USING WEAP AND SCENRIOS TO ASSESS SUSTAINABILITY OF WATER RESOURCES IN A BASIN.
Case study for Lake Naivasha catchment-Kenya

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by

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Disclaimer

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DEDICATION

THIS WORK IS DEDICATED TO MY LATE GRANDFATHER YOASI KITIMBO.
YOUR GREAT VISION FOR A GREAT FUTURE HAS BROUGHT ME THIS FAR. ITS UNFORTUNATE THAT YOU DID NOT LIVE TO SHARE THE FRUITS OF YOUR SWEAT

MAY YOUR SOUL REST IN PEACE

Abstract

This study, use of scenarios and WEAP to assess sustainability of water resources in a basin, focussed on use of established methodologies for development of scenarios to assess sustainable water management. To that effect, a stakeholder analysis was done through fieldwork interview and secondary literature. Interests, perceptions and influences of stakeholders were identified. The common interests in the catchment were found to be water availability and water quality. The key stakeholders in the catchment are found to be the large scale commercial farmers, Naivasha municipality and Kihoto village settlers.

Assessment of key drivers behind sustainable water management was done through analysis of available water abstraction records of registered water users and by remote sensing through image analysis. Irrigated agriculture was found to be the main driving force using approximately 87% of the water in the catchment. Image analysis for historical development irrigated agriculture was done. Results indicated that whereas there was a drastic development in irrigated agriculture between 1975 and 2000, there is little increase between 2000 and 2006.

Scenario development indicated that it is possible to develop informative scenarios from stakeholders' interests and main drivers of SWM. Results of selected decision variables indicate that; Over irrigation stands at over 100%, placement of greenhouses is key in sustainable management of water resources, there would be an economic collapse and environmental disaster if the a long drought such as one of the 1930s-1950s recurred and construction of a reservoir in the upper catchment would have a long term positive effect on water availability.

WEAP software was found to be ideal for integrated modelling of the physical and social economic aspects in the catchment, particularly it was found to be very flexible in modelling of the different scenarios. However, the software falls short in modelling some hydrological aspects such as the groundwater lake interaction and units used in presentation of some results for example rainfall as an output is presented as a volume, not depth.

Acknowledgements

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Last but not least I stretch out my hands to my family for always being there for me, and to my special friend Rebecca.

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Acronyms and abbreviations

WEAP	Water Evaluation and Planning
NWRMS	National water resources management strategy
LNMP	Lake Naivasha Management Plan
WAP	Water Allocation plan
SWM	Sustainable water management
SA	Stakeholder analysis
DPSIR	Driving force-pressure-State-Impact-Response
EEA	European Environmental Agency
MCM	Million cubic meters
LNWBM	Lake Naivasha water balance model
LNRA	Lake Naivasha Riparian Association
LNGG	Lake Naivasha Growers' Group
MWI	Ministry of water and Irrigation
WRMA	Water Resources Management Authority
KWS	Kenya wildlife service
WWF	World Wide Fund for Nature
MoF	Ministry of Finance
LNMC	Lake Naivasha Management Committee
KMFRI	Kenya Marine and Fisheries Research Institute
NMK	National Museum of Kenya
WRAP	Water Resources Assessment Project
NEMA	National Environment Management Authority
ICWE	International Conference on Water and Environment.

1. Introduction

1.1. Background

Odds are at stake over sustainable management and use of the finite water resources of Lake Naivasha catchment. Pressing water demand from an ever increasing booming irrigated floriculture and horticulture industry in the area has put a stress on the abstraction levels. Abstraction demands have further been stretched by the population pressure within the basin that has resulted from increasing numbers of migrant workers who have flocked the basin in search for employment from the irrigated commercial farms. The side effects of irrigated farming and population explosions, has been the pollution of the water as a result of the agro-chemical runoff and organic waste from the migrant workers through their unplanned poor settlement patterns. These have even been made worse by the loss of the lake's natural filter, the papyrus which has been cleared to create space for agriculture and settlement. Water quantity and quality problems are not only as a result of the emergency of irrigated agriculture but there is also catchment degradation mainly in the upper part the catchment through poor farming practices, mining river banks for sand, forest clearance and pastoral activities. All factors have added up leading to decline in water quantity and quality.

The uncoordinated development and poor planning of activities in the catchment has also led to secondly issues access to the lake which is said to be greatly limited rising concerns among many stakeholders. Biodiversity in the area is also claimed to have greatly reduced as a result of the negative social economic impacts on the water resources of the basin.

All the above issues call for answers as to whether the resource can sustain the demands put upon it. The key question is, can a booming floriculture and horticulture business co-exist sustainably with the water resources and environment?

1.1.1. Justification

Justification

Whereas management of the water resources of the catchment dates back to as far as 1929, an understanding of how different management and water use practices impact on the water resources of the catchment has not been assessed before. This research will assess the impacts of different water use and management practices through modelling of different scenarios on sustainable management of the water resources of the catchment in Water Evaluation and Planning (WEAP) software. The research will also attempt to carryout a social characterisation of the catchment's stakeholders based on their attributes in a framework of sustainable water resource management.

The work scale of the research implies that the approach to the subject is not in great detail.
Summarising the topic of the proposed research is justified by these reasons:

- Water is a finite resource
- Water is a very important economic and social resource in the area

– Lake Naivasha is a designated wet land of international importance “Ramsar site” making its preservation very important.
– There is a wide variety of users of water with apparently different interests, influences and objectives
– There is need to explore on how the future water resources of the catchment will look like in order to better plan for a sustainable social-economic development.

1.2. Research objectives

The main research objective for the proposed study is:

To assess water use and management practices in the catchment and organize the different stakeholders’ perceptions, interests and influences on sustainable water management into scenarios and model the subsequent scenarios in WEAP

Specific objectives

- To carryout an assessment of stakeholders related to sustainable water resource use and management in the catchment
- Generate scenarios from the concerns/views of the stakeholders and the catcment hydrological trends
- Model catchment and run the different scenarios using WEAP

1.3. Research questions

Table 1-1 Research questions

Objective	Research Questions
To carryout an assessment of stakeholders related to sustainable water resource use and management in the catchment	1. Who are the stakeholders in the catchment? 2. What are their interests, objectives and influence on the management of the water resources? 3. How can the stakeholders be classified? 4. What are the relations between the different categories of stakeholders?
Generate scenarios from concerns of the stakeholders	1. What is the action (interest, decision, goal) for which the scenario is to be developed? 2. How can the can the scenarios be modeled? 3. What information can we get from the developed scenarios?
Model catchment and run the different scenarios using WEAP	1. How well can the catchment be modeled in WEAP? 2. Is WEAP capable of appropriately modeling the different scenarios?

1.4. Conceptual framework

This considers the most basic understanding of sustainable water management, why there is need for sustainable water management in Lake Naivasha basin and how scenarios that help to aid sustainable water use and management can be developed and modelled in WEAP.

1.4.1. General understanding of SWM

Sustainable water management involves management of current water resources for equitable use in the future. It involves an understanding of the past, evaluation of the current situation and formulation of management scenarios of the current resources for the future, figure 1-1.

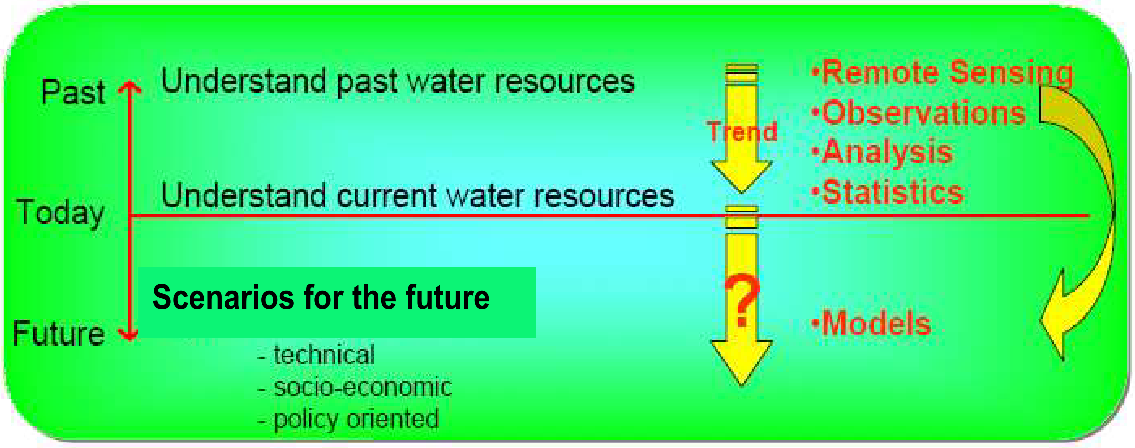

Figure 1-1 The concept of using simulation models in scenario analysis(Vanloon, Lasage, Mathijssen, & Droogers, 2007)

1.4.1.1. Understanding the past

Understanding of the past involves making observations, taking measurements and analysis of the measured parameters or variables of drivers that we have no control of. Examples of uncontrollable variables for which measurements or observations are made include population growth, climate change agricultural and industrial expansion. Measurement and observation is not only made of the physical quantities but also the social economic characteristics of the stakeholders involved. The measurements and observations seek to understand uncertainties, complexity and also to derive trends from the past. Measurements that are carried out in this study are mainly through remote sensing techniques and groundtruthing of already measured parameters.

1.4.1.2. Understanding current resources

Understanding of current water resources involves proper estimation of the water resources in the base year of study. It is the calibration stage for both water supply and demand. Stock is taken of supply and its management as well as demand. Preferences in supply and demand are set based on a proper understanding of the drivers as well as the stakeholder settings and their preferences.

1.4.1.3. Scenarios for the future

Understanding of the future is a complex thing because it uses knowledge of the past and information of the present to predict what the future might be. Predictions of what the future might be are always made by use of scenarios. However, the understanding of scenarios has often been loosely used. The word has been used in a colloquial way, often to mean mere options or alternatives for the future. Options and alternatives are about choice of something already in place, scenarios take the wider scope of developing the options or alternatives. Deeper understanding of scenarios and scenario processes is reviewed in chapter two and it is this meaning of scenarios that will be used throughout this research.

1.4.2. Stakeholder analysis

Stakeholder analysis in this research is kept simple as it is not the main focus of the research but still an important component. Conceptualisation of the analysis will be limited to the five steps of (Groenendijk & Dopheide, 2003)

1. Articulating the purpose. This is reflected in the problem definition and specific objective
2. Identification and listing of stakeholders. This is done through secondary literature and field interviews
3. Assessment of the stakeholders' attributes. Water use and management is largely governed by the interests of the various stakeholders. It is therefore the main attribute of stakeholders that needs to be assessed. Influence and importance of the stakeholders also dictates which interests are furthered and will also be important to assess. Relationship between stakeholders is important in trying to group the stakeholders.
4. Summarizing and analysis of complete set of findings. This is the stage at which scenarios are developed
5. Integration in project design (modelling in WEAP).

1.4.3. WEAP

WEAP is used as a water accounting tool in this research through management of both supply and demand. It is an inter-phase between supply and demand. WEAP is also used for the management of scenarios but as earlier hinted, scenarios are far much more complex than options and alternatives and WEAP cannot cope with the complexity and uncertainties involved in scenario development but rather picks up at later stage of simulation after structuring of the scenarios.

1.4.4. The need for assessment of sustainable water management in the catchment:

The need for assessment of sustainable water management in Lake Naivasha catchment can be derived from the broad principles devised during the International Conference on Water and Environment(ICWE, 1992) in Dublin, and the relevance for stakeholder analysis as outlined by(Grimble & Wellard, 1997).

- Freshwater is a finite and valuable resource that is essential to sustain life, the environment and development, and yet it cuts across different social, economic, administrative and political units. These different units bear a large number of different stakeholders with different agendas and interests. This state of affairs is true for Naivasha basin as it is characterised by multiple stakeholders having different interests in the limited water resources of the basin.
- The development and management of our water resources should be based on a participatory approach, involving users, planners and policy makers at all levels. This not only creates a sense of ownership of the management process but also helps highlight possible areas of competition, likely conflicts and possible tradeoffs since all interests are catered for.
- Water has an economic value and should therefore be seen as an economic good. The economy of Kenya heavily relies on the agricultural activities in Naivasha basin which in turn

heavily rely on the water resources of the catchment with an estimated annual return of 100million US dollars(Sayeed, 2001), Sustainable water management is therefore essential.

Summarizing the conceptual framework, places this research in the three phased framework for planning and decision making process based on the Simon model (1960) and further work from(Sharifi, 2003) of intelligence, design and choice. Much of the work scale of this research will deal with intelligence and design and very Little work will be done in the choice phase, only the interpretation of the different alternatives and their visualization will be dealt with as the other components within this phase require testing the research outcomes in the field, and they will form probable recommendations for further work.

2. Literature review

2.1. Meaning of sustainable water management

What is Sustainable Water Management (SWM)? The term uses two important concepts with respect to water: sustainability and management. In order to understand Sustainable Water Management, it is important to define these concepts.

