REGIONAL IMPACT OF CLIMATE CHANGE AND VARIABILITY ON WATER RESOURCES

(CASE STUDY LAKE NAIVASHA BASIN, KENYA)

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Regional Impact of Climate Change and Variability on Water Resources

By

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Disclaimer

Dedicated to:

Ayah - Bunda

and

My Shinta

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ABSTRACT

Water resources are interconnected with climate; the prospect of climate change and variability will implies the water resources and regional development. The impacts of climate change and variability in regional scale are estimated by defining scenarios for changes in climatic inputs to a hydrological model from the output of general circulation models (GCMs).

A physical-distributed based hydrological model, Soil and Water Assessment Tool (SWAT), is applied to estimate and understand the hydrological behaviour of Lake Naivasha Basin. The model was calibrated to adequately represent the discharge response to precipitation for the historic period of 1935-2000 using long-term measured records. To analyse and assess the Lake Naivasha water level fluctuation, discharge output from SWAT has been incorporated with Water Balance Model of Lake Naivasha.

Two periods of 30-years climate data has been used as base line and simulation condition. HadCM2GSa1 scenario is used for climate change and variability prediction, which reflect greenhouse gas forcing 1% increase per annum. The HadCM2GSa1 global mean temperature and precipitation change of the baseline (1961-1990) and 2010-2039 were provided to SWAT to simulate the changes in discharge due to changes in climate in regional scale.

The model predicts, without abstractions, that climate change would affect the lake water level 4 meter lower than the condition that states without any climate change. Abstraction of the lake would accelerate the lake water level depletion.

The major effects of climate change on the Lake Naivasha area and the water resources will be through changes in the hydrological cycle, temperature and precipitation. These factors are the controlling parameter of the lake water level and lake water volume and finally the water availability.

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1. Introduction

1.1. Background

Effect on the hydrological cycle and its associated water management system are considered among the most important impacts of climate change. Water resources are inextricably linked with climate, so the prospect of global climate change has serious implications for water resources and regional development. Efforts to provide adequate water resources for Africa is confront a number of challenges, including population pressure, problems associated with land use such as erosion/siltation, and possible ecological consequences of land-use change on the hydrological cycle. Climate change will make addressing these problems more complex (http://www.grida.no/climate/ipcc/regional/017.htm 2001)

Development of water resources management strategies in industry, agriculture, freshwater fisheries, tourism depends on appreciation of natural long-term climate variability. This is especially true for the vast dry land regions of East Africa, where inter-annual and decadal trends in precipitation have a dramatic impact on soil moisture availability, agricultural production, and water quantity/quality of the lake (Verschuren 1999).

Lake Naivasha is the only freshwater resource among many saline lakes in the Kenyan rift valley. Two perennial (Malewa and Gilgil) and an ephemeral (Karati) rivers drain into Lake Naivasha but the lake has no surface outlet. The water of the lake is very heavily used for agricultural irrigation, domestic, municipal, wildlife and geothermal projects. However, recent drop in the lake water level poses a treat to its sustainability.

The Intergovernmental Panel on Climate Change (IPCC) estimates that increased temperature are likely to lead to reduced lake level and outflow potentially requiring conjunctive use of ground and surface water sources to meet water demand (Wurbs 2002). Temperature rise, which likely to be accompany by more extreme precipitation and faster evaporation, will lead to greater wet and dry conditions. These condition shows that the climate change and variability study for the Lake Naivasha area is important.

Understanding of the behaviour of Lake Naivasha Basin through applying hydrological model will be helpful for future analysis of its sustainability, as the modelling strategy provides a general framework for evaluating the impacts of climate change and climate variability.

1.2. Objectives

The main objective of the research is to analyse and assess the regional impact of climate change and variability on Lake Naivasha Basin particularly on lake water level. The general frameworks are to achieve the objective include: to understand hydrological behaviour of the study area; to forecast the future climate change and variability condition in order to weigh up the impacts.

A physical-distributed based hydrological model appears to be suitable for these purposes (Abbot 1996). In order to assess the regional impact of climate change and variability, General Circulation Model (GCM) climate change scenario from the Inter Governmental Panel on Climate Change (IPCC) has been applied in order to incorporating the future hydrological and climate condition.

1.3. Research Approach

In order to achieve this research with scientific way and to arrive at a satisfied result, the following steps have been done. The research design diagram showed in figure 1.1.

1.3.1 Literature review

Literature review was done in for following topics

- Hydrologic data analysis
- Water balance and hydrological behaviour
- Hydrological Modelling and Physical-distributed model, to select the most appropriate model
- Climate Scenario Development and General Circulation Model (GCM) scenario from Inter-governmental Panel on Climate Change (IPCC).

1.3.2 Data collection

Collection of the required data for the study was divided into two stages; before and during the fieldwork. In general, the input data that was used for achieving of the study can be categorised as follows:

- Daily precipitation records for stations inside and around the basin
- Daily stream flow records for gauging stations on Malewa River, Gilgil River and its tributaries.
- Daily actual evaporation data
- Air temperature, relative humidity, dew point temperature, global radiation, wind speed
- Topographic, land use and soil maps.

Numerous data required for this study have been acquire by previous MSc students and archived in digital form. This archive have been opened and organized in particular format before data collection in the fieldwork. These procedures were done to avoid duplication of data or measurements.
The data that have been used are precipitation, evaporation, lake level, land use, soil, and contour map (for the Digital Elevation Model).

1.3.3 Field work activities

The fieldwork aimed at collecting of the missing data needed for the research, and characterising of Lake Naivasha Basin. The following activities have been done:

1.3.3.1 Meteorological data Collection

- Daily precipitation data (Naivasha D.O 9036002, N.Kinangop forest station 9036025, Geta forest station 9036241, N Kinangop Mawingo Scheme 9036264)
- Daily discharge data (2GB1 gauging station)
- Additional meteorological data as daily mean air temperature, daily dew point temperature or relative humidity, daily global radiation.

1.3.3.2 Field measurement

- Stream discharge measurements
- Electric conductivity measurements.

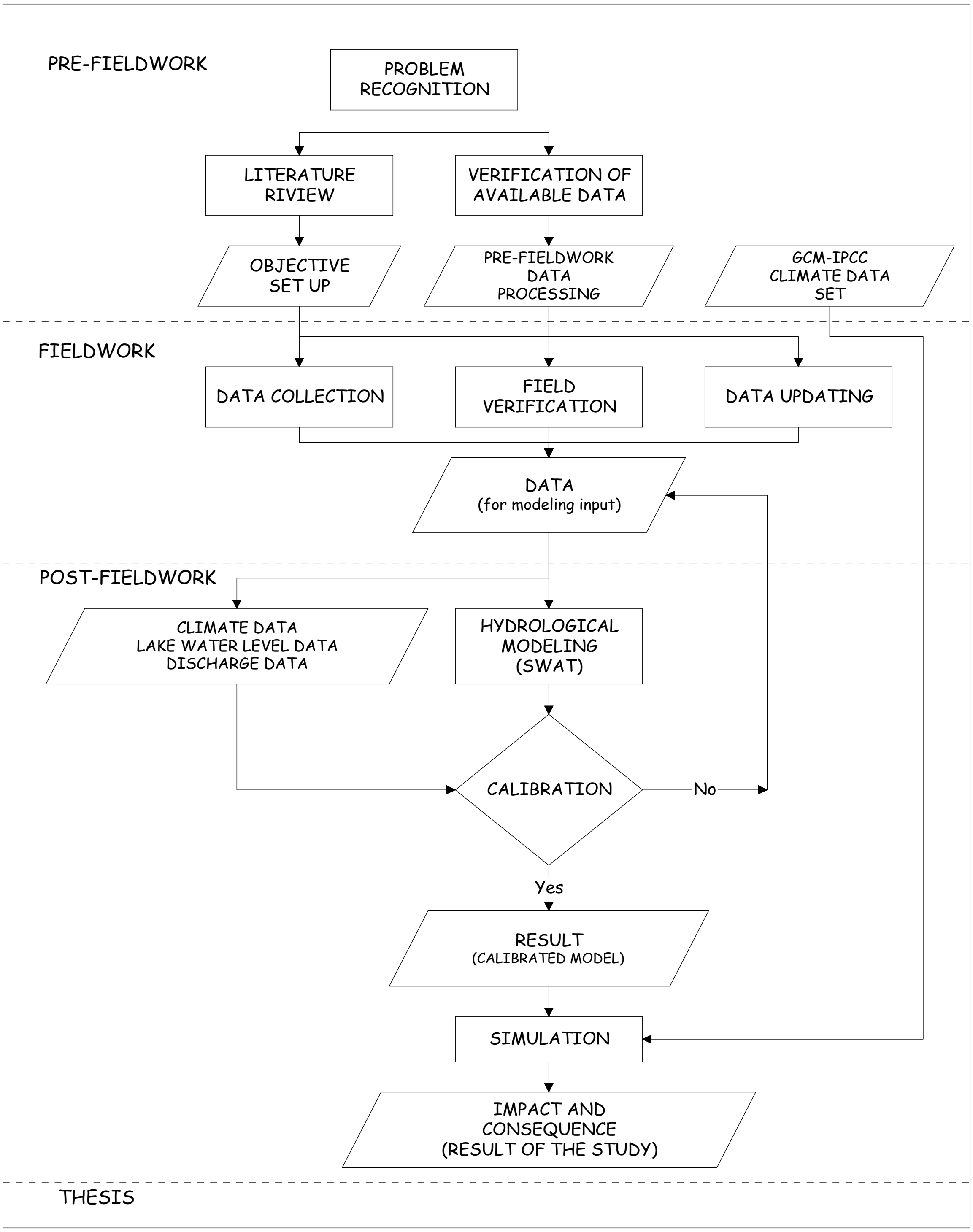


Figure 1.1 Diagram of Research design

1.3.4 Data analysis and modelling

The Soil and Water Assessment Tool (SWAT) model was chosen to be used in this research since it was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed (Neitsch 2002). The model can also integrate variation on soil, land use and management condition over long periods. Major components of the hydrologic balance and their interactions are simulated including surface runoff, lateral flow in the soil profile, groundwater flow, evapotranspiration, channel routing, and pond and reservoir storage. The primary considerations in model development were to stress land management, water quality loadings, flexibility in basin discretization, and continuous time simulation. Major components of the model include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow, and agricultural management. The model is public domain and generalized for use anywhere.

By using SWAT, to model Lake Naivasha Basin, the following steps were implemented:

- Watershed delineation using SWAT
- Land use/Soil Characterization
- Analysis of weather generator input file
- Analysis of meteorological data to extract the reliable periods for modelling
- Rainfall-runoff-lake level relationship using previous research results
- Model calibration

1.3.5 Regional Impact of Climate Change and Variability Assessment

To assess and analyse regional impact of climate change and variability, the following steps were applied:

- Implementing GCM IPCC Climate Change Scenario
- Analyse and assess the regional impact and consequences of climate change and variability on water resources, emphasizing on lake water level.

1.4 Thesis lay-out

This thesis is comprised of five chapters

Chapter 1 Introduction
Chapter 2 Methods and Materials
Chapter 3 Hydrological Modelling
Chapter 4 Climate Change Simulation
Chapter 5 Summary and Conclusion

Chapter 1 is the general introduction of the subject. The study area and the methodology are described in Chapter 2.

Chapter 3 concentrates on hydrologic modelling using Arc View Soil and Water Assessment Tool (SWAT 2000), which include the creation of hydrological data analysis, input data preparation and the calibration of the model. Chapter 4 is addressed on the implementation of the Climate Change Scenario from Inter-Governmental Panel on Climate Change in the calibrated model; finally Chapter 5 consist the research summary and conclusion.

2. Methods and Material

2.1. The Study Area

2.1.1. Introduction

Lake Naivasha Basin is located at 00 46’ to 00’52’S latitude and 36 15’ to 36 25’ longitude and UTM zone 37 with an altitude between 1900 m to 3200 m above mean sea level.

Situated in the highest part of the Rift Valley, this basin comprises an area of about 3300 sqkm, with an internal stream network system without visible outlet. Malewa River drains into the lake, which is the main source of surface water into the Naivasha area (figure 2.1).

The lake water is used for:

- Irrigation
- Generation of electricity
- Fish cultivation
- Drinking water & heritage of some wildlife
- Recreation
- Tourism

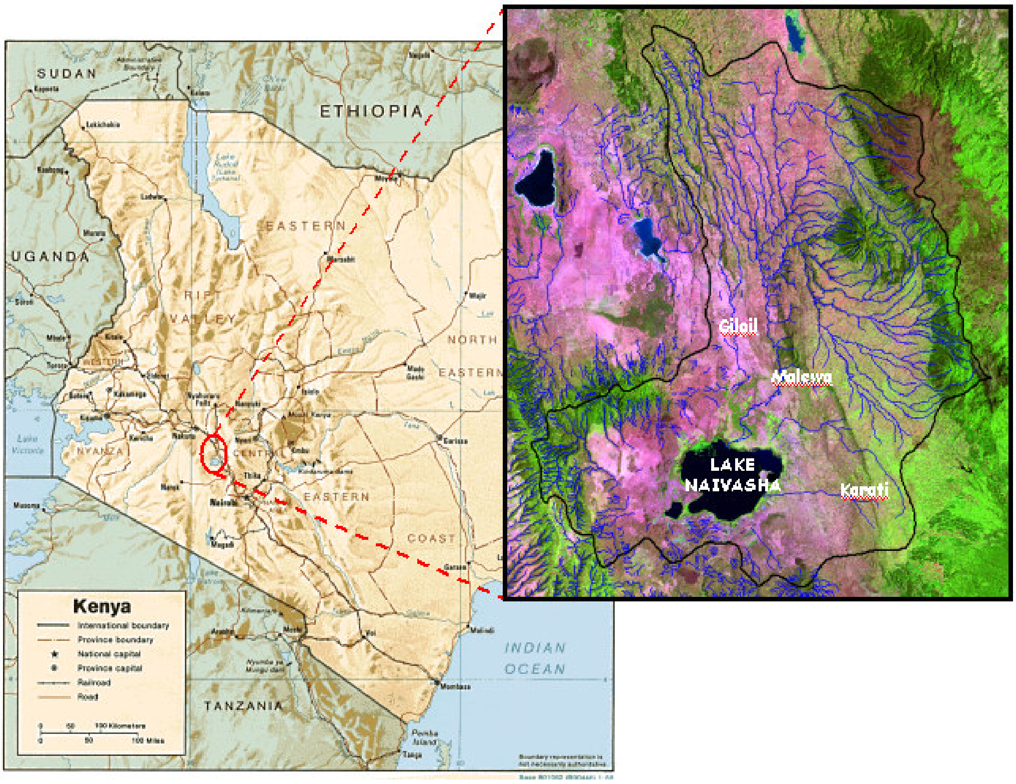
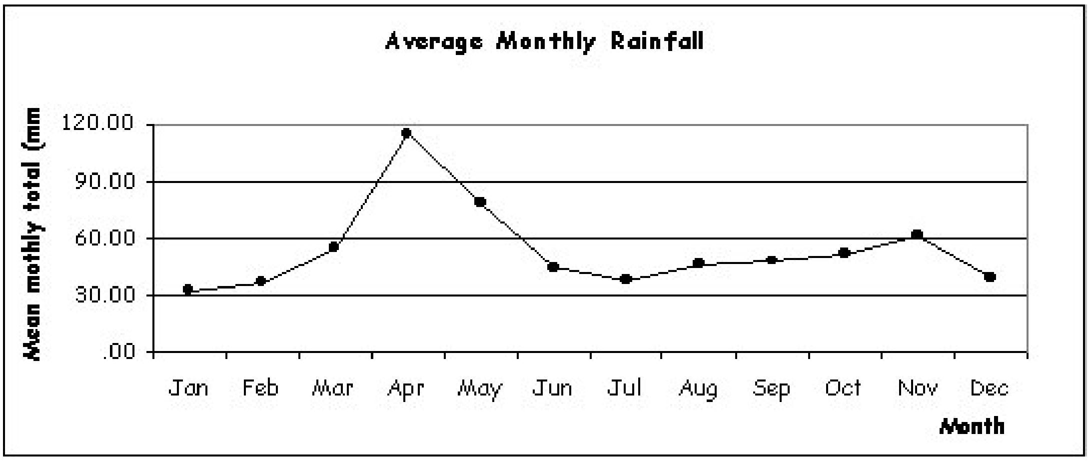


Figure 2.1 Overview of study area

2.1.2. Rainfall

The climate of the study area is a typical equatorial tropical climate with two rainy seasons (bimodal) followed by a dry season. The first rainy season is from March to May and is referred to as the “long rains". The second is named as "short rains" and goes from October to November. The "long rains" bring more precipitation compared to the second one or "short rains". The dry seasons are from December, January to February and from June to September. Relief controls the precipitation pattern (orographic) with much more rains in the higher altitude (Mmbui 1999).Figure 2.2 shows the yearly precipitation variation base on 42 years periods data.



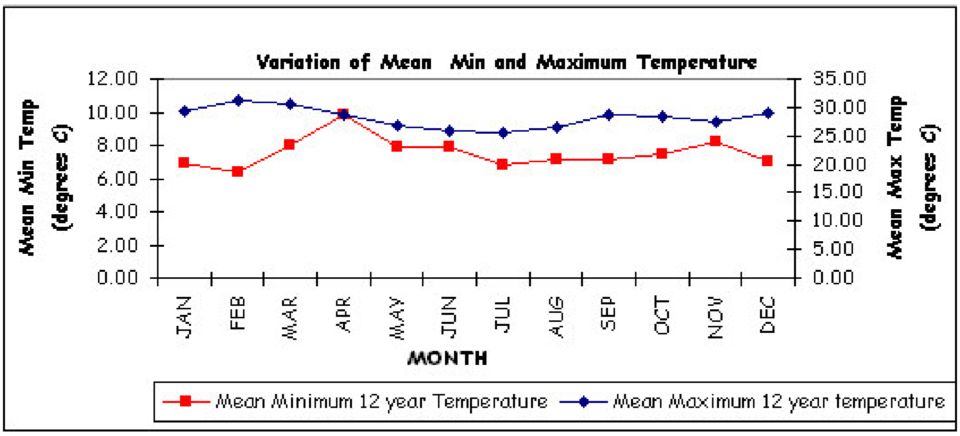
SOURCE: Mmbui, 1999

Figure 2.2 Variation of the monthly precipitation

2.1.3. Temperature

Lake Naivasha is located within one degree of the equator and is thus in the tropical zone, the annual temperature ranges approximately from 8 °C to 30 °C (Al Sabbagh 2001).

The mean maximum monthly temperature within the area is about 29°C and the mean minimum temperature is about 9°C. The temperature can be as low as 1 or 2° during the night. Figure 2.3 shows min/max temperature over 12 years periods. The warmest months are generally January, February and March whereas the coldest months are July and August (Chisakuta 2002).



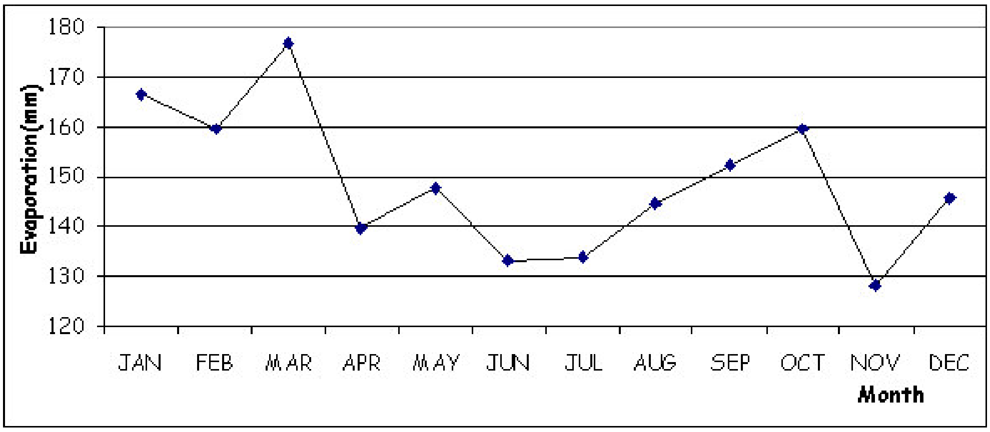
SOURCE: Chisakuta, 2002

Figure 2.3 Minimum and Maximum Temperature for a 12 year period (1990 - 2001)

2.1.4. Evaporation

Evaporation data have been collected in the Naivasha DO station, result of an average over 33 years of data from 1957 to 1990 is presented in figure 2.4. The evaporation rate was occurred using pan evaporation Class Pan American class A with pan coefficient equal to one.

The average monthly evaporation calculated by Ashfaque (1999), was 5 mm/day. The highest evaporation rate occurred in March and the lowest could be observed in November (Mmbui 1999). The yearly evaporation based on this record is estimated to be 1804.2 mm about 2.7 times greater than the annual precipitation in the area.



SOURCE: Mmbui, 1999

Figure 2.4 Daily mean pan evaporation (9036002 station)

2.1.5. Topography

Naivasha area of the Rift Valley is confined by the Nyandarua mountains (formerly the Aberdares mountain) to the east, the elevation exceeds 3990 m), and the Mau Escarpment to the west (the elevation exceeds 3000 m). The Kinangop Plateau forms a broad step between the Nyandarua range and the valley floor, east of Naivasha. The Mount Longonot stands on the South of the Lake (Al Sabbagh 2001).

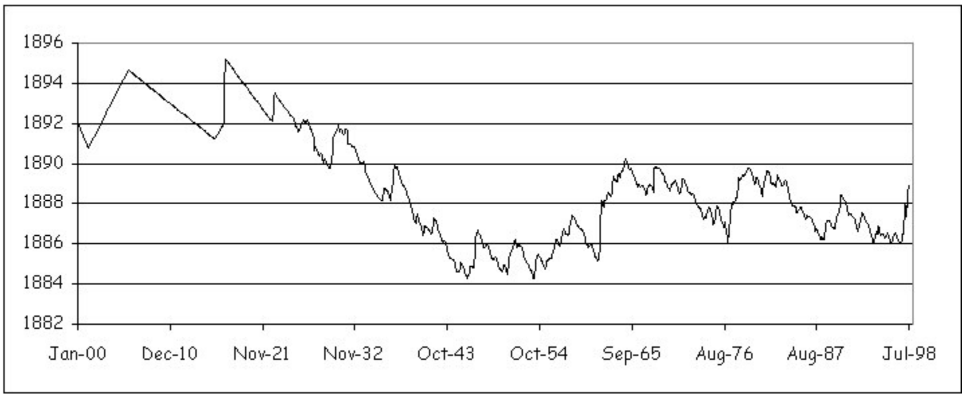
2.1.6. Rivers

Lake Naivasha Basin has a numerous rivers and its tributaries; three major rivers drains are Malewa, Gilgil and Karati. Malewa is the major river that fed the lake, contributing about 90% of the discharge (see figure 2.1). River Malewa basin area is about 1600 sqkm. Gilgil with basin of 527 sqkm and Karati area about 150 sqkm, are contributing the remaining 10 % of the discharge in to the lake.

Lake Naivasha and the surrounding basin drained by ephemeral streams, which disappear underground before reaching the lake.

2.1.7. The Lake

The Lake Naivasha Water Level have been observe since 1908, from three monitoring station that operated in different time (figure 2.5). These stations are located in different locations and have variable record duration. Station 2GD4 is located in Oloidien Lake situated on the southwest of the main lake. During low water levels, the two lakes are separated but become one lake at higher lake levels. This station has data from 1959 to 1992. Station 2GD6 located on the Eastern Shore of the main lake has data from 1967 to 1987. Station 2GD1 has data from 1908 to April 1982. This station is placed on the western shore of Crescent Island located on the eastern part of the lake. The hydrograph data for this station have been drawn by ministry of Water development, Kenya for the periods of 1908 to 1968. There are also some individual farmers neighbouring the lake which have monitored the lake levels at various times and kept the data in their farms.



SOURCE: Mmbui, 1999

Figure 2.5 Reconstructed observed average monthly lake levels (1900-1998)

2.1.8. Landuse

The semi-arid climate and the topography are greatly influencing the land cover of the area, which can broadly be grouped into:

- Forest
- Bushland
- Grassland
- Agricultural land

The natural forest within the study area comprises indigenous hardwood trees and grasses such as bamboos. Menegai Crater, the Eburru Hills, Mau Escarpment, Mount Longonot and the Nyandarua Escarpment are all host of hardwood forest, whereas bamboo is confined to the Nyandarua and Mau escarpment. These form the main watershed of the lakes.

The greatest proportions of the low-lying central part of the basin are rangelands. Rangelands are land carrying natural or semi-natural vegetation that provide a habitat suitable for wild or domestic ungulates and vary from shrubland to grassland to bushland (Graham 1998). Lake Naivasha shores are often encircled by ephemeral Papyrus colonies, and the lake surface covered by raft of Salvinia molesta (sometimes up to 25 % of the total surface area).

The main farming system in this area would commonly be referred to as mixed farming. Rain fed crop production is the most important activity within the basin. Slopes of the Nyandarua and Mau Mountains are the most common farming areas. Common crops include maize, wheat, potato, beans and sunflowers.

Irrigated crop farming is common near Lake Naivasha where large quantities of wheat, barley, french bean and fodder crops are grown. Other important horticulture products are flowers.

The livestock production by some dairy farms and *Masai* people is also a common practice (Al Sabbagh 2001).

2.2. Research Methods

In able to achieve the research objective, to analyse and assess the regional impact of climate change and variability on Lake Naivasha Basin, the following methods were implemented.

2.2.1. Methods for hydrological modelling

Prediction of hydrological effects of climate change is one of the most difficult issues which hydrology is confronted (Abbot 1996). With today's technology the impact of specified changes in precipitation, temperature and evaporation on river runoff, soil and moisture regime and groundwater recharge can be calculated with reasonable accuracy, and any number of simple models can be construct to simulate climate change.

To model the existing situation in the study area and be able to achieve the main objective, a physical-distributed hydrological model has been chosen, which take spatial variables and parameters into consideration.

Distributed hydrological models appear to be suitable for climate change modeling, but have not been used so far maybe due to lack of interdisciplinary interaction. A physically based model describes the natural system (here considered as the hydrological cycle, or part of it, as is currently conceived) using basic mathematical representations of the flows of mass, momentum and various forms of energy, for catchment or basin model (Abbot 1996).

Soil and Water Assessment Tool (SWAT) appears to be appropriate for the requirements, since it was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watershed with varying soil, land use and management condition over long periods of time (Neitsch 2002). The model operates on a daily time step (capable of simulating 100 years or more) and allows a basin to be subdivided into grid cells or natural sub-watersheds. Major components of the hydrological balance, and their interactions, are simulated including surface runoff, lateral flow in the soil profile, groundwater flow, evapotranspiration, channel routing, and pond and reservoir storage.
The Geographical Information Systems (GIS), which have been extended and integrated with the hydrological distributed model, were used to analyse and modelling the hydrological response. With input of spatial and topographic condition of the study area (Digital Elevation Model), watershed was delineated automatically by SWAT. Runoff was predicted separately for each Hydrological Response Unit (HRU) and routed to obtain the total runoff for the watershed. The process in the HRU was considered to be lumped. This increases accuracy and gives a much better physical description of the water balance.

In some extent, parameters of hydrologic models are not exactly known and therefore have to be determined by calibration. Parameter adjustments were carried out to correspond the model result to the actual condition.

In SWAT, water balance is the driving force behind everything that happens in the watershed. The hydrologic cycle as simulated by the model must conform to what is happening in the watershed. Simulation of the hydrology of a watershed can be separated into two major divisions. The first one is the land phase of the hydrologic cycle, which controls the amount of water reaching the main channel in each sub-basin. The second division is the water or routing phase of the hydrologic cycle, which can be defined as the movement of water through the channel network of the watershed to the outlet (Neitsch 2002).

2.2.1.1. Land Phase of the Hydrologic Cycle

The hydrologic cycle as simulated by SWAT is based on the water balance equation (Neitsch 2002):

$$SW_t = SW + \sum_{i=1}^{t} (R_i - Q_i - ET_i - P_i - QR_i)$$

Where;

SW_t	= final soil water content (mm)
SW	= soil water content available for plant uptake, defined as the initial soil water content minus the permanent wilting point water content (mm)
t	= time (days)
R_i	= amount of precipitation (mm)
Q_i	= amount of surface runoff (mm)
ET_i	= amount of evapotranspiration (mm)
P_i	= amount of percolation (mm)
QR_i	= amount of return flow (mm).

Schematic representation of the land phase of hydrological cycle is displayed in figure 2.6.

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Figure 2.7 shows the general sequence of processes used by SWAT to model the land phase of hydrology.

