Modelling Water Resource Management in Lake Naivasha

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in
Lake Naivasha

by

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Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Water Resource and Environmental Management

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I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

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By the name of Allah, the most Merciful, the most Compassionate

DEDICATION

The success of this thesis is dedicated to my Parents (Younis & Safa), for their encouragement to take this step in my life, and my special brothers Fadi and Mohamed Firas. Finally to both my sons Ahamad and Nader

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ABSTRACT

Integrated Water Resource Management

Water resources management in Lake Naivasha, and its surroundings, in Kenya is an issue of very high significance because of great socio-cultural, ecological and economic values. The basin comprises a biosphere reserve, a national park with a variety of wildlife, a significant livestock activity, a very fertile land for agriculture and a growing tourism industry.

The prevailing system of uncoordinated water resources management in the basin cannot sustain the ever-increasing water needs of the various expanding sectors. Therefore a strategy must be sought to integrate the various sectoral needs against the available water resources in order to attain both economic and ecological sustainability.

The study attempts to develop, for the first time in the Lake Naivasha Basin, an integrated water resource management model. In order to understand the situation in the whole catchment and identify where problems exist and the weakness that affect the catchment and their improvement.

The model shows that the main problem in the area is caused by number of identified water uses in agriculture sector, which is the driving force in the area. According to the study, water is mis-used by over-irrigation in fodder, grass and vegetable farming, although flower farms, a high income source for the area, are accused of causing the problem. Finally, over irrigation is a strong constraint to integrated water resource management.

The main problem is not the shortage of water but the lake of the management. It was recommended that a basin wide legally mandated body (involving all levels) be established to oversee water use. Other strategies include capacity building of stakeholders on water natural resources management policies, water rights and enforcement of laws.

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List of Abbreviation & Acronyms

OECD	Organization for Economic Co-operation and Development
SOE	Society of Operations Engineers
ITCZ	Inter-Tropical Convergence Zone
DPSIR	Driving force-Pressure-State-Impact-Response model
PSR	Pressure-State-Response
UN	United Nations
WHO	World Health Organization
WRM	Water Resource Management
IWRM em	Integrated Water
GWP	Global Water Partnership
DPSIR	Driving forces-Pressure-State-Impact-Response model
SOE	State of the Environment
WEAP	Water Evaluation and Planning System
GW	Ground Water

1. Introduction

1.1. Background

Water is a substance of great abundance on the Earth. A picture of the planet from space Figure 1-1 shows the huge volumes present in oceans, ice caps, glaciers and –although it cannot be seen – the ground. The Earth description as the 'blue planet' is not unfounded. However, of the huge volume present to us, over 97.5% of the water is saline. While this can be used for some purposes – it is unsatisfactory for our main human needs. Of the remaining 2.5% freshwater, which could be utilized by us, almost 70% of it is frozen in the polar ice caps, and a further 20% is stored in the ground – much of which is inaccessible (UN, 1999a & New Scientist, 2002). Even this small percentage is by far enough to satisfy every person on the planet's needs – if only supplies were distributed evenly around the world.

Figure 1-1: The planet Earth from space

In our current state of rapid urbanisation of many Third World Countries, excessive consumption in developed nations, and political tensions worldwide, one of the major limiting factors on future development is that of freshwater availability. As the disparity between the rich and the poor ever widens, so does the provision of services to cover their basic needs. Freshwater stands at the junction between environmental, health, sanitation, and housing or land use agendas (Keck, 2001) – its shortages can have a massive effect upon a society, from food supplies to industry, spread of disease and damage to natural systems.

The following quote from Agenda 21, Paragraph 18.2, summarises the importance of freshwater resources to us, and the steps that have to be taken to conserve our supplies (UN, 1999b):

"Water is needed in all aspects of life. The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases. Innovative technologies, including the improvement of indigenous technologies, are needed to fully utilise limited water resources and to safeguard those resources against pollution."

Over the last 50 years, changes in the way humans use water have been enormous. Major driving factors have been a growing population, economic development, improved living standards, resulting in increasing demands. Irrigated agriculture has played a significant role in changing the face of water resource utilisation as dam, diversion, delivery and drainage structures have been developed to store and distribute water for irrigation and to drain out surplus supplies. With more development, we find ourselves in a situation where we have widely different and competing interests in our water resources. Climate changes in response to global warming caused by carbon dioxide emission are difficult to predict in space and time. Resulting uncertainties require flexible and integrated water management to handle water surpluses, water shortages, and weather extremes. Long-term storage behind dams and in aquifers may be required. Rising sea levels will present problems in coastal areas.

The lack of water resources experienced in different parts of the world has now been recognized and analysed by different international organizations such as WHO, the World Bank, etc.

Recently published documents from the UN Environment Programme confirms that severe water shortage affects 400 million people today and will affect 4 billion people by 2050(Thomas & Durham, 2003).

Most of the projected global population increases take place in third world countries that already suffer from water, food, and health problems. Increasingly, the various water uses (municipal, industrial, and agricultural) must be coordinated with, and integrated into, the overall water management of the region. Sustainability, public health, environmental protection, and economics are key factors. More storage of water behind dams and especially in aquifers via artificial recharge is necessary to save water in times of water surplus for use in times of water shortage. Municipal wastewater can be an important water resource but its use must be carefully planned and regulated to prevent adverse health effects and, in the case of irrigation, un-due contamination of groundwater. While almost all-liquid fresh water of the planet occurs underground as groundwater, its long-term suitability as a source of water is threatened by non-point source pollution from agriculture and other sources and by aquifer depletion due to groundwater withdrawals in excess of groundwater recharge. In irrigated areas, groundwater levels may have to be controlled with drainage or pumped well systems to prevent water logging and Salinization of soil. Salty drainage waters must then be handled in an ecologically responsible way. Water short countries can save water by importing most of their food and electric power from other countries with more water, so that in essence they also get the water that was necessary to produce these commodities and, hence, are virtually embedded in the commodities. This "virtual" water tends to be a lot cheaper for the receiving country than developing its own water resources. Local water can then be used for purposes with higher social, ecological, or economic returns or saved for the future.

This complexity encouraged the UN to adapt the methodology of Integrated Water Resource Management (IWRM) in their report of sustainable development, (Nations, September 2002)

The rationale for the sustainable development and management of freshwater resources is clearly articulated in chapter 18 of Agenda 21. “Today it is widely recognized that an integrated approach to freshwater management offers the best means of reconciling competing demands with supplies and a framework where effective operational actions can be taken. It is thus valuable for all countries at all stages of development”

IWRM was previously mentioned in the Millennium Development Declaration of the UN, (Nations, 2000) article23 “To stop the unsustainable exploitation of water resources by developing water management strategies at the regional, national and local levels, which promote both equitable access and adequate supplies.”

This approach includes the:

- Development of alternative water resource;
- Protection of water resource to stabilize and improve its quality and quantity;
- Demand management implemented at the level of each river basin.

1.2. Research Problem

Increased water demand throughout the region because of increase in human population, which cause a strain on agricultural production, larger flower farms, household, industrial and other sector, which may lead to dry up Lake Naivasha during droughts.
This creates a stress in the supply (Lake Naivasha) and develops confusion about the responsibility for the stress in the lake Naivasha. It also creates conflicts of interest.
This research is looking to develop a clear picture through linking the Demand and the Supply in a model that can help to understand the real situation in the area.
This model was developed based on previous studies that have been carried out at ITC, and describes the work undertaken to date on the more complex computer based simulation models. These fall into the following broad categories:

- Water balance models
- Groundwater flow models
- Economic-water use models

These models have not been integrated overall understanding and assessment of water resource management, environmental impact and public health. Therefore, there is a need for an overall model that can help better understanding environmental behaviour, balancing the economic, environmental and socio-cultural factor, considering development possibilities for the future generation to achieve the concept “sustainable development”.

1.3. Main objective

The main objective of this research is development of an Integrated Water Resource Management (IWRM) model that can help to better understand water resource management issues, environmental and socio-economic impacts of various water resource management practices.

In order to achieve the main objective the following specific objectives were followed:

Specific Objectives	Research Question
To develop conceptual integrated water resource management model (IWRM) that can simulate the past performance of WRM during the period 1980-2000.	▪ What are the Water Resource Management (WRM) issues? ▪ What is the extension and boundary of the system (time and space)? ▪ What are the main processes affecting the Water Resource Management (WRM) issues? ▪ How to model and relate/integrate the above processes? ▪ What would be the overall structure of such a model?
Develop and validate an Integrated Management Model using WEAP (Water Evaluation And Planning System) software.	▪ How to model the conceptual model in WEAP? ▪ What are the data required for building a model using WEAP? ▪ How can Demand / Supply and transitions links be modelled in WEAP? ▪ How to validate the model?
Experiment with the model to understand the behaviour of the water resource management, and identify the existing weakness and strength of the model.	▪ Develop Different Scenarios and assess their impact? ▪ What are the impacts of the different policy option?
Study and analyse the results of the simulation model to make proper recommendation for better Management Plans of the lake	▪ Evaluate and assess the usefulness of the model for planning purposes ▪ How such a model could be used to improve the WRM of the lake? ▪ What is the impact if the new water management law is applied? ▪ What are the criteria and the Alternative that can be developed and tested in the model?
Generate and evaluate different scenarios using the WRM.	▪ How can these scenarios be evaluated? ▪ What are the lessons that can be learned from the scenarios? ▪ What are the recommendations and the conclusion that can be achieved?

1.4. Activities carried out:

1.4.1. Pre field work:

In this stage the main work was:

- Collect and review literature relevant to decision support system, integrated management, water management and others
- Review the available data at ITC data Base
- Build the conceptual model
- Prepare required Field map and questioner

1.4.2. Field Work

The Following work has been carried out:

- Field observation of farms allocating using GPS, Satellite images and maps.
- Interview people from the upper catchment, farms, other organizations such as municipal council, Geo-thermal Plant.
- GPS points were used to indicated the farms

1.4.3. Post Field work

- Process the field data
- Upgrade the conceptual model Figure 1-2

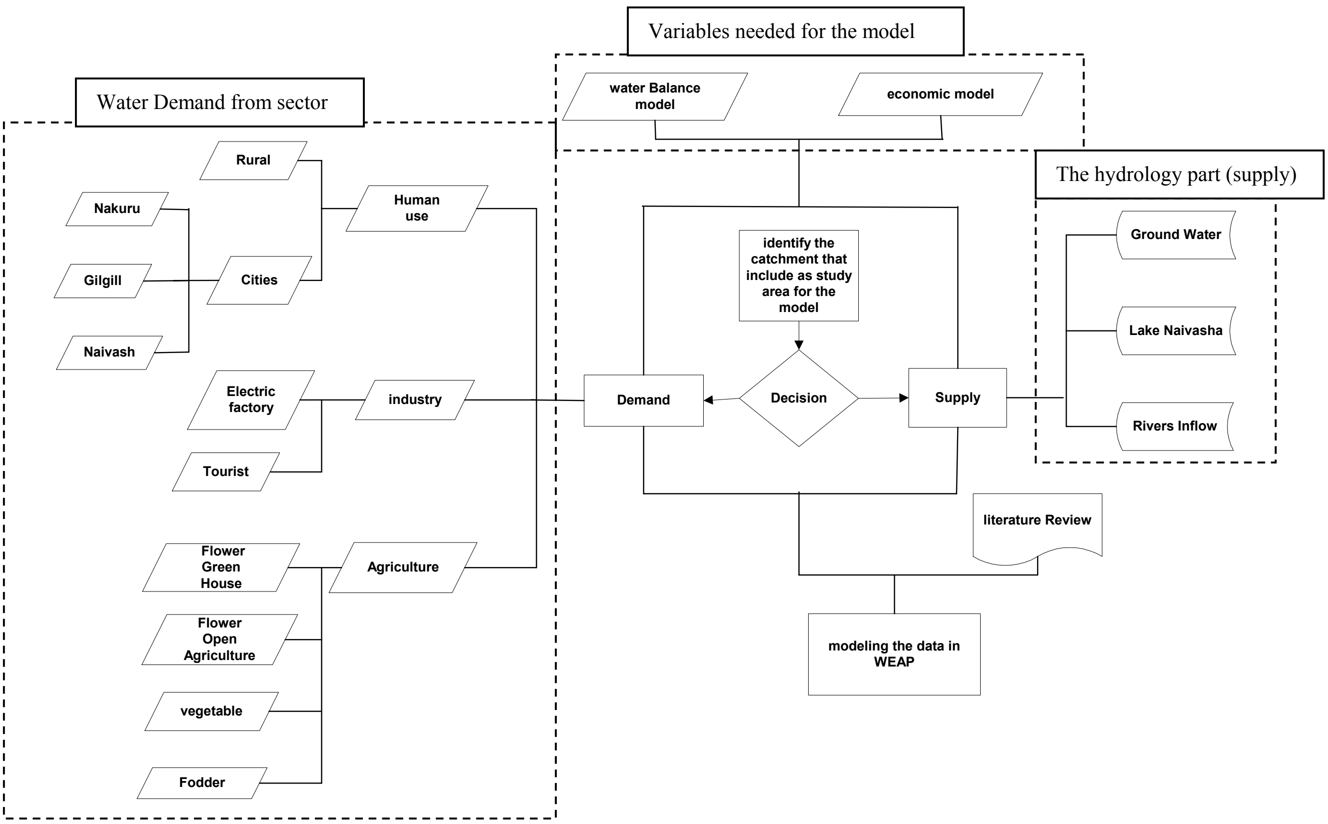


Figure 1-2: Final Conceptual Model (after field)

- Review of the previous work.
- Process the data in a proper way to be used in WEAP soft ware
- Processing satellite images (1976, 1985,1986,1999,2000,2003), to classify and indicate the irrigated area.
- Generate and integrate the study and analyse the results of simulation model to make proper recommendation for better Management Plans of the lake
- Generate and evaluate different scenarios using the WRMM, through multi-criteria system.

1.5. Reivew Previous work

Lots of review of previous work was needed to carry out this study, mainly:

- Water Balance model (Gitonga, April, 1999).
- Economic and Environments models(Ahammad, 2001).
- Productive and Sustainable use of water (Salah, 1999)

1.6. Thesis structure

- Chapter One, Introduction.

This chapter introduces the aim and objective of this study and why it was carried out. The conceptual model is developed on the basis of knowledge of the system as an integrated mathematical model. This model will be solved analytically.

- Chapter Two, Study Area

This chapter takes a glance at the study area from different angles (Climatic, Hydrological, ecological, geological, Economical)

- Chapter Three, Literature Review

This chapter includes some of the main articles, studies and research that were needed for this research.

- Chapter Four, Modelling Demand and Supply

Gathering the data from different models
Identifying the data and the process involved
Linking the data to build the model

- Chapter Five, Scenario Development

Build possible scenarios to run the model and compute the results

- Chapter Six, Scenario analysis

Analyse the results from the different scenarios that have been developed and the discussion of this study.

- Chapter Seven, Conclusions and Recommendation

2. Study Area & Socio-Economic Sititation

2.1. General Overview:

Kenya consists of five major basins: Lake Victoria, Rift Valley, Athi River, Tana River and Ewaso Ngiro basins. However, only two of these basins can be rated to have surplus water resources: Lake Victoria and Tana River. The other three basins have water deficits and often rely on inter-basin water transfers to meet their basic water needs.

The Great Rift Valley running north/south influences and determines the drainage pattern so that from the flanks of the Rift Valley, water flows westwards to Lake Victoria and eastwards to the Indian Ocean. The Rift Valley itself forms an internal drainage system.

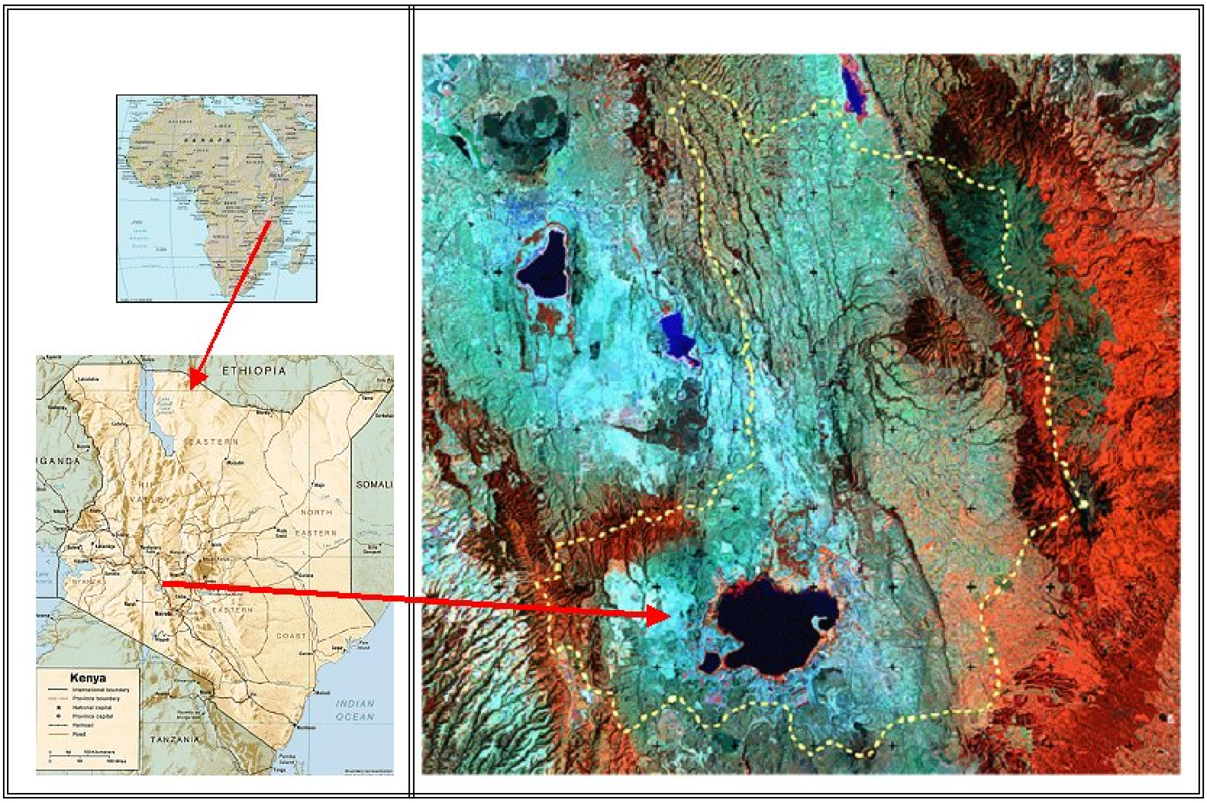


Figure 2-1: the maps of Africa, Kenya and Naivasha catchment image

Lake Naivasha is the only freshwater lake in the Rift Valley that is both ecologically and economically valuable, and is fringed by thick papyrus. Lake Naivasha is located at Latitude 0° 45' 0" S and Longitude36° 20' 0" E, in Nakuru District, about 100 Km northwest of Nairobi. It is situated in the rift valley in Kenya Figure 2-1, at an elevation of approximately 1880 meters above sea level. The lake is almost 13 kms across, but its waters are shallow with an average depth of 5 meters. Lake Naivasha provides water for agricultural irrigation within the region and is home to tourism and industrial recreation,(LakeNet, 2003; Ramsar Convention Bureau, 2000).

Lake Naivasha has the Aberdare Mountains and Kinangop plateau on the east and the Mau Escarpment on the west. It receives water from Malewa, Gilgill and Karati Rivers, which enter the lake to the north. The rivers contribute 90% of the incoming water from Malewa River; the reminder comes from Gilgill and seasonally from Karati. Lake Naivasha also receives water from underground seepage but loses some water by percolation due to the extremely porous volcanic rocks that form the lake basin.

2.2. Climate

The basin lies within the semi–arid belt of Kenya with mean annual rainfall estimated at 621 mm and annual evaporation exceeding precipitation by almost a factor of 3 (i.e., 186.5 cm;). The amount of rainfall that contributes to the surface and groundwater resources is estimated to range from 250 mm to 750 mm in arid and semi-arid areas and from 1 000 mm to 1 690 mm in the coastal belt, the highlands and the Lake Victoria basin. However, the actual contribution is less due to evapotranspiration. The movement of the inter-tropical convergence zone (ITCZ) provides two rainy seasons, which are followed by a dry season.

Relief and the monsoon winds usually directly influence annual rainfall. The rainfall follows a strong bimodal pattern with the long intensive rains falling in March-May and short and less intensive rains in October-December.

The rainfall is of considerable variation, with more than 1500 mm/year at the edges of the rift valley and decreasing rapidly to less than 200 mm/year in the valley bottom. The dry season occur intermittently between the two rainy seasons from January to February and from July to September.

2.3. Biological /Ecological notes

Lake Naivasha has fringing shoreline vegetation, with emergent plants like papyrus, and floating and submerged species, like Potamogeton sp., and Najas pectinata. The edges have a complex vegetation of terrestrial, water tolerant and wetland plants, due to frequent changes in water level. The sodic crater is dominated by blue-green algae, with soda tolerant Cyperus laevigatus around its rim. The river floodplains are dominated by papyrus. The entire wetland system is surrounded by woodland of Acacia xanthophloea. There are several hundreds of hippos Hippopotamus amphibius at Lake Naivasha. Other species of mammals, mainly living in the riparian lands, are buffalo Syncerus caffer, monkeys Colobus sp., and waterbuck Kobus ellipsiprymnus. Hell's Gate National Park, which has an access corridor to the lake, hosts many other species of game. There is an abundance of terrestrial birds at Lake Naivasha. In total, there are more than 350 bird species, including many waterfowl species like grebes, pelicans, cormorants, herons, storks, ibises, African darters, spoonbills, flamingos, 22 species of ducks and geese, waders, gulls and terns. The site is also important for raptors, like the eagle Haliaeetus vocifer, harriers Circus ranivorus and C. aeruginosus, and osprey Pandion haliaetus(Database, 1995).

2.4. Soils

Soil studies in the area were carried out extensively by Boateng, (2001). Basically the soils derived from weathering volcanic and basement rock system and occupy the floor of the rift valley in Naivasha as light grey or brown to pinkish non-calcareous soils.

The Rift valley floor is covered with sediments that accumulated in lakes during the Gamblian stage in the Pleistocene period. The lakebeds are mainly composed of reworked volcanic material or subsequently deposited pyroclastics. Along the fault scraps Middle Pleistocene trachytes are exposed.
In the upper catchment there are non- calcareous black or grey soils overlying yellow-brown compact sub soil with iron concretion. The soil in the Aberdare Mountains, Kinangop platea and the source of the Malewa River are young soils with predominantly morillonite clays. At the edge of the lake the soil is less alkaline and more liable to crack during drying whiles those along the north shore above the lake are generally high in exchangeable Na^+ and K^+, (Boateng, 2001).

2.5. Economic Importance

"On the one hand, the fundamental fear of food shortages encourages ever greater use of water resources for agriculture. On the other, there is a need to divert water from irrigated food production to other users and to protect the resource and the ecosystem. Many believe this conflict is one of the most critical problems to be tackled in the early 21st century". This was a key conclusion of the Framework for Action exercise of the Global Water Partnership (GWP, FFA, 2000, p58).
Availability of surface water in the country for socio-economic and ecological sustenance is primarily influenced by its quantitative distribution in space and time, and by its quality.
Malewa River provides the water for approximately 250,000 people within townships surrounding the lake, including Nakuru and Naivasha.
The area surrounding the lake offers a mild climate and natural beauty that has attracted tourists. Lake Naivasha also supports a productive fishery that provides jobs and income as well as being an important source of protein for local communities.

2.5.1. Human Uses:

Lake Naivasha and its riparian lands are entirely state-owned. Surrounding lands are privately owned. The lake is used for tourism and recreation by the people from Nairobi, and for water sports, fisheries, cutting of vegetation, and subsistence hunting. The surrounding lands are dominated by cultivation of flowers, vegetables, fruit and cereals, and tourism.

2.5.2. Population:

Naivasha is one of the fastest growing towns in Kenya. The growth is fuelled by the increasing horticulture and floriculture farming business around Lake Naivasha, tourist activities in the region, rural to urban migration as a result of falling farm incomes from traditional cash crops, and commercial enterprises and good prospects for job opportunities.
According to the 1999 Population and Housing Census report, the population for the Naivasha division was 158,679, with population growth at 3.5 % including the migration.

2.5.3. Flower Farming

The single most important commercial activity is horticulture and floriculture farming in the surrounding farms. This activity employs 30,000 people(JICA, 2003).
Flowers and vegetables farming are leading in the regional economy with net yearly return of 63.02 Million US $.

2.5.4. Tourism

Lake Naivasha and the neighbouring areas offer outstanding aesthetic scenery and recreational facilities. Tourism activities include boating, water-skiing; sport fishing, game viewing and bird watching. Thus the hotels and travel resorts are major business activities in the area.

2.5.5. Fisheries

Lake Naivasha has been for the last thirty years; the site of important commercial fisheries based on introduced species, predominantly Oreochroms leucostrictus, Tilapia Zilli and Micropterus salmoides [Muchiri et al, 1992] as mentioned by [Huaccho, 1998].
The yearly return from fisheries, as estimated by [(Salah, 1999)], is US $ 44,322.