2.1.1. Sustainability:

The (Brutland, 1987) report defines sustainable activities as ones where the needs of the present generation are met without compromising the needs of future generations.
What the Brutland definition implies is an equitable distribution of the resource not only spatially between users in a given location, but also temporally between users over time. The idea is to allocate the resource in such a way as for all, including the environment, to have an adequate share without making any one group worse off, both now and in the future.

2.1.2. Management

There has been a shift in recent years from the traditional ‘top-down’ approach to more open management systems where all levels of stakeholders have a say in the allocation and use of resources. If properly done, this system ensures that the needs and concerns of those most affected by the use of the resource are addressed, without loosing sight of the wider issues touching the society as a whole.

For effective management to be achieved, Information that will aid Understanding of the needs of stakeholders, as well as the possibilities, variation and limitations of the resource, is needed. This requires making an analysis of the historical data to have a good understanding of the resource itself but also requires an understanding of the relationships (level of communication) between various users and managers at the different levels. With the right information, appropriate strategies can be formulated to deal with the realities of resource management, such as distribution, access, rights, etc and only then can the resource be allocated and managed in a sustainable manner.

Therefore, SWM attempts to deal with water in a holistic fashion, taking into account the various sectors affecting water use, including political, economic, social, technological and environmental considerations.

From the above definition of sustainable water management, it is clear that for sustainable water management to be achieved there is need for a clear understanding of the water resource itself and the limitations it has. It is also important to understand the driving forces (pressures) that impact on water resources as well as the characteristics (needs/interests, influences and importance) of all the stakeholders in the catchment. This will then give the basic understanding of the resource or what is commonly called the current situation or business as usual. However, as already defined above, SWM, is equitable distribution of the resource now and for the future. To be able to look to the future, scenarios have to be used but prior to development of scenarios, stakeholder analysis has to be done.

2.2. Stakeholder analysis

2.2.1. Definition

Stakeholder analysis (SA) is a holistic approach or procedure for gaining an understanding of a system, and assessing the impact of changes to that system, by means of identifying the key actors or stakeholders and assessing their respective interests in the system (Grimble & Wellard, 1997).

Stakeholder analysis seeks to differentiate and study stakeholders on the basis of their attributes and of criteria appropriate to a specific situation (Groenendijk & Dopheide, 2003). Attributes include the interests of each stakeholder, the influence and importance of the stakeholders, and the networks and coalitions to which they belong.

To formulate the procedure/approach for SA, a theoretical framework that will form the basis for analysis is required. According to (Rowley, 1997), stakeholder theory development has centred around two related streams: 1) defining the stakeholder concept and 2) classifying stakeholders into categories that provide an understanding of individual stakeholder relationships.

In a water use and management framework and based on (Freeman, 1984), definition, stakeholders can be defined as any group or individual who can affect or is affected by sustainable water management and use. I will therefore define a stake here as the interest of a stakeholder in SWM and use. Conceptualisation and classification of stakeholders will therefore depend on the careful selection of stakeholder methodology.

2.2.2. Stakeholder methodology

The methodology for Stakeholder analysis reviewed here is one based on steps forwarded by(Groenendijk & Dopheide, 2003) as these steps are thought sufficient to satisfy the stakeholder analysis component in this research.

1. Articulate the purpose. As a logical first step in preparing a stakeholder analysis, one should establish the purpose of the analysis and the specific questions that the stakeholder analysis should address to meet this purpose. In addition, one should reflect on the conditions for the analysis, such as the available time and resources, and the general context within which the analysis is done(Hermans, 2005)

2. Identification and listing of stakeholders. This is done through secondary literature and field interview. In a limited time situation and for a rural setting such as Naivasha, the rural rapid appraisal (RRA) is normally appropriate for stakeholder identification. This technique has its origin and application in rural development-related research. RRA is described as a process of learning about rural conditions in an intensive, iterative and expeditious manner or any systematic activity design to draw inferences, conclusions, hypotheses, or assessments, including the acquisition of new information, during a limited period of time. It characteristically relies on small multidisciplinary teams that employ a range of methodological tools and techniques especially selected to enhance understanding of rural conditions in their natural context (direct observation, short questionnaire, semi-structured interviews and in depth interviews), with particular emphasis on tapping the knowledge of local inhabitants and combining this knowledge with modern scientific expertise, but minimizing prior assumptions(Kachondham, 2002). In a multi stakeholder environment and where interests are diverse, non scheduled semi-structured interviews are most helpful in understanding the stakeholder attributes. This form of interview has four characteristics(Frankfort-Nachmias & Nachmias, 1996):
    - It takes place with respondents known to have been involved in a particular experience
    - It refers to situations that have been analyzed prior to the interview
    - It proceeds on the basis of an interview guide specifying topics related to the research hypotheses
    - It is focused on the subjects' experiences regarding the situations under study.

Although the encounter between the interviewer and respondents is structured and the major aspects are explained, respondents are given considerable liberty in expressing their definition of a situation that is presented to them. This type of interview permits the researcher to obtain details of personal reactions and specific emotions. The interviewer, having previously studied the situation, is alert and sensitive to inconsistencies and omissions of data that may be needed to clarify the problem (Frankfort-Nachmias & Nachmias, 1996).

3 Assessment of the stakeholders' attributes. Water use and management is governed by interests, perceptions and influences/resources of the various stakeholders. These concepts are therefore briefly reviewed here.

- **Interests/objectives** are used to express the directions in which stakeholders would like to move: What is the problem they would hope to solve? What is the goal they would like to achieve? (Hermans, 2005)
- **Perceptions** and similar concepts such as belief systems, frames or cognitions refer to the image that actors have of the world around them, both of the policy making context consisting of actors and networks, and of the policy problem and its substantive characteristics (cf.(Hermans, 2005); Bennet et al., 1989)
- **Resources** refer to the practical means or instruments that stakeholders have to realize their interests/objectives. Resources are the "things over which they have control and in which they have some interest"(Coleman, 1990) . Resources may be material, related to monetary resources and budgets, but they may also be immaterial, for instance positions in a society, which associate stakeholders with an authorized set of actions in a process. Resources enable stakeholders to influence the world around

them, including other stakeholders, relations and rules in a system/network. The Influence created dictates which interests are furthered at the expense of the less influential stakeholders' interests.

When combined, the three concepts of perceptions, objectives and resources lead to actions. Resources can be used to act, but objectives are used to determine if the resulting actions are indeed useful to an actor, whereas perceptions are used to indicate whether a stakeholder also recognizes this link between the use of resources and realizing its objectives. If a stakeholder takes action, it will be likely to have an impact, be it large, small or even insignificant, on other actors or on its physical environmental, i.e. through actions a stakeholders interacts with its environment. Thus, the action links the stakeholders to its outside environment, to other stakeholders and to the stakeholder networks (Hermans, 2005). I therefore argue here that it is the process to actions and the resultant actions that form the backbone for scenarios.

4. Summarizing and analysis of complete set of findings. This is the stage at which scenarios are developed

5. Integration in project design (modeling in WEAP).

2.3. Scenario development

This section gives a brief review of what scenarios are, their usefulness in SWM and use, and how they are constructed. It will also look at WEAP software and its usefulness in scenario modelling.

2.3.1. Definition

Scenarios are archetypal descriptions of alternative images of the future, created from mental maps or models that reflect different perspectives on past, present and future developments (Greeuw et al., 2000).

Scenarios are focused descriptions of fundamentally different futures presented in coherent script-like or - narrative fashion. (Schoemaker, 1993)

Scenarios focus on the analysis of uncertainties, drivers of change and causal relationships associated with a potential decision (Wollenberg, Edmunds, & Buck, 2000). They are stories of what might be. Unlike projections, scenarios do not necessarily portray what we expect the future to actually look like. Instead scenarios aim to stimulate creative ways of thinking that help people break out of established ways of looking at situations and planning their actions (Wollenberg, Edmunds, & Buck, 2000). They stimulate a pro-active way of thinking rather than a reactive approach to issues. Scenarios focus on the analysis of uncertainties, drivers of change and causal relationships associated with a potential decision

From the three definitions of scenarios, it is clear that for a common resource that attracts multiple users, for example the water resources of Naivasha, scenarios can provide a better understanding of the resource and hence a better management and use. The fundamental elements of scenarios are the drivers of change in the system, the complexity and uncertainty in the system and the perceptions of the stakeholders involved.

2.3.2. Scenario types

(Greeuw et al., 2000) give four different types of scenarios as:

Forecasting and back casting scenarios. Forecasting scenarios explore alternative developments, starting from the current situation with or without expected/desired policy efforts.
Back casting scenarios reason from a desired future situation and offer a number of different strategies to reach this situation.

Descriptive and normative scenarios. Descriptive scenarios sketch an ordered set of possible events irrespective of their desirability or undesirability, while normative scenarios take values and interests into account.

Quantitative and qualitative scenarios. While quantitative scenarios are often model-based, qualitative scenarios are based on narratives.

Trend and peripheral scenarios. Trend scenario is a scenario that represents the extrapolation of the current trends, while a peripheral scenario includes unlikely and extreme events.

The four different types of scenarios have similarly been described by (Wollenberg, Edmunds, & Buck, 2000) as:-

- Vision - A vision of the desired, ideal future.
- Projection - Best guesses about the expected future.
- Pathway - Determination of how to get from the present to the future by comparing present and desired future (vision) scenarios.
- Alternatives - A comparison of options through multiple scenarios of either the vision, projection or pathway type

2.3.3. Why use scenarios (Wollenberg, Edmunds, & Buck, 2000)

- Scenarios encourage an understanding of the outside world and of how our inside world interacts with it
- Scenarios can encourage interaction among different groups, such as neighbouring villages that share a resource for example water resources of a water shed, government officials from different agencies or villagers and state water resource managers. Scenarios can enable these groups to engage in creative learning jointly
- Scenario-based techniques are tools for improving anticipatory rather than retrospective learning.
- The value of scenarios comes then from learning to think in new ways about the future and in making decisions appropriate to uncertain conditions. Through this process, people can improve their preparedness for the future and their capacity to adapt.

2.3.4. Scenario methods

This will involve making a choice on which scenario approach or combination of approaches that best suit(s) the purpose of the research. (Wollenberg, Edmunds, & Buck, 2000) lists four types of scenario approaches, that's, Vision, Projection, Pathway and Alternative scenarios or Forecasting/back casting, descriptive/normative, quantitative/qualitative and trend/peripheral scenarios (Greeuw et al., 2000). To arrive to the best approach, steps proposed by (Schoemaker, 1993) will be followed. These include:-

1. Define the issues you wish to understand better in terms of time frame, scope and decision variables. Whereas the research will focus on the entire catchment of Lake Naivasha, the reference that will be used in scenario development will be the lake. This is because, (a) the lake provides the best measurable variable, the lake level, and, (b) most of the water related activities and almost all the water resources of the catchment either have an influence on or are influenced by the lake because of it being located in the lower part of the catchment and the catchment having no surface water outlet. The time frame will be defined by the hydrological regimes because they can not be controlled by man. The decision variables will depend on the type of scenarios that are developed because SWM on a catchment scale is a complex thing and no single decision variable can be suitable to achieve SWM and use in such a multi-stakeholder situation. For the reader, a decision variable also known as a controllable input variable is defined as an unknown quantity representing a decision that needs to be made. It is the quantity the model needs to determine. It is a factor over which the decision maker has control. (http://home.ubalt.edu/ntsbarsh/ECON/SolQSB.doc as of 23/01/08)

2. Identify the major stakeholders or actors who would have an interest in these issues, both those who may be affected by it and those who could influence matters appreciably. Identify their current roles, interests and power positions.

3. Make a list of current trends or predetermined elements that will affect the lake level. Briefly explain each, including how and why it exerts an influence and also the causal effect relationship. A number of analytical frameworks explaining such a casual relationships have been developed, the Driving Force-Pressure-State-Impact-Response framework "DPSIR" proposed and used by European Environmental agency (EEA, 2000) and EUROSTAT will be used, figure 2-1. Attention will however be specifically be given to the driving forces which for Naivasha catchment are agriculture and population and to a very small extent industry.

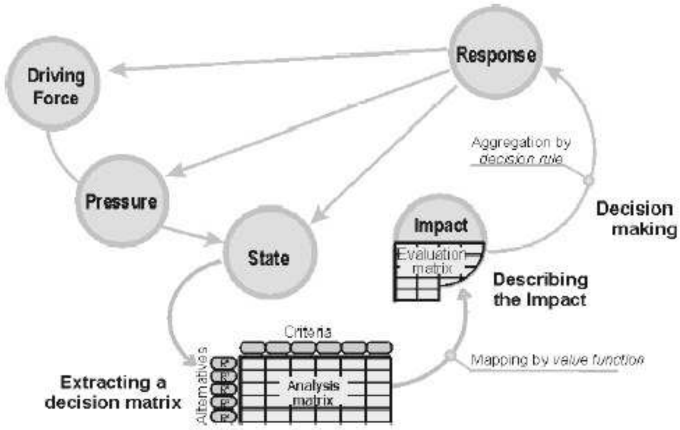

Figure 2-1 DPSIR concept, Source (after Giupponi, 2002)

4. Identify key uncertainties whose resolution will significantly affect the lake level. Briefly explain why these uncertain events matter, as well as how they interrelate. Key uncertainties in Naivasha catchment are the ever evolving irrigation techniques that have worked towards efficient water use. These are hard to predict but can easily be incorporated in modelling once in use. The other key uncertainty that also governs the biggest driving force of agriculture is the prices (market) for floricultures. Treatment of key uncertainties is done in subsequent chapters.
5. Construct forced scenarios by placing all positive outcomes of key uncertainties in one scenario and all negative outcomes in the other. Add selected trends and predetermined elements to these extreme scenarios.
6. Next assess the internal consistency and plausibility of these artificial scenarios. Identify where and why these forced scenarios may be internally inconsistent (in terms of trends and outcome combinations).
7. Eliminate combinations that are not credible or impossible, and create new scenarios (two or more) until you have achieved internal inconsistency. Make sure these new scenarios bracket a wide range of outcomes.
8. Assess the revised scenarios in terms of how the key stakeholders would behave in them.
9. Finally, reassess the ranges of uncertainty of the dependent (target) variables of interest, and retrace the above steps to arrive at decision scenarios that might be given to others to enhance their decision making under uncertainty.