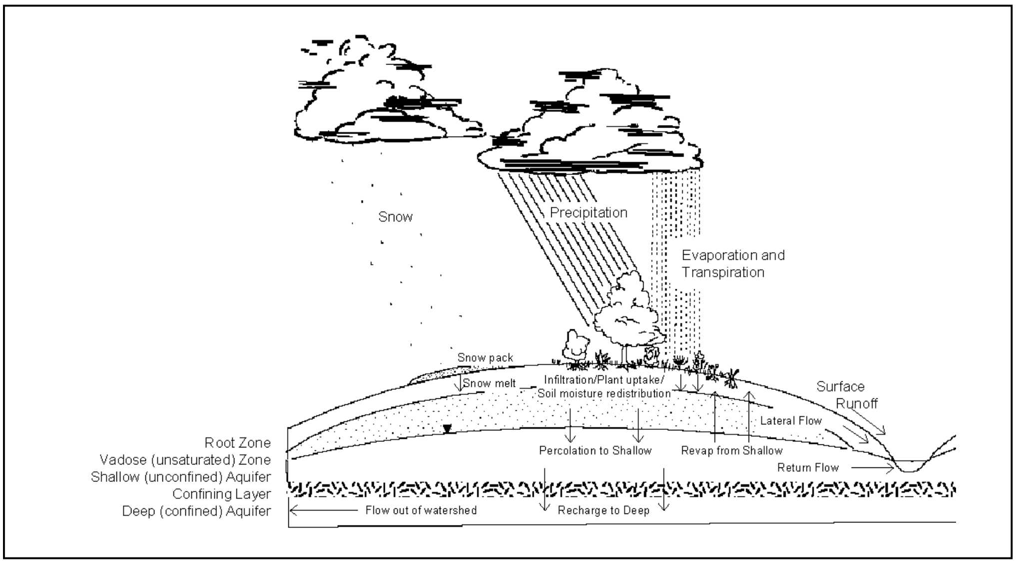


Figure 2.6 Schematic representation of the land phase of hydrological cycle (Neitsch 2002)

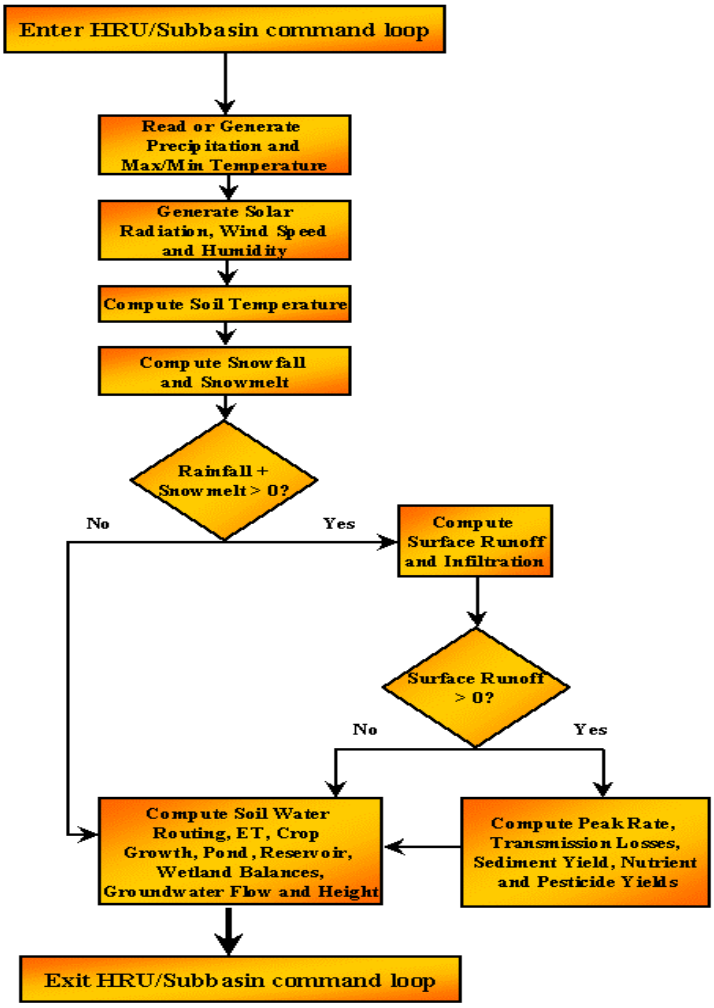


Figure 2.7 Hydrological Respons Unit (HRU)/Sub-basin command loop

(Neitsch 2002)

2.2.1.2. Routing Phase of the Hydrologic Cycle

Routing in the main channel can be divided into four components: water, sediment, nutrients and organic chemicals. Regarding to the research objective, which was to calculate the water quantity in the study area, only the water component was considered.

As water flows downstream, a portion may be lost due to evaporation and transmission through the bed of the channel. Another potential loss is the removal of water from the channel for agricultural or human use. Flow may be supplemented by the fall of rain directly on the channel and/or addition of water from point source discharges. Flow is routed through the channel using a variable storage coefficient method (Williams, 1969 in Neitsch 2002).

The water balance for reservoirs includes inflow, outflow, precipitation on the surface, evaporation, seepage from the reservoir bottom and diversions. The model offers three alternatives for estimating outflow from the reservoir. The first option allows the user to input measured outflow. The second option (designed for small and uncontrolled reservoirs) requires the users to specify a water release rate. When the reservoir volume exceeds the principle storage, the extra water is released at the specified rate. Volume exceeding the emergency spillway is released within one day. The third option, designed for larger, managed reservoirs, allows the user to specify monthly target volumes for the reservoir (Neitsch 2002). Figure 2.8 illustrates the different in-stream processes.

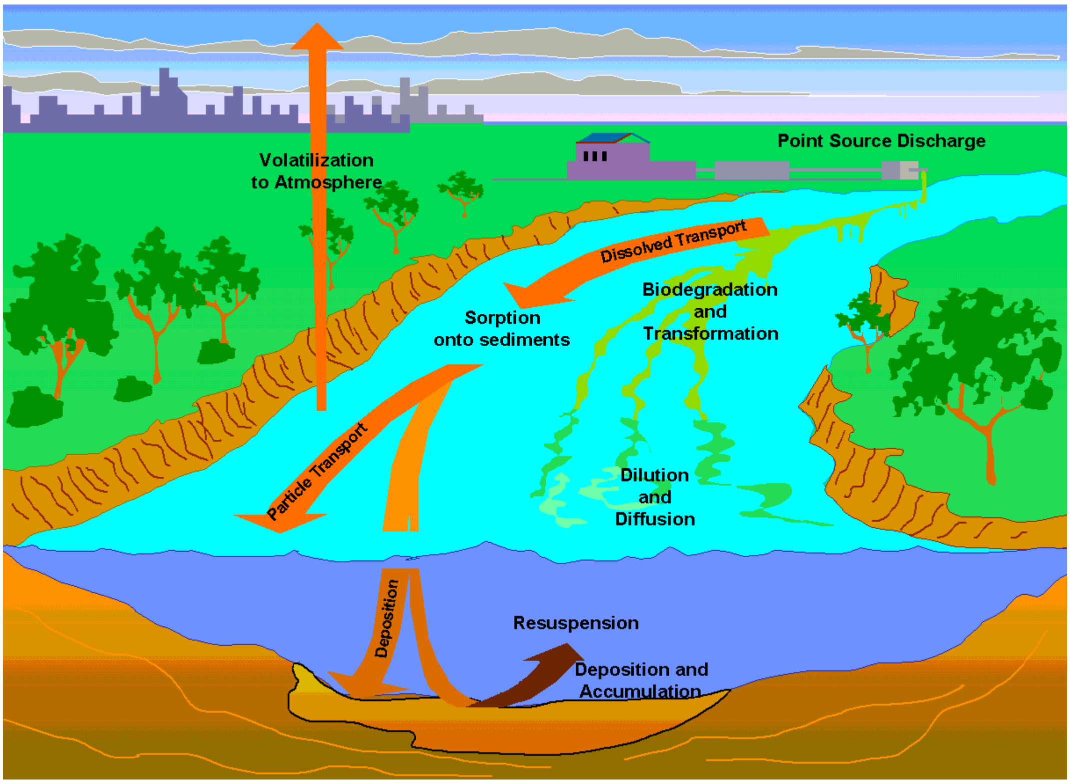


Figure 2.8 In-stream processes modelled by SWAT

(Neitsch 2002)

2.2.2. Methods for Determining the Lake Level Fluctuation

The next step was to incorporate the outflow from Malewa basin with the Water Balance Model of Lake Naivasha (Mmbui, 1999). This attempt was done to model the lake water level fluctuation; since the ability of the hydrologic model (SWAT) cannot directly model the lake water level.

A simple water balance base on mass conservation equation was satisfactorily implemented in the study area by Mmbui (1999). After several adjustments in the discharge of the lake, the model showed a correlation factor of 0.9 with the observed data. The water balance model is simulated for the period 1932 to 1998 and runs on monthly time steps.

The model equation used is formulated below:

$$dS = P - ET + R + GWin - GWout$$

Where;

P	= direct precipitation into the lake
ET	= evapotranspiration
R	= surface Runoff into the lake
GW_{in}	= ground water inflow into the lake
GW_{out}	= ground water out flow from the lake
dS	= change in lake storage.

In this research, the water balance model used the same concept for modelling the lake or a reservoir. Neitsch (2002) expressed the water balance of a reservoir as:

$$V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep} \quad (\text{m}^3 \text{ of water})$$

Where;

V = volume of water in the impoundment at the end of a day

V_{stored} = volume of water stored in the water body beginning of the day

V_{flowin} = volume of water entering the water body per day

$V_{flowout}$ = volume of water flowing out of water body per day

V_{pcp} = volume of precipitation falling on the water body per day

V_{evap} = volume of water removes by evaporation per day

V_{seep} = volume of water lost from water body by seepage

As mentioned in section 2.1.1, the Lake Naivasha gets the inflow from two perennial (Malewa and Gilgil) and an ephermal (Karati) Rivers without surface outlet. The Malewa basin contributes 90% of the total inflow through the lake. Based on this condition and in order to simplify the model, the Malewa Basin outflow was assumed as equal to the Lake inflow.

Mmbui (1999) has made a model base on precipitation-runoff-lake level relationship. The idea behind creating this model was to extend the flow series of the three major rivers (Malewa, Karati and Gilgil) to 1900 with a view to modelling the lake balance to that period. Two types of models were tried. The first was multi-linear regression between precipitation and total discharge from the cachment based on the above named three rivers. The second model is a spreadsheet simplification of the HBV model. The HBV model is a conceptual model for continuous computation of river discharge.

Mmbui (1999) was studied the long-term water balance of the basin and modelled on monthly time step for the period of 1932-1997. The Water Balance of Lake Naivasha Model revealed a groundwater out flow of 4.6 million m^3 per month and lake abstraction of 57 mcm/month, then its estimated a long-term average for the total combined inflow from River Malewa, Gilgil, Turasha, Karati and surface runoff into the lake which is about 2.26 mcm/month.

2.2.3. Methods for Climate Change and Variability Impact Assessment

A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. These type of scenarios often make use of climate projections (descriptions of modeled response of climate system to scenarios of greenhouse gas and aerosol concentration), by manipulating model outputs and combining them to the observed climate data (Mearns 2002)

Box 2.1 What Is Climate Change?

Climate Change in Inter-Intergovernmental Panel on Climate Change (IPCC) usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where ***Climate Change*** refers to a change of climate that is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time (IPCC, 2001).

By describing future climatic condition, different scenarios of climate change can be simulated. IPCC assesses the methods used to develop climate scenarios. Impact assessments have a very wide range of scenario requirements, ranging from global mean estimates of temperature and sea level, through continental-scale description of change in mean monthly climate, to point or basins-level detail about future change in daily or even sub daily climate (Mearns 2002)

Simulation is the time-varying description of a natural system computed by the hydrological model (Abbot 1996). Regarding this definition, in this research, the IPCC Scenario of climate change and variability had been simulated to acquire an overview of the climatic condition for the simulated years.

The effect of climate change on stream flow and groundwater recharge varies regionally and between climate scenarios, largely following projected change in precipitation (IPCC 2001). In general, the projected evaporation changes in average annual runoff are less robust than impact based solely on temperature change, because precipitation changes vary more than scenarios. At the basin scale, the effect of a given alteration in climate varies with physical properties and vegetation; in addition to land cover change.

2.3. Concluding Remark

To represent the complex hydrological behaviour of Lake Naivasha Basin, a physically base distributed model appears to be suitable. This model is useful for future analysis of Lake Naivasha sustainability, since modelling strategy provides a general framework for evaluating the impacts of climate change and climate variability.

Soil and Water Assessment Tool (SWAT) model is consider appropriate for this purpose, due to its capabilities and characteristics. Among the advantages of this approach are the capabilities to model watershed with lack of monitoring data and the possibility to quantify the relative impact of alternative input data (e.g. change in climate condition) on the variable of interest (Neitsch 2002)

The output of the model was incorporated with the Water Balance Model of Lake Naivasha based on multi-linear regression between precipitation and total discharge from the basin (Mmbui 1999) since SWAT has no capability to model the lake level fluctuation. The outflow from Malewa basin was assumed as the inflow of the lake.

Calibration is required to determine the hydrologic parameters of the models, which often are not exactly known. After calibrating the model against the historical data, the IPCC climate change scenario was run.

The simulation of the developed scenario was done to predict and assess the impact of climate change and variability regionally. The general modelling approach provided a general assessment of the role of climate change and variability to the lake water level fluctuation.

3. Hydrological Modeling

3.1. Introduction

The hydrological model used in this research, has adequately represented the discharge response to precipitation for the historic period of 1935-2000 using long-term measured records, including the physical processes inside. The discharge outflow from the basin was associated to lake water level.

In this chapter, the watershed-modelling framework is delineated starting from the digital description of the landscape (Digital Elevation Model). The aims are to identify and correlate the spatial boundaries and geomorphic characteristics of a hydrographical basin (and its sub-units) together with their hydrologic parameters (Land use and Soil type's maps).

Long periods of weather data are frequently needed to evaluate the long-term effects of proposed hydrological changes. The meteorological variables needed for most of the hydrological models include precipitation, maximum and minimum temperatures, solar radiation or some related variables.

3.2. Modelling Set-up

Apart from precipitation characteristics such as intensity, duration and distribution, there are a number of basin specific factors that have a direct influence on the occurrence and volume of runoff. Slope and basin size as well as soil type and vegetation (land use) are the affecting factors of runoff.

In the Soil and Water Assessment Tool (SWAT) model, watershed is partitioned into a number of sub watersheds or sub-basins for modelling purposes. This attempt gives advantages for dissimilar land use or soil properties to impact hydrology. By partitioning, one watershed is spatially referenced in relation to the others (Neitsch 2002).

Input information for each sub-basin is grouped or organized into climate, hydrologic response unit (HRU), ponds/wetlands, groundwater and the main channel /reach draining the sub-basin categories. Hydrologic response unit are lumped lands areas within the sub-basin that are comprised of unique land cover, soil and management combinations.

To set up the model and create the input files, the following steps were implemented:

- Watershed delineation
- Land use and soil definition
- Climate data definition
- Parameterisation

Each step is explained below.

3.2.1. Watershed Delineation

This process consist in the delimitation of the topographic features, it means the geographic area in which every drop of water drains to the network stream evaluated. Not only does a watershed drain, it also captures precipitation, filters and stores water, and determines its release.

The *Automatic Watershed Delineation* tool carries out advanced GIS functions to help in segmenting watersheds into several “hydrologically” connected sub-basin for use in watershed characterization and modeling (http://www.epa.gov/waterscience/basins/b3docs/sec8_2.pdf 2002).

The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the basin, which means that the larger the size of the basin the larger the time of concentration and the smaller the runoff efficiency.

The conventional methods for watershed delineation require a topographic map (or stereoscopically viewed aerial photographs) (Dingman 1994). Currently, topographic information is becoming available in the form of Digital Elevation Models (DEM). These are computer data files that give land-surface elevation at grid points. Although it is not an entirely straightforward exercise, it is possible to develop computer programs that can trace out water divides and stream networks by analysing the DEM (Fairfield and Leymarie, 1991 in Dingman 1994).

Delineation of stream network from a raster DEM is based on the eight-pour point algorithm (Jenson and Domingue, 1988). Flow vector grid is created filling the sinks (raising the elevation of the sink until overflow occurs). The flow accumulation grid is created by counting the number of contributing cells to each unit in the grid (cells whose flow path eventually passes through them). Cells which are potentially part of a stream network will have a larger flow accumulation value; whereas cells near watershed boundaries and where overland flow dominates will have a low flow accumulation value.

In this step, a DEM was prepared by using a contour map with 20 meters interval of the study area digitised before by previous MSc students. To cover the whole Lake Naivasha Basin, the missing part was digitised from a 1:125000-scale topography map using ILWIS 3.11. Although the contour interval size was different, it had to be used because it was the only available map containing the upper-catchment.

Digital Elevation Model was created using the contour interpolation function in ILWIS 3.11, with 20-meter-pixel size (figure 3.1.). After that, the DEM file was exported (as ASCII file) to SWAT interface program. The further processes were done in SWAT interface.

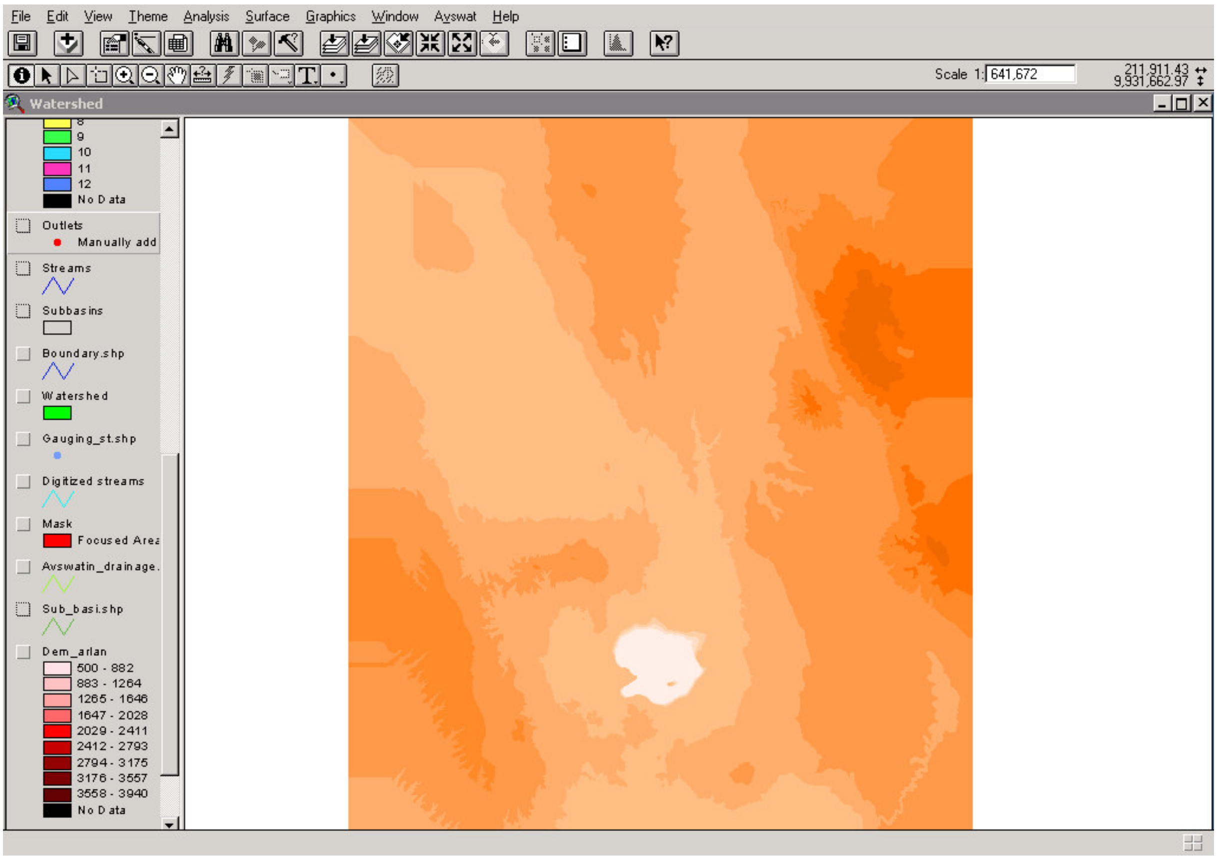


Figure 3.1 Digital Elevation Model

In order to reduce the processing area and focus on the area of interest, a clipping procedure was used to crop the watershed area. A comparison with the manual delineation from previous research was done. The SWAT delineation gave as result a total area of 3313.880 sqkm (figure 3.2). The existing watershed consists of around 3300 sqkm.

The second process of watershed delineation is *the burn-in* the DEM using digitised stream network. This process was performed to modify the DEM by raising the elevation values of all the cells excepting those that coincide with the digitised streams. The stream network for the whole watershed was already available (from previous MSc studies), but several updates were carried out, on the upper-catchments and the southeastern part of the lake, including almost every stream network in the study area (figure 3.3). The stream was also modified forcing the network to drain in one point, by artificially joining Malewa and Gilgil River.

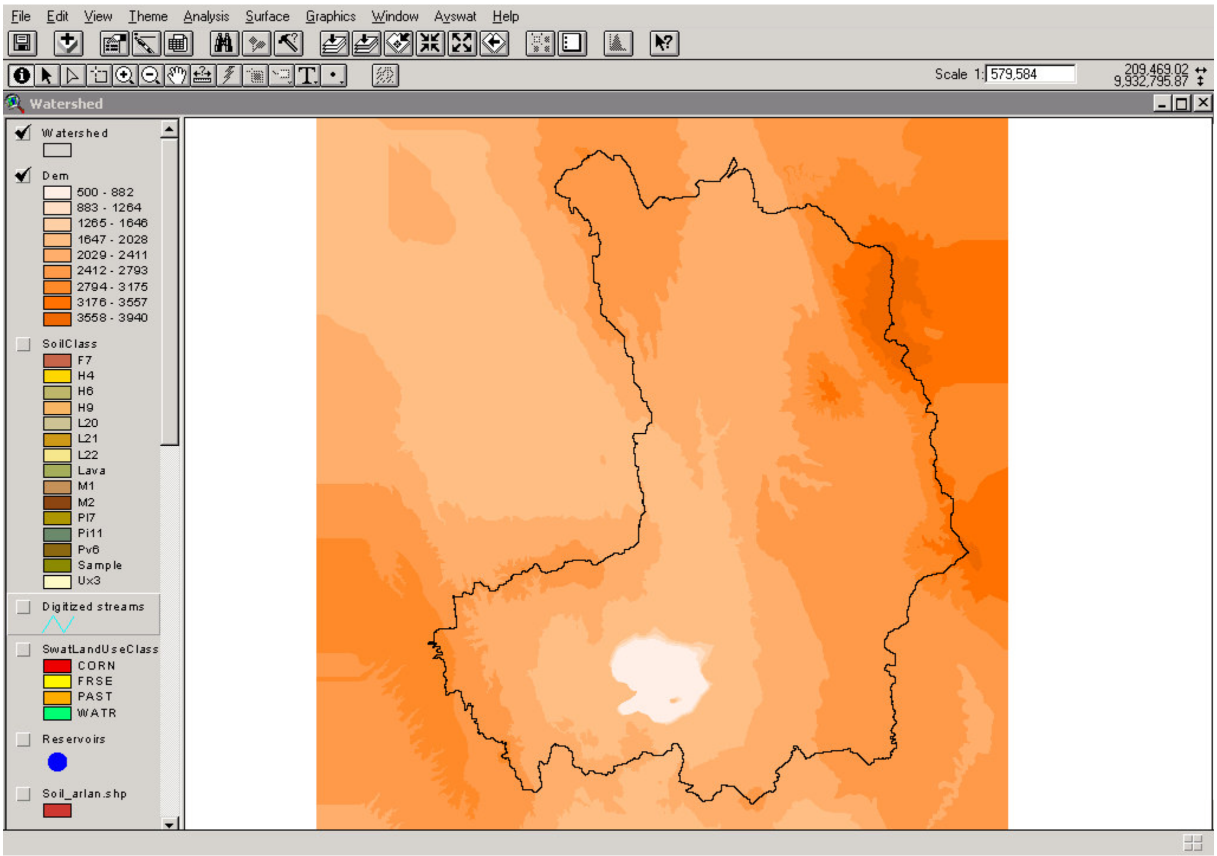


Figure 3.2 Watershed boundaries as result of SWAT model

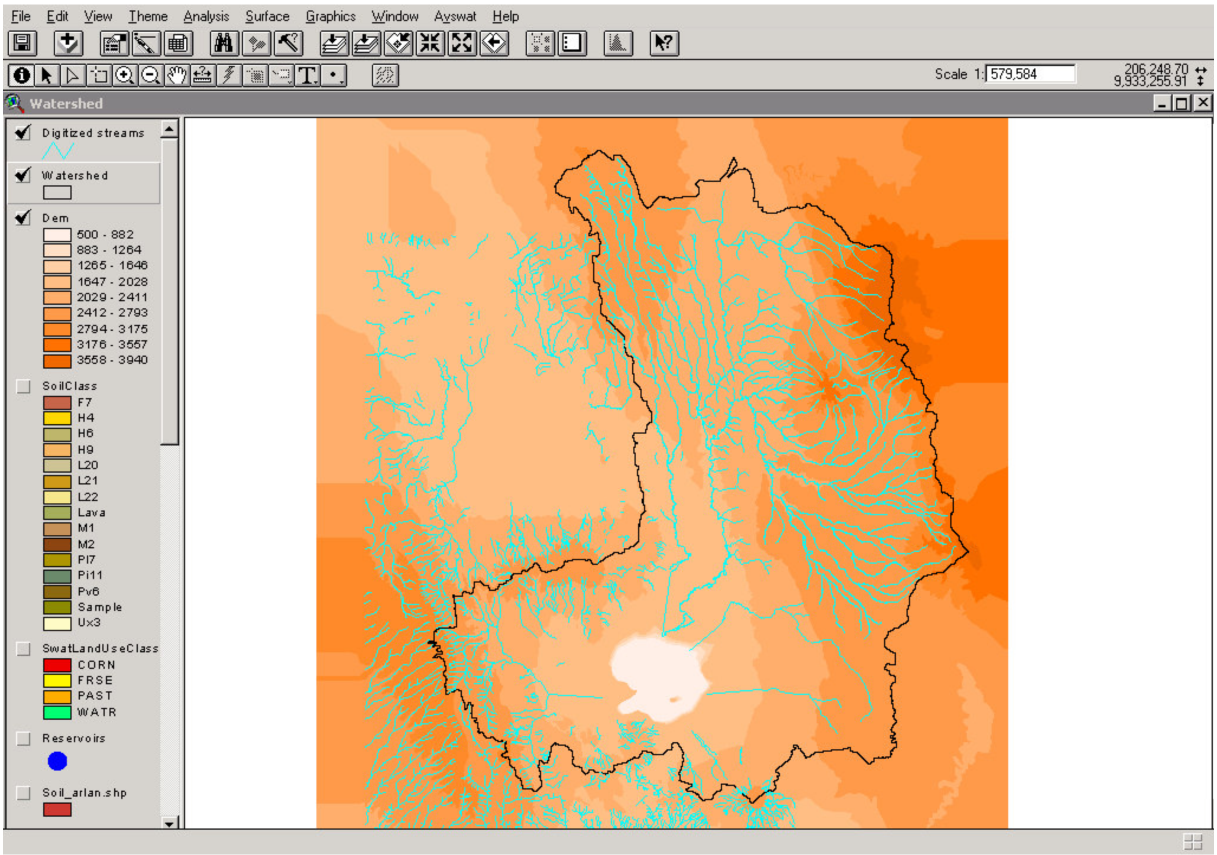


Figure 3.3 Stream network in the study area

The stream branches were controlled by using a specified threshold on the contributing number of grid cells (flow accumulation grid) making up the branch. The default definition of the sub-basin outlet points was executed by placing the downstream edge for each branch. By using the minimum value of thresholds, every small stream within the study area was covered. Figure 3.4 shows the stream network after implementing the minimum threshold value and removes the entire default outlet.

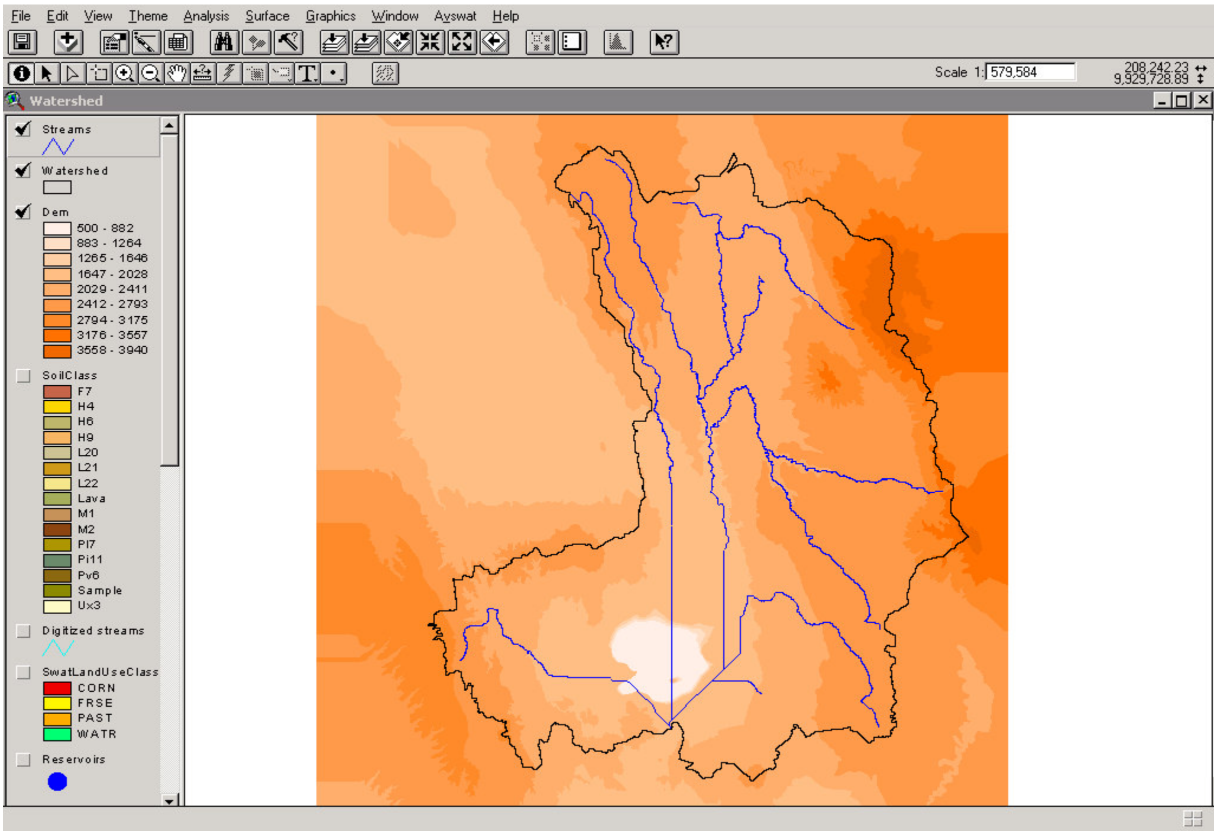


Figure 3.4 Stream network after implementing minimum threshold and removing outlets

The definition of the coordinate system in the DEM properties (Table 3.1) plays an important role determining the threshold value as number of contributing cells (expressed in hectare). From previous MSc studies (Podder 1998) a sub-basin map, based on field measurements, was acquired and used as reference for defining the outlet points manually, which replace the SWAT default ones.