2.6. Industries

Naivasha has a number of other important industries(JICA, 2003):

- Slaughterhouse, located 3 km away from the town centre, meets the current demand for meat. Other private slaughter slabs meet the demand in the rural areas.
- HOBRA, a spraying equipment industry. That produces spraying pumps
- Economic housing group, which manufactures wood, based products such as furniture, prefabricated houses ect.
- Breweries produce low quality of alcoholic drinks that are sold in the neighbouring region.
- Dalemere Diary farm produce a dairy products all of the country.
- Wine industry.
- Power supply the main energy for the town is the electricity supplied by Kenya Power and Lighting Company.
- Other industries include banking, carting, fishing, and commercial farming.

3. Literature Review

3.1. Introduction

The countries that are now facing water shortages are looking for alternative resources (water reuse and desalination) to increase the availability of potable water, as well as increasing the efficiency of the management of their conventional resources and schemes to optimise the water usage.
These solutions are completely in line with the sustainable solutions that the European Union's policy and the majority of the leading environmental institutions and governments are promoting through the Integrated Water Resource Management (IWRM)(Thomas & Durham, 2003).
"An integrated water resources perspective ensures that social, economic, environmental and technical dimensions are taken into account in the management and development of water resources" (http://www.worldbank.org).
Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.
IWRM could be defined as "a sustainable approach of the water management that recognizes its multidimensional character - time, space, multidiscipline (science/technology) and stakeholders (regulators/users/providers/neighbours) - and the necessity to address, embrace and relate these dimensions holistically so that sustainable solutions can be brought about." (Thomas, 2001)
The **time dimension** mainly refers to sustainable development: actions made now should be in harmony with the long term to protect the interests of future generations.
The **space dimension** recognizes that the natural unit for all water management efforts is the river basin or the watershed, and therefore it is necessary to – 'think globally" before "acting locally".
The **multidiscipline dimension** requires a large number of parameters to be considered in the decision making process:

- Economic, environmental/ecological and social impacts,
- Legislation and health issues,
- Technique and technology,
- Political and institutional issues,
- Socio-economic impacts,
- Historical and cultural issues

The **stakeholders dimension**. Stakeholders have to be involved in the decision process in order to incorporate all the conflicting aspirations of the different decision participants.

3.2. Integrated Water Resources Management (IWRM):

Integrated Water Resource Management (IWRM) as a concept allows, focusing on the detail of water use practices while stepping back and considering the bigger picture.
The generally accepted definition of sustainable development ''is development which meets the needs of the present, without compromising the ability of future generations to meet their own needs''

(Brundtland Report, 1987; quoted from the White Paper on Environmental Management for South Africa, South Africa, 1997).
There are a number of difficulties with such general definitions(Jonker, 2002)

1. It assumes a common understanding of what development means.
2. It assumes the present generation knows what the needs of future generations will be.
3. It does not explicitly link people and resources, the two elements in development.
4. It is impossible to measure at what stage of development future generations will be compromised.
5. It does not consider the different time spans between people's lifecycles and natural cycles.

A definition that addresses the difficulties mentioned above would be: " sustainable development is the improvement of people's livelihoods without disrupting the natural cycles".
''Integrated Water Resources Management is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'' (GWP; quoted from Mudege and Taylor, 2001) (Jonker, 2002).
The definition suggests managing things that cannot be managed, such as rainfall, wind and other natural processes; while people's activities can be manage. Therefore a more suitable definition of Integrated Water Resources Management would be: "managing people's activities in a manner that promotes sustainable development (improves livelihoods without disrupting the water cycle)".
With the integration of the conceptualisation of sustainable development and integrated water resources management, a framework is created within which to interrogate people's relationship with water.

3.3. Integrated Planning and Decision Support Systems for Sustainable Water Resources Management (IPDSS):

The report of the Conference on Multi-sectoral Integrated and Operational Decision Support System for sustainable use of water resources at the catchment scale (MULINO-DSS, 2002), identifies three main themes:

- The notion of sustainability;
- The scope of information and participation.
- The supporting role of information technology

in the process of water resource management as challenging issues for further research.
In this context, efforts devoted to local, national and international levels to regulate the uses of water in order to mediate between conflicting demands and, promote sustainable use of water so that future generations will also be able to meet their needs(Sharifi, 2003).
Geo-information technology through various remote sensing techniques offers appropriate technology for data collection from the Earth-surface, information extraction, data management, routine manipulation and visualization, but lacks development and analytical capabilities to support decision-making processes.
If agreement is going to be based on consensual rules, then understanding, argumentation, reasoning and dialogue are the ways to arrive at inclusive solutions that consider the entire set of stakeholder's objectives. In this context, there is a need for a decision aid to make use of development in various related fields and provide facility to:

- Understand the cause-effect relationships between various socio-economic driving forces and their impacts;
- Support the analysis of the effects and impacts of alternative policy-decision on allocation of resource and services;
- Furthermore, and most importantly, to provide a forum for debates, facilitate dialogues, negotiation and deliberation of various issues affecting stakeholders and construct a common language for discussion and deliberation over allocation of resources.

Integrating, all the relevant information and knowledge from different sectors and disciplines to support individuals and group collaboration processes for a more effective and transparent planning and decision-making process is called "Integrated Planning and Decision Support System (IPDSS)" (Sharifi, 2003).

The integration water resource management needs to look overall the basin and include all the elements in the basin that can effect and affected by the water Figure 3-1.

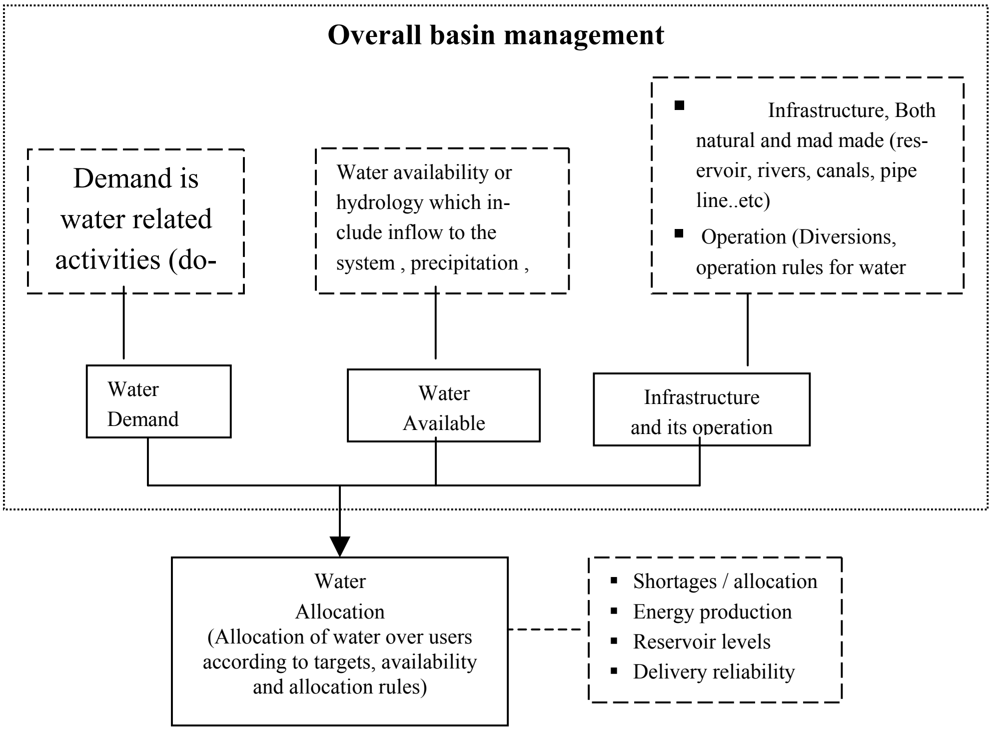


Figure 3-1: Schematic over view of water management elements

3.3.1. Water Resource Management Approaches

Water resource planning and management are becoming increasingly difficult due to the complex issues that water resource professional and resource management agencies must address. Clearly, there have been significant changes in the water utility industry over the past 20 years (AWWA, 1997). One major change is that there is now intense competition between water used for drinking, versus other uses such as recreation, agriculture, industry and hydroelectricity generation. In addition, intensive land uses in watershed and aquifer areas have caused degradation of water quality and contamination of sources of supply.

There are three major water resource-planning approaches utilised today in the water industry(Sharifi, 2003):

- Traditional supply-side planning assumes that the problems associated with the provision of a safe and adequate supply of potable water can be solved by developing additional capacity as it is needed. It narrowly focuses on the supply side, excludes non-utility interests, and does not allow the utility to be flexible in meeting competing demands and satisfying regulatory policy goals. It also does not take into account conservation, industrial water reuse, or reasonable assumptions about future trends in customer consumptions and demands.
- Least-cost planning includes a comprehensive evaluation of all supply and demand alternatives, where the end result is an attempt to minimize the cost, while creating a flexible plan allowing for uncertainty and a changing economic environment. It includes externalities such as cost and inclusion of non-utility participants' goal's to ensure the success of planning process.
- Integrated resource planning "IRP" is a new concept based on participation. It considers customers and other resource users as a stakeholder, and it provides for formal integration and coordination among the several government institutions that have regulatory responsibilities for water resource matters.

AWWA (1997) defines IRP as a continuing process that results in the development of a comprehensive water resource management plan. It defines and gives balanced considerations to supply and demand management planning alternatives. It includes analysis of engineering economic, societal and environmental costs and considerations, while balancing the needs of competing users and multiple objectives of the use of resources.
Integrated Water Resource (IRP) explicitly seeks to identify and manage risk and uncertainty and provides for coordination of planning between water utilities in a specific region.

3.3.2. Sustainable Water Resource Development

The main question is how to integrate the development in management and planning, sustainability concepts, with the growing number of disciplinary qualitative and quantitative models, and the advances in information technology. How to achieve sustainable ways of making use of resources in particular, sharing limited water resources, and how to implement adaptive co-management concept.
According to Hallding (2001) sustainable solutions can build on:
- Understanding of the sources the conflicts, including their natural, technical, institutional, social and cultural aspects.
- Participation of all the related stakeholders in the process, first to arrive at common understanding of the problem and to share as far as possible a vision about the future and ideas about the path to sustainable solutions.
- Examining the social, environmental and economic contests of the conflict, in order to assess different policy options to make the best use of limited water resources.

This may include regulation, financial sanctions and economic incentives, and increasing public awareness and participation, information dissemination and support for possible institutional change.
- Finally an organization to pursue the co-operation, a means of monitoring achievement, and implementation plans

3.3.3. Integrated water resource management in Naivasha Catchment

Lake Naivasha is an area of interest as it has a high economic value for Kenya. It provides a wide range of opportunities for various activities in the area, which in turn produced a conflict of interests between different stakeholders (upper catchment, farmers, urban people …etc.). Also this created a pressure on the lake water level and its quality.

An integrated water resource management plan in Lake Naivasha is needed to widen the picture and helps in addressing and solving the real problems in the area.

3.4. Analytical framework: The Driving forces-Pressure-State-Impact-Response (DPSIR) model of lake Naivasha

The most widely accepted indicator framework is the "Driving forces-Pressure-State-Impact-Response model" (DPSIR). The DPSIR model is an extension of the PSR (Pressure-State-Response) model, which was developed by Anthony Friend in the 1970s, and subsequently adopted by the OECD's State of the Environment (SOE) group. It defines five indicator categories Figure 3-2, Within the DPSIR framework; Eurostat (the Statistical Office of the European Communities) focuses on the Driving forces, Pressure and Response categories.
The Environmental Pressure Indices Project, conducted by Eurostat and financed by the European Commission's Environment DG, aims at a comprehensive description of the most important human activities that have a negative impact on the environment. The project reflects the efforts undertaken by the European Commission to provide decision-makers and the general public with the information necessary for the design and monitoring of an adequate environment policy for the European Union.(Jesinghaus, 1999)

Driving forces are underlying factors influencing a variety of relevant variables. Examples: the number of cars per inhabitant; total industrial production; GDP.

Pressure indicators describe the variables that directly cause environmental problems. Examples: toxic emissions, CO_2 emissions, noise etc. caused by road traffic; the parking space required by cars; the amount of waste produced by scrap cars.

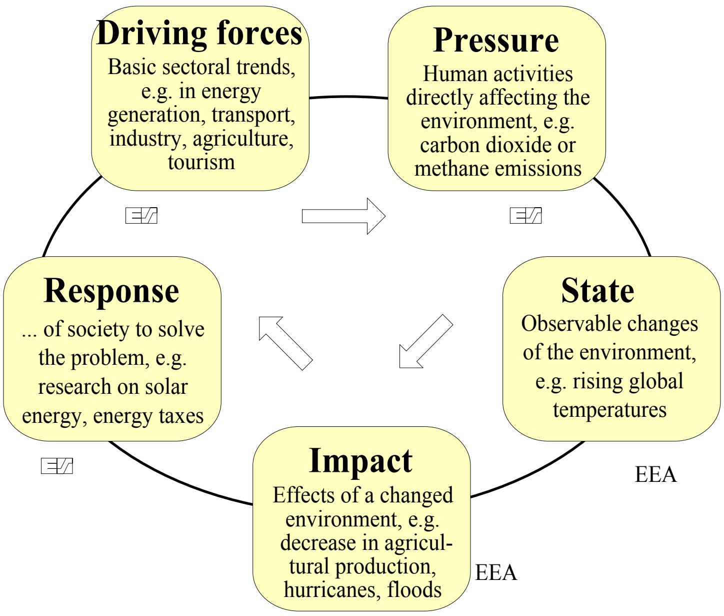


Figure 3-2: the indicators of the driving force ((Jesinghaus, 1999)

State indicators show the current condition of the environment. Examples: the concentration of lead in urban areas; the noise levels near main roads; the global mean temperature.

Impact indicators describe the ultimate effects of changes of state. Example: the percentage of children suffering from lead-induced health problems; the mortality due to noise-induced heart attacks; the number of people starving due to climate-change induced crop losses.

Response indicators demonstrate the efforts of society (i.e. politicians, decision-makers) to solve the problems. Examples: the percentage of cars with catalytic converters; maximum allowed noise levels for cars; the price level of gasoline; the revenue coming from pollution levies; the budget spent for solar energy research.(Jesinghaus, 1999)

3.4.1. The framework DPSIR model for Lake Naivasha was developed as follows:

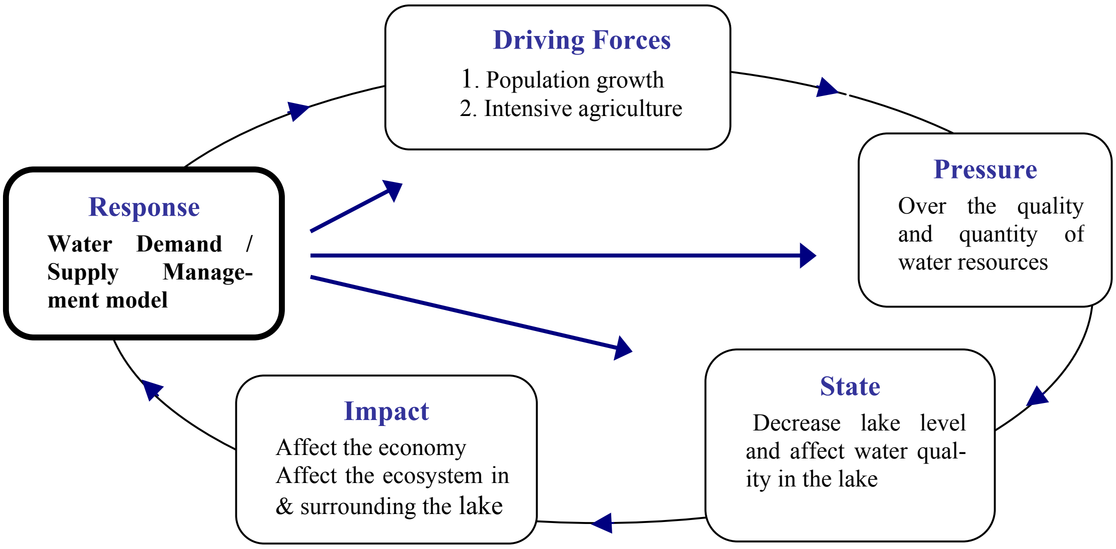


Figure 3-3: The Driving force-Pressure-State-Impact-Response model for lake Naivasha

Driving force in Lake Naivasha could be

1. Agriculture: Agriculture creates pressure and stress on water resources through direct abstraction for agricultural uses such as irrigation and watering of livestock, and by activities that are potentially polluting activities such as the use of fertilisers and pesticides.
   Agriculture is thus the most important Driving Force in the sustainable management of water, and current activities and trends are outlined in this section.
2. Population growth and urbanisation: Changes in population, population distribution and density are key factors influencing the demand for water resources.
3. Tourism, Industry and Climate change.

The driving forces in Naivasha basin produce a pressure on the quality and quantity of the water resources and deteriorate the state by lowering the lake level and influencing the economy and ecosystem of the catchment.
An adequate response to this situation is to develop an integrated water resource management model for the basin Figure 3-3. This would help in understanding and determining the real driving forces playing a role in the basin.

3.5. An over view of Water Evaluation and Planning system (WEAP):

WEAP incorporates water supply in the context of demand-side issues, water quality, and ecosystem preservation into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side issues such as water use patterns, equipment efficiencies, re-use options, prices and water allocation schemes on an equal footing with the supply side topics of river stream flow, groundwater, reservoirs and water transfers. WEAP operates as a laboratory for examining alternative water development and management strategies.

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The current accounts provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Alternative sets of future assumptions are based on policies, costs, technological development and other factors that affect demand, pollution, supply and hydrology. Scenarios are constructed consisting of alternative sets of assumptions or policies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

3.5.1. Scenario Analysis

With WEAP, first Current Account of the water system under study is created. Then, based on a variety of economic, demographic, hydrological, and technological trends a "reference" or "business-as-usual" scenario projection is established, referred to as a Reference Scenario. Then one or more policy scenarios are developed with alternative assumptions about future developments.

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir-operating rules are altered? What if water conservation is introduced? What if new sources of water pollution are added? What if a water-recycling program is implemented? What if a more efficient irrigation technique is implemented? What if climate change alters the hydrology? These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system.

3.5.2. Demand Management Capability

WEAP represent the effects of demand management on water systems. Water requirements may be derived from a detailed set of final uses, or "water services" in different economic sectors. For example, crop types, irrigation districts and irrigation techniques could break down the agricultural sector. An urban sector could be organized by county, city, and water district. Industrial demand can be broken down by industrial sub-sector and further into process water and cooling water. This approach places development objectives--providing end-use goods and services--at the foundation of water analysis, and allows an evaluation of effects of improved technologies on these uses, as well as effects of changing prices on quantities of water demanded. In addition, priorities for allocating water for particular demands or from particular sources may be specified by the user.

3.5.3. Environmental Effects

WEAP scenario analyses can take into account the requirements for aquatic ecosystems. They also can provide a summary of the pollution pressure different water uses impose on the overall system. Pollution is tracked from generation through treatment and outflow into surface and underground bodies of water.
Moreover, WEAP can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and stream flow simulations, reservoir operations, hydropower generation and project benefit-cost analyses.
There are many case studies that are supported by WEAP Applications (Institute-Boston, 2003).
In this thesis, water demand management is one of the options discussed in more detail. Once the basic reference scenario was developed, a series of simulations were investigated for diverse climatic situations from dry years to normal years in order to come out with conclusions.

4. Modeling Demand and Supply

4.1. Introduction

Modelling has become an essential tool in modern world of water management. It is used extensively and plays an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection of basic data (monitoring), among other things. Besides the fact that the use of models is becoming increasingly common in water management, a development can also be discerned in items of increasing co-operation in the modelling field.

The concept of a model is a very broad one; it is distinguished on the basis of the reason for the application, varying from policy analytical to scientific research models (detailed and narrow). Between the operational models (for real time control of structure, for example) and the calamity models, it is always possible to clearly distinguish between these fields.

4.2. Modeling Demand and Supply in WEAP:

The initial tasks in modelling with WEAP are to define the quantities of demand and supply of water. Modelling demand and supply using the WEAP software mainly depend on the current year that is defined as the starting year for the simulation. The characteristic of this "current year" is that it has all the available data for demand and supply, were the hydrological data (inflow, climatic, etc) as supply, and consumptions of all kinds as demand.

To start Modelling Demand and supply, the following must be identified:

- The Current Accounts represent the basic definition of the water system, as it currently exists. For this model the current account and the starting year for all scenarios was 1980 because the exploitation started then.
- The last year of the model, which is 2000 in this case study
- The trend for simulation, which is how these data will be modelled in WEAP and this will be defined for each component separately

Modelling in WEAP software was done using M'mbui water balance data from 1932 –2000 for the hydrology part. For the demand part mathematical expressions were used to allow the software to calculate different input parameters for the previous years.

The thesis focuses on the period between 1980 –2000 for scenario and analysis. This period was selected since the agricultural abstraction started in that year.

4.3. Algorithm Behind the Scenarios

- Annual Demand in WEAP

A demand site's (DS) was needed for water and it was calculated as the sum of the consumptions for all the demand site's bottom-level branches (Br). A bottom-level branch is one that has no branches below it.

$$Annual\ Demand_{DS} = (Total\ Activity\ Level_{Br}\ x\ Water\ Use\ Rate_{Br})$$

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back up to the demand site branch (where Br is the bottom-level branch, Br' is the parent of Br, Br'' is the grandparent of Br, etc.).

$$Total\ Activity\ Level_{Br} = Activity\ Level_{Br}\ x\ Activity\ Level_{Br'}\ x\ Activity\ Level_{Br''}\ x\ ...$$

- Monthly Supply Requirement

The supply requirement is the actual amount needed from the supply sources. The supply requirement takes the demand and adjusts it to account for internal reuse, demand side management strategies (DSMS) for reducing demand, and internal losses..

$$Monthly\ Supply\ Requirement_{DS,m} = (Monthly\ Demand_{DS,m}\ x\ (1 - Reuse\ Rate_{DS})\ x\ (1 - DSMSavings_{DS}))\ /\ (1 - Loss\ Rate_{DS})$$

- Inflows and Outflows of Water

This step computes water inflows to and outflows from every node and link in the system for a given month. This includes calculating withdrawals from supply sources to meet demand.

4.3.1. Inputs Parameters in WEAP

In order to define the inputs to the model the initial state and the tendency evolution of each input has to be entered.

The Software allows the three methods to define the projection of the surface water hydrology over the study period. They are:

- The Water Year Method: It is an in-built model in WEAP that allows the predictions of hydrological variables based on the analysis of historical inflow data. It uses the statistical analysis to identify the coefficients, which is used to replace the real data for future projection.
- Read From File Method: If monthly data on inflows to some or all of the rivers and local supplies are available, then the Read From File Method allows the system to be modelled using this sequence of real inflows data. The required file formats for these data files is ASCII Data File Format for Monthly Inflows.
- Expressions: If any equation can explain the physical or evolutionary problem required in WEAP analysis, this equation can be entered.

4.3.2. Water Balance in Naivasha Catchment (Supply)

In order to build up the hydrological data explained in the previous paragraph, the supply and demand will be entered.

The supply input elements related to the water balance in the catchment were studied by M'mbui, (1999), who developed the water balance of Lake Naivasha. They were calculated based on monthly time steps for the period 1932 to 1997; Figure 4-1.Vreugderhil (2001) updated the model until 2000. A brief summary of the findings of this research follows:

The water balance model shows a very good correlation between its components and the observed lake levels. The model further shows that the ground water plays a crucial role in the water budget of the lake and an exchange of water between the lake and Groundwater. Groundwater outflow from the lake averages 4.6 million cubic meters per month

The water balance equation is:

Lake volume change = inflow + rainfall - evaporation $\pm Q_{aq} - Q_{out}$ ………. (1)

Where Q_{aq} ; is the inflow to or out flow from a hypothetical dynamic ground water aquifer linked to the lake. It drives as:

$$Q_{aq} = c(H_{lake} - H_{aquifer}) \quad (m^3 month^{-1}) \text{ ……… (2)}$$

Where C is the hydraulic conductance of the aquifer (m^2 month $^{-1}$) and H is the water level (m).(Becht & Harper, 2002)

The current model used the data from January 1932 to September 2000 obtained from M'mbui water balance model. Finally, the model manages to reproduce with his model the real lake fluctuations as in Figure 4-1.

Figure 4-1 shows the observed lake level and the modelled lake level, and the difference between them after the year 1980 due to the abstraction in the area.

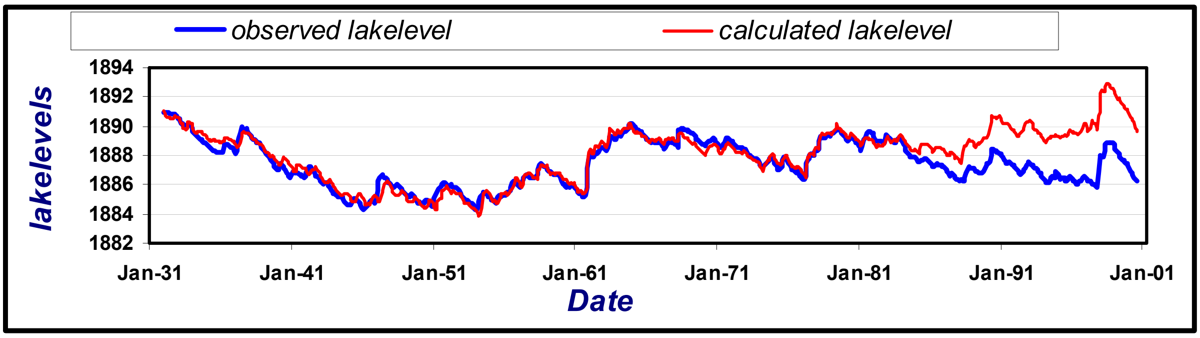


Figure 4-1:Naivasha Water Balance Graph from M'mbui thesis (the graph compare the modeled lake level and the observed lake level)

4.3.2.1. Model Discharge data for Lake Naivasha used in WEAP

Rivers

The water balance model defines the inflow to the lake as a total. In order to disaggregate the inflow into real components, the average percentage discharge to the lake from the main rivers were taken. This evaluation was decided after analysis of discharge data done by Lal Muthuwatta, and Robert Becht (personal communication).

