Water availability assessment using multi-objective decision support systems (MODSS)

A study around Lake Naivasha, Rift Valley Province, Kenya

by

Luisa Delfa Huaccho Huatuco
(Peru)

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In partial fulfilment of the requirements for the degree of Master of Science in Environmental Systems Analysis and Monitoring (ESM.2w) at the International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands

Board of Examiners:

Prof. Dr. A. M. J. Meijerink (Head of Water Resources Survey Division)
Ir. H. De Brouwer (first supervisor)
Dr. M. A. Sharifi (second supervisor)
Dr. Ir. C. Mannaerts (DoS ESM course)
Ir. C. de Wijs (external examiner)

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Abstract

This research deals with finding the optimal water use for irrigation in a multi-objective environment. In an agricultural context, water planning deals with the selection of suitable ways of water use that satisfy various objectives, according to certain constraints and resources.

Water supply and demand becomes a multi-objective problem, because it has to satisfy the requirements for each crop and comply with the biophysical suitability of the lake management priorities.

A formal technique like Linear Programming is used here to handle this specific multi-objective problem and to generate different alternative scenarios. The model optimises objective functions according to different approaches: economic, social and environmental.

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Summary

Concern of the study

The core of the present study is to develop scenarios regarding water use in irrigation. In the process, multiple objectives are considered on one side and on the other side the bio-physical and socio-economic conditions of the present resources.

Methodology

The use of linear programming for water use analysis is based on its capability to optimise objectives. The present study develops three approaches: economic, social and environmental in order to have an integral view of the problem and its possible solutions.

From the economic perspective the objective function considers to maximise the gross income, whereas the social point of view takes into account the maximisation of employment and for the third objective the minimisation of water use is regarded.

All approaches take into consideration irrigated agriculture for the following crops: maize, wheat, flowers, alfalfa, grass and vegetables regarding domestic and livestock needs.

The decision variable for the model is the number of ha of land per crop. The technical coefficients are the known numbers of the variable which represent benefits or consequences of the variable.

The scenarios

Three different models were developed per objective function, one for each type of year (dry, average or wet), regarding the change in prices and water use.

In the first scenario the purpose was to maximise the gross income from crop production, this scenario was chosen to represent the economic perspective of the problem.

In the second scenario the social perspective was taken into account by maximising employment generation from agricultural activities.

In the third scenario the aim was to minimise the water use due to the relation between the lake level and its water quality, thus this scenario represents the environmental perspective.

Finally, sensitivity analysis was performed in order to see what would be the effect on the results when changes are introduced to the right hand side values and to show the stability of the suggestions from each scenario.

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Chapter I : Introduction

1.1. Background.

Water scarcity is a growing problem in many countries especially in dry climates with rapidly growing populations (Postel, 1993). Adequate available surface water supplies per capita are declining as pollution increases and groundwater is withdrawn faster than it can be replenished. The World Watch Institute (Postel, 1993) has developed quantitative measures of "water stressed" (1000-2000 m^3/person year) and "water scarce" (<1000 m^3/person year). In those countries that are water scarce, a lack of water is considered to be a severe constraint on food production, economic development and protection of natural systems.

Twenty-six countries with a combined population of 230 million people fell into the water scarce category in 1993 and more are being added every year. By the end of the nineties it is expected that over 300 million people will live in water scarce countries. Environmental planning should incorporate water conservation features into all projects and plans. Water will become more important in the future as it becomes less available and conservation has other benefits that make the effort worthwhile. Water conservation will make more water available for higher priority items like food production and manufacturing, as would ordinarily be available and perhaps avoid unnecessary competition for scarce water.

In the past few years with the evolution in information and communication technology, new vistas have unfolded that hydrologic models have not taken full advantage of modern tools such as: Remote Sensing (RS), Geographic Information Systems (GIS), Risk and Reliability Analysis, etc.

RS is a powerful technology for data acquisition over extensive and even otherwise inaccessible areas. GIS technology can be used for data management: retrieval, manipulation, organization, etc. Risk and reliability analysis provides information on the accuracy of model results that the user wants to know about.

1.2. Problem recognition.

In general, natural resources in developing countries have not been used in harmony with the economical activities. It is necessary to take into account the equilibrium between the ecosystem and the productive sector. When managing natural resources most of the decision problems have a conflictive nature and various objectives are involved in the final decision.

Water supply and demand becomes a multi-objective problem, because it has to satisfy the requirements for each user (irrigation, grazing, domestic, tourism, industry and ecological preservance) and comply with the biophysical suitability of the lake management priorities.

This environmental study deals with the selection of suitable ways of using water for irrigated crops that satisfies various objectives according to certain constraints and resources.

1.3. Research objectives.

- To define the study area's environmental system and analyze its underlying ecological biophysical, social and economic structures and interactions in terms of water resources supply and demand.
- To apply multi-objective decision support systems necessary to present different scenarios to the decision makers of a sub-system: agricultural water use.
- To use Geographic Information Systems (GIS), aerospace survey techniques and modeling tools for environment data acquisition, analysis and management of the study area.
- To determine the objectives and constraints in order to define and evaluate the environmental conditions of Lake Naivasha natural resources.

1.4. Research questions.

- What is the major problem related to conflictive use of water in the study area?
- Who is the decision group related to water use and what are its main objectives?
- What is the role of the different crops in the water balance of Lake Naivasha?
- What is the optimal use of water?
- What are the possible alternatives to be generated?

1.5. Research methods.

In order to assess the water availability, the users' demand, the optimal use and the possible alternatives, the following tasks had to be completed:

Task 1: Problem recognition.

Methodology

- To revise previous works related with the subject of interest.
- To identify and describe the problem.

Task 2: To make an inventory of the supply, demand and restrictions.

Methodology

- Water supply:
  - To determine the hydrological regime of the study area through time series analysis for dry, average and wet years.
  - To analyze existing bore-hole/well data in terms of yield.

- Water demand:
  - Spatial location of irrigated areas through remote sensing image interpretation.
  - To obtain statistical data about: population, irrigation, livestock, etc. in terms of water requirement:
    - Scale: monthly, annually, etc.
    - Quantity.
- Restrictions
  - Regulations, law, competent authorities.
  - Protected areas.
  - Socio-economic situation.

Task 3: To perform fieldwork

Methodology

- To check the quantity of agricultural water use.
- To interview the different users of Lake Naivasha and decision makers:

  - To identify the mission and objectives.
- To adjust preliminary results (update the data).

Task 4: To create different potential scenarios

Methodology

- To implement the assessment using MODSS software.
  - Focusing mainly into minimum and maximum situations.
  - Performing sensitivity analysis.

Task 5: To derive strategies and recommendations.

Methodology

- To synthesize the experiences gained from this research project.
- To delineate some recommendations.

The methodology is described graphically in **Figure I-1.**

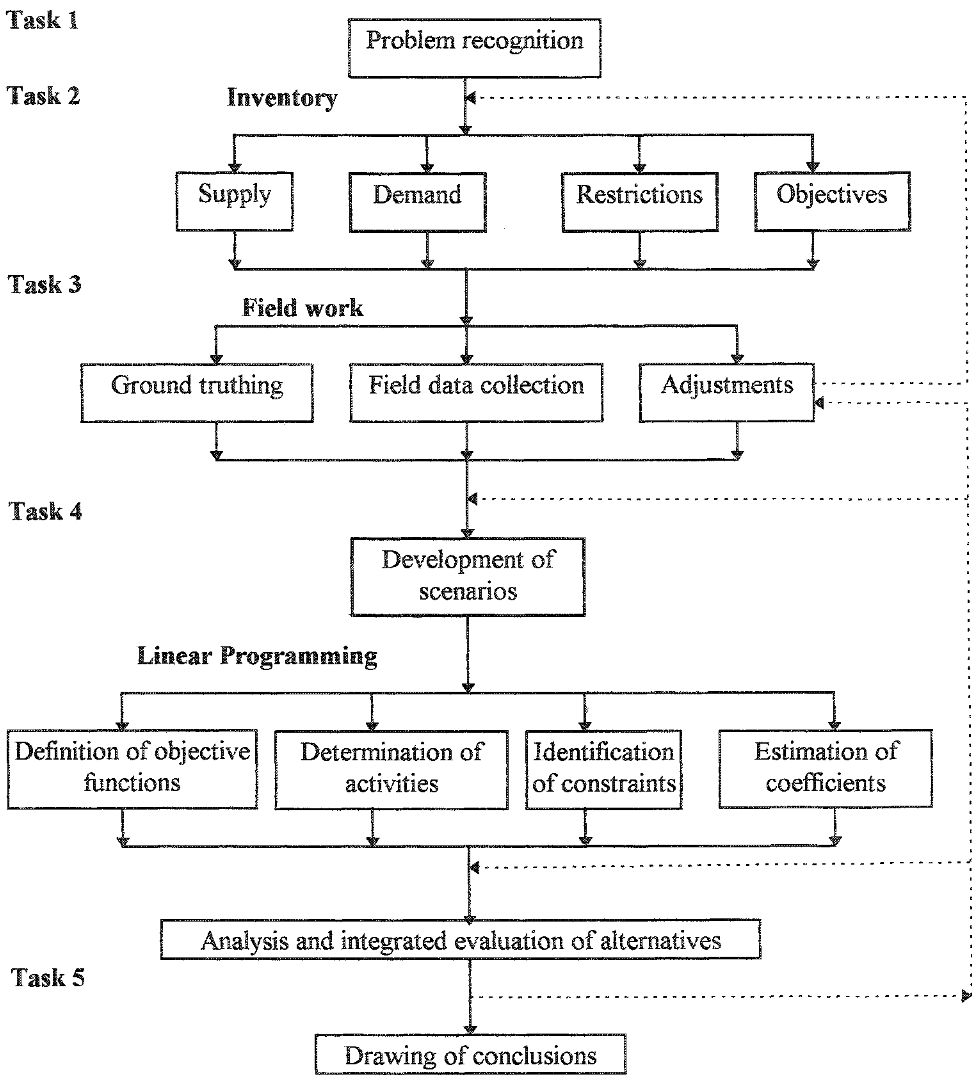


Figure I–1

Methodology used.

1.6. Set-up of the thesis.

Chapter II

Refers to a general description of: Decision Support Systems (DSS) and Linear Programming.

Chapter III

Describes the general aspects of the study area: geology, climate, hydrogeology, green / animal resources, human use of the lake, local economy and land resource management.

Chapter IV

Presents the data analysis of rainfall / runoff patterns and their relation, time series / frequency analysis and water balance.

Chapter V

It is concern with the mission identification, definition of objectives, integrated water management and users water requirement.

Chapter VI

Deals with production activities and the components of the model.

Chapter VII

Discusses the scenarios generation and their evaluation.

Chapter VIII

Presents the conclusions, discussions, study strengths / weaknesses and gives suggestions for further research.

Chapter II : Literature review

2.1 Decision support systems (DSS).

According to Gorry and Scott-Morton [25] DSS is a system that differs from the traditional ones, such as Electronic Processing of Data and the Management Information System (MIS) when dealing with complex problems.

Little [25] defines DSS as a set of procedures based in models for processing data and judgments, as a support tool for the manager to make decisions. He states that in order to be successful, a system must be simple, strong, easy to handle, flexible, complete in important subjects and have an easy communication medium.

During the 70's, this definition was accepted for the professionals and researchers. At the end of the decade, however, new definitions began to arise. Alter [25] defines the DSS by establishing a contrast with the traditional Electronic Processing of Data based on five dimensions, as shown in **Table II-1.**

Table II–1

Decision Support Systems (DSS) vs. Electronic Processing of Data (EPD)

DIMENSIONS	DSS	EPD
Use	Active.	Passive.
User	Manager.	Employee.
Aim	Efficacy.	Efficiency.
Horizon of time	Present and future.	Past.
Objective	Flexibility.	Consistency.

Another DSS definition was given by Moore and Chang [25] with the following characteristics:

- A flexible system.
- A system able to support the ad hoc analysis of the data and the modeling of the decisions.
- A system oriented to future planning.
- A system to be used at irregular non-predicted intervals.

Bonczek and others [25] defined the DSS as a computer based system which comprises three interactive components:

- A language system, which provides communication between the user and the other DSS components.
- A knowledge system or a field-problem storage deposit, incorporated in the DSS as data or procedures.
- A problem processor system, the link between the two previous components, that contains one or more potential abilities for the monitoring of one or more general problems required for the decision making process.

Finally Keen [25] applies the term DSS to the situations where a final system can be developed only by means of a flexible process of learning and evolution. He defines the DSS as the product of a development process in which the user, the programmer and the DSS itself are able to influence each other, giving as a result the evolution of the system and its pattern of use.

This definitions were compared and contrasted through the examination of the concepts employed to define a DSS (see **Table II-2**). It seems to be that the basis to define the DSS has been developed upon what it does and how it achieves the objective.

Table II–2

Concepts that are the base of DSS definitions

AUTHOR	DSS DEFINED IN TERMS OF
Gorry and Scott-Morton	Type of problem, system function (support).
Little	System function, interphase characteristics.
Alter	Pattern of use, objectives of the system.
Moore and Chang	Pattern of use, potential capabilities of the system.
Bonczek and others	System components.
Keen	Development process.

In this study, DSS is taken as an interactive, flexible and adaptable computer-based information system, specially developed to support the solution of a particular management problem for a better decision making. This system uses models (of standard and/or particular design), and it is built through an interactive process (in coordination with final users) supporting all the phases of the decision making and including a knowledge data base.

2.2. Linear Programming.

Linear Programming (LP) is a mathematical procedure for determining optimal allocation of scarce resources. LP is a procedure which has found practical application in almost all facets of business, from advertising to production planning. As a technique to solve problems, LP can be regarded as a science and as an art. As a science because it offers mathematical techniques and models to solve decision problems. It is an art due to the iterative process that it performs in the previous and posterior phases to the solution of a mathematical model.

Programming means in this context to plan and organize rather than to write instructions for performing calculations. In LP there are two important classes of objects: first, limited resources such as plant capacity, land, water resources, etc. and secondly, activities which consume or possibly contribute additional amount of the resources. The problem is to determine the best combination of activity levels which does not use more resources than are actually available.

It is generally true that with each constraint in a LP context one can associate some resources while for each decision variable there is a corresponding activity. LP applies directly only to situations in which the effects of the different activities engaged are linear. For practical purposes linearity has three main features:

- The effects of a single variable or activity by itself are proportional.

- The variables must be continuous (fractional values for decision variables must be allowed).

Solution outcomes are illustrated in **Figure II-1.**

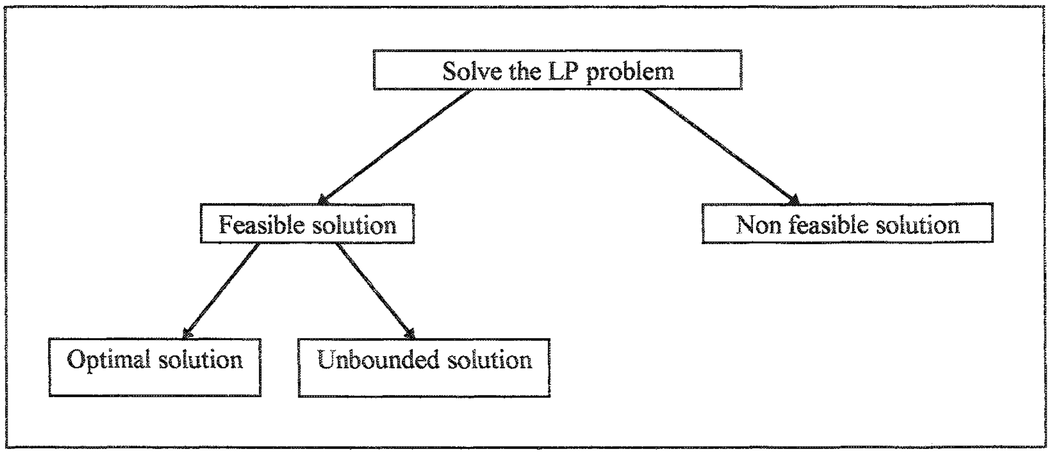


Figure II–1

Linear Programming solution outcomes

One of the reasons why it was decided to apply linear programming in an early stage of the research is the major shortcoming of the traditional approach, which is characterized by an independent and usually insufficiently coordinated search by each discipline for a technically feasible solution to the problem.

Thus, the hydrologist, irrigation engineer, agronomist and other members of the project team are elaborating and generating their specific data and proposals assuming that their proposals represent an optimal solution which has only to be incorporated in the final and comprehensive proposals of the team. This approach can result in sub-optimal solutions which may be feasible technically, but are economically unjustified, because the various technical disciplines may opt for capital intensive elegant and technologically advanced solutions, believing somewhat a priori in their economic superiority.

In awareness of this problem, an early attempt was made to develop and use a linear programming model that would include all the various activities assuming a multi-target function:

- Optimized economic return.
- Improvement in social conditions.
- Ecological preservation.

A decision model should be considered as a tool to "summarize" a decision problem in a way that allows a systematic identification and evaluation for all the decision alternatives of the problem. After that a decision can be made choosing the alternative which is considered to be the best among the available options.

There is a difference between the construction of the model and obtaining its solution. Normally the first step in the decision making process is to build the model. After that, a method to solve the problem must be found. In some cases there could be more than one way to solve the problem; in other cases the model could be so complex that it can be difficult to obtain an exact solution. In such a case we can be satisfied to obtain an approximate solution to the problem.

The general procedure of decision model building and the finding of its solution represents the central or main part of the decision making process. Although a real situation can imply a large number of variables and constraints, generally only a small fraction of them determine the behavior of the system. Therefore the simplification of the system in order to build the model should concentrate in the identification of the main variables, constraints and data important for the decision making.

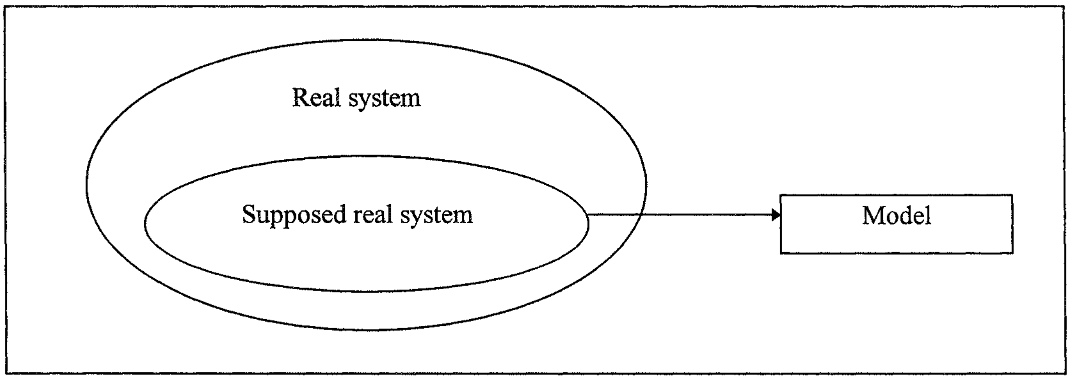


Figure II–2
Levels of abstraction when building a model

Figure II-2 shows the abstraction levels of a real situation to build a model. The "supposed real system" is an abstraction of the real situation which is obtained when concentrating in the identification of dominant factors (variables, constraints and parameters) which control the behavior of the real system. The model is an abstraction of the "supposed real system". It identifies the pertinent relations in the form of an objective function and a set of constraints.

If each of the factors had to be considered in an explicit way the problem would become difficult to solve but when defining the "supposed real system" (that makes to see the system as a whole instead of concentrated into the small details of the problem), it is more simple to think in terms of the supposed real system.

In general there are no fixed rules to perform the levels of abstraction. The reduction of factors that control the system to a relatively small number of important ones and the abstraction of a model from a "supposed real system" depends mainly upon the creativity and imagination of the analysts.

Regardless the accuracy or complexity of the models, they can result to be not practical if they are not feeded by confident data. Sometimes a model is constructed according to the hypotheses that those data can be obtained, but a posterior search can prove that such data is difficult to obtain. In that case it is necessary to rebuild the model in order to bypass the lack of data. Hence data availability can have a direct effect on the model approach.

The mathematical models calculation is commonly iterative by nature. This means that the optimal solution of a mathematical model is not available in one go. The final answer is obtained after some iterations, where each iteration "converges" the solution to an optimal level. The phases of an study using LP include:

- Problem definition (chapter V).
- Building of the model (chapter VI).
- Solution and evaluation of the model (Chapter VII).
- Implementation of the results.

For the first phase it is necessary to cover three main aspects:

- Description of the objective functions.

- Identification of decision variables.
- Determination of the constraints and requirements.

The second phase corresponds to the model building which quantifies the objective function and the constraints of the problem as a function of its decision variables. The third phase of the study is about the model solution, it is achieved using well-defined optimization techniques and it gives an "optimal" solution, which can be tested in order to know how stable is it. When introducing some changes to the input parameters, such a procedure is known as sensitivity analysis, which is specially needed when the parameters of the system cannot be estimated with accuracy. The last phase is the implementation of the results from the model, which must be transformed into detailed instructions to the individuals in charge of the operation of the system.

2.3. Terminology of Linear Programming.

LP uses a particular terminology, that is why some of the common terms are explained below.

2.3.1. Decision variables

They refer to the decision alternatives. Furthermore, their "value" is determined by optimizing (minimizing the costs or maximizing the gross incomes) an objective function, procedure which is the same as the classification of the decision alternatives. The optimization procedure is confined to the feasible values of the decision variables which satisfy all the constraints of the model.

2.3.2. Feasible solution

It is the solution which satisfies all the constraints, the variables are positive or zero.

2.3.3. Sensitivity analysis.

Sensitivity analysis is the term applied to the process of answering how much do the input data alter the recommendations of the model. It can reveal which pieces of information should be estimated most carefully.

2.3.4. Reduced cost

It is the amount by which the profit contribution of the variable must be improved before the variable in question would have a positive value in an optimal solution, a variable which already appears in the optimal solution will have a zero reduced cost.

2.3.5. Dual prices

Associated with each constraint there is a quantity known as the dual price. The dual price of a constraint is the rate at which the objective function value will improve as the right-hand side or constant terms of the constraint is increased in a small amount.

Chapter III :General Aspects of the Study Area

Lake Naivasha is situated in the Rift Valley Province of Kenya (see **Figure III-1)** its geographic coordinates are: 0^{o} 45' latitude South and 36^{o} 20' longitude East, it is situated at an approximate altitude of 1890 m.a.s.l. and it covers an area of 140 Km^2 that fluctuates with inflow. The catchment area is around 3300 Km^2 and it is drained by the following rivers: Malewa, Gilgil, Karati and Little Gilgil.

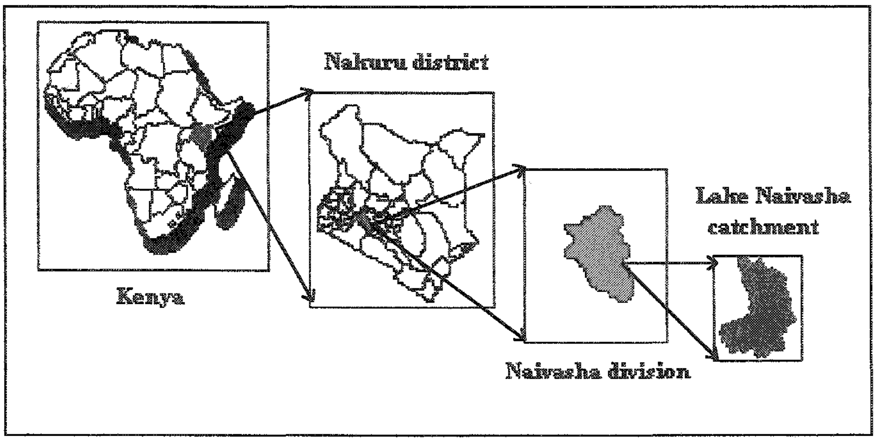


Figure III–1

Location of the Study area

The lake provides freshwater in a closed basin, which is maintained by different mechanisms, such as: dilute inflows, surface inflows, biochemical / geochemical sedimentation and seepage losses. Due to the freshness of the water and the fluctuations of the water level, a high species richness of aquatic plants, associated with succession on wet mud at the lake edge, exists. Papyrus is the main vegetation especially in the northern delta of the inflow rivers. This swamp was shown to affect the whole ecosystem through uptake of nutrients and sediments from the inflowing rivers and its subsequent slow release to the lake water as fine organic particulate matter and accumulation as swamp peat.

The inter-annual rainfall is irregular and the local rainfall around Naivasha is exceeded by annual evapotranspiration. The lake is always shallow with a maximum depth of 10 m and a mean depth of 5 m. 30% of the water of the lake is shallower than 3 m and it is capable of supporting submerged plant growth.

Water quality is linked to the water level in several ways. Direct river input is a major source of nutrients. Water quality is moderated by the presence of the swamp vegetation which tends to retain sediments and nutrients and thus smooth out seasonal fluctuations. Land use probably affects the extent to which runoff influences the lake directly and also the nutrients content of flooded soils.

The different plant communities of the lake-edge contributed to bird species richness and abundance. There was a significant relationship between the abundance of birds and the width of the submerged plant beds in 1987. They create a micro-environment of calmed water that results in a reduction of phytoplankton from settlement and/or littoral zooplankton grazing.

The wetland plant communities thus have a direct benefit to human uses of the lake in fisheries and in conservation and tourism. An indirect benefit is there because the lake shore's agriculture depends upon irrigation water of relatively low ionic composition. Land use, particularly conversion of swamp to grazing and cultivation, clearly had a direct effect upon the swamp vegetation in the mid 1980's. That effect is currently lessened due to the fact that the riparian owners (the Lake Naivasha Riparian Owners Association) has set a limit for cultivation to 50 m from the lake edge. In the future, however, it is likely that land use in the wider environs of Lake Naivasha will have a dramatic effect upon lake level.

Agriculture is very intensive because the combined effects of an equatorial solar regime and rich volcanic soils make the land's productivity limited only by water. Lake-water irrigation can overcome this limitation. Added to this is the use of cooling water by the Hell's Gate Geothermal Power Station (Africa's first geothermal plant). These present demands, together with the construction of a water supply reservoir for the expanding town of Nakuru (that will export a substantial proportion of the flow of the main river: Malewa, out of the upper catchment) will lead to a substantial environmental impact upon the lake in the next decade.

Lake Naivasha is of great interest and curiosity because it is the only fresh water lake in the Central Rift Valley and as a result it has been the most significant lake of the area in both economic and scientific terms.

Lake level fluctuation is a common feature of all lakes in the Rift Valley. Evidence of this is provided by both historical records and casual observations which indicate that the lake had at one time come close to be completely dried up.

3.1. Geology.

The physiography of Nakuru District is characterized by plain lands spread in the northern part, the Rift Valley in the central belts and highlands in the east and western sides.

The African Rift Valley is the most prominent structural phenomenon in East Africa. The geology of the area is characterized by volcanic rocks and Quaternary lacustrine deposits from large ancient lakes which were formed during pluvial periods. They became shallow or dried up completely during the inter pluvials. The last Rift Valley faults accompanied by major eruptions took place during the Upper Pleistocene when Mount Longonot (South of Lake Naivasha) was formed (Cole 1950).

Based on detail core analysis and radio carbon dating Richardson and Richardson (1972) suggest that, in the period 9200 BC to 5700 BC, Naivasha was about four times as extensive and 58 m, higher than it was in 1960. At the end of the Gamblian there was a dry interval during which the lakes dried up completely. One post-pluvial wet phase (Nakuran) may have occurred at about 2800 BC which rejuvenated the lakes. Since then they have been fluctuating near and below modern levels.

3.2. Climate.

Climatic conditions in the study area are quite diverse due to considerable differences in altitude and land forms. The annual temperature range is approximately from 7.9 °C to 28.2 °C (Kenya Government, 1988).

The rainfall regime within the lake catchment is influenced by the rain shadow from the surrounding highlands of the Nyandarua range (Aberdares). Rainfall is well distributed throughout the year but at Naivasha there is a discernible peak in April (Kenya Government, 1988). Naivasha experiences an average yearly rainfall of 660 mm approximately whereas the wettest slopes of the Nyandarua mountains within the lake's catchment receive as much as 1025 mm.

The evaporation experienced by Naivasha is between 1600 and 1800 mm so the runoff from the non-immediate catchment would seem to be broadly sufficient to maintain lake level.

3.3. Hydrogeology.

The study area is situated within the large African Rift System and geological evolution has considerably influenced geomorphology and hydrogeology in the area. Lake Naivasha basin is separated from Lake Elementaita and Lake Nakuru ones by the Eburru Volcanic chain.

In the Lake Naivasha basin, groundwater recharge is very low and comes essentially from the west area of the Lake (Mau escarpment) although previous isotropic and piezometric trend analyses indicate groundwater outlets to the south and to a lesser extent to the north.

3.4. Green resources.

Lake Naivasha catchment represents an important ecological site in Kenya due to the diversity of fauna and flora which are distributed through a range of vegetation zones (Harper, 1990). The diversity found is greater than any other Rift Valley Lake. The catchment vegetation can broadly be grouped into:

- Forest.
- Wooded grassland.
- Bushland.
- Grassland.

These vegetation types can be categorized into three eco-climatic zones (Pratt and Gwynne, 1977):

- Zone II (Humid to dry semi-humid) featuring natural forest, Montane Acacia woodland and intensive agricultural lands mainly around mountainous areas.
- Zone III (Dry sub-humid to semi-arid) having high agricultural potential.
- Zone IV (semi-arid) these are described as high potential rangelands which are important for grazing purposes.

The natural forest within the study area comprises indigenous hardwood trees and grasses such as bamboo. Menengai crater, Eburru hills, Mau escarpment, Mount Longonot and the Nyandarua escarpment are all host to hardwood forests, whereas bamboo is confined to the Nyandarua and Mau escarpments. These form the main watershed of the lakes. Naivasha's shores are often encircled by ephemeral papyrus colonies and the surface covered by rafts of Salvinia molesta (sometimes up to 25% of the total surface area).

3.5. Animal resources.

Large animals (see **Plate III-1),** including zebra, giraffe, lion and hippopotamus, frequent the lake margins. Flamingos are particularly attracted to Nakuru and Elementaita in great flocks where they sieve the blue-green algae (Spirulina) from the mud close to the shore line. Flamingo presence is determined by water level, and their absence has corresponded to periods of low water level (Vareschi, 1978), possibly because there is then a greater risk for predators.

3.6. Human use of the lake and surrounding land.

The Rift Valley is well known as a likely place of origin for mankind (Leakey, 1931). Within historic time Lake Naivasha and the land surrounding have been especially attractive to man because of the potable fresh water and surrounding vegetation. The game attracted to the lakes also encouraged hunting.

Before the colonial period, the whole area was used entirely for cattle herding by the roaming Massai herdsmen and other pastoral tribes. Following the completion of the East African railway line in 1901, which passes close to the lake, the land was given over in large part of settled agriculture as a result of British policy to recoup the cost of constructing the railway. The largest single estate in the area was the 100,000 acre ranch of Lord Delamere, between Nakuru and Njoro. Delamere's trial with sheep in the early part of this century was unsuccessful because of mineral deficiency in the natural grassland and impossibility of growing a close clover sward. The better land in the valley was eventually used successfully for ranching, milk production and for growing wheat. The problem of water supply was solved by drilling boreholes.

Since independence in 1963, the large estates have gradually been divided into small farms by land buying companies and cooperatives and given over to individual farmers. However cattle ranching and dairing continues side by side with irrigated temperate arable cropping, vegetable horticulture and flower growing on the more fertile volcanic soils, where irrigable water is available. The sub-division process continues to the extent that the land is sub-divided beyond any reasonable economic unit which is likely to lead to degradation of the environment.

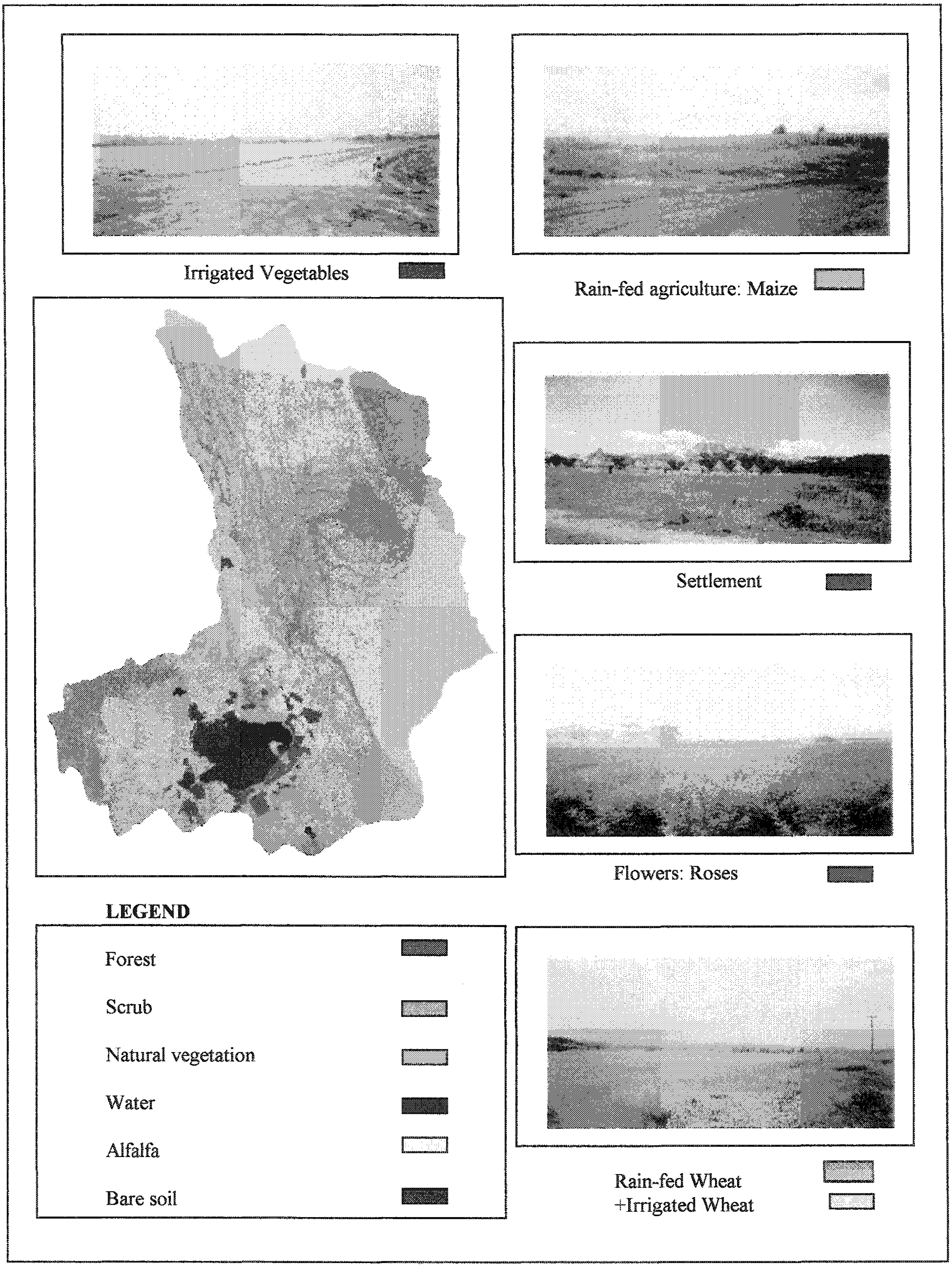
The land cover/use of the study area was determined using supervised classification based on a color composite image (combination of Band 4, 5 and 3) of Landsat TM imagery from January 1995, the results are shown in **Table III-1** and in **Figure III-2**.