One outlet location was specified to define the main watershed outlet by a *customized selection* tool and a process of tracing the flow direction from each grid cell until the outlet was performed in the sub-basin delineation. Some of the outlet points were placed on the gauging station position, for calibration purposes. This control points were not used in this research since the main consideration was the total amount of water yield coming into the lake. Due to time constrains the calibration of the stream flow was not performed.

Table 3.1 Coordinate System

Projection	Universal Transverse Mercator
Spheroid	Clarke 1880
Datum	Arc 1960
Zone	37
Central Meridian	39
Reference Latitude	0
Northing	10000000
Easting	500000
Scale factor	0.9996

Sub-basin partitioning is useful when different areas of the watershed have land use or soil types with properties dissimilar enough to impact hydrology.

After watershed and sub-basin boundaries determination process, the model calculates all geometric parameters of sub-basins and streams by raster-grid functions and stores them as attributes derived from the vector themes. For each sub-basin, slope and length of the main stream channel were calculated from inlet to outlet, and the longest stream channel was extended from each outlet to the most distance point.

Once accomplished the previous procedures, a reservoir was placed as representation of the lake. In the model, the position of the lake was deviated from the actual position, since the model calculate the accumulation of the total flow from every sub-basin in the lowest point. In this case, the model considers the edge of the DEM as the lowest point (Figure 3.5).

An attempt to locate the reservoir on the actual place of the lake was done by creating a sink inside it, before DEM interpolation. A lower altitude value was given to the contour line of the lake in order to create this sink, but after numerous tries, the streams still draining out of the actual area of the lake.

This failure was attributed to the model, which removes the sinks when it delineates the watershed in the DEM set up. The extreme values inside the lake were removed by *removing sink option*. Further attempts might be done by masking the area just before the streamline reaches the lake.

Finally, the reservoir was placed on the sub-basin 14.

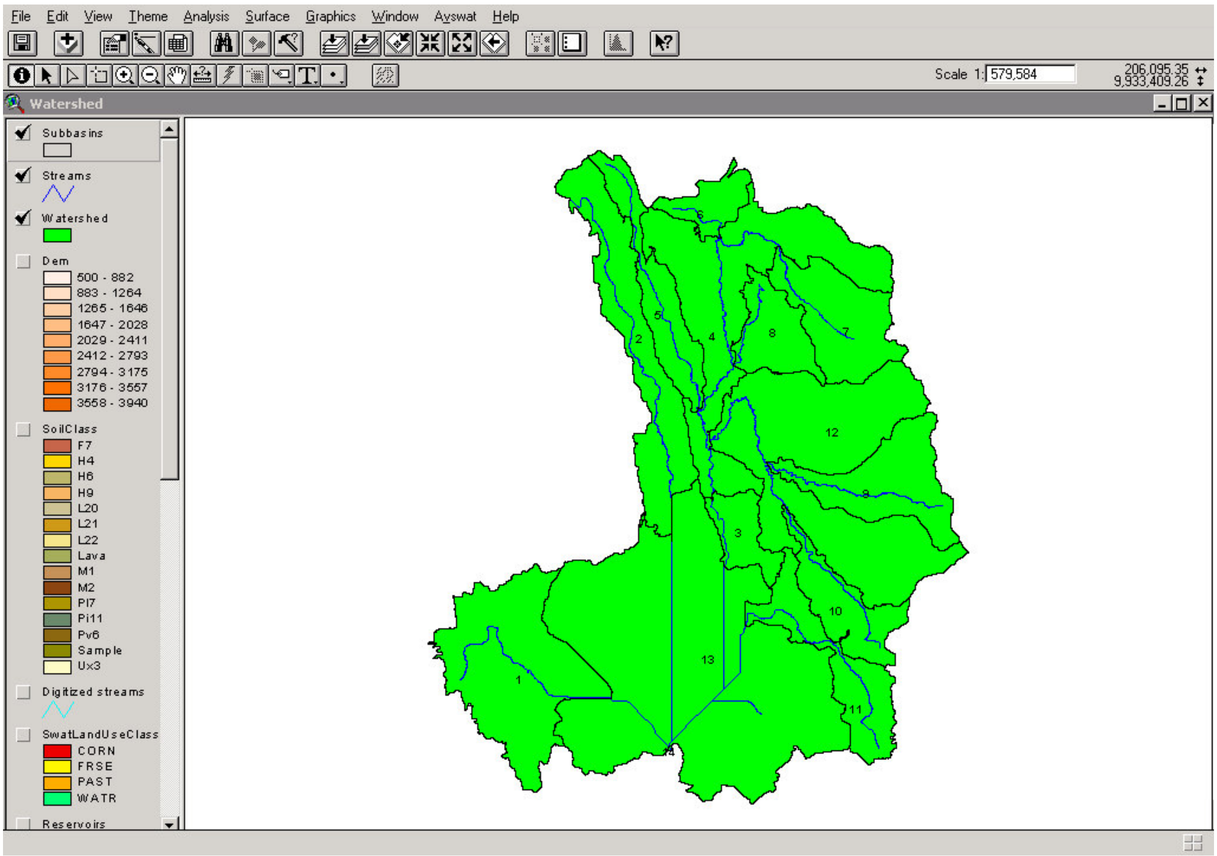


Figure 3.5 Results from the SWAT Watershed Delineation

3.2.2. Land Use and Soil Definition

The amount of rain lost due to interception storage on the plants depends on the type of vegetation and its growth stage. Standard values of interception are between 1 and 4 mm. More significant is the effect of vegetation (land use) on the infiltration capacity of the soil. Dense vegetation covers the soil from the raindrop impact and reduces the crusting effect.

In addition, the root system as well as the presence of organic matter in the soil increases the soil porosity allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving the water more time to infiltrate and evaporate.

The infiltration capacity depends, among others, on the porosity of the soil; which in turn determines the water storage capacity and affects the resistance of water to flow into deeper layers. The highest infiltration capacities are observed in loose, sandy soil while heavy clay or loamy soil has considerable smaller infiltration capacity.

This property depends furthermore on the moisture content prevailing in a soil at the beginning of a rainstorm. The initial capacity decreases with time until it reaches a constant value when the soil profile becomes saturated. This condition is only valid when the soil surface remains undisturbed.

Another factor to be considered is the average size of raindrop, which increases with the intensity of a rainstorm. In a high intensity storm the kinetic energy of raindrops is significant when hitting the soil surface. This causes a breakdown of the soil aggregates as well as soil dispersion. The driving of the fine particles into the upper soil pores, results in clogging of the pores and formation of a thin but dense and compacted layer at the surface, which highly reduces the infiltration capacity. This effect, often referred to as *capping*, *crusting* or *sealing*, explains why in arid and semi-arid areas (like Kenya), where high intensities rainstorms are frequent, significant quantities of surface runoff are observed even when the duration of the rainfall is short and the precipitation depth is comparatively small.

Soils with a high clay or loam content are the most sensitive to form a cap with the subsequent lowering in their infiltration capacities. On coarse sandy soil, the capping effect is comparatively small.

The soil and land use information used in this research was obtained from Land use and Soil maps created in previous researches. Those two maps were exported from ILWIS 3.11 to Arc View as shape file (*.shp format).

Reclassification of land use was done using land cover classes from USDA data set. In order to simplify the model, four land cover types were implemented for the area: Forest, Corn agriculture, Pasture and Water (Figure 3.6). The land use map was reclassified from the one created before by Al Sabbagh (Al Sabbagh 2001).

The soil map used, from Kenya Soil Survey Department, was also acquired from a previous MSc research (Podder 1998) (Figure 3.7).

For modelling simplification, in this research was assumed that, every sub-basin corresponds to one type of land use and soil type (as a dominant land use and soil type). However, it should be mentioned, that SWAT has the capability to incorporate different percentages of land use and soil type.

The hydrologic cycle, as simulated by the model, must conform the real situation in the watershed. Simulation of the hydrology of a watershed in the land phase of the hydrologic cycle, controls the amount of water reaching the main channel in each sub-basin.

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. The infiltration rate will decrease as the soil becomes saturated. When the application rate is higher than the infiltration rate, surface depressions start to be infilling. If the application rate continues to become higher than the infiltration rate and all the surface depressions have been filled, surface runoff will initiate (Neitsch 2002).

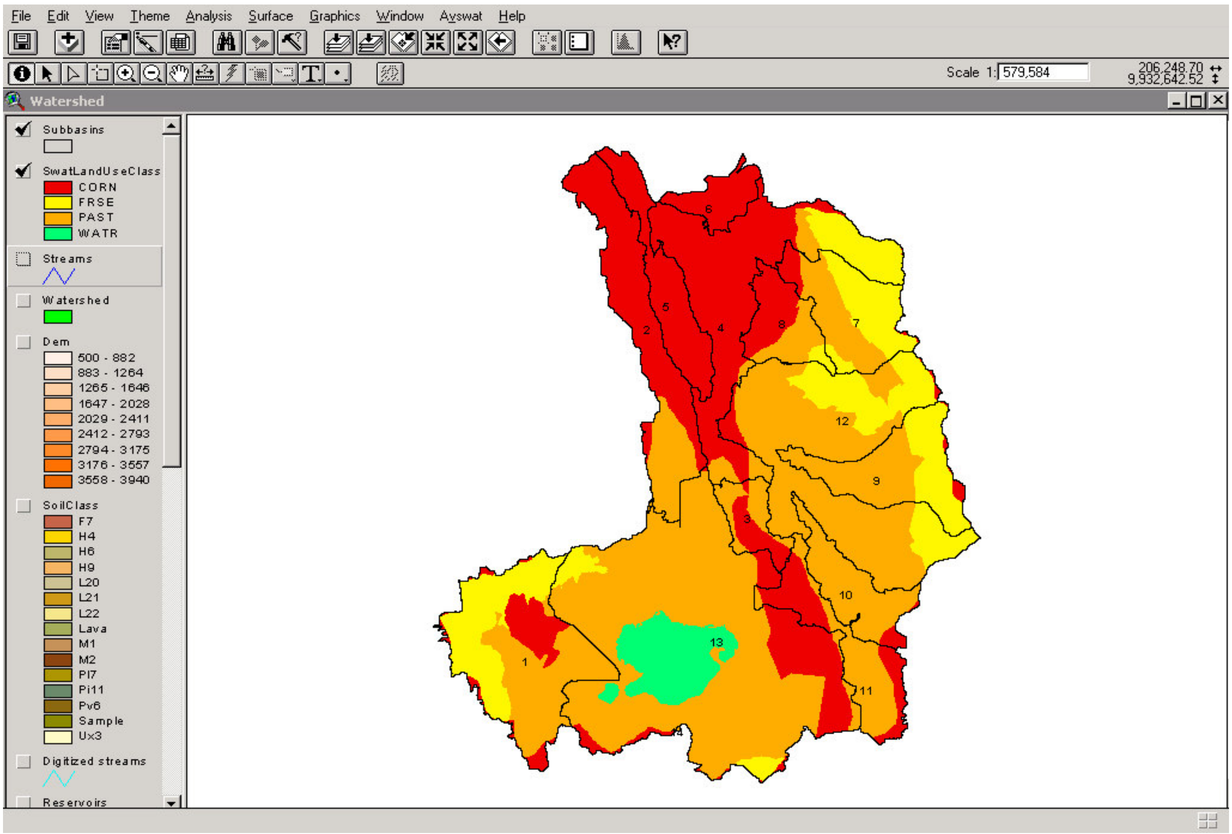


Figure 3.6 Land Use (reclassified) Map

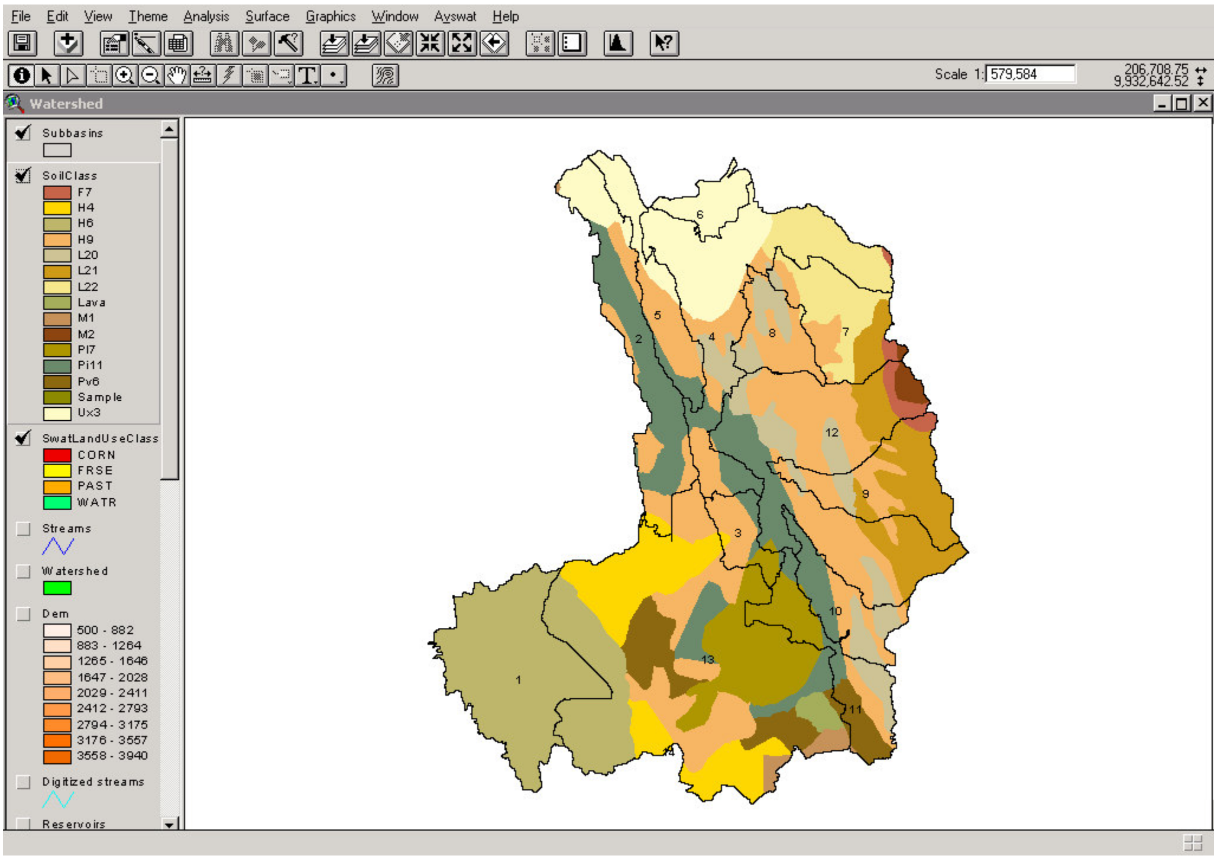


Figure 3.7 Soil (reclassified) Map

By dividing the watershed into sub-basin the model can reflect differences in evapotranspiration, regarding to the different land use and soils type. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. The process in the HRU is considered lumped. This increases the accuracy and gives a better physical description of the water balance.

The Soil Conservation Service (SCS) Curve Number Method was developed to provide a consistent base for estimating the amount of runoff under different land use and soil type (Neitsch 2002).

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

Where:

Q_{surf}	= accumulated runoff or precipitation excess (mm)
R_{day}	= precipitation depth for the day (mm)
I_a	= initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm)
S	= retention parameter (mm).

The retention parameter varies spatially due to changes in soil, land use, management and slope, and temporally due to change in soil water content. The retention parameter (S) is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

CN is runoff curve number for the day. The initial abstraction (I_a) is commonly approximate as 0.2 S and the equation becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{R_{day} + 0.8S}$$

Runoff will only occur when $R_{day} > I_a$. Curve number is based on the soils and land uses in the watershed.

SWAT consist two methods for calculating runoff: SCS Curve Number and Green Ampt. In this research, SCS Curve Number was used since Green and Ampt methods require hourly precipitation data (Neitsch 2002) which was not available.

3.2.3. Climate Data

Analysis of precipitation in the Lake Naivasha Basin was important, as this is the major factor to understand the basis of the variations in lake level and to forecast its future behaviour (Per Syren, 1986 in(Rupasingha 2002)). Daily climate records for the period of 1935-2000 were analysed to develop the climate-input files required for the model.

Data was collected for four monitoring station within and surrounding the Lake Naivasha Basin. The spatial distribution of the stations used in the study is listed in table 3.2. Measured precipitation data (from these stations) is presented in Appendix A. Figure 3.8 shows the rain gauge station distribution.

Table 3.2 Weather station spatial data

Station ID	Station Name	X	Y	Elevation (m amsl)
9036002	Naivasha DO	214315	9920714	1900
9036025	North Kinangop Forest Station	238582	9935474	2629
9036241	Geta Forrest Station	207148	9948369	2591
9036264	North Kinangop Mawingo Scheme	223586	9944688	2484

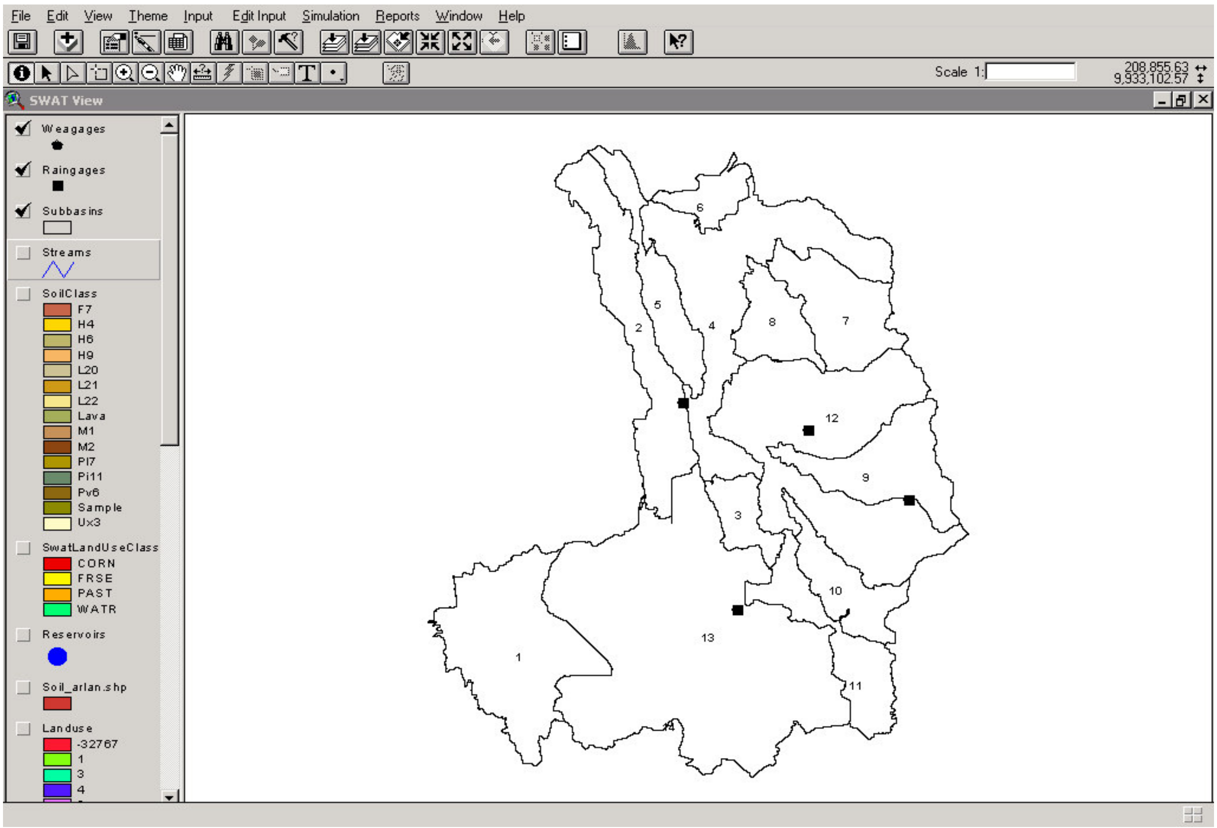


Figure 3.8 Rain gauge and weather stations location

The available daily precipitation data for the four stations is listed in table 3.3.

Table 3.3 Daily precipitation data availability

Station ID	Station Name	Available data
9036002	Naivasha DO	1935-1998
9036025	North Kinangop Forest Station	1957-1998
9036241	Geta Forrest Station	1958-1998
9036264	North Kinangop Mawingo Scheme	1964-1998

However, those data sets had many gaps of missing data, which became significant, since the data were not covered the dry periods of 1950's and the big floods at the beginning of 1960's. In addition, those gaps consisted from one until three months of missing data.

WXGEN weather generator model algorithm (Sharpley and Williams, 1990 in Neitsch 2002) was used in the precipitation data analysis, to generate climatic data and to fill the gaps in measured data in SWAT model.
A concept of the stochastic relationships that underlie the basic meteorological processes has been developed to simulate the meteorological variation of interest (Richardson, 1981 Neitsch 2002).

3.2.4. Weather Generator

The weather generator input file (*.wgn) encloses the statistical data needed to generate representative precipitation intensity and other climate variables from the daily precipitation and max/min temperature data. To create weather generator input file long-term data is required. Weather data definition set for the model consists of information about precipitation, temperature, solar radiation, wind speed, and relative humidity. In this study, data for weather generator input file (*.wgn) did not contain solar radiation, wind speed and relative humidity.

The precipitation generator is a Marchov chain-skewed (Nicks 1974 in Neitsch 2002) or Marchov chain-exponential model (William 1995 in Neitsch, 2002). A first order Marchov chain is used to define the day as wet or dry. When a wet or dry day is generated, skewed or exponential distribution is used to generate the precipitation amount.

3.2.4.1 Occurrence of wet or dry day

With the first order Markov chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.1 mm of rain or more (Neitsch 2002)

The probability of a wet day on day *i* given a wet day on day *i*-1 is P*i* (W/W), and the probability of a wet day on day *i* given a dry day on day *i*-1 is P*i* (W/D), for each month of the year. From these input the remaining transition probabilities can be derived:

$$P_i(D/W) = 1 - P_i(W/W)$$
$$P_i(D/D) = 1 - P_i(W/D)$$

Where P_i (D/W) is the probability of a dry day on day *i* given a wet on day *i*-1 and P_i (D/D) is the probability of a dry day on day I given a dry day on day *i*-1.

To define if a day is either wet or dry, a random number between 0.0 – 1.0 is generated. This random number is compared to the appropriate wet-dry probability, P_i (W/W) or P_i (W/D). If the random number is equal to or less than the wet-dry probability, the day is defined as wet. If the random number is greater than the wet-dry probability, the day is defined as dry.

3.2.4.2 Amount of precipitation

The skewed distribution was proposed by Nicks (1974) and is based on a skewed distribution used by Fiering (1967) to generate representative stream flow (Neitsch 2002).

The equation used to calculate the amount of precipitation on a wet day is:

$$R_{day} = \mu_{month} + 2 \cdot \sigma_{month} \cdot \left\{ \frac{\left[\left(SND_{day} - \frac{g_{month}}{6} \right) \cdot \left(\frac{g_{month}}{6} \right) + 1 \right]^3 - 1}{g_{month}} \right\}$$

Where:

R_{day} = amount of precipitation on a given day (mm)
μ_{month} = mean daily precipitation (mm) for the month
σ_{month} = standard deviation of daily precipitation (mm) for the month
SDN_{day} = standard normal deviation calculated for the day
g_{month} = coefficient of skewness for daily precipitation in the month.

The mean daily precipitation (mm) for the month is calculated:

$$\mu_{month} = \frac{PCPMM}{PCPD}$$

Where:

PCPMM = average mount of precipitation falling in month (mm)
PCPD = average number of days of precipitation in month.

The standard normal deviate (SDN) for the day is calculated:

$$SDN_{day} = \cos(6.283 \cdot rnd_2) \cdot \sqrt{-2 \ln(rnd_1)}$$

Where rnd_1 and rnd_2 are random number between 0.0 and 1.0

3.2.5. Potential Evapotranspiration

Potential evapotranspiration (PET) is a concept originally introduced by Thornhwaite (1948) as part of a climate classification scheme (Neitsch 2002). The concept defined PET as the rate at which evapotranspiration would occur from a large area uniformly covered with growing vegetation that has access to an unlimited supply of soil water content and that was not exposed to advection or heat storage effect.

As the evapotranspiration rate is strongly influenced by a number of vegetative surface characteristics, Penman (1956) redefined PET as "The amount of water transpired …by short green crop, completely shading the ground, of uniform height and never short of water". Grass type of vegetation has been used as reference crop by Penman, but later researchers have suggested that alfalfa at a height of 30 to 50 cm may be a more appropriate choice.

Potential evapotranspiration can be implemented in SWAT with three methods:

- Penman-Monteith
- Priestly-Taylor
- Hargreaves

Penman-Monteith is considered as the de-facto standard. However, also the method is most data demanding. The equation:

$$\lambda E = \frac{\Delta \cdot (H_{net} - G) + \rho_{air} \cdot c_p \cdot \left[(e_z^o - e_z) / r_a \right]}{\Delta + \gamma \cdot \left[1 + (r_c / r_a) \right]}$$

Where:

λ	= latent heat flux density (MJ $m^{-2}d^{-1}$)
E	= depth rate evaporation (mm d^{-1})
Δ	= slope of saturation vapor pressure – temperature curve (kPa $^oC^{-1}$)
H_{net}	= nett radiation (MJ m^{-2} d^{-1})
G	= heat flux density to the ground (MJ m^{-2} d^{-1})
ρ_{air}	= air density (kg m^{-3})
c_p	= specific heat at constant pressure (MJ m^{-2} d^{-1})
e_z	= water vapour pressure of air height z (kPa)
γ	= psychometric constant (kPa $^oC^{-1}$)
r_c	= pant canopy resistant (s m^{-1})
r_a	= diffusion resistance of the air layer (aerodynamic resistance) (s m^{-1}).

Priestly-Taylor equation is defined as:

$$\lambda E_o = \alpha_{pet} \cdot \frac{\Delta}{\Delta + \gamma} \cdot (H_{net} - G)$$

Where:

λ	= latent heat of vaporization (MJ kg^{-1})
E_o	= potential evapotranspiration (mmd^{-1})
α_{pet}	= P-T coefficient
Δ	= slope of saturation vapour pressure – temperature curve (kPa $^oC^{-1}$)
γ	= psychometric constant (kPa $^oC^{-1}$)
H_{net}	= net radiation (MJ m^{-2} d^{-1})
G	= ground heat flux (MJ m^{-2} d^{-1}).

Hargreaves equation is:

$$\lambda E_o = 0.0023 \cdot H_o \cdot (T_{max} - T_{min})^{0.5} \cdot (T_{avg} + 17.8)$$

With T_{avg}, T_{max} and T_{min} are average, maximum and minimum temperatures (^oC) and H_o is extraterestial radiation (MJ m^{-2} d^{-1})

3.3. Modelling Result

The model was run in monthly time step from January 1935 to December 2000. Monthly time step was chosen because it was the same time step for the Water Balance Model of Lake Naivasha input (Mmbui 1999). This model was based on regression between precipitation and total discharge from the basin. A correlation (R^2)= 0.9 between monthly values for river inflow, the average precipitation on the lake and the potential evapotranspiration was obtained.

The Water Balance Model of Lake Naivasha estimates the ground water outflow at 4.6 million cubic meters per month. Lake water abstraction, which was estimated in 57 million cubic meters per year, was not taken into the consideration.

As was already mentioned, solar radiation, wind speed and relative humidity data were not available. For this reason the Hargraves method was used for potential evapotranspiration calculation, since this method only use temperature as input (Neitsch 2002).

The result of the model (output file) is read in Dbase file (dbfs) since the interface converts the ASCII format to Dbase file. SWAT gives result for outflow from every sub-basin (*.rch file). The discharge (FLOW_OUT) values in sub-basin file (*.rch) file were used as the input for the Water Balance Model of Lake Naivasha. The result for the first run is shown in figure 3.9.

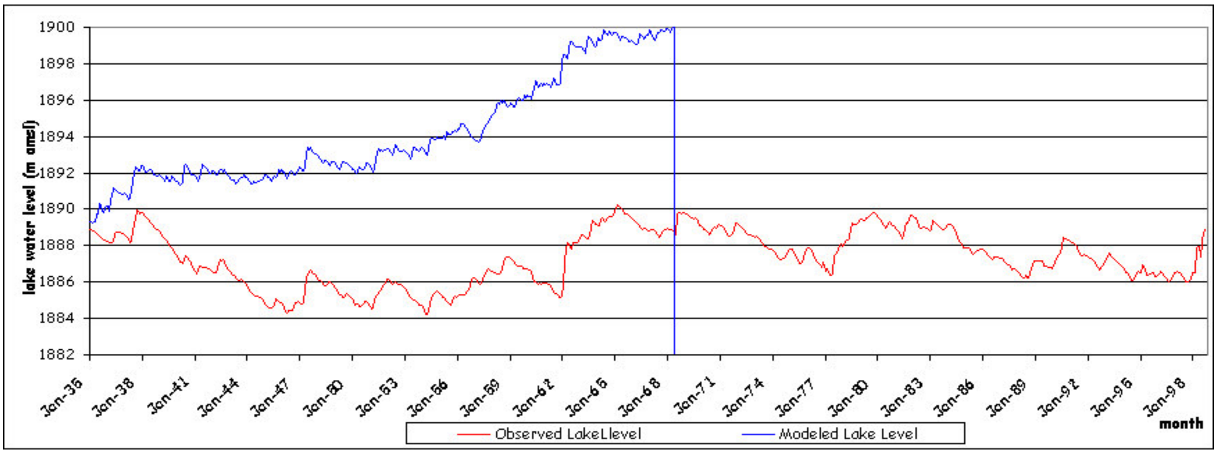


Figure 3.9 Lake Water Level (first run)

From figure 3.9 can be conclude that the model fails to plot the lake water level after 1968. This was due to the water balance model, which put a maximum threshold of 1900 m amsl for the lake water level calculation.

This result indicated that the inflow into the lake was too high. Possible explanations were a low evapotranspiration value and soil properties set up.

After analysing the sub-basin output file (*.bsb), it was deduced the model calculated a very low evapotranspiration value (around 30 % of the total precipitation).

An attempt to adjust the evapotranspiration value was done by correcting soil water content and the parameters that affect percolation. The water may be removed from the soil by plant uptake or evaporation. It can also percolate through the bottom of the soil profile and become aquifer recharge. The water can also form a lateral flow and contributes to the stream.