Total inflow to the lake from previous studies by M'mbui, (1999) contributed to the lake by:

- 40% from Malewa River
- 40% from Turusha River
- 20% from Gilgil River

Under the above assumptions, 3 flow series were created for input in WEAP.

WEAP Input Data:

The WEAP input data refers to the data that was integrated and used inside the software "WEAP".

River discharge

River discharge refers to the process of entering the inflow discharge from rivers using the Expression and read from file and using the actual data. The input data was integrated as below, figure 4-2:

- 40% from Malewa River : ReadFromFile(inflow_2000.txt) * 0.4
- 40% from Turusha River : ReadFromFile(inflow_2000.txt) * 0.4

- 20% from Gilgil River : ReadFromFile(inflow_2000.txt) * 0.2

(inflow_2000.txt) refers to the text file that included the total inflow discharge from 1932 to September 2000, (M'mbui, 1999) and (Vreugderhi,l 2000).

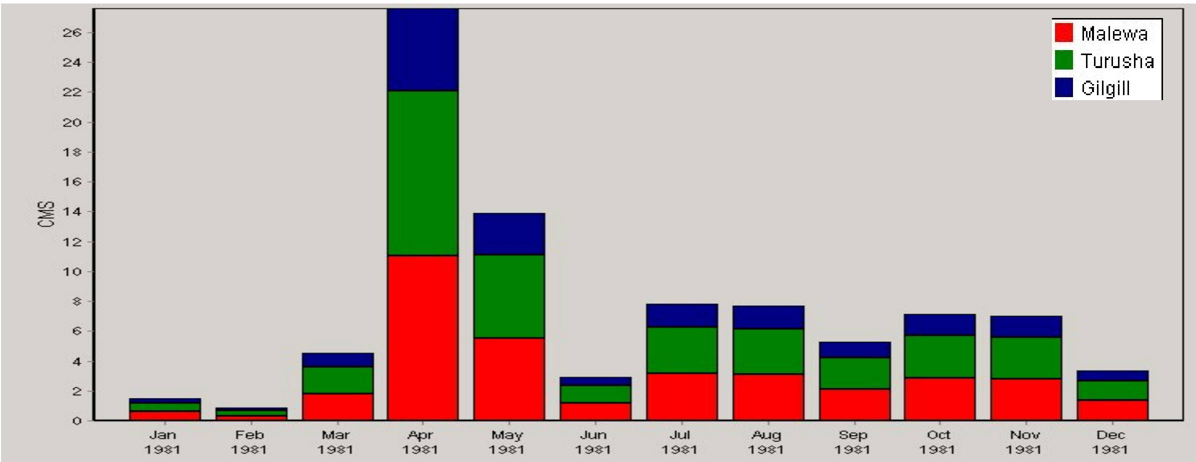


Figure 4-2: Head flow to the lake from rivers

Net Evaporation data:

Reservoir Evaporation is the monthly evaporation rate. It accounts for the difference between evaporation and precipitation on the reservoir surface; thus it can be positive or negative. A positive (negative) net evaporation represents a net loss from (gain to) the reservoir.

It was also prepared in text file (ReadFromFile(NetEvap.txt)), which included the net-evaporation as in the water balance model of 2000.

Water Year Method in WEAP

The Water Year Method allows use of historical data in a simplified form and exploration of the effects of future changes in hydrological patterns.

For example, using the Water Year Method to test the system under historic or hypothetical drought conditions. Hydrologic fluctuations are entered as variations from a Normal Water Year (the Current Accounts year is not necessarily a Normal water year). The Water Year Method requires data for defining standard types of water years (Water Year Definition), as well as defining the sequence of those years for a given set of scenarios (Water Year Sequence).

A water year type characterizes the hydrological conditions over the period of one year. The five types that WEAP uses--Normal, Very Wet, Wet, Dry, and Very Dry--divide the years into five broad categories based on relative amounts of surface water inflows.

This part was developed using the actual data identified as the Wet, Normal, and Dry year to help in understanding the climate change in one scenario but was not used in the reference scenario. That depended on the actual data.

To build up the water year method, averages of the annual inflow for each year since 1932 to 2000 were determined and are presented in Table 4-1. The minimum was taken as a very dry year and the maximum as very wet year, and then the normal year was mid point. Between the very Dry Year and the Normal Year there is a dry year.

For the Normal year and the very wet year there is the wet year, as presented in Table 4-1.

The definition factor defines each non-Normal water year type (Very Dry, Dry, Wet, Very Wet), and specifies how much more or less water flows into the system in that year relative to normal water.

Table 4-1: Indicating the water year method

Water Year Method	**The Average Inflow**	**Definition factor %**

V.Dry	1.4 to 11.5 Million m3	0.33
Dry	11.6 to 21.7 Million m3	0.66
Nor	21.8 to 32.1 Million m3	1
Wet	32.2 to 42.3 Million m3	1.33
V.Wet	42.4 to 52.5 Million m3	1.66

According to these categories the water year sequence has been categorised for the simulation years as given in (
Table 4-2. shows the data for the whole simulated period and is presented in Annex 4.

Table 4-2: the water Year method for the simulation years

Year	Average Annual inflow (m3)	Year Sequence
1980	13021169	Dry
1981	19338638	Dry
1982	21467567	Normal
1983	22718386	Normal
1984	8290409	V.Dry
1985	23682507	Normal
1986	16559255	Dry
1987	10451248	V.Dry
1988	35803128	Wet
1989	24322410	Normal
1990	42202751	Wet
1991	12973301	Dry
1992	26835623	Normal
1993	8315952	V.Dry
1994	22001785	Normal
1995	25550865	Normal
1996	24608898	Normal
1997	38105274	Wet
1998	52535378	V.Wet
1999	5410273	V.Dry
2000	1365986	V.Dry

4.3.2.2. Comparing WEAP model and M'mbui water balances.

The comparison of WEAP and M'mbui (WBM) water balances is presented below. Ground water (GW) inside the WEAP model does not have a mathematical link with the lake aquifer. For this reason two approaches were made. The first used M'mbui's WBM in Excel spreadsheet where the aquifer conductance was set to 0 m^2/month (WBM- GW). The second used WEAP model where the Seepage Demand from the lake was built in as 4.6 Mm^3/ month to account the real situation of outflow from the Lake.

Figure 4-3 shows 4-modelled graphs plotted together.

1) M'mbui water balance model (WBM, plotted in blue).

2) M'mbui water balance model without groundwater component (WBM- GW, plotted in black).
3) WEAP's water balance considering only inflow and net evaporation. (WEAP/inflow, plotted in green).
4) WEAP's water balance considering the demand representing the monthly seepage of the groundwater (WEAP, plotted in red).

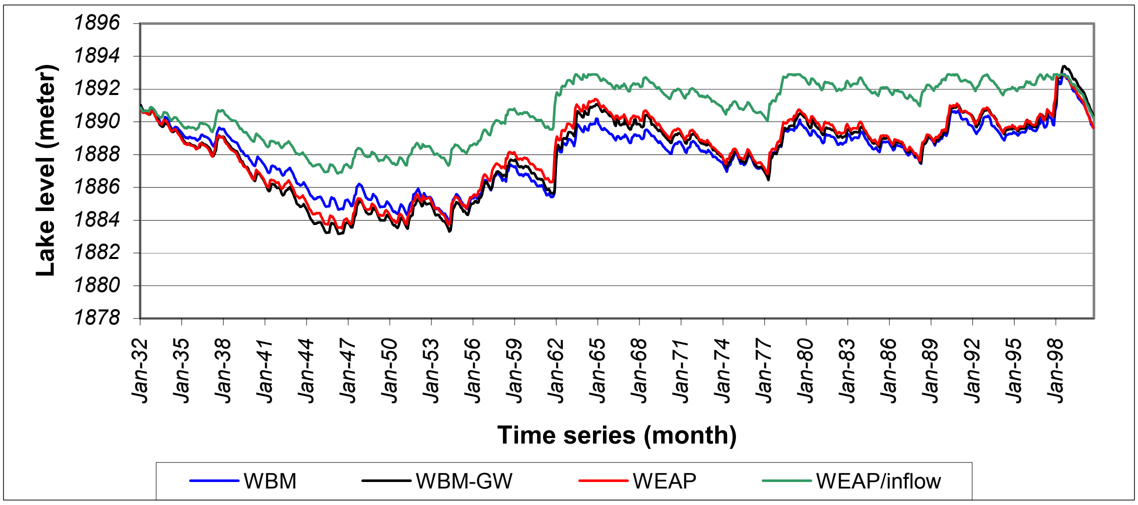


Figure 4-3:Combined water balanced modeled graphs

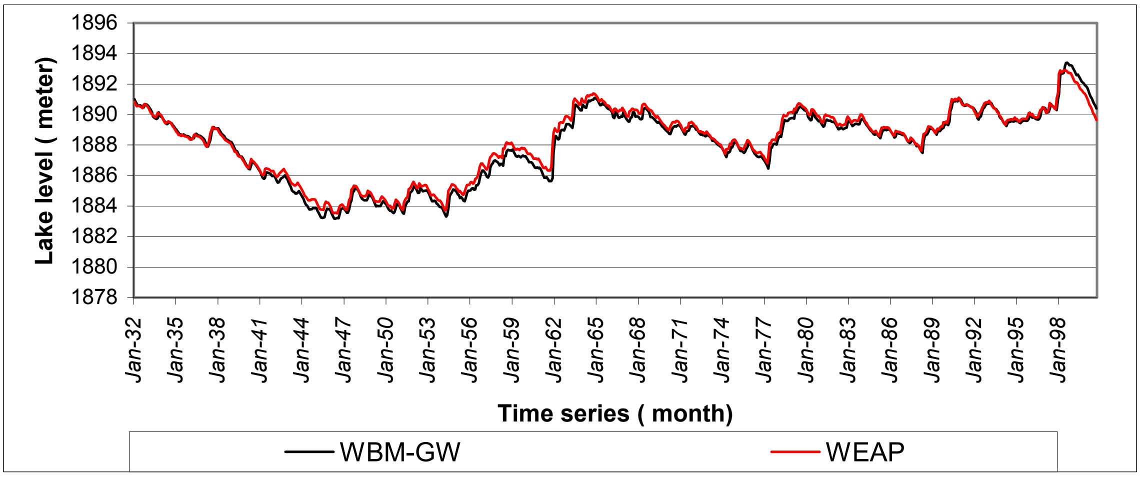


Figure 4-4: Lake level comparison between WEAP and M'mbui water balance model (1932-2000)

The analysis considered only the WBM-GW and WEAP models. By plotting the WEAP and the WBM-GW for Naivasha's water balance from 1932 to 2000 Figure 4-4; the two graphs have an average difference of 0.22 meters, a correlation of 0.993, and a mean square error of 0.13 4.
The lake level difference between the WBM-GW and WEAP models is due to the way that the WEAP software calculated the water balance. WEAP software takes into consideration the monthly variation of 30 and 31 days. The Excel spreadsheet water balance does not consider number of days per month. The above result was used in the hydrology part of the WEAP model by connecting it with the demand modelled.

4.3.3. Socio economic development related to the water abstraction (Demand in Naivasha catchment)

Demand of water for domestic use, agriculture, household use, and industry continues to increase rapidly in the basin. In this part the demand input data will be develop to be modelled in the software.

The WEAP software looked at the water balance as two parts, inflow and outflow, and computed water inflows to and outflow from every node and link in the system for a given month.
This included calculating withdrawals from supply sources to meet demand.
After the validation of Naivasha Supply part inside WEAP the Demand part in Naivasha catchment was addressed as follows:
Agriculture, population growth, industry and the climate changes that put stress on the water availability.

4.3.3.1. Modelling demand in WEAP

Demand analysis in WEAP is a disaggregated, end-use based approach for modelling the requirements for water consumption in an area. Using WEAP applying economic, demographic and water-use information to construct alternative scenarios that examine how total and disaggregated consumption of water evolve over time in all sectors of the economy. Demand analysis in WEAP is also the starting point for conducting integrated water planning analysis, since all supply and resource calculations in WEAP are driven by the levels of final demand calculated in the demand analysis.
WEAP provides flexibility in structuring data. These can range from highly disaggregated end-use oriented structures to highly aggregate analyses. Typically a structure would consist of sectors including households, industry and agriculture, each of which might be broken down into different subsectors end-uses and water-using devices. Structure the data to purposes, based on the availability of data, the types of analyses needed to conduct and unit preferences. Note creating different levels of disaggregation in each demand site and sector is possible.
In each case, demand calculations are based on a disaggregated accounting for various measures of social and economic activity (number of households, hectares of irrigated agriculture, industrial and commercial value added, etc.). In the simplest cases, these activity levels are multiplied by the water use rates of each activity (water use per unit of activity). Each activity level and water use rate can be individually projected into the future using a variety of techniques, ranging from applying simple exponential growth rates and interpolation functions, to using sophisticated modelling techniques that take advantage of WEAP's powerful built-in modelling capabilities. More advanced approaches can incorporate hydrologic processes to determine demand (e.g. crop evapotranspiration calculations to determine irrigation requirements).
To model the demand in WEAP two main parameters has to be identified

1. The Annual Activity level: The annual demand represents the amount of water required by each demand. Losses, reuse, and efficiency are accounted for separately. Water consumption is calculated by multiplying the overall level of activity by a water use rate. Activity Levels are used in WEAP's Demand analysis as a measure of social and economic activity.
   Activity levels for one of the hierarchical levels are typically described in absolute terms (in this case, the number of people in South City is 3.75 million in the Current Accounts), while the other levels are described in proportionate (i.e., percentage share or percentage saturation) terms. In the example shown above, 42% of the population lives in single-family households in 1998 and of these, 90% have showers. Notice that at the top level, the user chooses an absolute unit for the activity level (person). At lower levels, WEAP keeps track of the units, and hence knows that the percentage number entered at the second level is the share "of people". In general, WEAP lets you choose the numerator units for activity levels, while automatically displaying the denominator unit. When selecting an activity level unit, you can choose from any of the standard units. WEAP multiplies activity levels down each chain of branches to get a total activity.

This depend on the modelled for each demand element and the data availability

2. The Water Use Rate is the average annual water consumption per unit of activity. WEAP displays the denominator (person, in the example below) to emphasize that this is a rate per unit, not the total amount of water used by all showers.

4.3.3.2. Population:

Naivasha is one of the fastest growing towns in Kenya. The growth is fuelled by the increasing horticulture and floriculture farming business around Lake Naivasha, tourist activities in the region, rural to urban migration as a result of falling farm incomes from traditional cash crops, commercial enterprises and good job opportunities.
Population data was collected from various sources in the field and through several Internet demographic sources. (www.library.uu.nl/wesp/populstat/Africa/kenyag.htm). Total population for the catchment and the surrounding areas of several years are shown in Table 4-3.

Table 4-3:Population in Naivasha towns

	Year		
Naivasha	**1989**	**1977**	**1969**
Population	35000	11500	6900

In Table 4-4, the population for 1979, 1989 and 1999 is shown. This data is available on the website of www.citypopulation.de. The most recent data is of the 1999 census and is shown according to the administrative division in Kenya, which are Provinces, Districts, Divisions, Locations and Sub-locations. For these towns a linear interpolation was used to calculate growth for different years.

Additional data Table 4-4: Population of towns at Naivasha catchment.

Name	Status	Provinces	1979	1989	1999
Gilgil		RV	9,103	14,034	*20,362*
Naivasha	Mun	RV	11,491	34,519	32,222
Nakuru	Mun	RV	92,851	163,927	219,366
Ol Kalou	Town	CE	…	…	15,186

Source: 1999 Population Census Report, www.citypopulation.de. ,
NB: Total Population density excludes the prison population

Table 4-5 shows towns and villages inside the catchment. Those shown with an "*" are the ones which do not affect the lake level. Those without an "*" were included in the model with a population growth of 3.5% per year. Data in this table were collected during fieldwork from the Central Bureau of Statistics; Ministry of finance and planning, Nairobi.
Administrative subdivisions change constantly, making the interpretation of population values not always straightforward. Due to this only sub locations that are affecting the catchment were considered and included in the model.
The population of the towns and villages that affect the lake water level has been calculated backwards, using WEAP, for the period 1980-2000 using both the linear interpolation and the census growth rate. The population modelled is provided in Table 4-6.

Table 4-5: Population of villages at Naivasha catchment (villages without * are included in the model)

Not included (*)	Town & Villages	Population (1999)
	Naivasha East	**21659**
	Maiella	**11218**
*	Ndabibi	3626
	Malewa	**12701**
	Moindabi	**5028**
	Hell's Gate	**41492**
*	Kamara	42281
*	Nyandarua	479902
*	Ol kalou	98806
*	Ol Joro Orok	65229
*	Kipipiri	78893
*	N.Kinangop	67356
*	S.Kinangop	84373
*	Ndaragwa	85245
	Longonot	**25691**
Total included		**117789**

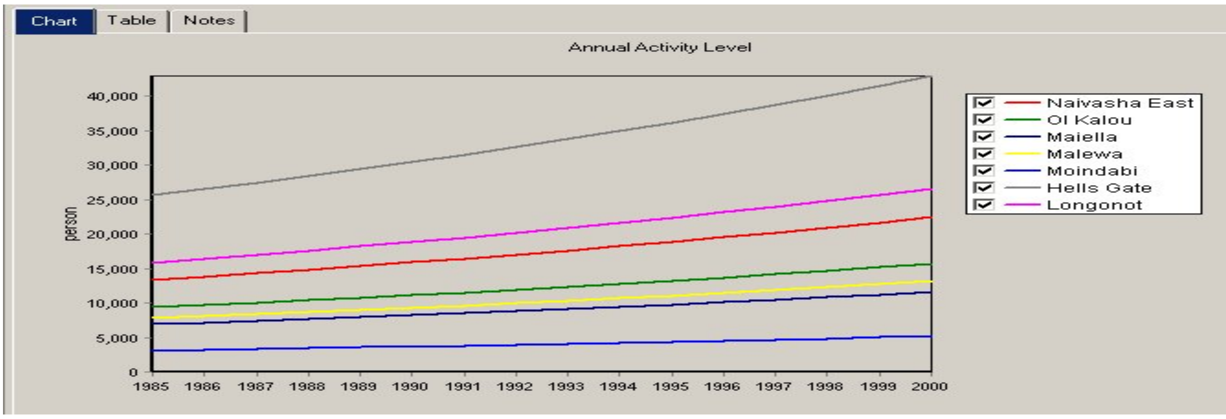


Figure 4-5: Population Growth in the Villages of Naivasha catchment

<u>Population Water Consumption in the Catchment:</u>

The Consumption for each town or village was assumed according to the Field interviews in the Municipal council of Naivasha

Table 4-6: Population water consumption in the catchment with their trends in WEAP

Town and Villages	Trend in WEAP	**Population Growth**	**Consumption** **"Annual activity level"**	**Consumption** **"Annual water use rate"**	**Water source**
	Linear Interpolation: Calculates a value in any given year by linear interpolation of a time-series of year/value pairs), here the linear interpolation has been used because the Population Census Report has data since 1979 till 1999		m^3/person/month	m^3/person/year	
Gilgil		Interp(1979,9103,1989,14034,1999, 20362)	2	24	pipe
Naivasha		Interp(1979,11491, 1989,34519,1999, 32222)	3	36	GW
Nakuru		Interp(1979, 92851, 1989,163927,1999, 219366)	3	36	pipe
Naivasha East	**Growth from 3.5%:** Calculates a value in any given year using a growth rate from the Start Value in the Start Year. The Star Year can be any year, past, present or future. This has been used for these villages because the available data was for 1999 within growth rate.	GrowthFrom(3.5%, 1999, 21659)	2	24	GW
Maiella		GrowthFrom(3.5%, 1999, 11218)	1.5	18	GW
Malewa		GrowthFrom(3.5%, 1999, 12701)	1.5	18	GW
Moindabi		GrowthFrom(3.5%, 1999, 5028)	1.5	18	GW
Hell's Gate		GrowthFrom(3.5%, 1999, 41492)	2	24	GW
Longonot		GrowthFrom(3.5%, 1999, 25691)	1.5	18	GW

NB: GW is the Ground water in Naivasha catchment

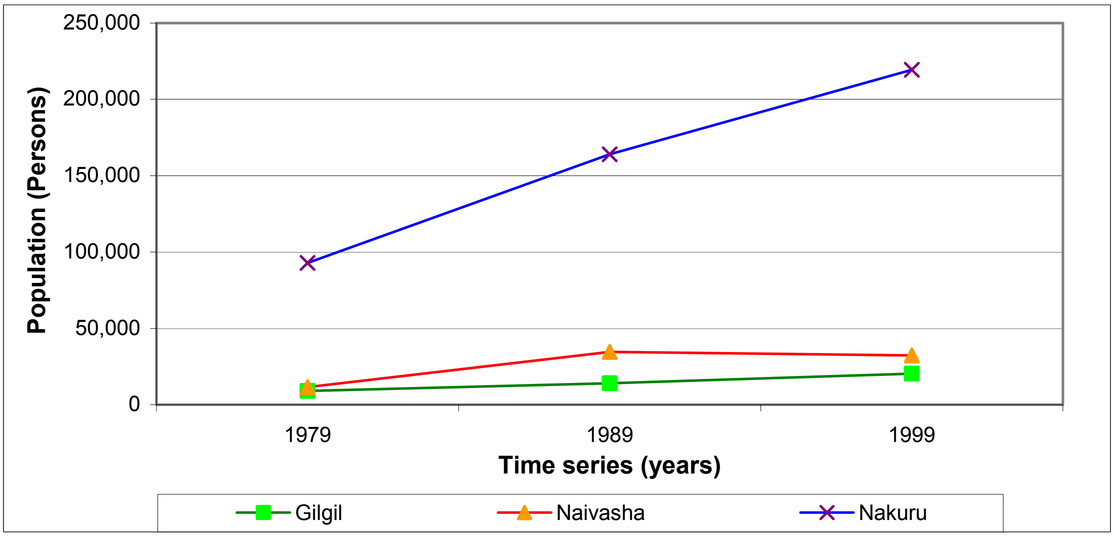


Figure 4-6: Linear Interpolation of Population Growth in the main towns of Naivasha catchment

The population demand for water was estimated according to field observation and personal communication with people from the area and from municipal council. This assumption varies according to the activities in the rural area and the urban area
The activity level in the towns and villages is the population growth, while the annual water use is shown in Table 4-6.
To calculate the population's total consumption, the population per area was multiplied by the amount of water per person per year and finally consumption of all the towns and villages was added.

4.3.3.3. Irrigation

Agriculture in the Naivasha catchment is one of the most important commercial activities; it is the driving force in the area and has a high irrigation water demand. Flower and vegetable farming are leading the regional economy with yearly turnover of 63 million US $ (Sayeed, 2001).
Sayeed (2001) studied in detail all the activities for the year 2000 to calculate water productivity in that catchment using an Excel spreadsheet. His study included the calculation for efficient irrigation and was used in this thesis [ANNEX- 1].
Different types of irrigation practices are used in the area such as pivots, dripping and sprinkling. Large farms have started using new technologies such as hydroponics soils, which recycle the water and, saves 40% of the applied water. It also increases the productivity and reduces the area of cultivated land.
The images in the database Table 4-8 were used to identify the irrigated area around Lake Naivasha Table 4-7.
To classify these images the following steps were made:

- Taking 96 GPS point in the field
- Field classification of farms in a printed image of Aster, 2003, with the help of Dominik Wambua, Ministry of Water Development, Nakuru, Kenya and Ms. Sally Share from Lake Naivasha Grower Group (LNGG)

- Compare the classification with old classified maps in the data base of ITC like Ahammad,(2000)Figure 4-17

From the images the following classes were identified:

- Flower indoor (I /D)
- Flower outdoor (O/D)
- Grass and fodder
- Vegetables
- Macadamia Nuts

Table 4-7: Irrigated Farms

	Area (km2)				
	1976	**1985-86**	**1995**	**2000**	**2003**
Abandoned	0	0	0	1.49	9.01
Flower I/D	0	0	2.38	5.50	11.91
Flower O/D	0	1.04	7.30	7.75	7.04
Grass & Fodder	11.67	8.94	16.01	13.83	5.76
Macadamia Nuts	0	1.23	1.23	1.23	1.23
Vegetable	2.59	15.27	18.96	18.15	16.98
Total	14.26	26.48	45.89	46.48	42.92

A temporal analysis, to determine land use changes, was performed using Landsat and Aster images. Table 4-7 shows the results from such analysis. It can be concluded that in the recent years, 2000 to 2003, agricultural areas have been decreasing. This is due to the application of high agricultural technology and the consequent higher productivity even when the cultivated area has reduced.