2.4. Previous work

Lake Naivasha is of great social, economic and ecological importance both to the local people living in the area and Kenya as a whole. A lot of studies have therefore been carried out in the past and this section will review some of those studies that are so much relevant to sustainable water use and management.

2.4.1. Lake water balance:

Several water balance studies for the lake have been done in the past a comparison of the different studies' findings is summarised in table 2-1. As hinted earlier, the lake is the ultimate tool for quick assessment of the water resources of the catchment and hence the reason for having a look at the findings of previous studies.

Table 2-1 water balance studies

Parameter	**McCann (1974)**	**Gaudet and Melack (1981) 1973**	**Ase, Sernbo**	**And Syren (1986)**	**ITC calculated**
	1957-1967		**1972-1974**	**1978-1980**	**average**
INPUT(MCM)					
Precipitation	132	103	115	142	121
		(range 77-114)	(range 84-149)	(range 127-167)	
River discharge	248	185	187	254	212
		(range 90-260)	(range 156-263)	(range 143-383)	
Surface runoff	NA	0.6	NA	NA	0.6
		(range 0.4-0.7)			
Seepage-in	NA	49	NA	NA	49
		(range 41-58)			
TOTAL INPUT					
	380	338	302	396	382.6
		(range 208-433)	(range 240-412)		
OUTPUT(MCM)					
Evapotranspiration	346	313	308	301	294
		(range 289-324)	(range 294-332)	(range 272-339)	
Seepage-out	34	44	NA	NA	39
		(17-78)			
Irrigation+ Industrial	NA	12	NA	NA	12
		(range 7-15)			
TOTAL OUTPUT					
	380	369	308	301	345
		(range 313-417)	(range 294-332)	(range 272-339)	
Storage change	**NA**	**-31**	**0.4**	**95**	**37.6**

2.4.2. Water use and management

This section reviews studies in the area that are thought to aid the objective of this research.(Alfarra, 2004), developed, for the first time in the Lake Naivasha Basin, an integrated water re-source management model using WEAP. The primary objective was to understand the situation in the whole catchment and identify where problems exist and the weakness that affect the catchment and their improvement. The findings were that the main problem in the area is caused by a number of un-registered water users in the agriculture sector, which is the main driving force in the area. According to the study, water is mis-used through over-irrigation in fodder, grass and vegetable farming. Similar findings are reported in the study by (Sayeed, 2001) on economic returns per cubic meter of water in what he termed "Dollars per drop". This was to be used as a primary Management Information Tool to regulate and manage the use of water resources among the competing sectors and to provide a safe environment. in relating water use and management,(Boix Fayos, 2002) performed a conflict analysis of water-related issues in the catchment area of Lake Naivasha. Essential to the analysis was 'mapping' the conflicts, which consisted of systematic collection of information about them and their dynamic. The conflict analysis included: analysis of the stakeholders values, research of the conflict sources, definition of a typology of conflicts, and assessment of conflict intensity from the perspective of the different stakeholders developing some indicators. The results indicated that the highest in the hierarchy are the conflicts related to the lake resources (fishing), in a second place the water supply of the town and settlements, and in a third place conflicts related to activities taking place in the upper catchment. The conflicts related with water are, most of the times, mixed with other type of land, tribal, social and economic conflicts, and some emotional-historical factors in relation with the inheritance of past colonial times. During water use assessment in the subsequent chapters a fall back on aspects of this study will be made.

3. Study area

3.1. Location of Study Area

The study area lies in the Eastern arm of the East African rift valley system. Administratively, it is located in Naivasha and Nyandarua Districts of the rift valley province, approximately 80km from Nairobi, the capital city of Kenya. It lies within the UTM zone 37 and coordinates:

X_{max} =251750.000, X_{min}=166000.000

Y_{max}=9992350.000, Y_{min}=9889400.000

Thus, it is bounded by latitude 0°07′ S and 0°56′ S and longitude36°04′E and 36°44′E. The study area is located in the central portion of the rift floor at a mean altitude of 1885m above mean sea level. The Naivasha catchment receives drainage from the Nyandarua Mountains (Aberdare Range) in the North East with elevation of about 3960m, to the East is the broad Kinangop Plateau that rises to a maximum altitude of 2740 m., to the south, the catchment is bounded by the Olkaria volcanic complex and to the West, the Mau Escarpment with an elevation of above 3000m bounds the catchment.

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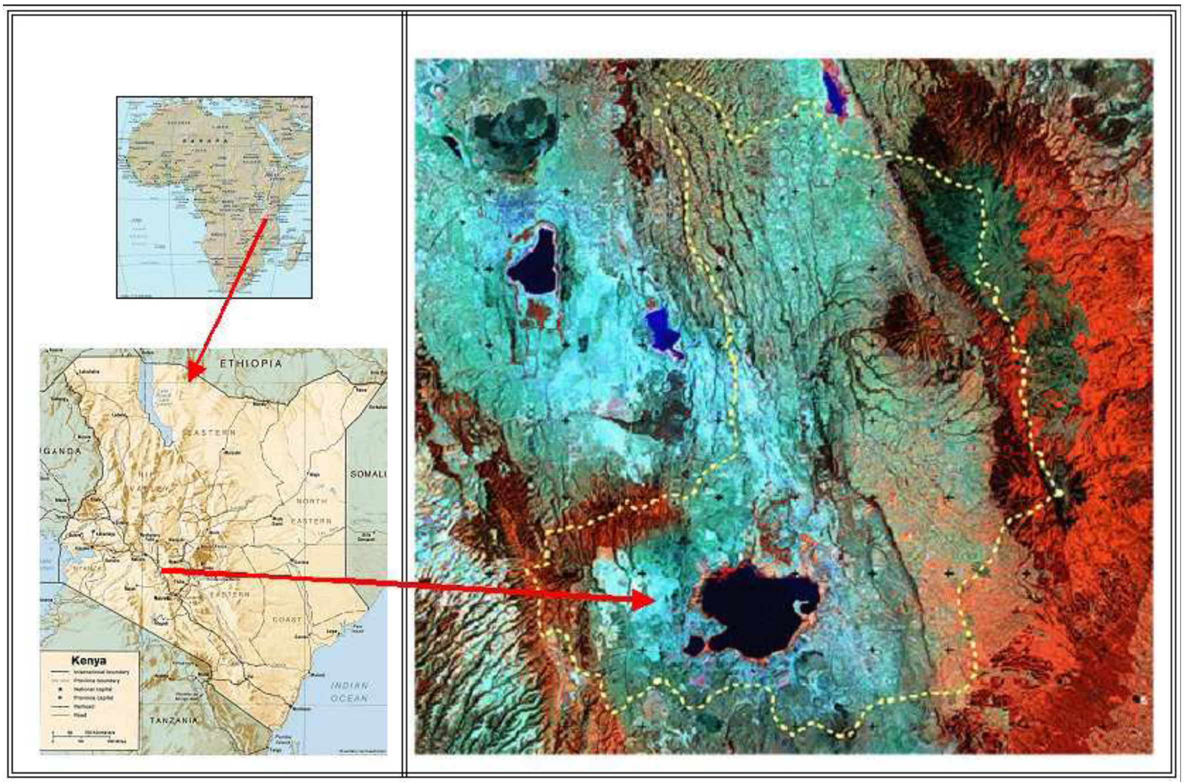

Figure 3-1 Aster image showing the catchment outline, Inset is map of Africa and Kenya (Source: ITC Naivasha database)

3.2. Climatic conditions:

The climate is humid to sub-humid in the highlands and semi-arid in the rift valley. The mean monthly maximum temperature ranges between 24.6oC to 28.3oC, and mean monthly minimum temperature between 6.8oC and 8oC. The average monthly temperature ranges between 15.9oC and 17.8oC. The warmest periods are from January to March and the coldest periods are from the months of July to August. The monthly potential evapotranspiration on the floor of the basin exceeds the rainfall by a factor of 2
to 8 for every month except April when the potential evaporation still exceeds rainfall. The winds are general calm in the morning while in the afternoons they can attain a speed of 11-15 kmhr-1. They are strongest in the months of August to October, with a speed of 21 kmhr-1. Their direction is from the southeast and northwest depending on the season. Extremely strong winds have been reported to occur through the window between the Longonot and Kijabe Hill (Ataya, 2000). The area experiences a relative humidity of less than 75%.

Rainfall

The area experiences a bimodal mode of rainfall with peak rains coming in march through to may. The second season rains are in October to December but they are much less than the first rains. Annual rainfall varies a lot within the catchment with rains in lower catchment (around Lake Naivasha) averaging 650mm a year and in the upper catchment average rainfall is 1250-1500mm a year.

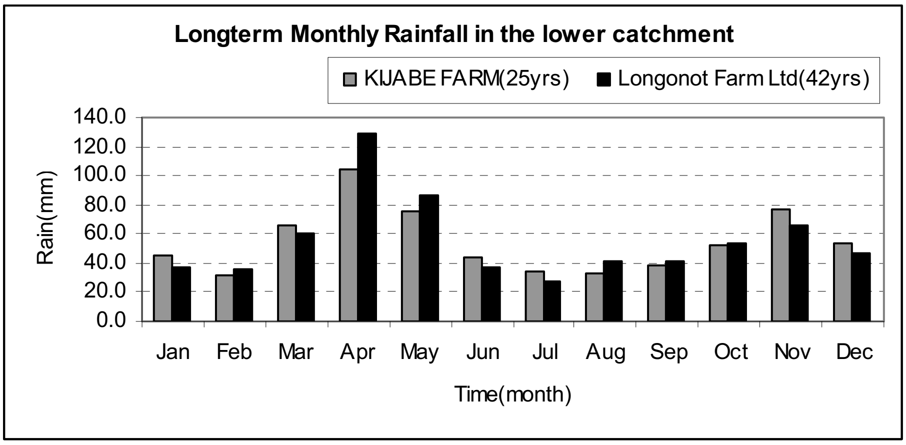

Figure 3-2 Monthly rainfall variation in the lower catchment.

3.3. Geology and geomorphology

The geology of the area is generally made of volcanic rocks and lacustrine deposits. The volcanic rocks consist of basalt, trachytes, ashes, tuffs, and agglomerates and acid lava.
Geomorphologic ally, much of the study area lies within the rift valley floor, however, to the west, are the Mau escarpment with a maximum elevation of about 3080m decreasing in height in both North and south directions. The margins are defined by both fault scarps which have steep and dissected slopes. The eastern margin has more faults and fractures compared to the western. It is comprised of the Bahati escarpment, Kinangop plateau and the South Kinangop fault scarp. The maximum elevation

is about 2740m on the Kinangop plateau. To the North, is the Menengai with a height of 2267m while to the south east is the longonot volcano with a height of 2776m and to the south is the Olkaria volcanic complex.

3.4. Drainage:

The catchment has an approximate area of 3200sq km and it is has no surface water outflow. All rivers drain into or towards Lake Naivasha which is located in the southern part of the catchment. The catchment is drained by two main perennial rivers, the Malewa and Gilgil that contribute 90% of the surface inflow to the lake. Malewa River rises on the western slopes of the Nyandarua range at an altitude of 3000 to 4000 m. Further down, the malewa is joined by Turasha River, which is also perennial and drains the north Kinangop plateau via deeply incised tributaries. The Gilgil River has its headwaters high in the Bahati forest and drains parts of the eastern slope of the Bahati escarpment. To the western side, is the Marmonet river which drains the Mau escarpment and flows towards the lake but recharges the alluviums of Ndabibi plains before reaching the lake. To the south, only Karati river provides perennial flow into the lake, all other streams originating from the Olkaria complex and Njorowa gorge terminate as alluvial fans on the Akira plains.

The lake itself is a shallow freshwater lake at mean altitude of 1887 m above sea level and a mean surface area of 145 km2. The lake ecosystem consists of a main lake, a smaller, sometimes separate during low lake levels, Oloidien lake located to the southwest of the main lake, and a detached crater lake to the west. Crater lake is the smallest. The lake also as an island to the east called Crescent Island. The part of the main lake surrounding Crescent Island is named Crescent Lake.