For a second run some adjustments were accomplished, as follows:

Firstly, soil properties related with soil structure (such as soil type, percentage of clay, percentage of loam, percentage of sand) needed to be set such as those related to the soil water content, field capacity and wilting point.

The soil properties were estimated from the soil type map.

The other parameters defined were bulk density (SOL_BD) and available water content (SOL_AWC) values in soil properties input file (*.sol).

Secondly, parameters related to the percolation needed to be defined. Percolation is calculated for every layer in the profile. In order to simplify the model, the soil was considered as one layer only. The adjustment was done to the saturated hydraulic conductivity (SOL_K) in the soil input file (*.sol). Several other parameters in the soil input file remained as default value or zero (0).

Figure 3.10 shows the result after soil properties adjustments.

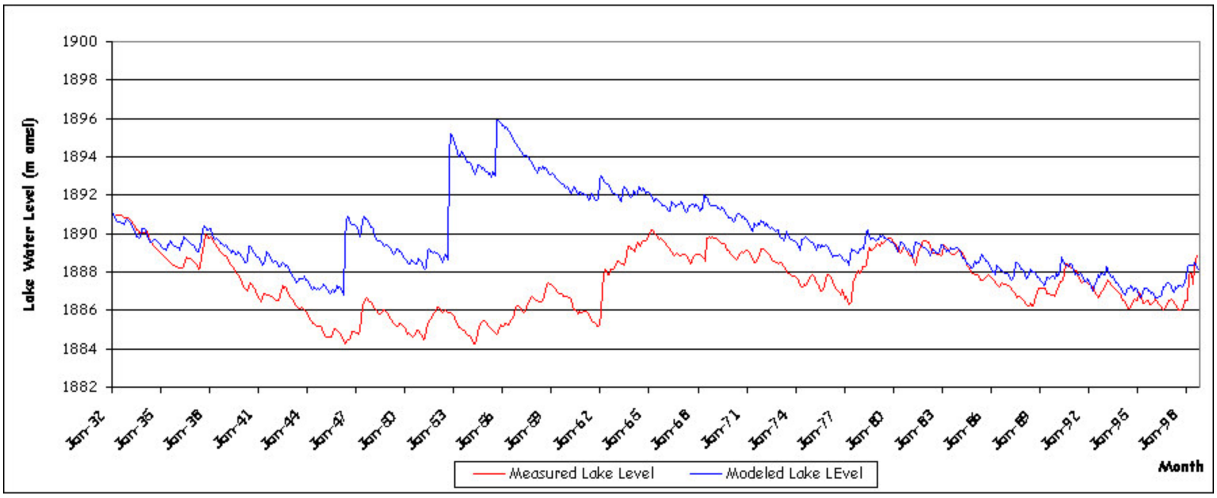


Figure 3.10 Lake Water Level (after soil properties adjustment)

Figure 3.10 shows that the water inflow into the lake is too high although the soil properties were modified but the evapotranspiration value shown a reasonable value (approximately 80% of the precipitation).

The next attempt was to assess the real stream condition that influence inflow into the lake. From previous MSc research (Mmbui 1999) and fieldwork experience, was observed that Karati River and "un-gauge" catchment (south-western part of the lake) have no influence to the lake inflow. Karati River has a temporary flow, for two months a year, during wet periods. Gilgil River, which has been deviated by farmers for irrigation has less influence to the lake water inflow (approximately 5 to 10 %). The major contributor is the Malewa basin (90% of the total inflow), which drains the water from upper-catchments.

From fieldwork experience, the water inflow came out from the upper-catchment, which has high precipitation intensities; and water springs. To integrate this condition into the model, the Malewa basin was assumed as the only basin that contributes to the water inflow. The outflow from sub-basin 3 was assumed as the water inflow into the lake (see figure 3.5). The outflow values was obtained from the SWAT main channel output file (*.rch).

The yearly precipitation in the Lake Naivasha Basin ranges from 600 mm/year in the lake area to 2000 mm/year in the upper-catchment (Kipipiri and Abedares Mountains).

This phenomenon evidence that orographic precipitation is significant in the study area. To estimate the orographic effect on precipitation and temperature, SWAT made elevation bands approach. Precipitation and min/max temperature are calculated for each band as a function of the respective lapse rate; the difference between the gage elevation and the average elevation was specified for the band.

Based on the algorithm found in SWAT Theoretical Documentation (Neitsch 2002), an script in Arc/View was developed by Dr. Turner (Oregon Department of Environmental Quality) to calculate the orographic precipitation. This script requires Digital Elevation Model (DEM) as the input for calculating the mean in the elevation band. The laps rate for precipitation and temperature was estimated as 10. The result obtained from the elevation band calculation, was filled in the sub-basin (*.sub) input file.
Figure 3.11 shows the result after implementing the inflow assumption and the orographic precipitation effect.

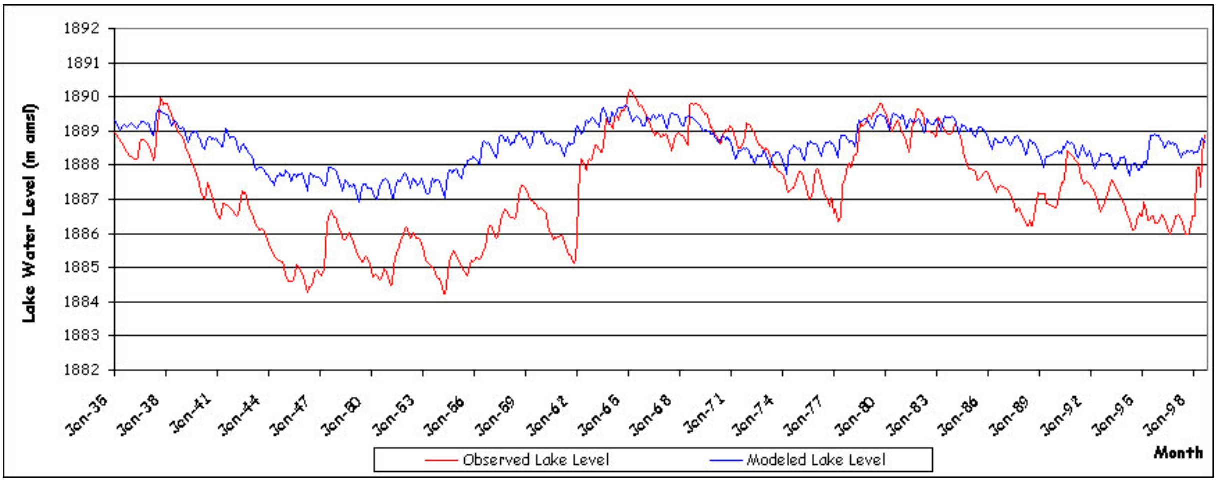


Figure 3.11 Lake Water Level (after implementing inflow assumption and orographic precipitation)

The model (figure 3.11) showed a very subdued representation of the fluctuation. The reason was that only Naivasha DO station (9036002) had daily precipitation data, from 1935-1998. Data from other stations (on the upper-catchment) were created using the weather generator, which produce daily precipitation based on long-term monthly statistic and probability.

Information on longer dryer and wetter periods (5-10 years) cannot be modelled then. Thus, the same month in every year of the whole data series had the same mean of precipitation.

Figure 3.12 shows the result of implementing daily precipitation data only from Naivasha DO (9036002) station. Because Naivasha DO station has the longest daily precipitation data series, can then be incorporated for model the dryer and wetter periods in the basin. In this attempt, the soil and groundwater parameter were adjusted as well. The result shown in figure 3.12 gave a correlation (R^2) 0.82.

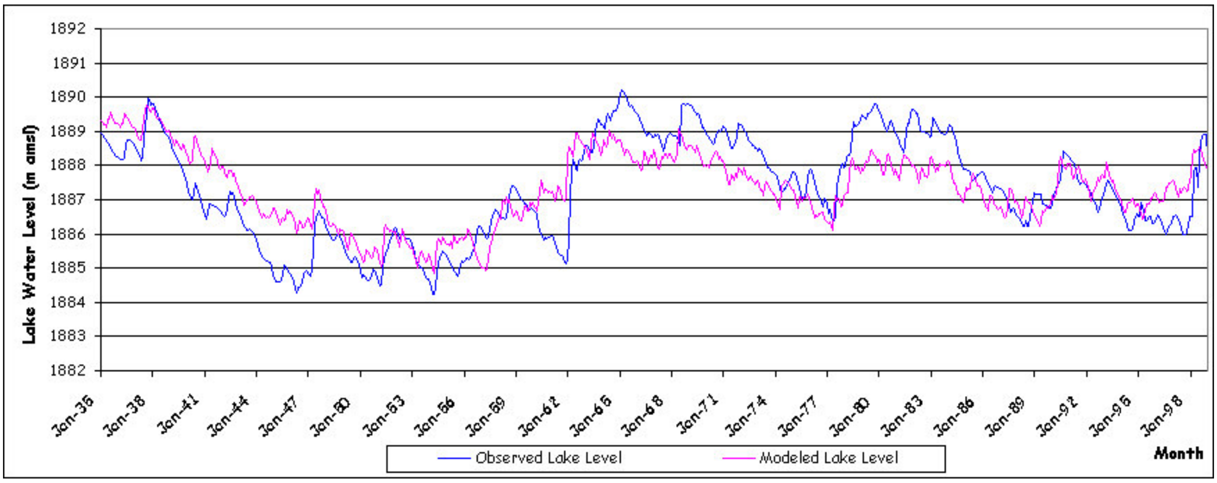


Figure 3.12 Lake Water Level (9036002 Station)

In order to have better control to model the dryer and wetter periods, the same algorithm implemented in the build-in weather generator was coded in the EXCEL spreadsheet.

Probability values were obtained by analysing daily precipitation data using SPSS Software. The missing data were not taken into consideration for the analysis.

Other analyses obtained from SPSS include mean, standard deviation and coefficient of skewness. These values were used for the weather generator. Appendix B displays the long-term statistical analysis for the precipitation data, from all rain station.

Realization processes were done by comparing the long-term lake water level fluctuation with the accumulated precipitation (from measured data filled by synthetic data).

Another *Realization processes* were done by incorporating the precipitation series (measured and synthetics data) with a reservoir model (bucket model) develop by Dr. Wolski (1999).

Figure 3.13 shows the result after implementing spreadsheet weather generator.

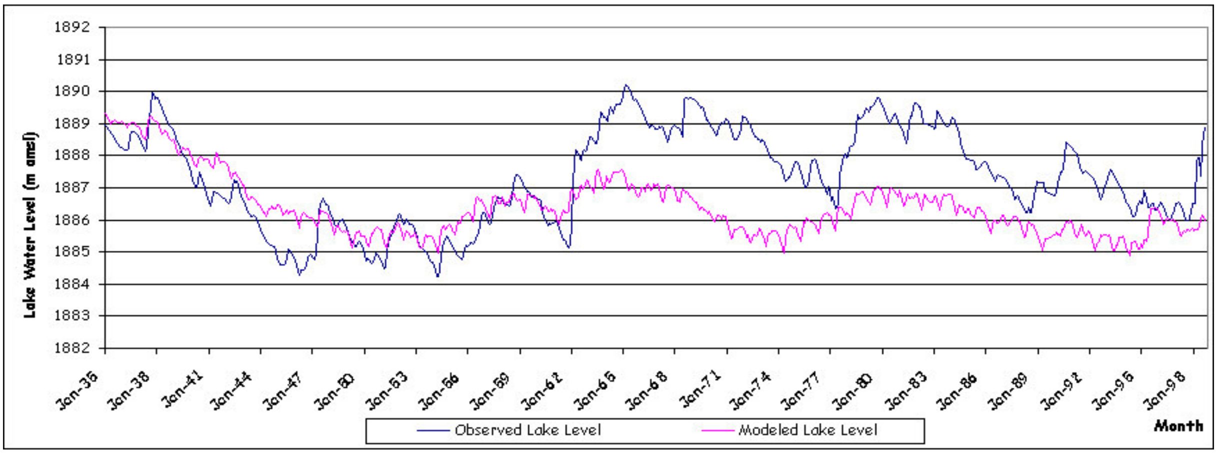


Figure 3.13 Lake Water Level (after implementing spreadsheet weather generator)

The result obtained in this time, showed that the long-term statistic implemented in the weather generator, fail to model the wetter periods.

Further attempt of modification was done by assigning an “individual mean” to every mean daily precipitation in the month (μ_{month}) value. The μ_{month} was substituted with the measured total monthly precipitation value, to incorporate the monthly deviation from the long-term average. This attempt allowed generating the dryer and wetter periods in the long-term measured lake water level.

In order to have daily precipitation series, to incorporate the precipitation missing data during dryer and wetter periods, some *realization processes* were done. This meant to have synthetic data close to the long-term precipitation fluctuation. Then, the chosen precipitation series were substituted to fill the missing data in the measured precipitation data. These combined data were processed in the *realization process* and run numerous times. The chosen precipitation data series were used for the input data. This was a “trial and error” process since to the “best-fit” for the missing data have to be selected among several results produced by the weather generator.

Result in figure 3.14 shows the dryer and wetter periods already incorporated in the long-term lake water level. Although the result still could be improved by parameterisation, due to time constraints, those attempts were stopped.

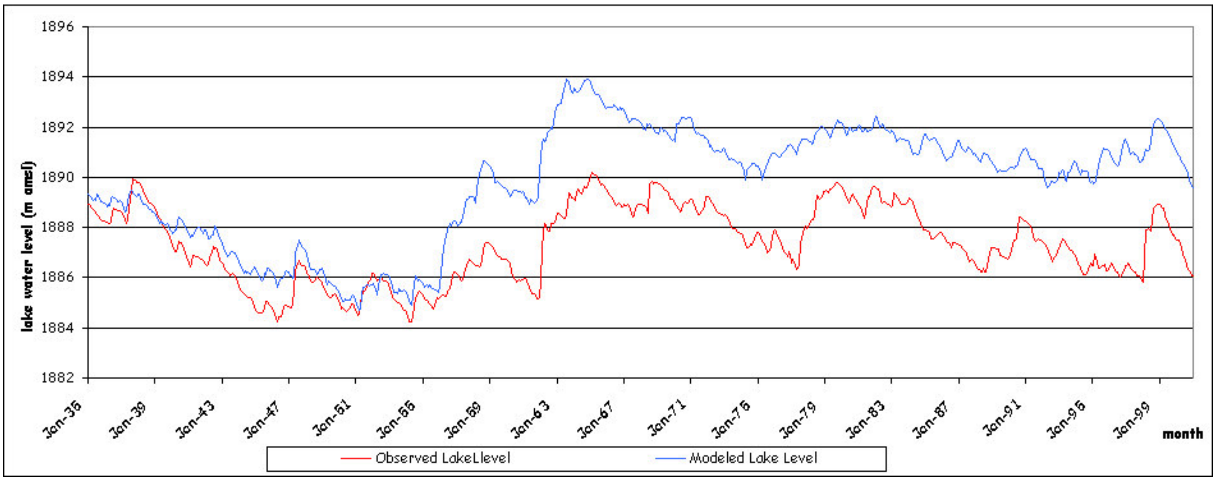


Figure 3.14 Lake Water Level (after implementing spreadsheet weather generator with modified mean)

The required deeper analysis of the parameterisation processes was beyond the objectives of this study due to its complexity and time constraints.

3.4. Model Calibration

Calibration is a process of testing a model with known input and output, used to adjust or estimate factors (Neitsch 2002). Parameters of hydrologic models often are not exactly known and therefore have to be determined by calibration process. A manual calibration depends on subjective assessment and can be a very time-consuming process. Calibration of a model allows reduce parameter uncertainty and therefore in simulation results. (http://www.unigiessen.de/ilr/frede/swat/calibration/calibration.html 2003).

To obtain a result close to the measured lake water level, the result should be calibrated. The calibrated parameters were those related to evapotranspiration value, base flow and surface flow. The adjustment of the following parameters was done for calibration, although several parameters had been defined in the earlier stage of parameterisation.

- Soil properties:
  - The soil available water value (SOL_AWC in *.sol)
  - Hydraulic conductivity value
- Hydrological Respond Units:
  - Soil evaporation compensation factor (ESCO in *.hru)
  - Plant uptake compensation factor (EPCO in *.hru)
- Groundwater:
  - Threshold depth of water in shallow aquifer for base flow (GWQMN in *.gw)
  - Groundwater revaporation coefficient (GW_REVAP in *.gw)
  - Threshold depth of water in shallow aquifer for revaporation (REVAPMN in *.gw)
- Management:
  - Adjusting Curve Number for each land cover (CN in *.mgt)

For calibrating the model, “trial and error” method was done. *Optimisation* of the model was not done, although using this option could decrease the subjectivity of trial and error calibration process.

Several attempts were done and a lot of time spent to calibrate the model. The process was stopped due to time constraints and because the study required also to cover regional climate change and variability impact assessment.

Result of the calibrated model is shown in figure 3.15.

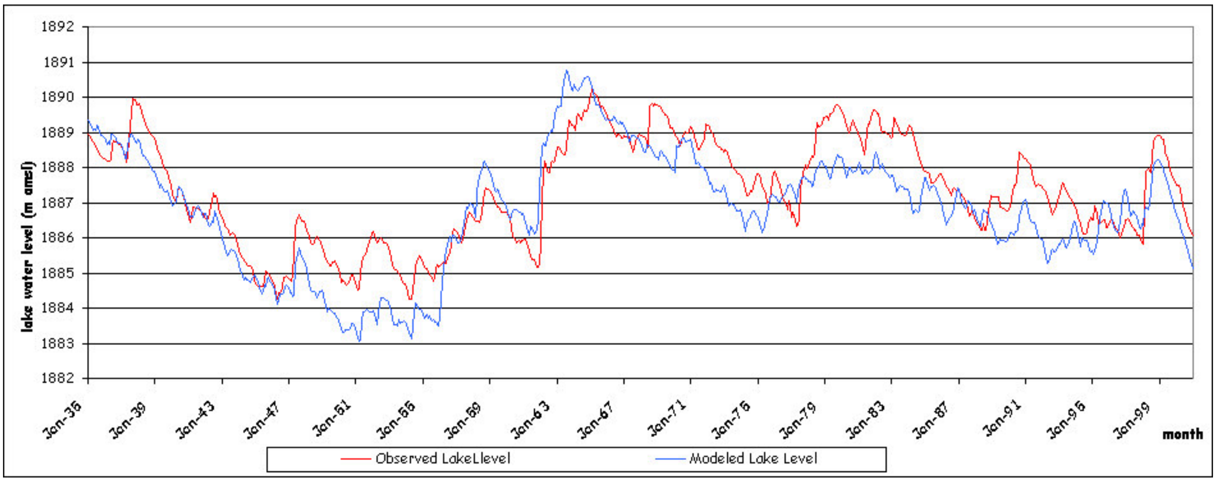


Figure 3.15 Lake Water Level (1935-2000)

The correlation with the measured lake water level was (R^2) = 0.77. Deviations between the curves are possibly due to temperature data, which were not modelled in the spreadsheet weather generator. The temperature data used still employed the long-term statistic.

Although it was not considered in the research, it should be mentioned that the real lake water level is influenced by water abstraction since the early 1980s; for this reason the modelled lake level might be higher than the measured one.

3.5. Concluding Remark

The integration of land phase processes was achieved by modifications and extensions to the original SWAT model. Since the model has no ability to calculate the lake water level, a model, which could incorporate the lake water level calculation process, was used. The Water Balance Model of Lake Naivasha (Mmbui 1999) was used to obtain the lake water level fluctuation graph. This model, based on regression between precipitation and total discharge from the basin, showed correlation between monthly values for river inflow, the average precipitation on the lake and the potential evapotranspiration. The Water Balance Model of Lake Naivasha estimates the ground water outflow at 4.6 million cubic meters per month. The abstraction, which has been estimated in 57 million cubic meters per year, was not taken into consideration.

Parameterisation in the model set up process was became a very fundamental phase; because of its complexity SWAT model requires every parameter defined specifically.

Malewa basin output was assumed as the inflow contributing to the lake water level, based on the condition that Malewa basin fed 90% of all water inflow.
The build-in weather generator considers long-term average of precipitation, which has disadvantages of control disability on the synthetic data output. For the study area, which has a complex condition of dry and wet period, this build-in weather generator failed to incorporate the fluctuation.

Weather data form 1935 to 1998 was used to evaluate the long-term effect of hydrological change. The unavailability of complete set of data series lead the creation of a weather generator for filling and generating weather data.

Building a spreadsheet weather generator gives the ability to control the output data. Changing the monthly mean precipitation value with an "individual mean", the basic algorithm of the weather generator was modified. This approach could incorporate the dry and wet periods into the lake water fluctuation.

Precipitation series selected after realization process using two approaches; compare the daily accumulation precipitation with measured lake water level and using reservoir model developed by Piotr Wolski (Wolski 1999).

The correlation, between the modelled with measured lake water level, was (R^2) 0.77 after calibration processes. The calibration for parameters such as soil properties, hydrological response unit (HRU), groundwater properties, and management practises was done manually.

The calibrated model result has several limitations. Temperature was generated by the long-term average in the weather generator. This affected the value of evapotranspiration, which explain the over predicted water level during the dry periods.

Water abstraction also plays an important role in the lake water level, agricultural expansion on the area surrounding the lake started since 1980s has been using water from the lake for irrigation practices. Sediment yield into the lake, which influences the lake depth, has not been taken into consideration either.

4. Climate Change Simulation

4.1. Introduction

In order to have a basis for assessing future impacts of climate change is necessary to obtain a quantitative description of the expected changes. Although there is increasing certainty among atmospheric scientists that increased atmospheric greenhouse gas concentrations will raise global temperatures, there is much less confidence in the estimation of how the climate will change at a regional scale (IPCC, 1996). However, it is precisely at this regional or local level (e.g. at the scale of a farm, a river basin or even an individual organism) that climate change will be felt. Since no method of providing confident predictions of climate change at these scales exists yet, an alternative approach is to specify a number of plausible future climates. These are termed "climate scenarios".

4.2. Climate Change Scenario

Scenarios can be described as pertinent, plausible, alternative futures. Their pertinence, in the case of climate change, is in providing information on how future human activities are expected to alter the composition of the atmosphere, how this may affect the global climate and how changes in climate may affect natural systems and human activities. This information is required to assist decision-makers in controlling future emissions of greenhouse gases and in managing resources that may be affected by climate change. The plausibility of scenarios can only be properly evaluated by scientific analysis and peer review (IPCC, 1996).

Box 4.1 Climate Change Scenario

Climate scenarios are plausible representations of the future that are consistent with assumptions about future emissions of greenhouse gases and other pollutants and with our understanding of the effect of increased atmospheric concentrations of these gases on global climate. A range of scenarios can be used to identify the sensitivity of an exposure unit to climate change and to help policy makers decide on appropriate policy responses. It is important to emphasise that climate scenarios are not predict ions, like weather forecasts are. Weather forecasts make use of enormous quantities of information on the observed state of the atmosphere and calculate, using the laws of physics, how this state wills volve during the next few days, producing a prediction of the future - a forecast. In contrast, a climatic scenario is a plausible indication of what the future could be like over decades or centuries, given a specific set of assumptions. These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumptions about the behaviour of the climate system over long time scales. It is largely the uncertainty surrounding these assumptions, which determines the range of possible scenarios.

Source: IPCC, 1996

The IPCC Data Distribution Centre and these Guidelines are attempts to assist that process. The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects (Smith and Hulme, 1998 in (http://ipcc-ddc.cru.uea.ac.uk/ 1996)).

Box 4.2 Inter-governmental Panel on Climate Change (IPCC)

Recognizing the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. It is open to all members of the UNEP and WMO. The role of the IPCC is to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change. It does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature.

The IPCC has three Working Groups and a Task Force

- Working Group I assesses the scientific aspects of the climate system and climate change.
- Working Group II addresses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it.
- Working Group III assesses options for limiting greenhouse gas emissions and otherwise mitigating climate change.
- The Task Force on National Greenhouse Gas Inventories is responsible for the IPCC National Greenhouse Gas Inventories Programme.

The Panel meets in plenary sessions about once a year. It accepts/approves/adopts IPCC reports, decides on the mandates and work plans of the Working Groups and the Task Force, the structure and outlines of its reports, the IPCC Principles and Procedures, and the budget. The Panel also elects the IPCC Chairman and the rest of its Bureau.

The IPCC completed its First Assessment Report in 1990. The Report played an important role in establishing the Intergovernmental Negotiating Committee for a UN Framework Convention on Climate Change by the UN General Assembly. The UN Framework Convention on Climate Change (UNFCCC) was adopted in 1992 and entered into force in 1994. It provides the overall policy framework for addressing the climate change issue.

The IPCC has continued to provide scientific, technical and socio-economic advice to the world community, and in particular to the Parties to the UNFCCC through its periodic assessment reports on the state of knowledge of causes of climate change, its potential environmental and socio-economic impacts and options for addressing it. Its Second Assessment Report, Climate Change 1995, provided key input to the negotiations, which led to the adoption of the Kyoto Protocol in 1997. The IPCC also prepares Special Reports and Technical Papers on topics where independent scientific information and advice is deemed necessary and it supports the UNFCCC through its work on methodologies for National Greenhouse Gas Inventories.

Source: http://www.ipcc.ch

A number of Global Circulation Model (GCM) was used to develop Climate Change Scenario. All models indicated interesting temperature changes at all locations with doubling of CO_2. Increase varied significantly not only from month to month but also from location to location. The climate change scenarios used over Kenya; the temperature increases ranged from 0.5 to 3 ^{0}C (http://unfccc.int/sessions/workshop/080802/documents/parties/kenya.pdf 1997).

In order to construct a regional climate scenario for a predicted global warming tendency the problem of downscaling should be solved. This means transformation of the applicable large-scale information produces by the GCM into climate elements for the desired region.

Regional climate change scenarios are of insufficient temporal resolution and, therefore, they are not design for an immediate quantitative estimation of hydrological impacts. Weather generators, which can provide the parameter of daily weather variables, are applied. As with this, weather generator the monthly resolution regional climate scenario into the daily stochastic process called weather (Huszar 1999).

For the reason of climate scenario data availability and accessibility, HadCM2 climate change scenarios have been implemented in the study. HadCM2 is a coupled atmosphere-ocean general circulation general model developed at the Hadley Centre and described in detail by John et al, 1997 (http://www.met-office.gov.uk/research/hadleycentre/models/HadCM2.html 2002) .

HadCM2 has a spatial resolution of 2.5° latitude by 3.75° longitude, giving a grid of 96 x 73 grid cells. This is equivalent to a surface resolution of about 417 km x 278 km at the Equator, reducing to 295 km x 278 km at 45 degrees of latitude (comparable to a spectral resolution of T42). The atmospheric component of HadCM2 has 19 levels and the ocean component 20. The scenario is using flux adjustment take makes it stable and realistic control climatology. HadCM2 scenario has been used for a wide range of climate-change experiments.

HadCM2 model is one of the results from climate-change experiments conducted using Hadley Centre computer model of the climate system. The models are two versions of coupled atmosphere-ocean general circulation model (HadCM2 and HadCM3).

The experiments assume that future emissions of greenhouse gases will follow the IS92a scenario, in which the atmospheric concentration of carbon dioxide more than doubles over the course of the 21st century. This is a “business as usual” scenario, which assumes mid-range economic growth but no measures to reduce greenhouse-gas emissions.

It is important to be aware that predictions from climate models are always subject to uncertainty because of knowledge limitation of how the climate system works and on the computing resources available. Different climate models can give different predictions. A range of results from Hadley Centre being included in Inter Governmental Panel on Climate Change Data Distribution Centre (IPCC DDC) as main source for supply for use in research projects.

Each HadCM2 file lists monthly data over a period of 30 years, which would result in 4320 maps for each basin. To be able to keep a clear overview of the data, the data will therefore be delivered in tabular form.

The initially, one greenhouse gas only integration, HadCM2GGa1 (first referred to as HadCM2GHG) used the combined forcing of all the greenhouse gases as an equivalent CO2 concentration. HadCM2GSa1 (first referred to as HadCM2SUL) used the combined equivalent CO_2 concentration plus the negative forcing from sulphate aerosols. HadCM2GGa1 simulated the change in forcing of the climate system by greenhouse gases since the early industrial period. There is a small amount of forcing (0.4 Wm^{-2}) prior to this simulation period representing the small increase in greenhouse gases from 1765 to 1860. The addition of the negative forcing effects of sulphate aerosols represents the direct radiactive forcing due to anthropogenic sulphate aerosols by means of an increase in clear-sky surface albedo proportional to the local sulphate loading refer to Mitchell et al, 1995 (http://www.cru.uea.ac.uk/link/experiments/1b_experi_contents.html 2003) for details of this method. The indirect effects of aerosols were not simulated.

These experiments simulated the observed climate system using estimated forcing perturbations since 1860. Johns et al., 1995 and Mitchell et al., 1995 have established that HadCM2's sensitivity is consistent with the real climate system. The agreement between the observed global-mean temperature record and that produced in these experiments is better for HadCM2GSa1 than for HadCM2GGa1. This implies that HadCM2GSa1 has captured the observed signal of global-mean temperature changes better than HadCM2GGA1 for the recent 100-year record.

4.3. Climate Change Simulation

4.3.1. Downscaling data

For the spatial downscaling process, the Lake Naivasha Basin boundary was used to mask the HadCM2GSa1 pixels; then the values for these pixels for all dates where extracted and put in an EXCEL table. Finally, the percentage of the basin that is represented by every pixel was determined, and this information was added.

To spatially visualize the pixels, the numbered pixels representing the basin were resample to the 30-second basin windows, so they could be displayed and overlaid with the basin vector file.

For downscaling precipitation and temperature data from global to regional data set, different approaches were used. In the “1961-1990” base line condition, the precipitation data has to be multiply by a correction factor. This correction factor is a fraction of actual and climate scenario base line condition. The absolute differences between the measured temperature and the global data set were used as the correction factor for the temperature data. The global data set was downscaled to all stations used in the study.

The precipitation correction factors for every station (fraction of difference) were obtained after calculating the accumulation of the actual and HadCM2GSa1 base line condition monthly precipitation.