Table 4-8: images without classifications

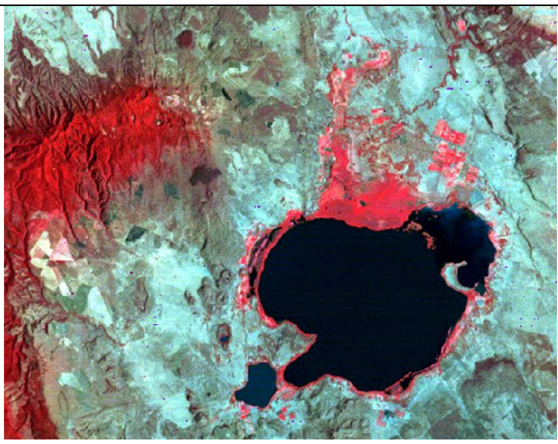
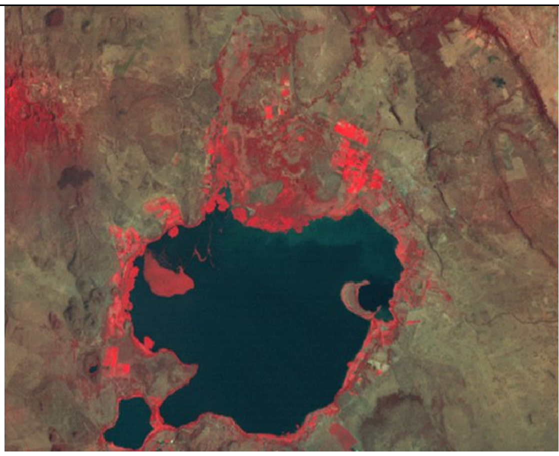
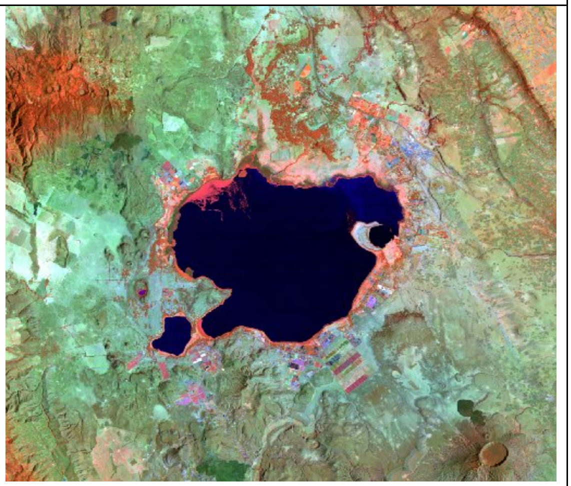
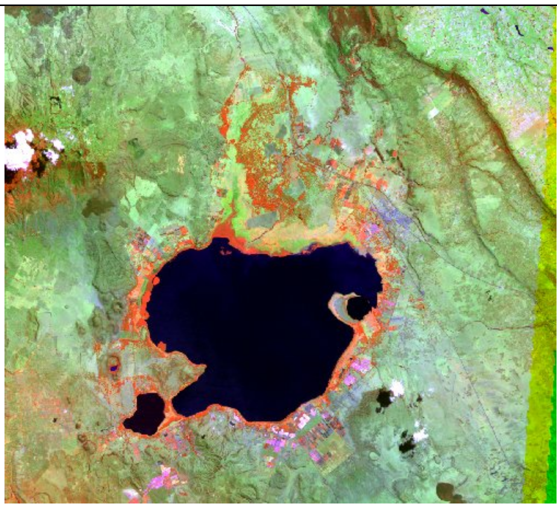
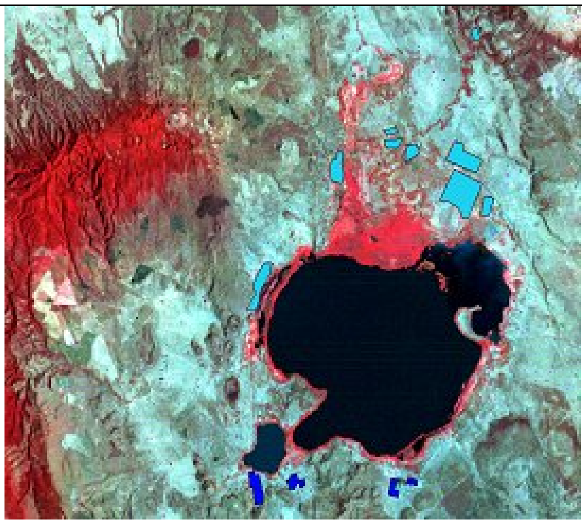
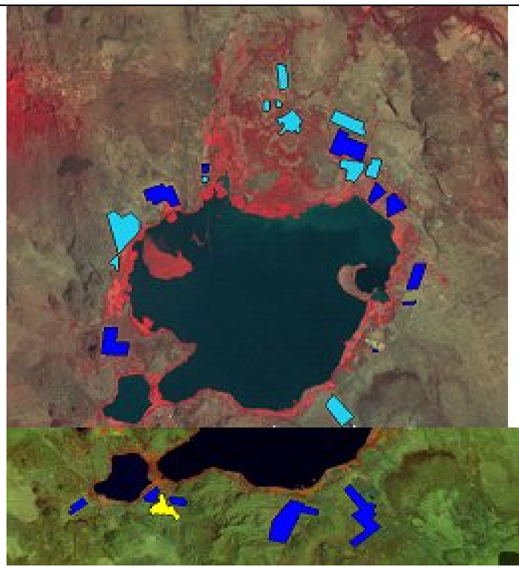
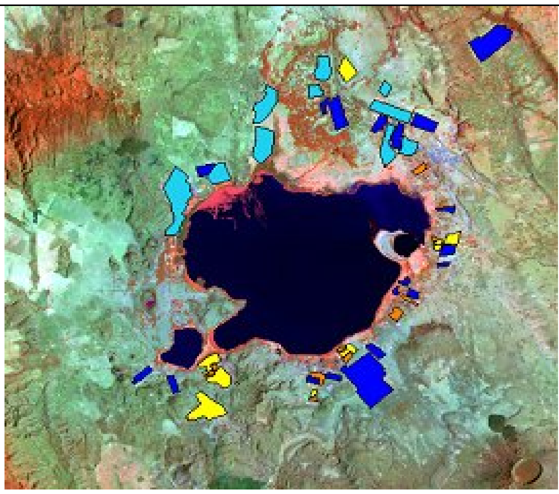
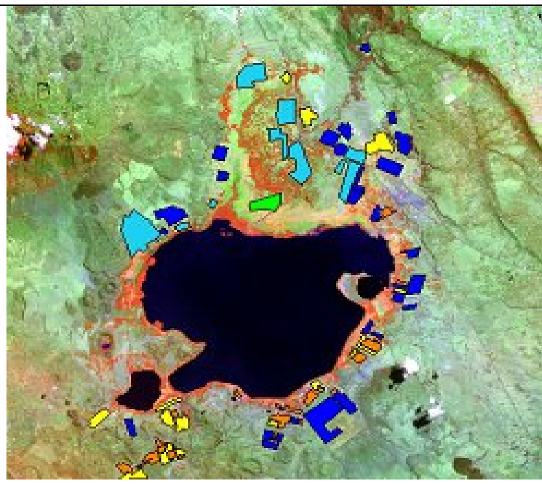
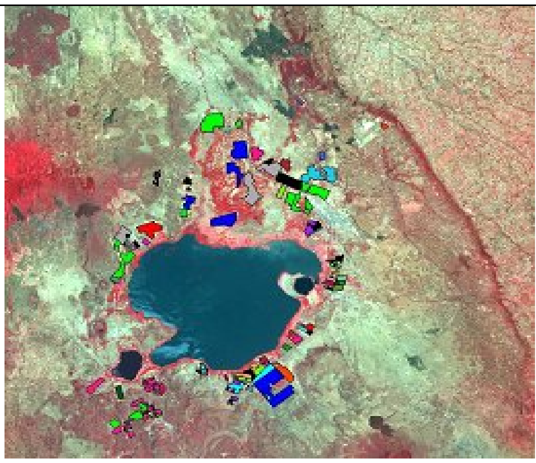
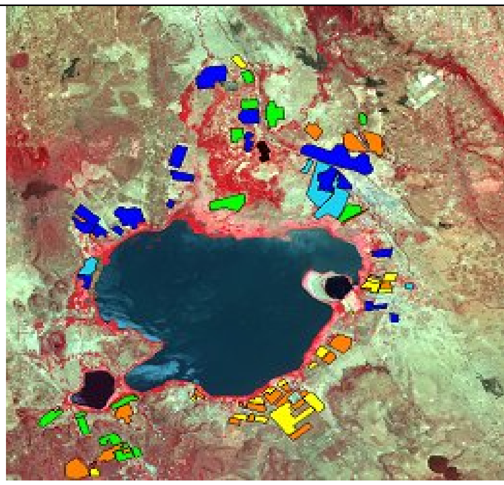
 **Figure 4-7: Landsat Images 1976**	 **Figure 4-8:Landsat Image January 1985**
 **Figure 4-9: Landsat Image January 1986**	 **Figure 4-10: Landsat Image January 1995**
 **Figure 4-11: Landsat Image May 2000**	 **Figure 4-12:Aster Image for March 2003 with the GPS point**

Table 4-9: Classified Images

 **Figure 4-13:Irrigated Farms1976**	 **Figure 4-14:Irrigated farms January 1985 & 1986**
 **Figure 4-15:Irrigated Farms January 1995**	 **Figure 4-16: Irrigated Farms May 2000**
 **Figure 4-17: classified Irrigated farms by Ahmmad, 2001**	 **Figure 4-18: Irrigated Farms March 2003**
Abondened; Flower I/D; Flower O/D; Grass & Fodder	Macadamia Nuts; Vegetable

Farming WEAP Input Data:

Table 4-10:Applied and required Irrigation (Ahammad 2001)

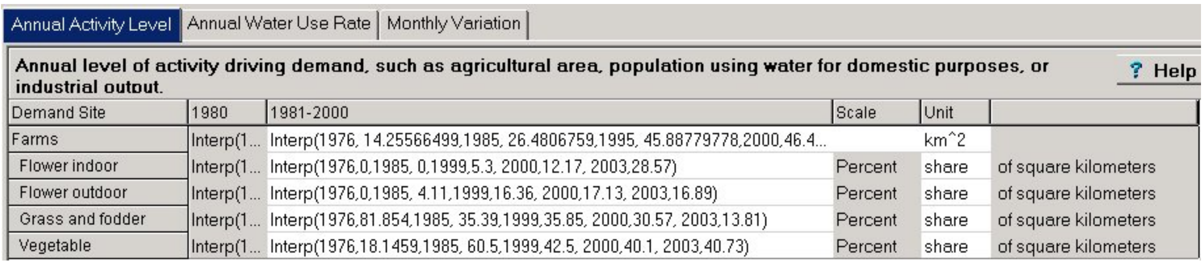
	Applied Irrigation					
Crops			Applied	Crop Requirement	Applied	Crop Requirement
	mm/day	**mm/year**	**m3/ha.yr**	**m3/ha.yr**	**m3/km2.yr**	**m3/km2.yr**
Indoor Flowers	5	1825	18250	18250	1825000	1825000
Open Flowers	8	2920	29200	19810	2920000	1981000
Grass	3.5	1155	11550	3060	1155000	306041
Fodder Crops	3.5	1155	11550	3060	1155000	306041
Vegetables	5.5	1815	18150	9660	1815000	966041

WEAP software farm input data requires two main parameters to be identified; 1) the area of cultivation and 2) the annual water use for each crop.

1) This parameter was calculated using satellite images where four main areas were identified. The irrigation data used was from Ahammad, (2001) Table 4-10. His calculations are given in annex 1.

   This parameter in WEAP corresponds to the *Annual Activity Level.* Figure 4-19 shows the data entered into WEAP as the total area of farms, and the percentage of each crop. The calculation was made as ratio in percentage form within the different years.

2) This parameter in WEAP corresponds to the *Annual Water Use Rate.* Applied irrigation and efficient irrigation values, shown in Table 4-10, were used as input in the different scenarios.


Annual Activity Level | Annual Water Use Rate | Monthly Variation

Annual level of activity driving demand, such as agricultural area, population using water for domestic purposes, or industrial output.

Demand Site	1980	1981-2000	Scale	Unit	
Farms	Interp(1...	Interp(1976, 14.25566499,1985, 26.4806759,1995, 45.88779778,2000,46.4...		km^2	
Flower indoor	Interp(1...	Interp(1976,0,1985, 0,1999,5.3, 2000,12.17, 2003,28.57)	Percent	share	of square kilometers
Flower outdoor	Interp(1...	Interp(1976,0,1985, 4.11,1999,16.36, 2000,17.13, 2003,16.89)	Percent	share	of square kilometers
Grass and fodder	Interp(1...	Interp(1976,81.854,1985, 35.39,1999,35.85, 2000,30.57, 2003,13.81)	Percent	share	of square kilometers
Vegetable	Interp(1...	Interp(1976,18.1459,1985, 60.5,1999,42.5, 2000,40.1, 2003,40.73)	Percent	share	of square kilometers

Figure 4-19: WEAP Farm data requirement

4.3.3.4. Industries

Power Supply

The Rift valley Geo-thermal plant has been in operation since 1987, and provides the main source of energy for the town electricity run by the Kenya Power and lighting Company (KPLC). The town residents normally use electricity for lighting. The town has an adequate supply of electricity, also for industrial use.

Table 4-11shows the Geo-thermal plant's water consumption collected at the facilities during a fieldwork visit.

Table 4-11: the Geothermal Plant Consumption as provided from the factory

Water for supply system	537164 m3 /year
Domestic	179266 m3 /year
Total	712430 m3 /year

WEAP Data Input

As part of the demand in the annual water usage rate, the Geo-thermal Plant annual water consumption was **712430 m^3**, for one annual level activity.

The other activity like the tourism, Industries and Social Institutions, was not included in the model because no reliable data from the currant year was available. In addition it was very difficult to make assumptions because the area had developed rapidly according to the faming activities.

4.3.3.5. Treatment Plant

VIAK of Sweden designed the existing Naivasha sewage system between 1974 and 1977. Phase one was designed for a population of 17,000, and phase two was expected to serve about 43,000 people by 2000, based on census figures publish by The Ministry of Economic and planning,(Consulting, 2003). The system designed for sewage treatment offering, 90% biochemical oxygen demand (BOD) reduction and killing of more than 99.7 of bacteria according to Naivasha sewage project preliminary design report Part 1 by VIAK (1975).

Table 4-12: Design Data for Naivasha Sewage Treatment Works (from VIAK 1975)

Total connected equivalent population	22200	person
Design average daily wastewater flow	2035	m^3/day
Design wastewater BOD loading	1220	kg /day

Table 4-13: Wastewater Quality for Naivasha treatment Plant

	Influent	Effluent
Biochemical oxygen demand BOD_5 mg/l	1200	300
Chemical Oxygen Demand COD mg/l	1680	400
Suspended Solid SS mg/l	280	40

Another treatment plant in the upper catchment belongs to the Catholic Hospital (personal oral field communication). The hospital comprises a big campus, with a population of about 1000 people, and depends on agriculture. They use water directly from Turusha River of approximately 40 m ^{3}/day and have two-treatment plants, which produce return flow of approximately 20-m3/ day to Turusha River. A future plan is to build a tank for capture of rainwater t. This plan will be in process by the next year, and will result in a reduction of abstraction from the river.

WEAP Input Data

- For Naivasha Wastewater in WEAP, the daily capacity is (2035 m^3/day) with removal of 25% of the BOD, Table 4-9 and Table 4-10.
- For the Catholic hospital, in supply and resource, the Return Flow Routing entered as 50 % to the hospital treatment plant and 100% for return flow from treatment Plant to river. By this the return flow to the river will be 20m^3/day

4.3.4. Pricing water

Pricing for domestic water supplied is applied in several towns in the catchment, who are connected the municipal council system. Water for agricultural use, and that of private boreholes, is not priced at all.

The municipal pricing system consists of the following. Those who connect themselves to the public system have to pay 21 Kenyan shilen/m^3 (0.23 US $). Those connecting themselves to the sewage system have to pay 75%(15.75 Kenyan shilen/m^3 = 0.18 us $) of the value of the water consumption. The trend is to make everyone apply for a meter in the towns and villages and to be connected to the sewage system, but to date not every one is connected to the system. On many farms around the lake meters have been installed.

5. Scenarios Development and Management

Water sustainability assessment requires a scenario approach for taking a long wide view that considers futures with fundamentally different development and environmental assumptions and policies. Using integrated water management scenarios, diverse stakeholders can engage in informed dialogues around balancing trade-offs and devising appropriate actions.
In this Chapter different scenarios built using WEAP as software are discussed. In WEAP the basic model was built using the real data to be used for scenario management and analysis Figure 5-1and Figure 5-2.
Develop a scenario, to propose a certain set of management actions to be implemented with the objective of understanding the effects of different elements that affect the lake level and what options to improve the management in the lake through integrated water resource management.

5.1. Referance Scenario (1980 – 2000)

The reference or business as usual scenario is the base scenario that uses the actual data, to help in understanding the best estimates about the studied period.
The objective of a reference scenario is to help people learn what likely could occur if current trend continue and to understand the real situation.
Reference scenarios can also be useful for identifying where knowledge is weak in analysing likely trends and where more information needs to be collected. They can be useful for designing contingency plans where there is a lot of risk and uncertainty.
In this study the basic model has been build using WEAP; reflects the Reference scenario, which replicates the real situation.

5.2. Efficient Irrigation Scenario

The efficient irrigation is how much of the water that is applied is actually retained within the effective plant root zone in an irrigation event. By "applied" we mean water leaving the nozzle of a pressurized system, or passing over the sill for border-strip systems (Environmental, 2000).
The main water use in the agricultural sector is for irrigation, with minor contribution to the water demand of live stock farming and fish farming. Irrigation is the subject of this scenario, even though in certain areas livestock watering can also represents a significant demand.
To calculate the effective applied irrigation we will consider the efficiency of the irrigation which has been studied in detailed by (Ahammad, 2001) .

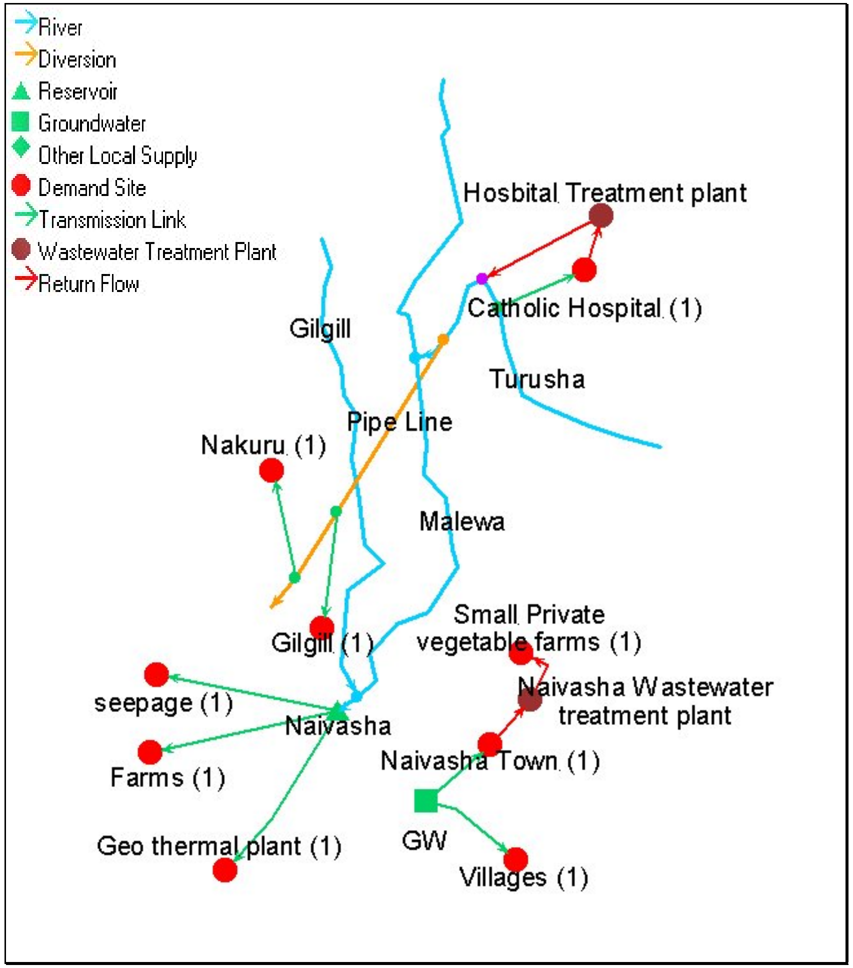


Figure 5-1: Model schema

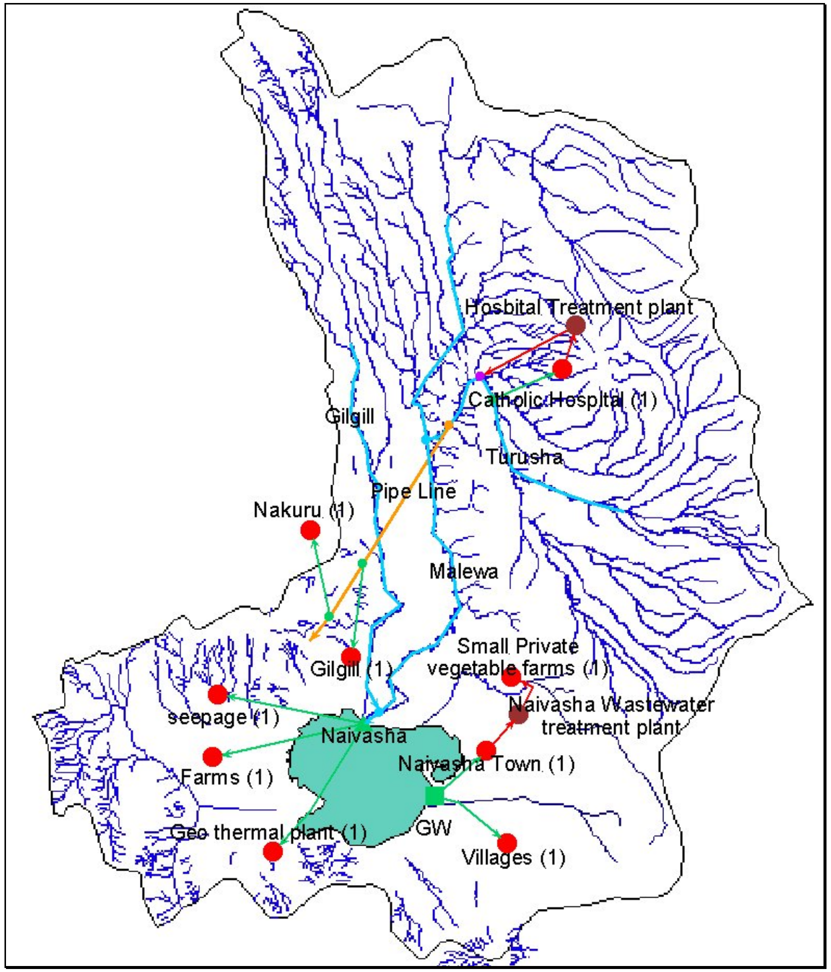


Figure 5-2: the Basic Model with catchment background

In this scenario we are going to apply his result to see the effect in the lake level (Table 5-4) when applying the Effective Applied Irrigation.

5.3. High Technology Scenario

According to the Field observation there were lots of water lost in irrigation and this water mostly goes back to the lake with some added chemical of pesticide and fertilizers that are used in the cultivation.
Few farmers started applying the idea of new reservoirs to collect surplus of water from the irrigation. Others use Hydroponics soils, which reduce water use when recycled but if the water is wasted, and then it soaks more water than the soil. By recycling, the water can be saved by 50 %, personal communication with farmers.

5.4. Water Pricing Scenario

Water charges are based on different policies, depending on the different availability of water resources. Charging water in Kenya is part of the new Kenyan act law (kenyaGoverment, 2002).
Pricing water is a good way to regulate external costs of water use providing a means of financing water service agencies and forcing compensation to users who are harmed by unregulated public and private systems.
Different inherited Practices ways in irrigation have been used, which lead to over irrigation in many farms. Pricing water can make the users revaluate their irrigation practices, as it has been also discussed with some farmers in the field.

5.5. The Water Year Method Scenario (2000-2013)

The Water Year Method allows using the historical data in a simplified form and to easily explore the effects of future changes in hydrological patterns, which can be a useful tool to test a hypothetical event.
In this Scenario the data that was prepared in chapter 4 will be used in the Water Year Method instead of the real data. It is very important to study this scenario because it helps to understand and to explore in simple way the sensitivity to climate change.
The most important parameter in the water Year Method is the coefficient for the water year definition.

6. Scenario Analysis and Results

6.1. Introduction

Scenario analysis aims to answer "What if…?" questions. Data are essential to evaluate the current and past situation, while models are indispensable in exploring options for the future.
This chapter deals with the result of the scenarios. The results were compared and linked with previous studies.
The main two studies that were linked to the results are M'mbui, 1999, which modelled the water balance of Lake Naivasha from 1932- 2000. Another study used in this chapter was Sayeed Ahammad, 2001, which studied in detail the individual farm outputs in the form of Dollars per cubic meter usage of water for different conditions of abstraction and use of water, and the net return from the irrigated farms and dairy sector.
The following graphs were directly obtained from the software scenarios and were used in Excel to be compared with other studies.