Table III–1

Land use type in the study area

Land type	Area (Ha)	Area (%)
Wheat (Irrigated)	231	0.07
Flowers (Irrigated)	3,598	1.09
Vegetables (Irrigated)	2,511	0.76
Alfalfa (Irrigated)	728	0.22
Grass (Irrigated)	285	0.09
Natural vegetation	4,268	1.29
Rain-fed agriculture	135,454	41.02
Forest	44,430	13.46
Bare soil	28,367	8.59
Scrub	96,125	29.11
Lava flow	462	0.14
Water	12,676	3.84
Settlement	1,074	0.33
Total	**330,209**	**100**

Figure III-2: Land use map



Recent population rises and migration have altered the land use patterns in the catchment. The population figures for Naivasha division are shown in **Table III-2***.

Table III–2

Population of Naivasha division

Place	Total population	Number of house holds
Naivasha township	11,491	2,856
Naivasha rural	38,858	9,473
Total Naivasha location	50,349	12,329
Kijabe location	9,653	2,087
Gilgil location	35,337	8,221
Total Naivasha division	**95,339**	**22,637**

The main farming system in this area is mixed farming. Land use pattern noted from the field survey in the area can be broadly categorized as follows:

- Rain-fed crop production is the most important economic activity within the catchment. The slopes of the Aberdares (Nyandarua mountains), Mau and Menengai are the most common farming areas. Common crops include maize, wheat, potatoes, Pyrethum, grass leys and sunflower.
- Irrigated crop farming is common near Lake Naivasha where Delamere produce large quantities of wheat, barley, French beans and fodder crops which include lucerne, desmodium, sorghum, etc. Delamere gets its irrigation water from boreholes most of which are electrically driven. Other important horticultural farms which draw their water directly from Lake Naivasha include Oserian and Sulmac, whose main products are flowers (carnations, statice, solidaster, cathamus, focal freeden, etc.) vegetables and fruits. Water is taken by powerful electrical pumps and canals (see **Plate III-2**).
- Extensive or range livestock production, is a livestock production system whereby livestock roam about freely in the range accompanied by a herdsman or herdsmen. The

* from a colleague: Miss Noha Donia

system is common in drier parts of the catchment such as Sakutiek, Longonot, etc. Main animals are cattle, sheep and goats (see **Plate III-3**).

- Intensive livestock production is a production system involving high skill levels. Common in dairy and beef ranches found in the area such as Manera dairy farm to the North of Naivasha town. The Kenya Agricultural Research Institute Centre to the north west of Naivasha is also important. Livestock productivity is high. Common livestock types include: cattle, pigs, sheep and goats.
- Individual livestock production refers to individuals who keep one or two cows tethered or grazed around the homestead. It also includes people keeping a small herd under zero grazing systems. Common animals include: cattle, sheep, goats, pigs and fowl (chicken, ducks, turkeys, etc.).
- As well as the natural forest already described there also exist plantations of exotic tree species. This are highly significant sources of timber and wood products due to their early maturation.

3.7. Local Economy.

Apart from agriculture there are additional economic activities in the study area which may be of relevance to hydrology and lake levels.

3.7.1. Energy generation

South of Lake Naivasha is the Olkaria Geothermal electricity generating facility. This plant produces 45 Mega watts which represents 6.1 % of Kenya's total electricity consumption (**See Plate III-4**).

3.7.2. Fishery

Lake Naivasha has been for the last thirty years, the site of important commercial fisheries based on introduced species, predominantly Oreochroms leucostrictus, Tilapia Zillii and Micropterus salmoides (Muchiri et al, 1992). The markets for these fish include the towns of Naivasha, Nakuru and Nairobi. These markets have grown significantly since 1975 (Lowery and Mendez, 1977). The harsh sodic waters of Elementaita and Nakuru do not support fisheries.

3.7.3. Tourism

It has represented a growing sector of the economy from the later 1920's when sport-fishing began. Since then safari and other recreational pursuits have steadily increased with foreign visitors, bringing substantial foreign revenue. The diversity of wildlife (rhinos, buffaloes, leopards, gazelles, antelopes, waterbucks, flamingoes, zebras, etc.) contribute to this area being important tourist destination. Hell's gate National Park is located some 12 Km south of Lake Naivasha, within the Naivasha catchment, and it is also a major tourist destination within this area.

3.7.4. Industry

Important commercial centres include Naivasha, Gilgil, Njoro and Ol-Kalou. Small industries manufacturing food stuffs have also spread to many parts of the region producing tomato sauce, chili sauce, juices, dairy products, etc.

Service industries like hotels and transport are well developed. Low class lodging are generally found in any commercial centre, medium and high class tourist hotels are located in major centers like Ol-kalou, Gilgil and in main towns such as Naivasha and within the parks.

3.8. Land resource management.

The following problems were identified:

- Inadequate water supply, for both human and livestock consumption.
- Lack of pasture/grazing. The area was once important for grazing. This has changed due to recent increases in human population prompting a change in economic activities.
- Land degradation. This area used to have large-scale European farms managed as large units. After independence the farms were subdivided into small units which has led to land degradation as the lands have exceeded their carrying capacity thereby threatening serious problems for human welfare.
- Forest/bush clearing. Sub-division and land allocations have led to bush clearing to open up land for cultivation. The trees are also used for firewood and as building materials. This has led to the shrinking of natural habitats for wildlife and problems of soil degradation and erosion.

In response the following conservation techniques were observed: tree planting, forest conservation and terracing.

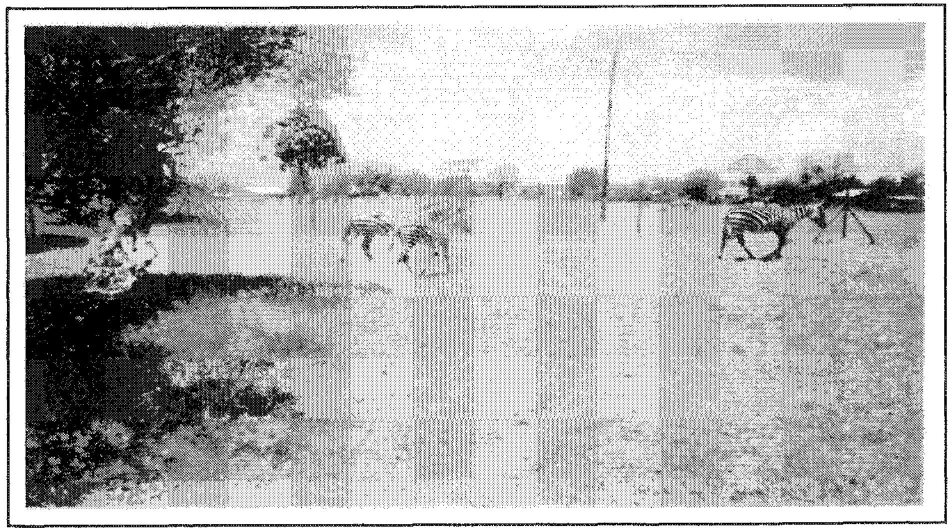


Plate III-1: Wildlife

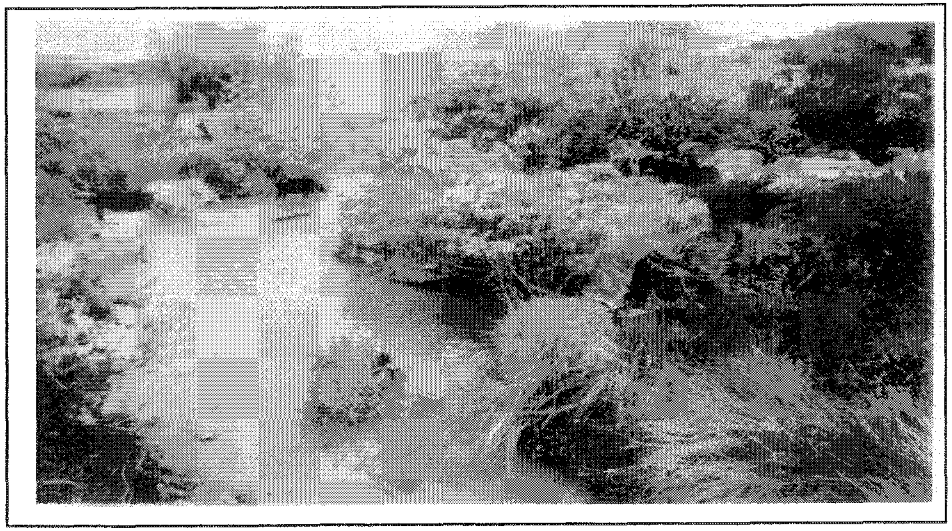


Plate III-3: Livestock

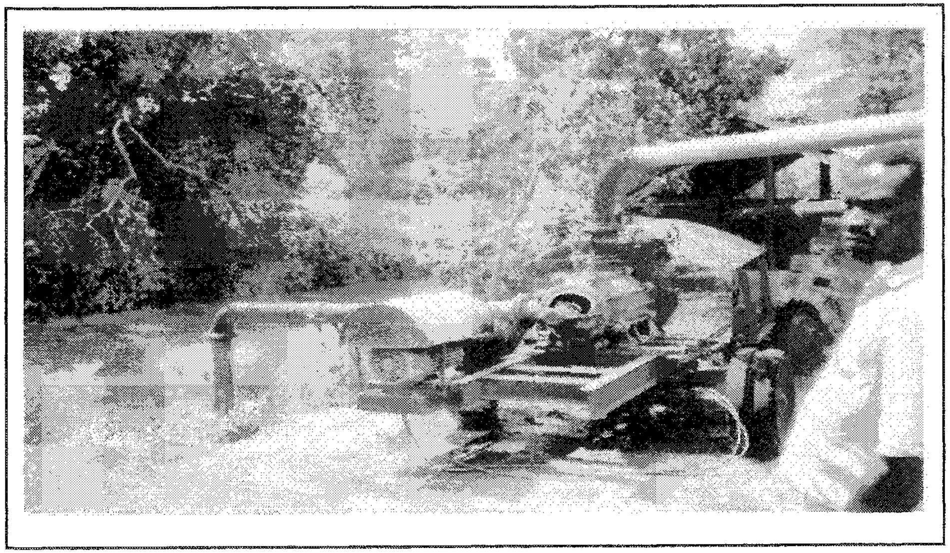


Plate III-2: Water abstraction

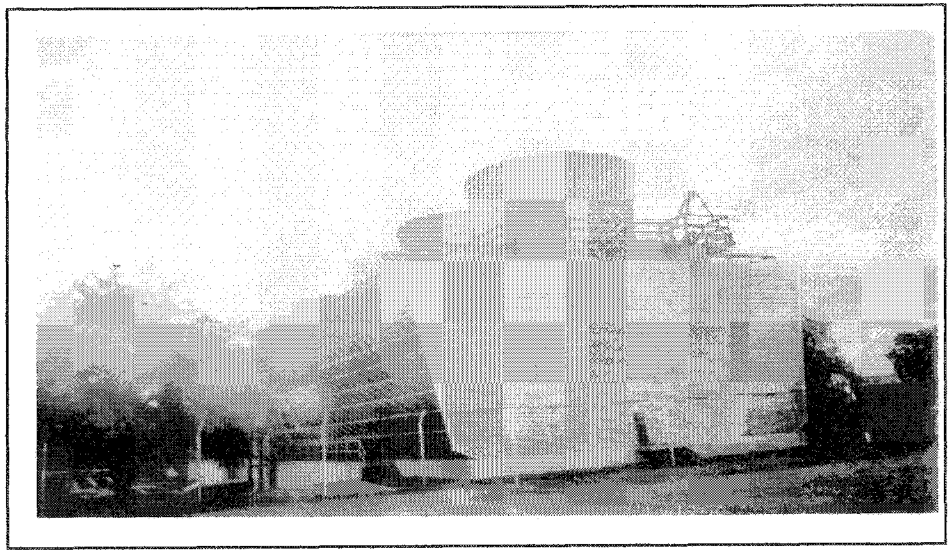


Plate III-4: Geothermal power generation

Chapter IV : Hydrological data analysis

4.1. Rainfall analysis.

In order to perform hydrological modeling or any further data analysis it is necessary to check whether the data to be used is consistent or not. In the Lake Naivasha catchment two rainfall stations Naivasha D.O. and Milmet were considered due to their long-term daily records which were required for this part of the study (missing data and zero values were taken as blanks). Data availability is shown in **Table IV-1**.

Table IV–1

Rainfall data available

Station	Period
Naivasha D.O.	1957 to 1994
Milmet	1959 to 1987

Due to availability of discharge data (see **Section 4.2**) for combined analysis the period 1960 to 1985 was chosen (see **Appendix IV-1 and IV-2**). The data has been checked using the mass curve method and consistency was found (see **Figures IV-1 and IV-2**).

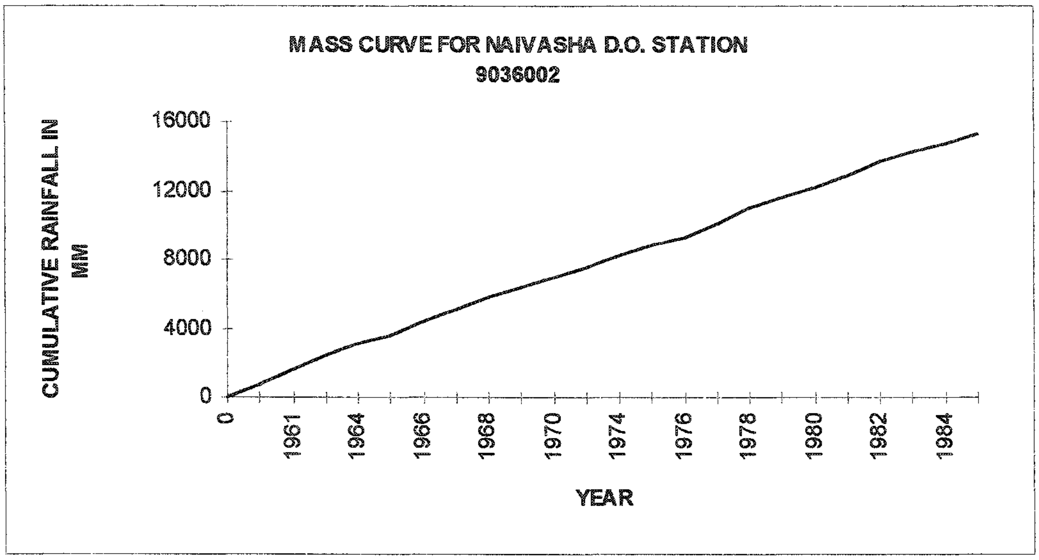


Figure IV–1

Mass curve for Naivasha D.O. station

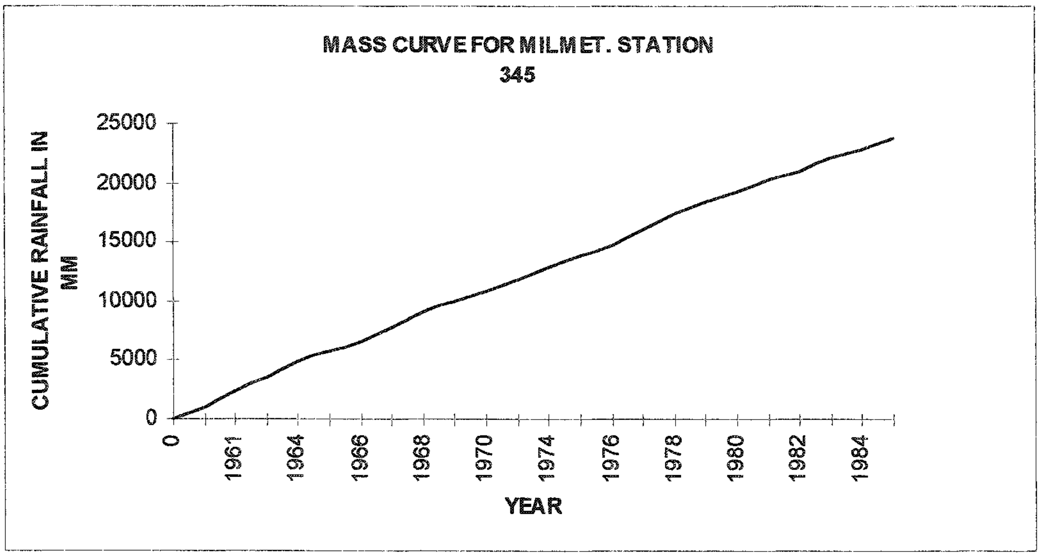


Figure IV–2

Mass curve for Milmet station

After determination of average monthly, average yearly rainfall for the catchment using the Thiessen Polygon method (see **Table IV-2**), it was observed that:

- The frequency of rainfall occurrence during the months from March to May and from October to December is high which matches with the long-rain season and short-rain season respectively.
- The average number of rainy days (see **Appendix IV-3**) shows that the temporal distribution of rainfall over the whole catchment is not uniform.

Table IV–2

Monthly and yearly average rainfall for each station

Station	Thiessen weight	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Yearly
N.D.O.	0.85	29	37	54	119	72	36	33	43	42	55	72	45	664
Milmet	0.15	32	39	61	150	152	66	94	101	79	81	80	31	1034

Three years were selected, using the rainfall probability of exceed calculation and its relationship with discharge specially regarding the rainfall distribution, to represent the dry, average and wet years as shown in **Table IV-3 and Appendix IV-4.**

Table IV–3

Probability of exceed

Year	Year type	Probability of exceed
1980	Dry	0.78
1979	Average	0.56
1964	Wet	0.26

4.2. Stream flow analysis.

In this catchment, discharge data of Malewa, Gilgil and Karati rivers were available as shown in **Table IV-4.** The period from 1960 to 1985 was chosen because Malewa river (see **Appendix IV-5**) contribution to the catchment discharge is the most important one (80%) of the group. The average and total yearly discharge, maximum average daily and maximum instantaneous flow data were available for the whole period. The maximum discharge from Malewa river belongs to the year 1961 for which the monthly average discharge has been plotted in **Figure IV-3**.

Table IV–4

Discharge data available

River	Station	Period
Malewa	GB1	1960 to 1985
Gilgil	GA5	1960 to 1988
Karati	GD2	1960 to 1982

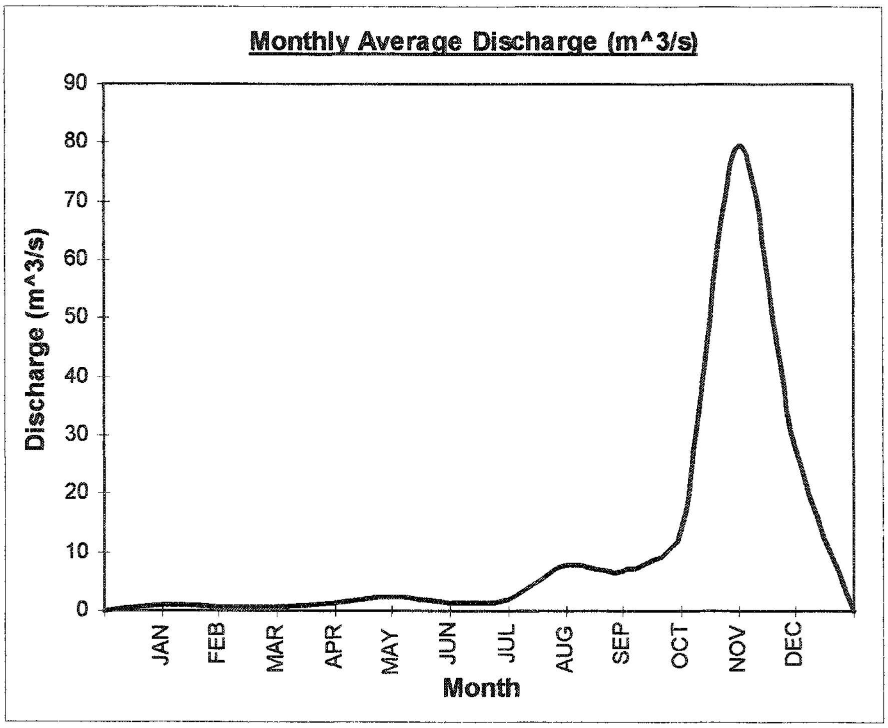


Figure IV–3

Monthly average discharge (year 1961)

4.3. Stream flow and rainfall analysis.

Stream flow and rainfall analyses were performed for the wet, average and dry years by separating the rainfall into three components: base flow, overland flow and losses (actual evapotranspiration and deep percolation), using the Timesplot program. Rainfall/runoff relation (see **Figure IV-4**) shows that losses are significant and inversely proportional to the amount of rainfall.

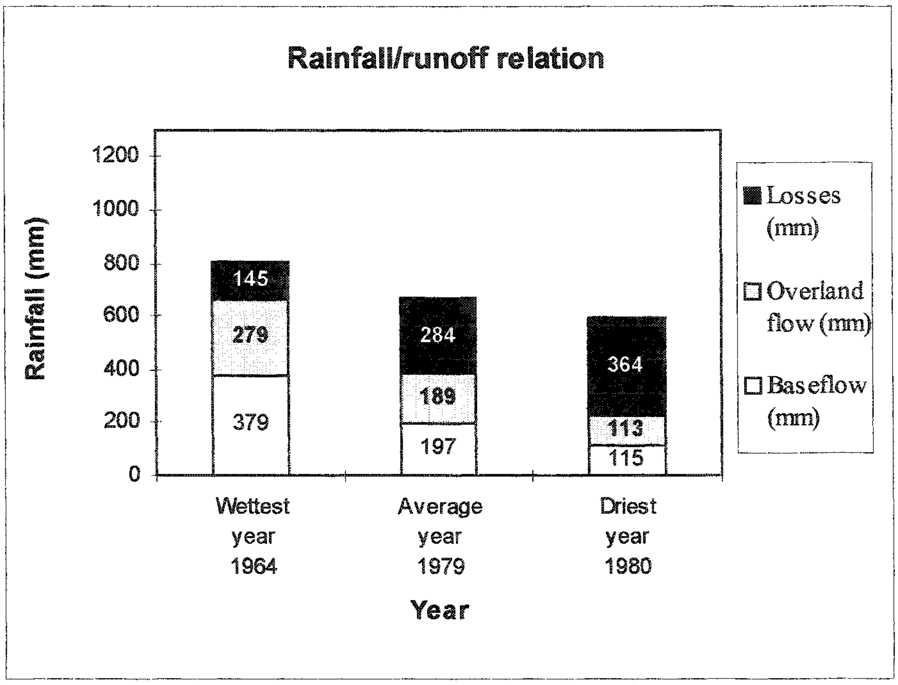


Figure IV–4
Rainfall/runoff relation

4.4. Runoff coefficient.

The runoff coefficient was calculated using the total areal yearly rainfall and discharge data for each year (see **Table VI-5**). The runoff coefficient variability can be explained by taking into account the vegetation cover, slope and frequency-duration-intensity of rainfall but mainly due to changes in soil moisture conditions.

Table IV–5

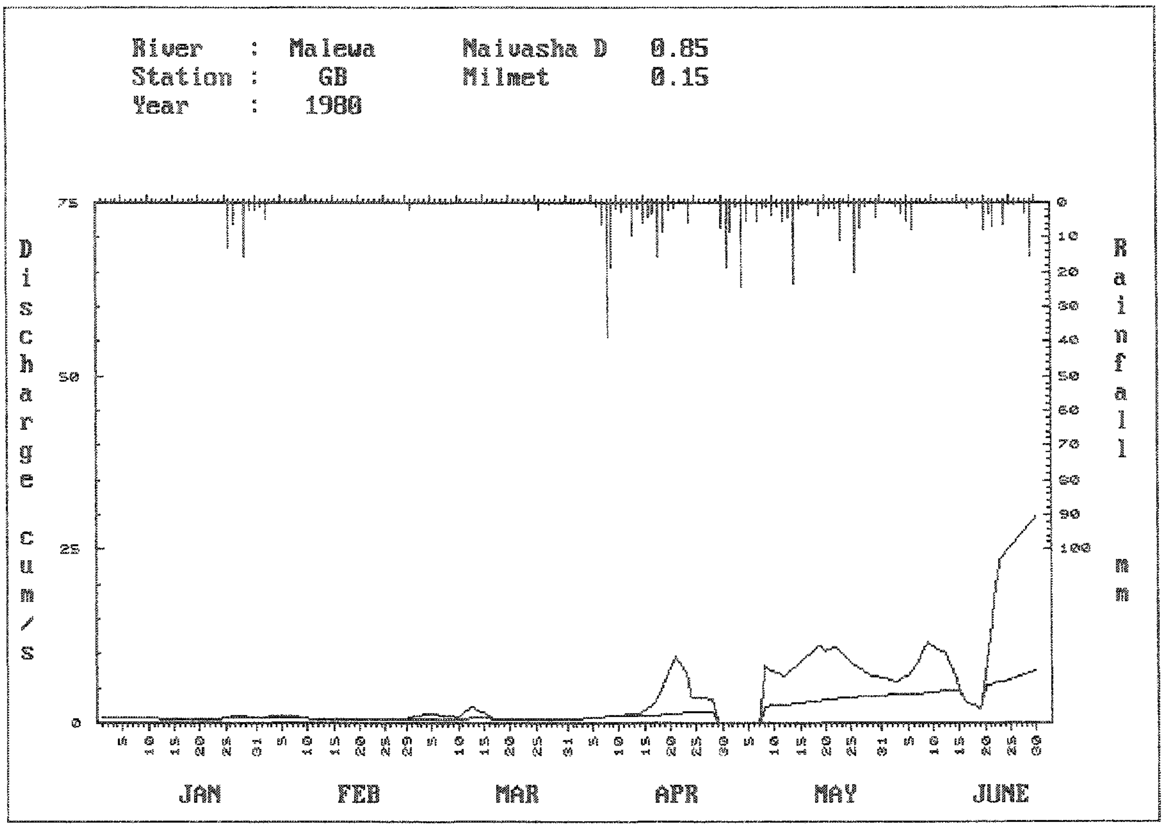
Runoff coefficient

Year	Areal Rainfall (mm)	Malewa Discharge (mm)	Runoff Coefficient
1960	713	179	0.25
1961	988	783	0.79
1962	970	687	0.71
1963	857	644	0.75
1964	**803**	**658**	**0.82**
1965	579	180	0.31
1966	757	350	0.46
1967	781	429	0.55
1968	843	681	0.81
1969	554	137	0.25
1970	634	460	0.73
1971	603	484	0.80
1972	494	237	0.48
1973	651	171	0.26
1974	753	378	0.50
1975	630	429	0.68
1976	545	184	0.34
1977	900	395	0.44
1978	988	547	0.55
1979	**670**	**386**	**0.58**
1980	**592**	**227**	**0.38**
1981	773	303	0.39
1982	712	286	0.40
1983	728	331	0.45
1984	460	86	0.19
1985	631	199	0.32

4.5. Time series for wet-average-dry years.

Runoff data were available and used to determine the monthly amount of overland flow and base flow (see **Appendix IV-6 and IV-7**). The Timesplot program, which is based on the filter method, was run using data of the representative years for a typical kind of year: dry, average and wet (see **Figures from IV-5 to IV-7**). The plot shows in the left-hand axis the amount of discharge (represented by a line graph) in cubic meters per second, the baseflow is separated from the overland flow by an almost horizontal line. For reading rainfall (plotted as a bar graph), it should be taken into account the right-hand axis which gives the amount of precipitation in milimeters.

The year 1980 was determined as the dry year, its graph shows a higher period of rainfall during April and May, there is small quantity of overland flow throughout the year except during the months of June and July. The year 1979 was taken as the average year for the period, the graph shows that the rainfall is almost uniform during the two first months of the year and that the peak baseflow contribution takes place during the months of February, May and July. The year 1964 was considered as the wet year, the rainfall period started from February to April with an effect on the baseflow which increased gradually to reach its peak in May, whereas the overland flow is higher during April, August and October.