Figure 4.1 shows the comparison between the measured and HadCM2GSa1 precipitation data set before implementing correction factor for station Naivasha DO (9036002)

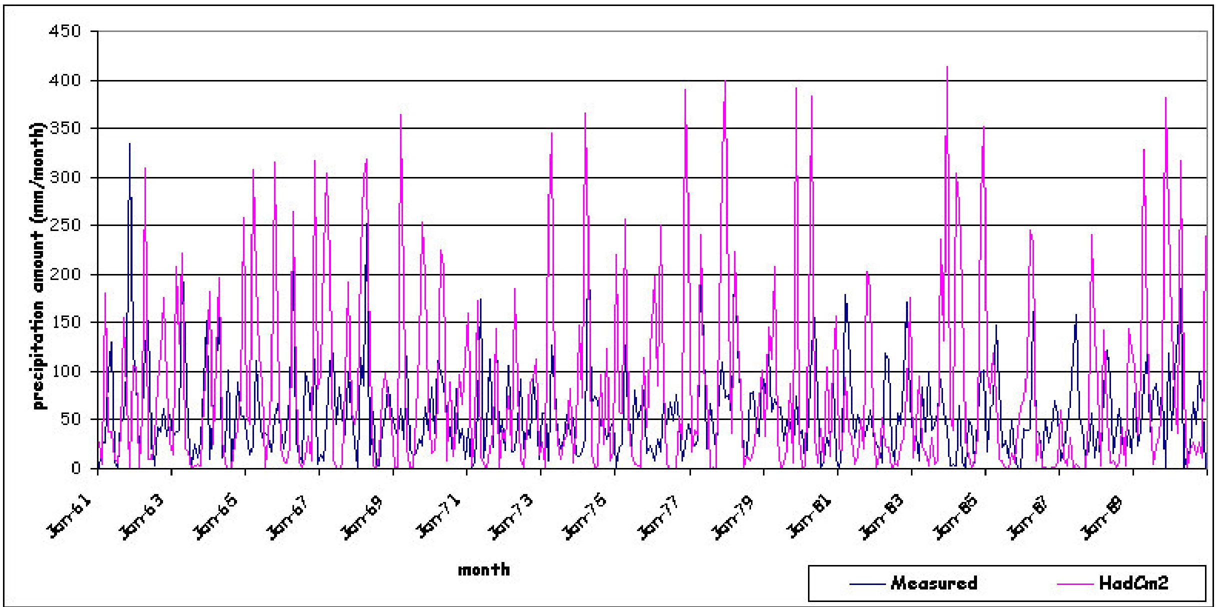


Figure 4.1 Monthly precipitation comparison between measured and baseline dataset (9036002 station)

The HadCM2GSa1 precipitation base line condition overestimates the monthly precipitation of 1961-1990 for station 9036002. A correction factor of 0.7 was implemented to adjust the HadCM2GSa1 precipitation scenario. This factor was calculated using *realisation process* for comparing the accumulation precipitation. The same value was also implemented to the 2010-2039 scenario.

Figure 4.2 shows the downscaled precipitation data for Naivasha DO (9036002) station, which was compared with the actual precipitation data for the base line condition.

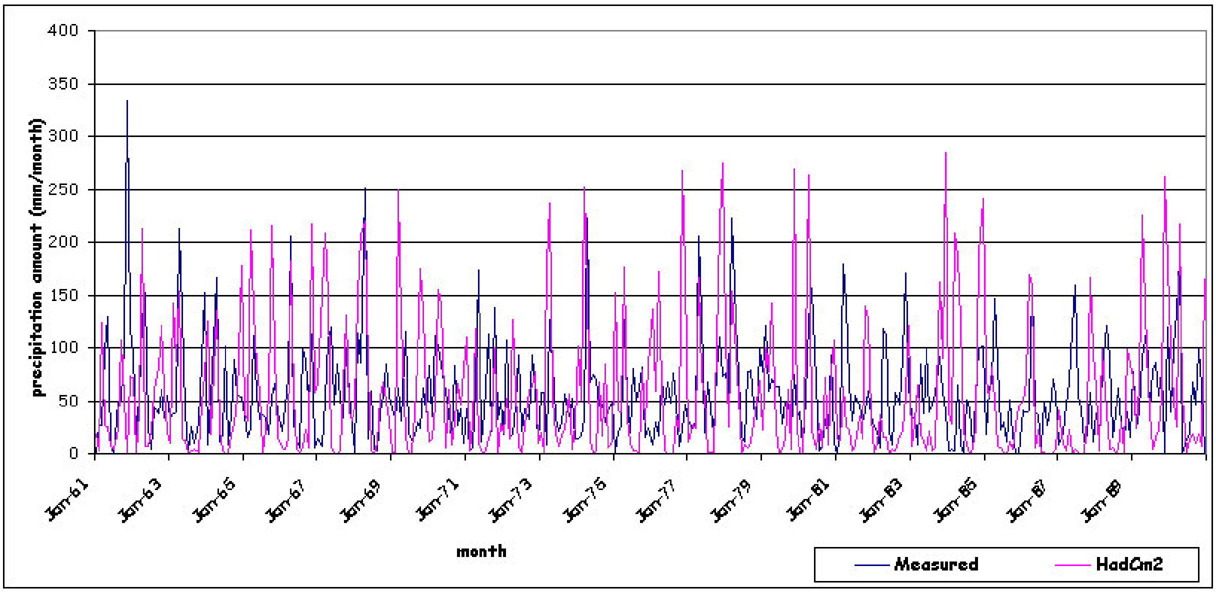


Figure 4.2 Downscaled monthly precipitation for the base line condition (compared with actual data)

The same methods of downscaling were implemented for three other weather stations (Appendix D). The correction factors (fraction of difference), which were implemented to downscaled the precipitation data, are shown in table 4.1.

Table 4.1 Correction factor for downscaling precipitation data set

Station	Down scaling Correction factor
9036002	0.7
9036025	1.2
9036264	1.1
9036241	1.25

Temperature data was downscaled by calculating the absolute difference between the 1961-1990 base line condition and 2010-2039 scenario data. Table 4.2 shows monthly average temperature in the base line condition (1961-1990) and scenario 2010-2039 for the whole basin.

Table 4.2 Monthly Average Temperature

Month	1961-1990 base line condition (^oC)	2010-2039 condition (^oC)
January	20.89	22.35
February	22.36	23.55
March	22.45	23.64
April	21.33	23.16
May	20.82	22.91
June	21.22	23.62
July	21.56	23.58
August	21.72	23.59
September	21.93	23.85
October	21.88	24.02
November	21.56	23.16
December	21.10	21.98

Figure 4.3 shows the monthly difference of temperature between base line condition and 2010-2039 scenario. These values were implemented to adjust the simulated 2010-2039 years by correcting the min/max monthly temperature in the SWAT weather data file (*.wgn).

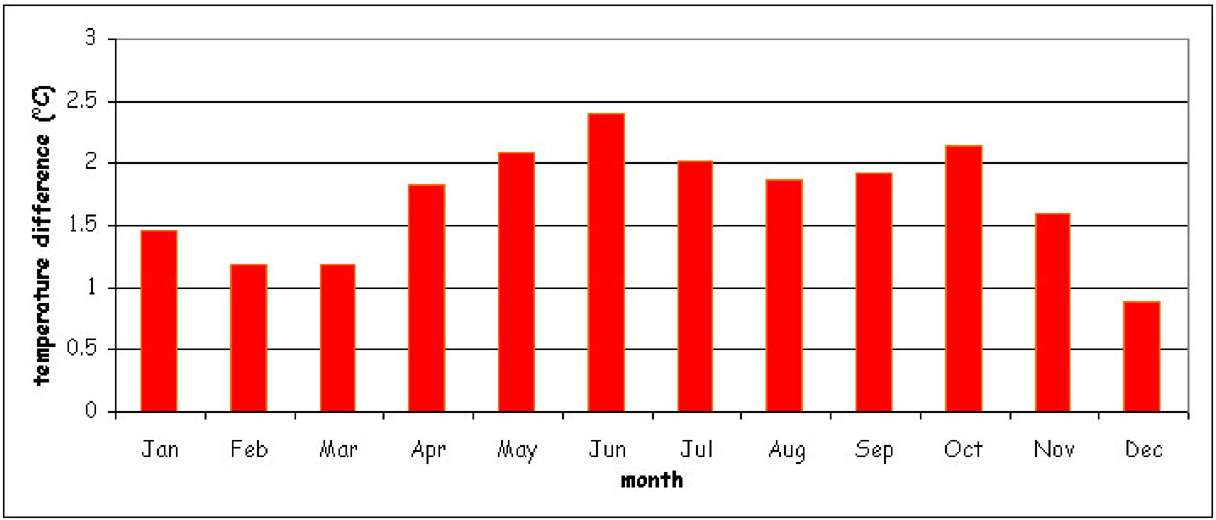


Figure 4.3 Absolute different of 2010-2039 scenarios and the 1961-1990 base condition

The main issue of using the GCM data set is the data reliability. The regional data set derived from global data set has reliability doubt of data, since the microclimate and micro hydrological cycle plays an important role in Lake Naivasha Basin.

4.3.2. Simulation Result

In the first attempt of implementing the climate scenario, the downscaled 2010-2039 HadCM2GSa1 monthly precipitation was generalised using the spreadsheet weather generator to obtain daily data set.

Statistic values obtained from long-term measured data in each station were replaced by the scenario statistic. The probabilistic data in the weather generator, such as number of rainy days, wet-dry days and wet-wet days, were still referred to the long-term measured data for every station. This assumption was made due to difficulties calculating the scenarios probability value.

The daily precipitation data was implemented in SWAT calibrated model after being generalised in the spreadsheet weather generator.

The simulated lake water level after implementing the downscaled HadCM2GSa1 Climate Scenario was compared with "business as usual", without climate change, simulation result (figure 4.4).

The graph shows a less confidence result, the problems were seemed to be in the weather generator. This reason was most likely caused by the failure to generate daily precipitation value, which appears too high.

The model shows increasing lake water level and the model failed to incorporate the lake water level above 1900 m amsl, which is the Water Balance Model of Naivasha upper threshold.

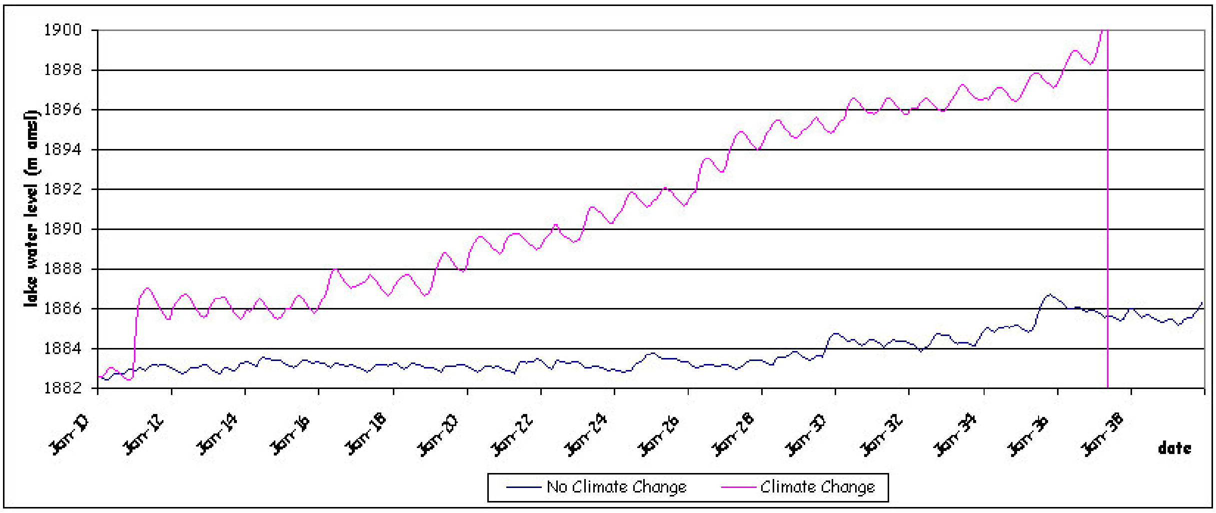


Figure 4.4 Comparison of Simulated Lake Water Level in 2010 – 2039 (first simulation attempt)

Second attempt was done by using the same statistic and probability as the long-term measured data from each station. The HadCM2GSa1 downscaled mean monthly precipitation was assigned to every mean daily precipitation in the month (μ_{month}) value. The monthly mean was assumed as the "individual mean value", regarding the approach of incorporating the wet and dry periods in the SWAT calibration process. Figure 4.5 shows the result of second attempt.

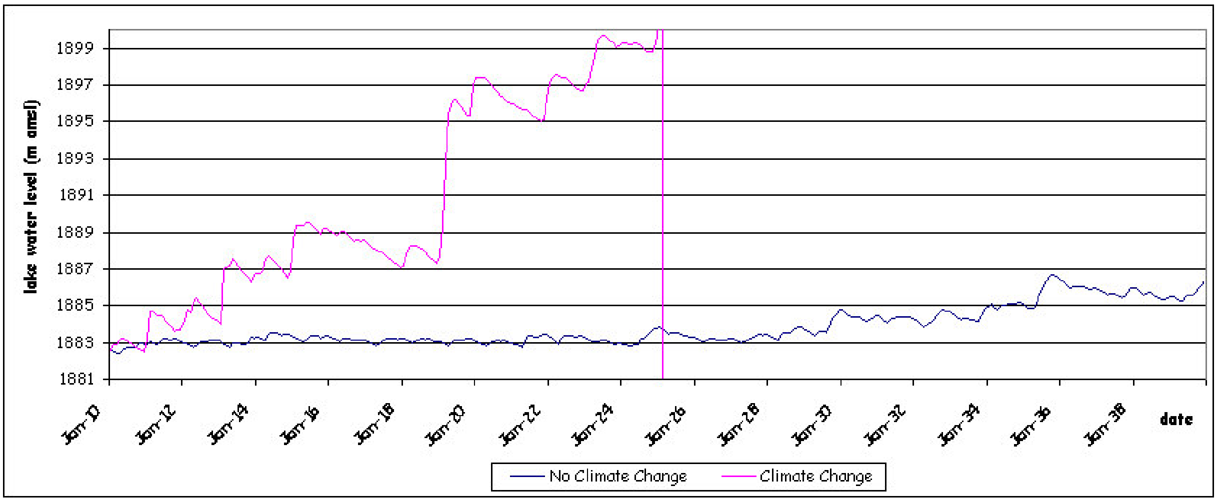


Figure 4.5 Comparison of Simulated Lake Water Level in 2010 – 2039 (second simulation attempt)

The second attempt also failed to model the climate change condition. The result shows that the HadCM2GSa1 monthly data cannot be implemented to generalise the daily precipitation.
Obviously, the HadCM2GSa1 scenario, which was derived from IS92a Global Circulation Model scenario, has been renewed by latest scenario of SRES 2000. The SRES 2000 from IPCC appears to be more appropriate for the climate change and variability impact regional assessment.

A next attempt, shown in figure 4.6, was done by correcting the "business as usual" simulation result on 2010-2039 periods.

The daily precipitation data was corrected by fraction of change. The fraction of change was considered as 1.4 % (http://www.cru.uea.ac.uk/link/hadcm2/HadCM2_changes.html 2002). The min/max temperature data in the weather station file in SWAT (*.wgn) was adjusted by implementing the monthly difference for the four weather stations. Appendix E shows the Global Mean Temperature, Precipitation, CO2 and Sea-level Changes (w.r.t. 1961 - 1990) for the HadCM2 Integrations

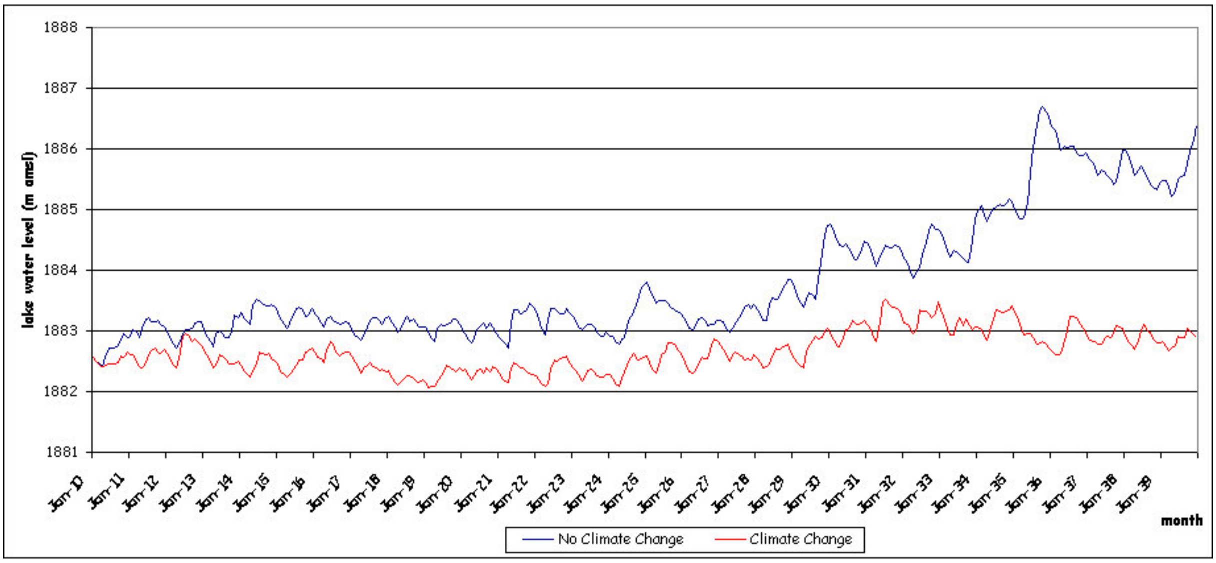


Figure 4.6 Simulated Lake Water Level in 2010 – 2039 (third simulation attempt)

Many adjustments in the GCM have been made to improve the usefulness of these models in the development of regional climate scenario. Although GCM outputs are physically plausible, they often fail to reproduce even the seasonal patterns of present day climate observed at the regional level (Mutua 1998).

In the climate change simulation, the output failed to reproduce the seasonal patterns of present day climate observed at the regional level, since they are using the long-term statistic. The lake water level has depleted to an average water level of 1882.7 m amsl from the last measured lake water level of 1886.4 m amsl (last observation is July 2002).

In the last year of "business as usual" simulation the lake water level would be 3 meter higher than its occurrence in the climate change simulation. The lowest lake water level appears around 2020's almost at the bed level of the lake (1881.2 m amsl). The lake water level increases on the 2030's, most likely due to the seasonal pattern of wet periods, which was showed also in the "business as usual" simulation.

From the simulation result, the lake water level would decrease even without climate change condition. The lake water level varies with time, as well as rivers and groundwater, due to natural water balance between inflow (precipitation and runoff) and outflow (evaporation, seepage or surface outflow).

The climate change will have impact in regional scale, to accelerate lake water level depletion.

Given the magnitude and rate of change in climate projected by the IPCC, regional climate change will present even greater challenges for human and natural systems with the increase in extreme events.

Social community in lake Naivasha can also affect the lake water level by water abstraction, land use changes, effluent return and river diversion.

4.4. Concluding Remark

Climate scenario modelling is an appropriate method for providing confident predictions of climate change at regional as well as global scale. This approach has been used, as basis for assessing future impacts of climate change because is necessary to obtain a quantitative description of the expected changes.

Climate change is a phenomenon of global significance, but their effects are expected to be most outstanding at regional level.

The Hadley Centre HadCM2 GSa1 Climate Scenario was the Global Circulation Model (GCM) used for this study. This scenario was combined with a hydrological model (SWAT) in order to assess the impact of potential future climate change and variability on water resources, emphasising on Lake Naivasha water level. The general modelling approach provided a general assessment of the role of climate change and variability on lake water level.

For the precipitation data, downscaling process was calculated multiplying the global data set by a fraction of measured data and the climate scenario base line condition data of 1961-1990. Further on the same correction factors were implemented in the 2010-2039 scenario. Downscaling procedure, was applied to every station used in the study (9036002, 9036025, 9036241, and 9036264 stations)

The method for temperature downscaling was done by correcting the *absolute difference* of the base line condition and the scenario. The difference between temperature of the base line condition and the 2010-2039 scenario was incorporated to the min/max average value in the weather station file (*.wgn) for predicting the "2010-2039" condition.

As was showed earlier in this chapter the downscaling became the major limitation, because monthly precipitation need to be generalized by weather generator in order to have daily precipitation data.

The HadCM2GSa1 global data set failed to represent the monthly precipitation data for the study area. The latest SRES 2000 scenarios appear to be the more appropriate to represent the climate change scenario, although it was not implemented in this study.

The approach of implementing the precipitation fraction change of 1.4% gave a result that showed the water level of the lake Naivasha is going to decrease due to climate change.

Average of the simulated lake water level for 2010-2039 periods is 1882.7; it depicts a decrease of around 4 meter from the 1884.4 m amsl in the latest measured data (on July 2002). The simulation for 2020's shows the lake water level depleted almost to the bed level of 1881.2 m amsl.

The major concern of using the global data set is their reliability. The regional data set derived from global data set has not reliability, since the microclimate and micro hydrological cycle plays an important role in Lake Naivasha Basin. In order to construct a "trustworthy" regional climate scenario, the problem of downscaling should be solved. Although GCM outputs are physically plausible, they often fail to reproduce even the seasonal patterns of present day climate observed at the regional level.

Planning an effective response to the threat of climate change should incorporate the likely impacts of climate change on social, economic and environmental systems and explore possible means of adapting to future changes.

5. Summary and Recomendations

5.1. Research Summary

Soil and Water Assessment Tool (SWAT) appears to be an appropriate model to represent the hydrological behaviour for the climate change and variability impact assessment. This physically base model can help in understanding the complex hydrological behaviour and to analyse future management options for Lake Naivasha Basin.

In this study, SWAT was improved by modification and extension, incorporating the Water Balance Model of Lake Naivasha in order to analyse the lake water level fluctuation.

Every parameters in SWAT was defined specifically, some were also modified and assumed.

In order to evaluate the effect of hydrological change, a long set of weather data is necessary. In this study the 1935-200 data was used.

The unavailability of a complete set of data determined the creation of a spreadsheet weather generator to fill and generate the missing data. Building weather generator has brought the ability to control the wet/dry periods on the generalized output data.

Temperature simulation was not considered in the spreadsheet weather generator, the min/max values were calculated from the long-term average.

Sediment yield carried into the lake and the water abstraction from the lake, were neglected in the calculation in this research.

The correlation between calibrated hydrological model and the measured lake water level was (R^2) = 0.77. Parameters such as soil properties, Hydrological Response Unit, groundwater properties, and management practises were calibrated manually. The parameterisation and calibration required "trial and error" process, which consumed a lot of time.

A general assessment of the role of the future climate change and variability on the lake water level was provided by incorporating the Hadley Centre HadCM2 GSa1 Climate Scenario into the calibrated model.

The general framework in order to implement a climate scenario, derived from a General Circulation Model, is the downscaling process to the regional or smaller scale.

Downscaling the precipitation data was done by multiplying the global data set with a correction factor. This correction factor was calculated as a fraction of the difference between measured and climate scenario data on *the base line condition* (1961-1990) for every station used in the study (9036002, 9036025, 9036241, and 9036264 stations). The same correction factors were implemented for the 2010-2039-simulation period.

The method used to downscale the temperature data was correcting the scenario with an absolute difference value, between the measured and the scenario, in the base line condition. Those difference values were applied for correcting the min/max average value in the 2010-2039-simulation period.

The downscaled HadCM2 GSa1 scenario failed to represent the future 2010-2039 simulation condition, since it produced water level higher than the threshold for "Water Balance Model of Lake Naivasha". The scenario that was produced by 92a GCM (1992) should be replaced by a more recent one, such as SRES 2000.

An approach was implemented by correcting "business as usual" simulation result for 2010-2039 period with a precipitation fraction change of 1.4%. This attempt gave as conclusion that the climate scenario provides a confidence prediction of climate change at regional scale.

The regional data derived from global data set has less reliability, since it fails to incorporate the microclimate and micro hydrological cycle, which plays an important role in Lake Naivasha Basin.

The major effects of climate change on the Lake Naivasha area and the water resources will be through changes in the hydrological cycle, temperature and precipitation. These factors are the controlling parameters of the lake water level and volume, and consequently the water availability.

5.2. Recommendation

SWAT is appropriate to model the whole complexity of hydrological process of the study area, although it should be improved by defining those parameters, which were assumed in this research. The soil properties and the land use type should be defined in more detail, by a specific study of land use classification and soil properties.

Good quality of daily climate data will increase the capability to understand the hydrological process; also detailed measurement of daily precipitation, temperature, solar radiation will be useful to give better insight of the climate behaviour. More *Data Loggers*, which can measure daily data, should be installed in the area. Data collection, which becomes very essential for the management of the water resources, has not been a major concern in the area.

Climate change and variability have major impact at a regional scale, affecting the microclimate and micro hydrological cycle. Although scenario data was unable to reproduce the seasonal pattern of the climate variability, the climate change shows lake water depletion of around 4 meter from the present recorded level.

Water reduction of the lake would have significant effect to the water users surround the lake, such as agricultural farm, flower farm, cattle farm, fisheries and tourism industry. Lake water abstraction, which has been predicted in 57 million cubic meters per year (Mmbui 1999), which was not incorporated in the model, obviously will accelerate the lake water depletion.

Water resources management in lake Naivasha should take the climate change and variability impact into consideration.

For future studies, social and economic impact should also be considered. The impact on hydrological cycle and water resources as the implication of lake water level depletion should also being evaluated.

Adaptation capacities of the human and environmental system need to be analysed. The Inter-governmental Panel on Climate Change already states, "Adaptation has the potential to reduce adverse impacts of climate change and enhance beneficial impacts, but will incur costs and will not prevent all damages"(http://www.grida.no/climate/ipcc_tar/wg2/642.htm 2001).

Effective management would require treaties, political commitment, institutions, capacity, information, and finance. Many involved stakeholders in the regional scale make the water management difficult. Coordinated action among them should determine whether the region cans effectively adapts to change in the hydrology of Lake Naivasha Basin Rivers and the lake itself.