6.2. Reference Scenario (1980-2000)

The following results were obtained from the Actual Situation (reference) scenario:

Reservoir Storage Elevation

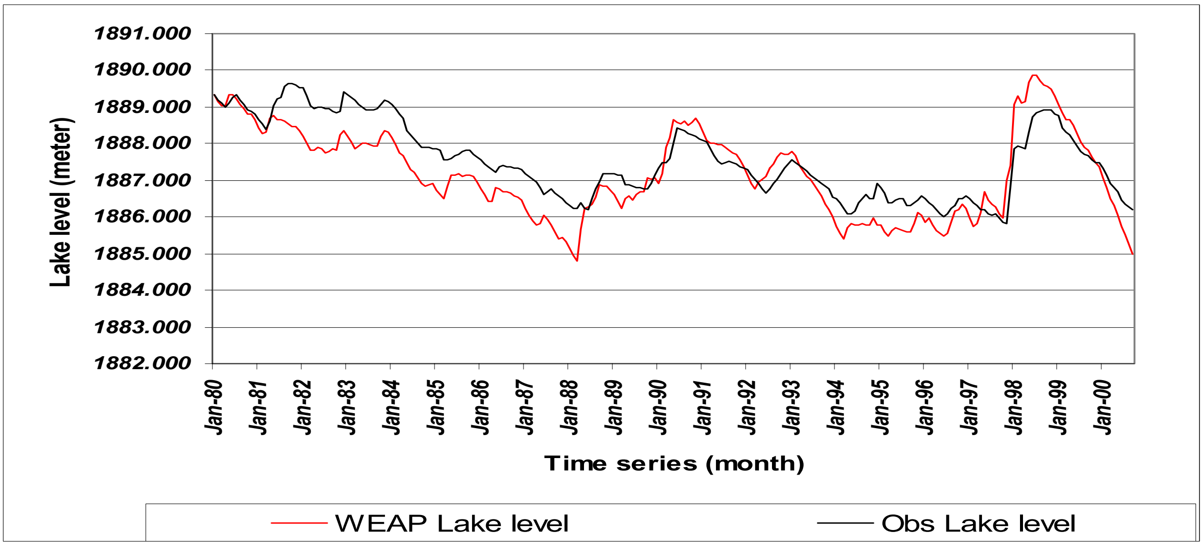


Figure 6-1: The comparison between the calculated reservoir elevation (WEAP) and the observed lake level

The graph of the Reservoir Storage Elevation that was obtained from WEAP model as total water balance included all the demand parts and the observed lake level. The correlation between the two graphs was 0.86 with an average difference of (0.36 m), with mean square error of 0.5.

Figure 6-1 shows that the period from 1980 until 1988 needed to be calibrated.

To calibrate the model, water demand from 1980 to 1988 needed to be reduced. Given that the main demand in the basin is agriculture Figure 6-2, this was done for agriculture and the main towns in the basin.

1. In the defined time period, the main type of irrigation was for vegetables, fodder and grass. The annual water use for grass and fodder was reduced for that period by using the linear interpolation. The interpolation was for the years 1980 (annual water consumption 400000 m^3) and 1988 (annual water consumption 2310000 m^3). For vegetables the interpolation was for 1980 (annual water consumption 700000) and 1988 (annual water consumption 1815000 m^3).
2. Another change was in Nakuru, Gilgill, and Naivasha. For the main towns, Nakuru and Naivasha, the annual water consumption per person was reduced to 24 m^3. This was done by using a linear interpolation between the years 1980 (annual water consumption 24 m^3) and 1988 (annual water consumption 36 m^3). In Gilgill a smaller town, the annual water use consumption per person for the year 1980 was 18 m^3, and for 1988 it was 27 m^3.

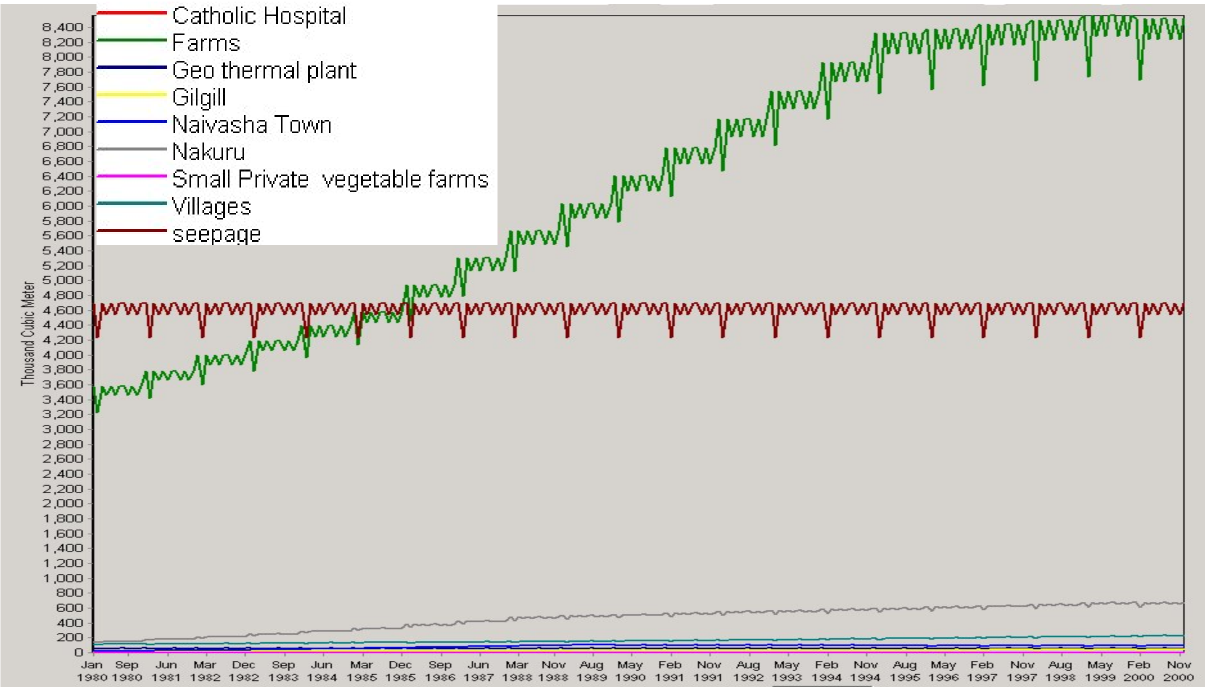


Figure 6-2: The demand in Naivasha catchment

By running the models after the previous change, Figure 6-3 shows that the graphs correlate by 0.89 after calibration. The mean square error for the modelled Lake Level was 0.28; while the average difference between the observed lake level and the WEAP modelled lake level was 0.03.

The two graphs are following the same trend with high correlation but they are not identical because the demand in the model has many of assumptions and linear interpolations in the modelling which in reality are not fully accurate.

This can be improved if more historical and detailed data about the demand can be collected.

Also population consumption depends on the assumptions made by the municipal council which maybe an estimate higher than real consumption.

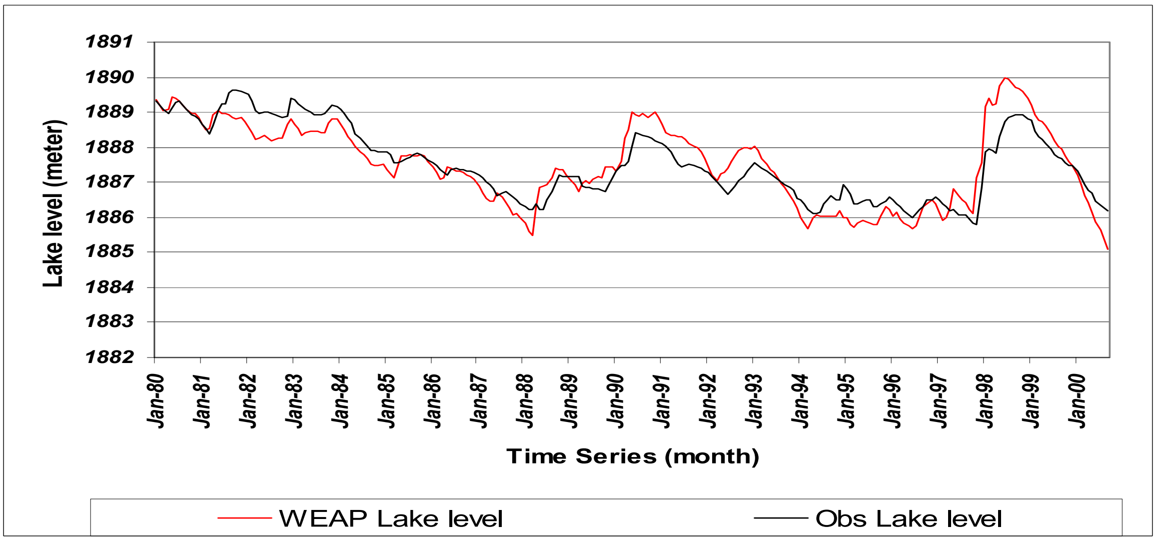


Figure 6-3: The comparison between the calculated reservoir elevation (WEAP) and the observed lake level after calibration

The water demand in the basin

To study the water demand in the area Figure 6-2 shows that the main consumption in the basin is agricultural demand.

To study the other demand, Figure 6-6 shows that:

- Nakuru town has a high demand but it is not located in the catchment and the town depends on other sources of water supply. Nakuru consumes a specific amount of water from Turusha River through a pipeline that affects the inflow to Lake Naivasha. So the unmet demand in Figure 6-4 was expected. The average unmet demand was 156 thousand m^3 /month, if the months with no unmet demand are included while the average for the months that have unmet demand only was 205 thousands m^3 /month.
- Figure 6-4 shows two peaks of unmet demand due to the fact that the Turusha river inflow decreases Figure 6-5. The inflow of Turusha River was assumed to be 40% of the total inflow to Lake Naivasha, due to the fact that to date there is no specific discharge data for this river. At present there is a river disaggregated water balance model still being calibrated. This assumption caused unmet demand for Gilgill town in the years 1992 (18 thousands m^3 in January) and in 2000 for the months (February, March, April, Jun) with average of 24 thousand m^3. Meanwhile this town has other sources for water as ground water and rain fed small reservoirs.
- The previous study carried out by M'mbui showed that, 1999 the expected increase in the demand water consumption in catchment averaged by 60 Million cubic meters per year. This was an expected as total consumption. Meanwhile, the average total annual consumption in Naivasha catchment reported in this study was 66 million cubic meters, which includes all the demand in the catchment.
- Figure 6-2 shows that the main demand in the area is the agricultural consumption, which also means that the main force in the basin is agriculture.

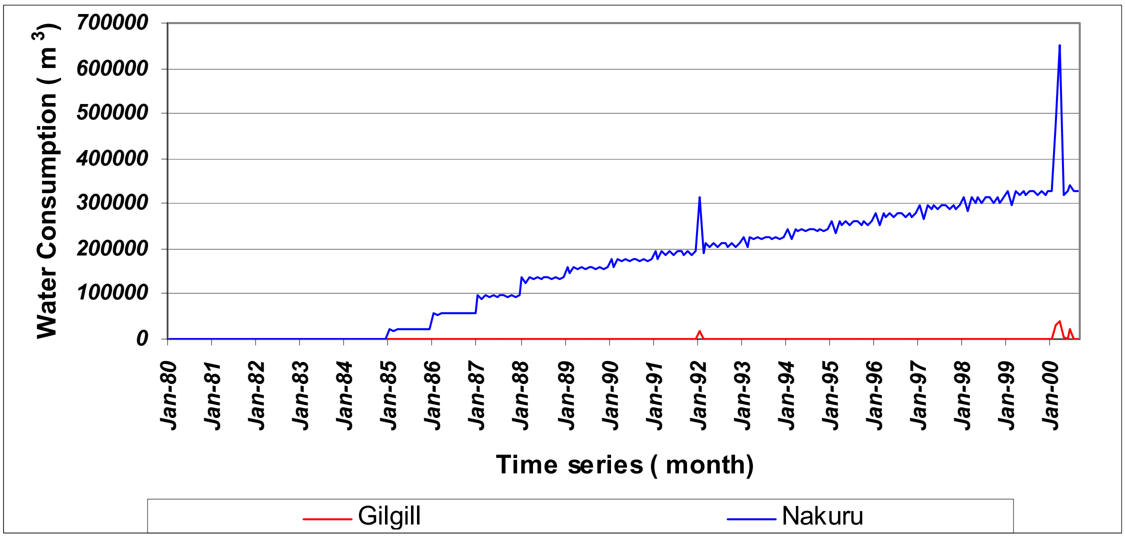


Figure 6-4: The unmet demand in the basin

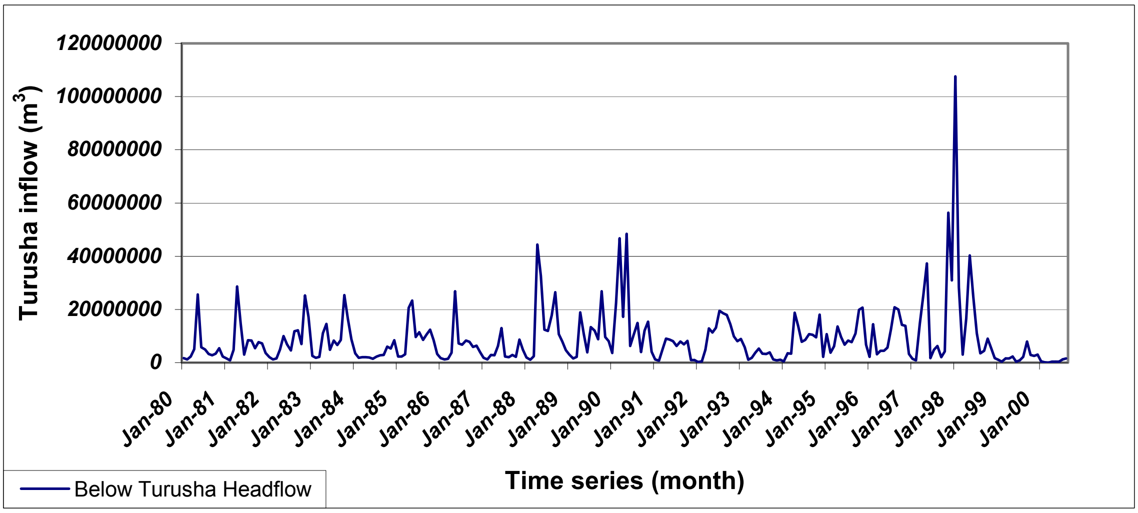


Figure 6-5: Turusha River inflow

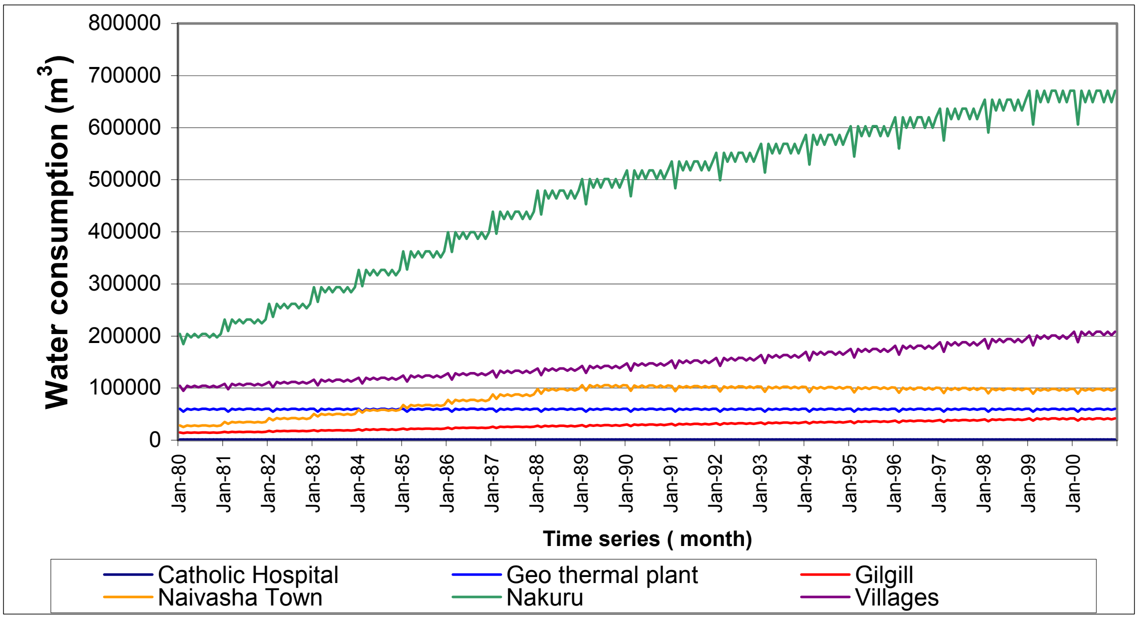


Figure 6-6: The water demand in Naivasha catchment

Farms

Agriculture is the main activity in the area that affects the lake level in the catchment as discussed below:

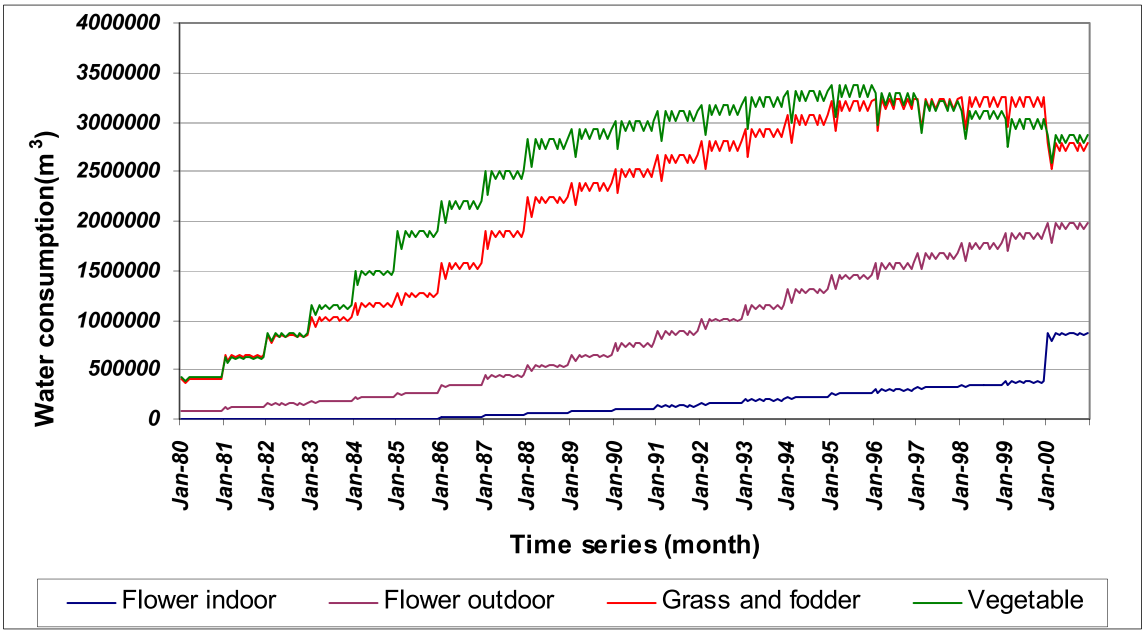


Figure 6-7: the water demand for farms (applied irrigation)

Table 6-1: Average Annual water consumption per crop in the area

Year	Flower indoor	Flower outdoor	Grass and fodder	Vegetable
	Thousand m^3			
1980	0	87	402	425
1981	0	117	628	614
1982	0	149	834	848
1983	0	185	1011	1131
1984	0	223	1150	1469
1985	0	265	1245	1865
1986	16	345	1537	2155
1987	35	433	1858	2456
1988	56	529	2207	2767
1989	79	634	2342	2867
1990	104	747	2477	2959
1991	132	868	2612	3044
1992	161	998	2747	3121
1993	193	1136	2883	3190
1994	228	1282	3019	3252
1995	264	1436	3155	3307
1996	291	1538	3166	3226
1997	319	1640	3177	3144
1998	346	1742	3188	3062
1999	374	1846	3199	2980
2000	860	1937	2735	2819
Average	165	864	2170	2414

- Figure 6-7 shows that the main activity in the area is cultivation, mainly vegetable grass and fodder. In (1985 -1986) there were changes in the types of cultivation. Fodder decreased as compared to vegetables and the flower farming began.
- This area is famous for flower farming, which is less than 30% of the cultivated area. The trend is an increase in flower farms and reduction in the vegetable farms, which is more than 70% of the cultivated area.
- Meanwhile the average annual total consumption per crop for flower farming is less than vegetables, grass and fodder farming Table 6-1.
- The net profit from flower farming is much higher than for vegetables and fodder, even though less area is cultivated for flower farming. Table 4-1 shows the net profit that has been calculated by Ahammad, (2001).

Table 6-2:Net Profit from farming

	Net profit	
Flower	28824	US $/ha.yr
Fodder	1097	US $/ha.yr
Vegetable	9053	US $/ha.yr

6.3. High Technology Scenario

Flower farming is the main source of income in that part of the world. Naivasha controls the flowering business in Kenya. The flowering industry has expanded rapidly in the recent years providing an income of $63 million annually, Most of the carnations and roses grown in Kenya's are sent to the European markets. Therefore it is considered the country's best sources of foreign exchange.
The flowering business provides many job opportunities to the local people, although the local people believe some of the lake's problems, such as pollution and falling water levels, are aggravated by farming. .
Flower farmers claim that they are doing their best to reduce their impact on the lake, and blame it to the other sources of pollution, which is beyond their control. Flower farmers are concerned with the economical side, and they want to improve the lake level because it directly affects their source of income.
One of the biggest flower farms in the area has done this, and their accomplishment in improving farm management and good farming practice is evident
It is noticed that roses have been moved to indoor farms due to high disease pressure outdoors, reducing the use of pesticide and increasing the productivity on average 250 saleable stems per m2 gross, i.e. 2.5 million \ Ha. Now by applying the Hydroponics, water use will be reduced by at least 40 % to 50% when recycled but if run to waste it is dehydrated than soil.
Currently farmers' use for roses five litres of water per stem sold, and 40 cubes \ ha \day for soil, 60 cubes\ha \ day hydroponics. Later this amount will change as the plants grow.
Also carnations plantations have moved indoors and that saves lots of water. Indoor carnation plantations use the same amount of water as outdoor plantations; but with the recycling of 50 % of the water results in a huge water saving and increased productivity.
Outdoor growing produces 5 stems m^2 \ week, indoors 10 stems\m2\week gross. Thus half the area is needed to hit the same target.
Hydroponics outperforms soil by 100 % i.e. double production per unit area in carnations.
To change from flower outdoor farming to flower indoor farming the cost will be 70000 US dollars / hectare. At the same time flower indoor drip lines cost 3600 US dollars /hectare and to go to hydroponics soil they have to add the beds which cost 7800 US dollar, according to one of the biggest farmers' field information.
There were no statistics figures provided for gypsophila. These crops are representing a small portion of the total flower farming.
Some farmers apply hydroponics soils outdoors with water reuse of 50%.
Using the previous information will try to find answers for the following questions as different scenarios to study the impact on the lake level:

- What would happen if efficent irrigation applied?
- What would happen if hydroponic soil, which saves 50% of water, were applied to all indoor flowers?
- What would happen if to outdoor flowers if a resevoir were built to re-use the extra water ?
- What would happen if outdoor flowers were moved indoors?
- What would happen if outdoor flowers were moved indoors and used hydroponic soils?

Table 6-3: The type of cultivated area in percentage with respect to the total cultivated area in that year.

	The % of total cultivated area (Km^2)				
	1976	1985-86	1995	2000	2003
Flower I/D	0	0	5	12	28
Flower O/D	0	4	16	17	17
Grass & Fodder	82	35	36	31	14
Vegetable	18	61	43	40	41

Table 6-3 shows the percentage of the cultivated area for each crop that has been calculated using the satellite images

6.3.1. Efficient Irrigation Scenario

If agricultural producers adopt technically efficient irrigation methods to produce higher net incomes through increased crop yields and increased efficiency in nutrient and chemical use, the result would be reduced labour costs and more efficient water use.

One definition of on-farm irrigation efficiency is the ratio of water stored and depleted in the crop root zone for crop consumption to the total water diverted from the stream for irrigation. One method to increase on-farm efficiency, defined in this way, would be to encourage producers to apply water more consistently across fields. This enables crops to maintain, keep or increase their consumptive water use from reduced stream diversions.

This scenario is looking to the effect of applying the crop requirement irrigation on the lake level. What will be the impact on the lake level if farmers applied irrigation equal to the crop requirement on their cultivation? How will the situation be improved?