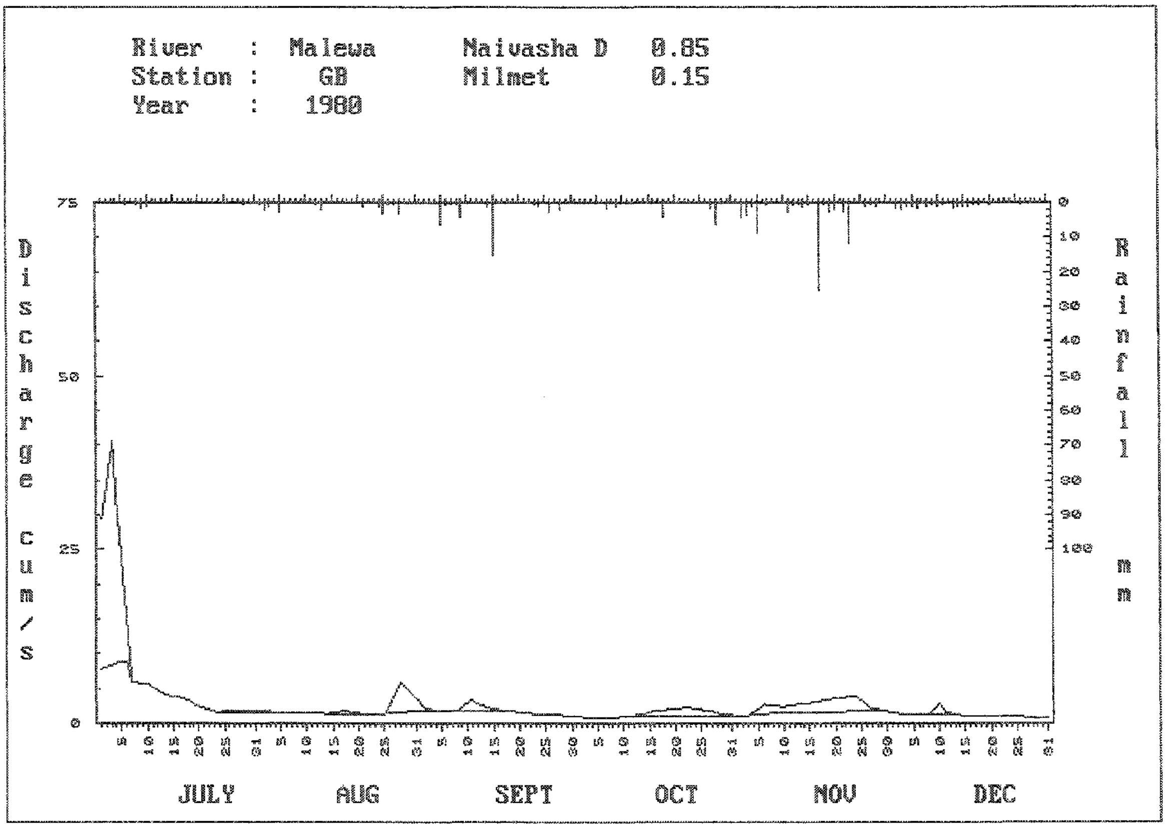
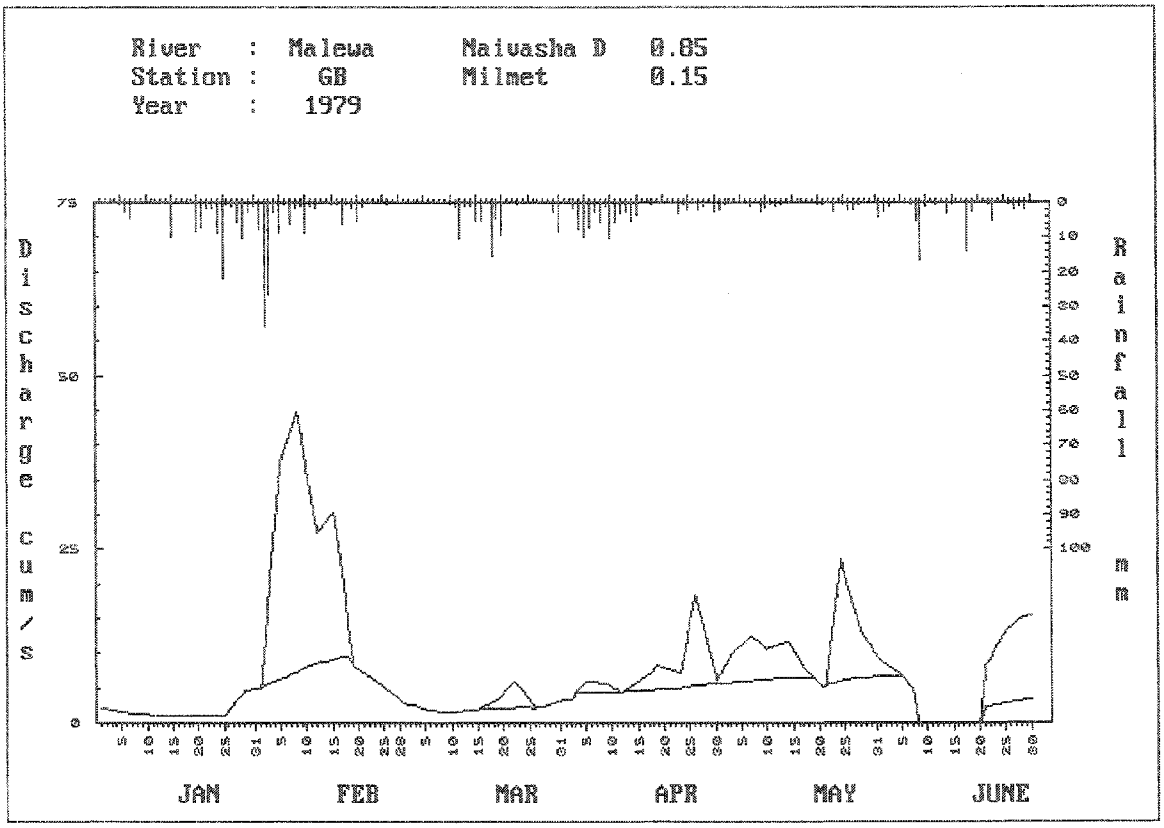


Figure IV–5

Rainfall/Runoff time series dry year (1980)



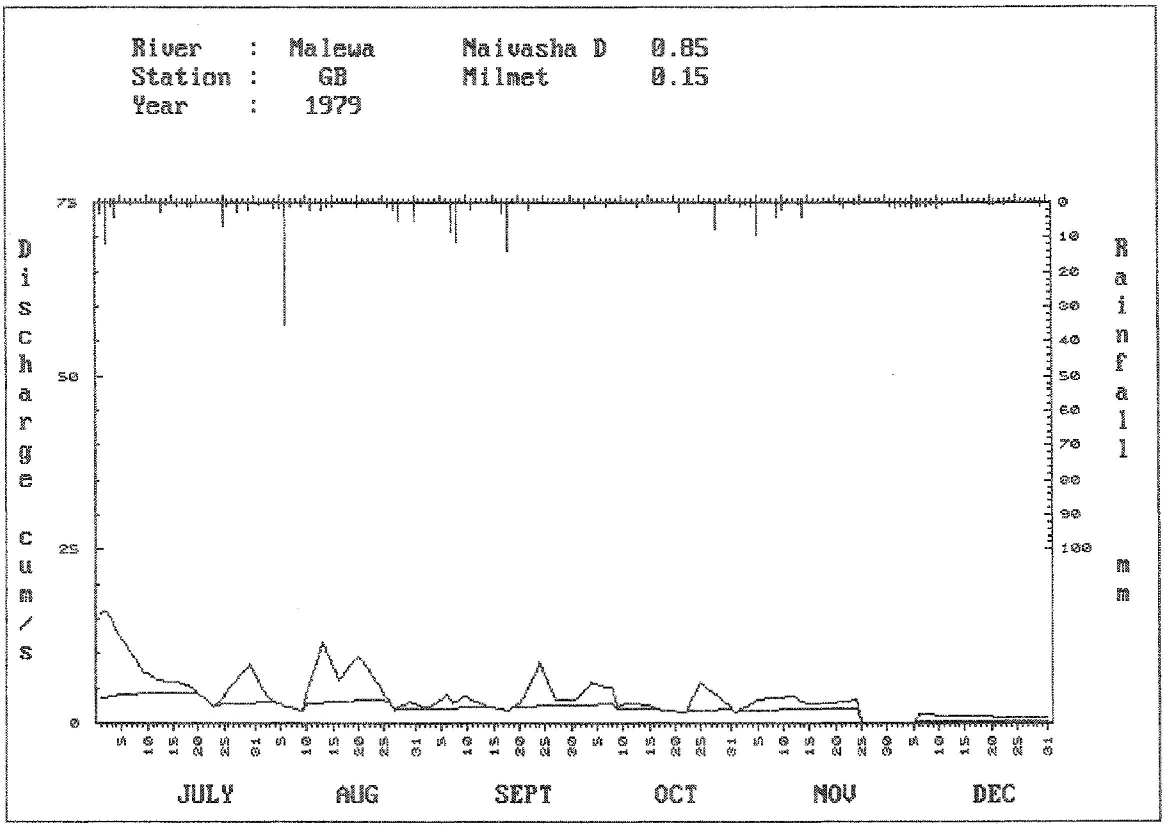
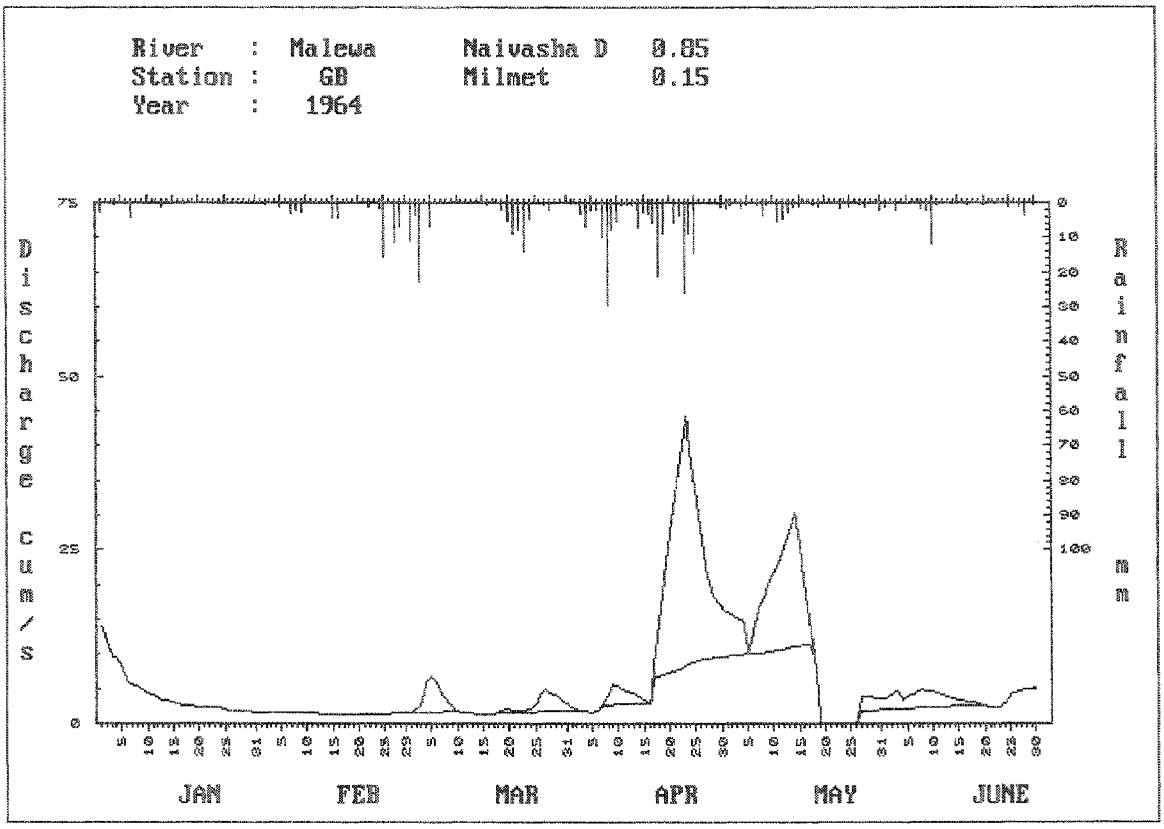


Figure IV–6

Rainfall/Runoff time series average year (1979)



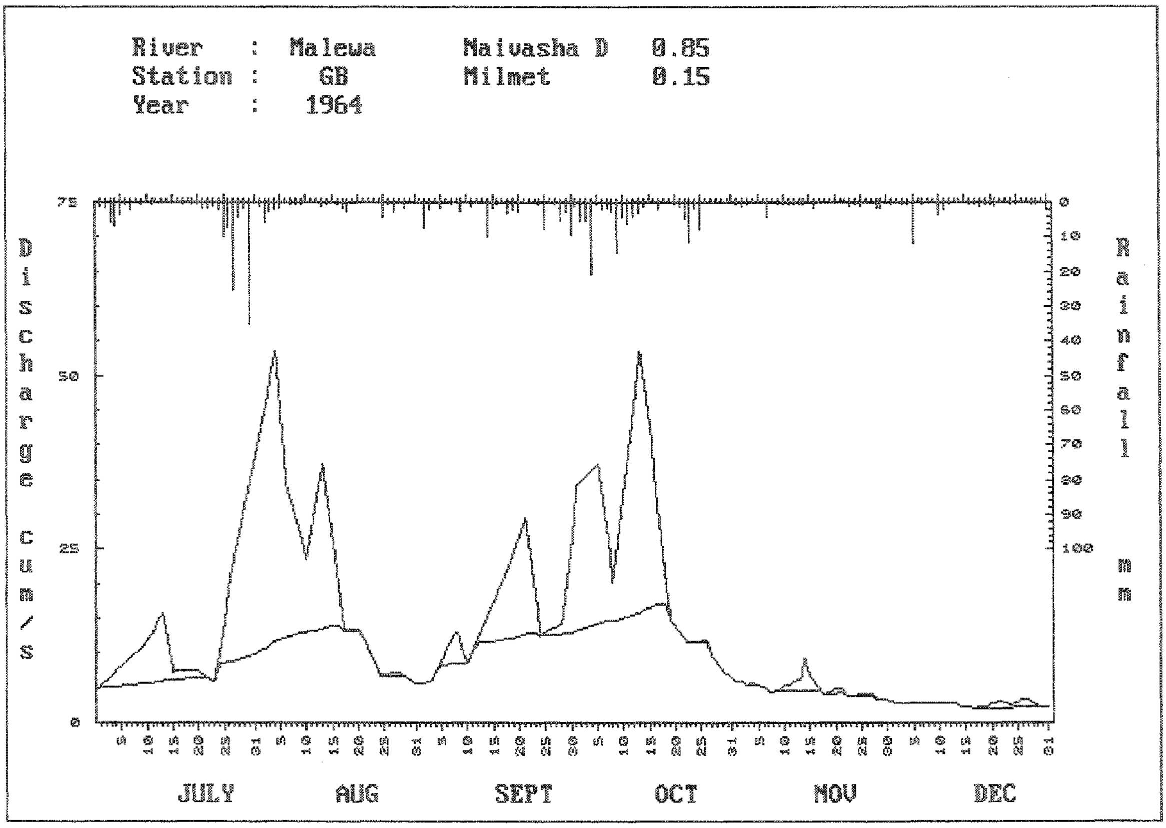


Figure IV–7

Rainfall/Runoff time series wet year (1964)

4.6. Frequency analysis.

It was performed using the Rankplot program, which allows to attach certain probability to hydrological events of interest, such as flood prediction and rainfall distributions (see **Table IV-6, Figures IV-8 and IV-9**).

Table IV–6

Frequency analysis result for rainfall and discharge events

Probability of exceed / Return period / Event (in mm)	0.78 (1980) 1.28	0.56 (1979) 1.79	0.26 (1964) 3.85
Annual Total Rainfall Naivasha D.O. station	559	635	742
Annual Total Rainfall Milmet station	817	986	1242
Annual Total Discharge for Malewa River	206	302	467

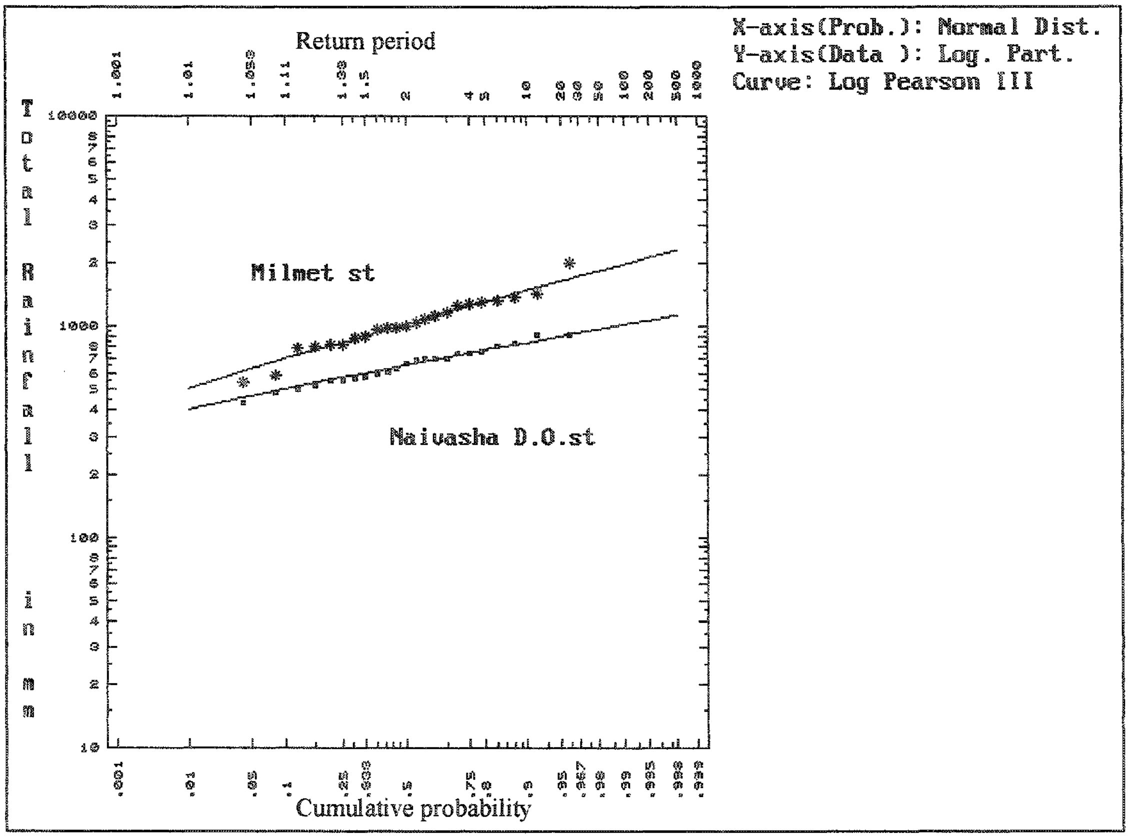


Figure IV–8

Annual Total Rainfall frequency analysis

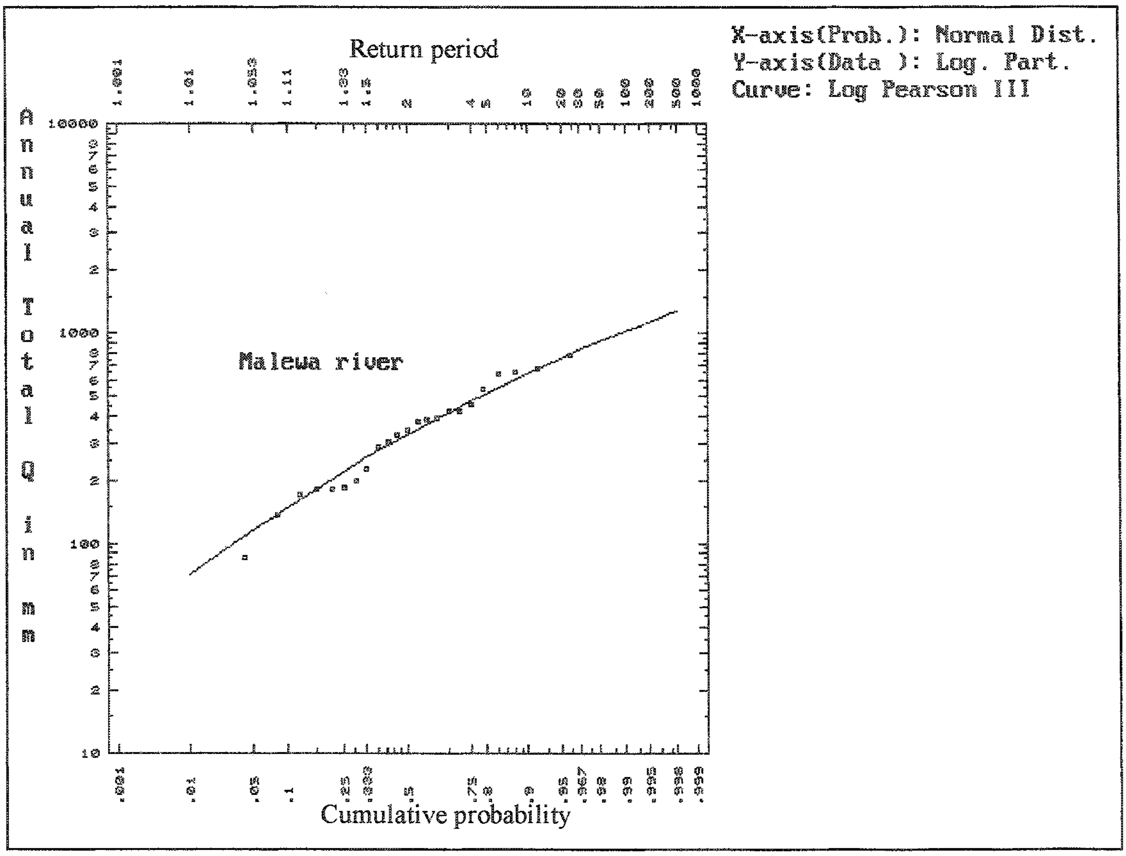


Figure IV–9

Annual Total Discharge frequency analysis

4.7. Water balance.

Water balance is one of the most important mass balance in the nature world. Water transmission is driven by hydrologic cycle according to the law of mass action, keeping its quantity in balance.

The Thornthwaite and Mather method was used to calculate the water balance from year to year with the data available (1960 to 1985). Four input parameters:

precipitation, direct runoff, reference evapotranspiration and Kc values, were needed to calculate the irrigation requirements in mm per month.

The precipitation was taken as described in **section 4.1** whereas the direct runoff was calculated by means of baseflow separation using the Timesplot program from year to year. The two remaining parameters were taken from the report "Crop water requirements" (FAO) as well as using the program Cropwat version 5.7 (October, 1991) that requires meteorological data such as: wind speed, radiation, sunshine hours, temperature, etc. and also characteristics of the crop like duration of each growing stage: initial, mid-season, late season and planting date.

Five irrigated crops were selected: wheat, flowers, alfalfa, vegetables and grass. The Kc value was taken as an average of initial, middle and last developing stage because there is a continuos pattern of harvesting and planting, it was assumed that at a given time there are plots of the same size and each of them contains crops in the last phase, initial and middle developing stages, respectively. For the case of wheat a different approach was applied because there is planting once a year and after harvesting no crop is planted, therefore bare soil occupies that place. The initial stage Kc value was established for all the remaining months were no crop is present and the irrigation requirements in that period was taken as zero.
The Water Holding Capacity (WHC) parameter, see **Table IV-7**, was required in order to start the calculation, it was estimated from the rooting depth (average values) and the maximum predicted Etcrop value (mm/day) and combining them using table Nr.32 given in the document mentioned above.

Table IV–7

Water holding capacity

Crop	WHC (mm)
Wheat	89
Flowers	40
Alfalfa	108
Vegetables	51
Grass	84

The irrigation water requirement for different crops change according to the year type as shown in **Table IV-8**. In order to show the variation of monthly irrigation requirements for the whole period of analysis they were plotted as shown in **Figures from IV-10 to IV-14**, it is worth to mention that the irrigation requirements for the year 1962 are not representative because daily rainfall recordings were not complete for that year. Further details are given in **Appendix IV-8**.

Table IV–8

Yearly Irrigation water requirement for different crops per year type

Year type / Crop	Dry year (1980) (m3/ha)	Average year (1979) (m3/ha)	Wet year (1964) (m3/ha)
Wheat	1740	1310	1280
Flowers	3260	1890	1780
Alfalfa	2960	1870	1620
Vegetables	3320	1960	1860
Grass	2800	1490	1420

Due to the use of average values, it is necessary to realize that the values stated above could be underestimated or overestimated according to the case, so those values should be taken only as a reference about how much water is used by agricultural activities.

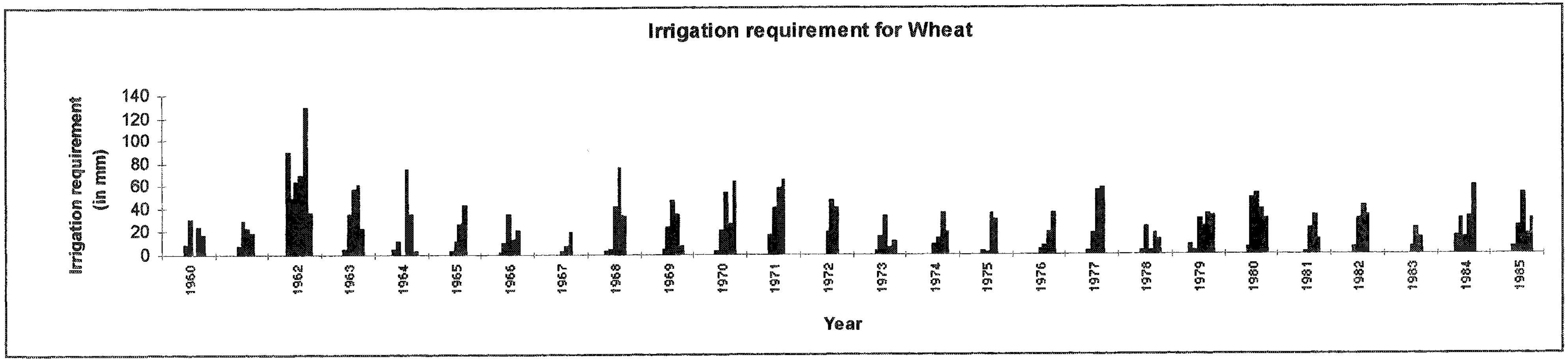


Figure IV–10

Irrigation requirement for wheat

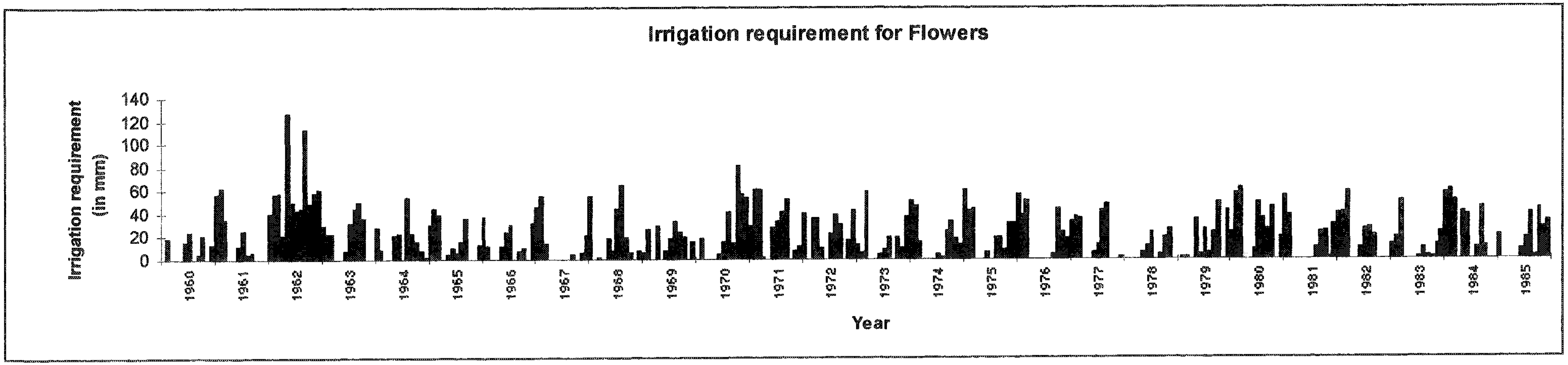


Figure IV–11

Irrigation requirement for flowers

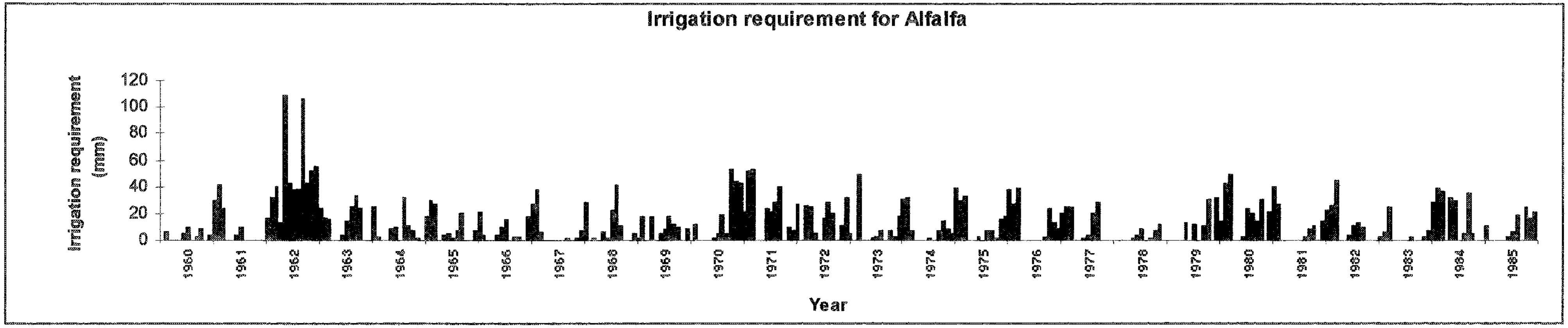


Figure IV–12

Irrigation requirement for alfalfa

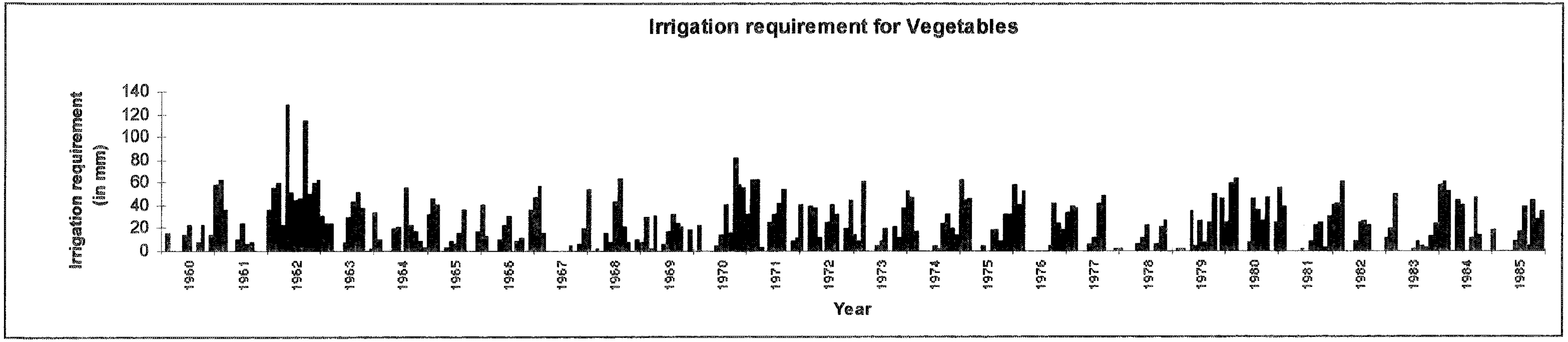


Figure IV–13

Irrigation requirement for vegetables

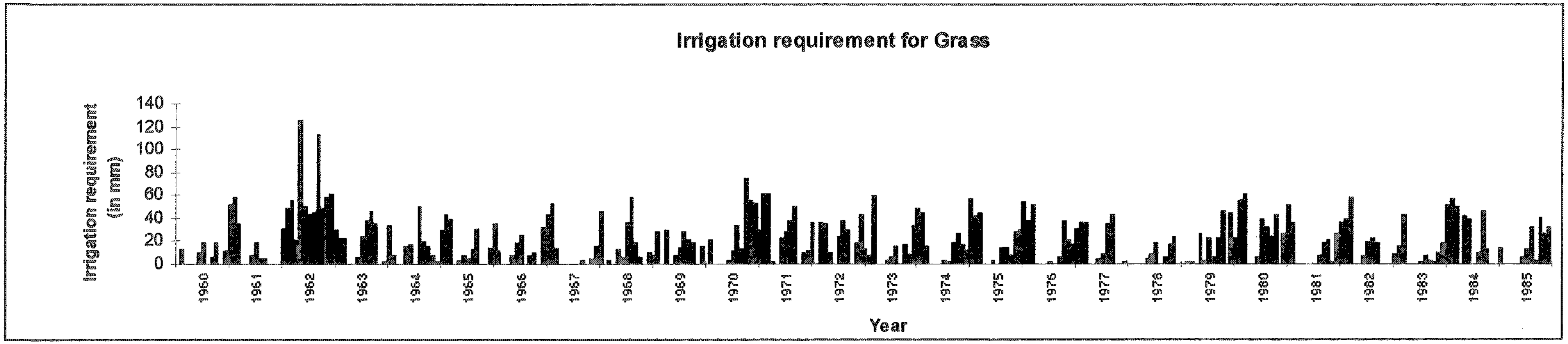


Figure IV–14

Irrigation requirement for grass

For water budget regarding the effect of climate and agricultural practices on the Lake level the following formulae were used:

$$P_{lake} + Qs + Q_{ing} = E_{lake} + Q_{outg} + dSc$$
$$P_{lake} + Qs + Q_{ing} = E_{lake} + Q_{outg} + Irreq + dSt$$

P_{lake} = Precipitation on the lake

Qs = Discharge into the lake

Q_{ing} = Groundwater Inflow into the lake

E_{lake} = Evaporation from the Lake

Q_{outg} = Groundwater outflow from the lake

Irreq = Irrigation requirement for main crops.

dSc = Change in the storage due to climatic conditions.

dSt = Total change in the storage.

The correspondent values for the representative years are shown in **Table IV-9**.

Table IV–9

Water budget in million of m^3

Year	Plake	Qs	Qing	Elake	Qoutg	Irreq	dSc	dSt
1964	99	321	34	224	34	13	196	183
1979	86	189	34	224	34	14	50	36
1980	78	111	34	224	34	23	-35	-59

Those values were obtained from different sources, precipitation and discharge from this chapter, whereas groundwater outflow and Evaporation figures were taken from a publication of the Ministry of Energy about hydrogeology in the area surrounding Lake Naivasha, the value for the ground water outflow was an estimate of the groundwater recharge parallel study*. **Figure IV-15** shows the comparison between the real and the calculated effect of the agricultural practices and climatological conditions on the lake level.

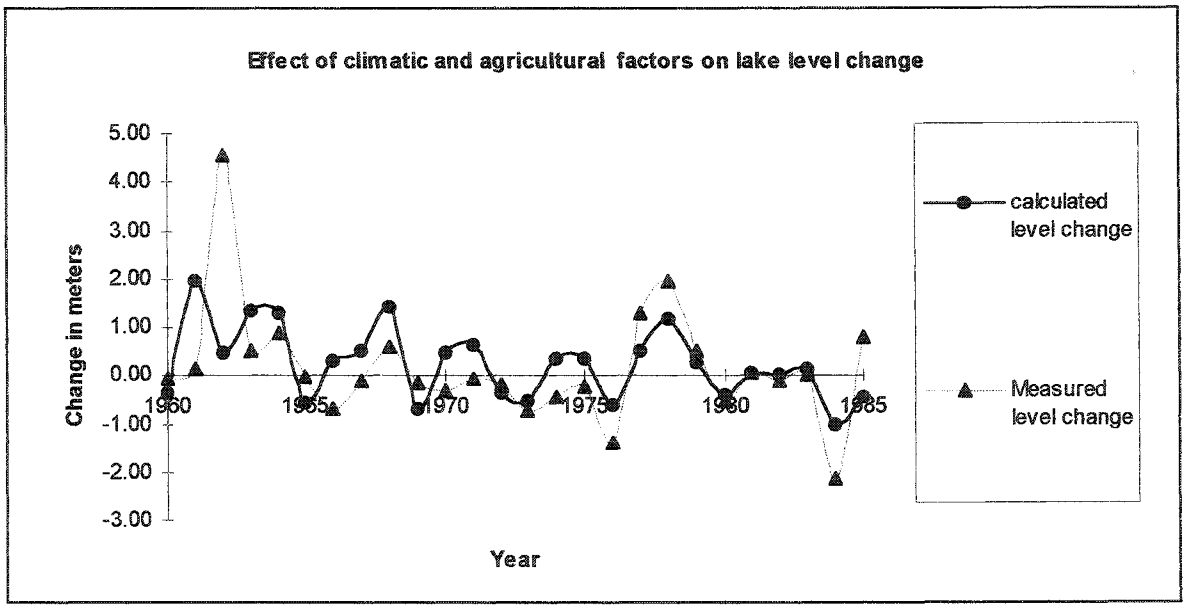


Figure IV–15

Effect of climatic and agricultural factors in lake level

* From a colleague: Ms. Angella Graham

Chapter V : Problem formulation

5.1. Mission identification.

The general description of what is intended to be done is known as mission. It is the guideline to be taken into account when selecting the objectives and activities throughout the whole process. In this study the mission consist in finding suitable ways of using water with a minimum negative effect on the environment. It is necessary to preserve the water resources in order to sustain the growing population, to satisfy food requirements, to generate sources of employment, to increase the farm enterprise gross income, etc.