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APPENDIX

APPENDIX A.1 Lake Water Level 1932-2002

Jan-32	1890.98	Mar-35	1888.65	May-38	1889.14	Jul-41	1886.75	Sep-44	1885.02
Feb-32	1890.98	Apr-35	1888.57	Jun-38	1889.04	Aug-41	1886.71	Oct-44	1884.81
Mar-32	1890.98	May-35	1888.50	Jul-38	1888.96	Sep-41	1886.66	Nov-44	1884.70
Apr-32	1890.98	Jun-35	1888.44	Aug-38	1888.92	Oct-41	1886.60	Dec-44	1884.62
May-32	1890.98	Jul-35	1888.38	Sep-38	1888.88	Nov-41	1886.55	Jan-45	1884.59
Jun-32	1890.89	Aug-35	1888.32	Oct-38	1888.82	Dec-41	1886.50	Feb-45	1884.61
Jul-32	1890.86	Sep-35	1888.28	Nov-38	1888.69	Jan-42	1886.54	Mar-45	1884.61
Aug-32	1890.83	Oct-35	1888.25	Dec-38	1888.55	Feb-42	1886.78	Apr-45	1884.63
Sep-32	1890.86	Nov-35	1888.21	Jan-39	1888.43	Mar-42	1887.03	May-45	1884.83
Oct-32	1890.83	Dec-35	1888.19	Feb-39	1888.35	Apr-42	1887.26	Jun-45	1885.07
Nov-32	1890.77	Jan-36	1888.18	Mar-39	1888.28	May-42	1887.16	Jul-45	1885.03
Dec-32	1890.67	Feb-36	1888.18	Apr-39	1888.15	Jun-42	1887.20	Aug-45	1884.97
Jan-33	1890.55	Mar-36	1888.27	May-39	1888.01	Jul-42	1887.07	Sep-45	1884.90
Feb-33	1890.49	Apr-36	1888.67	Jun-39	1887.92	Aug-42	1886.87	Oct-45	1884.84
Mar-33	1890.37	May-36	1888.75	Jul-39	1887.85	Sep-42	1886.70	Nov-45	1884.72
Apr-33	1890.22	Jun-36	1888.74	Aug-39	1887.72	Oct-42	1886.63	Dec-45	1884.57
May-33	1890.16	Jul-36	1888.73	Sep-39	1887.60	Nov-42	1886.56	Jan-46	1884.39
Jun-33	1890.06	Aug-36	1888.69	Oct-39	1887.45	Dec-42	1886.47	Feb-46	1884.26
Jul-33	1890.06	Sep-36	1888.65	Nov-39	1887.25	Jan-43	1886.34	Mar-46	1884.43
Aug-33	1890.06	Oct-36	1888.60	Dec-39	1887.12	Feb-43	1886.24	Apr-46	1884.44
Sep-33	1890.06	Nov-36	1888.51	Jan-40	1887.06	Mar-43	1886.17	May-46	1884.46
Oct-33	1890.06	Dec-36	1888.42	Feb-40	1887.02	Apr-43	1886.09	Jun-46	1884.62
Nov-33	1890.10	Jan-37	1888.31	Mar-40	1887.26	May-43	1886.12	Jul-46	1884.86
Dec-33	1890.10	Feb-37	1888.15	Apr-40	1887.47	Jun-43	1886.15	Aug-46	1884.89
Jan-34	1889.82	Mar-37	1888.31	May-40	1887.38	Jul-43	1886.12	Sep-46	1884.91
Feb-34	1889.59	Apr-37	1888.79	Jun-40	1887.25	Aug-43	1886.05	Oct-46	1884.85
Mar-34	1889.52	May-37	1889.15	Jul-40	1887.14	Sep-43	1885.94	Nov-46	1884.79
Apr-34	1889.44	Jun-37	1889.55	Aug-40	1886.99	Oct-43	1885.82	Dec-46	1884.78
May-34	1889.36	Jul-37	1889.95	Sep-40	1886.79	Nov-43	1885.64	Jan-47	1884.97
Jun-34	1889.29	Aug-37	1889.91	Oct-40	1886.69	Dec-43	1885.53	Feb-47	1885.58
Jul-34	1889.21	Sep-37	1889.78	Nov-40	1886.56	Jan-44	1885.43	Mar-47	1886.29
Aug-34	1889.13	Oct-37	1889.80	Dec-40	1886.43	Feb-44	1885.35	Apr-47	1886.48
Sep-34	1889.06	Nov-37	1889.81	Jan-41	1886.64	Mar-44	1885.30	May-47	1886.58
Oct-34	1888.98	Dec-37	1889.70	Feb-41	1886.89	Apr-44	1885.25	Jun-47	1886.66
Nov-34	1888.91	Jan-38	1889.57	Mar-41	1886.88	May-44	1885.20	Jul-47	1886.55
Dec-34	1888.84	Feb-38	1889.46	Apr-41	1886.83	Jun-44	1885.20	Aug-47	1886.48
Jan-35	1888.78	Mar-38	1889.34	May-41	1886.82	Jul-44	1885.19	Sep-47	1886.47
Feb-35	1888.72	Apr-38	1889.24	Jun-41	1886.79	Aug-44	1885.18	Oct-47	1886.37

Nov-47	1886.18	Jan-51	1884.56	Mar-54	1884.50	May-57	1886.37	Jul-60	1885.92
Dec-47	1886.11	Feb-51	1885.05	Apr-54	1884.83	Jun-57	1886.50	Aug-60	1885.87
Jan-48	1886.02	Mar-51	1885.28	May-54	1885.19	Jul-57	1886.63	Sep-60	1885.91
Feb-48	1885.85	Apr-51	1885.47	Jun-54	1885.32	Aug-57	1886.73	Oct-60	1885.92
Mar-48	1885.83	May-51	1885.51	Jul-54	1885.42	Sep-57	1886.68	Nov-60	1885.95
Apr-48	1885.81	Jun-51	1885.66	Aug-54	1885.48	Oct-57	1886.59	Dec-60	1885.96
May-48	1885.88	Jul-51	1885.82	Sep-54	1885.43	Nov-57	1886.51	Jan-61	1885.85
Jun-48	1885.99	Aug-51	1885.88	Oct-54	1885.37	Dec-57	1886.49	Feb-61	1885.73
Jul-48	1886.04	Sep-51	1885.99	Nov-54	1885.27	Jan-58	1886.47	Mar-61	1885.60
Aug-48	1885.92	Oct-51	1886.15	Dec-54	1885.17	Feb-58	1886.46	Apr-61	1885.47
Sep-48	1885.85	Nov-51	1886.19	Jan-55	1885.12	Mar-58	1886.45	May-61	1885.38
Oct-48	1885.76	Dec-51	1886.09	Feb-55	1885.01	Apr-58	1886.53	Jun-61	1885.37
Nov-48	1885.63	Jan-52	1885.98	Mar-55	1884.94	May-58	1886.73	Jul-61	1885.29
Dec-48	1885.50	Feb-52	1885.85	Apr-55	1884.90	Jun-58	1887.07	Aug-61	1885.18
Jan-49	1885.39	Mar-52	1885.94	May-55	1884.82	Jul-58	1887.33	Sep-61	1885.15
Feb-49	1885.31	Apr-52	1886.01	Jun-55	1884.75	Aug-58	1887.40	Oct-61	1885.27
Mar-49	1885.27	May-52	1885.93	Jul-55	1884.92	Sep-58	1887.39	Nov-61	1885.86
Apr-49	1885.19	Jun-52	1885.87	Aug-55	1885.12	Oct-58	1887.36	Dec-61	1887.16
May-49	1885.19	Jul-52	1885.87	Sep-55	1885.23	Nov-58	1887.28	Jan-62	1887.82
Jun-49	1885.31	Aug-52	1885.86	Oct-55	1885.18	Dec-58	1887.25	Feb-62	1888.17
Jul-49	1885.34	Sep-52	1885.81	Nov-55	1885.21	Jan-59	1887.14	Mar-62	1888.05
Aug-49	1885.25	Oct-52	1885.71	Dec-55	1885.29	Feb-59	1887.02	Apr-62	1887.89
Sep-49	1885.16	Nov-52	1885.58	Jan-56	1885.31	Mar-59	1886.95	May-62	1887.84
Oct-49	1885.10	Dec-52	1885.40	Feb-56	1885.27	Apr-59	1886.88	Jun-62	1888.15
Nov-49	1884.94	Jan-53	1885.23	Mar-56	1885.28	May-59	1886.86	Jul-62	1888.17
Dec-49	1884.74	Feb-53	1885.14	Apr-56	1885.45	Jun-59	1886.85	Aug-62	1888.15
Jan-50	1884.79	Mar-53	1885.08	May-56	1885.53	Jul-59	1886.73	Sep-62	1888.21
Feb-50	1884.77	Apr-53	1885.01	Jun-56	1885.61	Aug-59	1886.73	Oct-62	1888.42
Mar-50	1884.68	May-53	1884.99	Jul-56	1885.82	Sep-59	1886.74	Nov-62	1888.59
Apr-50	1884.64	Jun-53	1884.94	Aug-56	1886.13	Oct-59	1886.72	Dec-62	1888.59
May-50	1884.69	Jul-53	1884.84	Sep-56	1886.24	Nov-59	1886.66	Jan-63	1888.52
Jun-50	1884.82	Aug-53	1884.74	Oct-56	1886.23	Dec-59	1886.63	Feb-63	1888.45
Jul-50	1884.95	Sep-53	1884.70	Nov-56	1886.13	Jan-60	1886.55	Mar-63	1888.40
Aug-50	1884.93	Oct-53	1884.69	Dec-56	1886.03	Feb-60	1886.25	Apr-63	1888.38
Sep-50	1884.85	Nov-53	1884.58	Jan-57	1885.92	Mar-60	1886.05	May-63	1888.59
Oct-50	1884.72	Dec-53	1884.42	Feb-57	1885.86	Apr-60	1885.99	Jun-63	1889.00
Nov-50	1884.62	Jan-54	1884.25	Mar-57	1885.95	May-60	1885.92	Jul-63	1889.36
Dec-50	1884.50	Feb-54	1884.25	Apr-57	1886.13	Jun-60	1885.84	Aug-63	1889.31

Sep-63	1889.19	Nov-66	1888.90	Jan-70	1888.79	Mar-73	1888.16	May-76	1887.06
Oct-63	1889.20	Dec-66	1888.89	Feb-70	1888.74	Apr-73	1888.03	Jun-76	1887.00
Nov-63	1889.12	Jan-67	1888.92	Mar-70	1888.63	May-73	1887.95	Jul-76	1886.93
Dec-63	1889.07	Feb-67	1888.83	Apr-70	1888.72	Jun-73	1887.93	Aug-76	1886.82
Jan-64	1889.43	Mar-67	1888.70	May-70	1888.90	Jul-73	1887.85	Sep-76	1887.06
Feb-64	1889.52	Apr-67	1888.57	Jun-70	1888.99	Aug-73	1887.80	Oct-76	1886.87
Mar-64	1889.39	May-67	1888.43	Jul-70	1889.03	Sep-73	1887.80	Nov-76	1886.60
Apr-64	1889.33	Jun-67	1888.54	Aug-70	1888.99	Oct-73	1887.77	Dec-76	1886.73
May-64	1889.52	Jul-67	1888.75	Sep-70	1889.07	Nov-73	1887.73	Jan-77	1886.50
Jun-64	1889.62	Aug-67	1888.85	Oct-70	1889.15	Dec-73	1887.63	Feb-77	1886.34
Jul-64	1889.61	Sep-67	1888.92	Nov-70	1889.12	Jan-74	1887.50	Mar-77	1886.37
Aug-64	1889.61	Oct-67	1888.94	Dec-70	1889.03	Feb-74	1887.33	Apr-77	1886.53
Sep-64	1889.72	Nov-67	1888.92	Jan-71	1888.89	Mar-74	1887.21	May-77	1887.41
Oct-64	1889.88	Dec-67	1888.89	Feb-71	1888.78	Apr-74	1887.25	Jun-77	1887.62
Nov-64	1890.07	Jan-68	1888.87	Mar-71	1888.61	May-74	1887.33	Jul-77	1887.81
Dec-64	1890.22	Feb-68	1888.81	Apr-71	1888.50	Jun-74	1887.32	Aug-77	1888.02
Jan-65	1890.16	Mar-68	1888.72	May-71	1888.50	Jul-74	1887.47	Sep-77	1888.06
Feb-65	1890.08	Apr-68	1888.59	Jun-71	1888.61	Aug-74	1887.55	Oct-77	1887.95
Mar-65	1890.01	May-68	1889.75	Jul-71	1888.72	Sep-74	1887.72	Nov-77	1888.03
Apr-65	1889.91	Jun-68	1889.80	Aug-71	1888.89	Oct-74	1887.82	Dec-77	1888.26
May-65	1889.77	Jul-68	1889.82	Sep-71	1889.23	Nov-74	1887.83	Jan-78	1888.31
Jun-65	1889.71	Aug-68	1889.75	Oct-71	1889.21	Dec-74	1887.78	Feb-78	1888.29
Jul-65	1889.76	Sep-68	1889.81	Nov-71	1889.21	Jan-75	1887.62	Mar-78	1888.45
Aug-65	1889.68	Oct-68	1889.79	Dec-71	1889.11	Feb-75	1887.47	Apr-78	1888.96
Sep-65	1889.60	Nov-68	1889.75	Jan-72	1889.04	Mar-75	1887.34	May-78	1889.28
Oct-65	1889.53	Dec-68	1889.75	Feb-72	1888.98	Apr-75	1887.20	Jun-78	1889.16
Nov-65	1889.44	Jan-69	1889.69	Mar-72	1888.90	May-75	1886.99	Jul-78	1889.15
Dec-65	1889.34	Feb-69	1889.61	Apr-72	1888.75	Jun-75	1887.03	Aug-78	1889.20
Jan-66	1889.24	Mar-69	1889.56	May-72	1888.66	Jul-75	1887.08	Sep-78	1889.25
Feb-66	1889.14	Apr-69	1889.48	Jun-72	1888.59	Aug-75	1887.27	Oct-78	1889.42
Mar-66	1889.04	May-69	1889.50	Jul-72	1888.57	Sep-75	1887.66	Nov-78	1889.47
Apr-66	1888.94	Jun-69	1889.45	Aug-72	1888.52	Oct-75	1887.86	Dec-78	1889.44
May-66	1888.86	Jul-69	1889.32	Sep-72	1888.51	Nov-75	1887.89	Jan-79	1889.36
Jun-66	1888.94	Aug-69	1889.12	Oct-72	1888.44	Dec-75	1887.79	Feb-79	1889.52
Jul-66	1888.96	Sep-69	1889.11	Nov-72	1888.50	Jan-76	1887.64	Mar-79	1889.51
Aug-66	1888.90	Oct-69	1889.01	Dec-72	1888.47	Feb-76	1887.49	Apr-79	1889.57
Sep-66	1888.82	Nov-69	1888.91	Jan-73	1888.38	Mar-76	1887.32	May-79	1889.64
Oct-66	1888.83	Dec-69	1888.86	Feb-73	1888.27	Apr-76	1887.16	Jun-79	1889.73

Jul-79	1889.79	Sep-82	1888.89	Nov-85	1887.72	Jan-89	1887.17	Mar-92	1887.03
Aug-79	1889.79	Oct-82	1888.85	Dec-85	1887.64	Feb-89	1887.16	Apr-92	1886.90
Sep-79	1889.73	Nov-82	1888.89	Jan-86	1887.55	Mar-89	1887.15	May-92	1886.77
Oct-79	1889.61	Dec-82	1889.41	Feb-86	1887.46	Apr-89	1886.89	Jun-92	1886.64
Nov-79	1889.55	Jan-83	1889.35	Mar-86	1887.37	May-89	1886.86	Jul-92	1886.77
Dec-79	1889.46	Feb-83	1889.25	Apr-86	1887.29	Jun-89	1886.84	Aug-92	1886.91
Jan-80	1889.32	Mar-83	1889.18	May-86	1887.20	Jul-89	1886.82	Sep-92	1887.04
Feb-80	1889.20	Apr-83	1889.09	Jun-86	1887.38	Aug-89	1886.80	Oct-92	1887.18
Mar-80	1889.09	May-83	1889.00	Jul-86	1887.40	Sep-89	1886.77	Nov-92	1887.32
Apr-80	1888.98	Jun-83	1888.93	Aug-86	1887.38	Oct-89	1886.75	Dec-92	1887.45
May-80	1889.13	Jul-83	1888.92	Sep-86	1887.36	Nov-89	1886.93	Jan-93	1887.56
Jun-80	1889.28	Aug-83	1888.92	Oct-86	1887.34	Dec-89	1887.13	Feb-93	1887.48
Jul-80	1889.33	Sep-83	1888.97	Nov-86	1887.32	Jan-90	1887.32	Mar-93	1887.40
Aug-80	1889.20	Oct-83	1889.08	Dec-86	1887.28	Feb-90	1887.48	Apr-93	1887.32
Sep-80	1889.08	Nov-83	1889.19	Jan-87	1887.19	Mar-90	1887.49	May-93	1887.24
Oct-80	1888.93	Dec-83	1889.15	Feb-87	1887.11	Apr-90	1887.60	Jun-93	1887.16
Nov-80	1888.88	Jan-84	1889.09	Mar-87	1887.03	May-90	1888.02	Jul-93	1887.08
Dec-80	1888.82	Feb-84	1888.97	Apr-87	1886.94	Jun-90	1888.43	Aug-93	1887.00
Jan-81	1888.67	Mar-84	1888.79	May-87	1886.81	Jul-90	1888.40	Sep-93	1886.92
Feb-81	1888.53	Apr-84	1888.69	Jun-87	1886.63	Aug-90	1888.35	Oct-93	1886.84
Mar-81	1888.37	May-84	1888.37	Jul-87	1886.70	Sep-90	1888.30	Nov-93	1886.76
Apr-81	1888.63	Jun-84	1888.26	Aug-87	1886.75	Oct-90	1888.25	Dec-93	1886.54
May-81	1889.04	Jul-84	1888.14	Sep-87	1886.66	Nov-90	1888.19	Jan-94	1886.50
Jun-81	1889.23	Aug-84	1888.02	Oct-87	1886.57	Dec-90	1888.14	Feb-94	1886.40
Jul-81	1889.25	Sep-84	1887.91	Nov-87	1886.49	Jan-91	1888.09	Mar-94	1886.23
Aug-81	1889.56	Oct-84	1887.90	Dec-87	1886.40	Feb-91	1888.04	Apr-94	1886.10
Sep-81	1889.64	Nov-84	1887.88	Jan-88	1886.31	Mar-91	1887.85	May-94	1886.10
Oct-81	1889.65	Dec-84	1887.87	Feb-88	1886.23	Apr-91	1887.66	Jun-94	1886.16
Nov-81	1889.59	Jan-85	1887.86	Mar-88	1886.22	May-91	1887.52	Jul-94	1886.40
Dec-81	1889.54	Feb-85	1887.81	Apr-88	1886.38	Jun-91	1887.44	Aug-94	1886.50
Jan-82	1889.53	Mar-85	1887.57	May-88	1886.23	Jul-91	1887.48	Sep-94	1886.60
Feb-82	1889.31	Apr-85	1887.56	Jun-88	1886.21	Aug-91	1887.53	Oct-94	1886.50
Mar-82	1889.04	May-85	1887.61	Jul-88	1886.50	Sep-91	1887.48	Nov-94	1886.50
Apr-82	1888.98	Jun-85	1887.67	Aug-88	1886.75	Oct-91	1887.43	Dec-94	1886.92
May-82	1889.01	Jul-85	1887.72	Sep-88	1886.97	Nov-91	1887.38	Jan-95	1886.80
Jun-82	1889.01	Aug-85	1887.77	Oct-88	1887.19	Dec-91	1887.34	Feb-95	1886.64
Jul-82	1888.95	Sep-85	1887.83	Nov-88	1887.18	Jan-92	1887.28	Mar-95	1886.40
Aug-82	1888.95	Oct-85	1887.81	Dec-88	1887.17	Feb-92	1887.16	Apr-95	1886.40

May-95	1886.47	Jul-98	1888.84	Sep-01	1886.39
Jun-95	1886.50	Aug-98	1888.89	Oct-01	1886.41
Jul-95	1886.51	Sep-98	1888.91	Nov-01	1886.50
Aug-95	1886.30	Oct-98	1888.92	Dec-01	1886.52
Sep-95	1886.30	Nov-98	1888.92	Jan-02	1886.42
Oct-95	1886.40	Dec-98	1888.82	Feb-02	1886.27
Nov-95	1886.45	Jan-99	1888.79	Mar-02	1886.16
Dec-95	1886.56	Feb-99	1888.44	Apr-02	1886.04
Jan-96	1886.50	Mar-99	1888.31	May-02	1886.53
Feb-96	1886.40	Apr-99	1888.24	Jun-02	1886.53
Mar-96	1886.30	May-99	1888.10	Jul-02	1886.40
Apr-96	1886.20	Jun-99	1887.94		
May-96	1886.07	Jul-99	1887.80		
Jun-96	1886.00	Aug-99	1887.70		
Jul-96	1886.10	Sep-99	1887.68		
Aug-96	1886.24	Oct-99	1887.57		
Sep-96	1886.30	Nov-99	1887.49		
Oct-96	1886.50	Dec-99	1887.49		
Nov-96	1886.50	Jan-00	1887.34		
Dec-96	1886.56	Feb-00	1887.13		
Jan-97	1886.50	Mar-00	1886.93		
Feb-97	1886.40	Apr-00	1886.79		
Mar-97	1886.30	May-00	1886.69		
Apr-97	1886.20	Jun-00	1886.47		
May-97	1886.21	Jul-00	1886.35		
Jun-97	1886.09	Aug-00	1886.27		
Jul-97	1886.06	Sep-00	1886.20		
Aug-97	1886.07	Oct-00	1886.09		
Sep-97	1885.97	Nov-00	1886.08		
Oct-97	1885.85	Dec-00	1886.02		
Nov-97	1885.80	Jan-01	1886.01		
Dec-97	1886.84	Feb-01	1886.02		
Jan-98	1887.88	Mar-01	1885.87		
Feb-98	1887.96	Apr-01	1885.94		
Mar-98	1887.91	May-01	1886.15		
Apr-98	1887.85	Jun-01	1886.13		
May-98	1888.31	Jul-01	1886.15		
Jun-98	1888.75	Aug-01	1886.33		

APPENDIX A.2 Monthly precipitation Data

MEAN MONTHLY RAINFALL													
NAIVASHA D.O ID 9036002													
1957-1994													
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**
1957	11.6774												11.67742
1958	15.8065	43.4839	20	7.80645	33.3871	7.06452	26.3226	3.87097	5.903226	11.80645	20.80645	26.29032	222.5484
1959			17.4516	0	0	0	5.06452	20	16.3871	8.967742	27.12903	4.774194	99.77419
1960	17.871	9.06452	45.129	34.2903	12.8065	2.54839	1.22581	28.9032	18.09677	9.806452	21.16129	14.70968	215.6129
1961	0		8.45161	32.1667	42	2.9	0	16	16.83333	33.16129	111.5667	37.83871	300.9183
1962	0	0	0	0	0	0	0	0	0	18.51613	0	0	18.51613
1963	10.9032	13.6071	12.6774	70.8333	42.4839	13.2333	0.77419	8.12903	3.5	9.322581	29.13333	49.22581	263.8233
1964	2.96774	18.0345	34.1613	55.2667	3.48387	6.63333	32.9032	2.6129	12.5	28.80645	18.4	17.45161	233.2216
1965	11.2258	5.32143	7.77419	36.8667	18.0645	10.7	11.8065	10.9677	6.033333	17.48387	22	12.74194	170.986
1966	6.6129	16.0714	23.7419	68.7333	9.09677	4.26667	1.80645	31.871	29.3	16.48387	37.63333	1.741935	247.3596
1967	4.70968	2.67857	16.3226	36.3	38.5161	15.3667	27.2258	16.8065	11.46667	31.96774	19	8.032258	228.3926
1968	0.58065	36.6774	27.5807	81.0968	4.45161	19.0645	1.16129	0.80645	12.54839	17.90323	27.12903	17.87097	246.871
1969	15.1613	8.96774	21.871	8.16129	40.8387	6.41936	4.6129	5.83871	9.516129	8.290323	20.19355	13.83871	163.7097
1970	26.6774	11.4194	35.5807	35.6129	26.5161	18.871	8.51613	3.74194	27.19355	0	0	0	194.129
1971	13.4516	0.74194	2.03226	20.6452	56.0645	3.77419	12.6774	36.3871	7.032258	44.41935	10.54839	15.93548	223.7097
1972	6	34.3871	5.67742	6	14.9355	29.7742	6.67742	13.6452	10.35484	29.83871	20.6129	3.258065	181.1613
1973	18.4516	18.7742	2.58065	41	27.1613	10.8065	6.6129	9.64516	18.03226	11.29032	16.80645	4.387097	185.5484
1974	4.32258	5.45161	10.3548	71.9677	21.6129	24.1936	22.6774	14.3548	14.83871	9.741935	13.16129	15.93548	228.6129
1975	0.54839	6.90323	8.32258	41.0323	17.6774	6.58065	25.9032	16.3226	19.93548	26.25806	5.064516	7.903226	182.4516
1976	2.51613	9.6129	5.45161	22.2581	14.871	21.871	15.6129	24.4516	15.35484	2.419355	7.483871	14.83871	156.7419
1977	9.96774	7.90323	9.87097	66.129	42.129	6.48387	21.6452	13.4839	6.064516	25.32258	35.32258	23.41935	267.7419
1978	24.6129	17.4839	71.7419	40.3548	23.7742	4.83871	3.51613	24.871	25.6129	14.3871	10.48387	31.67742	293.3548
1979	25.0645	39.0968	18.9677	22.8065	0	20.4516	9.09677	16	15.35484	6.806452	24.06452		197.7097
1980	12.6129	2.09677	0	40.5161	49.6129	21.7742	0.70968	2.54839	10.3871	6.451613	30.12903	3.129032	179.9677
1981	0.09677	7.90323	57.6452	45.8065	21.1936	10.1613	17.6774	14.4516	9.548387	13.51613	19.19355	11.48387	228.6774
1982	7.96774	6.70968	2	38.1613	35.9032	6.67742	2.64516	18.5161	14.80645	29.87097	55.06452	21	239.3226
1983	11.4516	10.9032	2.67742	27.1936	12.3226	32.1613	12.7742	14.9032	18.83871	29.67742	19.12903	12.54839	204.5806
1984	1.03226	1.45161	0.96774	20.7097	2.67742	0	16.4839	13.5807	2.225806	16.77419	32.35484	32.87097	141.129
1985	5.74194	20.5807	21.5161	47.4516	27.3548	7.22581	9.3871	3.6129	16.45161	5.354839	6.83871	8.612903	180.129
1986	13.1613	12.871	13.0968	51.9355	12.9355	11.8387	2.45161	15.6774	8.709677	13.51613	22.58065	18	196.7742
1987	2.64516	6.22581	14.7742	21.871	38.129	51.2258	17.6129	13.5484	3.709677	5.935484	18.64516	3.677419	198
1988	12.4839	3.16129	26	39.1613	29.2258	5.16129	12.2258	20.0968	8.709677	5.548387	13.3871	5	180.1613
1989	30.9032	7.67742	12.5484	29.3548	37.6129	12.0968	25.8387	27.4194	18.32258	25.6129	15.19355	32.09677	274.6774
1990	17.2258	32.1613	41.9677	61.5161	24.4839	4.67742	6.12903	25.0323	15.03226	32.64516	20.48387	7.709677	289.0645
1991	2.32258	1	22.7742	23.1613	20.2258	24.1613	4.03226	5.09677	7.16129	21.03226	22.77419	5.064516	158.8064
1992	7.67742	4.22581	4.25807	30.6129	29.9677	26.9032	30.4839	7.22581	20.48387	34.87097	9.290323	19.64516	225.6452
1993	60.3226	5.32258	1.83871	6.48387	12.5484	19.5484	0.03226	4.25807	5.806452	15.93548	11.29032	9.225806	152.6129
1994	2.54839	10.4516	18.0968	36.6452	22.5807	17.2903	22.8387	5.64516	3.83871	0	67.25806	11.93548	219.129
TOTAL	417.323	438.423	645.903	1319.91	866.645	486.745	427.161	510.323	465.8914	639.7419	861.314	523.871	7603.25

station	9036025												
	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1957	71.1	70.3	48.8	161.4	153.5	126.8	34.1	49.2	101.4	90.2	37.2	60.3	1004.3
1958		121.5	113.6	106.3	199.2	119.5	114.2	55.2	60.5	68.7	95	93.7	1147.4
1959	82.2		77.4	68.5	161.1	61.8	51.7	65.1		54.2	97.5	34.9	754.4
1960		23.4	87.8	146.5		51.1	64.2	60.5	174.7	60.6	129.6	31.8	830.2
1961	97.8		58.5	148	195.9	55.7	10.2	148.7	130.8	182.7	342.3	194.8	1565.4
1962		15	60.3	153.3		94.6	56.9	121.4	222.1	151	85.5	98.2	1793.9
1963	13	88	80	200.9	237.7	63.7	40.9	86.2	48.8	69.1	129.2	253.9	1311.4
1964	64	169.7	136.4	154	256.3	154.6	51.2	51.8	88.1	127.9	59.9	50.4	1364.3
1965	32.2	15.6	76.2	163.1	220.7	62.2	106	77.2	77.4	85.8	111.4	67.6	1095.4
1966	8.1	38.5	120.5	228.2	109.3	32.2	26.7	118.9	144.4	99.7	174.4	9.9	1110.8
1967	11.4	16.5	45.2	143.7	286.2	97.5	92.6	50	74.5	76.5	145.3	47.4	1086.8
1968		155	173.4	253.5	82.3	47.2	16.8	68.3	66.2	79.6	72.9	53.4	1068.6
1969	260.4	48.4	49.8	38.5	135	32.5	39	104.5	64	67.9	63.6	23.8	927.4
1970		38.6	178.9	118.4	197.3	89.2	73.3	79.2	170	66.3	76.2	31.7	1119.1
1971	6.7	21	12.2	133	194.7	63.9	113.4	155.8	40.1	76.1	54.3	80.4	951.6
1972		124	22.2	63.5	112.9	167.1	84.2	114.4	57.6	134.8	134.9	44.9	1060.5
1973	15.9	73.8	6.8	130.6	148.7	110.7	40.2	67.7	122.1	71.5	41.5	5.5	835
1974		33.5	113.6	151.7	69.3	150.1	127.4	56.3	169.7	103.6	85	21.5	1081.7
1975	23	18.2	36.3	94.5	117	65.6	79.5	139.2	118.9	186.7	44	77.9	1000.8
1976		24.5	68.8	116.3	106.6	140.1	238.4		88.5	83.3	92.6	58.3	1017.4
1977	112	52.3	11.4	409.3	241	74.4	126.5	96	67	114.1	212.5	162.8	1679.3
1978	105.1	84	192.1	223.7	164.7	49.3	46.6	98.8	189.6	101.5	31.3	76.5	1363.2
1979	48	142.8	92.5	125	117.2	156.1	59.5	63	85.5	71.4	74.5	7	1042.5
1980	12.5	84.5	44.1	142.2	240.9	131.2	21.5	42.9	54	118.2	116.2	22.5	1030.7
1981		40.4	233.1	192.5	234.2	150.7	113	95.6	68.4	63	96.1	113.7	1400.7
1982	18.8	23.1	15.3	185.8	145	85.5	76.8	71	82.4	119.6	149.5	59.3	1032.1
1983		31.6	62.1	164.4	74.4	94	86.5	111.6	106.1	285.8	115.1	111.3	1242.9
1984	10.5	11.2	17	121.5	25.9	28.2	191	139	40.6	130.1	123	82.3	920.3
1985		71.7	123.2	194.6	155	139.8	107.2	56.2	108	120	130.5	17.7	1223.9
1986	31	16.5	79.9	251.6	93.2	58.7	16.5	78.6	57	42.6	88.5	75.1	889.2
1987		2.7	49.5	89.4	148.2	142.9	17.8	86.6	126.6	32.2	212.7	7.3	915.9
1988	46.9	0	91.8	378.6	169.6	48.8	53.2	137.9	138.7	49.8	111.3	38.9	1265.5
1989	90.2	55.5	48.3	188.8	116.4	66.7		187.2	150.1	157.6	140.9	170.2	1371.9
1990		56.9	199.7	239.1	171.9	99.8	53.4	92	100.9	85.5	100.8	55.5	1255.5
1991	21.6	40	132.3		128	163.4	34.6	50.5	97.3	150.3	45.8	29.5	893.3
1992	0	22.4	26.4	229.7	147.4	136.6	135.1	116.3	107.1	168.2	75.2	65.6	1230
1993	124.6	83.2	33.8	77.2	105	96.3	40.5	72.6	48.2	51.3	81.1	32	845.8
1994	0	103.7	85.1	200.5	196.2	107.2	38.6	55.8	166.6	125.2	216.2	29.3	1324.4
1995	0	67.5	190.9	52.8	110	139.2	93.5		120.8		123		897.7
1996	38	84.8	71.3	51	60	137.6		138.5	137.5	88.3	96.1	12.4	915.5
1997	13.1	0	52.7	270.9	29.7		64.2	130.1	43.2	170.5	192	116.8	1083.2
1998	197.8	119.7	51.2	225.6	278.8	174.8	66	22.7	166.2	72.8	69.9	17.1	1462.6