The efficient irrigation data in Table 4-10 was used in this scenario

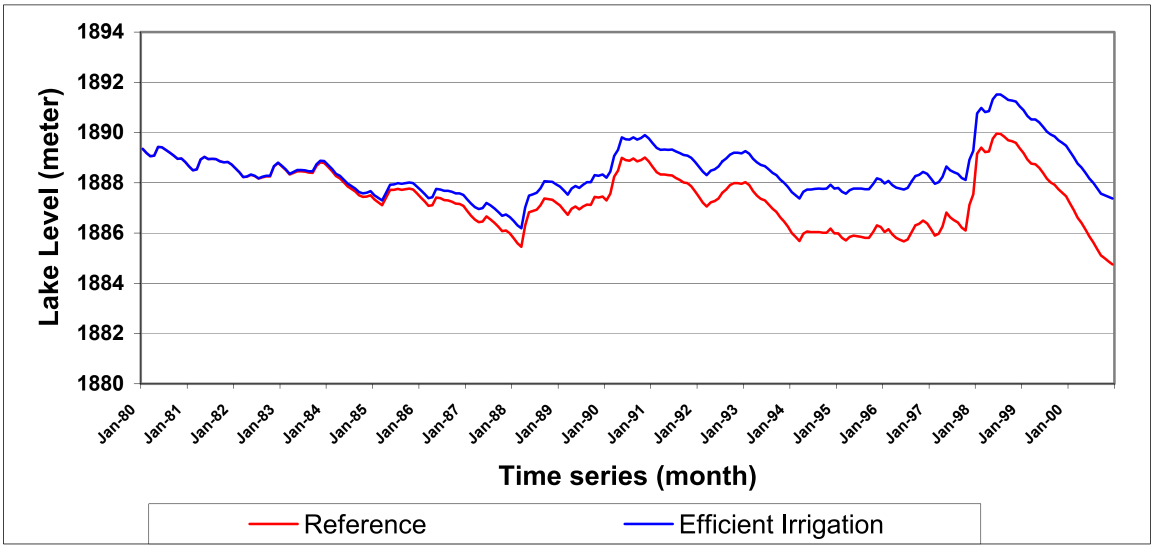
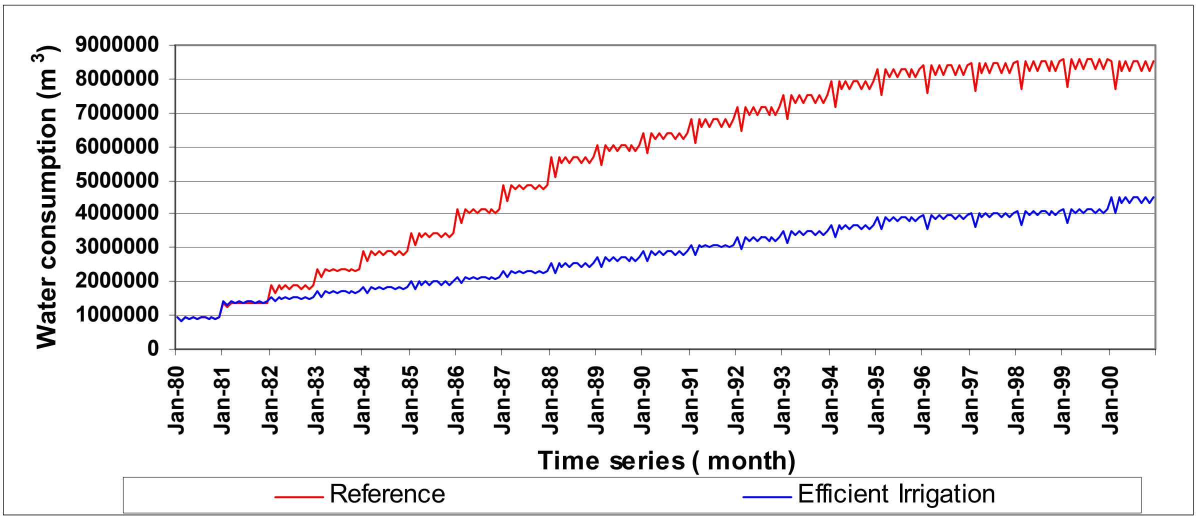


Figure 6-8: Lake Level difference according to reference and efficient irrigation scenario

Running this scenario, Figure 6-8 shows that the lake level will increase by an average of (1 m / month). This means that the average agricultural demand will be reduced by 3 million m^3 / month Figure 6-10 if the efficient irrigation is applied to all crops.



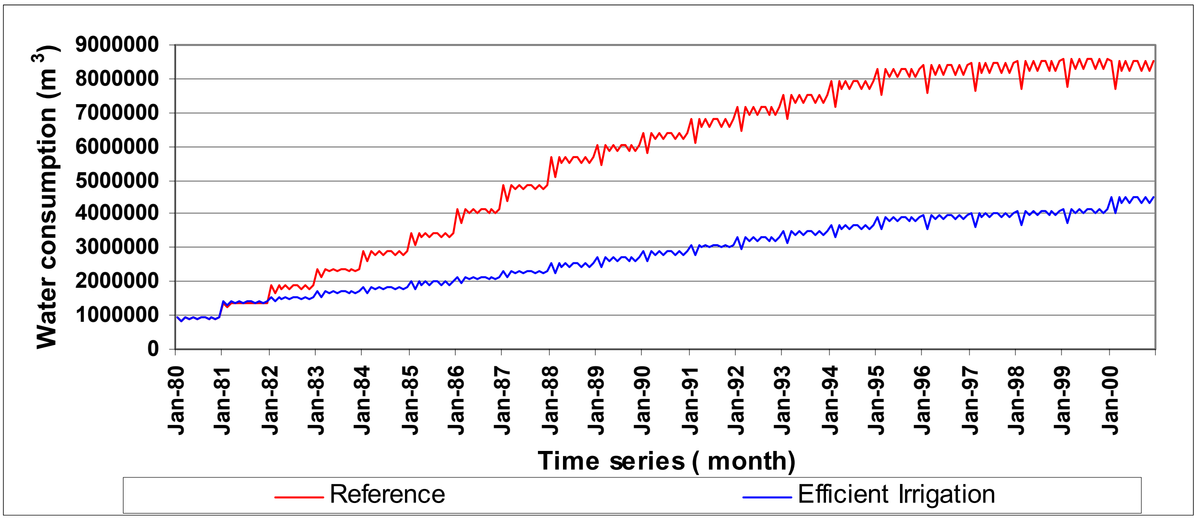


Figure 6-9: Different water consumption according to reference and efficient irrigation scenarios.

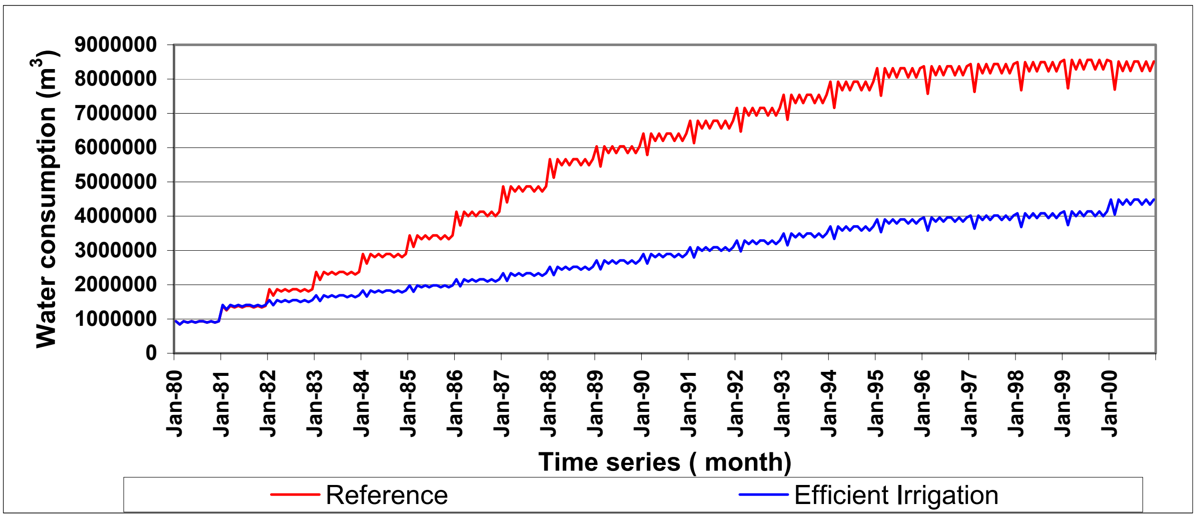


Figure 6-9: Different water consumption according to reference and efficient irrigation scenarios.

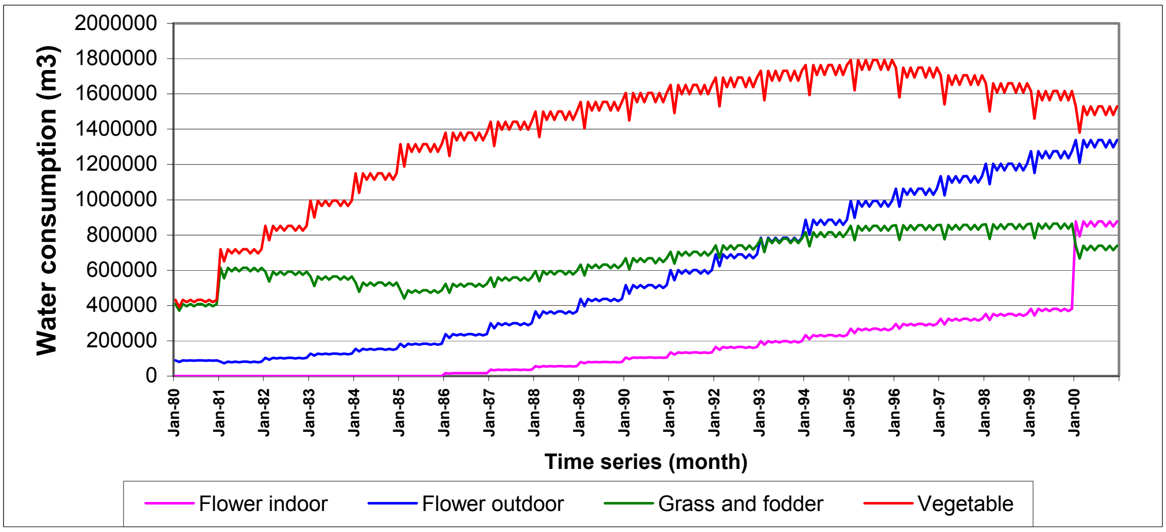


Figure 6-10: farm water demand in efficient irrigation scenario

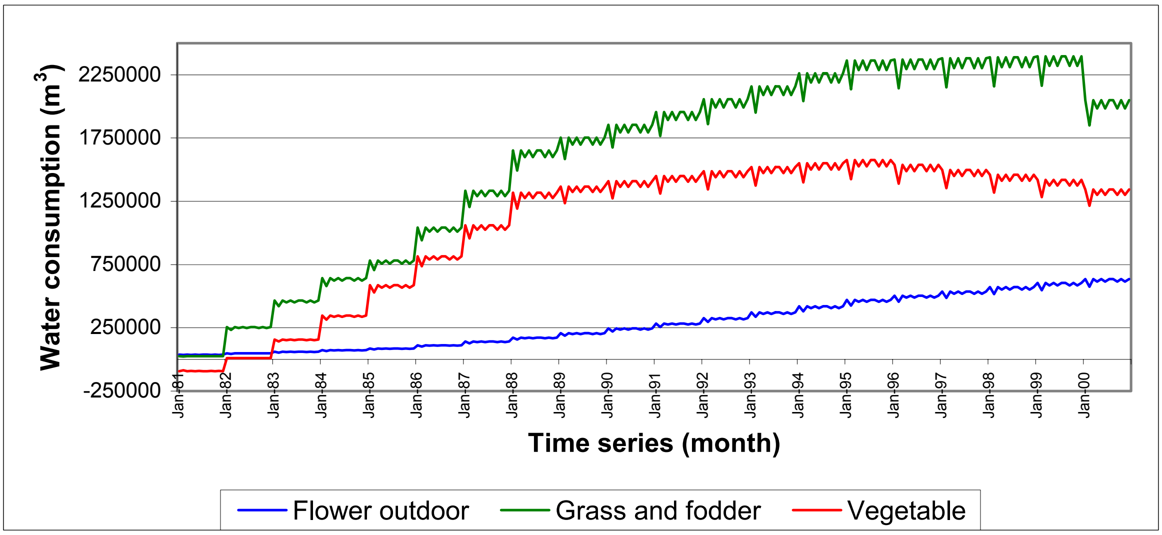


Figure 6-11: the amount of water that can be saved using effective Irrigation applied

After studying the different kinds of cultivation and re-evaluating the types of irrigation applied by farmers it is concluded that:
The vegetables grass and fodder are over irrigated as shown in Figure 6-11. This is because of the way that farmers irrigate like sprinkling and pivots, without taking into account any agricultural aspect to calculate the amount of water needed for irrigation.

According to relevant FAO sources, such as report NO**. 11, 1996,** the type of irrigation has to be selected according to different aspects such as the scale of cultivation, crop type, climate, kind of soil and the scale of applied technology (high, medium or poor). All the previous aspects have to be taken in consideration when applying sprinkling, pivots and dripping irrigation. This can affect the efficiency of irrigation.

Table 6-4: the amount of water that can be saved if effective irrigation is applied

	Flower indoor	Flower outdoor	Grass and fodder	Vegetable
	Thousands m^3			
Max	0	635	2397	1580
Min	0	35	24	-94
Average	0	290	1580	1071

Traditional irrigation such as pivots and sprinkling are cheaper than dripping, which encourage the farmers to use them without considering the over irrigation because the water is also free Table 6-4 Applying efficient irrigation leads to reduced amount of water for cultivation. . If there is excess water, this can be reused as explained in the next scenario.

A simple calculation shows the percentage of over irrigation by type Table 6-4.the equation used is given below.

$$PercentageofOverirrigation = \left(\frac{Crop\,\mathrm{Re}\,quierment}{AppliedIrrigation} - 1 \right) \times 100$$

Table 6-5: The percentage of over irrigated water per Km^2

	Percentage
Indoor Flowers	0
Open Flowers	32
Grass	74
Fodder Crops	74
Vegetables	48

Table 6-5 shows the percentage of over irrigation per crop type. Considering the area (km^2) of cultivation, this clearly indicates that fodder and grass over irrigate by 74 %, vegetable farming by 48%, and out door flower farming was 32%

By linking these results with those of Table 6.2 and Table 6.3, it can be concluded that the main problem is cause by fodder and grass farming. However, vegetable farming must not be ignored.

Outdoor flower farming over irrigates by 32%, but the area of cultivation is smaller than for vegetables, grass and fodder. This sector has a much higher net profit, and is always looking for improvement in cultivation techniques to increase productivity.

6.3.2. Building Reservoir for Reuse of Flower out door

Figure 6-12: Pictures from the field show the return flow from flowers outdoors

The outdoor flower irrigation is higher than the applied effective irrigation that has been calculated in by Ahammad, (2001) as shown in Table 4-10.

Mostly the extra water, carrying chemicals, goes back to lake as return flow.

The flower farmers are trying to reduce the water consumption from the lake through two new methods:

- Building a reservoir to collect the extra water from the applied irrigation. This will reduce the water consumption through reuse, and reduce the fertilizers. Fifty percent of the collected water will be reused, which will reduce the over irrigation that has been calculated in Table 6-5.
- Using the hydroponics soils for outdoor flowers, because its increases the productivity up to 100% per unit area, and extends the life of the mother plant. An example is the carnation plant, which will increase from 18 months to 3 years. At the same time this will also save the water through reuse by 50 %.

From the above it can be concluded that by applying the reuse of 50% in the outdoor flower, either by using the hydroponics soils or by building a reservoir, the lake level will increase by 11.62 million m^3 during year 2000.

Figure 6-13 and Figure 6-14 show the increase in lake level which can average 00.2 meter / month, and reduce demand 451 thousands m^3 / month

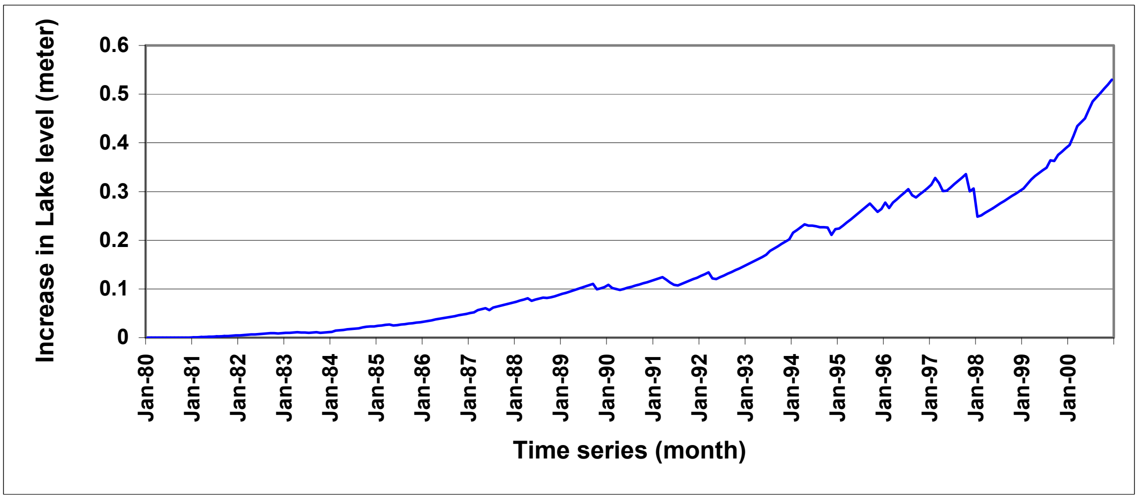


Figure 6-13: the increase in lake level if the water reuse in outdoor flower farming

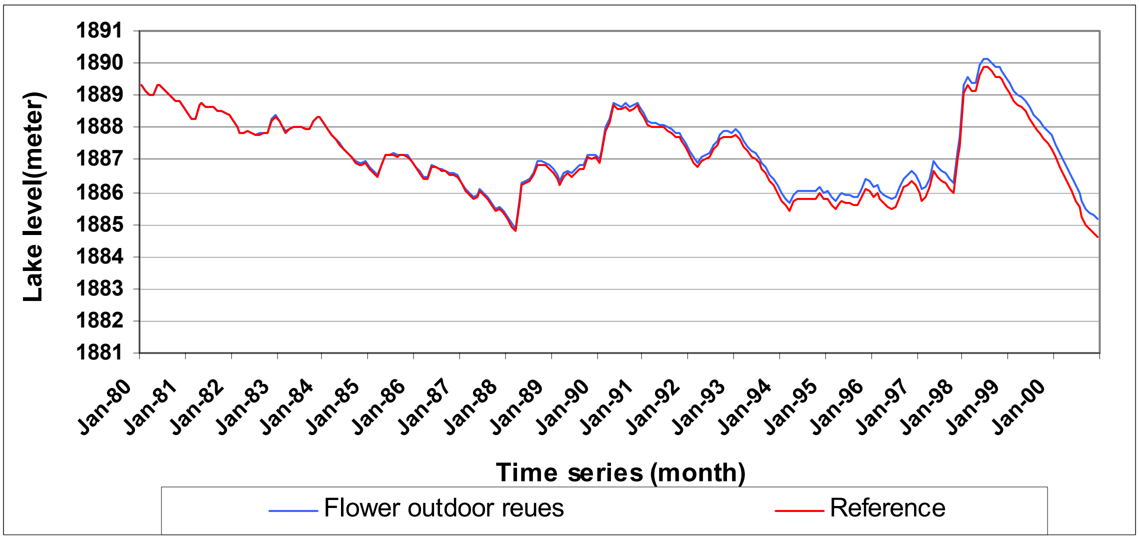


Figure 6-14: The change in the lake level by applying reuses water in outdoor flower farming

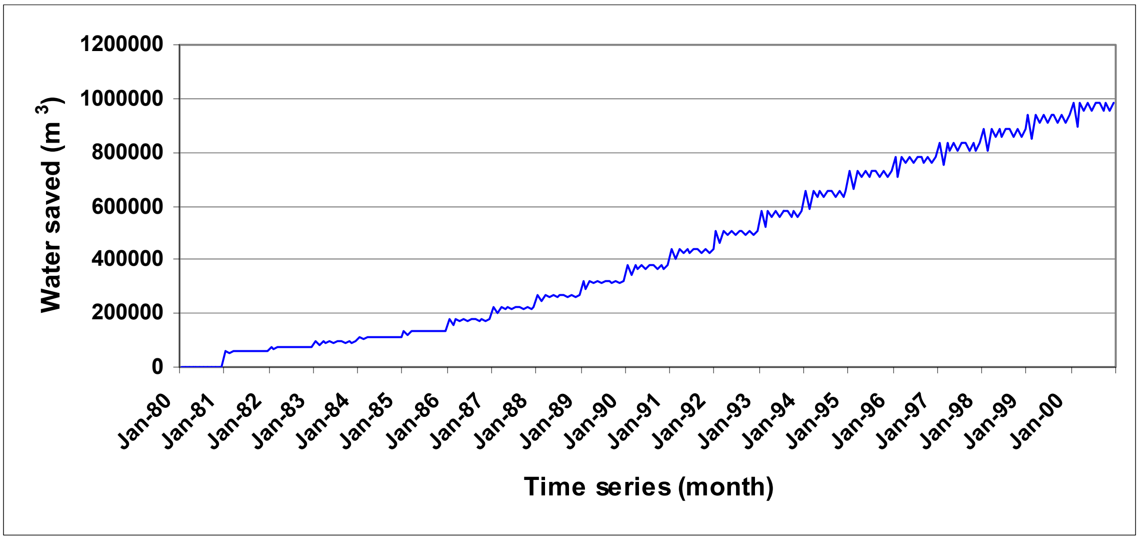


Figure 6-15: the amount of water that can be saved when applying the reuse of the water in outdoor flower farming

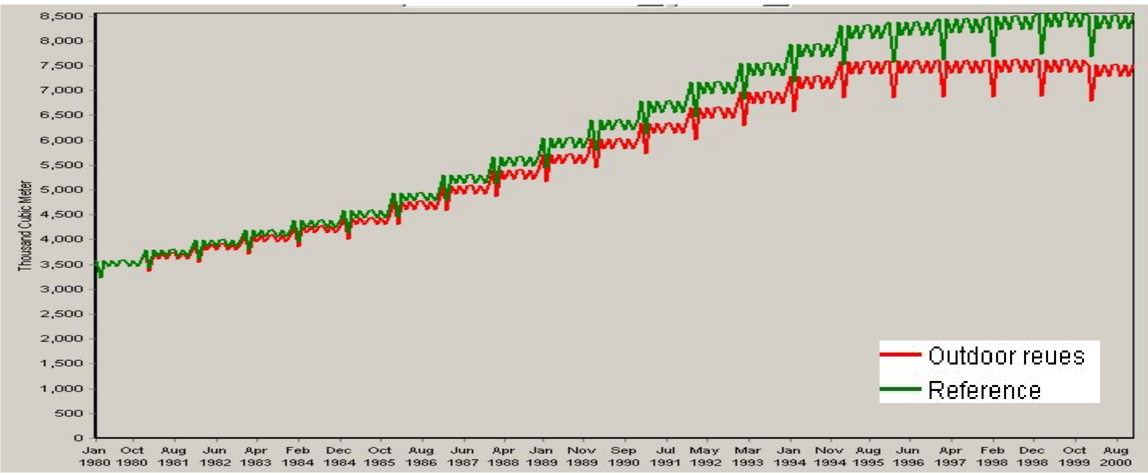


Figure 6-16: the difference in the water demand for out doors flower farming and the reference

6.3.3. Flower Indoor using the Hydroponics soils:

The cultivated area of indoor flowers is small in comparison to other types of cultivations Table 6-3. Assuming that all indoor flower farming will apply hydroponics soils, 50% of the irrigation water will be saved by reuse.

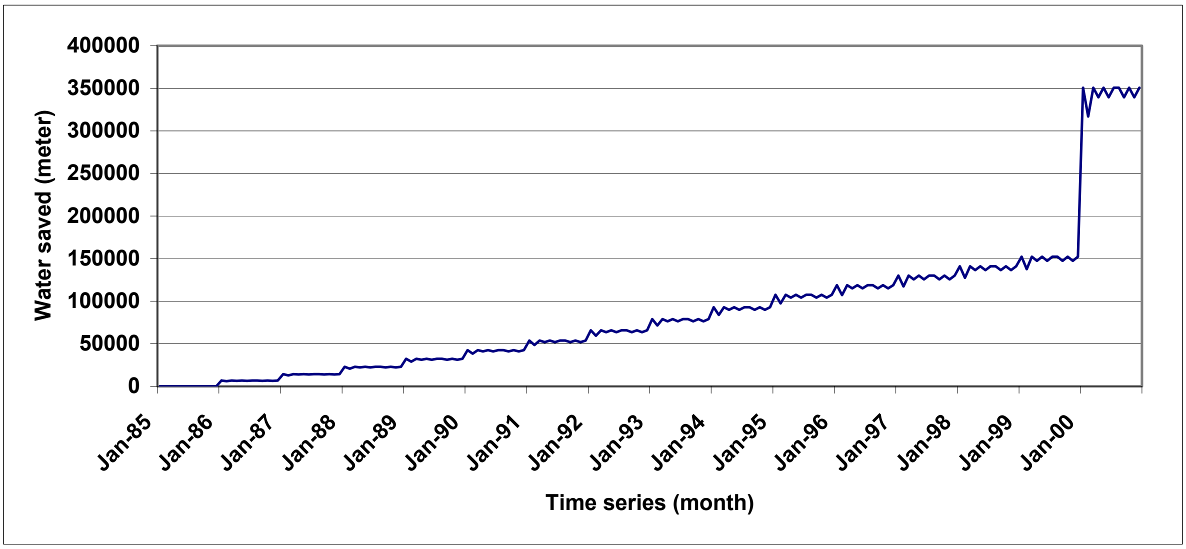


Figure 6-17: the amount of water that could be saved from flower indoor by applying the hydroponics soils

Figure 6-17 shows the amount of water that could be saved using the hydroponics soils for indoor flowers. This amount of water is calculated as the difference between the demands in the hydroponics scenario and the reference scenario. This indicates that water can be reduced on average by 92 thousand m^3/month.