5.2. Objectives.

The different objectives to be taken into account are summarized as follows:

- To maximize the gross income.
- To maximize employment generation or labor opportunities from agriculture.
- To minimize the water use.

5.3. Integrated water management.

A model for integrated water management helps to develop solutions for water resources and environmental problems by combining all the essential components into an optimization scheme. The model incorporates or accumulates all of the interactive forces or influences. Hence, it aids the decision making process and keeps the policy results within the intersection of the social goals of the management policy and the legal constraints.

The integrated water management should be accomplished within a spatial unit called watershed through the instrument of modeling. It can be viewed as a three or more dimensional process centered around the need for water, the policy to meet the needs and the management to implement the policy.

The management must be dynamic and evolve with time in response to changing needs and objectives. The elements, their interactions, and the effects on the natural as well as external constraints constitute the basis upon which the integrated water management is to be built.

5.4. Users water requirement.

A serious threat to the ecological and economic sustainability of the Lake is the amount of water abstracted each year. Increased demand for water abstraction from surface and ground water sources for agriculture, domestic and other purposes had been observed taking into account the recent water resources assessment study carried out in the study area by the Ministry of Water Development from November 1996 till October 1997 (see **Appendix V-1**).

Water quantity requirements for different uses are given in **Table V-1**, which is based upon the policy of the local representative of the Ministry of Water Development (MOWD).

Table V–1

Water quantity for different uses

Use	Sub-division	Quantity of water
Domestic	Urban Rural	227 lt/person day 45.5 lt/person day
Irrigation	-	22.5 m^3/ha day
Livestock	Large Small	45.5 lt/ head day 9 lt/ head day
Wildlife	-	same as livestock
Industry	-	variable
Tourism	-	same as urban domestic
Fishery	-	variable

Using the water resources assessment studies survey forms it was possible to determine an estimate of the water demand in the catchment, which accounts for 77 million m^3/year approximately, whereas the water abstraction from the Lake was estimated to be around 35 million m^3/year. Those points which were identifiable by X and Y coordinates were plotted as shown in **Figure V-1**.

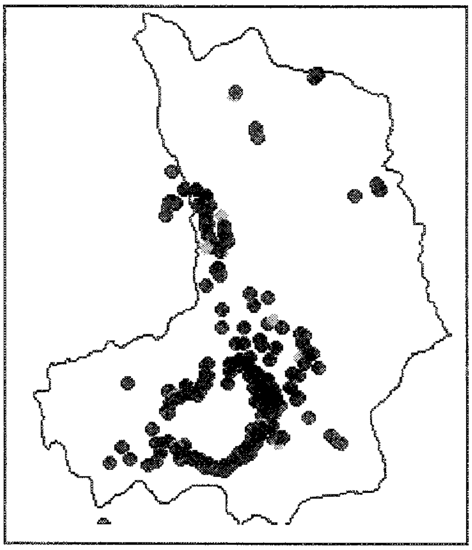


Figure V-1

Survey Points of Water Resources Assessment Studies

From analysis of the forms data it was derived that:

- The main water supply comes from surface water whereas groundwater (boreholes and springs) account from 20 to 25% of the resources (see **Figure V-2**).
- Not all the water sources are suitable for the different users and **Figure V-3** shows that fact, e.g. surface water is taken mainly for agriculture whereas groundwater is used preferable for domestic purposes.
- When regarding water demand, it is visible that the major water consumption belongs to agriculture, the rest of the users account for 15% all together approximately (see **Figure V-4**). That is why a deeper analysis has been performed regarding the water use from agricultural purposes.

- The area for the main irrigated crops was determined by means of satellite image interpretation, see **Figure V-5, V-6 and Table V-2**.

Table V–2

Area per irrigated crop

Crop	Area (ha)
Wheat	231
Flowers	3,598
Alfalfa	728
Vegetables	2,511
Grass	285
Total	**7,353**

The water consumption for agricultural purposes from the forms were analyzed against the theoretical calculation from this study (assuming that water abstaction is constant and subtrating the calculated water need of agricultural purposes) and the results are shown in **Table V-3**. Further details are given in **Appendix V-2**.

It can be seen that water abstraction exceeds much more the requirement of the crops, but although the differences are quite high it should be taken into account that in the theoretical approach the area determination was based in the interpretation of a satellite image from January 1995 whereas the survey forms are dated from 1996 to 1997. At the same time it was considered that the whole amount of abstraction is used for irrigation, because the use for other purposes had been neglected. Furthermore, the water balance which gives the water requirement per crop is based mainly on average values. For that reason underestimation or overestimation is likely to happen.

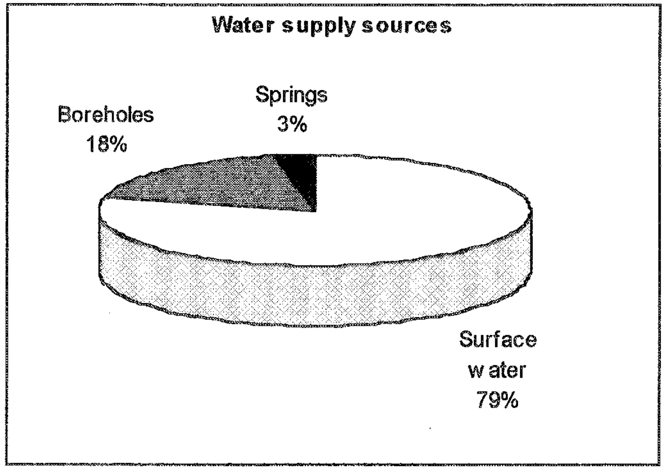


Figure V-2

Water supply sources

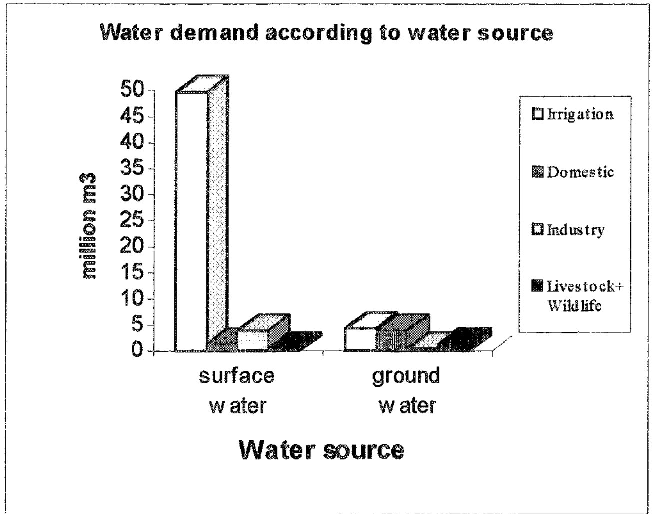


Figure V-3

Water demand vs. water source

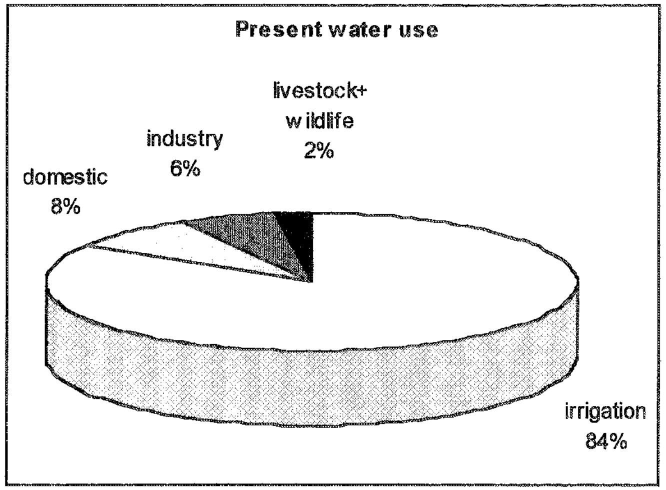


Figure V-4

Present water use

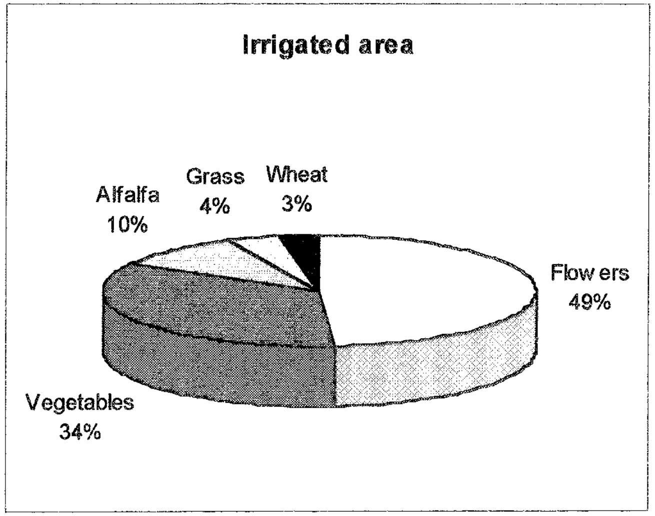


Figure V-5

Irrigated area

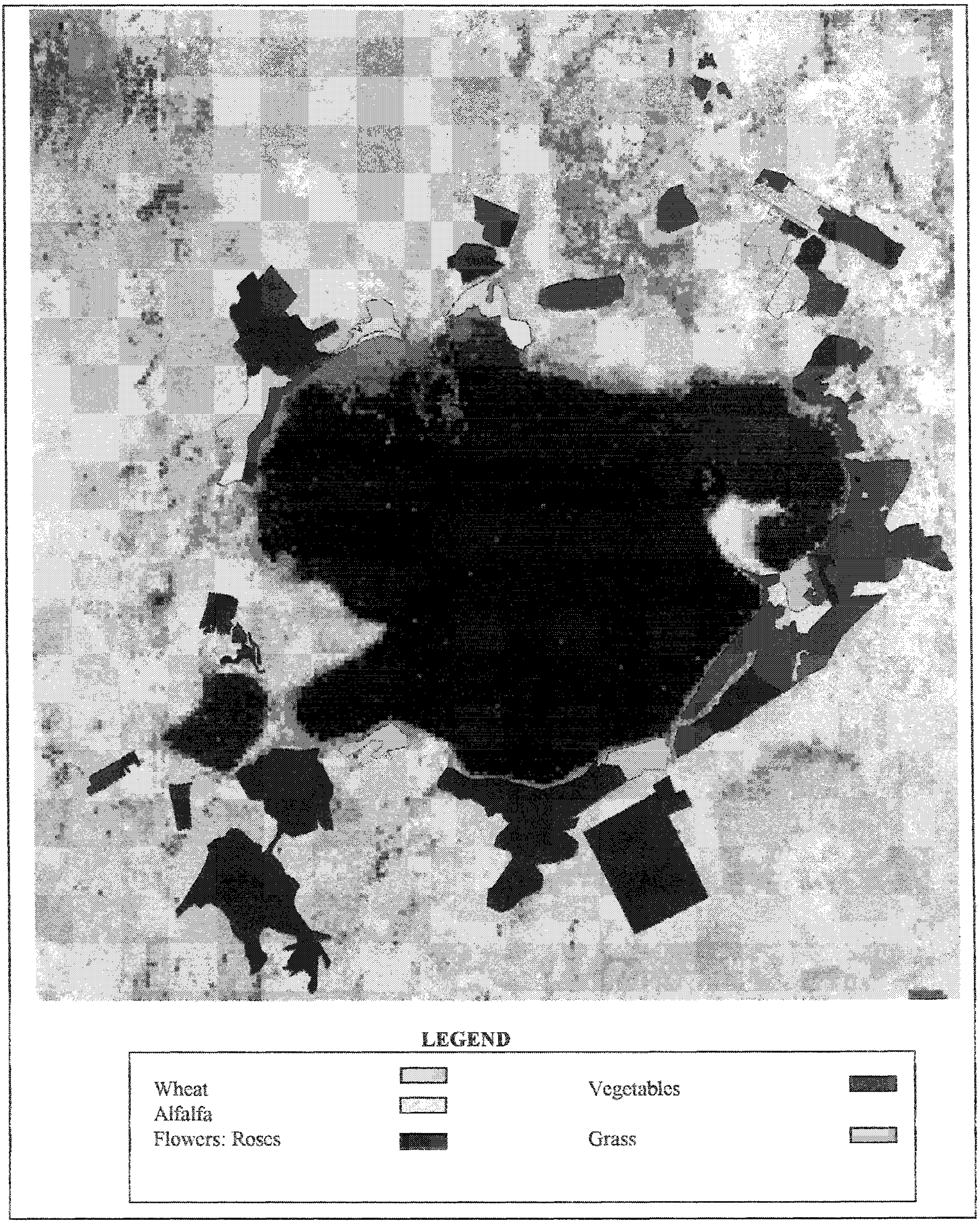


Figure V-6

Satellite image interpretation of irrigated areas

Table V–3

Comparison between the survey forms and the theoretical approach

Crop	Declared (1)		Calculated (2)				Difference (1)-(2)			
	Area (ha)	**Abstraction (10^6 m3/y)**	**Area (ha)**	**High Need (10^6 m3/y)**	**Average Need (10^6 m3/y)**	**Low Need (10^6 m3/y)**	**Area (ha)**	**High Water use (10^6 m3/y)**	**Average Water use (10^6 m3/y)**	**Low Water use (10^6 m3/y)**
Flowers	3639.40	13.35	3598	11.73	6.80	6.40	41.40	1.62	6.55	6.94
Vegetables	641.00	7.08	2511	8.34	4.92	4.67	-1870.00	-1.26	2.16	2.41
Alfalfa	656.23	16.26	728	2.15	1.36	1.18	-71.77	14.10	14.90	15.08
Grass	23.60	3.21	285	0.80	0.42	0.40	-261.40	2.42	2.79	2.81
Wheat	140.00	0.30	231	0.40	0.30	0.30	-91.00	-0.11	-0.01	0.00
total	**5100**	**40**	**7353**	**23**	**13.81**	**12.95**	**-2253**	**17**	**26**	**27**

Chapter VI : Model design

6.1. Production activities.

In order to produce crops, several activities have to be performed, which are described below on yearly basis.

6.1.1. The yield of crops

The yield is assumed to be independent from the type of year (dry, average or wet). The yield of crops is required to satisfy local needs in order to provide food to people as well as feed for livestock which is mainly cattle (more than 90% of the total). Most of the large farms are involved in flower production for export. These are concentrated around Lake Naivasha and use the Lake water for irrigation and they are owned by both multinational firms and individuals.. **Table VI-1** shows the amount of yield and the production requirement per crop.

The production requirement of alfalfa and grass were taken as maximum because the amount of fodder coming from those crops is not enough to meet the feed requirement of the cattle in the study area, so it is assumed that other fodder crops like maize are used to achieve that level.

Table VI-1

Crop Yield/ha

Crop	Yield (Tons/ha)	References	Food requirement	References
Wheat	2	[*]	459	[11]
Flowers	91	[*]	0	[*]
Alfalfa	15	[9]	10920	[maximum]
Vegetables	28	[9]	282	[11]
Grass	6	[8]	1637	[maximum]

6.1.2 Labor required

Labor is required to support crop production activities like: land preparation (ploughing and harrowing), seeding/planting, weeding/maintenance, irrigation, fertilizing, pest controlling and harvesting (cutting, carrying, trashing, cleaning).

The power for land preparation activity is assumed to be different according to the crop. By definition the labor force consists on the segment of the population aged between 15 and 59 years, and only the 37% of the total population is assumed to be active participants in the labor market either as people in employment or as job-seekers. Out of this local labor force, it is estimated that about 60% will be engaged in agricultural related activities and the rest in other activities. **Table VI-2** shows the amount of labor needed per crop activity.

* From fieldwork

Table VI-2

Labor requirement

Item	labour requirement (workdays/ha)				
	wheat	**flowers**	**alfalfa**	**vegetables**	**grass**
Total	**29**	**150**	**43**	**50**	**43**
References	[*]	[18]	[*]	[18]	[*]

6.1.3. Material inputs required

Material inputs required by crop production activity that are considered into the model are: Urea and pesticides. **Table VI-3** shows the amount of urea and pesticides needed per crop.

Table VI-3

Urea and pesticides needed per crop

Crop	Urea		Pesticides	
	(Tons/ha)	**References**	**(Tons/ha)**	**References**
Wheat	0.30	[9]	0.007978	[27]
Flowers	2.40	[**]	0.166224	[**]
Alfalfa	0.08	[9]	0.022739	[27]
Vegetables	2.40	[**]	0.040836	[**]
Grass	0.50	[15]	0.006095	[27]

The limiting amounts of fertilizer and pesticides were assumed to be 800 and 15000 Tons respectively. Those values were calculated by using the area obtained in **section 5.4** and the doses amount applied per crop.

* From fieldwork

** From a colleague: Mr. De Silva.

6.1.4. Farm gate price

Farm gate prices are various, in fact the quality of grain and the conditions of surplus products practically determine their level. The farm gate prices depend also upon the kind of year in which crops are planted (dry, average or wet). **Table VI-4** shows the prices per crop. During a dry year the prices rise 30% approximately, whereas during a wet year they just maintain their average price (from personal communication with a colleague: Mr. Kwacha)

Table VI-4

Prices per crop

Crop	Price (million KSh/ton)		
	Dry year	Average and Wet	References
Wheat	0.021667	0.016667	[*]
Flowers	0.052143	0.040110	[*]
Alfalfa	0.009079	0.006984	[10]
Vegetables	0.022364	0.017203	[4]
Grass	0.009079	0.006984	[10]

For a variety of reasons only a portion of the plant biomass is eaten by animals. About 20% of the total net biomass (Bn) is in roots; a portion of the biomass is not eaten (particularly under low inputs) due to low palatability; some biomass is loss during trampling, fire and wind; and part is consumed by invertebrate animals. It is generally assumed that between a third and two thirds of the total biomass yield of an area will be consumed by stock depending on the environment. In this study it is assumed that 60% of the total yield is utilized by the cattle, that quantity of fodder represents milk and meat that were used to give an economic value to those crops[**].

[*] From fieldwork

[**] The prices of milk and meat were obtained from personal communication with a kenyan ITC student: Mr. Nyabenge

6.1.5. Irrigated area

See **section 5.4 (Table V-2).**

6.1.6. Water need

See **section 4.7 (Table IV-8**).

6.2. The components of the model.

The model consists of decision variables, technical coefficients, constraints and objective functions. The conceptual model is described in **Appendix VI-1.**

6.2.1 Decision variables.

Decision variables are the choice variables which are defined as:

X_i where: i = the i-th irrigated crop.

X means the number of hectares dedicated to crop i and it is calculated by the model. The crops considered are: wheat, flowers, alfalfa, vegetables and grass. So that i=1 is wheat, i=2 is flowers, i=3 is alfalfa, i=4 is vegetables and i=5 is grass.

6.2.2. Technical coefficients

The technical coefficients are the known-defined constants which are related to the variables, they can be stated using scalar or parameter notation.

a) Scalars.

The scalar statement is used to declare or initialize a parameter of dimensionality zero. For instance: $AREA_t$, is the total irrigated area available.

b) Parameters.

Parameter is a data type that encompasses scalars:

P_i where: i = the i-th irrigated crop.

For a specific purpose, a general notation of a constant (P) will be replaced by a specific notation, such as: $YIELD_i$, $LABOR_i$ $PESTICIDE_i$, $UREA_i$, WATER USE_i, etc. The $LABOR_i$ represents the workdays per hectare that requires the i-th crop.

6.2.3. The constraints

Several constraints were considered by the model. Capacity constraints: the water requirement, the availability of labor and land. Input materials supply: pesticides and urea. Minimum requirement of production was also considered. The constraints of the conceptual model were stated as follows:

- Capacity constraints.

$$\sum_{i=1}^{5} X_i <= AREA$$

Equation VI-1

where *AREA*= the total irrigated area.

$$\sum_{i=1}^{5} (LABOR_i * X_i) <= MANFORCE$$

Equation VI-2

where *MANFORCE*= the man force availability.

$$\sum_{i=1}^{5} (WUSE_i * X_i) <= SUPPLY$$

Equation VI-3

where *SUPPLY*= the water quantity availability.

- Input materials supply.

$$\sum_{i=1}^{5} (UREA_i * X_i) <= \mathrm{UREAL}$$

Equation VI-4

where UREAL= the urea limit amount.

$$\sum_{i=1}^{5} (PESTICIDE_i * X_i) <= \mathrm{PESTL}$$

Equation VI-5

where PESTL= the pesticide limit amount.

- minimum requirement of crop production activities.

$$\sum_{i=1}^{5}(YIELD_i * X_i) >= FOOD_i$$

Equation VI-6

where $FOOD_i$ = the required amount production of the i-th crop.

- Non negativity of variables.

$$\sum_{i=1}^{5} Xi >= 0$$

Equation VI-7

6.2.4. The objective functions.

1) Maximize the gross income.

$$\text{Max}\,(\sum_{i=1}^{5} (YIELD_i * PRICE_i * X_i))$$

Equation VI-8

2) Maximize employment.

$$\text{Max}\,(\sum_{i=1}^{5} (LABOUR_i * X_i))$$

Equation VI-9

3) Minimize the water use.

$$\text{Min}\,(\sum_{i=1}^{5}(WUSE_i * X_i))$$

Equation VI-10

To solve the previous equations three models were generated for each objective function for the different years: dry, average and wet. The conceptual formulation was translated into a language compatible with the GAMS software (see **Appendix VI-2**).

Chapter VII : Scenarios Generation and Evaluation

7.1. Developing the scenarios.

The present study came up with three scenarios: maximising gross income, maximising employment and minimising the water use. The results of those scenarios are shown in **Table VII-1 and VII-2**, they are described and evaluated in the next sub-sections.

The scenarios were supported by a set of data (stated in the previous chapter) which can be used by the Decision Makers to assess the alternatives. The set of information are: land, water, yield, price, labour requirements, limits for fertiliser and pesticide supply.

Table VII-1

Results of the model

Objective	Units	Scenario 1			Scenario 2			Scenario 3		
		dry	average	wet	dry	average	wet	dry	average	wet
Gross income	[million ksh]	22,383	17,218	17,218	22,206	17,082	17,082	13,898	10,691	10,691
Employment	[workdays]	753,650	753,650	753,650	809,040	809,040	809,040	485,420	485,420	485,420
Water use	[10^6 m3]	19	11	10	23	13	12	13	8	7

Table VII-2

Consequences of the model

Item	Units	Scenario 1	Scenario 2	Scenario 3
urea	[10^-1 Tons]	1,154	1,215	725
pesticides	[Tons]	800	800	503
yield of wheat	[Tons]	459	459	459
yield of flowers	[10^-2 Tons]	4,268	4,218	2,640
yield of alfalfa	[10^-1 Tons]	1,092	1,092	1,092
yield of vegetables	[Tons]	282	282	282
yield of grass	[10^-1 Tons]	164	1,050	164
area of wheat	[ha]	230	230	230
area of flowers	[ha]	4,690	4,636	2,902
area of alfalfa	[ha]	728	728	728
area of vegetables	[ha]	10	10	10
area of grass	[ha]	273	1,750	273
total area	[ha]	5,930	7,353	4,142

water use efficiency

Scenario	Unit	dry	average	wet
1	[Ksh/m^3]	1,201	1,572	1,684
2	[Ksh/m^3]	983	1,309	1,397
3	[Ksh/m^3]	1,085	1,412	1,518

7.1.1. Scenario 1: maximising gross income

According to Brown (1979) the gross income assess the performance of an enterprise purely in terms of the benefits it yields without considering the cost to produce them. The scenario of maximising farm gross income can be regarded as a strategy to achieve the maximum income for local population. The scenario allows the maximum level of income achievement subject to the availability of resources in the study area. **Table VII-3** shows the achievement level of the objective and the consequences of scenario 1.

Table VII-3

Achievement level and consequences of scenario 1

(Maximising gross income)

Item	Yearly Units	Value		
		Dry	Average	Wet
Maximise gross income	***million Ksh***	***22,383***	***17,218***	***17,218***
Employment generation	workdays	753,650		
Water use	m^3	19	11	10
Efficiency of water use	Ksh/ m^3	1,201	1,572	1,684
pesticide	tons	800		
urea	tons	11,543		
Yield				
Wheat	tons	459		
Flowers	tons	426,760		
Alfalfa	tons	10,920		
Vegetables	tons	282		
Grass	tons	1,637		
Area				
Wheat	ha	230		
Flowers	ha	4,690		
Alfalfa	ha	728		
Vegetables	ha	10		
Grass	ha	273		
Total Area	ha	5,930		

a. The achievement level of gross income

The achievement level of the present scenario is between 17 and 22 thousand million of Ksh. From the economic return point of view this scenario is the best.

b. The achievement level of employment

The achievement level of employment is around 750 thousand workdays. It represents the intermediate level when compared with the value from other scenarios.

c. The achievement level of water use

The achievement level of water use of the present scenario ranges from 10 to 19 million m3. These achievement level is better than the one from the second scenario but worse than the others.

d. The consequences of scenario 1

The scenario shows some consequences which are stated in **Table VII-3**. It uses 80% of total area for irrigation, the model tries to get the maximum income by starting from the crops which give more economic advantage but it is limited by the amount of pesticides supply, because by coincidence those crops highly profitable need also higher inputs amount. This scenario uses the full amount of pesticides and 11.5 thousand tons of fertiliser. **Figure VII-1** shows the achievement level of scenario 1.

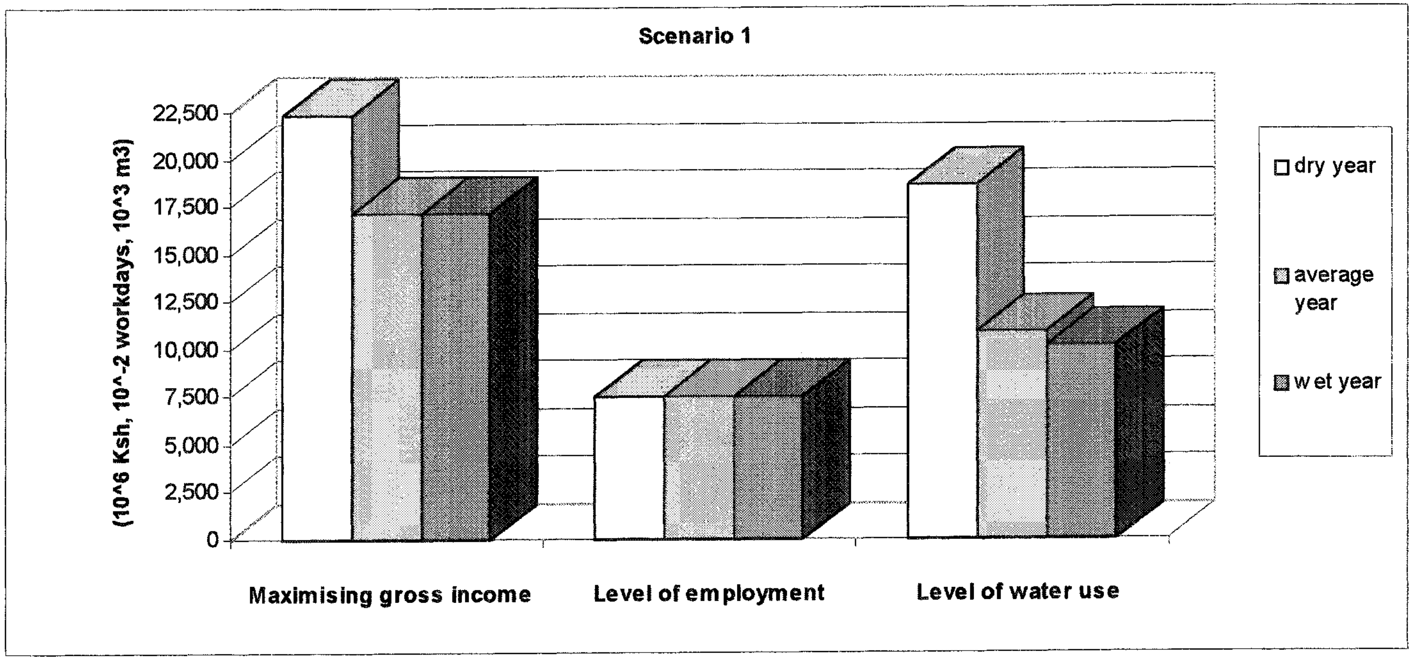


Figure VII-1

Achievement level of scenario 1 (Maximise gross income)

7.1.2. Scenario 2: maximising employment

This scenario aims at the maximum generation of employment from agricultural activities. **Table VII-4** shows the achievement level of goals and the consequences of scenario 2.

Table VII-4

Achievement level and consequences of scenario 2

(Maximising employment generation)

Item	Yearly Units	Value		
		Dry	Average	Wet
Gross income	million Ksh	22,206	17,082	17,082
Maximise employment	***workdays***	***809,040***		
Water use	m^3	23	13	12
Efficiency of water use	Ksh/ m^3	983	1,309	1,397
pesticide	tons	800		
urea	tons	12,152		
Yield				
Wheat	tons	459		
Flowers	tons	421,830		
Alfalfa	tons	10,920		
Vegetables	tons	282		
Grass	tons	10,499		
Area				
Wheat	ha	230		
Flowers	ha	4,636		
Alfalfa	ha	728		
Vegetables	ha	10		
Grass	ha	1,750		
Total Area	ha	7,353		

a. <u>The achievement level of gross income</u>

The achievement level of gross income by this scenario ranges from 17 to 22 thousand million Ksh. From the economic point of view this scenario represents an intermediate level.

b. <u>The achievement level of employment</u>

The level of employment by this scenario is around 800 thousand workdays. From the social point of view this is the best scenario.

c. <u>The achievement level of water use</u>

The achievement level of water use of the present scenario is around 12 and 23 million m3. These amount is the highest from the three scenarios therefore it is the worst scenario from the ecological point of view.

d. <u>The consequences of scenario 2</u>

The scenarios shows a different level of consequences which are stated in **Table VII-4**. It uses the total area available, in this case the limiting factors are the supply of pesticides and the land itself, because the model tries to maximise the number of workdays, starting for those crops which provide more employment generation. At the same time it uses all the pesticide supply and the highest amount of fertiliser.

Figure VII-2 shows the achievement level of scenario 2.

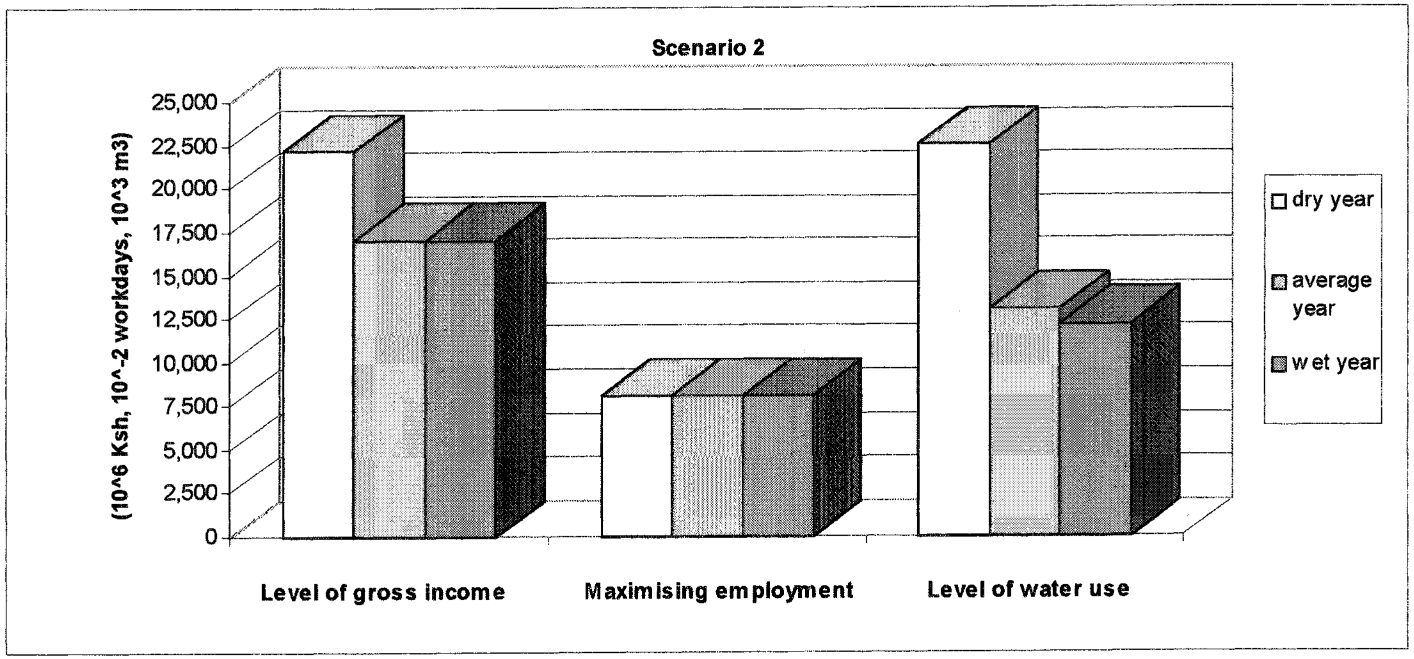


Figure VII-2

Achievement level of scenario 2 (Maximise employment)

7.1.3. Scenario 3: minimising water use

According to Harper et al (1993) lake level rise provides further nutrient influx from flooded soils whilst lake level fall results in concentration of nutrients. That is why this scenario has been considered because water use is linked directly with the lake water level change and it can be regarded as a strategy to increase the water quality. The scenario limits the water use subject to the requirement of production and minimum employment from agricultural activities in the study area. **Table VII-5** shows the achievement level of the objective and the consequences of scenario 3.