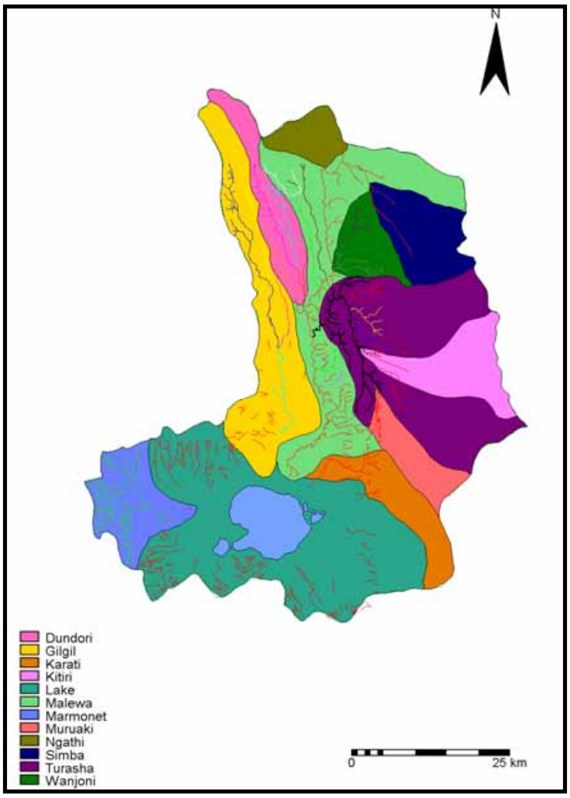

Figure 3-3 Drainage map of the Naivasha catchment (Source: ITC Naivasha data base)

3.5. Land cover and Land use

Land cover is strongly related to the main land uses in Naivasha catchment. It can be observed that immediately around the lake a band of irrigated agriculture exists, also on the valley floor and to the East and Westside of the Lake, Savannah woodland and shrubs and vegetation appear in a wide area where more grazing activities take place. In the higher areas of the catchment different types of agriculture (normally rain fed) and forest cover appears.

From the land cover map it can be seen that the main land use within the catchment is agriculture which includes irrigated crop farming (horticulture, vegetables, fruits) around the lake and mixed farming (wheat, maize, potatoes, beans and sunflowers) on the rain-fed slopes of the escarpment.

Dairy farming is mainly practiced on large estates on the north-eastern shores of the lake. The Southeast area of the catchment (Longonot area) is used as intensive grazing land by Masai pastoralists, as well as part of the Ndabibi plains, Moindabi area. The low lying central parts of the catchments carry natural and semi-natural vegetation (grassland, bushland, acacia, cactus trees, savannah and shrub) that provide suitable habitat for wildlife and indigenous livestock farming. Game sanctuaries for wildlife are mainly set to the west of the area. Settlements are mainly concentrated around the main towns with a few homes within the estates and farms.

The wetlands that are found around the shores of the lake are reputable for the existence of Papyrus swamps. They are mainly used as indicators of hydrological regimes, modifiers of water quality and as habitats for numerous animals and birds.

The Eburru Hills, Mau, Longonot and Nyarandua escarpments are all hosts to indigenous hardwood forests that form the main watersheds of the lake basin. The bamboo forests are confined to the Nyarandua and Mau escarpments.

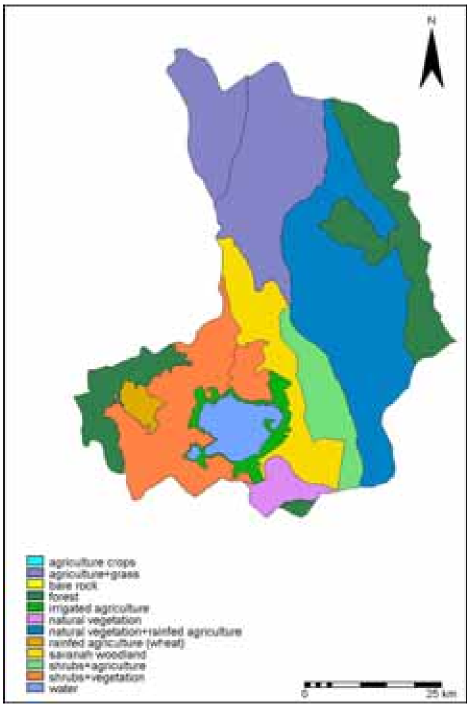

Figure 3-4 Land cover map of Naivasha (source, ITC database)

3.6. Social economic characteristics

The catchment area of Lake Naivasha is located partially in the administrative districts Nakuru, Naivasha and in the Nyandarua. The population of the Naivasha basin is placed at 812,389 according to the 1999 population census (WAP). The economy of Naivasha is largely dependant on the basin's natural resources. Its unique combination of high altitude, fertile soils, ample water and warm days make Naivasha so suitable for the production of horticultural goods and attendant development in the basin. The basin's economy, therefore, is overwhelmingly agriculturally based. The brunt of Naivasha's agricultural production is based on the production of flowers and horticulture goods. In this way, Naivasha's economy is intimately connected to the global economy dealing with the export of fresh horticulture products that fetch an estimated $60million annually. Not all of Naivasha's agriculture is based on vegetables and flowers. Large scale wheat interests also occur in the basin, as does smallholder agriculture. There is very little industry in the basin with the most common being the power generation at Olkaria geothermal and the beef and diary industry. There is however a series of additional human values contained within the basin which includes:

Tourism plays an important role in Naivasha. Its spectacular scenery, water sports, birding, national parks and proximity to Nairobi have all contributed to the development of significant tourism capacity. Tourism around Naivasha is estimated to be worth $ 11.5 millions annually, much of it derived from domestic tourism, particularly day-trippers from Nairobi.

Naivasha's fishery is based on a series of introduce species, particularly tilapia and black bass. The fishery has grown largely as result of the market represented by the approximately 30,000 migrant workers attracted to Naivasha area by the horticulture farms. Many of these are from western Kenya, where fish forms a traditional part of the diet. Fish industry returns are estimated at $230,000 per annum.

4. Methodology And Materials

Introduction

The methodological design of this study is based on analytical tools derived from both physical and social sciences. Given that the goal of research (scenario development for SWM) requires quite deep knowledge and overview of different physical, social economic and historical aspects of the area, steps and depth will be kept simple but appropriate to achieve the study objectives in the limited time available. A schematic representation of the breakdown and sequence of the study process is hence here Shown in Figure4-1.

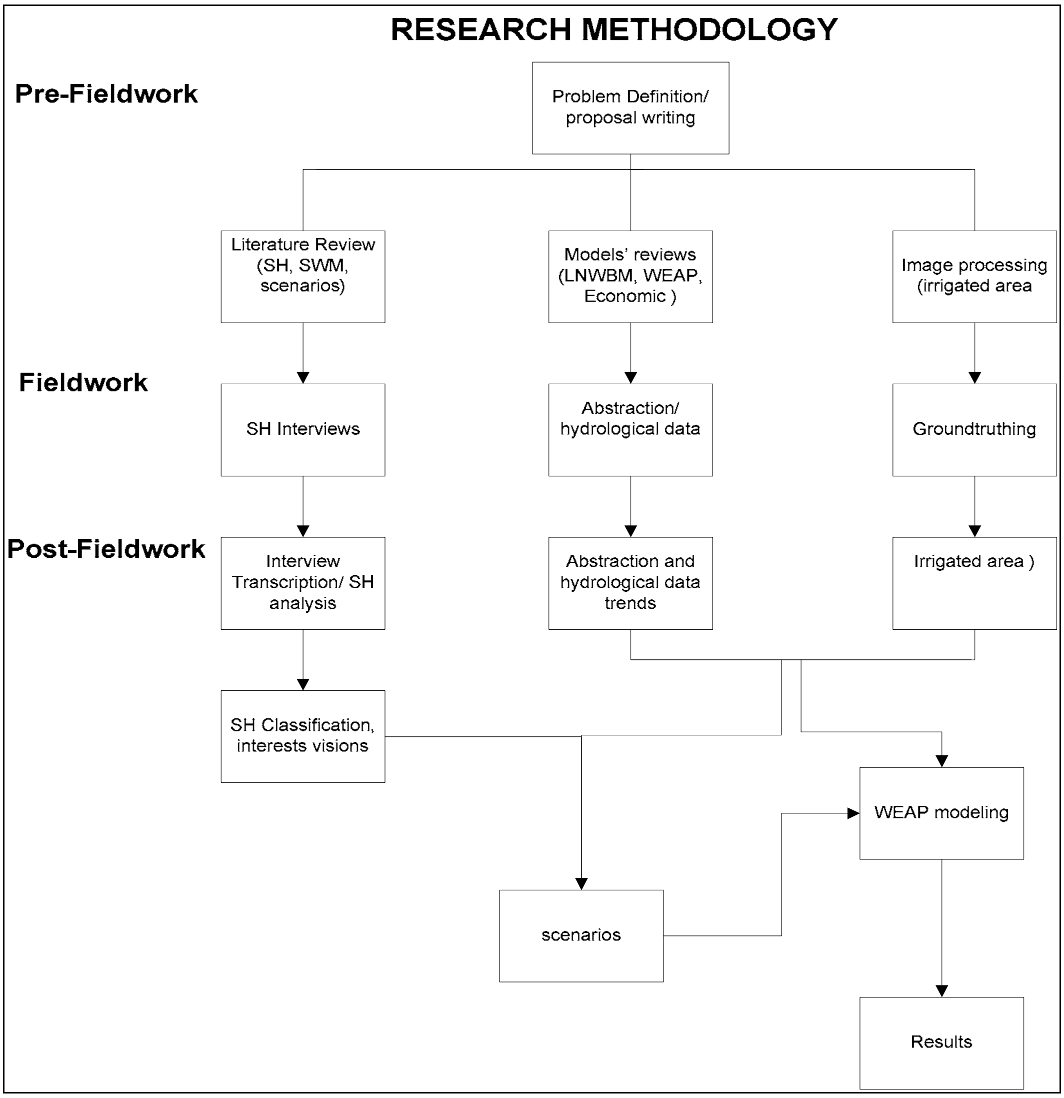

Figure 4-1Schematic of the research methodology

The research is three phased with the main stages being pre-fieldwork, fieldwork and post field work as shown in Figure 4-1. phase one is for fieldwork preparation, in a second stage, the fieldwork is carried out, the main goal of this second period is the data acquisition mainly on stakeholder interests, social economic factors relating to water resource management and hydrological data collection. In a third stage, post-fieldwork, the data collected is analyzed.

4.1. Materials and prefieldwork

4.1.1. Data preparation

In the preliminary stages of the study a literature review and preparation for fieldwork was carried out. Review of the proposal and literature on SWM, scenarios and stakeholder analysis was done. The scale of the work was decided and a preliminary list of stakeholders in the study area was developed. Review of the previous models thought important to the study was done, reviewed models include the Lake Naivasha Water balance model (LNWBM), Economic model for the study area and WEAP model.

4.1.2. Image processing

This involved searching for the appropriate images that would be used for estimation of the irrigated area. An aster image of June 29th 2006 was found appropriate for the task, it was pre-processed and then irrigated areas where digitized out as polygons and coded. As a first result, this gives the total irrigated area and the irrigated area per farm. The polygons would then be used in the field to identify the irrigation type as well as the main crops grown per farm.
Four other images for historical trace of the irrigated area were processed, these included;

- Landsat multispectral scanner (MSS) for 1975
- Landsat MSS for 1986
- Landsat thematic mapper (TM) for 1995
- Landsat TM for 2000

4.1.3. Hydro meteorological data

The following data was analyzed for completeness and time span it covers in order to have an overview of data that needs to be collected during fieldwork, it includes;-
Rainfall data,
Lake evaporation/evapotranspiration data,
Lake Naivasha levels data,
River discharge data for, Malewa, and Gilgil.

4.2. Fieldwork

The data acquisition in the field takes into account the limited time available and the unfamiliarity with the study area. Three main data sets were collected during the field work period namely:

4.2.1. Stakeholder interviews

Given the objective of the research and the scale at which it is undertaken, catchment level, only representative stakeholders of the larger groups were interviewed. Attention was given to identifying (or confirming) the main stakeholders and how they could be grouped, understanding the social and physical environment of the area and identifying the current and old water management issues as well views on how the future water resources should look like. To achieve this, non scheduled structured interview format based on RRA technique was used (cf. chapter2). A check list to guide the interviewees was used though the interviewees were at liberty to express all their feelings about SWM.

4.2.2. Hydro meteorological data collection

This involved collection of the data from various government offices as well as from private individuals involved in collection of such data. Field visits to the measuring stations was also done to have a general appreciation of the station settings and to also ascertain how the station settings can influence results. Measurements for cross sections and discharge rate of some river sections had been targeted, however, the period of fieldwork coincided with peak flows in the rivers and this was not possible.

4.2.3. Water abstraction data

Water abstraction data mainly from the irrigated commercial farms was collected along with the irrigation techniques and the acreage of the farms. Groundtruthing of pre-processed satellite image was also carried out to establish the irrigation types as well as the main crops grown per farm.

4.3. Post fieldwork

This has involved processing of the data collected from the field, modelling of the catchment using the processed data and thesis write up. A detailed description of the post field work activities is contained in the subsequent chapters.