Indoor flower farming began in 1986. This date was obtained by interpolation of the years (1985 – 1995). Due to this the graphs and analysis have been done in a shorter period than the simulation period.

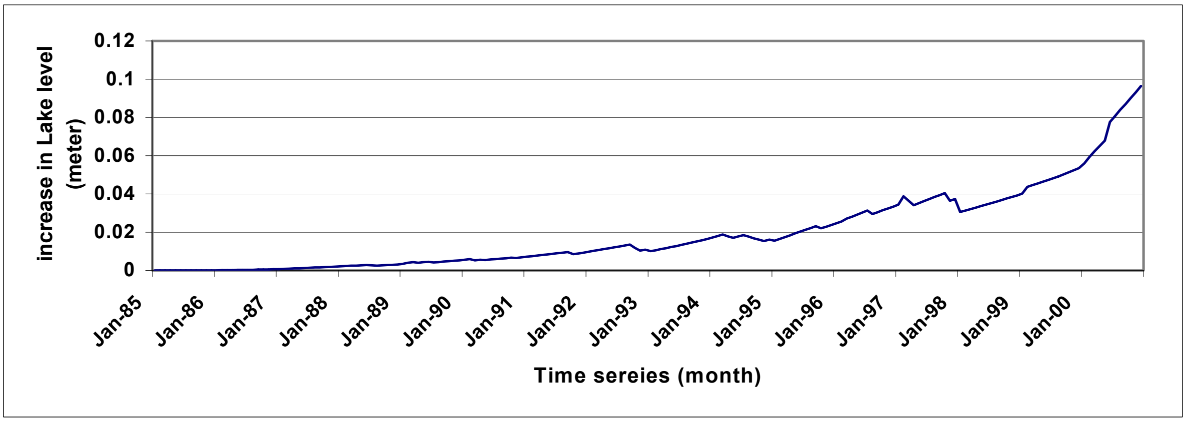


Figure 6-18: The increase in lake level

6.3.4. What will be the impact if all flower farms moved indoors?

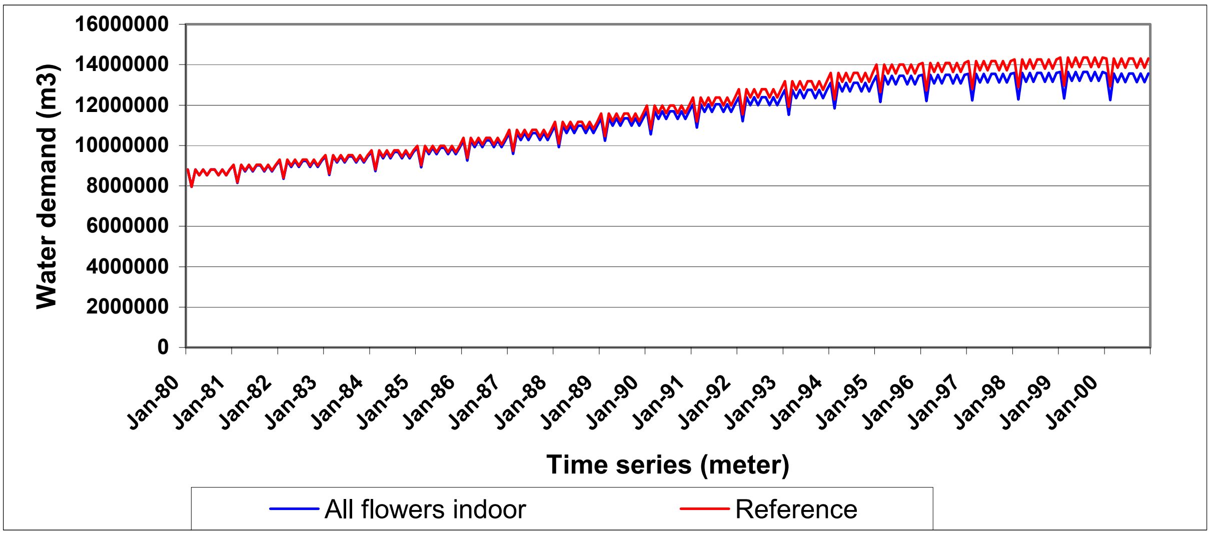


Figure 6-19: the difference in the water demand for indoor flower farming and the reference

If all the flower farms moved indoors, an average of 338 thousands m^3 / month and total of 8.72 Million m^3 water would have been saved in the year 2000.
The water consumed would be reduced to an average of 3.38 thousands m^3/ month, and for the year 2000 the total annual reduction in consumption would be 8.72 Million m^3.

.

6.4. Water Pricing Scenario

In Kenya, the new acting law 2002 governs the current water-pricing schema for irrigation and other purposes. It is intended to make farmers improve their irrigation practices and use a suitable way of irrigation to reduce the water consumption in the area.
In the study area the municipal councils are trying to make the towns pay for water delivery (21 Kenyan shilling =0.233 $), mainly to cover the delivery cost. Until now not every one is connected to the system.
Kenya law describes the installation of water metering for every abstraction point. However some farmer's install bypasses Figure 6-20

Figure 6-20: Pass by pipe (water metering)

In fact, water pricing in the irrigation schema is important because big farms are trying to apply the best irrigation practices to save water and to increase productivity of their farms thus to saving money spent on water.
Vegetable and fodder farms use poor irrigation technology. Therefore they will be forced by the water pricing and metering system to revaluate their irrigation practices.
With respect to the flower farming net profit, if water pricing in the agricultural sector is set even at 1% Table 6-6, it is sufficient to make the vegetable and fodder farmers reduce their cultivation or improve their irrigation system.

Table 6-6: the water price according to the net profit

		Water Price			
	Net profit	**1%**	**2%**	**3%**	
Flower	28824	288	576	865	**US $/ha.yr**
Fodder	1097	11	22	33	**US $/ha.yr**
Vegetable	9053	91	181	272	**US $/ha.yr**

According to Table 6-6, based on flower net profit, the calculation of the percentage portion of water price regarding for vegetable farming Table 6-7 is that 3 % of their net profit will encourage them to change their habits in their irrigation system.

For fodder and grass 26 %, of the water price would make the farmer reduce the type of cultivation.

The assumption for the scenario is that fodder and grass cultivation is reduced by 50%, this is meant to predict the lake level changes.

Table 6-7: percentage portion of water price regards flower net profit farming

	Net profit	% Of water price		
Flower	28824	1	2	3
Fodder	1097	26	53	79
Vegetable	9053	3	6	10

When the model is run the lake level increases by 0.5 meter / month on average, while in the year 2000 it reaches one meter per month on average.

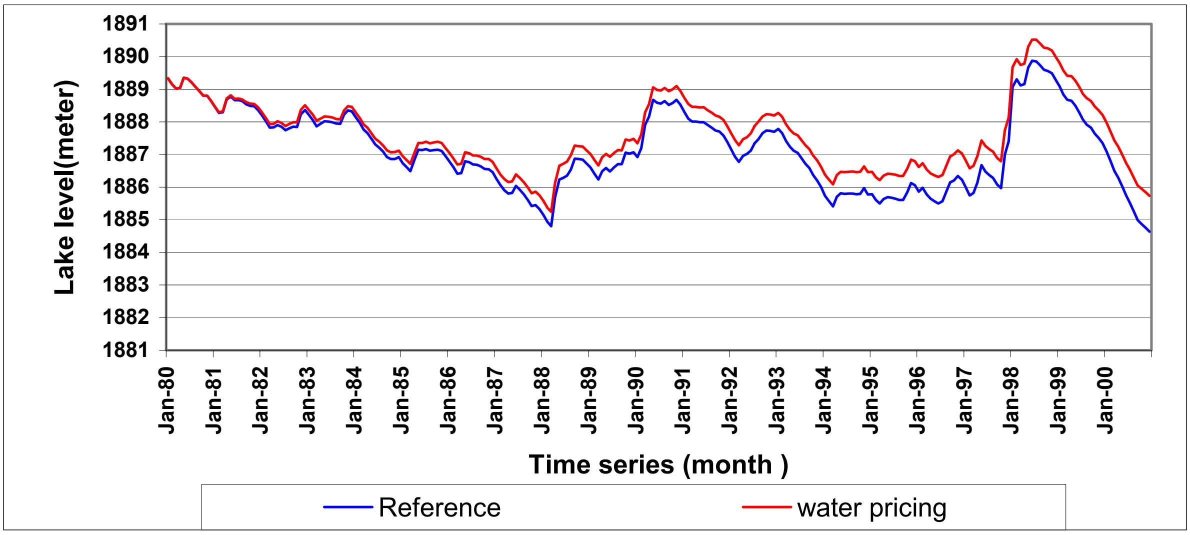


Figure 6-21: The change in the lake level when grass and fodder farming reduced the area to 50%

If the assumption in the water price scenario includes that the cultivated areas of fodder and grass are reduced, and the rest of the area including vegetable farming applied efficient irrigation, what will happen to the lake level?

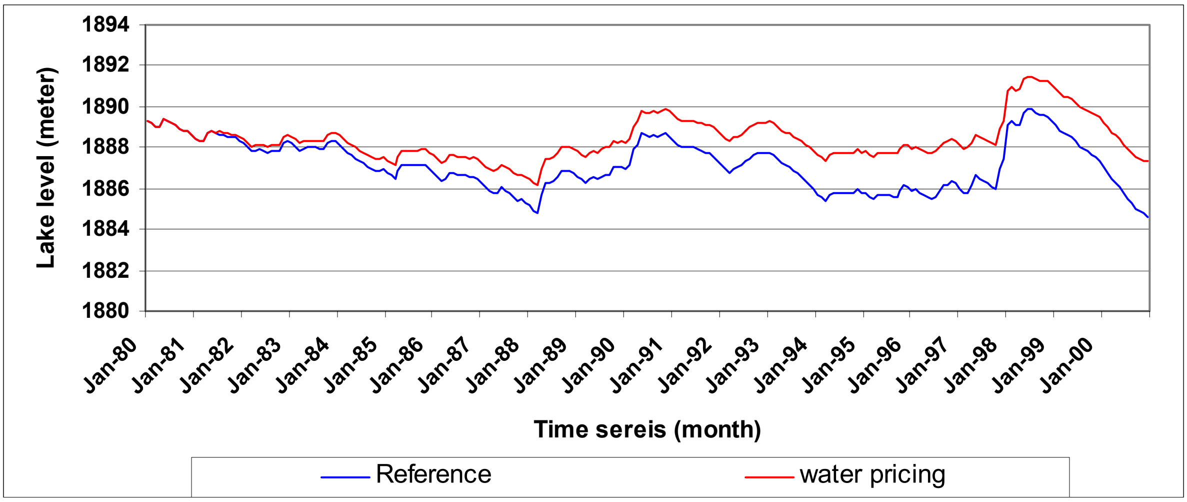


Figure 6-22: Lake Level difference according to reference and pricing water scenario (reducing the area of fodder and grass by 50% and apply effective irrigation for vegetable, fodder and grass)

Figure 6-22 shows increase in the lake level with average 1.2 meter / month while in the year 2000 the increase in lake level was 2.5 meter / month. This indicates a reduction in the demand by 3.5 million m^3 / months on average

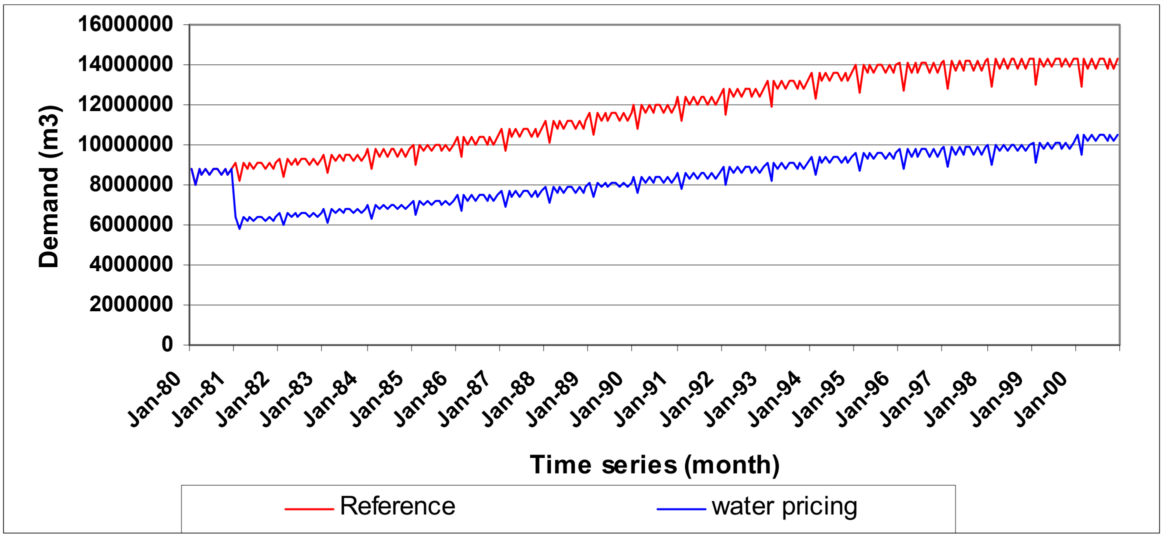


Figure 6-23the difference in the water demand for pricing water farming and reference scenario

6.5. Water Year Method and Climate Change Scenario

Based on the water year method definition (refer to chapter 4), the lake is level almost equal in its variation of the reference lake level; therefore we conclude that the definition of the years (Dry - Very Dry – Normal - Wet - Very Wet) was good Figure 6-19.
But in this case the coefficient needs to be redefined to calibrate the water year method to reach the reference lake level.

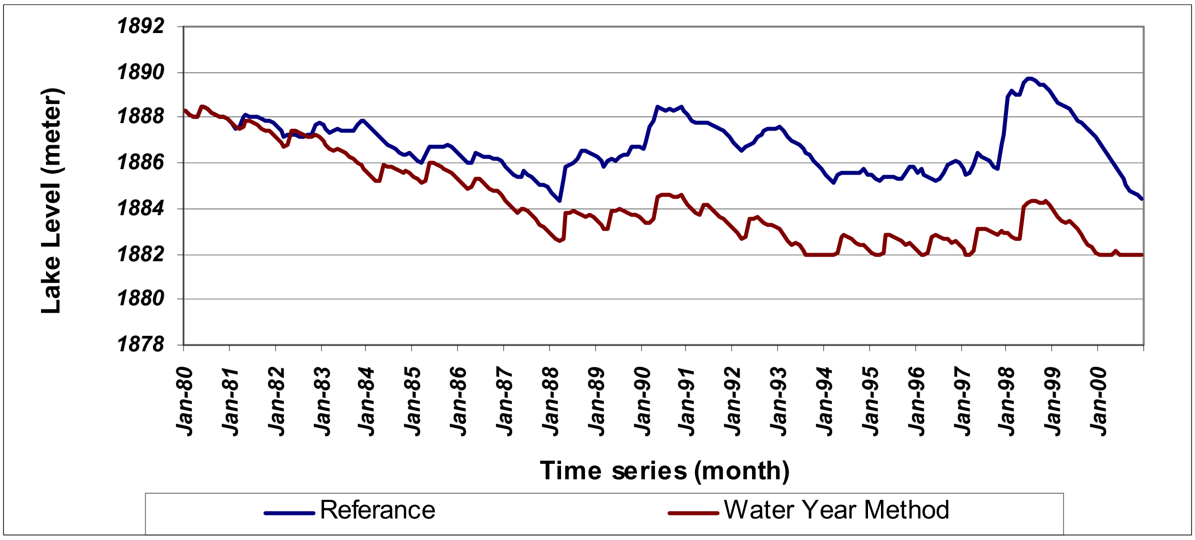


Figure 6-24: Lake level

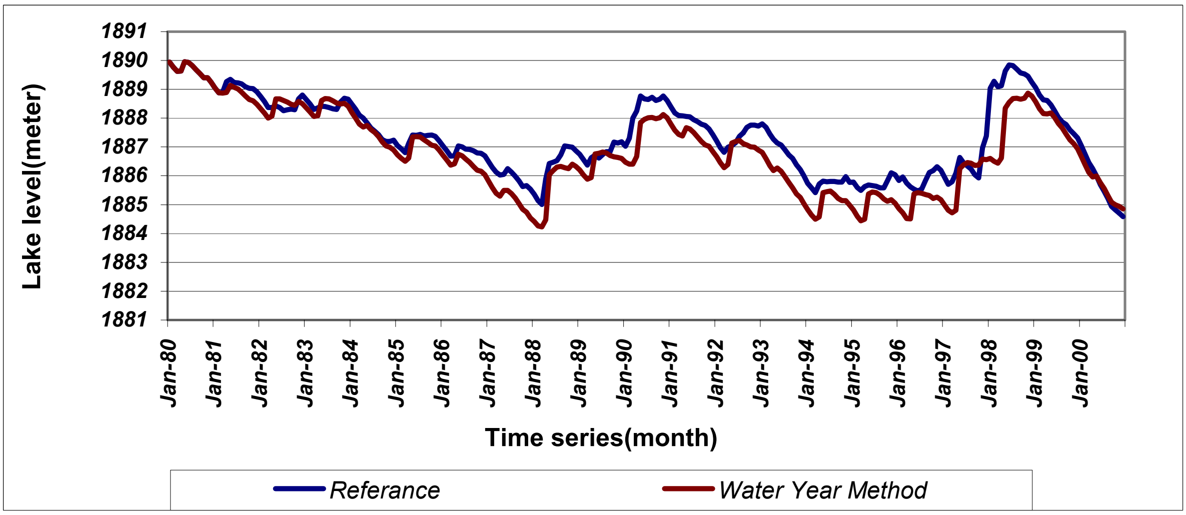


Figure 6-25: the lake level for water year method after calibration

When the sequence of water year types (Very Dry, Dry, Normal, Wet, Very Wet)
Table 4-2, and water year definition were specified, the suitable coefficients are given in Table 4-2:
Very Dry = 0.3131
Dry = 0.5594
Normal = 1
Wet = 1.6538
Very Wet = 2.2426
The water year definition specifies how much more or less water flows into the system in that year relative to a normal water year.
These fractions are derived from historical flows by statistical analysis. The years are first grouped into five sets (quintiles), and then their variation from the norm is computed to reach this coefficient. The years simply had to be sorted from lowest to highest for 1932-2000 for the average annual inflow. Finally the coefficient was computed as the average divided by the normal water year average.

By running the water year method model using the two elements (water year types and coefficient) the lake level, correlated to the reference lake level with correlation coefficient a (0.94), and the mean square error was 0.5 Figure 6-20.

The above water year method has been developed to study the effect on the lake level if the climates change in the future. . It does not give accurate results but can provide a prediction of the future according to the provided water year method.

The graph shows three cycles after the very dry years during 40's and 50's decade. They differ in their period, which varies from 6 to 14 years as shown in Figure 6-26 for the following scenario to explore the future, the assumption will be taking a water year method cycle from 1978 to 1990, which is the medium cycle.

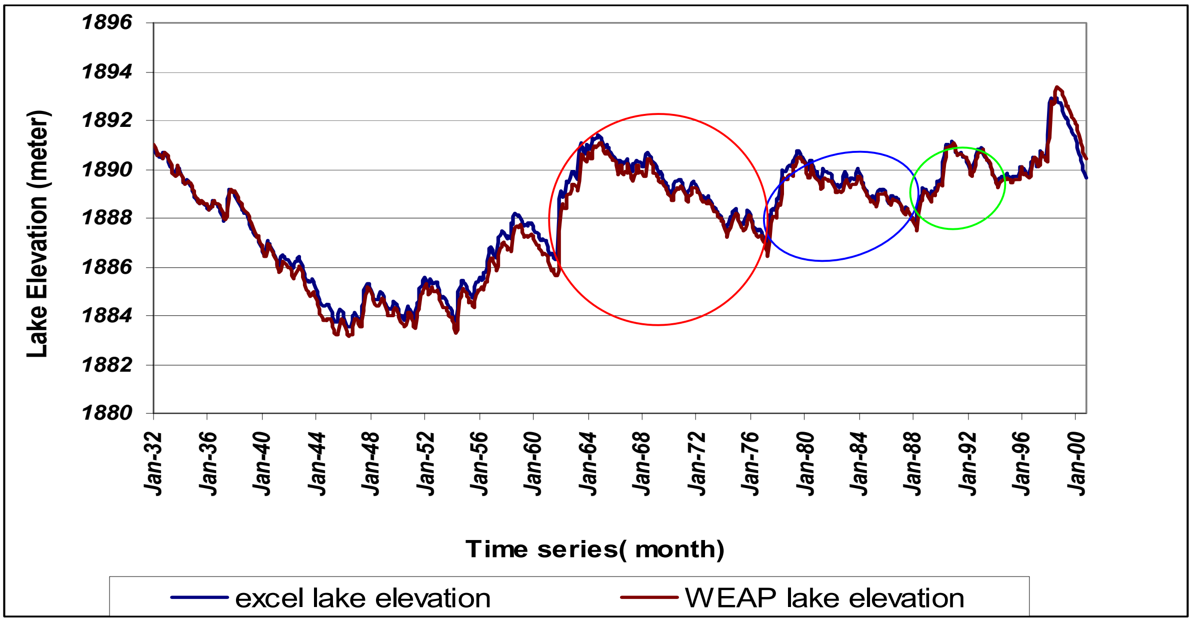


Figure 6-26: lake water level cycle identification

The Water Year Method (1980 –2013)

The water year method looks at the hydrological issues so the demand issues will be fixed. It helps to explore what could possibly happen in the future if the climate changes, and more dry years or wet years coming.

The water year method can indicate the future possibilities, taking into consideration that it is not as accurate as the real data.

This can be a strong tool in management and planning to explore the possible future impacts of climate change on the lake level.

The middle cycle of the water year method for the period from 1978 to 1990 was repeated for the next 13 years (2001 until 2013).