Table VII-5

Achievement level and consequences of scenario 3

(Minimising water use)

Item	Yearly Units	Value		
		Dry	Average	Wet
Gross income	million Ksh	13,898	10,691	10,691
Employment generation	workdays		485,420	
Minimise water use	***m^3***	***13***	***8***	***7***
Efficiency of water use	Ksh/ m^3	1,085	1,412	1,518
pesticide	tons		503	
urea	tons		7,251	
Yield				
Wheat	tons		459	
Flowers	tons		264,040	
Alfalfa	tons		10,920	
Vegetables	tons		282	
Grass	tons		1,637	
Area				
Wheat	ha		230	
Flowers	ha		2,902	
Alfalfa	ha		728	
Vegetables	ha		10	
Grass	ha		273	
Total Area	ha		4,142	

a. The achievement level of gross income

The achievement level of gross income of the present scenario is between 10 and 13 thousand million of Ksh. From the economic point of view this scenario is the worst, due to the low production of flowers which gives the highest contribution to the income.

b. The ideal achievement of employment and the achievement level

The achievement level of employment is around 485,000 workdays. One of the constraints considered in this scenario was the minimum level of employment which served to control the output, otherwise it was meaningless. Even then this scenario generates the highest unemployment, because it just covers the minimum requirements. Therefore from the social point of view this scenario is the worst.

c. The achievement level of water use

The achievement level of water use of the present scenario is around 7 and 13 million m3. These achievement level is the best from the ecological point of view.

d. The consequences of scenario 3

The scenario shows a different level of consequences which are stated in **Table VII-5**. It uses only 56% of the total area available. At the same time it uses the smallest quantity of input materials like fertiliser and pesticides

Figure VII-3 shows the achievement level of scenario 3.

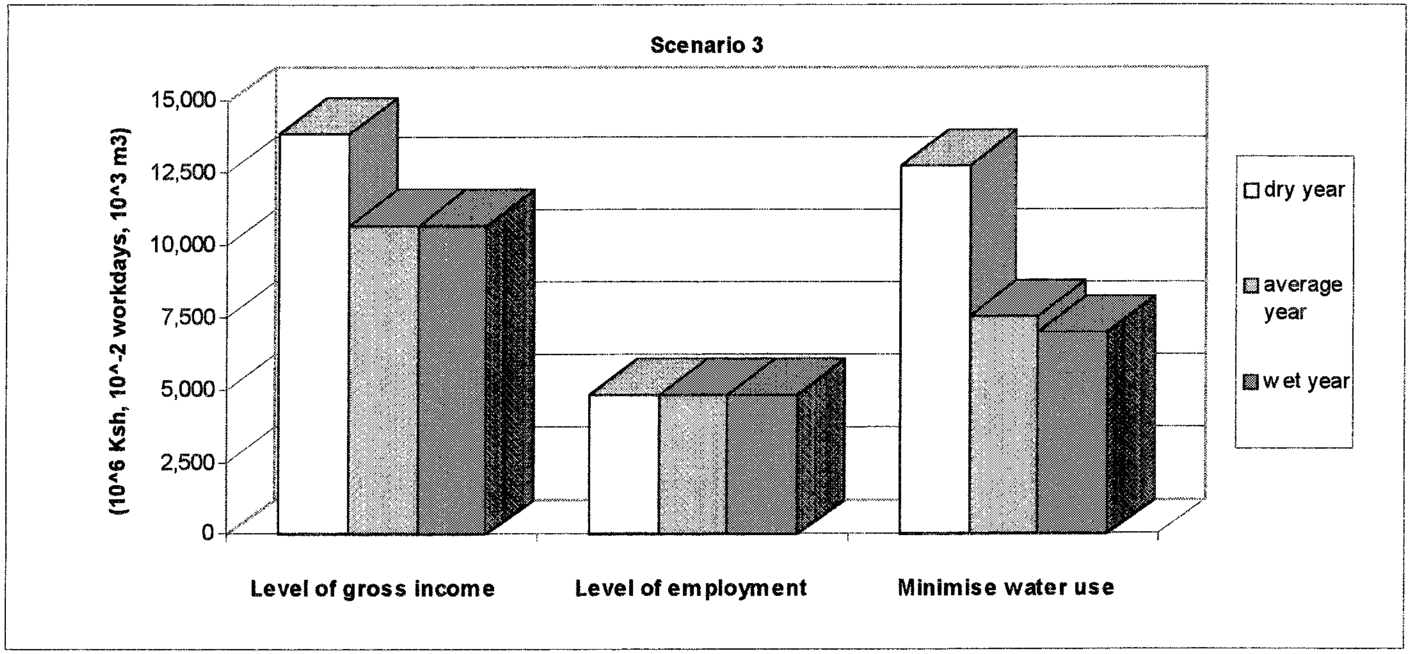


Figure VII-3

Water use from the different scenarios

The overall evaluation of the three scenarios described above was performed by comparing the consequences of each of them, **Figure VII-4 and VII-5*** show that scenario 1 is the most attractive when taking into consideration water use efficiency, which relates the gross income (scenario 1) and the water use (scenario 3). On the other side scenario 2 gives considerable benefits such as high yields and optimising the social conditions in the study area.

7.2. Sensitivity analysis.

In reality the technical coefficients are estimations, the data to formulate those estimations are rather imperfect, so the parameters of the original formulation can represent optimistic or pessimistic points of view which protect the interests of that particular group of people.

Therefore an optimal solution can be considered as such when it can be verified that its behaviour is adequate for other reasonable representations of the problem. Due to these reasons it is important to perform a sensitivity analysis to see the effect of the parameters change into the optimal solution. The principal aim of this kind of analysis is to identify the sensitive parameters, in order to pay special attention in their estimation and to select a solution that gives adequate results in the major part of the probable values.

* The units of z-axis are indicated in table VII-2

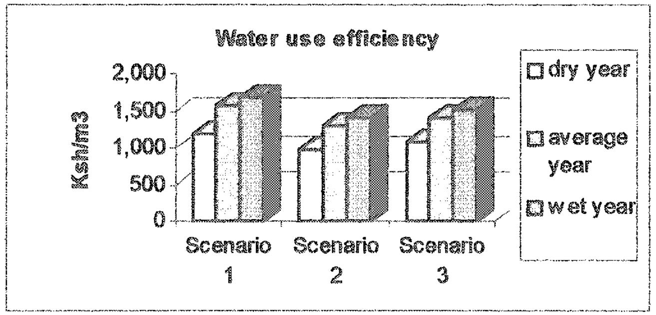


Figure VII-4: Water use efficiency

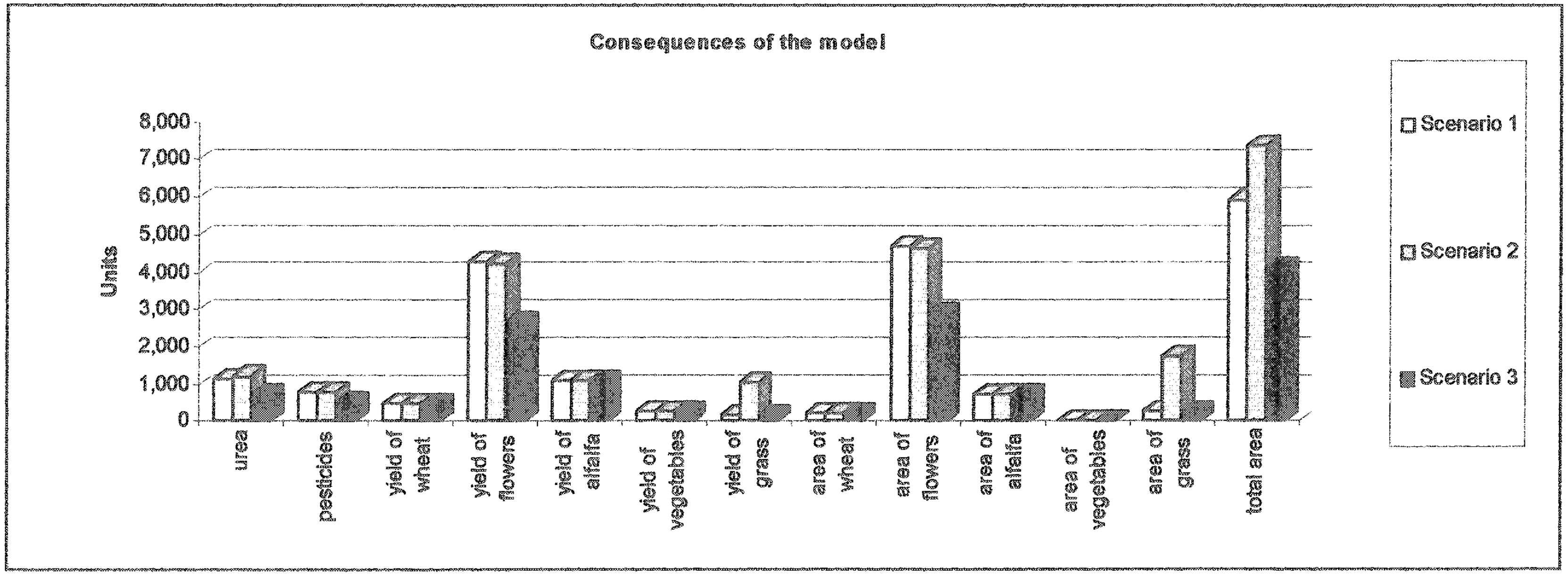


Figure VII-5: Consequences of the model

7.2.1. Shadow prices

Shadow prices measure the marginal value of the resources: right hand side (R.H.S), it is the rate at which Z (objective function) can increase / decrease with a slightly increase / decrease on the quantity available of that resource. They are used to support the final management decision regarding the assignation of resources. **Table VII-6** shows the results of the sensitivity analysis for the model involved in this study.

For instance when incrementing the pesticide supply from 800 to 801 tons the objective function of maximising employment changes positively from 8.0904 $*10^5$ to 8.0971 $*10^5$ workdays, which represents an increment according to the pesticide limit shadow price stated in the original optimal solution.

Table VII-6

Sensitivity analysis result

R.H.S. parameter	Scenario 1			Scenario 2	Scenario 3		
	Dry	Average	Wet	All year types	Dry	Average	Wet
Pesticide limit	28.546	21.958	21.958	668.211	0	0	0
Urea limit	0	0	0	0	0	0	0
Land	0	0	0	38.927	0	0	0
Yield requirement							
Wheat	-0.092	-0.071	-0.071	-7.629	$5.55*10^{-4}$	$4.72*10^{-4}$	$4.68*10^{-4}$
Flowers	0	0	0	0	0	0	0
Alfalfa	-0.034	-0.026	-0.026	-0.741	$1.35*10^{-4}$	$8.85*10^{-5}$	$7.40*10^{-5}$
Vegetables	-0.019	-0.015	-0.015	-0.579	$7.98*10^{-5}$	$4.75*10^{-5}$	$4.52*10^{-5}$
Grass	-0.020	-0.015	-0.015	0	$3.11*10^{-4}$	$1.58*10^{-4}$	$1.52*10^{-4}$

From the sensitivity analysis it can be said that scenario 3 is highly stable because it has the smallest shadow prices, the opposite happens to scenario 2. Therefore scenario 1 is the intermediate scenario in stability.

Chapter VIII : Conclusions

The present chapter is divided into: conclusions, study strengths / weaknesses and suggestions for further research.

8.1. Conclusions.

Some conclusions of the present study can be described from the research objectives, as follows:

- To define the study area's environmental system and analyze its underlying ecological biophysical, social and economic structures and interactions in terms of water resources supply and demand.

Discussion

Lake Naivasha and surrounding areas have an important potential for developing both natural attraction and man activities. From the analysis of the situation in the study area, three main needs were detected: labor opportunities, financial resources and water availability. Those needs were linked together and related to a typical kind of year, in hydrological terms: dry, average or wet year.

- To apply multi-objective decision support systems necessary to present different scenarios to the decision makers of a sub-system: agricultural water use.

Discussion

Decision support systems were used by means of a mathematical model which is Linear Programming, different scenarios were generated and from each of them the achievement levels were calculated for all the objectives which represent three extreme points of view: economic, social and ecological. In each of those perspectives water quantity involved in irrigated agriculture was considered, because it accounts for around 84% of the total amount of water demand in the area.

It is left to the decision makers the final choice, because this type of systems "support" but do not "replace" the decision maker.

- To use Geographic Information Systems (GIS), aerospace survey techniques and modeling tools for environment data acquisition, analysis and management of the study area.

Discussion

During pre-field work a preliminary land use map was generated, afterwards it was checked and changed using supervised classification and pasting the irrigated areas and settlements which were identified it was possible to come up with the land use map given in chapter 3 and to calculate the area of the different cover types (Chapter 5).

- To determine the objectives and constraints in order to define and evaluate the environmental conditions of Lake Naivasha natural resources.

Discussion

The objective functions were defined as: maximization of gross income, maximization of employment and minimization of water use. Several constraints were identified in order to build up the model, such as: land, yield, farm gate price, water, labor, and so on. Due to lack of data other constraints involved were not considered such as: production costs, so the model was simplified, in order to make the relations between the parameters clear enough to find a logical sequence on the results.

8.2. Study strengths and weaknesses.

The Multi-objective decision making problem of water use planning considered by the present study has both strengths and weaknesses, as described below.

8.2.1. Study strengths

- A model is used to understand and attempt the real world complex problem of water use management and decision making. By building the model the answer is stated in a particular way, the computer program helped in stating the problem.
- The model required the analyst to reveal the hidden assumptions, which are inevitable in any kind of research. This required condition of the model can make the method better communicated, debated, refuted and falsified. The present study

needed to make assumptions about the expected yield, required labor, material inputs, price, etc. per crop production activity.

- If new information related to the complexity of the problem comes up and it causes inconsistency with the earlier assumptions, then the model should be modified, hence, the model has flexibility to adapt whatever the system needs.
- By using the model, alternative scenarios can be evaluated more clearly. Decision makers know the ideal value, the achievement level of the targets and the consequences of each scenario, so it is up to them the final choice.

8.2.2. Study weaknesses

- The more complex the problem the more data involved. This means the more time to be consumed by the work, not only required by the amount of data, but also required by the accuracy and care in calculating the data.
- In building the conceptual model, a good understanding of the real-world complex problems of decision making, the mathematical knowledge has to be held by the analyst.
- When the conceptual model and data must be translated into a software, the analyst has to generate the computer program. In this part the experience of handling the software is needed. This means that trial and error activities of finding the proper computer program which represents the conceptual model, which is a time consuming activity.
- The technique of Linear Programming is based on the following four assumptions:

a) That the physical requirement of each production factor per unit of farm enterprise is fixed. A constant input-output ratio (or transformation coefficient) is assumed, irrespective of the scale of operation.

b) That both the farm resources and the farm enterprises are divisible and additive in order to achieve the goal maximization.

c) That each farm enterprise is independent of the others, and the selection of one does not need the selection of the other.

d) That the number of enterprises adoptable is finite and consequentely choices and combination can be made only within this finite number of enterprises.

These assumptions can be regarded as shortcomings from the technique used.

8.3. Suggestions for further research.

The present study has several beneficiaries related to the decision making process and water use planning, specifically in Naivasha Division, Kenya. Some suggestions are stated as follows:

- The method used by the present study can be developed and completed for multi-level management, at District and National level.
- An integration with the water quality research would be very beneficial, in order to have a wider approach of the water resources in the study area.
- A complex model regarding more input parameters involved in production activities can make the "supposed system" to be closer to the "real system".
- To deeply analyze not only irrigated agricultural water use, but also domestic, industrial, livestock, etc. water demand would give more accurate estimates.

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Appendices

Appendix IV-1

Yearly Rainfall data

9036002 Naivasha D.O. station

Year	Rainfall (mm)	Cum Rain (mm)	Max.Daily rain (mm)
1960	668.4	668.4	50.8
1961	916.5	1585	50.0
1962	57.4	1642	29.2
1963	802.1	2387	51.1
1964	**710.1**	**3097**	**40.1**
1965	520.9	3618	32.0
1966	748.0	4366	47.0
1967	699.0	5065	34.3
1968	765.3	5830	44.7
1969	507.5	6338	45.5
1970	601.8	6940	46.9
1971	693.5	7633	70.7
1972	561.6	8195	55.8
1973	575.2	7515	41.9
1974	708.7	8224	39.5
1975	565.6	8789	52.0
1976	485.9	9275	28.9
1977	830.0	10105	51.3
1978	909.4	11014	38.7
1979	**612.9**	**11627**	**38.7**
1980	**557.9**	**12185**	**42.3**
1981	708.9	12894	33.8
1982	741.9	13636	55.3
1983	634.2	14270	43.6
1984	437.5	14708	47.4
1985	558.4	15266	40.8

Average **664**

345 Milmet station

Year	Rainfall (mm)	Cum Rain (mm)	Max.Daily rain (mm)
1960	968.2	968.2	55.4
1961	1391.9	2360	45.0
1962	1141.2	3501	48.3
1963	1167.9	3528	53.6
1964	**1330.4**	**4858**	**48.5**
1965	908.0	5766	55.9
1966	811.3	6578	45.5
1967	1246.7	7824	86.4
1968	1282.5	9107	52.8
1969	814.8	9922	39.1
1970	819.7	10741	49.2
1971	89.1	10831	3.3
1972	113.9	10944	5.4
1973	1083.4	11825	99.1
1974	1004.2	12829	48.0
1975	994.8	13824	27.0
1976	880.2	14704	51.4
1977	1299.0	16003	38.0
1978	1433.4	17436	53.0
1979	**995.0**	**18431**	**35.5**
1980	**782.5**	**19214**	**35.1**
1981	1133.8	20348	38.9
1982	545.0	20893	39.0
1983	1258.5	22151	45.6
1984	585.6	22737	66.4
1985	1039.9	23777	94.1

Average **1034**

Appendix IV-2

Monthly Rainfall data

NAIVASHA D.O. STATION (9036002) **Rainfall (mm)**

Year	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1960	55	28	140	106	40	8	4	90	56	30	66	46
1961	0	0	26	97	130	9	0	50	51	103	335	117
1962	0	0	0	0	0	0	0	0	0	57	0	0
1963	34	38	39	213	132	40	2	25	11	29	87	153
1964	**9**	**52**	**106**	**166**	**11**	**20**	**102**	**8**	**38**	**89**	**55**	**54**
1965	35	15	24	111	56	32	37	34	18	54	66	40
1966	21	45	74	206	28	13	6	99	88	51	113	5
1967	15	8	51	109	119	46	84	52	34	99	57	25
1968	2	114	86	251	14	59	4	3	39	56	84	55
1969	47	28	68	25	127	20	14	18	30	26	63	43
1970	83	35	110	110	82	59	26	12	84	0	0	0
1971	42	2	6	64	174	12	39	113	22	138	33	49
1972	19	107	18	19	46	92	21	42	32	93	64	10
1973	57	58	8	127	84	34	21	30	56	35	52	14
1974	13	17	32	223	67	75	70	45	46	30	41	49
1975	2	21	26	127	55	20	80	51	62	81	16	25
1976	8	30	17	69	46	68	48	76	48	8	23	46
1977	31	25	31	205	131	20	67	42	19	79	110	73
1978	76	54	222	125	74	15	11	77	79	45	33	98
1979	**78**	**121**	**59**	**71**	**0**	**63**	**28**	**50**	**48**	**21**	**75**	**0**
1980	**39**	**7**	**0**	**126**	**154**	**68**	**2**	**8**	**32**	**20**	**93**	**10**
1981	0	25	179	142	66	32	55	45	30	42	60	36
1982	25	21	6	118	111	21	8	57	46	93	171	65
1983	36	34	8	84	38	100	40	46	58	92	59	39
1984	3	5	3	64	8	0	51	42	7	52	100	102
1985	18	64	67	147	85	22	29	11	51	17	21	27
Avg.month	**29**	**37**	**54**	**119**	**72**	**36**	**33**	**43**	**42**	**55**	**72**	**45**

Appendix IV-2

Monthly Rainfall data

MILMET STATION **Rainfall (mm)**

Year	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1960	14	0	98	86	249	23	105	125	85	84	93	7
1961	0	0	59	59	151	63	117	178	152	147	329	138
1962	77	9	48	247	238	109	106	129	113	65	0	0
1963	76	59	83	247	195	19	27	60	35	36	149	182
1964	**7**	**70**	**0**	**237**	**140**	**65**	**169**	**153**	**188**	**220**	**13**	**69**
1965	53	36	44	182	73	25	100	51	29	150	166	0
1966	3	82	38	199	56	72	76	0	93	88	99	7
1967	5	0	60	125	284	140	160	248	70	124	0	31
1968	0	105	122	339	169	84	70	80	42	96	128	48
1969	105	50	59	18	131	43	62	0	129	151	59	8
1970	146	0	85	214	127	18	82	129	0	0	0	19
1971	0	0	0	13	18	12	0	19	12	4	3	9
1972	0	10	4	3	28	17	9	10	4	10	16	2
1973	36	58	0	49	315	47	129	135	172	67	56	21
1974	0	12	160	117	126	43	99	148	132	115	43	8
1975	5	12	4	145	140	115	106	174	108	123	45	17
1976	2	6	5	175	141	108	113	115	134	13	64	6
1977	31	26	28	316	200	94	72	71	36	96	248	81
1978	35	179	205	138	136	115	198	83	100	138	57	49
1979	**139**	**108**	**100**	**116**	**127**	**60**	**99**	**125**	**0**	**18**	**102**	**1**
1980	**39**	**0**	**33**	**182**	**183**	**35**	**25**	**80**	**41**	**24**	**137**	**4**
1981	0	20	164	183	120	96	130	178	134	55	54	0
1982	20	35	7	195	195	40	54	0	0	0	0	0
1983	22	39	10	102	218	110	129	198	121	181	59	68
1984	0	0	78	27	16	69	79	62	41	75	107	32
1985	12	101	96	180	167	101	138	86	83	23	54	0
Avg.monthly	**32**	**39**	**61**	**150**	**152**	**66**	**94**	**101**	**79**	**81**	**80**	**31**

Appendix IV-3

Monthly number of rainy days

NAIVASHA D.O. STATION (9036002)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOT
1960	7	5	14	18	5	2	2	7	5	5	7	8	85
1961	0	0	8	13	14	4	0	13	12	21	22	11	118
1962	0	0	0	0	0	0	0	0	0	9	0	0	9
1963	14	10	11	20	24	5	3	5	4	9	20	15	140
1964	**5**	**14**	**15**	**18**	**6**	**6**	**10**	**5**	**8**	**14**	**14**	**14**	**129**
1965	9	4	9	18	11	5	11	10	8	9	18	13	125
1966	8	11	13	18	6	6	4	14	12	8	13	3	116
1967	4	4	13	20	16	10	10	6	9	14	20	9	135
1968	1	17	16	21	10	9	3	6	7	14	21	11	136
1969	10	9	14	11	16	7	4	4	10	5	17	8	115
1970	19	8	15	19	16	8	5	6	12	0	0	0	108
1971	9	1	5	20	17	6	11	18	7	8	11	16	129
1972	11	14	5	9	17	15	6	10	9	15	22	6	139
1973	13	12	4	13	8	9	8	5	16	13	15	4	120
1974	5	6	10	23	10	14	14	10	13	11	14	14	144
1975	3	6	9	17	13	6	11	12	15	12	6	6	116
1976	4	11	8	14	14	13	14	13	6	8	10	9	124
1977	10	11	13	24	18	7	15	12	6	13	22	13	164
1978	9	10	20	25	10	8	10	15	11	17	14	16	165
1979	**11**	**19**	7	**20**	**0**	**12**	**6**	7	**8**	**11**	**13**	**0**	**114**
1980	7	**2**	**0**	**16**	**23**	**12**	**2**	**5**	7	7	**17**	**4**	**102**
1981	1	3	16	15	13	5	8	7	7	5	11	8	99
1982	4	4	4	12	13	3	2	9	9	18	23	9	110
1983	6	12	3	13	6	8	6	3	10	10	9	8	94
1984	2	3	2	11	3	0	9	11	4	7	15	8	75
1985	3	7	8	17	10	4	4	4	6	6	9	5	83
Avg.monthly	7	**8**	**9**	**16**	**12**	7	7	**8**	**9**	**10**	**14**	**8**	**115**

Appendix IV-3

Monthly number of rainy days

MILMET STATION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOT
1960	5	0	16	17	20	12	19	16	22	14	10	3	154
1961	0	0	4	12	17	14	17	26	24	29	28	13	184
1962	8	2	9	24	21	18	23	17	22	12	0	0	156
1963	8	9	6	23	20	6	9	14	5	8	17	22	147
1964	**2**	**10**	**0**	**22**	**23**	**15**	**25**	**23**	**25**	**24**	**4**	**12**	**185**
1965	5	2	5	19	14	12	14	16	9	23	21	0	140
1966	1	10	11	24	14	13	22	0	16	17	11	3	142
1967	2	0	8	21	18	15	16	18	12	17	0	2	129
1968	0	16	15	30	24	13	12	14	7	20	18	4	173
1969	9	12	10	3	16	9	19	0	9	19	11	4	121
1970	15	0	14	19	12	9	12	20	0	0	0	6	107
1971	0	0	1	16	20	13	0	22	13	11	10	6	112
1972	1	14	3	3	23	16	11	12	7	13	15	4	122
1973	8	9	0	11	17	14	14	18	18	8	8	2	127
1974	0	1	13	20	19	11	21	20	15	12	8	4	144
1975	1	1	1	15	22	20	17	22	18	14	10	2	143
1976	1	3	4	13	19	17	17	17	15	5	8	5	124
1977	9	6	5	21	28	16	12	14	9	19	27	14	180
1978	7	9	17	19	17	14	26	15	15	23	12	6	180
1979	**15**	**17**	**10**	**12**	**19**	**13**	**13**	**14**	**0**	**6**	**16**	**1**	**136**
1980	**2**	**0**	**4**	**13**	**23**	**16**	**13**	**16**	**8**	**8**	**15**	**3**	**121**
1981	0	4	14	21	15	11	21	25	20	9	11	0	151
1982	3	5	3	21	29	14	16	0	0	0	0	0	91
1983	5	7	2	12	26	14	21	25	24	28	10	12	186
1984	0	0	16	10	1	18	17	19	10	18	13	7	129
1985	4	3	12	24	24	16	18	18	13	9	9	0	150
Avg.monthly	**4**	**5**	**8**	**17**	**19**	**14**	**16**	**16**	**13**	**14**	**11**	**5**	**144**

Appendix IV-4

Probability of exceed

YEAR	TOTAL RAIN (mm)	No.RAINY DAYS	RANK ORDER	PROBABILITY EXCEDENCE	
1984	460	83	1	0.96	
1972	494	136	2	0.93	
1976	545	124	3	0.89	
1969	554	116	4	0.85	
1965	579	127	5	0.81	
1980	**592**	**105**	**6**	**0.78**	**Dry**
1971	603	126	7	0.74	
1975	630	120	8	0.70	
1985	631	93	9	0.67	
1970	634	108	10	0.63	
1973	651	121	11	0.59	
1979	**670**	**117**	**12**	**0.56**	**Average**
1982	712	107	13	0.52	
1960	713	95	14	0.48	
1983	728	108	15	0.44	
1974	753	144	16	0.41	
1966	757	120	17	0.37	
1981	773	107	18	0.33	
1967	781	134	19	0.30	
1964	**803**	**137**	**20**	**0.26**	**Wet**
1968	843	142	21	0.22	
1963	857	141	22	0.19	
1977	900	166	23	0.15	
1962	970	31	24	0.11	
1961	988	128	25	0.07	
1978	988	167	26	0.04	

Appendix IV-5

Monthly river discharge

MALEWA RIVER (GB1 STATION)
Discharge (m^3/sec)

Year	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1960	1	1	1	2	2	2	2	4	5	5	6	2
1961	1	1	1	1	2	1	2	8	7	14	79	28
1962	15	2	2	3	31	9	8	7	24	17	6	3
1963	4	2	1	18	33	10	3	9	5	2	3	28
1964	**4**	**1**	**3**	**14**	**12**	**4**	**13**	**22**	**15**	**25**	**5**	**3**
1965	3	1	1	2	8	2	3	3	2	2	4	2
1966	1	1	1	10	6	3	2	8	14	4	13	2
1967	1	1	1	1	18	9	16	12	4	6	7	4
1968	1	2	12	40	20	12	9	12	3	3	6	6
1969	1	2	1	1	6	1	1	2	4	1	2	1
1970	2	1	2	15	11	9	7	10	12	11	4	2
1971	1	1	1	2	11	8	10	30	14	6	3	3
1972	2	4	2	1	1	5	3	10	3	3	9	2
1973	2	1	1	1	1	3	3	8	5	3	3	1
1974	1	1	1	6	2	4	15	7	16	11	6	2
1975	1	1	1	1	2	3	7	22	19	16	4	1
1976	1	1	1	1	2	1	5	8	9	2	1	2
1977	1	0	1	7	10	2	10	14	7	3	11	7
1978	4	2	12	17	19	3	8	1	12	11	8	3
1979	**2**	**20**	**3**	**7**	**11**	**6**	**7**	**5**	**4**	**3**	**2**	**1**
1980	**1**	**1**	**1**	**3**	**7**	**13**	**8**	**2**	**2**	**1**	**3**	**1**
1981	0	1	1	23	0	0	0	11	9	6	3	2
1982	1	1	1	2	7	4	3	9	5	4	12	6
1983	0	0	0	0	0	3	5	11	6	17	12	6
1984	2	1	1	1	1	1	1	2	1	1	1	3
1985	0	1	1	0	11	8	9	7	0	0	0	0
Average monthly	**2**	**2**	**2**	**7**	**9**	**5**	**6**	**9**	**8**	**7**	**8**	**5**

Appendix IV-6

Monthly baseflow and overland flow

MALEWA RIVER (GB1 STATION) **Baseflow (m^3/sec)**

Year	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1960	1	1	1	2	2	1	1	2	2	3	3	1
1961	1	1	1	1	1	1	1	4	4	10	28	19
1962	11	2	1	3	10	5	6	5	11	9	5	3
1963	3	2	1	5	16	7	2	4	4	2	2	9
1964	**4**	**1**	**2**	**5**	**6**	**3**	**7**	**11**	**11**	**13**	**4**	**2**
1965	2	1	1	2	4	2	2	2	2	2	2	2
1966	1	1	1	4	3	2	2	4	7	3	6	2
1967	1	1	1	1	7	6	8	7	4	3	4	3
1968	1	2	5	11	15	7	6	7	3	2	4	3
1969	1	1	1	1	2	1	1	2	2	1	1	1
1970	1	1	1	4	6	5	4	5	7	7	3	2
1971	1	1	1	1	4	4	6	13	11	5	2	2
1972	2	2	1	1	1	2	2	4	3	2	4	2
1973	1	1	1	1	1	2	2	4	3	2	1	1
1974	1	0	1	2	2	3	6	5	9	8	4	2
1975	1	1	0	1	1	2	4	11	13	10	4	1
1976	1	1	1	1	1	1	2	4	4	1	1	1
1977	1	0	1	3	2	1	2	5	5	3	5	2
1978	2	2	7	9	9	3	4	1	6	7	6	3
1979	**2**	**7**	**2**	**5**	**6**	**2**	**4**	**3**	**2**	**2**	**2**	**0**
1980	**1**	**1**	**1**	**1**	**2**	**5**	**4**	**2**	**2**	**1**	**2**	**1**
1981	0	0	1	7	0	0	0	3	5	4	2	1
1982	1	1	1	2	3	2	2	4	4	3	6	5
1983	0	0	0	0	0	1	2	4	4	9	8	3
1984	2	1	1	1	1	1	1	1	1	0	0	1
1985	0	1	1	0	4	5	4	5	0	0	0	0
Avg.monthly	**2**	**1**	**1**	**3**	**4**	**3**	**3**	**5**	**5**	**4**	**4**	**3**

Appendix IV-6

Monthly baseflow and overland flow

MALEWA RIVER (GB1 STATION) **Overland flow (m^3/sec)**

Year	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV	DEC
1960	0	0	0	1	1	0	0	2	4	2	2	0
1961	0	0	0	0	1	0	1	4	3	4	51	10
1962	4	0	0	0	21	3	2	2	13	8	1	1
1963	1	0	0	13	17	3	0	5	1	0	1	20
1964	**0**	**0**	**1**	**9**	**5**	**1**	**6**	**11**	**5**	**12**	**0**	**0**
1965	1	0	0	0	5	0	1	1	0	0	2	0
1966	0	0	0	6	3	1	0	4	8	1	7	0
1967	0	0	0	0	11	3	8	5	0	3	3	1
1968	0	0	7	28	5	5	3	5	0	1	3	3
1969	0	1	0	0	4	0	0	0	2	0	0	0
1970	1	0	1	11	5	4	3	5	5	4	1	0
1971	0	0	0	0	7	4	4	17	3	1	0	1
1972	0	2	0	0	0	3	1	5	0	1	5	0
1973	0	0	0	0	0	1	1	4	1	1	2	0
1974	0	0	0	3	1	2	8	2	7	3	1	0
1975	0	0	0	1	1	1	3	12	6	6	0	0
1976	0	0	0	0	1	0	3	4	4	1	0	1
1977	0	0	0	4	8	1	8	8	3	1	6	5
1978	2	0	5	8	10	0	4	1	7	5	3	1
1979	**0**	**13**	**1**	**3**	**5**	**4**	**4**	**3**	**1**	**1**	**1**	**1**
1980	**0**	**0**	**0**	**2**	**4**	**8**	**4**	**1**	**0**	**0**	**1**	**0**
1981	0	0	0	16	0	0	0	8	4	2	1	1
1982	0	0	0	1	4	1	1	5	1	1	6	1
1983	0	0	0	0	0	2	3	7	3	8	4	3
1984	0	0	0	0	0	0	0	0	0	1	0	2
1985	0	0	0	0	7	3	4	3	0	0	0	0
Avg.monthly	**0**	**1**	**1**	**4**	**5**	**2**	**3**	**5**	**3**	**3**	**4**	**2**