station	9036241												
	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1958	41.6	138.5	110.9	112.1	170.5	101.1	170.2	80.1	64.4	106.1	37.8	83.8	1217.1
1959		16.4	66.1	98.9		110.6	91.2	126.1	83.2	117.6	65.8	25.3	801.2
1960			79.9	135.3	140.1	67	97.2	121.5		49	144.5	25.3	859.8
1961	56.1	33.8	15.2	103.6	193.3	92	59.1	172.6	111.2	199.4	265.4	106.9	1408.6
1962		0	62.8	176.2	167.3	195.7	78.1	99.1	254.8	224.8	79.7	67.5	1406
1963	201.4	70.5	61.7	257.3	194.5	66.9	52.1	87.4	14	84.2	100.4	252.3	1442.7
1964	40.5	31.8	169.7	209.5	187.6	82.7	115.6	133.5	134	109.1	35	52.6	1301.6
1965	14.5	6.8	48.4	105.6	134.2	79.9	76.5	88.8	158.2	88.9	60.8	62	924.6
1966	0	28.1	91.6	193.7	89	115.6	139.2	130.6	142.7	96	128.1	43.2	1197.8
1967	0	15	69.4	136	169.1	74.4	127.4	49.1	125.9	86.7	94.5	23.9	971.4
1968		142.9	156.9	200.4	81	102.2	79	119.5	69.5	87	49.7	24.8	1112.9
1969	140.8	17.5	65.8	48.4	182	40.9	84	92.2	146.7	56.8	52.5	5	932.6
1970		74.7	124.1	205	150.4	81.6	92.9	109.6	190.3	103.8	115.8	17.6	1265.8
1973	12.9	111.1	5.7	115.8	158.4	83.2	119.3	102.5	103.7	76.6	68.4	11	968.6
1974		18.6	61.2	121.6	125	132.8	162.6	95.2	218.2	159.3	53.2	4.5	1152.2
1975	17	27.4	24.6	111.6	193.5	93.3	115	141.9	162.7	141.7	37.9	24.5	1091.1
1976		11.2	42.1	89.3	91.5	122.8	133.1		82.2	74.9	62.8	34.4	6165.4
1977	79.8	85.9	24.6	351.1	248.3	92	201.1	104.4	105.6	107.5	144.1	99.5	1643.9
1978	129.7		200		159.2	139	119.6	110	197	97.5	86.8	101.6	1340.4
1979	34.3	111.5	85.2	201.6	130	190	76.7	128.6		61.7	79.7	30.3	1129.6
1980	13.2	18.8	40.6	141.9	322.2	175.4	10.5	83.3	92.9	142.5	79.9	32	1153.2
1981		16.9	197.5	181.3	284.9	79.4	180.5	120.4	137.3	84.9	40.4	74.6	1398.1
1982	16.3	37.9	25	158.5		90.9	65.4	173	102.1	144.2	165.9	53.5	1032.7
1983		46	72.1	246.6	141.1		130.3	127.3	145.6	231.7	190.5	68	1399.2
1984	18	6.2	22.5		28.8	47.5	127	140.7	101.5	103.6	104.7	60.9	761.4
1985		37.3	46.2	254.1	265	121.7	76.8	89.7	122.6	95.4	79.5	5.8	1194.1
1986	12.5	13	49.9	309.8	178.6	103					75.2	58.2	800.2
1987			60.3	92.4	134.5		44.7	56.9	129	56		0	573.8
1988	18.4	0	94.4	328.7	224.6	182.4	151.3	110.7	240.5	44.2	152	20.6	1567.8
1989	57.2	21.8	64.2	39.4	68.3	50		150	166.7				617.6
1990			181.9	200.9	134.8	45.8	87.4	127.1	92.4	116.6	73.6	28.8	1089.3
1991	29.4	16	86.2		129	143	77.6	130.8	69	117			798
1992	20.8	11.2	30.6	183.4	168.5	260.5	206.9	110.5	103.6	185.6	64.9	74.4	1420.9
1993	116.9	85	6.8	56.1	139.7	95.2	68.8		106.3				674.8
1995									123				123
1996			28.4	31.3	104.1	229.5	125.3	239.9	135.5		123.8	50.3	1068.1
1997	18		23	259.1	25.1	150	82.3	67.6	50.8	98.2	167.3	59	1000.4
1998	234.7	90.8		198.6	195.4	177.1	121.6	77.7	152	72.9	95.4		1416.2
Grand Total	1324	1342.6	2595.5	5655.1	5509.5	4015.1	3746.3	9319.4	4435.1	3621.4	3176	1682.1	46422.1

station	9036264												
	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1964	60.5									116	76.2	13.5	266.2
1965		12.5	82.3	142.9	158.8		12.6	51.3	13.1	108.4	80.8	336.8	999.5
1969	206.5	95.6	47.4	48.9	206.4	29.1	57.8	76.6	121.9	49.7	61	30.2	1031.1
1970		7.2	139.6	224.5	251.2	100.9	71.2	120.7	96.7	103.6	26.9	12.9	1155.4
1971	17.1	0.4	10.1	98	222.1	91.3	110.5	196.6	97.2	47.6	39.6	56.2	986.7
1972		108.3	12.8	61.2	66.6	174.4	83.3	142.8	63.6	138.8	135.8	32.3	1019.9
1973	18.7	48.8	2.5	41.6	146.7	61.4	42.1	79.6	125.4	50.7	54.7	0	672.2
1974		5.3	43.3	176.1	111.5	132.2	129.4	56.8	137.8	62	59.1	17.6	931.1
1975	15.8				224.5	92.9	97.6		89.9	154.9	12.4		688
1976										56.5	78.5	15.5	150.5
1977	76.1	32.4	9	337.2	285	117	120.7	97.1	72.7	128	139.2	69.5	1483.9
1978		90.7	138.4	173.8	99.4	65.2	47.1	30					644.6
1979					141.5	105.5	50.1	112.5	73	57.3	103.1		643
1980	4.2						20.8	39.1	77.9		42.5	21.4	3646.2
1981		31.3	205.2	289.1	169.6	82.7	169.5	114.9	103.1	73.8	38.7	50.1	1328
1982	0	3.1	10.3	192.2	176.4	145.2	88.7	129.5	77	119.5	105.1		1047
1983		53	0	308	122.5	89.8	119.1	144.5	90	102.9	125.2	57.8	1212.8
1984	10	0	0	89.5	27	20	87.3	117.5	57	24	73		505.3
1985		75	76.9	194.1	281.1	73.4	77.4	90.2	69.9	68.5	108.3		1114.8
1986	13.2			275.5	179.5	77.1	92.5	112.1	52.4	61.9	40	64.1	968.3
1987		31.5	52.5	155.7	194.7	120.3	31.7	58.5	40.6	73.8	125.2	4.3	888.8
1988					193.6	131.5	96.2	102.5	110.7	67.1	69.9	0	771.5
1989	52.2	25.2	47	117.7	58.1	28		103.6		187.2	94.1	123.8	836.9
1991			81.5		99.6	121.4	37.6	112.5	30.7	57.3	16.5	32	589.1
1992	20	5.4	8	201.8	151.7	84.2	89.3	82.8	102.5	112.4		65.6	923.7
1993	95.1	76.2	0	79.7	94.6	123.7	41.5	35.3	35.8	28.7	30.6	44.9	686.1
1994	0	34.5	57.7	219.9	142.9	174.4	24.2	56	60.6	58.1	177.4	0.3	1006
1995		19	70.6	96.1	93.7	69.6					122.8	46.2	518
1996	5	16.8	40.8	30.5	113.6	169.8	110.1	123.3	56.6	146.6	88.7	9.3	911.1
1997	21.8	0	23.1	202.1	41.7	100	63.5	39	1	71.7	179		742.9
1998	154.7	75.4	14.8	169.4	260	148	77.2	78.2	169.3	40.5	72.1	4	1263.6
Grand Total	770.9	847.6	1173.8	3925.5	4314	2729	2049	2503.5	2026.4	5807.8	2376.4	1108.3	29632.2

APPENDIX B Weather Generator Statistic and Probability Value

Station 9036002

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Pwd	0.13	0.14	0.20	0.32	0.24	0.18	0.13	0.18	0.20	0.22	0.28	0.19
Pww	0.45	0.41	0.48	0.65	0.53	0.46	0.43	0.42	0.35	0.48	0.57	0.45
mean	30.30	35.40	54.00	114.90	70.20	43.80	32.10	39.90	42.00	51.00	63.30	37.50
sd	3.92	4.14	5.04	7.38	6.30	4.43	4.18	4.26	4.43	4.39	4.82	3.60
skew	5.34	5.63	4.58	3.04	4.21	5.98	6.48	5.72	5.12	4.30	4.14	4.73
Number rainy days	4.66	5.19	8.29	13.19	9.49	7.00	5.29	6.84	6.65	8.68	11.16	7.28

Station 9036025

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Pwd	0.12	0.16	0.21	0.36	0.31	0.25	0.21	0.26	0.27	0.27	0.30	0.17
Pww	0.54	0.51	0.56	0.68	0.63	0.61	0.53	0.55	0.62	0.60	0.65	0.54
mean	52.50	61.20	80.40	166.20	151.50	99.60	71.40	88.20	105.00	100.80	111.90	62.70
sd	4.83	5.24	6.10	8.42	7.97	6.12	5.33	5.81	6.10	6.31	6.00	5.33
skew	4.01	4.24	3.88	2.36	2.03	2.88	4.49	3.47	2.55	3.36	2.37	4.46
Number rainy days	4.38	6.64	9.95	15.50	13.98	11.38	9.26	10.86	12.12	12.14	13.90	8.05

Station 9036241

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Pwd	0.12	0.13	0.18	0.36	0.29	0.28	0.29	0.31	0.30	0.27	0.28	0.15
Pww	0.51	0.49	0.54	0.67	0.67	0.64	0.59	0.65	0.65	0.65	0.65	0.45
mean	54.00	46.80	70.50	168.60	151.80	116.70	102.00	110.40	126.60	107.70	96.60	49.20
sd	5.13	4.67	5.92	9.13	8.01	6.51	6.19	6.02	6.65	5.96	5.50	4.94
skew	4.45	4.87	4.03	3.37	2.17	2.22	3.27	3.43	2.29	2.43	2.41	6.41
Number rainy days	4.05	4.89	8.11	14.18	13.29	12.03	11.79	13.53	12.95	11.71	11.61	5.89

Station 9036264

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Pwd	0.11	0.10	0.13	0.28	0.32	0.27	0.21	0.23	0.23	0.25	0.25	0.11
Pww	0.48	0.54	0.49	0.72	0.66	0.55	0.60	0.61	0.58	0.62	0.68	0.48
mean	44.10	39.60	47.70	165.60	151.20	100.50	74.40	90.30	79.20	82.20	82.80	44.70
sd	4.45	3.88	4.60	9.01	8.24	6.46	4.74	5.94	5.05	5.04	4.43	5.51
skew	4.31	4.30	4.51	2.43	2.55	3.43	3.08	3.79	2.75	3.16	2.49	7.32
Number rainy days	3.09	3.69	5.28	12.16	13.97	10.06	10.16	10.84	9.63	11.88	13.03	4.44

APPENDIX C.1 Discharge Measurement N1

*** DISCHARGE MEASUREMENTS ***											
River:	Nandrasi				Photo Nr:						
Cross num:	N1				UTM X:			232803			
date/time :	15-09-2002/11.50				UTM Y:			9941446			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Surface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0.25	0		0.15							
2	0.57	0.32	0.32	0.15	16	16	16	16	0.085	0.085	0.085
3	0.89	0.64	0.32	0.18	34	34	34	34	0.152	0.152	0.152
4	1.21	0.96	0.32	0.15	64	64	64	64	0.277	0.277	0.277
5	1.53	1.28	0.32	0.18	90	86	90	86	0.379	0.379	0.379
6	1.85	1.6	0.32	0.18	106	104	106	104	0.451	0.451	0.451
7	2.17	1.92	0.32	0.18	90	94	90	94	0.396	0.396	0.396
8	2.49	2.24	0.32	0.18	80	80	80	80	0.345	0.345	0.345
9	2.81	2.56	0.32	0.15	88	84	88	84	0.371	0.371	0.371
10	3.13	2.88	0.32	0.12	60	62	60	62	0.265	0.265	0.265
11	3.5	3.25	0.37	0							

Flow Measurement by Velocity-Area Method

No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m²)		(m³/s)
Left Bank	0.25		0.15						0			
1	0.57	0.32	0.15	0.6 depth	16	60	0.27	0.085	0.32	A1	0.048	0.006
				surface	16	60	0.27			A2	0.025	
2	0.89	0.64	0.18	0.6 depth	34	60	0.57	0.152	0.32	A3	0.028	0.008
				surface	34	60	0.57			A4	0.028	
3	1.21	0.96	0.15	0.6 depth	64	60	1.07	0.277	0.32	A5	0.025	0.014
				surface	64	60	1.07			A6	0.025	
4	1.53	1.28	0.18	0.6 depth	88	60	1.47	0.379	0.32	A7	0.028	0.021
				surface	88	60	1.47			A8	0.029	
4	1.85	1.60	0.18	0.6 depth	105	60	1.75	0.451	0.32	A9	0.029	0.026
				surface	105	60	1.75			A10	0.029	
4	2.17	1.92	0.18	0.6 depth	92	60	1.53	0.396	0.32	A11	0.029	0.023
				surface	92	60	1.53			A12	0.029	
4	2.49	2.24	0.18	0.6 depth	80	60	1.33	0.345	0.32	A13	0.029	0.019
				surface	80	60	1.33			A14	0.028	
4	2.81	2.56	0.15	0.6 depth	86	60	1.43	0.371	0.32	A15	0.025	0.018
				surface	86	60	1.43			A16	0.023	
4	3.13	2.88	0.12	0.6 depth	61	60	1.02	0.265	0.32	A17	0.020	0.013
				surface	61	60	1.02			A18	0.029	
Right Bank	3.50	3.25	0.00						0.37			
								Sum	3.25		0.504	0.149

APPENDIX C.2 Discharge Measurement N6

*** DISCHARGE MEASUREMENTS ***

River:	Nandrasi	Photo Nr:		
Cross num:	N6	UTM X:		234389
date/time :	9/15/2002	UTM Y:		9943332

Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Suface		0.6 depth	surface	average
	(m)	(m)	(m)	(m)							
1	0.25	0		0.15							
2	0.75	0.5		0.15			162	162	0.000	0.693	0.346
3	1.25	1		0.13			114	120	0.000	0.502	0.251
4	1.75	1.5		0.15			98	98	0.000	0.422	0.211
5	2.25	2		0.1			50	54	0.000	0.226	0.113
6	2.5	2.25		0.1					0.000	0.026	0.013
7											
8											
9											
10											

Flow Measurement by Velocity-Area Method

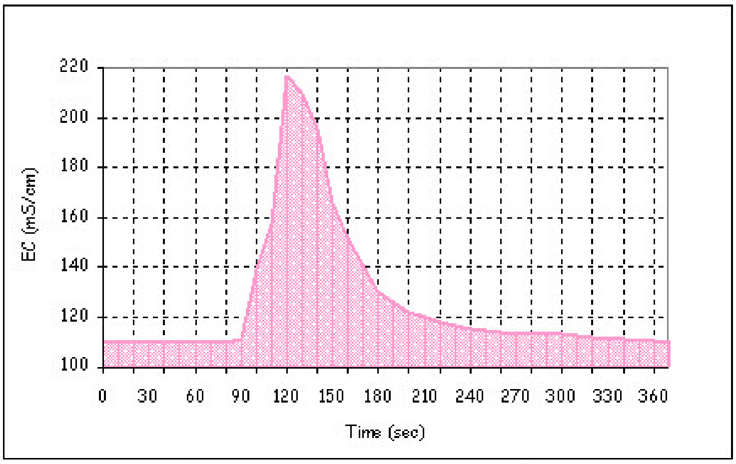
Date/Time : 15 Sept 2002 / 14:50		Current meter:	a:	0.2544
Site:	N6(Nandarashi)	Pitch of propeller: (m)	b:	0.006
X	234389			
Y	9943332			

No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity at point	avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	0.25		0.15							0			
1	0.75	0.50	0.1500	surface	162	60	2.70	0.693	0.693	0.50	A1	0.075	0.077
					162	60	2.70	0.693			A2	0.036	
2	1.25	1.00	0.13	surface	114	60	1.90	0.489	0.502	0.50	A3	0.034	0.034
					120	60	2.00	0.515			A4	0.034	
3	1.75	1.50	0.15	surface	98	60	1.63	0.422	0.324	0.50	A5	0.036	0.023
					98	60	1.63	0.422			A6	0.034	
4	2.25	2.00	0.1	surface	50	60	0.83	0.218	0.226	0.50	A7	0.028	0.015
					54	60	0.90	0.235			A8	0.038	
Right Bank	2.50	2.25	0							0.25			
									Sum	**2.25**		**0.315**	**0.149**

Flow Measurement by Gulp Dilution Method

Date/Time : 7 may 2002 / 10:30	Conductivitymeter : HACH session	Salt : 624.43 g
Site:	Time interval : 10 second	

No	Time (second)	EC (µS/cm)	dif.EC	Area
initial	0	110	0	0.0
1	10	110	0	0.0
2	20	110	0	0.0
3	30	110	0	0.0
4	40	110	0	0.0
5	50	110	0	0.0
6	60	110	0	0.0
7	70	110	0	0.0
8	80	110	0	0.0
9	90	110.9	0.9	4.5
10	100	139	29	149.5
11	110	157	47	380.0
12	120	217	107	770.0
13	130	210	100	1035.0
14	140	196	86	930.0
15	150	166	56	710.0
16	160	152	42	490.0
17	170	141	31	365.0
18	180	130	20	255.0
19	190	126	16	180.0
20	200	122	12	140.0
21	210	120	10	110.0
22	220	118	8	90.0
23	230	116.5	6.5	72.5
24	240	116	6	67.5
25	250	114.7	4.7	48.5
26	260	113.7	3.7	42.0
27	270	113	3	33.5
28	280	113	3	30.0
29	290	113	3	30.0
30	300	113	3	30.0
31	310	112.5	2.5	27.5
32	320	112	2	22.5
33	330	111.5	1.5	17.5
34	340	111	1	12.5
35	350	110.5	0.5	7.5
36	360	110.5	0.5	5.0
37	370	110	0	2.5
			SUM	6048.0



Time (T) =	290	second
Cm =	20.9	µS/cm
	0.0209	mS/cm
NaCl =	0.0136	g/l
Q =	158.8396	l/s
	0.159	m3/s

[1 mS/cm = 0.65g/l of NaCl]

APPENDIX C.3 Discharge Measurement N7

*** DISCHARGE MEASUREMENTS ***											
River:	Nandrasi				Photo Nr:						
Cross num:	N7				UTM X:			234673			
date/time :	14-09-2002/16:25				UTM Y:			9945822			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Surface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0.2	0		0.05							
2	0.6	0.4	0.4	0.12	80	78	80	78	0.341	0.341	0.341
3	1	0.8	0.4	0.15	78	74	78	74	0.328	0.328	0.328
4	1.4	1.2	0.4	0.15	90	90	90	90	0.388	0.388	0.388
5	1.8	1.6	0.40	0.12	70	74	70	74	0.311	0.311	0.311
6	2	1.8	0.2	0.14							
7											
8											
9											
10											

Flow Measurement by Velocity-Area Method												
Date/Time :	14-09-2002/16:25											
Site:	N7											
X	234673											
Y	9945822											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	0.20		0.05						0			
1	0.6	0.40	0.12	0.6 depth	79	60	1.32	0.341	0.40	A1	0.041	0.023
				surface	79	60	1.32			A2	0.026	
2	1	0.80	0.15	0.6 depth	76	60	1.27	0.328	0.40	A3	0.029	0.019
				surface	76	60	1.27			A4	0.030	
3	1.4	1.20	0.15	0.6 depth	90	60	1.50	0.388	0.40	A5	0.030	0.023
				surface	90	60	1.50			A6	0.029	
4	1.8	1.60	0.12	0.6 depth	72	60	1.20	0.311	0.40	A7	0.026	0.014
				surface	72	60	1.20			A8	0.018	
Right Bank	2.00	1.80	0.00						0.20			
								Sum	**1.80**		**0.227**	**0.078**

APPENDIX C.4 Discharge Measurement N10 (day 1)

*** DISCHARGE MEASUREMENTS ***											
River:	Nandrasi				Photo Nr:						
Cross num:	1				UTM X:			229994			
date/time :	9/12/2002				UTM Y:			9939821			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Suface		0.6 depth	surface	avg in vertical
	(m)	(m)	(m)	(m)							
1	0.2	0		0.48							
2	0.6	0.4	0.4	0.55	33	34	32	36	0.150	0.152	0.151
3	1	0.8	0.4	0.52	31	34	53	55	0.146	0.235	0.191
4	1.4	1.2	0.4	0.44	32	31	54	56	0.143	0.239	0.191
5	1.8	1.6	0.4	0.44	44	39	43	43	0.182	0.188	0.185
6	2.2	2	0.4	0.44	26	26	31	29	0.122	0.137	0.130
7	2.6	2.4		0.44							
8											
9											
10											

Flow Measurement by Velocity-Area Method												
Date/Time : 12 Sept 2002 / 15:25			Current meter:			a:						
Site:	N10(Nandarashi)		Pitch of propeller:		(m)	b:						
X	229994											
Y	9939821											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	0.20		0.48						0			
1	0.6	0.40	0.55	0.6 depth	33.5	60	0.56	0.151	0.40	A1	0.213	0.049
				surface	34	60	0.57			A2	0.109	
2	1	0.80	0.52	0.6 depth	32.5	60	0.54	0.191	0.40	A3	0.106	0.039
				surface	54	60	0.90			A4	0.100	
3	1.4	1.20	0.44	0.6 depth	31.5	60	0.53	0.191	0.40	A5	0.092	0.034
				surface	55	60	0.92			A6	0.088	
4	1.8	1.60	0.44	0.6 depth	41.5	60	0.69	0.185	0.40	A7	0.092	0.050
				surface	43	60	0.72			A8	0.176	
5	2.2	2.00	0.44	0.6 depth	26	60	0.43	0.130	0.40	A7	0.088	0.034
				surface	30	60	0.50			A8	0.176	
Right Bank	2.60	2.40	0.44						0.40			
								Sum	**2.40**		**1.239**	**0.206**

APPENDIX C.5 Discharge Measurement N10 (day 2)

*** DISCHARGE MEASUREMENTS ***												
River:	Nandrasi				Photo Nr:							
Cross num:	1				UTM X:			229994				
date/time :	9/12/2002				UTM Y:			9939821				
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Suface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0.25	0		0.55							
2	0.65	0.4	0.4	0.55	36	38	46	50	0.163	0.210	0.186
3	1.05	0.8	0.4	0.52	38	42	56	60	0.176	0.252	0.214
4	1.45	1.2	0.4	0.47	34	34	56	58	0.152	0.248	0.200
5	1.85	1.6	0.4	0.4	36	34	46	46	0.156	0.201	0.178
6	2.25	2	0.4	0.45	28	24	28	24	0.122	0.122	0.122
7	2.7	2.45		0.45							
8											
9											
10											

Flow Measurement by Velocity-Area Method												
Date/Time : 14 Sept 2002 / 09:45			Current meter:			a:						
Site:	N10(Nandarashi)		Pitch of propeller:		(m)	b:						
X	229994											
Y	9939821											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m²)		(m³/s)
Left Bank	0.25		0.55						0			
1	0.65	0.40	0.55	0.6 depth	37	60	0.62	0.186	0.40	A1	0.220	0.061
				surface	48	60	0.80			A2	0.109	
2	1.05	0.80	0.52	0.6 depth	40	60	0.67	0.214	0.40	A3	0.106	0.044
				surface	58	60	0.97			A4	0.102	
3	1.45	1.20	0.47	0.6 depth	34	60	0.57	0.200	0.40	A5	0.097	0.038
				surface	57	60	0.95			A6	0.093	
4	1.85	1.60	0.4	0.6 depth	35	60	0.58	0.178	0.40	A7	0.086	0.045
				surface	46	60	0.77			A8	0.165	
5	2.25	2.00	0.45	0.6 depth	26	60	0.43	0.122	0.40	A7	0.091	0.033
				surface	26	60	0.43			A8	0.180	
Right Bank	2.70	2.45	0.45						0.45			
								Sum	2.45		1.247	0.221

APPENDIX C.6 Discharge Measurement N11

*** DISCHARGE MEASUREMENTS ***												
River:	Nandrasi				Photo Nr:							
Cross num:	N11				UTM X:			228457				
date/time :	14-09-2002/11.30				UTM Y:			9939129				
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Suface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0.1	0		0							
2	0.55	0.45	0.45	0.55	44	44	39	40	0.193	0.173	0.183
3	1	0.9	0.45	0.6	46	48	44	44	0.205	0.193	0.199
4	1.45	1.35	0.45	0.6	36	40	46	44	0.167	0.197	0.182
5	1.9	1.8	0.45	0.55	32	30	30	26	0.141	0.130	0.135
6	2.4	2.3	0.5	0.45	16	18	18	18	0.089	0.093	0.091
7	2.9	2.8		0							
8											
9											
10											

Flow Measurement by Velocity-Area Method												
Date/Time :	14-09-2002/11.30											
Site:	N11(Nandarashi)											
X	228457											
Y	9939129											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	0.10		0.00						0			
1	0.55	0.45	0.55	0.6 depth	44	60	0.73	0.183	0.45	A1	0.186	0.057
				surface	39.5	60	0.66			A2	0.127	
2	1	0.90	0.6	0.6 depth	47	60	0.78	0.199	0.45	A3	0.132	0.053
				surface	44	60	0.73			A4	0.135	
3	1.45	1.35	0.6	0.6 depth	38	60	0.63	0.182	0.45	A5	0.135	0.048
				surface	45	60	0.75			A6	0.127	
4	1.9	1.80	0.55	0.6 depth	31	60	0.52	0.135	0.45	A7	0.127	0.049
				surface	28	60	0.47			A8	0.236	
5	2.4	2.30	0.45	0.6 depth	17	60	0.28	0.091	0.50	A7	0.122	0.026
				surface	18	60	0.30			A8	0.169	
Right Bank	2.90	2.80	0.00						0.50			
								Sum	**2.80**		**1.494**	**0.233**

APPENDIX C.7 Discharge Measurement N12

*** DISCHARGE MEASUREMENTS ***											
River:	Nakatishu				Photo Nr:						
Cross num:	N12				UTM X:			228530			
date/time :	14-09-2002/12.45				UTM Y:			9938955			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Surface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0.4	0		0.16							
2	0.83	0.43	0.43	0.22	20	20	24	24	0.100	0.115	0.107
3	1.26	0.86	0.43	0.3	16	16	28	28	0.085	0.130	0.107
4	1.69	1.29	0.43	0.3	18	20	28	26	0.096	0.126	0.111
5	2.12	1.72	0.43	0.32	16	14	24	20	0.082	0.107	0.095
6	2.55	2.15	0.43	0.35	20	20	24	22	0.100	0.111	0.106
7	3	2.6		0.32							
8											
9											
10											

Flow Measurement by Velocity-Area Method

Date/Time :	14-09-2002/12.45											
Site:	N12											
X	228530											
Y	9938955											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m²)		(m³/s)
Left Bank	0.40		0.16						0			
1	0.83	0.43	0.22	0.6 depth	20	60	0.33	0.107	0.43	A1	0.088	0.015
				surface	24	60	0.40			A2	0.052	
2	1.26	0.86	0.3	0.6 depth	16	60	0.27	0.107	0.43	A3	0.060	0.013
				surface	28	60	0.47			A4	0.065	
3	1.69	1.29	0.3	0.6 depth	19	60	0.32	0.111	0.43	A5	0.065	0.015
				surface	27	60	0.45			A6	0.067	
4	2.12	1.72	0.32	0.6 depth	15	60	0.25	0.095	0.43	A7	0.068	0.020
				surface	22	60	0.37			A8	0.141	
5	2.55	2.15	0.35	0.6 depth	20	60	0.33	0.106	0.43	A7	0.073	0.023
				surface	23	60	0.38			A8	0.147	
Right Bank	3.00	2.60	0.32						0.45			
								Sum	2.60		0.825	0.086

APPENDIX C.8 Discharge Measurement N13

*** DISCHARGE MEASUREMENTS ***

River:	Kitiri				Photo Nr:							
Cross num:	N13				UTM X:			228371				
date/time :	14-09-2002/13.40				UTM Y:			9939070				

Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Surface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	4	0		0.6							
2	3.6	0.4	0.4	0.57	34	34	40	42	0.152	0.180	0.166
3	3.2	0.8	0.4	0.51	38	36	40	38	0.163	0.171	0.167
4	2.8	1.2	0.4	0.45	34	36	36	36	0.156	0.159	0.157
5	2.4	1.6	0.40	0.42	32	32	36	34	0.145	0.156	0.150
6	2	2	0.4	0.6	32	32	34	36	0.145	0.156	0.150
7	1.6	2.4	0.4	0.35	28	26	34	34	0.126	0.152	0.139
8	1.2	2.8	0.4	0.25	34	34	36	34	0.152	0.156	0.154
9	0.8	3.2	0.4	0.3	22	24	36	36	0.111	0.159	0.135
10	0.4	3.6	0.4	0.31	20	20	34	34	0.100	0.152	0.126
11	0.1	3.9	0.3	0.22							

Flow Measurement by Velocity-Area Method

Date/Time :	14-09-2002/13.40
Site:	N13
X	228371
Y	9939070

No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	4.00		0.60						0			
1	3.6	0.40	0.57	0.6 depth	34	60	0.57	0.166	0.40	A1	0.231	0.057
				surface	41	60	0.68			A2	0.111	
2	3.2	0.80	0.51	0.6 depth	37	60	0.62	0.167	0.40	A3	0.105	0.034
				surface	39	60	0.65			A4	0.099	
3	2.8	1.20	0.45	0.6 depth	35	60	0.58	0.157	0.40	A5	0.093	0.028
				surface	36	60	0.60			A6	0.083	
4	2.4	1.60	0.42	0.6 depth	32	60	0.53	0.150	0.40	A7	0.089	0.037
				surface	35	60	0.58			A8	0.157	
4	2	2.00	0.6	0.6 depth	32	60	0.53	0.139	0.40	A7	0.113	0.044
				surface	35	60	0.58			A8	0.202	
4	1.6	2.40	0.35	0.6 depth	27	60	0.45	0.135	0.40	A7	0.074	0.024
				surface	34	60	0.57			A8	0.105	
4	1.2	2.80	0.25	0.6 depth	34	60	0.57	0.000	0.40	A7	0.068	0.000
				surface	35	60	0.58			A8	0.075	
4	0.8	3.20	0.3	0.6 depth	23	60	0.38	0.000	0.40	A7	0.063	0.000
				surface	36	60	0.60			A8	0.090	
4	0.4	3.60	0.31	0.6 depth	20	60	0.33	0.000	0.80	A7	0.128	0.000
				surface	34	60	0.57			A8	0.186	
Right Bank	0.10	3.90	0.22						0.30			
								Sum	**4.30**		**2.070**	**0.223**