5. Data Analysis

5.1. Introduction

Three main data sets are analysed namely; stakeholders, water use (demand) data and to a small extent hydrological data. From the interviews performed and other secondary data (papers, existing maps and previous MSc thesis) stakeholder analysis is done. Demand data analysis is also done based on water abstraction records, water use inventory and image analysis. Expected outputs are area under irrigation and water use rate per unit irrigated area. Hydrological data is analysed for trends, low, medium and high flows. Generally the analysis looks at deriving trends, un-concealing complexities and uncertainties. These then form the basis for scenarios as the main outputs which scenarios are then modelled in WEAP from which graphical visualization of the impacts is made.

5.2. Stakeholder analysis

This analysis will seek to differentiate and study stakeholders based on their attributes with regard to sustainable water use and management in the catchment. Classification will be made of stakeholders based on their interests, importance and influences to the objective of the study with a final goal of developing possible scenarios on sustainable water use and management.

The scenarios developed will look at developing an understanding of how the different attributes of the stakeholders impact on sustainable water use and management. The challenge therefore is to develop credible scenarios from the stakeholder attributes.

To have a quick over view of a section of the stakeholders, a broad based setup of water management structure in Kenya is shown figure5-1. The catchment, the level at which this study is conducted, falls at level three from the bottom of the pyramid of the management structure.

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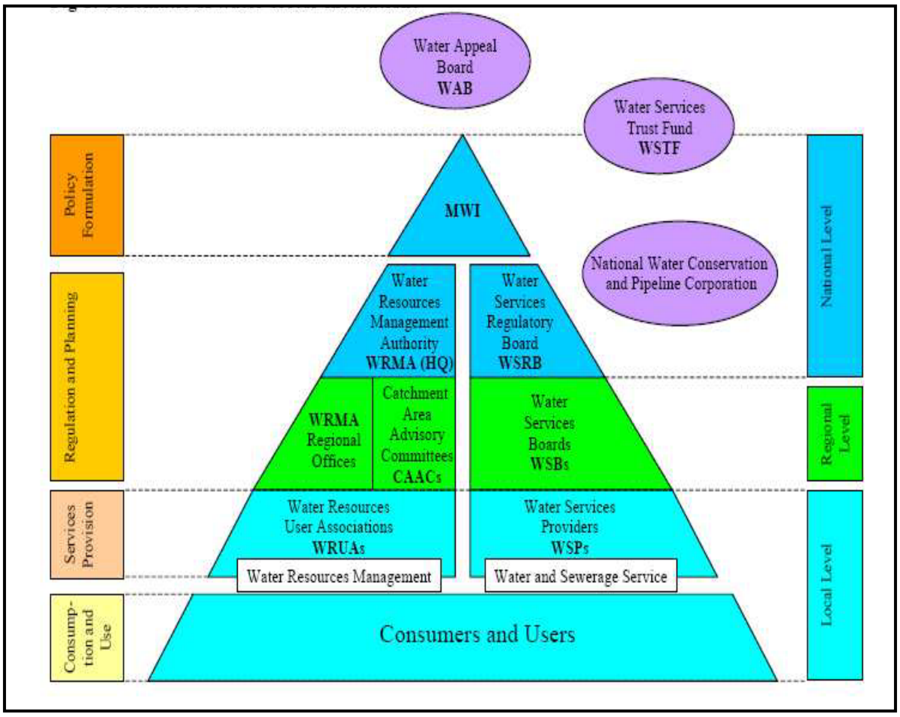

Figure 5-1: Kenya Water resources management structure (source: (GoK, 2007))

5.2.1. Stakeholder analysis methodology

The methodology adopted in the analysis of stakeholders is summarised in figure 5-2. The process involves a detailed analysis of the interview transcriptions and secondary data. Stakeholders and their interests are identified. An assessment and classification both the stakeholders and interests is then done.

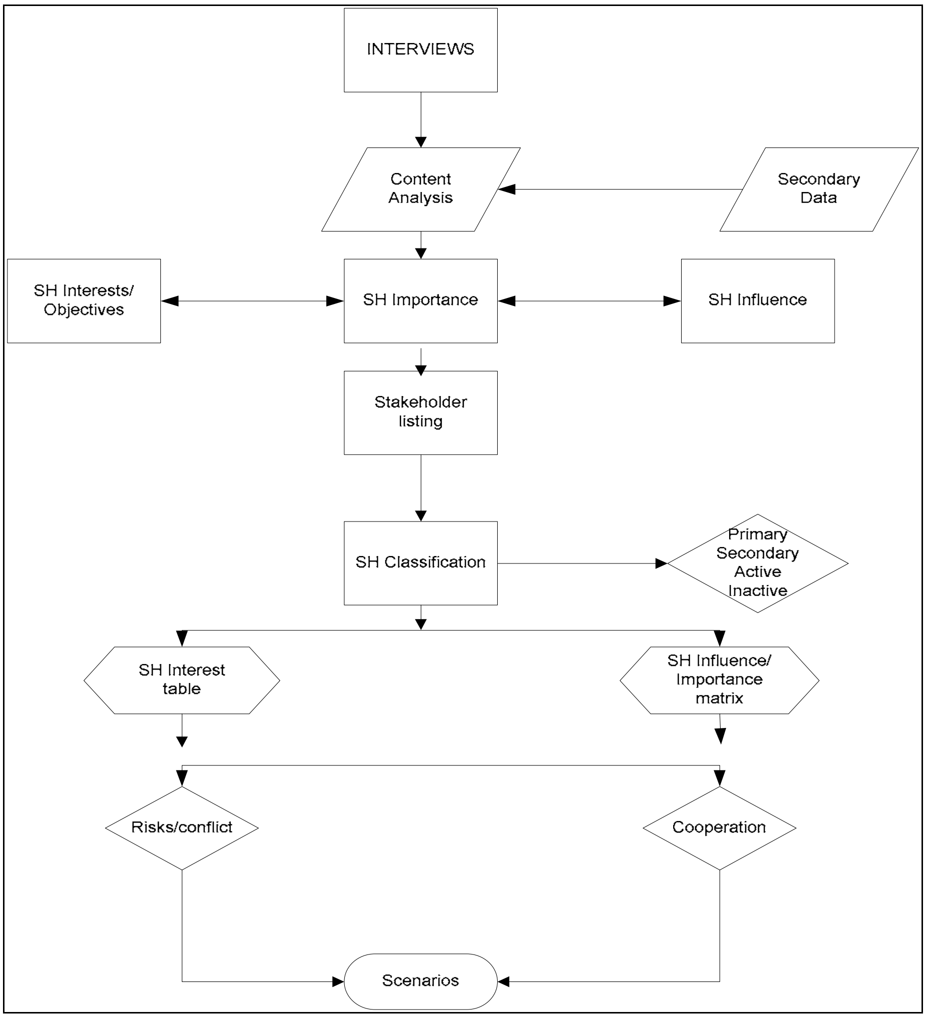

Figure 5-2 stakeholder analysis methodology

5.2.2. Description of Stakeholder in basin based on their interests

From the interview responses, various secondary data and direct observations, a description of stakeholders based on one broad attribute of interest is derived. This does not pretend to give a comprehensive classification of stakeholders, but rather an overview of the stakeholders from which the classification will be derived at a later stage.

Riparian land owners: these are of three categories; the well organized educated rich and influential land owners around the lake (LNRA) with nature conservation interests, though a few elements within this group would want to develop the riparian land for commercial interests. The second group is Kihoto village settlers, which comprises of poor peasant farmers whose gardens and homesteads are within the riparian land itself and during high lake levels their gardens extend into the Lake and the third category is the riparian land owners along the river banks mainly in the upper catchment. This category is mainly comprised of peasantry subsistence farmers who are interested in cultivating the riparian land for two main reasons, (a) the soils closer to the river banks are allegedly fertile and (b) during dry seasons, it is easy for the farmers to irrigate their crops.

Large scale commercial farmers: main interest for this category of stakeholders is water abstraction either from the lake or the rivers. They are mainly located in the lower catchment though they have since 2002 extended to the upper catchment. Because they employ so many people and are so integral to the area's economy, large scale floriculture and horticulture interests are among the most powerful in the basin. They are also potentially a serious threat to the lake in the form of sizable abstractions, and the pollution they can possibly cause through the agro-chemicals

Mid and upper catchment small scale farmers: Substantially numerous are the small scale farmers within the upper and mid-catchment, whose interests relate directly to water abstraction rights, as well as the role they play in reducing the lake's water quality through inappropriate land use practices. These stakeholders have also been at the centre of tree planting mainly along the river banks to reduce soil erosion.

Migrant labourers: these have become one of the largest population groups around the lake shores. Their interest in the water resources of the catchment occurs through the commercial farms that employ them, water abstraction by their settlements for domestic use, and pollution that may be as a result of poor sanitation and flooding of pit latrines during rainy seasons is a concern.

Municipalities and towns: the lake falls within the Naivasha municipality, the Kenya government's third biggest revenue earner. The municipality is supplied with water from the lake and groundwater sources around the town. The lake is also used for sewerage disposal, and is viewed as the municipality's prime source of economic wealth. Besides water abstraction and sewerage disposal, the municipality also has interests in the overall management of the Lake Naivasha since it falls with in its administrative boundaries. Other urban areas, such as Gilgil town and, Nakuru municipality, that are outside the basin also have important interests because part of their water demand is supplied by Naivasha's main influent, Malewa

Beef and diary farmers: these include diary and beef farmers whose interests are water abstraction for watering the livestock as well as fodder irrigation

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Masai pastoralists, there are about 20,000 with approximately 200,000 heads of cattle(Czuczor, 1997) in the neighbouring Nakuru and Narok districts whose main interest is seeking access to the lake to water their animals. They view private land owners around the lake (LNRA) as impediments to their access to the lake's water, while the LNRA is concerned about the damage thousands of cattle cause to the lakeshore, as well as the nutrient contributions they make to the water. Further away from the lake, pastoralists often clash with private land owners as well as national park authorities over grazing rights.

Government departments: Naivasha falls within the jurisdiction of many Kenya government ministries and departments, not least the ministry of finance that collects approximately $100millions annually from the area (Sayeed, 2001), ministry of water and irrigation with the overall mandate of management of water resources, and the ministry of Environment and Natural resources. The Kenya Wildlife Services (KWS) has the overall mandate of management of the RAMSAR site, it also has responsibility for the game that wanders about much of the lake's riparian land, and is supposed to deal with compensation claims brought by those who have been wounded by wildlife, or lost livestock to wildlife. The fisheries department plays a key role in the management of the lake's fisheries. The ministry of tourism has interests because of Naivasha's substantial tourism sector. The forestry department is responsible for various forest reserves within the basin, including some that play a vital role in the basin's hydrology. Government interests can be summarized as being managerial and economic.

Fishermen: these include legally sanctioned fishermen, as well as their counterparts who operate illegally. 200 to 300 poachers exploit the lake, and on any one day there are 30 to 40 poachers on the lake, both groups fish for their lively hood. Within this batch of interests are included those of the lake Fish Resource management committee of the LNMC, who work to curb illegal fishing activities. Fishing interests are also derived from various fish sales outlets and suppliers of fishing gears and boats. A final set of fishing interests are the many sports fishermen that are attracted to the lake by its black bass.

Tourists and hoteliers: Lake Naivasha area boosts of an enormous number of bird species that attract many bad watchers. Besides birdwatchers, the lake attracts many other visitors keen to indulge in the area's remarkable beauty for example the attractive acacia trees and the co-existence wildlife with large scale commercial farming. Tourism interests are not restricted to hotels and other accommodation alone, but include tourists' guides, curio manufacturers and sellers, and people seeking water sport fishing, skiing and sailing.

Olkaria Geothermal field: this is located just outside the catchment to the south west. It generates electricity through geothermal fumaroles that are said to get their water through the bottom leakage of the lake.the plant also abstracts about one million cubic meters of water annually from the lake for domestic and industrial purposes. With as much as 15% of the country's power supply derived from this field, virtually every electricity consumer in Kenya has a stake in the field. Recently, a farm has tapped a steam well to supply warmth to its flowers. Visitors to the area's Hell's gate national park are also to some extent attracted by the site of the fields and many geysers.

Researchers: in its time, Lake Naivasha has attracted considerable research attention, which has included substantial work by the University of Leicester (of the UK), the International Institute for Geo-information Science and Earth Observations-ITC (of the Netherlands), and the US research and conservation NGO, Earth Watch. Many of these channel their activities through Elsamere, a conservation trust located on the lake shore. Research is also commissioned by LNRA. The Kenya marine and Research Institute (KMFRI) maintains a permanent station on the lake.

Conservationists: Key interests here include: - promotion and preservation of the Ramsar Site established in 1995, Aquatic species, Terrestrial species – (hippos, buffaloes), Avian species – (fish eagles), Aquatic & Terrestrial vegetation; these interests are being fronted by Earth Watch and Elsamere, both of whom are research as well as conservation stakeholders. The World Wildlife Fund (WWF) is also developing activities in the Malewa river catchment. IUCN has also played an important role in the development of the management process of the lake, and encouraged its application for Ramsar designation. IUCN's contributions in this respect have earned it a permanent seat on the LNMC. The ornithological department of the Nation Museum of Kenya (NMK) also made important contributions to this process. Additional conservation interests are more amorphous, and include legions of Kenyan and international birdwatchers, as well as many riparian land owners, whose principal motivation for contributing towards the lake's management is the maintenance of its natural beauty and biodiversity.