Appendix IV-7

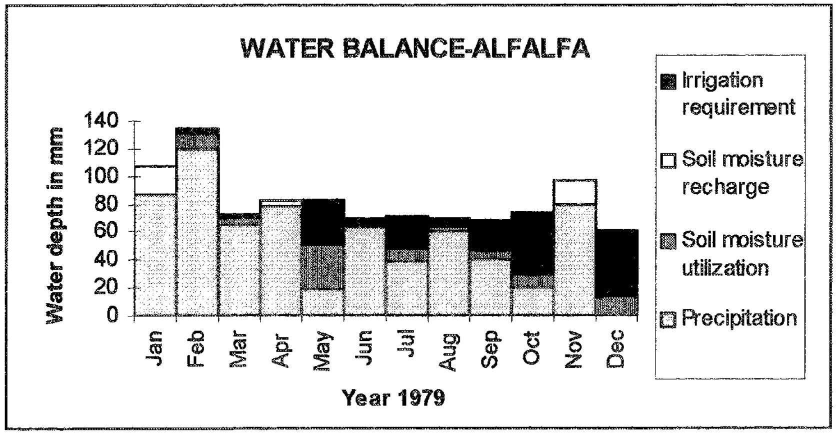
Yearly discharge, base flow and overland flow

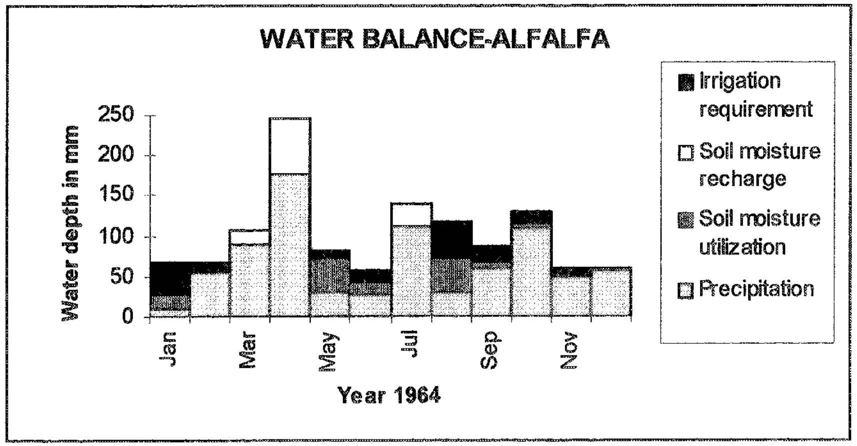
	Discharge				Baseflow				Overland flow			
Year	Avg.Yearly Q (m^3/sec)	Total Q (m^3*10^-6)	Total Q (mm)	Max.avg.Daily Q (m^3/sec)	Avg.Yearly Q (m^3/sec)	Total Q (m^3*10^-6)	Total Q (mm)	Max.avg.Daily Q (m^3/sec)	Avg.Yearly Q (m^3/sec)	Total Q (m^3*10^-6)	Total Q (mm)	Max.avg.Daily Q (m^3/sec)
1960	2.76	87	179	14	1.74	55	113	4	1	32	66	10
1961	12.12	382	783	177	6.02	190	389	41	6	192	394	136
1962	10.63	335	687	146	6.00	189	388	25	5	146	299	121
1963	9.97	314	644	143	4.82	152	311	19	5	163	333	125
1964	**10.15**	**321**	**658**	**54**	**5.85**	**185**	**379**	**17**	**4**	**136**	**279**	**37**
1965	2.78	88	180	20	1.89	60	122	5	1	28	57	16
1966	5.41	171	350	42	2.89	91	187	10	3	80	163	32
1967	6.63	209	429	92	3.74	118	242	10	3	91	187	82
1968	10.50	332	681	168	5.55	176	360	23	5	157	321	145
1969	2.13	67	137	25	1.44	45	93	4	1	22	45	21
1970	7.12	225	460	51	3.91	123	252	8	3	101	208	43
1971	7.49	236	484	57	4.29	135	277	19	3	101	207	38
1972	3.66	116	237	24	2.23	70	144	6	1	46	93	19
1973	2.65	84	171	21	1.70	54	110	5	1	30	61	16
1974	5.85	184	378	33	3.47	110	224	10	2	75	153	23
1975	6.64	209	429	55	4.01	126	259	16	3	83	170	39
1976	2.84	90	184	23	1.58	50	103	7	1	40	81	16
1977	6.11	193	395	57	2.43	77	157	7	4	116	237	50
1978	8.47	267	547	47	4.75	150	307	12	4	117	241	35
1979	**5.98**	**189**	**386**	**45**	**3.05**	**96**	**197**	**10**	**3**	**92**	**189**	**35**
1980	**3.51**	**111**	**227**	**41**	**1.77**	**56**	**115**	**9**	**2**	**55**	**113**	**32**
1981	4.69	148	303	59	1.41	44	91	11	3	104	212	48
1982	4.43	140	286	20	2.77	87	179	8	2	52	107	12
1983	5.12	161	331	38	2.60	82	113	11	3	79	218	27
1984	1.33	42	86	14	1.00	32	65	5	0	10	21	8
1985	3.08	97	199	18	1.58	50	102	7	1	47	97	11
	Qmax	**382**	**year 1961**									

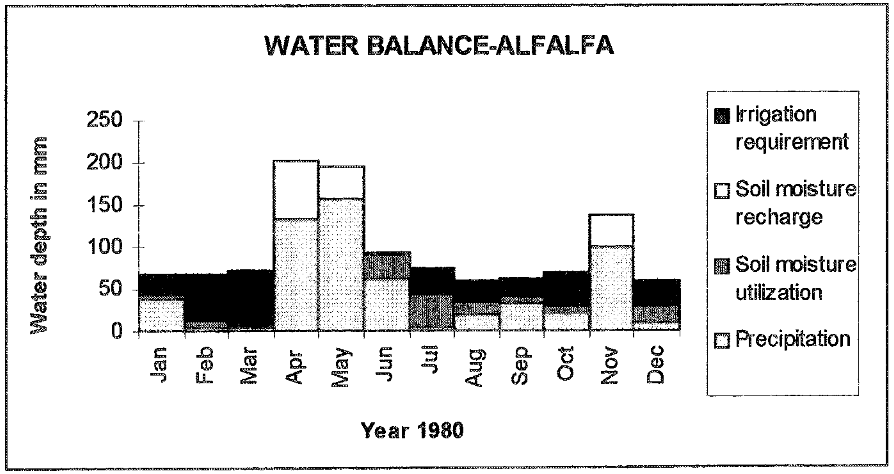
Appendix IV-8

Thornthwaite and Mather Water balance for main crops
Crop: Alfalfa

MONTH	IRreq (mm/year)		
	DRY 1980	**AVERAGE 1979**	**WET 1964**
JAN	24	0	39
FEB	56	5	10
MAR	62	2	0
APR	0	0	0
MAY	0	32	11
JUN	4	4	14
JUL	30	22	0
AUG	27	7	44
SEP	22	22	19
OCT	40	45	15
NOV	0	0	8
DEC	30	48	3
TOT	**296**	**187**	**162**
(m3/ha)	**2960**	**1870**	**1620**



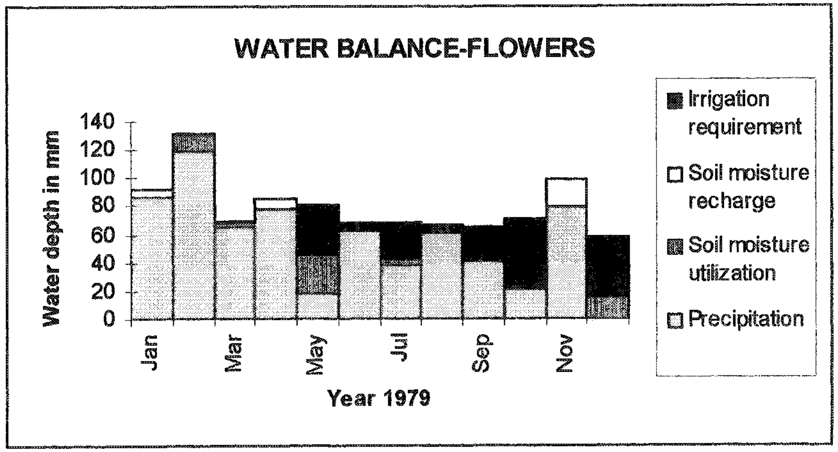


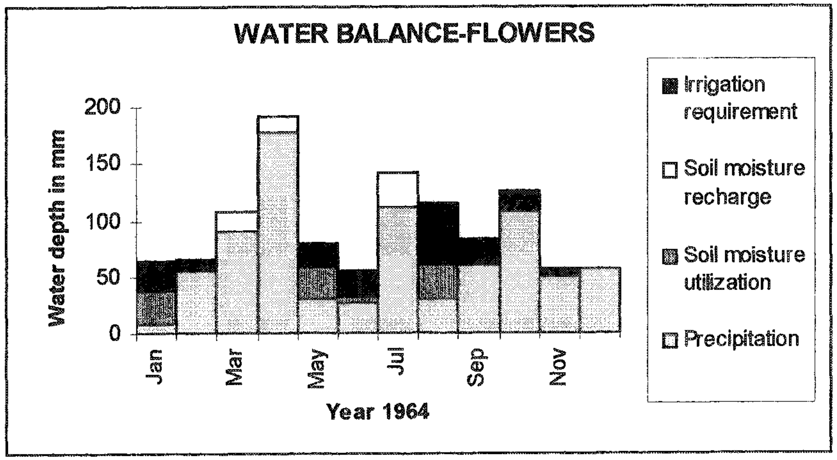


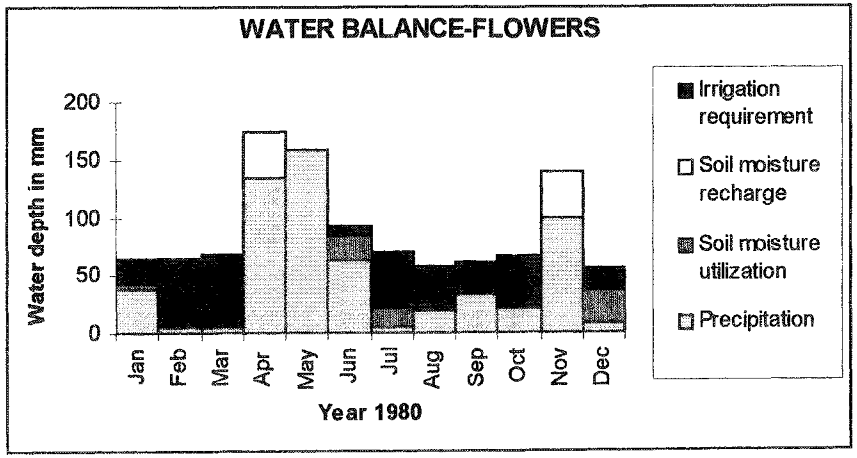
Appendix IV-8

Thornthwaite and Mather Water balance for main crops
Crop: Flowers

MONTH	IRreq (mm/year)		
	DRY 1980	**AVERAGE 1979**	**WET 1964**
JAN	23	0	27
FEB	57	2	8
MAR	62	1	0
APR	0	0	0
MAY	0	35	21
JUN	8	4	22
JUL	49	26	0
AUG	36	6	54
SEP	26	24	22
OCT	45	49	16
NOV	0	0	7
DEC	20	42	1
TOT	**326**	**189**	**178**
(m3/ha)	**3260**	**1890**	**1780**



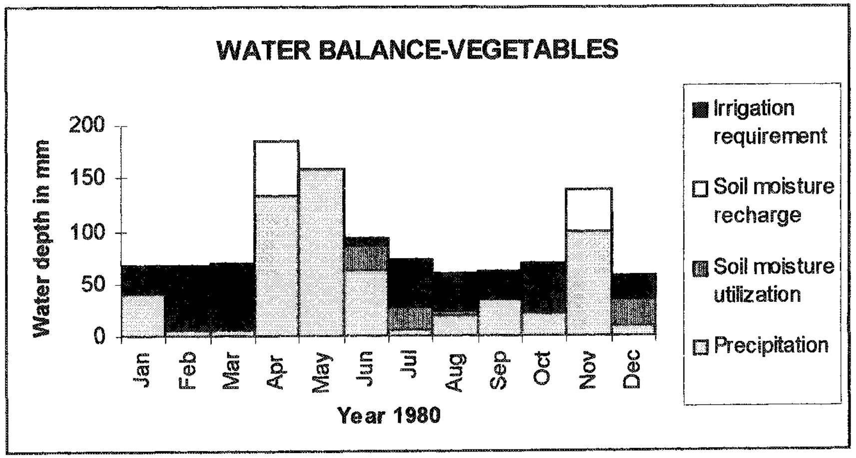


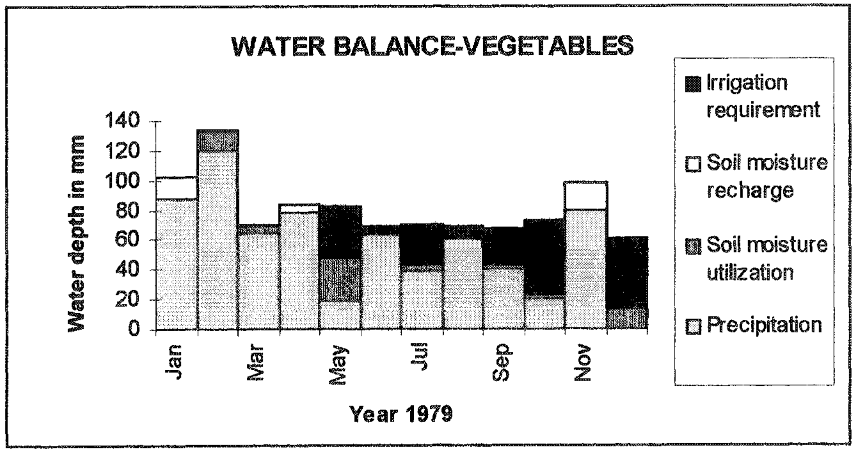


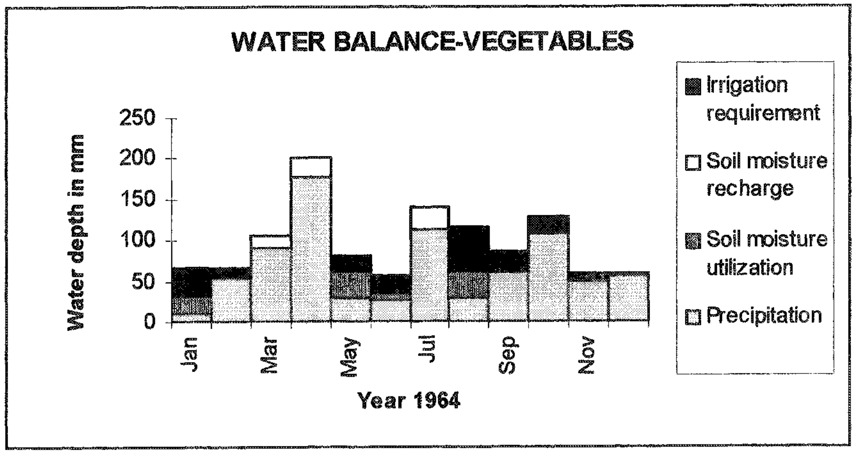
Appendix IV-8

Thornthwaite and Mather Water balance for main crops
Crop: Vegetables

MONTH	IRreq (mm/year) DRY 1980	AVERAGE 1979	WET 1964
JAN	24	0	33
FEB	59	2	9
MAR	63	2	0
APR	0	0	0
MAY	0	34	19
JUN	7	5	21
JUL	46	26	0
AUG	35	7	55
SEP	27	25	22
OCT	46	50	17
NOV	0	0	8
DEC	24	46	2
TOT	**332**	**196**	**186**
(m3/ha)	**3320**	**1960**	**1860**



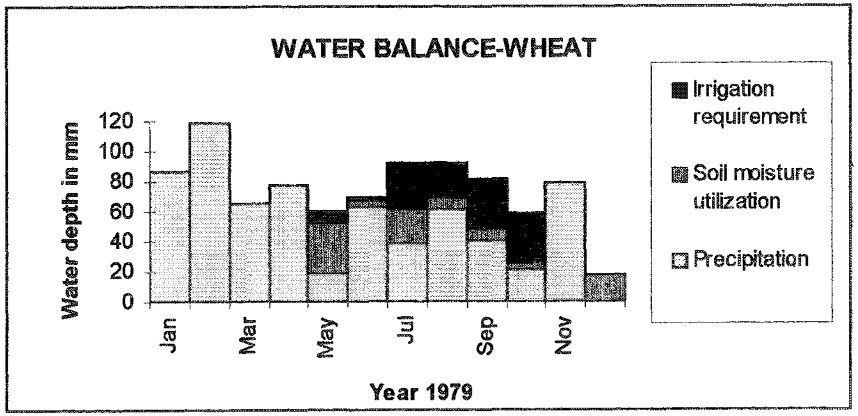


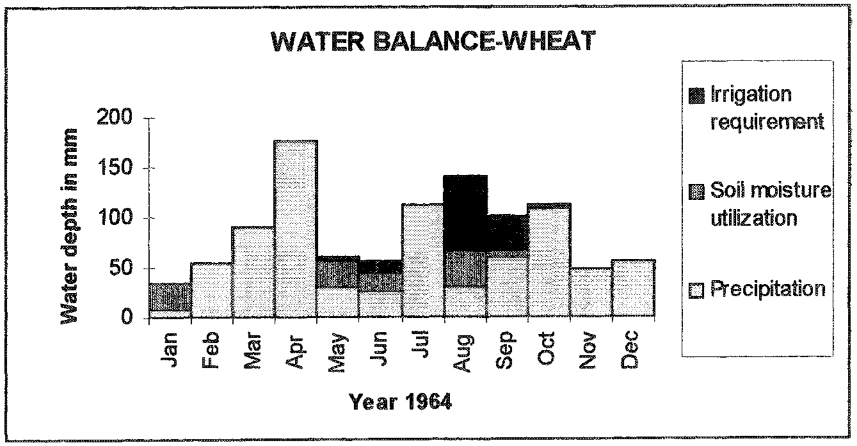


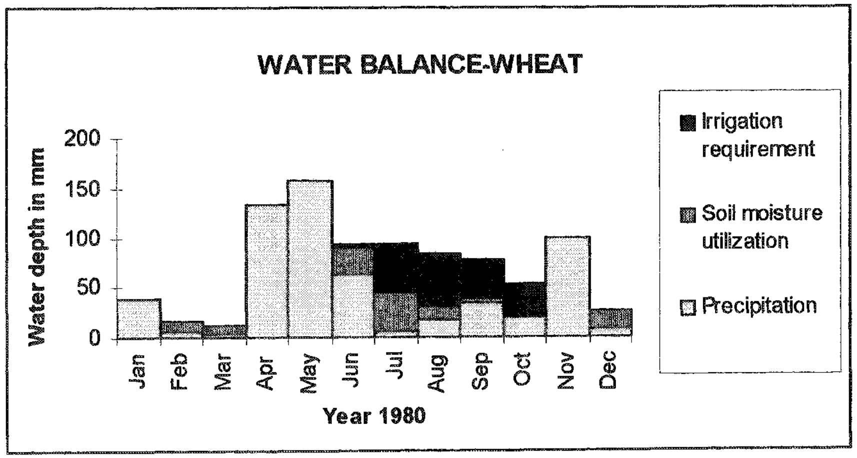
Appendix IV-8

Thornthwaite and Mather Water balance for main crops
Crop: Wheat

MONTH	IRreq (mm/year)		
	DRY 1980	**AVERAGE 1979**	**WET 1964**
JAN	0	0	0
FEB	0	0	0
MAR	0	0	0
APR	0	0	0
MAY	0	8	4
JUN	5	3	12
JUL	49	30	0
AUG	52	23	74
SEP	39	34	34
OCT	31	33	3
NOV	0	0	0
DEC	0	0	0
TOT	**174**	**131**	**128**
(m3/ha)	**1740**	**1310**	**1280**



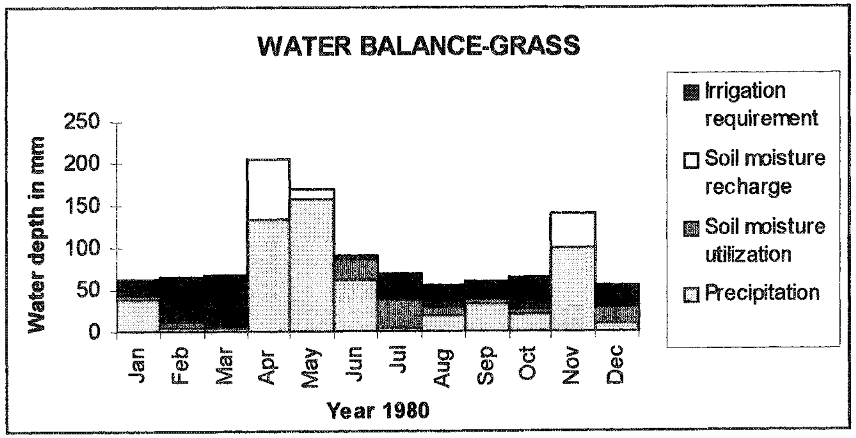


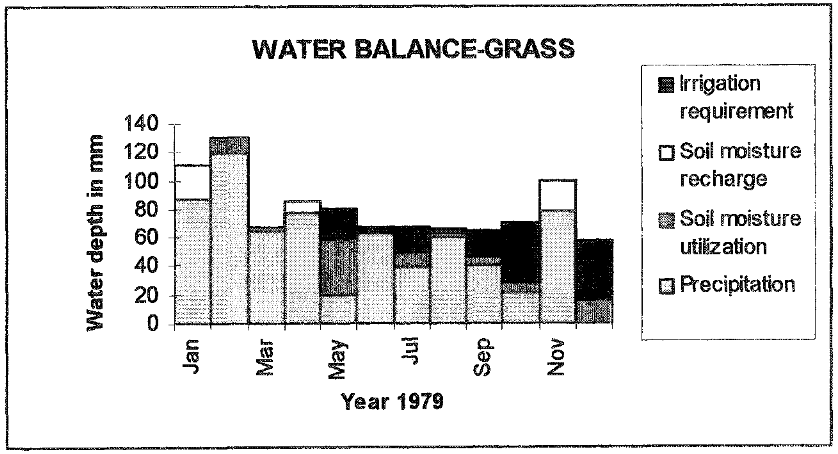


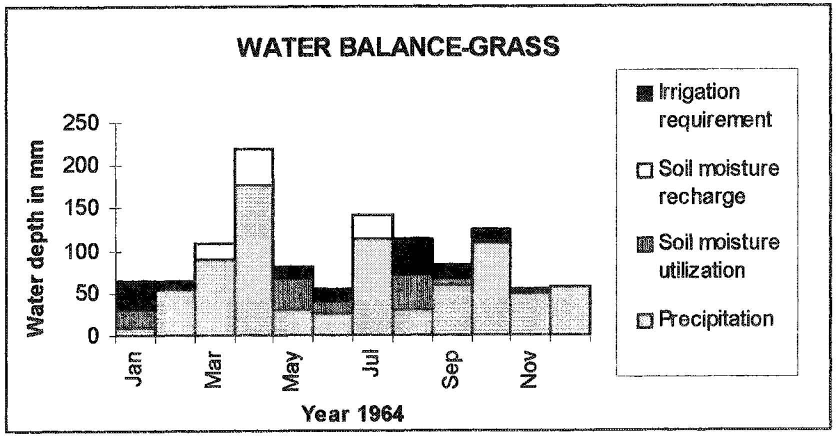
Appendix IV-8

Thornthwaite and Mather Water balance for main crops
Crop: Grass

MONTH	IRreq DRY 1980	(mm/year) AVERAGE 1979	WET 1964
JAN	20	0	32
FEB	52	1	6
MAR	58	0	0
APR	0	0	0
MAY	0	21	12
JUN	4	2	14
JUL	32	19	0
AUG	27	4	44
SEP	21	18	17
OCT	39	41	12
NOV	0	0	5
DEC	26	42	0
TOT	**280**	**149**	**142**
(m3/ha)	**2800**	**1490**	**1420**







Appendix V-1

Water resources assessment study data

Sr. No.	Name	X	Y	Water Source	Crop Name	Irrigation (ha)	Domestic (People)	Livestock (L.U)	Wildlife (Animals)	Industry (m3/y)	Abstraction (m3/s)	Time (s/y)	Demand (m3/y)
BH001	ABERDARE ESTATES LTD.	215036	9917353	N/A	N/A	0.00	0	0	0	0	0.00000	31536000	0.00
BH002	MWANGI KAGUTHA	214349	9916714	N/A	Vegetables	0.00	5	8	0	0	0.00067	328500	219.00
BH003	GITHEKE	214297	9916634	N/A	Cabbage, sukuma, Irish potatoes, carrots, beans	0.80	20	8	0	0	0.00400	7776000	31104.00
BH004	JACKMAN	214115	9916392	N/A	N/A	0.00	3	0	0	0	0.00063	243000	151.88
BH005	BEE'S GARDEN	214083	9916180	N/A	N/A	0.00	16	0	0	0	0.00037	1314000	486.67
BH006	LAKE NAIVASHA HOLIDAY VILLAS	214041	9916056	N/A	N/A	0.00	35	0	0	0	0.00500	1944000	9720.00
BH007	THITHINO	214000	9915900	N/A	N/A	0.00	0	0	0	0	0.00000	0	0.00
BH008	HORTITEC(K) LTD.	213974	9915479	N/A	N/A	0.00	50	2	0	0	0.00222	9720000	21600.00
BH009	LAKE CROPS	214042	9915576	N/A	N/A	0.00	15	2	0	0	0.00074	5256000	3898.20
BH010	THREE POINT OSTRICH FARM LTD.	214789	9915467	N/A	N/A	0.00	40	42	0	0	0.00056	5256000	2920.00
BH011	MDUNGU GATHINJI	212804	9915486	N/A	N/A	0.00	8	1	0	0	0.00050	2628000	1314.00
BH012	JOHN VAUGHAM	213684	9915525	N/A	N/A	0.00	8	2	0	0	0.00036	5832000	2106.00
BH013	ARMITABE	213700	9915600	N/A	N/A	0.00	5	0	0	0	0.00027	1944000	518.40
BH014	C.C.BENGOUGH	213934	9915143	N/A	N/A	0.00	3	0	0	0	0.00067	438000	292.00
BH015	LAKE NAIVASHA COUNTRY CLUB	213014	9914325	N/A	Lawn	0.00	200	0	0	0	0.00039	3888000	1512.00
BH016	CRESCENT ISLAND	211300	9914600	N/A	N/A	0.00	12	0	0	0	0.00094	657000	620.50
BH017	BUSHY ISLAND	211736	9913755	N/A	N/A	0.00	11	0	0	0	0.00389	985500	3832.50
BH018	SANCTUARY FARM	212053	9912421	N/A	N/A	0.00	100	0	0	0	0.00064	2916000	1869.23
BH019	MUNYAKA	211268	9912042	N/A	N/A	0.00	20	120	0	0	0.00025	3888000	972.00
BH020	AIRSPRAY LTD.	?	?			0.00	0	0	0	0	0.00000	0	0.00
BH021	LAKE NAIVASHA VINEYARDS	211115	9910901	N/A	N/A	20.00	50	12	0	496.4	0.00631	15552000	98064.00
BH022	SAFARILAND CLUB	209965	9909989	N/A	N/A	0.00	400	0	0	0	0.00200	7776000	15552.00
BH023	KIUWATER PROJECT	215200	9913100	N/A	Lettuce, onions, tomatoes, carrots, sukuma, English potatoes, French beans, cabbages	0.00	700	80	0	0	0.00417	1944000	8100.00
BH024	LONGONOT	209355	9910245	N/A	Vegetables, Lucerne	0.00	0	0	0	0	0.00069	10512000	7300.00
BH025	LONGONOT	209208	9910831	N/A	Citrus fruits: oranges, grass	0.00	2	0	0	0	0.00972	10512000	102200.00
BH026	JOAN FOOT	209054	?	N/A	N/A	0.00	15	4	0	0	0.00364	23328000	84823.20
BH027	DR. BUNNY	208953	9909624	N/A	N/A	0.00	8	8	0	0	0.00133	5256000	7008.00
BH028	LONGONOT HORTICULTURE LTD.	208953	99?7606	N/A	N/A	0.00	230	0	0	0	0.00400	5256000	21024.00
BH029	YMCA CAMP	206572	9907866	N/A	Vegetables	0.00	20	4	0	0	0.00111	7776000	8640.00
BH030	SHER AGENCIES LTD.-SIMBA	207245	9908316	N/A	N/A	0.00	5	0	0	0	0.00511	31536000	161184.00
BH031	SHER AGENCIES LTD.-SHER	205271	9908126	N/A	N/A	0.00	0	0	0	0	0.00536	31536000	169068.00
BH032	SUSWA WATER SUPPLY	204975	9908101	N/A	N/A	0.00	0	4800	14000	0	0.00000	27594000	0.00
BH033	SUSWA WATER SUPPLY	204975	9908101	N/A	N/A	0.00	0	4800	14000	0	0.00000	27594000	0.00
BH035	FISH EAGLE INN	203222	9908465	N/A	N/A	0.00	10	6	0	0	0.00375	2628000	9855.00
BH036	MRS. MORSON	203168	9908688	N/A	Lawn	0.00	2	0	0	0	0.00140	1642500	2293.57
BH037	ELSAMERE LTD.	201266	9909867	N/A	Grass	0.00	0	0	0	0	0.00118	7776000	9175.68
BH038	OSERIAN DEVELOPMENT COMPANY LTD.	194187	9908739	N/A	Grass	8.00	600	88	0	0	0.10867	6804000	739368.00
BH039	OSERIAN DEVELOPMENT COMPANY LTD.	194187	9908739	N/A	Grass	8.00	0	88	0	0	0.09883	31536000	3116808.00
BH040	HOMEGROWN SOUTH LAKE ROAD	213971	9915708	N/A	N/A	0.10	8	0	0	0	0.00067	657000	438.00
BH041	HOMEGROWN	213394	9921504	N/A	N/A	0.00	600	0	0	0	0.02000	15768000	315360.00
BH042	WETAM INVESTMENTS LTD.	214485	9916881	N/A	N/A	0.00	20	36	0	0	0.00385	1314000	5055.25
BH043	BRIXIA MARIO	203919	9923812	N/A	Vegetables	32.00	0	0	0	0	0.01111	23328000	259200.00
BH044	LOLDIA LIMITED	200538	9921954	N/A	N/A	0.00	500	800	1000	0	0.01000	6570000	65700.00
BH045	LOLDIA LIMITED	200996	9920960	N/A	Lucerne and wheat	8.00	0	0	0	0	0.02000	15552000	311040.00
BH046	LOLDIA LIMITED	202789	9921176	N/A	Bananas, oranges	0.00	10	2	0	0	0.00133	11664000	15552.00
BH047	LOLDIA LIMITED	203036	9922058	N/A	N/A	24.00	0	0	0	0	0.02000	15552000	311040.00