APPENDIX C.9 Discharge Measurement N14

*** DISCHARGE MEASUREMENTS ***											
River:	Kitiri				Photo Nr:						
Cross num:	N14				UTM X:			226210			
date/time :	14-09-2002/15:20				UTM Y:			9939727			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Surface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0	0		0							
2	0.5	0.5	0.5	0.29	8	8	10	10	0.056	0.063	0.059
3	1	1	0.5	0.4	14	14	14	14	0.078	0.078	0.078
4	1.5	1.5	0.5	0.62	14	16	20	22	0.082	0.104	0.093
5	2	2	0.50	0.75	20	20	22	22	0.100	0.107	0.104
6	2.5	2.5	0.5	0.85	20	20	20	20	0.100	0.100	0.100
7	3	3	0.5	0.78	18	20	20	24	0.096	0.107	0.102
8	3.5	3.5	0.5	0.84	18	18	20	20	0.093	0.100	0.096
9	4	4	0.5	0.82	14	14	20	18	0.078	0.096	0.087
10	4.5	4.5	0.5	0.45	16	18	18	18	0.089	0.093	0.091
11	5	5	0.5	0							

Flow Measurement by Velocity-Area Method												
Date/Time :	14-09-2002/15:20											
Site:	N14											
X	226210											
Y	9939727											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	0.00		0.00						0			
1	0.5	0.50	0.29	0.6 depth	8	60	0.13	0.059	0.50	A1	0.109	0.011
				surface	10	60	0.17			A2	0.079	
2	1	1.00	0.4	0.6 depth	14	60	0.23	0.078	0.50	A3	0.093	0.016
				surface	14	60	0.23			A4	0.114	
3	1.5	1.50	0.62	0.6 depth	15	60	0.25	0.093	0.50	A5	0.141	0.028
				surface	21	60	0.35			A6	0.163	
4	2	2.00	0.75	0.6 depth	20	60	0.33	0.104	0.50	A7	0.179	0.039
				surface	22	60	0.37			A8	0.194	
4	2.5	2.50	0.85	0.6 depth	20	60	0.33	0.100	0.50	A9	0.206	0.041
				surface	20	60	0.33			A10	0.208	
4	3	3.00	0.78	0.6 depth	19	60	0.32	0.102	0.50	A11	0.199	0.041
				surface	22	60	0.37			A12	0.199	
4	3.5	3.50	0.84	0.6 depth	18	60	0.30	0.096	0.50	A13	0.206	0.040
				surface	20	60	0.33			A14	0.209	
4	4	4.00	0.82	0.6 depth	14	60	0.23	0.087	0.50	A15	0.206	0.034
				surface	19	60	0.32			A16	0.182	
4	4.5	4.50	0.45	0.6 depth	17	60	0.28	0.091	0.50	A17	0.136	0.028
				surface	18	60	0.30			A18	0.169	
Right Bank	5.00	5.00	0.00						0.50			
								Sum	**5.00**		**2.993**	**0.278**

APPENDIX C.10 Discharge Measurement N15

*** DISCHARGE MEASUREMENTS ***											
River:	Rumaru				Photo Nr:						
Cross num:	N15				UTM X:			226178			
date/time :	14-09-2002/16.20				UTM Y:			9939827			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.6Depth		Surface				
	(m)	(m)	(m)	(m)					0.6 depth	surface	avg in vertical
1	0	0									
2	0.4	0.4	0.4	0.2	66	66			0.286		0.286
3	0.7	0.7	0.3								
4											
5											
6											
7											
8											
9											
10											

Flow Measurement by Velocity-Area Method												
Date/Time :	14-09-2002/16.20											
Site:	N15											
X	226178											
Y	9939827											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m^2)		(m^3/s)
Left Bank	0.00		0.00						0			
1	0.4	0.40	0.2	0.6 depth	66	60	1.10	0.286	0.40	A1	0.040	0.020
Right Bank	0.70	0.70	0.00						0.30	A2	0.030	
								Sum	**0.70**		**0.070**	**0.020**

APPENDIX C.11 Discharge Measurement 2GB7

*** DISCHARGE MEASUREMENTS ***											
River:	Malewa				Photo Nr:						
Cross num:	1				UTM X:			212101			
date/time :	9/19/2002				UTM Y:			9964638			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					0.2Depth		0.8 depth				
	(m)	(m)	(m)	(m)					0.2 depth	0.8 depth	avg in vertical
1	0.5	0		0.77							
2	0.75	0.25	0.25	0.85	30	30	34	30	0.137	0.145	0.141
3	1.25	0.75	0.5	0.85	38	38	38	38	0.167	0.167	0.167
4	1.75	1.25	0.5	0.88	38	40	40	42	0.171	0.180	0.176
5	2.25	1.75	0.5	0.88	36	38	38	34	0.163	0.159	0.161
6	2.75	2.25	0.5	0.85	30	34	30	26	0.145	0.130	0.137
7	3.25	2.75	0.5	0.82	32	28	24	28	0.137	0.122	0.130
8	3.75	3.25	0.5	0.65	26	28	24	24	0.126	0.115	0.120
9	4.25	3.75	0.5	0.65	28	24	22	24	0.122	0.111	0.117
10	4.75	4.25	0.5	0.45	24	24	20	18	0.115	0.096	0.106
11	5.25	4.75	0.5	0.35	22	24	18	16	0.111	0.089	0.100
12	5.75	5.25	0.5	0.22							
13	5.9	5.4									

Flow Measurement by Velocity-Area Method												
Date/Time : 12 Sept 2002 / 15:25			Current meter:				a:					
Site:	N10(Nandarashi)		Pitch of propeller:			(m)	b:					
X	229994											
Y	9939821											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m²)		(m³/s)
Left Bank	0.50		0.77						0			
1	0.75	0.25	0.85	0.6 depth	30	60	0.50	0.141	0.25	A1	0.208	0.044
				surface	32	60	0.53			A2	0.106	
2	1.25	0.75	0.85	0.6 depth	38	60	0.63	0.167	0.50	A3	0.213	0.071
				surface	38	60	0.63			A4	0.214	
3	1.75	1.25	0.88	0.6 depth	39	60	0.65	0.176	0.50	A5	0.218	0.077
				surface	41	60	0.68			A6	0.218	
4	2.25	1.75	0.88	0.6 depth	37	60	0.62	0.161	0.50	A7	0.218	0.105
				surface	36	60	0.60			A8	0.436	
5	2.75	2.25	0.85	0.6 depth	32	60	0.53	0.137	0.50	A7	0.214	0.087
				surface	28	60	0.47			A8	0.421	
Right Bank	3.25	2.75	0.82						0.50			
								Sum	**2.75**		**2.467**	**0.385**

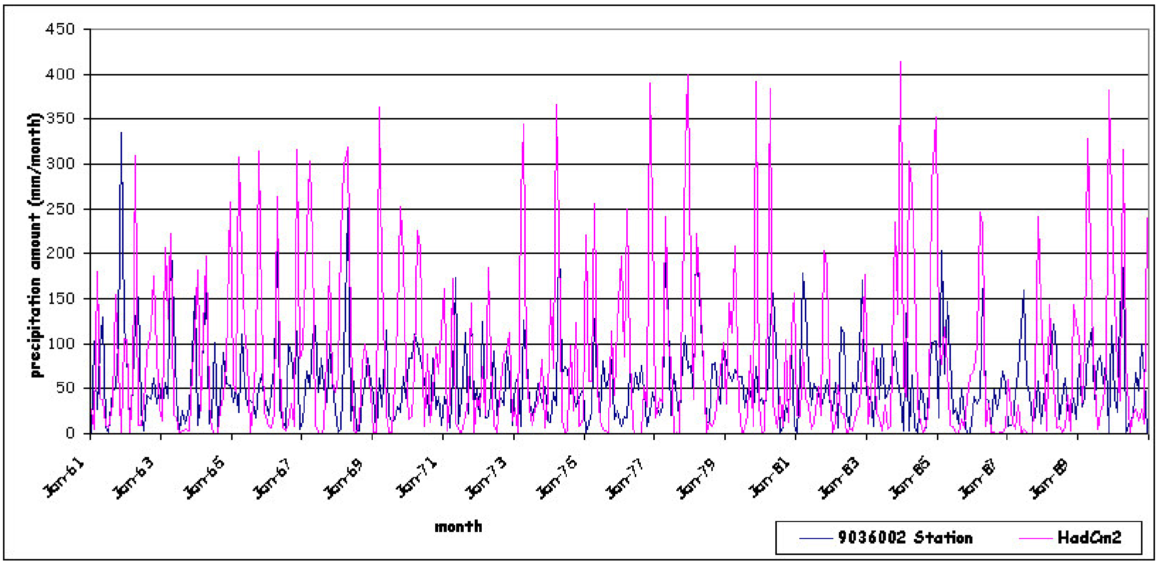
APPENDIX C.12 Discharge Measurement Turasha (before junction)

*** DISCHARGE MEASUREMENTS ***											
River:	Turasha (before juction)				Photo Nr:						
Cross num:	1				UTM X:			210747			
date/time :	9/21/2002				UTM Y:			9945470			
Vertical No.	Tape position	Distance from base	Width	Depth	Revolution				Velocity(m/s)		
					surface		0.8 depth				
	(m)	(m)	(m)	(m)					0.2 depth	0.8 depth	avg in vertical
1	0.6	0		0.1							
2	1.12	0.52	0.52	0.29	36	36			0.159		0.159
3	2.12	1.52	1	0.3	36	40			0.167		0.167
4	3.12	2.52	1	0.3	60	60			0.260		0.260
5	4.12	3.52	1	0.45	60	60			0.260		0.260
6	5.12	4.52	1	0.39	64	64			0.277		0.277
7	6.12	5.52	1	0.25	52	50			0.222		0.222
8	7.12	6.52	1	0.33	46	46			0.201		0.201
9	8.12	7.52	1	0.25	44	42			0.188		0.188
10	8.9	8.3	0.78	0.07							
11											
12											
13											

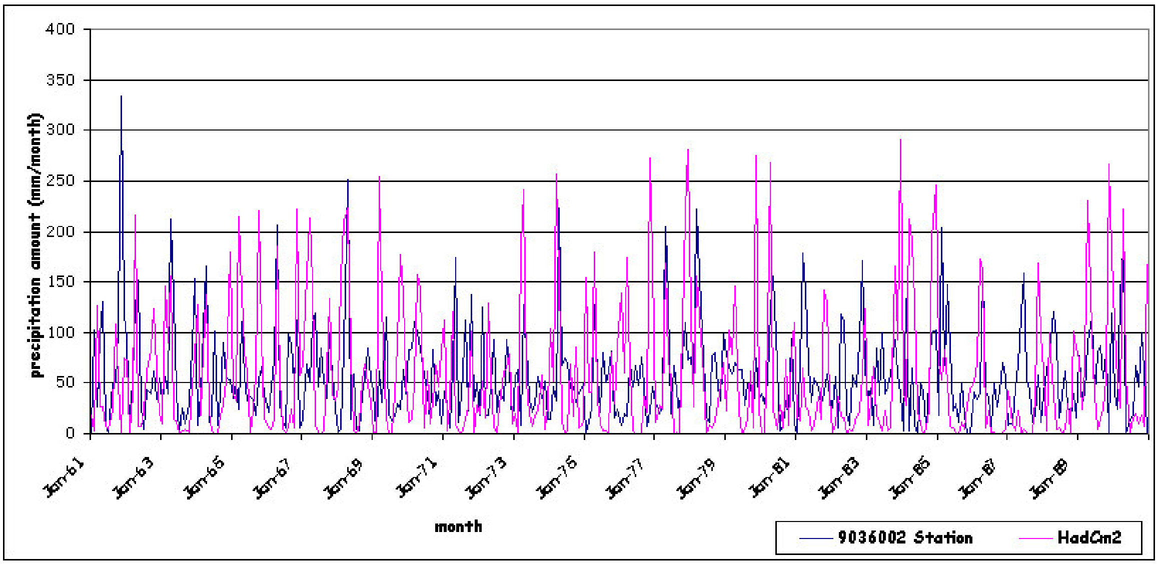
Flow Measurement by Velocity-Area Method												
Date/Time : 12 Sept 2002 / 15:25			Current meter:			a:						
Site:	N10(Nandarashi)		Pitch of propeller:		(m)	b:						
X	229994											
Y	9939821											
No.Point	Measuring-Tape position	Distance from initial point	Depth	Meter position	Revolutions	Time	n	Velocity avg. in vertical	Width	Area		Discharge
	(m)	(m)	(m)	(m)		(second)	(R/T)	(m/s)	(m)	(m²)		(m³/s)
Left Bank	0.60		0.10						0			
1	1.12	0.52	0.29	0.6 depth	36	60	0.60	0.159	0.52	A1	0.126	0.032
				surface						A2	0.076	0.000
2	2.12	1.52	0.3	0.6 depth	38	60	0.63	0.167	1.00	A3	0.149	0.050
				surface						A4	0.150	0.000
3	3.12	2.52	0.3	0.6 depth	60	60	1.00	0.260	1.00	A5	0.150	0.081
				surface						A6	0.161	0.000
4	4.12	3.52	0.45	0.6 depth	60	60	1.00	0.260	1.00	A7	0.206	0.167
				surface						A8	0.435	0.000
5	5.12	4.52	0.39	0.6 depth	64	60	1.07	0.277	1.00	A7	0.184	0.149
				surface						A8	0.355	0.000
Right Bank	6.12	5.52	0.25						1.00			
								Sum	**5.52**		**1.992**	**0.480**

APPENDIX D.1 Comparison of precipitation data for 9036002 weather station.

Graph of comparison the measured data and the HadCm2 data before downscaled:

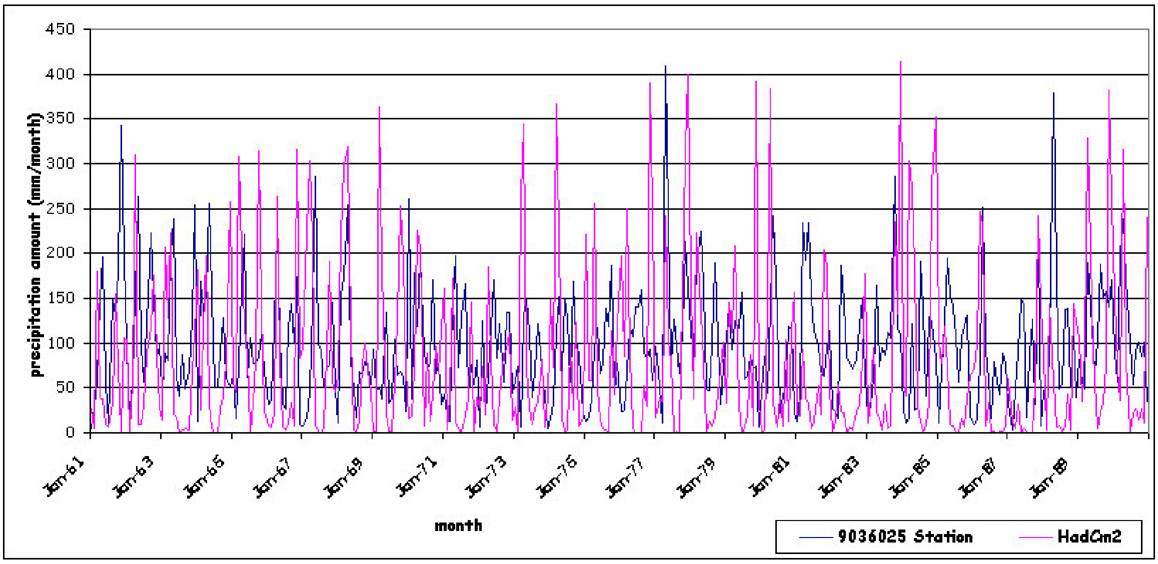


- Applying correction factor = 0.7

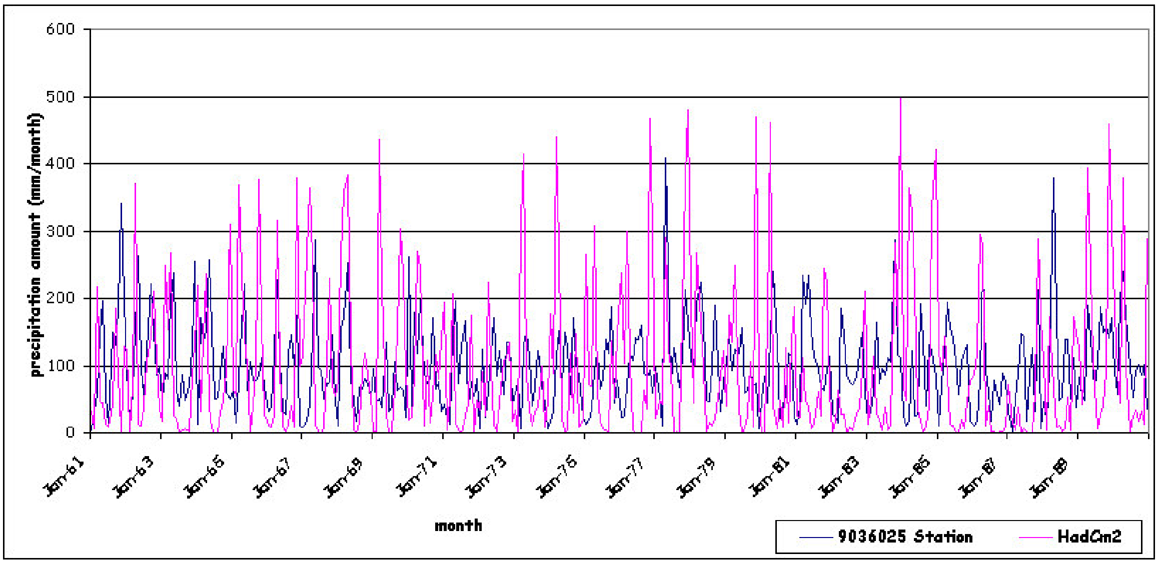


APPENDIX D.2 Comparison of precipitation data for 9036025 weather station.

Graph of comparison the measured data and the HadCm2 data before downscaled:

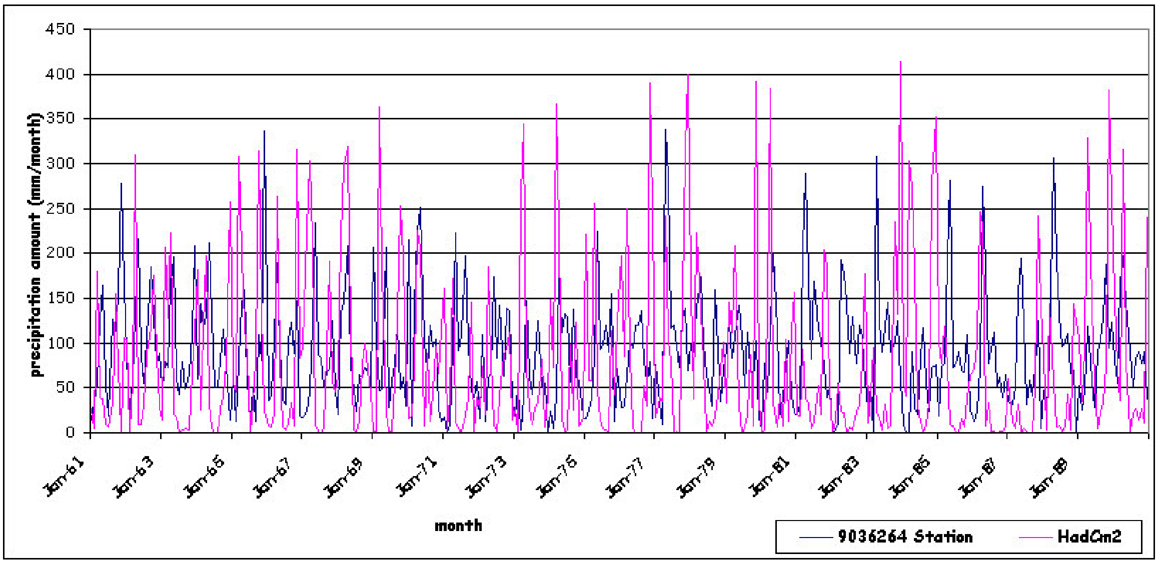


- Applying correction factor = 1.2

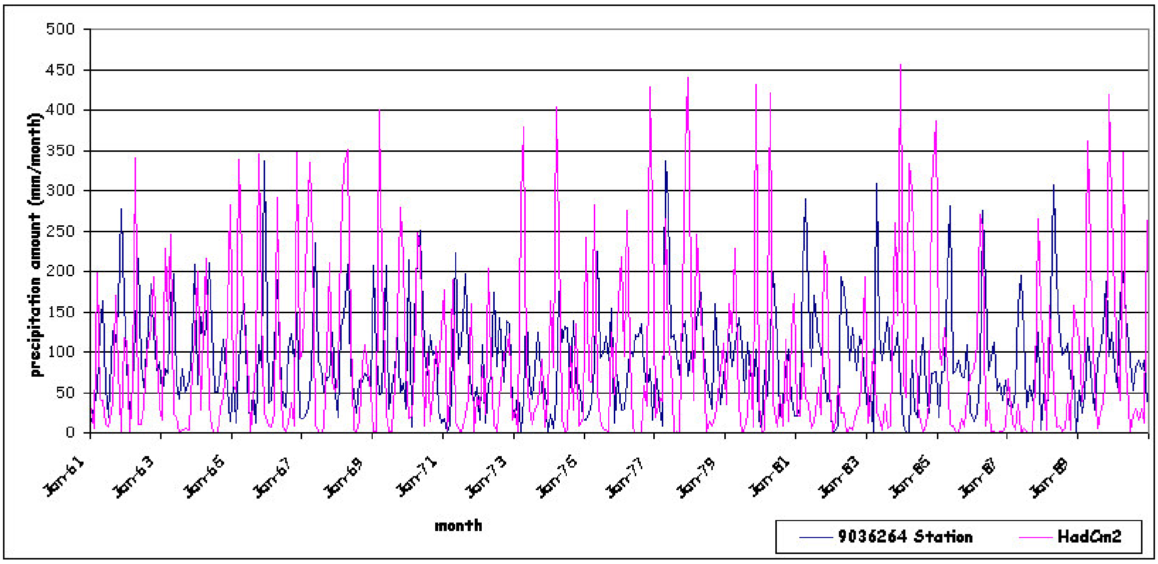


APPENDIX D.3 Comparison of precipitation data for 9036264 weather station.

Graph of comparison the measured data and the HadCm2 data before downscaled:

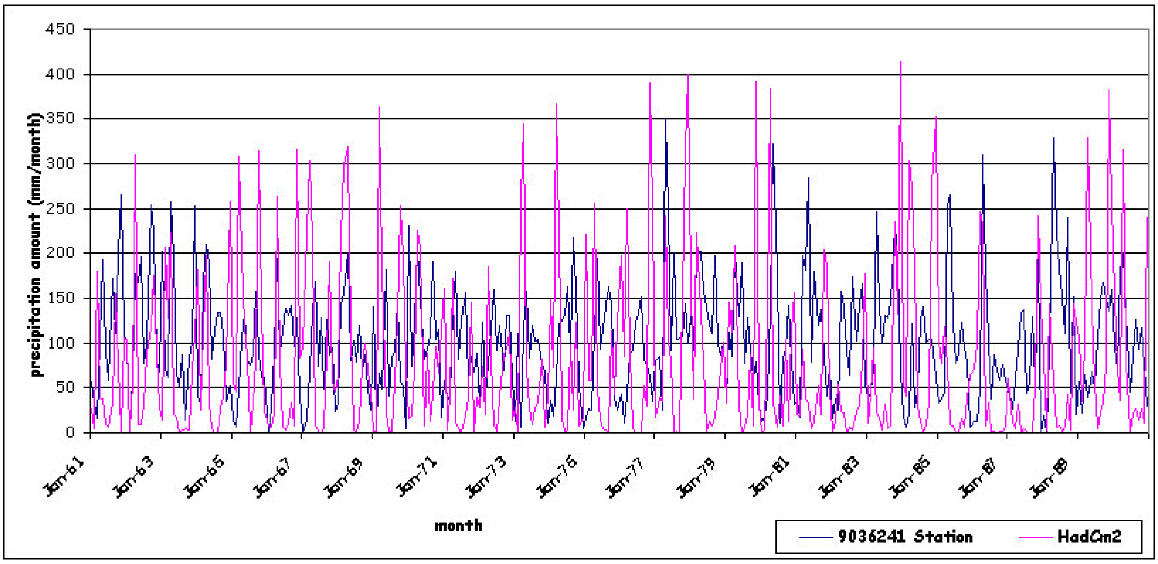


- Applying correction factor = 1.1

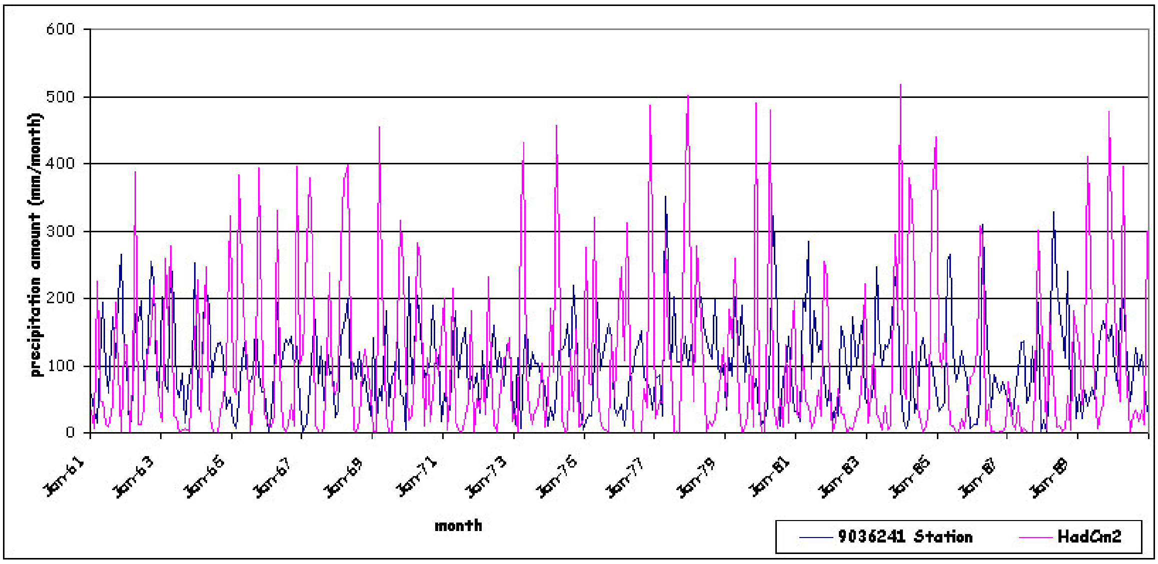


APPENDIX D.4 Comparison of precipitation data for 9036241 weather station.

Graph of comparison the measured data and the HadCm2 data before downscaled:



- Applying correction factor = 1.25



APPENDIX E.1 HadCM2 Climate Scenario -Global Mean Temperature, Precipitation, CO2 and Sea-level Changes (w.r.t. 1961 - 1990) for the HadCM2 Integrations

Notes:
* The CO2 concentration has been estimated assuming an IS92 a mix of greenhouse gases and concentration / forcing relationships reported in the IPCC Second Assessment Report.
* Sea-level rise is calculated as thermal expansion from HadCM2, plus ice-melt contributions calculated off-line using the model of Jonathan Gregory (Gregory J.M. and Oerlmans J. 1998 Simulated future sea-level rise due to glacier melt based upon regional and seasonally resolved temperature changes. *Nature* 391 416-419)

.	2020s				2050s				2080s			
	D T (°C)	D P (%)	CO2 (ppmv) *	Sea-Level (cm)	D T(°C)	D P (%)	CO2 (ppmv) *	Sea-Level (cm)	D T (°C)	D P (%)	CO2 (ppmv) *	Sea-Level (cm)
GGa1	1.21	2.19	447	12.4	2.10	3.49	554	24.8	3.17	5.18	697	41.1
GGa2	1.20	2.08	447	12.6	2.02	3.28	554	24.6	3.03	4.77	697	40.6
GGa3	1.16	1.89	447	13.0	2.06	3.36	554	25.5	3.07	4.80	697	41.4
GGa4	1.20	2.00	447	12.7	2.03	3.18	554	25.3	3.01	4.74	697	41.4
GGaX	1.19	2.04	447	12.7	2.05	3.33	554	25.0	3.07	4.87	697	41.1
.												
GSa1	0.94	1.40	447	8.2	1.58	2.23	554	16.9	2.58	3.87	697	29.5
GSa2	0.93	1.45	447	8.2	1.54	2.19	554	17.1	2.47	3.70	697	30.1
GSa3	0.94	1.40	447	8.3	1.61	2.36	554	17.3	2.49	3.64	697	29.7
GSa4	0.91	1.31	447	8.4	1.50	2.14	554	17.3	2.51	3.71	697	30.1
GSaX	0.92	1.39	447	8.3	1.56	2.23	554	17.1	2.51	3.73	697	29.9
.												
GGd1	0.98	1.84	398	11.5	1.53	2.75	443	21.5	1.95	3.53	498	33.0
GGd2	0.84	1.52	398	9.5	1.38	2.40	443	18.9	1.92	3.36	498	29.8
GGd3	0.88	1.56	398	7.6	1.43	2.56	443	17.7	1.97	3.45	498	29.2
GGd4	0.98	1.72	398	6.2	1.50	2.68	443	15.8	1.94	3.48	498	27.0
GGdX	0.92	1.66	398	8.7	1.46	2.60	443	18.5	1.94	3.46	498	29.7
.												
GSd1	0.74	1.05	398	7.9	1.40	2.49	443	15.8	1.84	3.23	498	25.4
GSd2	0.76	1.32	398	8.9	1.29	2.35	443	16.6	1.77	3.16	498	25.7
GSd3	0.84	1.39	398	9.5	1.34	2.27	443	17.3	1.81	3.17	498	26.6
GSd4	0.81	1.33	398	9.5	1.37	2.37	443	17.6	1.87	3.37	498	27.2
GSdX	0.79	1.27	398	8.9	1.35	2.37	443	16.8	1.82	3.23	498	26.2