The Media: although the media is outside the basin, it has played a major role in influencing the activities in Lake Naivasha basin. Most fascinating about the media, is the reporting of only "eye catching" issues because they believe it is such issues that make news, this has in a way improved the management of the water resource through avoiding of controversial issues. Conflict escalations that are attributed to the media are those between LNRA and the Masai pastoralists.

5.2.2.1. Analysis of impact of interests

Analysis is done by assessing the potential impact of the stakeholders' activities and interests on SWM and use. Activities or interests that enhance SWM are graded as positive (+) impacts whereas those that deter SWM are graded as negative (-) impacts. From the analysis of the activities and interests, a listing of the stakeholders and their interests in the catchment is made, table 5-1.

5.2.2.2. Stakeholder interest table

A stakeholder interest table is a tabular summary of stakeholders, their interests, potential impact of the interests on the objective of the study. Table 5-1 presents the summary of the above analysis.

Table 5-1: stakeholders, their interests, importance of the interests and the impact of the interests.

NO	STAKEHOLDER	INTEREST	POTENTIAL IMPACT
1	2.Naivasha municipality	1. Abstraction(urban water supply) 2. waste water disposal(lake) 3. management interests	- - ?
2	1.Nakuru and Gilgil municipalities	1. Abstraction(urban water supply)	-
3	3. large commercial farms	1. Abstraction (commercial irrigation) 2. Agro-chemical disposal (lake) 3. conservation interests 4. Increased revenue	- - + ?
4	4. LNRA	1. management (LNMP) 2. biodiversity 3. access to lake 4. Ramsar site	+ + ± +
5	5. LNGG	1. Abstraction (commercial irrigation) 2. management (WAP)	- +
6	6. Kihoto village	1. Abstraction (domestic & ltd irrigation) 2. Land use	- -
7	7. Tourism/Hoteliers	1. Water abstraction 2. Biodiversity 3. sport fishing 4. increased revenue 5. Beautiful scenery	- ? ? ? +
8	9. Masai pastoralist	1. Abstraction (Livestock watering) 2. Access to the lake 3. Land use(range land for grazing)	- - -
9	10. Beef/diary industries	1. Abstraction-(Livestock and fodder watering)	-
10	11.Upper & mid catchment small scale farmers	1.Land use for basic livelihood (sedimentation) 2. Abstraction (for domestic and ltd irrigation)	- -
11	12. Olkaria geothermal	1. Power generation 2. Abstraction (industrial & domestic)	? -
12	8. Fishermen	1. Increased fish catch 2. Access to the lake	
13	13.MWI/WRMA/WRUA	1. Regulation(permit issuance) 2. Monitoring and assessment	+ +
14	14. KWS	1. Biodiversity (Conservation of wildlife 2. Increased number of tourists 3. Ramsar site designation	? -?
15	15. WWF/Forestry dept	1. Biodiversity 2. Nature conservation 3. Better land use practices	+ + +
16	16. MoF	1. Increased revenue	-?
17	17. Researchers	1. Assessment	+
18	18. Media	1. Reporting	+/-/?

Across tabulation of the stakeholders and the interests (still in the stakeholder interest table context), is presented in table 5-2. This will help to have a quick visualization of potential areas of; conflict of interests, competition, and cooperation. The totals at the bottom of the table indicate the number of stakeholders involved in a particular interest. The level of concern for a particular interest will form the basis for scenario formation at a later stage for example attention will have to be drawn to interests like water abstraction and water management because they are potential areas of competition, conflict and cooperation.

Totals for the columns represent the number of stakeholders with interest in the specified interest. This means that the higher the number of stakeholders, the higher the importance of the interest. On the other hand totals for the rows indicate the number of interests that a particular stakeholder has in SWM and may therefore represent the importance of the stakeholders depending on how important the interests the stakeholder participates in are.

Table 5-2: cross tabulation of stakeholders and their interests: (√) represents participation in the interest & (+) or (-) represents the impact of the interest on SWM

Stakeholder	No	water abstraction	impact	Waste disposal	impact	Access to lake	impact	Land use	impact	Tourism	impact	Biodiversity	impact	Water management	impact	Electricity generation	impact	Total interests
Primary Stakeholder																		
Naivasha Municipality	1	√	–	√	–	√		√	–				–			√		**5**
Nakuru & Gilgil Municipality	2	√	–													√		**2**
Large commercial farmers	3	√	–	√	–	√	–	√	–					√		√		**6**
Kihoto Village settlers	4	√		√	–	√	–	√	–				–		–	√		**5**
Tourists & Hoteliers	5	√				√	+			√	+	√	+			√		**5**
Masai Pastoralists	6	√	–	√	–	√	–	√	–						–			**4**
Milk/Beef industries	7	√	–		–			√							–	√		**3**
Upper & Mid catchment farmers	8	√	–					√	–					√	–			**3**
Olkaria Geothermal	9	√	–								+					√		**2**
Secondary stakeholders																		
LNRA	10		+			√	+	√			+	√	+	√	+			**5**
LNGG	11		–			√	–	√						√	–	√		**5**
WRMA/WRUA	12		+											√	+			**2**
Fishermen	13	√				√					–	√	–					**2**
GoK_Finance ministry	14									√						√		**2**
WWF/Forestry Department	15							√	+	√	+	√	+					**2**
KWS/NEMA	16	√				√	+			√	+	√	+	√	+			**4**
Researchers	17		+									√	+					**2**
Media	18													√				**1**
Total SHs		**11**		**4**		**9**		**9**		**4**		**6**		**7**		**9**		

5.2.2.3. Assessment of importance of stakeholders

This is based on table 5-2, now, taking the earlier assumption that the more the number of stakeholders in an interest, the higher the importance of that interest, and further assuming that the number of stakeholders in a particular interest is equal to the weight of that interest, then I derive a value stakeholder-interest cross tabular table 5-3. This table is then used for working out the total weight of the stakeholders. The higher the final weight of the stakeholder, the higher will be the importance of that stakeholder and vice versa. I define the threshold for low or high importance as:

Threshold= (Highest weight – Lowest weight)/2

= (49-7)/2

=20.5

Table 5-3: Stakeholder-interest value table

No	Stakeholder/Interests	water abstraction	Waste disposal	Access to lake	Land use	Tourism	Biodiversity	Water management	Electricity generation	Total No.Interests	Total weight
	Primary Stakeholder										
1	Naivasha Municipality	11	4	9	9				9	**5**	**42**
2	Nakuru & Gilgil Municipality	11							9	**2**	**20**
3	Large commercial farmers	11	4	9	9			7	9	**6**	**49**
4	Kihoto Village settlers	11	4	9	9				9	**5**	**42**
5	Tourists & Hoteliers	11		9		4	6		9	**5**	**39**
6	Masai Pastoralists	11	4	9	9					**4**	**33**
7	Milk/Beef industries	11			9				9	**3**	**29**
8	Upper & Mid catchment farmers	11			9			7		**3**	**27**
9	Olkaria Geothermal	11							9	**2**	**20**
	Secondary stakeholders										
10	LNRA			9	9		6	7		**5**	**31**
11	LNGG							7		**5**	**7**
12	WRMA/WRUA							7		**2**	**7**
13	Fishermen	11		9			6			**2**	**26**
14	GoK_Finance ministry					4			9	**2**	**13**
15	WWF/Forestry Department				9	4	6			**2**	**19**
16	KWS/NEMA	11		9		4	6	7		**4**	**37**
17	Researchers						6			**2**	**6**
18	Media							7		**1**	**7**
	Total No. stakeholders	**11**	**4**	**9**	**9**	**4**	**6**	**7**	**9**		

5.2.3. Stakeholder importance-influence matrix

Based on the derived importance and influence as the broad criteria, the stakeholders are relatively placed in a 2X2 matrix figure 5-3. Stakeholder numbers in table 5-1 have been used to represent the stakeholders in this matrix. The position of the stakeholder groups in the matrix helps to indicate the relative risks posed by these stakeholders and the potential coalition of their support for sustainable water use and management.

Importance is as earlier defined whereas influence is based on how powerful a stakeholder is in influencing decisions that affect SWM and use. This could be through financial strength, political influence or by virtue of the status of the stakeholder in society. The reader is therefore cautioned that the judgements made over influence may be subjective, non the less much effort has been made to make it objective.

Importance ↑		
High	**A** (1) Naivasha Municipality (6) Kihoto Village Settlers (7) Tourists/Hoteliers (10) Upper & Mid Catchment Farmers	**B** (3) Commercial Farmers (4) LNRA (9) Milk/Beef Industry (14) KWS/NEMA
Low	**D** (2) Nakuru/Gilgil Municipality (11) Olkaria Geothermal (17) Researchers	**C** (13) WRMA (15) WWF/Forestry (8) Fishermen (18) Media (12) WRMA (5) LNGG

Low **Influence** → High

Figure 5-3: Stakeholder importance-influence matrix, the numbers represent the stakeholder groups. See also table5-1

According to (Groenendijk & Dopheide, 2003) quadrants A, B and C (fig 5-3) are the key stakeholders of the project, those who can significantly influence the project or are most important if the project objectives are to be met. The implications of each box are summarized below.

A. Stakeholders of high importance to water resource management but with low influence. (Stakeholders 1, 6, 7, 10). This implies that they will require special initiatives if their interests are to be protected.
B. Stakeholders with high degree of influence on SWM and use and who are of high importance to its success (stakeholders 3, 4, 9, 14). Resource managers need to establish a good working relationship with this group.

C. Stakeholders with high influence, who can affect SWM and use but whose interests are not the targets of the project (stakeholders 5, 8, 12, 13, 15 & 18). These stakeholders may be a source of significant risk and they need careful monitoring and management
D. These stakeholders are of low influence on and of low importance to SWM and use and may require little monitoring or evaluation and are of low priority (stakeholders, 2, 11,17).

The implications are therefore that scenarios are developed based on the attributes of the stakeholders in boxes A and B as these are the most sensitive to physical SWM and use

5.2.4. Visions of stakeholders

5.2.4.1. Kihoto Village settlers

Favour a high water level, even if it eats up much of their gardens, it is easy for them to irrigate their crops unlike in dry seasons when it recedes by over 3km in which case digging trenches that long and over 3m deep is a very big problem. Proposes that the vision can be achieved through regulated pumping by using horse pipes of not more than 3” diameter and for not more than 8 hours a week. Main control to be on the large commercial farms.

5.2.4.2. Fisher men:

These too would want to see a lake with High water level, this causes bigger breading areas for the fish and therefore increases the fish yield. To achieve this, pumping, mainly by the large commercial farms has to be regulated. When asked to how much water, they could not readily give an answer, their interest is to see water levels rise and it can only be through reduced abstraction by the main abstractors.

5.2.4.3. Lower catchment Commercial farmers

Prefer high water levels because lying of pipes to the pumping station is cheaper due to reduced distance and yet provides sufficient depth for the pump heads. This is to be achieved through efficient water use, and WRMA should be encouraged to increase its monitoring activities.

5.2.4.4. Upper catchment commercial farmers:

Their vision is to have more water available in the catchment through construction of a dam that is deep enough in the upper catchment. They argue that the area volume ratio of the lake in the lower catchment is very big allowing for a lot of open water evaporation. A dam in the upper catchment would therefore regulate the area of the lake and hence reduce evaporation rate because temperatures and wind speed in the upper catchment are lower and precipitation is higher than in the lower catchement where much of the water is currently stored. Secondly, they argue that the dammed water can used to generate hydro- electricity which is an important requirement for the upper catchment people.

5.2.4.5. Hoteliers

These ones too prefer a high water level because it brings the wildlife closer to the compounds of the hotels which is a great tourist attraction. Hippos and giraffes were singled out as the most interesting and common to the hotel compounds during high lake levels. Hoteliers however have got no idea how this can be achieved and or maintained.

5.2.4.6. LNRA

Would like to see high water levels for the lake but not only high water levels, but also the water quality should be improved. This will be ideal for provision of breading grounds for biota. Proposed ways to achieve this is through implementation of the management plan, water act, EMCA, and NEMA to be brought aboard as a strong supervisor. Also, only light farming if any should be done on the riparian land.

General impression from stakeholders' visions

Two common issues emerge from stakeholder visions namely, a higher lake level and good water quality. The path to attaining a higher lake level seems common/central to all stakeholders that is water use efficiency by irrigated commercial farms as well as strengthening of the water permitting system, the only deviation being the irrigated commercial farms in the upper catchment who suggest a regulated release to the lake through construction of a reservoir in the upper catchment to reduce on the evaporation rate from the lake due to its shallow depth and hence a very big volume to surface area ratio.
Water quality improvement, suggestions for better farming practice in the upper catchment is suggested along with tree planting. Construction of sewage system for Naivasha municipality and better organized settlements around the lake are also suggested and well as better treatment of agrochemical effluents.