Appendix V-1

Water resources assessment study data

Sr. No.	Name	X	Y	Water Source	Crop Name	Irrigation (ha)	Domestic (People)	Livestock (L.U)	Wildlife (Animals)	Industry (m3/y)	Abstraction (m3/s)	Time (s/y)	Demand (m3/y)
BH048	MALEWA BAY	203786	9925304	N/A	N/A	20.00	100	1600	0	0	0.01932	11664000	225309.60
BH049	MALEWA BAY	204040	9925879	N/A	N/A	8.00	250	800	0	0	0.01739	11664000	202824.00
BH050	BISLETI	208036	9924408	N/A	N/A	0.00	7	2	0	0	0.00040	2628000	1051.20
BH051	KARI-NAIVASHA STATION	211455	9923721	N/A	Lucerne, mapier grass, Rhodes	40.00	400	800	0	0	0.02225	15768000	350838.00
BH052	DELAMERE ESTATES LTD.-dairy factory	211822	9923166	N/A	Fodder, crops, wheat, beans	0.00	600	96	0	0	0.05250	11664000	612360.00
BH053	DELAMERE ESTATES LTD.-dairy factory	211838	9921745	N/A	Fodder, crops, wheat, beans	0.00	13240	320	0	0	0.02167	7776000	168480.00
BH054	DELAMERE ESTATES LTD.-dairy factory	212334	9922728	N/A	Wheat, vegetables	45.00	15	0	0	0	0.04750	7776000	369360.00
BH055	DELAMERE ESTATES LTD.-dairy factory	213126	9921647	N/A	N/A	0.00	720	480	0	0	0.02000	11664000	233280.00
BH056	N.W.C.P.C	213068	9923017	N/A	N/A	0.00	0	0	0	0	0.01000	31536000	315360.00
BH057	PRISON DEPT.	213040	9922959	N/A	?	10.00	2000	40	0	0	0.00667	31536000	210240.00
BH058	DELAMERE ESTATES LTD.-dairy factory	213929	9922953	N/A	Wheat, barley, Soya, beans, maize	120.00	0	288	0	0	0.09722	13104000	1274000.00
BH059	DELAMERE ESTATES LTD.-dairy factory	212346	9923999	N/A	N/A	0.00	2	240	0	0	0.04125	7776000	320760.00
BH060	DELAMERE ESTATES LTD.-dairy factory	211769	9924324	N/A	N/A	0.00	61	640	0	0	0.00400	15552000	62208.00
BH061	DELAMERE ESTATES LTD.-dairy factory	211300	9924682	N/A	N/A	0.00	10	240	0	9125	0.03361	11664000	392040.00
BH062	CRATER LAKE	194535	9914610	N/A	N/A	0.00	40	0	4599	0	0.00118	13140000	15457.75
BH063	NAIVASHA TOWN COUNCIL	216194	9918712	N/A	N/A	0.00	0	0	0	0	0.00238	23652000	56370.60
BH064	NAIVASHA TOWN COUNCIL	215119	9919522	N/A	N/A	0.00	0	0	0	0	0.00231	23652000	54662.40
BH065	MIRERA SUSWA	215784	9912357	N/A	N/A	0.00	400	0	0	0	0.01000	2628000	26280.00
BH066	MIRERA SUSWA	215884	9913478	N/A	N/A	0.00	200	0	0	0	0.00286	9720000	27772.20
BH067	NYAMAMITHI	216441	9913361	N/A	N/A	0.80	6	6	0	0	0.00222	3888000	8640.00
BH068	MDINDABI	190925	9909573	N/A	N/A	0.00	4500	0	0	0	0.00278	1314000	3650.00
BH069	TANGI TATU	189794	9911609	N/A	N/A	0.00	3200	0	0	0	0.00321	657000	2105.69
BH070	NDIBITHI WATER PROJECT	190546	9922333	N/A	N/A	0.00	4000	0	0	0	0.00118	18396000	21640.85
BH071	K.C.C. A	209044	9925558	N/A	N/A	0.00	0	0	0	0	0.00039	23652000	9198.00
BH072	K.C.C. NAIVASHA DEPOT-dairy factory	208994	9925762	N/A	N/A	0.00	300	0	0	29200	0.00125	23652000	29565.00
BH073	NAIVASHA MIXED SECONDARY SCHOOL	215386	9920048	N/A	Cabbages, trees	0.00	1200	8	0	0	0.00111	10512000	11680.00
BH074	NAIVASHA BOARDING	214731	9921791	N/A	N/A	0.00	630	11	0	0	0.00133	11664000	15552.00
BH075	D.N. HANDA SECONDARY SCHOOL	214903	9921142	N/A	N/A	0.00	400	0	0	0	0.00197	1944000	3834.00
BH076	KORONGO	197473	9917458	N/A	Cabbage-Gloria	8.00	6	0	0	0	0.01444	5832000	84240.00
BH077	KORONGO	197369	9917697	N/A	?	0.00	100	144	0	0	0.00417	2628000	10950.00
BH078	KORONGO	197085	9917865	N/A	Lucerne	8.00	0	160	0	0	0.00400	7776000	31104.00
BH079	ROCCO	197900	9919883	N/A	Vegetables	2.00	60	120	0	0	0.01000	2628000	26280.00
BH080	OLSUSWA	197350	9920982	N/A	Bombards	0.00	300	1200	0	0	0.00262	31536000	82589.28
BH081	OLSUSWA	197587	9921066	N/A	Bomarodes	80.00	0	1200	0	0	0.00262	31536000	82589.28
BH082	NORTH LAKE NURSERIES	198438	9920205	N/A	Roses	1.40	200	0	0	0	0.00889	10512000	93440.00
BH083	NYANJUGU INVESTMENTS LTD.	203662	9922465	N/A	Flowers	2.00	600	64	0	0	0.02000	23328000	466560.00
BH084	NYANJUGU	203526	9922907	N/A	N/A	0.00	80	0	0	0	0.01389	23328000	324000.00
BH085	NYANJUGU	203241	9922550	N/A	N/A	4.00	100	64	0	0	0.01000	23328000	233280.00
BH086	TOP LODGE ANNEX-KINAMBA	218815	9919882	N/A	N/A	0.00	30	0	0	0	0.00091	10512000	9554.24
BH087	PEPPERCORN	217713	9921912	N/A	?	0.00	350	48	0	0	0.00067	2628000	1752.00
BH088	MARARO	220590	9916729	N/A	N/A	0.00	750	0	0	0	0.00083	5832000	4860.00
BH089	KENYA WILDLIFE SERVICE	216056	9918670	N/A	Lawn	0.10	2000	0	3000	0	0.00400	10512000	42048.00
BH090	**KINJA NURSERIES**	**196522**	**9912459**	**N/A**	**Fruits**	**0.00**	**150**	0	**0**	**0**	**0.00052**	**31536000**	**16509.97**
BH091	KINJA NURSERIES	197205	9912864	N/A	Flowers	1.60	40	48	0	0	0.00055	7776000	4302.76
BH092	KARI-NAIVASHA	211162	9923803	N/A	N/A	0.00	0	0	0	0	0.019055556	31536000	600936.00
BH093	KARI-NAIVASHA	211181	9923803	N/A	N/A	0.00	0	0	0	0	0	11826000	0.00
BH095	NGUNYUMU WATER PROJECT	187845	9909103	N/A	N/A	0.00	400	400	0	0	0.00045	2916000	1312.20
BH096	MUNDUI ESTATE	195957	9910799	N/A	Vegetables, fruits	0.40	20	120	480	0	0.00139	13104000	18200.00

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Sr. No.	Name	X	Y	Water Source	Crop Name	Irrigation (ha)	Domestic (People)	Livestock (L.U)	Wildlife (Animals)	Industry (m3/y)	Abstraction (m3/s)	Time (s/y)	Demand (m3/y)
BH097	MUNDUI ESTATE	195403	9912384	N/A	N/A	0.00	0	120	480	0	0.00139	18345600	25480.00
BH098	NYONDIA WATER PROJECT	217983	9924138	N/A	N/A	0.00	10000	800	0	0	0.02686	5832000	156633.75
BH099	NYONJORO WATER PROJECT	219411	9926765	N/A	N/A	0.00	300	120	0	0	0.00182	4860000	8835.75
BH100	KINAMBA WATER PROJECT	219179	9920236	N/A	N/A	0.00	800	80	0	0	0.00080	7776000	6220.80
BH102	NUNJORO	219848	9929261	N/A	Fruits, apples, grapes	0.80	150	98	0	0	0.00505	6804000	34360.20
BH103	DAIRY TRAINING INSTITUTE	213052	9928937	N/A	N/A	0.00	221	30	0	0	0.00225	31536000	70956.00
BH104	NAIVASHA DISTRIC HOSPITAL-laboratory	214886	9920722	N/A	N/A	0.00	200	0	0	36.5	0.00129	6570000	8447.14
BH105	ST. FRANCIS XAVIER	214733	9920622	N/A	N/A	0.00	300	3	0	0	0.00204	11826000	24134.69
BH106	NORTH KARATI WATER PROJECT	219112	9923847	N/A	N/A	0.00	200	240	0	0	0.00125	2916000	3645.00
BH107	OLARAGWAI LTD.	214492	9926591	N/A	?	32.00	17	0	0	0	0.02500	11664000	291600.00
BH108	MARULA HOUSE	207741	9925649	N/A	N/A	0.00	20	160	0	0	0.00056	15768000	8760.00
BH109	MARULA OFFICE	208746	9928943	N/A	N/A	0.00	300	240	0	0	0.00129	9198000	11824.54
BH110	MARULA HOMEGROWN	209505	9926445	N/A	N/A	0.00	2	168	0	0	0.00060	3942000	2365.20
BH111	MARULA MOSORORIGA	210009	9929228	N/A	N/A	0.00	12	160	0	0	0.00020	9198000	1839.60
BH112	MARULA DAWSON	210018	9931758	N/A	N/A	0.00	5	240	0	0	0.00100	10512000	10512.00
BH113	MARULA-KIBIRO	203831	9938931	N/A	N/A	0.00	50	640	0	0	0.00206	7776000	15994.80
BH114	NJERU	202261	9952185	N/A	N/A	0.00	7	17	0	0	0.00111	4860000	5400.00
BH115	DIRECTOR OF WATER DEVELOPMENT	208464	9970629	N/A	N/A	0.00	10000	0	0	0	0.00111	31536000	35040.00
BH116	OL-KALOU WATER SUPPLY	208576	9971081	N/A	N/A	0.00	3000	0	0	0	0.00222	31536000	70080.00
BH117	ESTATE LEASING LTD.	212730	9914282	N/A	Fruit trees, lawn, over head	0.80	8	0	0	0	0.00056	3888000	2160.00
SP001	PEMBROKE SCHOOL	206732	9945915	Gilgil	N/A	0.00	200	6	0	0	0.00013	31536000	4204.80
SP002	NGOKOTI	186836	9898816		N/A	0.00	50000	0	0	0	0.00046	31536000	14506.56
SP003	OLARAGWAI	215568	9928544	Malewa	N/A	0.00	0	0	0	0	0.00060	31536000	18921.60
SP004	MAJIMOTO	198756	9952599	Gilgil	N/A	0.00	0	0	0	0	0.00000	31536000	0.00
SP005	SAMUEL NJATHA	?	?	Malewa	N/A	0.00	3000	160	0	0	0.00060	31536000	18921.60
SP006	SAMUEL NJATHA	?	?	Malewa	N/A	0.00	40	8	0	0	0.00013	31536000	3942.00
SP007	JOHN NIMMO HOT SPRINGS-picnic swimming	220080	9925806	Malewa	N/A	0.00	0	0	0	3058.992	0.00010	31536000	3058.99
SP008	KIRIMA	220241	9930381	Malewa	N/A	0.00	0	0	0	0	0.00000	7776000	0.00
SP009	LODGES	219812	9929634	Malewa	Lawn	0.00	0	0	0	0	0.00000	31536000	0.00
SP010	GAKUMBI	221481	9927330	Malewa	N/A	0.00	100	32	0	0	0.00040	31536000	12614.40
SP011	MBOGO	220805	9927889	Karati	N/A	0.00	260	28	0	0	0.00072	31536000	22705.92
SP012	MBOGO	220933	9927579	Karati	N/A	0.00	50	4	0	0	0	15552000	0.00
SP013	S.W.NJENGA	222482	9925256	Maraigushu	N/A	0.00	115	32	0	0	0.00004	31536000	1261.44
SP014	LITTLE GILGIL SPRING	206332	9950542	Karunga	N/A	0.00	0	0	0	0	0.04368	31536000	1377492.48
SP015	SAMUKA	204329	9952281	Karunga	N/A	0.00	0	0	0	0	0.12194	31536000	3845499.84
SW001	ABERDARE STATES	213363	9917165	L. Naivasha	Cabbages gloria, french beans	21.20	30	56	0	0	0.25000	550800	137700.00
SW002	WETAM INVESTMENTS	213013	9916931	L. Naivasha	White maize, mapier grass	3.20	35	41	0	0	0.00200	3888000	7776.00
SW003	MUGUKU	213692	9916912	L. Naivasha	Flowers	0.80	8	0	0	0	0.00500	1944000	9720.00
SW004	BOFFER	213786	9916797	L. Naivasha	French beans, maize, tomatoes	24.00	20	21	0	0	0.02000	7776000	155520.00
SW005	JACKMAN	213776	9916591	L. Naivasha	N/A	0.00	16	29	0	0	0.00118	1134000	1334.12
SW006	BEES GARDEN	213779	9916321	L. Naivasha	Lucerne	0.10	0	12	0	0	0.00667	3888000	25920.00
SW008	MWANGI GATERI	213537	9916200	L. Naivasha	French beans, chillies, gloria cabbages, onions, tomatoes	7.20	20	10	0	0	0.11800	7776000	917568.00
SW009	MATIRU MGURE	213526	9916054	L. Naivasha	Cabbages, confen, sukuma, irish potatoes, onions, beans	0.80	0	0	0	0	0.08900	3888000	346032.00
SW011	LAKE CROP	213490	9915918	L. Naivasha	Artichoke, leeks, egg plant, spinach, white onions, parsnip, cabbage, carrots, turnips, beetot and garlic	0.50	30	8	0	0	0.00200	3888000	7776.00
SW012	HORTITEC LTD.	213557	9915686	L. Naivasha	Flowers	2.00	0	0	0	0	0.00400	9720000	38880.00
SW013	THREE POINT OSTRICH FARM	213300	9916200	L. Naivasha	French beans, gloria, cabbages	30.00	0	0	0	0	0.03889	11664000	453600.00
SW014	LANDMARK	213330	9915540	L. Naivasha	N/A	0.00	0	0	0	0	0.02800	0	0.00
SW015	RICHARD WILCOCH	213400	9915600	L. Naivasha	Roses, flowers	7.00	25	12	0	0	0.00314	7776000	24390.00

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SW016	AMOROSO-motor vehicle workshop	212987	9915221	L. Naivasha	Lucerne, fresno, chillies	15.00	20	54	0	0	0.01300	7776000	101088.00
SW017	J.F. CAMPBED CLAUSE	212900	9915300	L. Naivasha	Maize lucerne, grass-fodder	3.64	14	10	0	0	0.00568	6804000	38658.06
SW018	ELSAGRO	213188	9914679	L. Naivasha	French beans, delphium	19.00	0	0	0	0	0.02222	8748000	194400.00
SW019	C.C. BENGOUGH	212813	9914729	L. Naivasha	Lawn & flowers around the house	0.40	8	8	0	0	0.02000	5832000	116640.00
SW020	COUNTRY CLUB	212562	9914762	L. Naivasha	Grass (lawn)	20.00	0	0	0	0	0.02217	2916000	64638.00
SW021	COUNTRY CLUB	212562	9914762	L. Naivasha	N/A	0.00	200	0	0	0	0.00100	1944000	1944.00
SW022	LOTUS ISLAND-KIJABE	211800	9914700	L. Naivasha	Grass	0.70	50	0	0	0	0.00400	7776000	31104.00
SW023	KNABE HILL	212668	9914121	L. Naivasha	Citrus fruits: oranges, grapes.	10.60	10	4	0	0	0.01230	11664000	143467.20
SW024	VINEYARDS	212858	9913799	L. Naivasha	Grapes, flowers	20.00	80	8	0	0	0.00900	9720000	87480.00
SW025	SANCTUARY	211556	9913158	L. Naivasha	Lucerme, maize, dats	12.00	0	272	0	0	0.16700	13608000	2272536.00
SW026	CRESCENT ISLAND	211276	9913342	L. Naivasha	Carrots, cabbages, tomatoes, etc.	0.10	0	0	0	0	0.00700	972000	6804.00
SW027	CRESCENT ISLAND	211400	9914600	L. Naivasha	Lawn, flowers	0.10	4	0	0	0	0.00040	5241600	2096.64
SW029	OSIRUA	210721	9911763	L. Naivasha	Flowers: roses	20.00	0	0	0	0	0.02900	13140000	381060.00
SW031	NINI	210539	9911695	L. Naivasha	Flowers: roses, french beans	18.00	0	0	0	0	0.02700	23328000	629856.00
SW032	VINEYARDS	210556	9911345	L. Naivasha	Grapes, flowers	13.00	50	12	0	1825	0.01000	9720000	97200.00
SW033	SAFARI LAND	209875	9910213	L. Naivasha	Vegetables: cabbages, spinach, peppers, onions, beans, potatoes	24.28	200	71	2	0	0.00740	3888000	28771.20
SW034	LONGONOT	209309	9910345	L. Naivasha	Flowers-Lisianthus, vegetables-gloria, citrus fruits: lemon and orange	4.50	101	56	0	0	0.00694	7776000	54000.00
SW035	LONGONOT HORTICULTURE	208348	9909766	L. Naivasha	Vegetables, rumer beans & flowers eustoma	75.00	0	0	0	0	0.04167	28908000	1204500.00
SW036	KEDONG RANCH	208348	9909766	L. Naivasha	N/A	0.00	150	3600	14000	0	0.01203	15724800	189134.40
SW037	KIPABURGI	208535	9909429	L. Naivasha	Grass	14.00	75	320	0	0	0.00667	7776000	51840.00
SW038	GITAU KIO	207111	9908848	L. Naivasha	Roses	20.00	0	0	0	0	0.04167	9720000	405000.00
SW039	SHER AGENCIES	206570	9908710	L. Naivasha	Roses	25.00	0	0	0	0	0.04167	13608000	567000.00
SW040	KIMWATU	206366	9908117	L. Naivasha	Roses & summer flowers	50.00	0	0	0	0	0.08333	13608000	1134000.00
SW041	SARA NYAMBURA KAMAU	205547	9908104	L. Naivasha	Roses	60.00	0	0	0	0	0.04167	13608000	567000.00
SW042	SULMAC FLOWERS	205028	9908265	L. Naivasha	Flowers, roses & carnations	521.04	10000	0	0	0	0.33472	11664000	3904200.00
SW043	SULMAC FLOWERS	204220	9908468	L. Naivasha	Flowers, roses	1954.65	0	0	0	0	0.01722	17496000	301320.00
SW044	LONGONOT HORTICULTURE	203882	9908578	L. Naivasha	Flowers, ammi	1.20	10	0	0	0	0.00100	7776000	7776.00
SW045	FISHER'S MAN CAMP	203447	9909085	L. Naivasha	Flower garden	0.40	400	0	0	0	0.00063	6570000	4106.25
SW046	GOLDSMITH	202974	9909232	L. Naivasha	Flowers, geraniums, seeds	20.23	400	0	0	0	0.01177	15768000	185536.80
SW047	KAMERE	202557	9909569	L. Naivasha	Maize	0.80	100	24	0	0	0.03390	4860000	164754.00
SW048	KPC OLKARIA	201727	9910073	L. Naivasha	N/A	0.00	800	0	0	183600	0.05000	7884000	394200.00
SW049	ELSAMERE	201087	9910046	L. Naivasha	Lawn	0.10	152	0	0	0	0.00040	31536000	12614.40
SW050	OSERIAN	200233	9909972	L. Naivasha	Lawn	0.80	11	8	0	0	0.00017	3888000	673.91
SW051	OSERIAN	199412	9909715	L. Naivasha	Flowers	24.00	20	0	0	0	0.00023	1944000	453.59
SW052	OSERIAN	199334	9909999	L. Naivasha	Flowers	121.41	0	0	0	0	0.01500	9720000	145800.00
SW053	KPC OLKARIA	199427	9909704	L. Naivasha	N/A	0.00	900	0	0	955635.7	0.30550	19710000	6021405.00
SW054	OSERIAN	199259	9909981	L. Naivasha	Flowers	480.00	0	0	0	0	0.23000	15768000	3626640.00
SW055	HOMEGROWN (PELICAN)	212446	9919760	L. Naivasha	Runner beans	72.50	800	74	0	0	0.04000	15552000	622080.00
SW056	BRIXIA BRUNO	203847	9923397	L. Naivasha	Cabbages, onions, tomatoes, beans	8.00	100	0	0	0	0.01700	15552000	264384.00
SW057	BRIXIA MARIO	203573	9923935	L. Naivasha	Cabbages, onions, beans, tomatoes	22.86	0	0	0	0	0.02000	15552000	311040.00
SW058	LOLDIA	200927	9920819	L. Naivasha	Wheat	120.00	0	0	0	0	0.01500	15552000	233280.00
SW059	LOLDIA (WINDMILL)	202486	9920514	L. Naivasha	Grass	0.80	60	0	0	0	0.00200	15768000	31536.00
SW060	LOLDIA	203173	9921750	Gilgil	Wheat	20.00	0	0	0	0	0.00530	15552000	82425.60
SW061	BISLETI	207879	9924570	Malewa	Vegetables, oranges	0.20	0	0	0	0	0.01113	1944000	21627.00
SW062	MORENDAT	209468	9925451	Malewa	Macadamia nut, grapes	240.00	200	0	0	0	0.02200	5832000	128304.00
SW063	KIMATA	205989	9940327	Gilgil	Cabbages	1.60	3	6	0	0	0.01300	3888000	50544.00
SW064	LIHANDA ADAKHALILA	205926	9940947	Gilgil	Cabbage, tomatoes	0.81	15	0	0	0	0.00095	3888000	3693.60
SW065	WANDERI	205638	9941202	Gilgil	Cabbage, tomatoes, onions	0.80	10	4	0	0	0.00400	5832000	23328.00
SW066	DANIEL MWAGO	205415	9941604	Gilgil	Capscum, pepper	1.20	6	0	0	0	0.00250	5832000	14580.00

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Water resources assessment study data

Sr. No.	Name	X	Y	Water Source	Crop Name	Irrigation (ha)	Domestic (People)	Livestock (L.U)	Wildlife (Animals)	Industry (m3/y)	Abstraction (m3/s)	Time (s/y)	Demand (m3/y)
SW067	FRANCIS KAHURA	205638	9941249	Gilgil	Cabbages	0.80	0	1	0	0	0.00286	7776000	22216.03
SW068	GEOFFREY MBUTHIA KAVITI	205487	9941388	Gilgil	Cabbages, tomatoes	0.20	5	0	0	0	0.00500	6804000	34020.00
SW069	MORRIS GITHINJI	205793	9941666	Gilgil	Tomatoes, cabbages, onions	0.81	0	0	0	0	0.00670	9720000	65124.00
SW070	NIEDERBACHER	207270	9946247	Little Gilgil	?	0.10	20	48	0	0	0.00200	5256000	10512.00
SW071	TANINIA	213045	9915158	L. Naivasha	Aconitum flowers	2.83	0	0	0	0	0.02567	10512000	269843.04
SW072	BRIXIA	204022	9923700	L. Naivasha	Cabbages, onions, tomatoes, french beans	16.00	0	0	0	0	0.01700	15552000	264384.00
SW073	KCC FACTORY	209054	9925670	Malewa	N/A	0.00	480	0	0	29200	0.01500	6480000	97200.00
SW074	KORONGO	197302	9917754	L. Naivasha	?	70.20	0	0	0	0	0.02000	31536000	630720.00
SW075	OLSUSWA	197673	9918983	L. Naivasha	Bomarodes, lucerne, sudan grass	242.81	0	450	0	0	0.03300	17496000	577368.00
SW076	SHALIMER FLOWERS	199296	9920229	L. Naivasha	Flowers	120.00	7000	0	0	0	0.03900	7776000	303264.00
SW077	NORTH LAKE NURSERIES	198498	9919713	L. Naivasha	Sudan grass	48.56	0	320	0	0	0.06940	10512000	729532.80
SW078	SAFARI HORTICULTURE	?	?	L. Naivasha	Flowers	150.00	1000	0	0	0	0.05220	31536000	1646179.20
SW079	NGIGE	213476	9918471	L. Naivasha	French beans	8.90	0	4	0	0	0.01700	7776000	132192.00
SW080	MUNDUI			L. Naivasha	?	462.95	0	0	0	0	0.00000	0	0.00
SW081	OLOLERAI	200026	9912056	L. Naivasha	Limes	2.00	16	70	0	0	0.00235	5832000	13705.20
SW082	MORSON	204027	9908915	L. Naivasha	Nil	0.40	6	2	0	0	0.00400	972000	3888.00
SW083	NDERIT	198554	9911578	L. Naivasha	Grass	0.81	20	0	0	0	0.00060	11664000	6998.40
SW084	NDERIT	198554	9911281	L. Naivasha	Grass	0.80	15	0	0	0	0.00060	11664000	6998.40
SW085	KIARIE	212917	9918962	L. Naivasha	Vegetables	0.20	0	0	0	0	0.00400	5832000	23328.00
SW086	NDEGWA	213264	9918971	L. Naivasha	French beans	2.27	0	0	0	0	0.01670	2916000	48697.20
SW087	MUTHONI	212838	9919095	L. Naivasha	Maize, french beans	0.40	0	0	0	0	0.00500	2916000	14580.00
SW088	PEARL FLOWERS	212575	9919511	L. Naivasha	Summer flowers	4.05	0	0	0	0	0.00250	7776000	19440.00
SW089	KEIRU	213239	9918910	L. Naivasha	N/A	0.00	20	14	0	0	0.00000	3931200	0.00
SW090	KIGIO	211095	9937322	Malewa	N/A	0.00	50	292	700	0	0.00031	31536000	9703.38
SW091	KENYA RAILWAYS CORPORATION	203900	9949000	Gilgil	N/A	0.00	0	0	0	0	0.00395	31536000	124465.00
SW093	FRANCIS NJAU	198016	9957695	Kariandus	Tomatoes	1.21	3	0	0	0	0.00095	11664000	11108.57
SW094	MUTHORA	197829	9952656	Kariandus	Coben cabbage	2.02	2	0	0	0	0.00285	11664000	33242.40
SW095	MINISTRY OF ENVIRONMENT	198016	9952695	Kariandus	Tree seedlings	0.40	0	0	0	0	0.00000	23328000	0.00
SW096	GOODWILL SELF HELP WATER PROJECT	197632	9952026	Kariandus	Cabbages, tomatoes, maize	16.00	0	0	0	0	0.02180	31536000	687421.73
SW097	DIATOMITE INDUSTRIES-cooling machines	197032	9950524	Kariandus	N/A	0.00	150	0	0	558345.98	0.01810	3888000	70372.80
SW098	LAKE FLOWERS LTD-Flowers industry	212062	9919356	L. Naivasha	Flowers, roses	4.00	150	0	0	6636.43	0.02000	7776000	155520.00
SW099	OLARAGWAI LTD-cattle spraying	214002	9932308	Mahindu	Vegetables	1.21	50	8	2	72	0.00200	3888000	7776.00
SW100	OLARAGWAI LTD	214979	9932990	Mahindu	?	0.80	60	16	1	0	0.00082	4860000	3976.36
SW101	HOMEGROWN	210956	9926771	Malewa	Runner beans	9.00	0	0	0	0	0.06900	8748000	603612.00
SW102	DAIRY TRAINING INSTITUTE	212847	9929768	Malewa	?	0.00	4000	30	0	0	0.00220	15768000	34689.60
SW103	MORENDAT NORTH	210885	9926483	Malewa	Macadama nut	202.35	300	200	0	0	0.05000	7776000	388800.00
SW104	NYONJORO	219714	9929434	Lodges spring	Vegetables	0.00	0	0	0	0	0.00120	31536000	37843.20
SW105	OLMOROGI-dairy cleaning	211712	9935466	Malewa	N/A	0.00	90	196	0	181	0.00046	12636000	5791.50
SW106	OLMOROGI	214200	9936700	Biazi	Cabbages	4.05	1	0	0	0	0.00252	31536000	79555.40
SW107	OLMOROGI	214000	9936700	Biazi	Maize	1.62	0	0	0	0	0.00368	31536000	116086.43
SW108	MARULA	207405	9922428	Malewa	Lucerne	163.73	0	0	0	0	0.42614	11664000	4970454.30
SW109	MARULA	208140	9925554	Malewa	French beans	28.33	0	0	0	0	0.05200	9720000	505440.00
SW110	MARULA	208356	9925873	Malewa	Lucerne	161.71	0	0	0	0	0.63345	11664000	7388588.79
SW111	MARULA HOMEGROWN	209466	9926429	Malewa	Strawberries	20.23	20	0	0	0	0.00000	11664000	0.00
SW112	MARULA	206401	9934823	Little Gilgil	N/A	0.00	40	200	0	0	0.00072	31536000	22705.92
SW113	MARULA	206496	9931794	Little Gilgil	Natural grass	48.56	0	0	0	0	0.02079	31536000	655633.44
SW114	MUNUNGA LTD.	206962	9947004	Little Gilgil	N/A	0.00	17	64	0	0	0.00018	23328000	4241.03
SW115	NDUME LTD.-cooling machinery	204816	9945092	Little Gilgil	?	0.00	0	0	0	9621.4	0.00090	3942000	3547.80

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Water resources assessment study data

Sr. No.	Name	X	Y	Water Source	Crop Name	Irrigation (ha)	Domestic (People)	Livestock (L.U)	Wildlife (Animals)	Industry (m3/y)	Abstraction (m3/s)	Time (s/y)	Demand (m3/y)
SW116	OSIRUA	206240	9944532	Little Gilgil	Vegetables	0.40	40	0	0	0	0.00012	7884000	977.62
SW117	ABDRICO	206773	9947790	Little Gilgil	N/A	0.00	21	5	0	0	0.00051	31536000	16209.50
SW118	ADBRICO	206808	9947313	Little Gilgil	?	0.40	21	9	0	0	0.00031	31536000	9776.16
SW119	MONAR	206926	9946356	Little Gilgil	N/A	0.00	19	8	0	0	0.02394	1458000	34909.12
SW120	MAINA KARANJA	206894	9945999	Little Gilgil	Green peppers, cupscums	8.09	11	0	0	0	0.00180	31536000	56764.80
SW121	GILGIL COUNTRY CLUB	206894	9945999	Little Gilgil	?	0.00	102	0	0	0	0.00004	31536000	1195.05
SW122	RIVER HOUSE	?	?	Little Gilgil	Vegetables	0.20	3	0	0	0	0.00036	31536000	11352.96
SW123	PETER CHEGE	206588	9948838	Little Gilgil	Vegetables, cabbages, onions and fruits	9.31	18	0	0	0	0.00830	15768000	130874.40
SW124	OSIRUA	206162	9944328	Little Gilgil	?	8.08	0	0	0	0	0.00210	4860000	10226.25
SW125	KONGONI	?	?	L. Naivasha	Onions	0.80	0	0	0	0	0.00024	10512000	2488.08
SW126	KONGONI	195483	9909538	L. Naivasha	N/A	0.00	58	96	0	0	0.00167	10512000	17520.00
SW127	PORTMANS BRIDGE	?	?	Malewa	Vegetables	0.10	5	10	0	0	0.00040	3942000	1576.80
SW128	MURINDATI WATER SUPPLY	?	?	Gilgil	N/A	0.00	800	0	0	0	0.00720	31536000	227059.20
SW130	KANYORA-power generation	203700	9950400	Gilgil	?	0.20	0	0	0	26535.5	0.00092	31536000	29163.50
SW130A	DRIPLAND	203977	9947096	Gilgil	Lucerne, barley	0.00	0	0	0	1659089.25	0.05261	31536000	1659089.25
SW131	DRIPLAND	204488	9946350	Depression	?	8.09	15	120	0	0	0.01276	31536000	402489.15
SW132	NJENGA	203604	9950424	Gilgil	Sukuma and cabbages	11.00	20	0	0	0	0.02130	7776000	165628.80
SW132A	NJOROGE	203700	9945000	Gilgil	?	3.03	0	0	0	0	0.00080	31536000	25382.10
SW133	HOME AFFAIRS	203600	9948450	Gilgil	N/A	6.06	0	0	0	0	0.00161	31536000	50887.21
SW134	GITUKUI	?	?			0.00	0	0	0	0	0.00000	31536000	0.00
SW138	MUNYONGORI	203700	9949400	Murindati	?	2.02	0	0	0	0	0.00063	31536000	19896.15
SW139	MAC CILLIVRAY	202200	9954700	Gilgil	?	0.20	0	0	0	0	0.00013	31536000	4164.65
SW140	KAHUHO FARMERS-power generation	203800	9953730	Gilgil	N/A	0.00	0	0	0	120282.1	0.00384	31536000	120942.75
SW141	BEGG-power generation	205770	9941170	Gilgil	N/A	0.00	0	0	0	66360.65	0.00231	31536000	72996.35
SW142	KIMANI-power generation	203700	9950600	Gilgil	N/A	0.00	0	0	0	16589.25	0.00055	31536000	17417.80
SW143	NASON	203700	9950700	Gilgil	?	2.52	0	0	0	0	0.00069	31536000	21710.20
SW144	GITHENDE	?	?	Gilgil	?	2.02	0	0	0	0	0.00055	31536000	17253.55
SW145	CHOKEREIRA-power generation	203721	9951991	Spring of Gilgil	N/A	0.00	0	0	0	66360.65	0.00231	31536000	72996.35
SW146	KIANDA WATER ASSOCIATION	221869	9973689	Malewa	Vegetables, cabbages	3.20	0	0	0	0	0.00087	31536000	27564.80
SW146A	MINISTRY OF HOME AFFAIRS	203800	9948400	Gilgil	N/A	0.00	0	0	0	28221.8	0.00094	31536000	29546.75
SW147	MALEWA WATER ASSOCIATION	221813	9973680	Malewa	N/A	0.00	300	0	0	0	0.00220	31536000	69379.20
SW148	MATHAGA	221932	9973850	Malewa	Carrots, cabbages	1.21	30	13	0	0	0.00083	31536000	26174.88
SW149	WITEITHIE WATER PROJECT	222048	9973883	Malewa	N/A	0.00	0	0	0	0	0.00000	5832000	0.00
SW150	STEPHEN KIRAGU	222048	9973883	Malewa	N/A	0.00	0	0	0	0	0.00000	31536000	0.00
SW151	THOME WATER PROJECT	222280	9974049	Malewa	N/A	0.00	0	0	0	0	0.00000	31536000	0.00
SW152	WAITE MURAGURI-fish farming	222280	9974049	Malewa	N/A	0.00	0	0	0	7327.375	0.00023	31536000	7327.38
SW153	KIEMI "A" WATER PROJECT	212167	9965164	Malewa	N/A	0.00	362	248	0	0	0.00069	31536000	21900.00
SW154	SALIENT SECONDARY SCHOOL	212358	9963349	Malewa	N/A	0.00	775	0	0	0	0.00450	12480	56.16
SW156	KAHARA	212200	9964500	Malewa	N/A	0.00	0	0	0	0	0.00000	5832000	0.00
SW157	MUGITIRI WATER PROJECT	232450	9954697	Mahisimiti	N/A	0.00	6000	1200	0	0	0.00367	31536000	115831.73
SW158	RUTUBA WATER PROJECT	232814	9954857	Mahisimiti	Eligium, cut flowers	40.47	48	0	0	0	0.21000	31536000	6622560.00
SW159	GATHUTHI WATER ASSOCIATION	232073	9955679	Ntoya	N/A	0.00	150	48	0	0	0.00041	5832000	2385.82
SW160	LUKA MURUTHI	232111	9955681	Ntoya	Potatoes, onions	0.80	12	0	0	0	0.00045	31536000	14191.20
SW161	DAMSON MATHU	232102	9955754	Ntoya	Cabbages, onions	1.20	15	16	0	0	0.00045	31536000	14191.20
SW162	MBURU	226200	9912500	Kew creek	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW163	KINYANJUI			Kigogo	?	0.80	0	0	0	0	0.00024	31536000	7719.75
SW164	MWANGI	197500	9951700	Kariandus	?	0.80	0	0	0	0	0.00023	31536000	7374.83
SW165	GITONGA-power generation			Tongi tongi	?	0.20	0	0	0	38157.1	0.00133	31536000	41967.70

