	5.31	Acceptable
L25	0.69	0.52	0.55	1.63	0.01	0.05	0.03	0.004	0.40	1.88	0.84	0.15	0.02	0.01	3.48	3.30	2.73	Acceptable

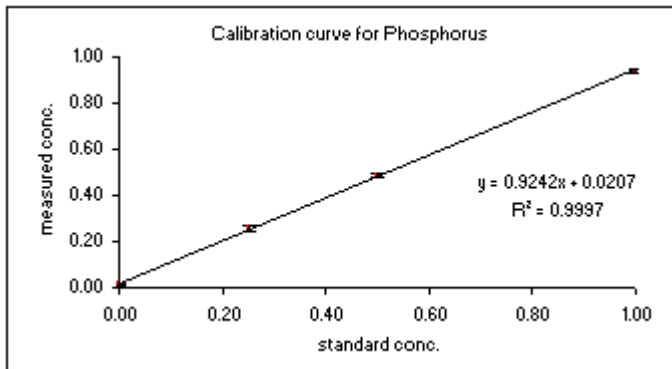E-2 Calibration curve of standard solution for spectrophotometer HACH DR/2010

Calibration curve for Ammonia

$y = 1.0989x - 0.2883$
$R^2 = 0.9957$

NH$_3$conc	1st	2nd	3rd	avg	SD
0	0.1	0.1	0.0	0.07	0.06
0.5	0.2	0.3	0.1	0.20	0.10
1	0.8	0.8	0.6	0.73	0.12
2	1.9	1.9	1.9	1.90	0.00
5	5	4.5	4.8	4.77	0.25
10	10.7	11	11.1	10.93	0.21

unit : mg/l

Calibration curve for Chloride

$y = 1.0229x + 0.1333$
$R^2 = 0.9998$

Cl$^-$conc	1st	2nd	3rd	avg	SD
0	0	0	0	0.00	0.00
5	5.2	5.7	5.3	5.40	0.26
10	10.3	10.4	10.5	10.40	0.10
20	20.3	20.7	20.6	20.53	0.21

unit : mg/l

Calibration curve for Phosphorus

$y = 0.9242x + 0.0207$
$R^2 = 0.9997$

PO$_4$—P conc	1st	2nd	3rd	avg	SD
0.00	0.02	0.01	0.01	0.01	0.01
0.25	0.27	0.25	0.25	0.26	0.01
0.50	0.48	0.5	0.49	0.49	0.01
1.00	0.94	0.93	0.95	0.94	0.01

unit : mg/l

Calibration curve for Phosphate

$y = 0.9207x + 0.0674$
$R^2 = 0.9995$

PO$_4^-$conc	1st	2nd	3rd	avg	SD
0.00	0.06	0.03	0.03	0.04	0.02
0.77	0.85	0.78	0.76	0.80	0.05
1.53	1.49	1.52	1.49	1.50	0.02
3.07	2.88	2.84	2.91	2.88	0.04

unit : mg/l

Calibration curve for Nitrogen

$y = 0.8302x - 0.0173$
$R^2 = 0.9981$

NO$_3$-N conc	1st	2nd	3rd	avg	SD
0.0	0.1	0.0	0.0	0.03	0.06
0.2	0.1	0.1	0.1	0.10	0.00
0.5	0.4	0.4	0.4	0.40	0.00
1.0	0.8	0.8	0.8	0.80	0.00
2.5	2.1	2.0	2.1	2.07	0.06

unit : mg/l

Calibration curve for Nitrate

$y = 0.8288x - 0.0499$
$R^2 = 0.9992$

NO$_3^-$ conc	1st	2nd	3rd	avg	SD
0.00	0.2	0.0	0.1	0.1	0.1
0.89	0.5	0.6	0.6	0.57	0.06
2.21	1.7	1.7	1.7	1.70	0.00
4.43	3.6	3.8	3.6	3.67	0.12
11.07	9.1	9.1	9.2	9.13	0.06

unit : mg/l

Calibration curve for Sulphate

$y = 1.0809x + 0.5398$
$R^2 = 0.9981$

SO$_4^{2-}$ conc	1st	2nd	3rd	avg	SD
0	0	0	0	0.0	0.0
7	8	8	7	7.7	0.6
10	12	13	13	12.7	0.6
25	27	28	27	27.3	0.6
40	43	44	44	43.7	0.6

unit : mg/l

E-3 Surface Water Standards

Parameter	Units	Statistics	Standard Value for Class				
			Class 1	Class 2	Class 3	Class 4	Class 5
1. Color, odor, taste	-	-	n	n	n	n	-
2. Temperature	°C	-	n'	n'	n'	n'	-
3. pH	-	-	n	5-9	5-9	5-9	-
4. Dissolved Oxygen	mg/l	P20	n	6	4	2	-
5. BOD (5 days, 20°C)	mg/l	P80	n	1.5	2.0	4.0	-
6. Coliform bacteria							
7. NO_3-N	mg/l	Max.	n	0.5			-
8. NH_3-N	mg/l	-	n	0.5			-
9. Phenols	mg/l	-	n	0.005			-
10. Copper (Cu)	mg/l	-	n	0.1			-
11. Nickle (Ni)	mg/l	-	n	0.1			-
12. manganese (Mn)	mg/l	-	n	1.0			-
13. Zinc (Zn)	mg/l	-	n	1.0			-
14. Cadmium (Cd)	mg/l	-	n	0.005*			-
15. Chromium Hexavalent	mg/l	-	n	0.05			-
16. Lead (Pb)	mg/l	-	n	0.05			-
17. Total Mercury	mg/l	-	n	0.002			-
18. Arsenic (As)	mg/l	-	n	0.01			-
19. Cyanide (CN)	mg/l	-	n	0.005			-
20. Radioactivity							
21. Total Organochlorine	mg/l	-	n	0.05			-
22. DDT	µg/l	-	n	1.0			-
23. Alpha-BHC	µg/l	-	n	0.02			-
24. Dieldrin	µg/l	-	n	0.1			-
25. Aldrin	µg/l	-	n	0.1			-
26. Heptachlor &	µg/l	-	n	0.2			-
27. Endrin	µg/l	-	n	none			-

Remark: P Percentile value   *   when water hardness not more than 100 mg/l as $CaCO_3$

n naturally   **   when water hardness more than 100 mg/l as $CaCO_3$

n' naturally but change not more than 3°C

Based on Standard Methods for the Examination of Water and Wastewater recommended by APHA: American Public Health Association, AWWA: American Water Works Association and WPCF: Water Pollution Control Federation

Class 1 Extra clean freash surface water resources used for:
1. conservation not necessary pass through water treatment process require only ordinary process for pathogenic destruction
2. ecosystem conservation where basic organisms can breed naturally

Class 2 Very clean fresh surface water resources used for:
1. consumption which requires ordinary treatment process before use
2. aquatic organism of conservation
3. fisheries
4. recreation

Class 3 Medium clean fresh surface water resources used for:
1. consumption but passing through an ordinary treatment process before using
2. agriculture

Class 4 Fairly clean fresh surface water resources used for:
1. consumption but requires special water treatment process before using
2. industry

Class 5 The sources which are not classification in class 1-4 and used for navigation

Source: Notification of the National Environmental Board, No. 8, B.E. 2537 (1994), issued under the Enhancement and Conservation of national Environmental Quality Act B.E. 2535 (1992), published in the Royal Government Gazette, Vol.111, Part 16, dated February 24, B.E.2537 (1994).