For scenario development, there is a common vision of high water level and water of good quality. However, the pathways to achieving the vision are quite different, this forms a good ground for development of pathway scenarios as the stakeholders can then be able to clearly understand the implications of their suggestions.

5.3. Water use and demand

An assessment of major demand components for their variability is made with an objective of establishing the sector that drives demand in the catchment. Detailed assessment will then be zoomed in on the major driving sector to better understand the complexity and uncertainties involved therein. Preliminary assessment is based on the 1997/8 Water resources assessment project (WRAP) inventory of water resources users in the catchment and population data projections by (Rural_Focus, 2006) based on the 1999 population census (Appendix2). A summary of the water use components is presented in table5-4

Table 5-4 Registered water requirement in the catchment

Demand type	Quantity	Units	Water requirement(MCMyr$^{-1)}$	
Irrigation	5897	Hectares	56.6	72%
Livestock	32005	Livestock units	0.5	1%
Wildlife	29013	Livestock units	0.9	1%
Domestic	812389	People	17.1	22%
Industry			3.8	5%
Total			**79**	100%

The assumptions used were used during data collection by WRAP were

- Average water use per hectares per year of 9500 m^3
- Water use per person per year in the rural area =16m^3
- wate^r use per person per year in urban areas =36m^3
- one livestock unit= 1.25cows or 1.5wildlife

From table 5-3, irrigation sector stands out as the biggest water consumer in the catchment at 72% of the total water consumption. Also the figure of 9500m3 per hectare per year has been contested by many farmers as it was not based on crop water requirement calculations(Mpusia, 2006).

Detailed assessment of irrigation requirements and water use practices will be made with a purpose of understanding the complexity and uncertainties involved and this then will be used as a basis for scenario development

5.3.1. Irrigation water use and demand

This section will focus on quantification of water use by the irrigated commercial farms as they are thought to be the biggest driving force behind water use as per results from stakeholder analysis. Estimation of the area under irrigation per crop and by irrigation type is done using remote sensing techniques. The general trend of historical development of irrigated area is also investigated. Thereafter, the amount of water used for irrigation per hectare per crop per annum is also estimated using metered water abstraction records for about 20 farms collected from the field

5.3.1.1. Estimation of area under irrigation as of 2006

Polygons that were digitized from the aster image of April 1st 2006 prior to field work were classified into irrigated area by crop type classes using ground truth data collected from the field. This enabled a quick visualisation of the special distribution of the irrigated area by crop type, Figure 5-4. The areas of the polygons for each crop type were then computed through rasterisation of the polygons and using the histograms to get the area under irrigation per crop type and the overall irrigated area as of 2006, table 5-5.

Table 5-5: Irrigated area by crop type.

Crop	Area (ha)	%
roses	1028	23.0
roses & carnations	730	16.3
roses,hypericum	21	0.5
flowers	132	3.0
Total flowers	**1911**	**42.8**
babycorn	**205**	4.6
babycorn & beans	**143**	3.2
babycorn & beans &cabbage	**45**	1.0
babycorn & beans&cabbage	**124**	2.8
babycorn,beans,onions	**905**	20.3
beans/tomatoes	**21**	0.5
cabbage	**373**	8.4
cabbage and beans	**6**	0.1
Total vegetables	**1822**	**40.8**
grass	286	6.4
grass & lucerne	26	0.6
grass,lucerne	14	0.3
Lucerne	163	3.6
Lucerne,babycorn,beans	176	3.9
Total fodder	**665**	**14.9**
macadamia	50	1.1
Eucalyptus	17	0.4
TOTAL	**4467**	**100.0**

5.3.1.2. Estimation of historical development of irrigation in the basin

This was done using the following images from ITC database:

- Landsat multispectral scanner (MSS) for 1975
- Landsat MSS for 1986
- Landsat thematic mapper (TM) for 1995
- Landsat TM for 2000
- Aster 2006

The images were assigned the same geo reference and then the landsat MSS (80mX80m) and landsat TM(30mX30m) were resampled to the pixel size of Aster(15mX15m). The irrigated area for each year from the corresponding images was digitized to delineate the areas under irrigation. The digitized polygons were rasterised and areas under irrigation for the different years were read out from the histograms, table 5-5.

In order to allow for a quick visualisation of the history of irrigation(rate of development and dropout), in one map, the respective raster maps for the different years were converted to binary maps of 1 or 0, where 1 indicates irrigated area and 0 indicates non irrigated areas. The resultant binary maps were then coded by multiplying the respective maps of 1975, 1986, 1995, 2000 and 2006 by 2^0, 2^1, 2^2, 2^3, 2^4 respectively. The binary coded maps were then summed into a combined binary map, this had values ranging from 0 to 31. This map was then sliced into six classes of irrigated1975only, irrigated1986, only irrigated1995only, irrigated2000 only, irrigated2005only and irrigated more than one year, figure 5-5. the corresponding irrigated areas for the years are presented in table 5-6.

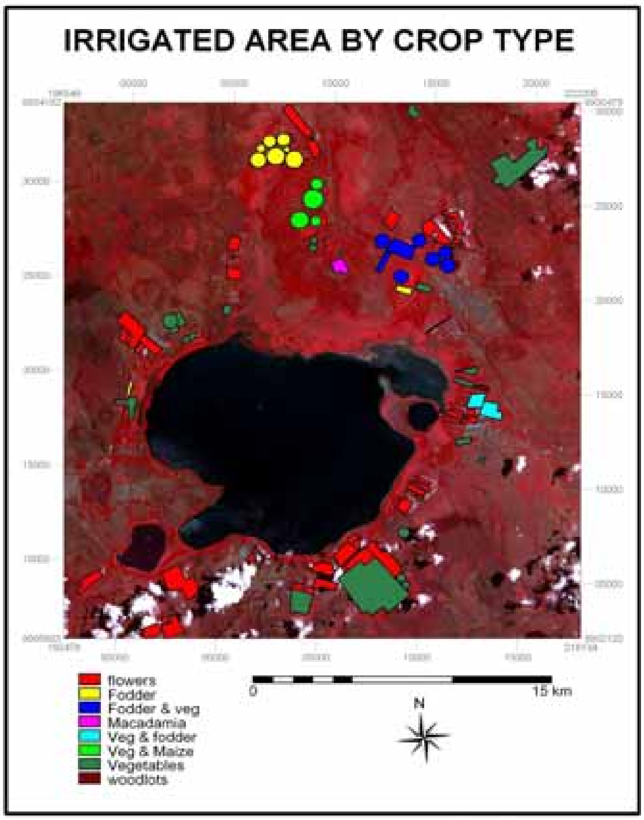

Figure 5-4 Irrigated area by crop type

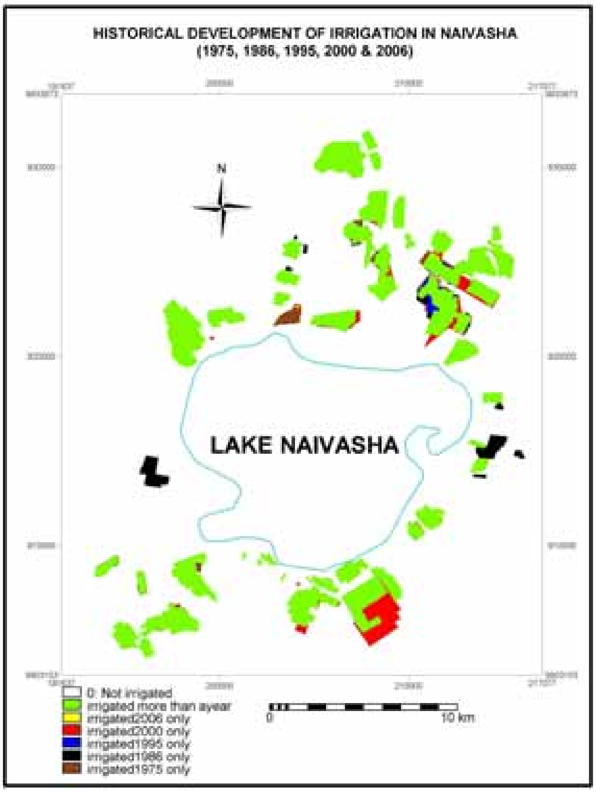

Table 5-6Time series of irrigated area

Year	Area(ha)	Change(ha)
1975	714.7	0
1986	1033.6	318.9
1995	2338.3	1304.7
2000	4314.6	1976.3
2006	4467.2	152.63

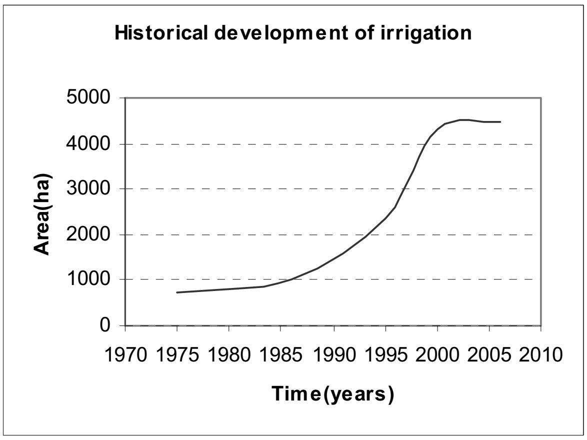

Figure 5-5Historical development of irrigation in Naivasha, right, the graphical representation

5.3.1.3. Water use

This has taken into account computation of the water supply source types for the different crops using the water permits database of registered water users WRMA and table 5-4. The results are presented in table 5-7. Thereafter, computation of applied irrigation per hectare and by crop type has been done using abstraction records form LNGG members. the aim is to establish how much water is abstracted for irrigation per crop type per hectare per year. This was done through identification of farms that are known to grow a single crop type. The abstraction data was then checked for consistence in abstraction rates over the data period and the area under irrigation over the same period. This was done to avoid situations where water abstraction could have decreased due to reduction in the irrigated area rather than due to improved irrigation techniques. Figure 5-6 presents results for annual applied irrigation per crop.

Table 5-7: source of water for the irrigated crops.

	Area under irrigation by crop type						
Water source	**flowers**	**fodder**	**vegetables**	**macademia**	**woodlots**	**Total/Source**	
Groundwater	397	579	763	0	0	**1739**	**39%**
Lake	1460	0	976	0	17	**2453**	**55%**
River	53	119	52	50	0	**274**	**6%**
Total	**1910**	**698**	**1791**	**50**	**17**	**4466**	**100%**

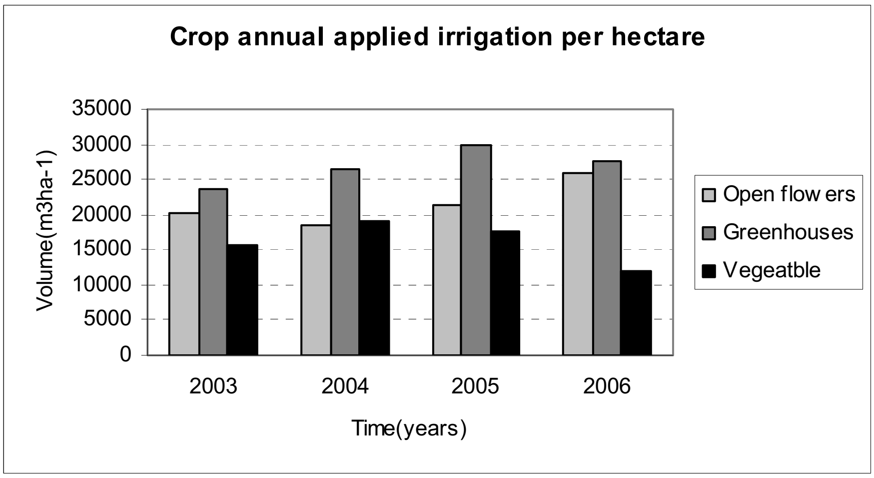

Figure 5-6 applied irrigation per hectare per year based on LNGG data.

6. WEAP modelling

6.1. Introduction

WEAP modelling will consist of four phases; the first phase will consist of modelling the supply using the precipitation soil moisture method. This will be then followed by the model calibration phase during the period when no major abstraction was taking place, modelling of demand and its optimisation to fit the observed lake levels will then follow before the final phase of scenario modelling.

6.2. WEAP

WEAP software was developed by the Stockholm Environment Institute (SEI). It operates at a monthly step on the basic principle of water balance accounting. The user represents the system in terms of its various sources of supply (e.g. rivers, groundwater, and reservoirs), withdrawals, water demands, and ecosystem requirements.
WEAP applications generally involve the following steps (SEI, 2001):
•Problem definition including time frame, spatial boundary, system components and configuration;
•Establishing the 'current accounts', which provides a snapshot of actual water demand, resources and supplies for the system;
•Building scenarios based on different sets of future trends based on policies, technological development, and other factors that affect demand, supply and hydrology;
•Evaluating the scenarios with regard to criteria such as adequacy of water resources, costs, benefits, and environmental impacts.