Appendix V-1

Water resources assessment study data

Sr. No.	Name	X	Y	Water Source	Crop Name	Irrigation (ha)	Domestic (People)	Livestock (L.U)	Wildlife (Animals)	Industry (m3/y)	Abstraction (m3/s)	Time (s/y)	Demand (m3/y)
SW166	NUNJORO			Rays spring	?	0.00	0	0	0	0	0.00085	31536000	26877.51
SW167	NGETETI	228400	9953800	Oleolondo	?	0.00	0	0	0	0	0.00016	31536000	4964.00
SW168	NYAKAIRU	224500	9913900	Nyakairu	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW169	GACHOKA			Nyairoko	?	0.81	0	0	0	0	0.00023	31536000	7128.45
SW170	MBURU			Kew creek	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW171	KEDONG RANCH LTD.			Lorogwa	?	0.00	0	0	0	0	0.00184	31536000	58067.85
SW172	KINUNGI F.C.S. LTD.			Dry	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW173	MBURU	226250	9912570	Kew creek	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW174	MBURU	225400	9912600	Kew creek	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW176	OL-ARAGWAI LTD.	216250	9931740	Mahindu	?	0.20	0	0	0	0	0.00093	31536000	29196.35
SW177	GATHIMA			Gathima	?	1.62	0	0	0	0	0.00047	31536000	14764.25
SW178	ERERI COMPANY LTD.			Tongi tongi	N/A	0.00	0	0	0	0	0.00127	31536000	39982.10
SW179	PEPONI			Bush buck creek	?	0.00	0	0	0	0	0.00000	31536000	0.00
SW180	NJONGE	200100	9954800	Kigogo	?	0.80	0	0	0	0	0.00024	31536000	7555.50

Appendix V-2

Comparison between water resources assessment study and the theoretical approach

Farm	Survey Number	Declared irrigated land			Satellite image				Difference (million m3/y)
		Area (ha)	Land use	Abstraction (m3/y)	Polygons	Area (ha)	Land use	Theoretical need (m3/y)	
Marula	SW108	163.73	Alfalfa	4970454	pol1,3,4,5,6,50	216.5	Vegetables	718780	
	SW109	28.3	Beans	505440	pol2,7	82.9	Alfalfa	244555	
	SW110	161.7	Alfalfa	7388589					
	SW111	20.2	Strawberries	0					
	sub-total	**373.93**		**12864483**		**299.4**		**963335**	**11.90**
Delamere	BH053	0	Alfalfa	168480	pol8,9,13,14,15	451.4	Vegetables	1498648	
	BH054	45	Vegetables	369360	pol10,16	219.1	Alfalfa	646345	
	BH058	120	Vegetables	1274000					
	BH061	120	Vegetables	392040					
	sub-total	**285.00**		**2203880**		**670.5**		**2144993**	**0.06**
Kari	BH051	40	Alfalfa	350838	pol11	84	Alfalfa	247800	
					pol12	21.4	Vegetables	71048	
	sub-total	**40.00**		**350838**		**105.4**		**318848**	**0.03**
Lake flowers	SW098	4	Flowers	155520	pol20	7.1	Flowers	23146	
Pearl flowers	SW088	4	Flowers	19440	pol51	1.3	Flowers	4238	
	sub-total	**8.00**		**174960**		**8.4**		**27384**	**0.15**

Appendix V-2

Comparison between water resources assessment study and the theoretical approach

Farm	Survey Number	Declared irrigated land			Satellite image				Difference
		Area (ha)	Land use	Abstraction (m3/y)	Polygons	Area (ha)	Land use	Theoretical need (m3/y)	(million m3/y)
Muguku	SW003	0.8	Flowers	9720	pol21	1.1	Flowers	3586	
					pol24	3.3	Alfalfa	9735	
	sub-total	**0.80**		**9720**		**4.4**		**3586**	**0.01**
Bees' garden	SW006	0.1	Alfalfa	25920	pol22	3.4	Alfalfa	10030	
Hortitec	SW012	2	Flowers	38880	part of pol25	7.7	Flowers	25102	
Richard Wilcoch	SW015	7	Flowers	24390	part of pol25				
	sub-total	**9.10**		**89190**		**11.1**		**35132**	**0.05**
Loldia	SW058	120	Wheat	233280	pol45	80.4	Wheat	139896	
	BH045	8	Alfalfa	311040	pol46	20	Alfalfa	59000	
	SW060	20	Wheat	62208	pol47	150.3	Wheat	261522	
	sub-total	**148.00**		**606528**		**250.7**		**460418**	**0.15**
Brixia	SW072	16	Vegetables	264384	part of pol49	100.6	Vegetables	333992	
Brixia Bruno	SW056	8	Vegetables	264384	part of pol49				
Brixia Mario	SW057	22.9	Vegetables	311040	part of pol49				
Brixia Mario	BH043	32	Vegetables	259200	part of pol49				
	sub-total	**78.90**		**1099008**		**100.6**		**333992**	**0.77**
Korongo	BH076	8	Vegetables	84240	pol43	115.1	Vegetables	382132	
Korongo	BH078	8	Alfalfa	31104	part of pol42	207.5	Alfalfa	612125	
Olsuswa	SW075	242.8	Alfalfa	577368	part of pol42				
Rocco	BH079	2	Vegetables	26280	part of pol42				
	sub-total	**260.80**		**718992**		**322.6**		**994257**	**-0.28**
Nyanjugu investments	BH083	2	Flowers	466560	pol48	100.1	Flowers	326326	
North Lake Nurseries	BH082	1.4	Flowers	93440	part of pol44	474.4	Flowers	1546544	
Shalimer flowers	SW076	120	Flowers	84240	part of pol44				
Olsuswa	BH080	80	Flowers	82589	part of pol44				
Olsuswa	BH081	80	Flowers	82589	part of pol44				
	sub-total	**283.40**		**809419**		**574.5**		**1872870**	**-1.06**
Homegrown pelican	SW055	72.5	Runner beans	622080	pol17,18,19	1545.2	Vegetables	5130064	
Muthoni	SW087	0.4	Vegetables	14580	pol17,18,19				
Kiarie	SW085	0.2	Vegetables	23328	pol17,18,19				
Ndegwa	SW086	2.3	French beans	48697	pol17,18,19				
Ngige	SW079	8.9	French beans	132192	pol17,18,19				
Aberdare	SW001	21.2	Vegetables	137700	pol17,18,19				
Boffer	SW004	24	Vegetables	155520	pol17,18,19				
Mwangi gateri	SW008	7.2	Vegetables	917568	pol17,18,19				
Githeke	BH003	0.8	Vegetables	31104	pol17,18,19				

Appendix V-2

Comparison between water resources assessment study and the theoretical approach

Farm	Survey Number	Declared irrigated land			Satellite image				Difference (million m3/y)
		Area (ha)	Land use	Abstraction (m3/y)	Polygons	Area (ha)	Land use	Theoretical need (m3/y)	
Three point ostrich	SW013	30	Vegetables	453600	pol17,18,19				
Mathew mgure	SW009	0.8	Vegetables	346032	pol17,18,19				
Homegrown south lake	BH040	0.1	Vegetables	438	pol17,18,19				
Amoroso	SW016	15	Alfalfa	0	pol17,18,19				
J.F. Campbed clause	SW017	3.6	Alfalfa	38658	pol17,18,19				
Taninia	SW071	2.8	Flowers	269843	pol17,18,19				
Elsagro	SW018	19	Vegetables	194400	pol17,18,19				
Crescent island	SW026	0.1	Vegetables	6804	pol17,18,19				
Lake crop	SW011	0.5	Vegetables	7776	pol17,18,19				
	sub-total	**209.40**		**3400320**		**1545.2**		**5130064**	**-1.73**
C.C Bengough	SW019	0.4	Alfalfa	116640	pol26	36	Flowers	117360	
Estate Leasing LTD.	BH117	0.8	Alfalfa	2160					
Knabe hill	SW023	10.6	Fruits	143467					
Vineyards	SW024	20	Fruits	87480					
	sub-total	**31.80**		**349747**		**36**		**117360**	**0.23**
Longonot	SW034	4.5	Flowers	54000	part of pol30	166.1	Flowers	541486	
Vineyards	SW032	13	Grapes and flowers	97200	part of pol30				
Osirua	SW029	20	Flowers	381060	part of pol30				
Nini	SW031	18	Flowers	629856	part of pol30				
	sub-total	**55.50**		**1162116**		**166.1**		**541486**	**0.62**
Sulmac flowers	SW042	521	Flowers	3904200	part of pol34,35	749.9	Flowers	2444674	
Sulmac flowers	SW043	1954.7	Flowers	301320	part of pol34,35				
					settlement	63			
	sub-total	**2475.70**		**4205520**		**686.9**		**2444674**	**1.76**
Longonot horticulture	SW044	1.2	Flowers	7776	part of pol33	753.6	Flowers	2456736	
Morson	SW082	0.4	Nil	3888	part of pol33				
Fisherman's camp	SW045	0.4	Flowers	4106	part of pol33				
Goldsmith	SW046	20.2	Flowers	185537	part of pol33				
Gitau Kio	SW038	20	Flowers	405000	part of pol33				
Sher agencies	SW039	25	Flowers	567000	part of pol33				
Kimwatu	SW040	50	Flowers	1134000	part of pol33				
Sara Nyambura Kamau	SW041	60	Flowers	567000	part of pol33				
	sub-total	**177.20**		**2874307**		**753.6**		**2456736**	**0.42**
Oserian	SW054	480	Flowers	3626640	pol37,38,39	1271.3	Flowers	4144438	
	SW052	121.4	Flowers	145800	settlement	33			
	SW051	24	Flowers	454					
	BH039	8	Grass	3116808					
	sub-total	**633.40**		**6889702**		**1238.3**		**4144438**	**2.75**

Appendix V-2

Comparison between water resources assessment study and the theoretical approach

Farm	Survey Number	Declared irrigated land: Area (ha)	Declared irrigated land: Land use	Declared irrigated land: Abstraction (m3/y)	Satellite image: Polygons	Satellite image: Area (ha)	Satellite image: Land use	Satellite image: Theoretical need (m3/y)	Difference (million m3/y)
Kinja nurseries	BH091	1.6	Flowers	4303	pol40,41	125.9	Flowers	410434	
Elsamere	SW049	0.1	Grass	12614	part of pol36	73.6	Grass	205344	
Oserian	SW050	0.8	Lawn	674	part of pol36				
Longonot	BH024	0	Vegetables	7300	pol31	61.3	Vegetables	203516	
Kipaburgi	SW037	14	Grass	51840	pol32	124.5	Grass	347355	
Sanctuary	SW025	12	Alfalfa	2272536	part of pol28,29	107.6	Alfalfa	317420	
	SW027	0.1	Alfalfa	2097	part of pol28,29				
	BH018	0	Alfalfa	1869	part of pol28,29				
Lotus island kijabe	SW022	0.7	Grass	31104	pol27	87.1	Grass	243009	
	sub-total	**29.30**		**2384337**		**580**		**1727078**	**0.66**
	TOTAL	**5100.23**		**40193066.74**		**7353.70**		**23721518.50**	**16.48**

Appendix VI-1

Conceptual model

To maximise gross income.

Decision variable: X(i)
Where:
X = land in ha per crop i.
i= crop: wheat, flowers, alfalfa, vegetables, grass (1,...,5).
For year type: dry, average and wet, do:

Max Gross income = Σ{yield(i)*price(i)*X(i)}

Subject to:

Σ{Water demand (i)[m3/ha]*X(i)[ha]} <= supply [million m3]=variable 1
Σ{Yield[tons/ha] (i)*X(i)[ha]} >= Required production [Tons]
Σ{Labour requirement (i)[workdays/ha]*X(i)[ha]} <= Man force [workdays]=variable 2
Σ{Pesticide effective use (i) [Tons/ha]*X(i)[ha]} <= Total pesticide supply[Tons]
Σ{Urea effective use (i)[Tons/ha]*X(i)[ha]} <= Total fertiliser supply[Tons]
Σ{X[ha] (i)}<=Total area [ha]

To maximise employment.

Decision variable: X(i)
Where:
X = land in ha per crop i.
i= crop: wheat, flowers, alfalfa, vegetables, grass (1,...,5).
For year type: dry, average and wet, do:

Max Employment = Σ{labour(i)*X(i)}

Subject to:

Σ{Water demand (i)[m3/ha]*X(i)[ha]} <= supply [million m3]=variable1
Σ {yield(i)*price(i)*X(i)}= Gross output= variable2
Σ{Yield[tons/ha] (i)*X(i)[ha]} >= Required production [tons]
Σ{Labour requirement (i)[workdays/ha]*X(i)[ha]} <= Man force [workdays]
Σ{Pesticide effective use (i) [Tons/ha]*X(i)[ha]} <= Total pesticide allowed[Tons]
Σ{Urea effective use (i)[Tons/ha]*X(i)[ha]} <= Total fertiliser allowed[Tons]
Σ{X[ha] (i)}<=Total area [ha]

To minimise water use.

Decision variable: X(i)
Where:
X = land in ha per crop i.
i= crop: wheat, flowers, alfalfa, vegetables, grass (1,...,5).
For year type: dry, average and wet, do:

Min water use (i) = Σ{water use(i)*X(i)}

Subject to:

Σ{Water demand (i)[m3/ha]*X(i)[ha]} <= supply [million m3]
Σ{Yield[tons/ha] (i)*X(i)[ha]} >= Required production [tons]
Σ{Labour requirement (i)[workdays/ha]*X(i)[ha]} >= agricultural labour [workdays]
Σ {yield(i)*price(i)*X(i)}= Gross output= variable2
Σ{Pesticide effective use (i) [Tons/ha]*X(i)[ha]} <= Total pesticide allowed[Tons]
Σ{Urea effective use (i)[Tons/ha]*X(i)[ha]} <= Total fertiliser allowed[Tons]
Σ{X[ha] (i)}<=Total area [ha]

Appendix VI-2

Gams models

```
$TITLE drygross
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
       i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat               459
         Flowers               0
         Alfalfa           10920
         Vegetables          282
         Grass              1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat               29
         Flowers            150
         Alfalfa             43
         Vegetables          50
         Grass               43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat               0.007978
         Flowers             0.166224
         Alfalfa             0.022739
         Vegetables          0.040836
         Grass               0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat               0.300000
         Flowers             2.400000
         Alfalfa             0.080000
         Vegetables          2.400000
         Grass               0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat                0.001740
         Flowers              0.003260
         Alfalfa              0.002960
         Vegetables           0.003320
         Grass                0.002800/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat                 2
        Flowers               91
        Alfalfa               15
        Vegetables            28
        Grass                 6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat                 0.021667
        Flowers               0.052143
        Alfalfa               0.009079
        Vegetables            0.022364
        Grass                 0.009079/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/;


VARIABLES
        x(i)    ha in cases
        z       gross income in  million ksh
        laborv  labour in workdays
        ratiov  ratio dimensionless
        waterv  water in million m3;

POSITIVE VARIABLE x;

EQUATIONS
```

```
gross         define objective function

yldreq(i)     satisfy yield requirement for use i
pestlim       observe pesticide limit
urealim       observe urea limit
labreq        workdays requirement
watreq        water requirement
ratreq        ratio value
Land          observe area for crop i;

gross..       z=e=sum((i),yield(i)*price(i)*x(i));

yldreq(i)..   yield(i)*X(i)=g=food(i);
pestlim..     sum((i), pesticide(i)*x(i))=l=pestl;
urealim..     sum((i), urea(i)*x(i))=l=ureal;
land..        sum((i), x(i))=l=areat;
labreq..      laborv=e=sum((i), labour(i)*X(i));
watreq..      waterv=e=sum((i), wuse(i)*X(i));
ratreq..      ratiov=e=sum((i), yield(i)*price(i)*x(i)/wuse(i));

Model drygross /all/;
solve drygross using lp maximizing z;
display x.l,x.m;
```

***

```
$TITLE avggross
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
       i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat                 459
         Flowers                 0
         Alfalfa             10920
         Vegetables            282
         Grass                1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat                  29
         Flowers               150
         Alfalfa                43
         Vegetables             50
         Grass                  43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat                 0.007978
         Flowers               0.166224
         Alfalfa               0.022739
         Vegetables            0.040836
         Grass                 0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat                 0.300000
         Flowers               2.400000
         Alfalfa               0.080000
         Vegetables            2.400000
         Grass                 0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat                  0.001310
         Flowers                0.001890
         Alfalfa                0.001870
         Vegetables             0.001960
         Grass                  0.001490/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat                   2
        Flowers                 91
        Alfalfa                 15
        Vegetables              28
        Grass                   6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat                   0.016667
        Flowers                 0.040110
        Alfalfa                 0.006984
        Vegetables              0.017203
```

```
        Grass                 0.006984/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/;


VARIABLES
        x(i)    ha in cases
        z       gross income in  million ksh
        laborv  labour in workdays
        ratiov  ratio dimensionless
        waterv  water in million m3;

POSITIVE VARIABLE x;

EQUATIONS

gross        define objective function

yldreq(i)    satisfy yield requirement for use i
pestlim      observe pesticide limit
urealim      observe urea limit
labreq       workdays requirement
ratreq       ratio requirement
watreq       water requirement
Land         observe area for crop i;

gross..      z=e=sum((i),yield(i)*price(i)*x(i));

yldreq(i)..  yield(i)*X(i)=g=food(i);
pestlim..    sum((i), pesticide(i)*x(i))=l=pestl;
urealim..    sum((i), urea(i)*x(i))=l=ureal;
land..       sum((i), x(i))=l=areat;
labreq..     laborv=e=sum((i), labour(i)*X(i));
ratreq..     ratiov=e=sum((i), yield(i)*price(i)*x(i)/wuse(i));
watreq..     waterv=e=sum((i), wuse(i)*X(i));

Model avggross /all/;
solve avggross using lp maximizing z;
display x.l,x.m;
```

***

```
$TITLE wetgross
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
        i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat                 459
         Flowers                 0
         Alfalfa             10920
         Vegetables            282
         Grass                1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat                 29
         Flowers              150
         Alfalfa               43
         Vegetables            50
         Grass                 43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat                0.007978
         Flowers              0.166224
         Alfalfa              0.022739
         Vegetables           0.040836
         Grass                0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat                0.300000
         Flowers              2.400000
         Alfalfa              0.080000
```

```
        Vegetables          2.400000
        Grass               0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat               0.001280
         Flowers             0.001780
         Alfalfa             0.001620
         Vegetables          0.001860
         Grass               0.001420/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat                2
        Flowers              91
        Alfalfa              15
        Vegetables           28
        Grass                6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat                0.016667
        Flowers              0.040110
        Alfalfa              0.006984
        Vegetables           0.017203
        Grass                0.006984/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/;


VARIABLES
        x(i)     ha in cases
        z        gross income in  million ksh
        laborv   labour in workdays
        ratiov   ratio dimensionless
        waterv   water in million m3;

POSITIVE VARIABLE x;

EQUATIONS

gross        define objective function

yldreq(i)    satisfy yield requirement for use i
pestlim      observe pesticide limit
urealim      observe urea limit
labreq       workdays requirement
ratreq       ratio requirement
watreq       water requirement
Land         observe area for crop i;

gross..      z=e=sum((i),yield(i)*price(i)*x(i));

yldreq(i)..  yield(i)*X(i)=g=food(i);
pestlim..    sum((i), pesticide(i)*x(i))=l=pestl;
urealim..    sum((i), urea(i)*x(i))=l=ureal;
land..       sum((i), x(i))=l=areat;
labreq..     laborv=e=sum((i), labour(i)*X(i));
ratreq..     ratiov=e=sum((i), yield(i)*price(i)*x(i)/wuse(i));
watreq..     waterv=e=sum((i), wuse(i)*X(i));

Model wetgross /all/;
solve wetgross using lp maximizing z;
display x.l,x.m;
```

***

```
$TITLE dryemploy
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
        i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat               459
         Flowers               0
```

```
        Alfalfa          10920
        Vegetables         282
        Grass             1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat              29
         Flowers           150
         Alfalfa            43
         Vegetables         50
         Grass              43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat             0.007978
         Flowers           0.166224
         Alfalfa           0.022739
         Vegetables        0.040836
         Grass             0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat             0.300000
         Flowers           2.400000
         Alfalfa           0.080000
         Vegetables        2.400000
         Grass             0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat              0.001740
         Flowers            0.003260
         Alfalfa            0.002960
         Vegetables         0.003320
         Grass              0.002800/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat               2
        Flowers             91
        Alfalfa             15
        Vegetables          28
        Grass               6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat               0.021667
        Flowers             0.052143
        Alfalfa             0.009079
        Vegetables          0.022364
        Grass               0.009079/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/;


VARIABLES
        x(i)    ha in cases
        z       gross income in  million ksh
        grossv  profit in million Ksh
        ratiov  ratio dimensionless
        waterv  water in million m3;

POSITIVE VARIABLE x;

EQUATIONS

employ         define objective function

yldreq(i)     satisfy yield requirement for use i
pestlim       observe pesticide limit
urealim       observe urea limit
grossreq      gross income achievement
ratioreq      ratio value
watreq        water use
Land          observe area for crop i;

employ..      z=e=sum((i),labour(i)*X(i));

yldreq(i)..   yield(i)*X(i)=g=food(i);
pestlim..     sum((i), pesticide(i)*x(i))=l=pestl;
urealim..     sum((i), urea(i)*x(i))=l=ureal;
land..        sum((i), x(i))=l=areat;
ratioreq..    ratiov=e=sum((i), yield(i)*price(i)*x(i)/wuse(i));
grossreq..    grossv=e=sum((i), yield(i)*price(i)*x(i));
watreq..      waterv=e=sum((i), wuse(i)*X(i));

Model dryemploy /all/;
```

```
solve dryemploy using lp maximizing z;
display x.l,x.m;
```

***

```
$TITLE avgemploy
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
       i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat                 459
         Flowers                 0
         Alfalfa             10920
         Vegetables            282
         Grass                1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat                 29
         Flowers               150
         Alfalfa               43
         Vegetables            50
         Grass                 43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat                 0.007978
         Flowers               0.166224
         Alfalfa               0.022739
         Vegetables            0.040836
         Grass                 0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat                 0.300000
         Flowers               2.400000
         Alfalfa               0.080000
         Vegetables            2.400000
         Grass                 0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat                  0.001310
         Flowers                0.001890
         Alfalfa                0.001870
         Vegetables             0.001960
         Grass                  0.001490/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat                   2
        Flowers                 91
        Alfalfa                 15
        Vegetables              28
        Grass                   6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat                   0.016667
        Flowers                 0.040110
        Alfalfa                 0.006984
        Vegetables              0.017203
        Grass                   0.006984/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/;


VARIABLES
        x(i)     ha in cases
        z        gross income in  million ksh
        grossv   gross income in million Ksh
        ratiov   ratio dimensionless
        waterv   water in million m3;

POSITIVE VARIABLE x;

EQUATIONS

employ        define objective function
```

```
yldreq(i)     satisfy yield requirement for use i
pestlim       observe pesticide limit
urealim       observe urea limit
grossreq      gross income
ratioreq      ratio requirement
watreq        water use
Land          observe area for crop i;

employ..      z=e=sum((i),labour(i)*X(i));

yldreq(i)..   yield(i)*X(i)=g=food(i);
pestlim..     sum((i), pesticide(i)*x(i))=l=pestl;
urealim..     sum((i), urea(i)*x(i))=l=ureal;
land..        sum((i), x(i))=l=areat;
ratioreq..    ratiov=e=sum((i), yield(i)*price(i)*x(i)/wuse(i));
grossreq..    grossv=e=sum((i), yield(i)*price(i)*x(i));
watreq..      waterv=e=sum((i), wuse(i)*X(i));

Model avgemploy /all/;
solve avgemploy using lp maximizing z;
display x.l,x.m;
```

***

```
$TITLE wetemploy
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
        i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat                 459
         Flowers                 0
         Alfalfa             10920
         Vegetables            282
         Grass                1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat                  29
         Flowers               150
         Alfalfa                43
         Vegetables             50
         Grass                  43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat                 0.007978
         Flowers               0.166224
         Alfalfa               0.022739
         Vegetables            0.040836
         Grass                 0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat                 0.300000
         Flowers               2.400000
         Alfalfa               0.080000
         Vegetables            2.400000
         Grass                 0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat                  0.001280
         Flowers                0.001780
         Alfalfa                0.001620
         Vegetables             0.001860
         Grass                  0.001420/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat                   2
        Flowers                 91
        Alfalfa                 15
        Vegetables              28
        Grass                   6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat                   0.016667
        Flowers                 0.040110
        Alfalfa                 0.006984
        Vegetables              0.017203
        Grass                   0.006984/;
```

```
SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/;


VARIABLES
        x(i)    ha in cases
        z       gross income in  million ksh
        grossv  profit in million Ksh
        ratiov  ratio dimensionless
        waterv  water in million m3;

POSITIVE VARIABLE x;

EQUATIONS

employ         define objective function

yldreq(i)      satisfy yield requirement for use i
pestlim        observe pesticide limit
urealim        observe urea limit
grossreq       profit per cubic meter
ratioreq       profit per cubic meter
watreq         water use
Land           observe area for crop i;

employ..       z=e=sum((i),labour(i)*X(i));

yldreq(i)..    yield(i)*X(i)=g=food(i);
pestlim..      sum((i), pesticide(i)*x(i))=l=pestl;
urealim..      sum((i), urea(i)*x(i))=l=ureal;
land..         sum((i), x(i))=l=areat;
grossreq..     grossv=e=sum((i), yield(i)*price(i)*x(i));
ratioreq..     ratiov=e=sum((i), yield(i)*price(i)*x(i)/wuse(i));
watreq..       waterv=e=sum((i), wuse(i)*X(i));

Model wetemploy /all/;
solve wetemploy using lp maximizing z;
display x.l,x.m;
```

***

```
$TITLE drywuse
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
        i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat                 459
         Flowers                 0
         Alfalfa             10920
         Vegetables            282
         Grass                1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat                  29
         Flowers               150
         Alfalfa                43
         Vegetables             50
         Grass                  43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat                 0.007978
         Flowers               0.166224
         Alfalfa               0.022739
         Vegetables            0.040836
         Grass                 0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat                 0.300000
         Flowers               2.400000
         Alfalfa               0.080000
         Vegetables            2.400000
         Grass                 0.500000/
```

```
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat                    0.001740
         Flowers                  0.003260
         Alfalfa                  0.002960
         Vegetables               0.003320
         Grass                    0.002800/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat                     2
        Flowers                   91
        Alfalfa                   15
        Vegetables                28
        Grass                     6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat                     0.021667
        Flowers                   0.052143
        Alfalfa                   0.009079
        Vegetables                0.022364
        Grass                     0.009079/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/
laborl     agricultural labour /485424/;



VARIABLES
        x(i)     ha in cases
        z        water use in  million m3
        laborv   labour in workdays
        ratiov   ratio dimensionless
        grossv   gross income in million ksh;

POSITIVE VARIABLE x;

EQUATIONS

watuse         define objective function

yldreq(i)     satisfy yield requirement for use i
pestlim       observe pesticide limit
urealim       observe urea limit
labreq        workdays use
grossreq      gross income
ratioreq      ratio value
Land          observe area for crop i;

watuse..       z=e=sum((i),wuse(i)*X(i));

yldreq(i)..   yield(i)*X(i)=g=food(i);
pestlim..     sum((i), pesticide(i)*x(i))=l=pestl;
urealim..     sum((i), urea(i)*x(i))=l=ureal;
land..        sum((i), x(i))=l=areat;
labreq..      sum((i), labour(i)*X(i))=g=laborl;
grossreq..    grossv=e=sum((i),yield(i)*price(i)*x(i));
ratioreq..    ratiov=e=sum((i),yield(i)*price(i)*x(i)/wuse(i));

Model drywuse /all/;
solve drywuse using lp minimizing z;
display x.l,x.m;
```

***

```
$TITLE avgwuse
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
        i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
        /Wheat                  459
         Flowers                  0
         Alfalfa              10920
```

```
        Vegetables          282
        Grass              1637/

labour(i)  (workdays per ha) for crop i in cases
        /Wheat              29
        Flowers            150
        Alfalfa             43
        Vegetables          50
        Grass               43/
pesticide(i)  (tons per ha) for crop i in cases
        /Wheat             0.007978
        Flowers            0.166224
        Alfalfa            0.022739
        Vegetables         0.040836
        Grass              0.006095/
urea(i)  (tons per ha) for crop i in cases
        /Wheat             0.300000
        Flowers            2.400000
        Alfalfa            0.080000
        Vegetables         2.400000
        Grass              0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
        /Wheat              0.001310
        Flowers             0.001890
        Alfalfa             0.001870
        Vegetables          0.001960
        Grass               0.001490/
yield(i) yield (in  tons per ha) for crop i in cases
       /Wheat               2
        Flowers             91
        Alfalfa             15
        Vegetables          28
        Grass               6/
price(i)  price in million kenian shillings per ton for crop i in cases
       /Wheat               0.016667
        Flowers             0.040110
        Alfalfa             0.006984
        Vegetables          0.017203
        Grass               0.006984/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/
laborl     agricultural labour /485424/;


VARIABLES
        x(i)    ha in cases
        z       water use in  million m3
        laborv  labour in workdays
        ratiov  ratio dimensionless
        grossv  gross income in million ksh;

POSITIVE VARIABLE x;

EQUATIONS

watuse         define objective function

yldreq(i)      satisfy yield requirement for use i
pestlim        observe pesticide limit
urealim        observe urea limit
labreq         workdays use
grossreq       gross income
ratioreq       ratio dimensionless
Land           observe area for crop i;

watuse..        z=e=sum((i),wuse(i)*X(i));

yldreq(i)..    yield(i)*X(i)=g=food(i);
pestlim..      sum((i), pesticide(i)*x(i))=l=pestl;
urealim..      sum((i), urea(i)*x(i))=l=ureal;
land..         sum((i), x(i))=l=areat;
labreq..       sum((i), labour(i)*X(i))=g=laborl;
grossreq..     grossv=e=sum((i),yield(i)*price(i)*x(i));
ratioreq..     ratiov=e=sum((i),yield(i)*price(i)*x(i)/wuse(i));

Model avgwuse /all/;
```

```
solve avgwuse using lp minimizing z;
display x.l,x.m;
```

***

```
$TITLE wetwuse
$OFFUPPER

* Objective
* Set definition and declarations (yearly)

SETS
       i  crops  /Wheat, Flowers, Alfalfa, Vegetables, Grass/

PARAMETERS

food(i) production requirement(in  tons) for crop i in cases
       /Wheat                 459
        Flowers                 0
        Alfalfa             10920
        Vegetables            282
        Grass                1637/

labour(i)  (workdays per ha) for crop i in cases
       /Wheat                  29
        Flowers               150
        Alfalfa                43
        Vegetables             50
        Grass                  43/
pesticide(i)  (tons per ha) for crop i in cases
       /Wheat                 0.007978
        Flowers               0.166224
        Alfalfa               0.022739
        Vegetables            0.040836
        Grass                 0.006095/
urea(i)  (tons per ha) for crop i in cases
       /Wheat                 0.300000
        Flowers               2.400000
        Alfalfa               0.080000
        Vegetables            2.400000
        Grass                 0.500000/
wuse(i)  water use (million m3 per ha) for crop i in cases
       /Wheat                  0.001280
        Flowers                0.001780
        Alfalfa                0.001620
        Vegetables             0.001860
        Grass                  0.001420/
yield(i) yield (in  tons per ha) for crop i in cases
      /Wheat                   2
       Flowers                 91
       Alfalfa                 15
       Vegetables              28
       Grass                   6/
price(i)  price in million kenian shillings per ton for crop i in cases
      /Wheat                   0.016667
       Flowers                 0.040110
       Alfalfa                 0.006984
       Vegetables              0.017203
       Grass                   0.006984/;

SCALAR

areat      total area in ha /7353/
pestl      pesticide supply in tons /800/
ureal      fertilizer supply in tons/15000/
laborl     agricultural labour /485424/;


VARIABLES
        x(i)    ha in cases
        z       water use in  million m3
        laborv  labour in workdays
        ratiov  ratio dimensionless
        grossv  gross income in million ksh;

POSITIVE VARIABLE x;

EQUATIONS
```

```
watuse         define objective function

yldreq(i)     satisfy yield requirement for use i
pestlim       observe pesticide limit
urealim       observe urea limit
labreq        workdays use
grossreq      gross income
ratioreq      ratio value
Land          observe area for crop i;

watuse..       z=e=sum((i),wuse(i)*X(i));

yldreq(i)..   yield(i)*X(i)=g=food(i);
pestlim..     sum((i), pesticide(i)*x(i))=l=pestl;
urealim..     sum((i), urea(i)*x(i))=l=ureal;
land..        sum((i), x(i))=l=areat;
labreq..      sum((i), labour(i)*X(i))=g=laborl;
grossreq..    grossv=e=sum((i),yield(i)*price(i)*x(i));
ratioreq..    ratiov=e=sum((i),yield(i)*price(i)*x(i)/wuse(i));

Model wetwuse /all/;
solve wetwuse using lp minimizing z;
display x.l,x.m;
```

***