Table 6-8: Definition of the Water Year Method (1980-2013)

Year	Year Method
1980	Dry
1981	Dry
1982	Normal
1983	Normal
1984	V.Dry
1985	Normal
1986	Dry
1987	V.Dry
1988	Wet
1989	Normal
1990	Wet
1991	Dry
1992	Normal
1993	V.Dry
1994	Normal
1995	Normal
1996	Normal
1997	Wet
1998	V.Wet
1999	V.Dry
2000	V.Dry

Year	Year Method
2001	Wet
2002	Normal
2003	Dry
2004	Dry
2005	Normal
2006	Normal
2007	V.Dry
2008	Normal
2009	Dry
2010	V.Dry
2011	Wet
2012	Normal
2013	Wet

By modelling the demand in Table 6-9 and Table 6-10.using the following mathematical expressions:

1. Exponential forecasting is used to estimate future values based on a time series of historical data. The new values are predicted using linear regression to an exponential growth model (y = m + x^c)
   The expression equation is
   ExpForecast(Year1, Value1, Year2, Value2,... YearN, ValueN)

2. Another expression that has been used is growth rate that allows calculation of a value in any given year using the form
   GrowthFrom(GrowthRate, StartYear, StartValue)

Table 6-9: Modeling the demand in Naivasha catchment

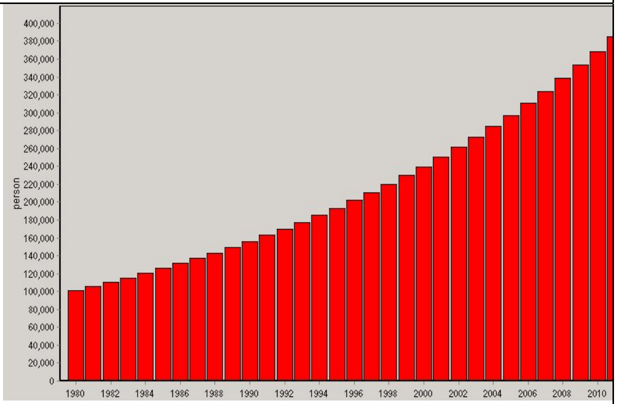
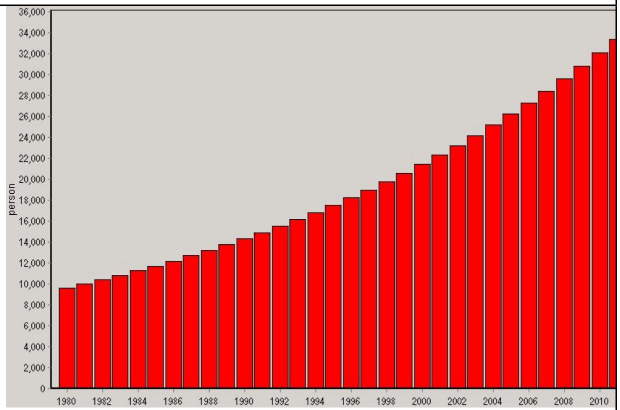
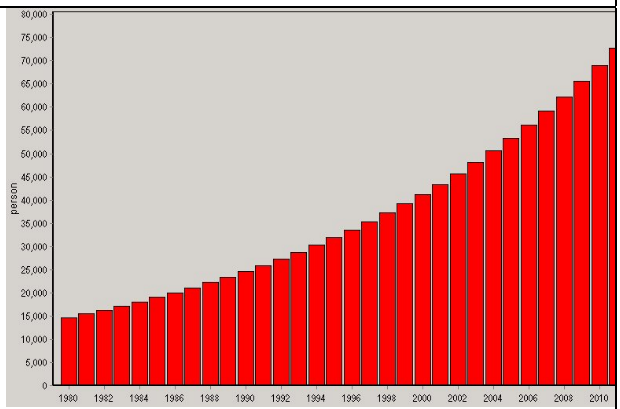
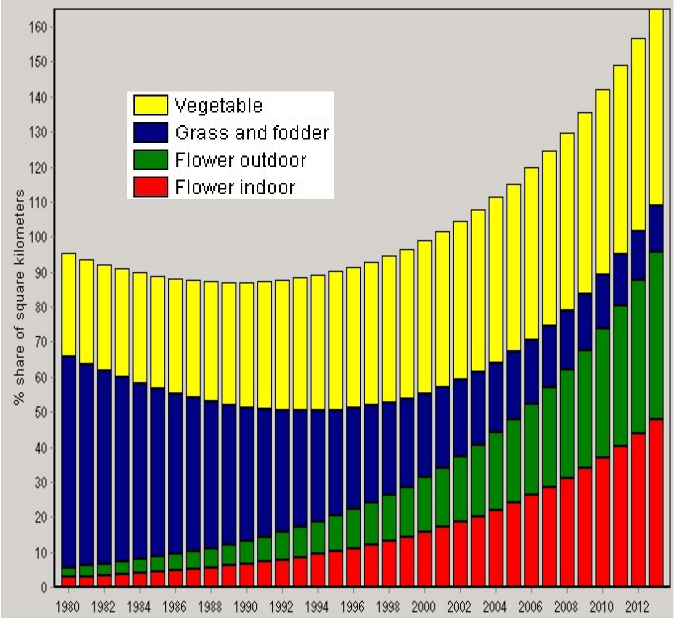
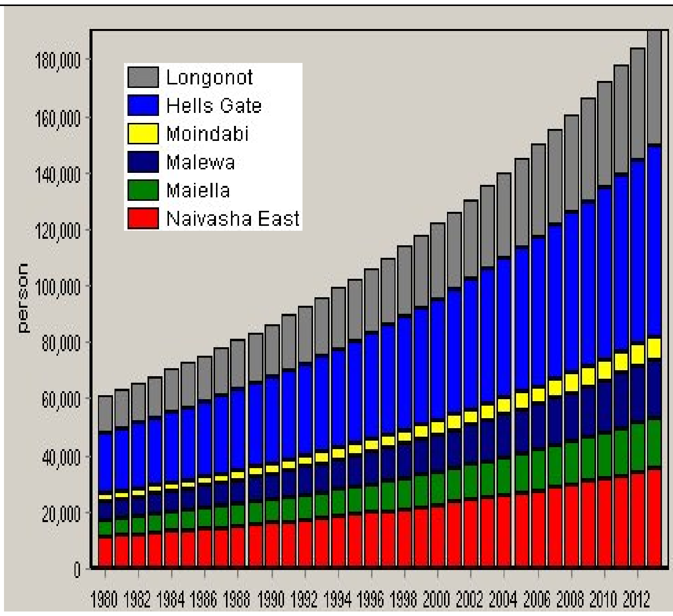
Demand	Modelled expression (1980-2013)	Graph of the annual activity
Nakuru Town	ExpForecast(1979, 92851, 1989,163927,1999, 219366)	
Gilgill Town	ExpForecast(1979,9103, 1989,14034,1999, 20362)	
Naivasha Town	ExpForecast(1979,11491, 1989,34519,1999, 32222)	

Table 6-10: Modeling the demand in Naivasha catchment

Demand	Modeled expression (1980-2013)	Graph of the annual activity
Flower indoor	ExpForecast(1985, 4.11,1999,16.36, 2000,17.13, 2003,16.89)	
Flower outdoor	ExpForecast(1985, 4.11,1999,16.36, 2000,17.13, 2003,16.89)	
Grass and fodder	ExpForecast(1976,81.854,1985, 35.39,1999,35.85, 2000,30.57, 2003,13.81)	
Vegetable	ExpFore-cast(1976,18.1459,1985, 60.5,1999,42.5, 2000,40.1, 2003,40.73)	
Naivasha East	GrowthFrom(3.5%, 1999, 21659)	
Maiella	GrowthFrom(3.5%, 1999, 11218)	
Malewa	GrowthFrom(3.5%, 1999, 12701)	
Moindabi	GrowthFrom(3.5%, 1999, 5028)	
Hells Gate	GrowthFrom(3.5%, 1999, 41492)	
Longonot	GrowthFrom(3.5%, 1999, 25691)	

WEAP software and the water year method allows modelling to study the future by using different expressions to project the demand
The demand was modelled with respect to the data in the reference scenario, which means that the demand for water consumption for each part is kept as it was in the reference scenario, and the model included the growth and the water year method.

Running the model using the demand growth as prepared in Table 6-9 and Table 6-10, and the water year method in Table 6-8, gives an idea about how the lake level will fluctuate. Figure 6-27 shows the modelled lake level for the study period of 1980 2013.

This indicates the predicted lake level if the demand keeps growing with the same levels of activity and water consumption. The lake level will continue the same fluctuation pattern without reaching a critical point of dryness even though the water year method cycles has two very dry years (2007-2010) and another three dry years (2003, 2004, 2009).

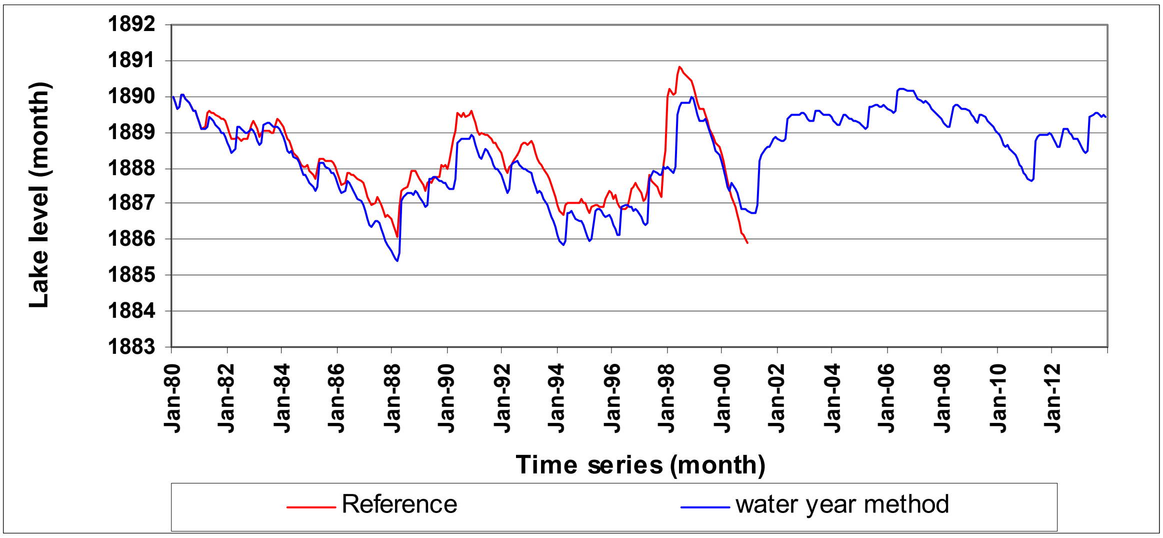


Figure 6-27: Reference and projected modeling lake level

Figure 6-28 shows that agriculture is still the main driving force in the area and the impact of the population growth is much less.

The water year method is a tool to explore and model the future to study different impacts in the area.

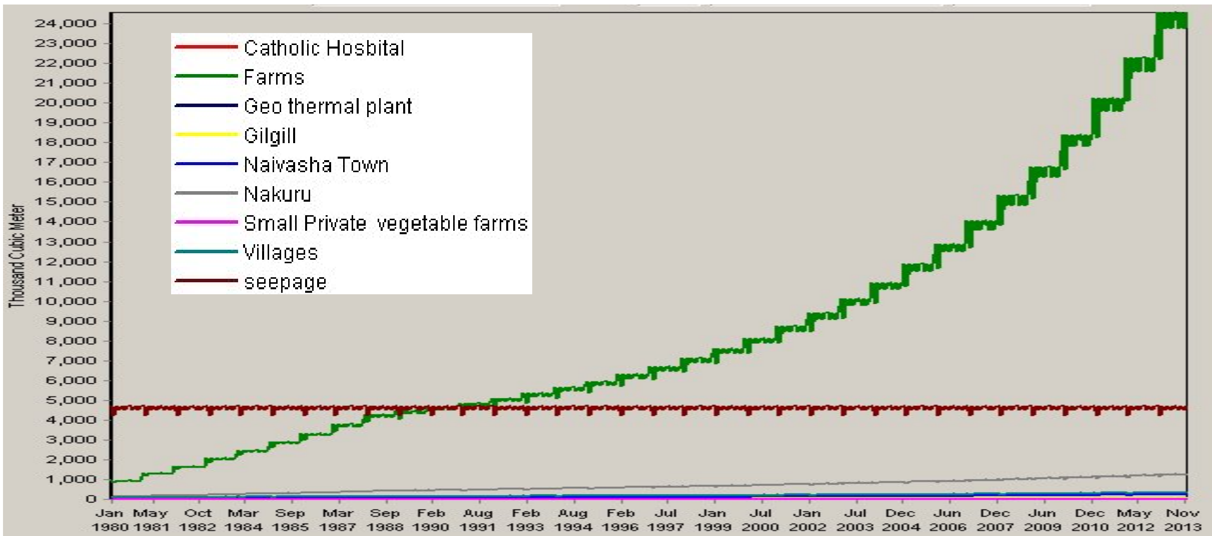


Figure 6-28: the demand in Naivasha catchment for the period (1980-2013)

7. Conclusions & Recommendations

7.1. Introduction

This chapter deals with the conclusions and recommendation. Section 7.2 explains the conclusions that derived from different scenarios evaluated in the report, and section 7.3 present the recommendation . Freshwater is a critical resource in the transition to a sustainable future. As it courses through the hydrological cycle, water is the life-blood of food production, commerce, human needs, and innumerable aquatic ecosystems. Water resources are finite, while water demands are increasing dramatically, driven by the relentless growth of human activity in recent decades.
Complex conflicts have emerged, between competing users, between stakeholders along common source of water, and between economic growth itself and environmental preservation.
Lake Naivasha is a vital source of fresh water for the regions economic activities that include farming, horticulture, geothermal power generation, fishing and tourism.
From the previous analysis the lake does not suffer from water shortage but a severe miss management through out the whole area.
Since different scenarios have been considered, conclusions are presented separately for each scenario.

7.2. Conclusions

Integrated Water Resource Management goes beyond the traditional description of the resource and integrating or balancing demand. The concept embodies integration across sectors, integration of use, integration of demand, integration with the environment as well as integration with the people. Modelling demand and supply help to observe and understand a wide long-term vision of the problem. With this aspect the area, which needed to be carried out, can be identified and helped in solving the conflict of interest between the stakeholders.
To build a Demand /Supply model the more data collected, the closer the model will be to the circumstance of the catchment and the more effectively it will identify problems.

<u>The Reference Scenario</u>

The main driving force in the Lake Naivasha basin and the surrounding is the agricultural production with uncoordinated development in the area.
The activities in the upper catchments do not affect the inflow to the lake or the lake level due to the fact that cultivation depends on the rain and the catholic hospital does not use a significant amount of water.
Most of the water is used within the agricultural sector for irrigation and a minor quantity by livestock farming.

Flower farming which occupy less than 30% of the area, 34 million cubic meter/year (2000), and has an annual return net profit of (45.1 **Million US $/yr**) manages adequately the water resources, in contrast to the vegetable, fodder and grass farming which occupies 70% of the area, 67 million cubic meter/year (2000) with a net profit of (15.8 **Million US $/yr**).

Effective Irrigation Scenario

According to the effective applied irrigation that has been calculated by Ahammad, (2001) the following were concluded:
Grass and fodder farming covers more than 70 % of the cultivated area and uses low technology irrigation methods, this is three times higher than that needed by the crop. Vegetable farming also use about 48 % of water more than is required.
On the other hand, indoor and outdoor flower farming, which covers less than 30 % of the cultivated area, uses high technology irrigation methods. This reduces the over irrigation caused by outdoor flower farming.

High Technology Scenario

Both mechanisms, saving irrigation water and raising water productivity are applied in the flower-farming sector.
Flower farming managed to double their productivity, for the same cultivated area and amount of water, by using the Hydroponics soils.
Outdoor flower farming can reduce its water abstraction by building reservoirs or using Hydroponics soils to reuse excess water, and by applying the effective applied irrigation method.

Water Pricing Scenario

The new acting water law is important and can play a good role in improving the water management in the area, by applying water metering and water pricing. Water metering is assumed to increase population awareness of water use.
The installation of water meters frequently is in line with public concerns for better use of water resources and the request for a better management of the water environment. Reliable water metering is a stringent requirement for the implementation of effective water charges.
Water Pricing is an important issue and it should be implemented according to the benefit or the economic return for which it is used.
Usually applying such ideas will not be embraced by every one, never the less this should be carried out to avoid vegetable, grass and fodder farmers from using water irrationally.

Water Year Method scenario

WEAP, Water Evaluation and Planning System, is an effective tool for water planning. It provides a comprehensive, flexible and user-friendly framework for water resource assessment.
WEAP also uses the water year method, which helps to explore the future under several user-defined assumptions like climate change, the amount of demand consumption and others.
Using the water year method to model and predict the future lake level shows that if the demand keeps growing with the same activity and water consumptions, the lake level will continue the same fluctuation pattern without reaching a critical point of dryness.

7.3. Recommendations

Based on the results and analysis of different parameters that can affect the Lake level and the catchment the following points are recommended:

- There is need to develop networks to share information and experiences on water resources management Information Systems (collect, use, and exchange information and experiences on water resources)
- There is a need to improve the management of existing irrigation systems especially in the sector of vegetable, fodder and grass farming, and this can be done through exchanging the experience with other farmers in the area.
- To develop a new cadre of professionals with an integrated vision of water resources planning and management who, in addition to their specific training, will broaden their post-graduate level knowledge of social, environmental, economic and legal issues in order to acquire the appropriate training to implement integrated management
- To extend the water pricing to include activity other than non-domestic use as industries and agricultural.
- Include in the modelling software the connection between the ground water and lake Naivasha, an important part of the catchment.
- Explore other factors, such as the pollution generated by agriculture, that may strengthen the models and thus planning and management capacities.

ANNEX

ANNEX- 1

Irrigation Requirement (Ahammad, 2001)

This sheet has been prepared to estimate supplementary irrigation water requirement and currently applied effective irrigation in m3/ha.year for the enlisted main crops Flower, Vegetables, Wheat, Fodder Crops, Grass and Macadamia Nuts.

Important Parameters

1] Required number of days for irrigation per year

The numbers of days have been estimated comparing field data and out lines given in FAO 33.

2] Crops per year

Estimated on the basis of field information.

3] Etact – Actual Evapotranspiration

The actual evapo-transpirations for the crops have been calculated for the study area [Mekonnen 1999]. The actual evapotranspiration for the year for each crop is estimated by multiplying Etact in mm/day by the required number of days for irrigation per year.

Etact (mm/year) = Etact (mm/day) * Irr.Req. (Days/year)

Etact (m3/ha.yr) = Etact (mm/year) * 10

Rainfall (m3/ha.yr) = Regional Rainfall (mm) * 10

The value “Regional rainfall” has been entered directly from worksheet “Regional constants”.

4] Assumed Effective Rainfall (m3/ha.yr)

= (Irrigation Reqd (days/yr.)/ 365) * Rainfall (m3/ha.yr)

To get estimate of supplementary irrigation requirement, it has been assumed that the crop concerned will get rain water of yearly rainfall proportionate to the number of required irrigation days to the number of days in a year.

5] Irrigation Water Requirement (m3/ha.yr)

= Etact (m3/ha.yr) – Assumed Effective Rainfall (m3/ha.yr)

The assumed effective rainfall has been deducted from the actual evapotranspiration to estimate the supplementary irrigation water requirement.

6] **Applied Irrigation (mm/day) ,** The figures are based on field information.

7] Applied Irrigation (mm/year)

= Applied Irr (mm/day) * Irrigation Required (days/yr.)

8] Applied Irrigation (m3/ha.yr)

= Applied Irrigation (mm/year) * 10

9] Effective Applied Irrigation (m3/ha.yr)

= Applied Irrigation (m3/ha.yr) – Assumed Effective Rainfall (m3/ha.yr)

To get the effective application of irrigation water the assumed effective rainfall has been subtracted from the current rate of application.

ANNEX- 2

Other Demands not included in the model

Tourist

The diversity of wildlife contributes to the area of Lake Naivasha and the neighbouring to make it one of the most attractive areas for tourist. Tourism related activities, such as boating, water skiing, sport fishing, game viewing, birds watching and game drive circuits such as the famous Hell's Gate.

Thus hotels and travel resorts are major business in the town. The yearly return from tourism is estimated as US $ 6.58 million (Saleh, 1999)

Other Industries:

	Types of Business	1999/2000	2000/2001
1	Wholesale	40	150
2	Catering	261	191
3	Motor Repair	21	39
4	Shops, Kiosks, Hawkers	849	1108
5	Manufacturing	9	52
6	Distribution	6	11
7	Commercial Farming	12	68
8	Fishing	2	6
9	Industries	24	25
10	Miscellaneous	339	50

Source: Naivasha Municipal Council, Town Treasurer Department.

Social Institutions

Pre Primary school: there are 37 pre-primary schools. The total children enrolled are currently 5,394.

Primary schools: there are 47 primary schools within the Municipality. Currently the number of students is 19,792. Some schools are understaffed, especially in the rural area.

Secondary schools: there are 8 schools in the Municipality. The current Population is 2687 student against 152 teachers; the ratio is 1:18.

Vocational Training: There are 3 training centres in the Municipality. They include National Youth Service(NYS) , Diary Training Institute (DTI), and the Kenya Wildlife Service Training Institute (KWS).

(Waveren et al., 1999)

ANNEX- 3

Economic farming (Ahammad, 2001)

Tables related to the net profit that has been calculated by Ahammad Sayeed research that held in 2001.

	Net Profit	
Flower	28824.06936	US $/ha.yr
Vegetable	9053.780607	US $/ha.yr
Fodder	1097.43639	US $/ha.yr
Grass	219.2212915	US $/ha.yr
Wheat	612.5247616	US $/ha.yr

		Production	Total	Return	Gross
Crops	**Area**	**Cost**	**Investment**		**Return**
	(ha)	**US $/ha.yr**	**Million US $/yr**	**US $/ha.yr**	**Million US $/yr**
Flower Open	952.1855				
Flower GH	613.62				
Flower Overall	1565.8055	43953.73064	68822993	72777.8	113955879.5
Vegetables	1623.0935	2065.891525	3353135	11119.67213	18048267.56
Fodder	756.399	773.614182	585161	1871.050572	1415260.782
Wheat	164.306	371.1014679	60974.2	983.6262295	161615.6913
Grass	561.28	296.0287085	166155	515.25	289199.52
Macadamia Nuts	360.7	204.2118698	73659.22	6128	2210369.6
Total Agriculture	5031.584	14520.69124	73062078	27045.27892	136080592.7

	Gross	Total	Net
	Return	**Investment**	**Return**
	M. US $/yr	**M. US $/yr**	**M. US $/yr**
Flowers	113.9558795	68.82299318	45.13288634
Vegetables	18.04826756	3.35	14.69826756
Fodder	1.42	0.59	0.83
Wheat	0.161615691	0.06	0.101615691
Grass	0.28919952	0.166154993	0.123044527
Macadamia Nuts	2.2103696	0.073659221	2.136710379
Livestock	6.178839344	5.25	0.928839344
Total Net return			63.95136384

ANNEX- 4

The water Year method table includes the Year method depending on the Average annual inflow.

Average (annual inflow)		
Year	Average Annual inflow (m3)	Year Method
1932	15948539.9	Dry
1933	14790781.67	Dry
1934	10036859.67	V.Dry
1935	12098201.46	Dry
1936	17179997.02	dry
1937	26753488.87	Normal
1938	8312873.239	V.Dry
1939	5499630.669	V.Dry
1940	12561342.17	Dry
1941	15096198.91	Dry
1942	15085094.27	Dry
1943	8074761.287	V.Dry
1944	8205639.302	V.Dry
1945	12010937.67	Dry
1946	13977516.1	Dry
1947	23692537.49	Normal
1948	12502925.33	Dry
1949	12214909.51	Dry
1950	12636643.72	Dry
1951	25560376.04	Normal
1952	12602761.17	Dry
1953	6198856.699	V.Dry
1954	23396738.7	Normal
1955	15336393.96	Dry
1956	27547406.81	Normal
1957	21659243.42	Dry
1958	27129838.46	Normal
1959	12951737.52	Dry
1960	9643122.731	V.Dry
1961	35421872.17	Wet
1962	34843945.89	Wet
1963	37275509.72	Wet
1964	26619327.79	Normal
1965	11806871.53	Dry

Average (annual inflow)		
Year	**Average Annual inflow (m3)**	**Year Method**
1977	35397161.72	Wet
1978	36738108.38	Wet
1979	23517288.32	Normal
1980	13021168.92	Dry
1981	19338638.38	Dry
1982	21467566.93	Normal
1983	22718385.65	Normal
1984	8290409.261	V.Dry
1985	23682507.08	Normal
1986	16559255.07	Dry
1987	10451248.39	V.Dry
1988	35803128.36	Wet
1989	24322410.22	Normal
1990	42202751.1	Wet
1991	12973301.49	Dry
1992	26835622.54	Normal
1993	8315951.632	V.Dry
1994	22001784.78	Normal
1995	25550864.52	Normal
1996	24608898.15	Normal
1997	38105273.67	Wet
1998	52535378.15	V.Wet
1999	5410273.452	V.Dry
2000	1365986.372	V.Dry

References

1. Ahammad, S. (2001). *Economy versus Environment: how a System with RS & GIS can Assist in Decision for water resource managemnt.* International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherland.

2. Becht, R., & Harper, D. (2002). Towards an understanding of human impact upon the hydrology of Lake Naivasha, Kenya. *Hydrobiologia., 488*, 1-11.

3. Boateng, R. O. (2001). *Assesment of the use of the Ground water for irrigation in the southern part of lake Naivasha , kenya.* International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede.

4. Consulting, D. I. (2003). *Preliminary Study on Sewerage and Drainage System of Naivasha Town in Kenya*. Naivasha: JICA, Japan International Cooperation Agency

5. Ministry of Local Goverment.

6. Database, R. S. (1995). *A Directory of Wetlands of International Importance*. Ramsar Information Sheet. Retrieved 28 oct 2003, 2003, from the World Wide Web: http://www.wetlands.org/RDB/Ramsar_Dir/Kenya/ke002D02.htm

7. Environmental, L. (2000). *Designing Effective and Efficient Irrigation systems* (MAF Policy Technical Paper 00/09). Bureau: MAF Information Bureau.

8. Gitonga, M. m. S. (April, 1999). *Study of Long-term Waterbalance of Lake Naivasha, Kenya.*, INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES, Enschede, The Netherland.

9. Institute-Boston, S. E. (2003). Water Evaluation and Planning System. Boston: http://www.weap21.org/index.asp.

10. Jesinghaus, J. (1999). *Indicators for Decision-Making*: European Commission, JRC/ISIS/MIA, TP 361, I-21020 Ispra (VA).

11. JICA. (2003). *Preparatory study on the water & swearage System of Naivasha Town in Kenya.*: Japan International Cooperation Agency.

12. Jonker, L. (2002). Integrated water resources management: theory, practice, cases. *Physics and Chemistry of the Earth, Parts A/B/C, 27*(11-22), 719-720.

13. kenyaGoverment. (2002). *Kenya Gazette Supplement Acts*. Nairobi: Republic of Kenya.

14. LakeNet. (2003, 07 May 2003). *Naivasha*. Retrieved 23-July, 2003, from the World Wide Web: http://www.worldlakes.org/initiative/naivasha_profile.htm

15. Nations, U. (2000, 18 September 2000). *Resolution adopted by the General Assembly*

16. *United Nations Millennium Declaration*. United Nations. Retrieved, from the World Wide Web: http://www.un.org/millennium/declaration/ares552e.pdf

17. Nations, U. (September 2002, 26 August-4 September 2002). *Report of the World Summit onSustainable development* [Technical report]. United Nations. Retrieved, from the World Wide Web: http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter18.htm

18. Ramsar Convention Bureau. (2000, 26 April 2002). *The Annotated Ramsar List of Wetlands of International Importance,KENYA* [web page]. Ramsar Convention Bureau. Retrieved 20-July, 2003, from the World Wide Web: http://www.ramsar.org/profiles_kenya.htm

19. Salah, A. (1999). *Productive and sustainable use of water.* International Institute for Aero-space Survey and Earth Sciences (ITC), Enschede.

20. Sharifi, M. A. (2003, 11 October 2003). *Integrated Planning and Decision Support Systems for Sustainable; Water Resources Management: Concepts, Potentials and Limitations.* Paper presented at the Seminar on Water Resources Management for Sustainable Agricultural Productivity, Lahore, Pakistan.

21. Thomas, J.-S., & Durham, B. (2003). Integrated Water Resource Management: looking at the whole picture*1. *Desalination, 156*(1-3), 21-28.

22. Waveren, I. R. H. v., Ir.S.Groot, drs.H.scholten, Geer, d. i. F. C. v., dr.J.H.M.Wosten, ir.R.D.Kozen, & ir.J.J.Noort. (1999). *Good modeling practice handbook.*