As a scenario generation tool, WEAP's strength is in its ability to place water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis. It places demand-side issues such as water use patterns, equipment efficiencies, re-use strategies, costs, and water allocation schemes on an equal footing with supply-side topics such as stream flow, groundwater resources, reservoirs, and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g., evapotranspirative demands, runoff, base flow) and engineered components (e.g., reservoirs, groundwater pumping) of water systems, allowing the planner access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use(SEI, 2005)

6.3. Hydrology (supply) modeling

The total available amount of water is determined by the rainfall over the whole catchment. The bulk of the rain falls in the higher parts of the catchment, the Abadere mountain ranges. A large part of this water is used by the vegetation (evapotranspiration) and the excess flows into Lake Naivasha. Only During very intense storms does some direct run-off from the area surrounding the lake flow into the lake but this amount is a negligible fraction of the total flow into the lake. The lake water recharges the shallow aquifers around the lake and these shallow aquifers loose again water to the deep (geothermal) aquifer system figure 6-1.

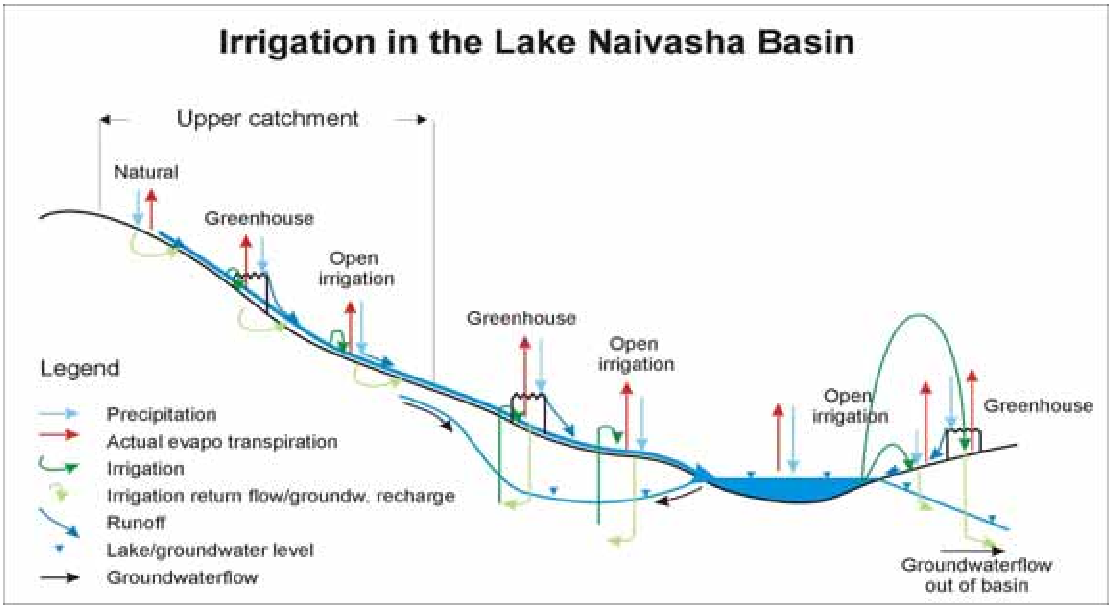

Figure 6-1 Schematic representation of the hydrological setting of the catchment

The hydrology of the catchment has been modelled using the soil moisture method of WEAP. This one dimensional, 2-compartment (or "bucket") soil moisture accounting scheme is based on empirical functions that describe evapotranspiration, surface runoff, sub-surface runoff (i.e., interflow), and deep percolation for a watershed unit. This method allows for the characterization of land use and/or soil type impacts to these processes. The deep percolation within the watershed unit can be transmitted to a surface water body as base flow fig 6-2. The choice for the method is because of is near perfect representation of the catchment characteristics. Also, the method requires a single input variable, precipitation.

Precipitation over the catchment has been represented using a single station rainfall series, (North Kinangop Forest station r9036025) figure 6-3 and three representative sub catchments with a total area of 1200km2.

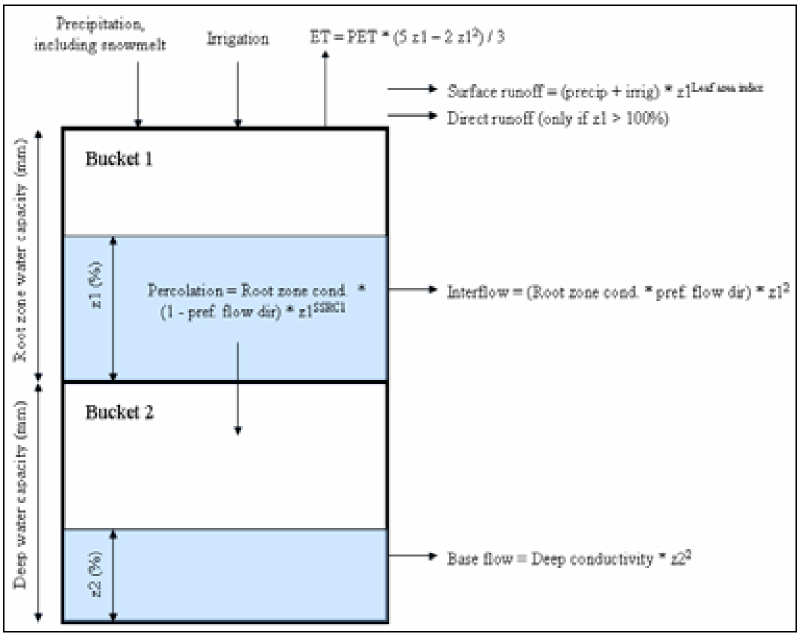

Figure 6-2 Two bucket soil moisture model (SEI, 2005)

Other parameters used in the hydrological model are summarised in table 6-1

Table 6-1 parameters used in the hydrology model

PARAMETER	VALUE	UNITS
Area	1200	Km^2
Crop coefficient	1	
Soil water capacity	100	Mm
Deep water capacity	1450	Mm
Leaf area Index	2.3	
Root zone conductivity	180	Mm/month
Deep conductivity	50	Mm/month
Preferred flow direction	0	
Initial% soil moisture Z1	25	%
Initial% deep moisture Z2	75	%
Average temperature	18	^oC
Relative humidity	75	%
Average wind speed	2	Ms^{-1}
Latitude	-0.5	degrees

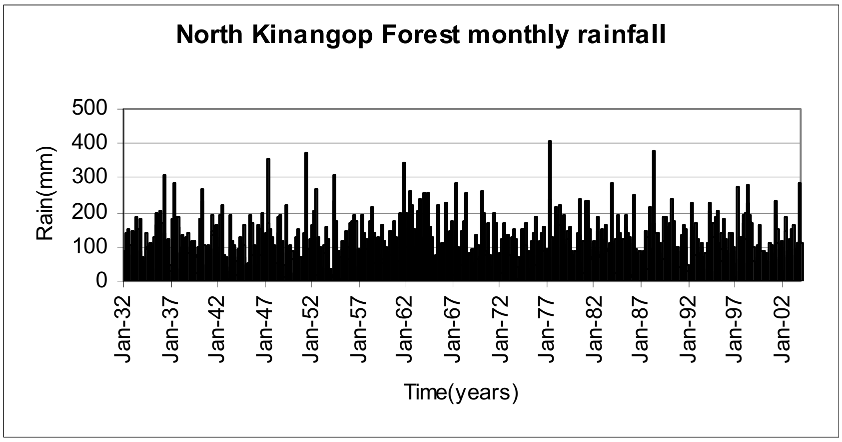

Figure 6-3 Time series of rainfall data used in modeling hydrology

6.4. Modelling demand

Demand has been modelled using demand quantities and water use calculated in chapter 5 (section 5.3) and estimations from previous studies (Ahmad, 1999; Alfarra, 2004; Mekonnen Gebremichael, 1999; Mpusia, 2006; Sayeed, 2001). The schematic for relative distribution of demand is shown in figure 6-2 and the demand components are as summarised in table 6-2.

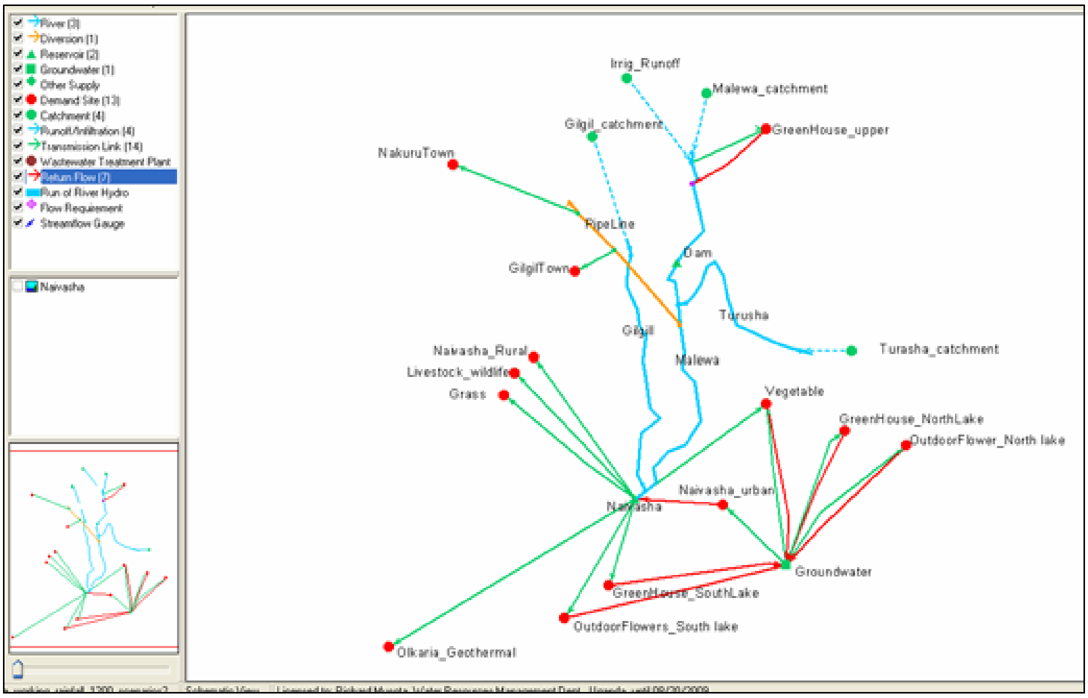

Figure 6-4 schematic set up of demand in the model.

Current account for demand:

The current account provides a snapshot of actual water demand, resources and supplies for the system, in other words it gives the initial modelling conditions, normally for the first year of modelling. The current account year is 2000, this is because this is when the demand component activity levels are fairly known. Initial conditions for the hydrology component have already been defined above, here, the initial conditions for demand are defined based on calculations and finding in section 5.3 and literature, table 6-2.

Table 6-2 Demand input components

Demand site	Quantity	Units	Annual water use(m^3) per unit
Greenhouses upper catchment	0	ha	26467
Greenhouses North lake	288.4	ha	26467
Green houses south lake	832.6	ha	26467
Outdoor flowers North lake	310	ha	21468
Outdoor flowers south lake	465	ha	21468
Vegetables	1815	ha	16116
Grass/Fodder	1383	ha	9570
Nakuru and Gilgil town	0.232	m^3s^{-1}	7300000
Naivasha urban	58000	people	36
Naivasha Rural	750000	people	16.61
Olkaria geothermal	1		712430
Livestock/wildlife	61018	LU	16.61

6.5. Calibration

The model has been calibrated using lake level data for the period 1932 to 1975 for the hydrological component. The calibration period was chosen because during this period, there was no major human water abstraction that could affect the lake levels appreciably. Optimization was done by adjusting the leaf area index as well as the root zone conductivity and deeper conductivity. Calibration had then to be done for the demand components so that the activity rates of the different demand components as well as the water use rates could fit the observed lake levels for the period 1976 to 2004.

7. Scenario development

This chapter will look at scenario development within the context of the study objectives (SWM and use). The methodology for scenario development that will be followed is the one described in chapter two. The reader is reminded of the differentiation of scenarios from options, scenarios in this section will aim at un-concealing the uncertainties and complexity with regard to SWM and use. This therefore implies that a lot of reference will be made to chapter 5 as foundation for scenarios.

7.1. Setting the Scenario modelling time frame and decision variables

7.1.1. Time frame

Use has been made of the historical lake level and river discharge data (1932-2006) that is dependant on precipitation to define the modelling time frame. A modelling period of 20years (2000-2020) is used, basing on the hydrological regimes of high moderate and low (green orange and red respectively) lake levels as shown in (Fig7-1). Justification for this criterion for choice of the time frame is based on the fact that SWM and use is best achieved when accurate historical and current data on demand and supply is available. However, much as historical and current data on demand may sometimes be available, it is very dynamic owing to its dependency to actions and interests of stakeholders that are themselves extremely dynamic. This therefore makes measurement and reliability of demand extremely difficult let alone derivation of trends. On the other hand, supply in the case of Naivasha basin, is fairly measurable as it is dependant on precipitation that has been measured consistently over a period of time, making it possible to derive trends.

7.1.2. Decision variables

The choice of the decision variables will depend on the design of the scenario and the purpose that the scenario seeks to inform. Therefore, a number of decision variables will be used and in some cases may be more than one in a scenario. The measure of quantitative success of the decision variable will be the impact it creates on the lake levels whereas qualitative success will be qualified descriptively.

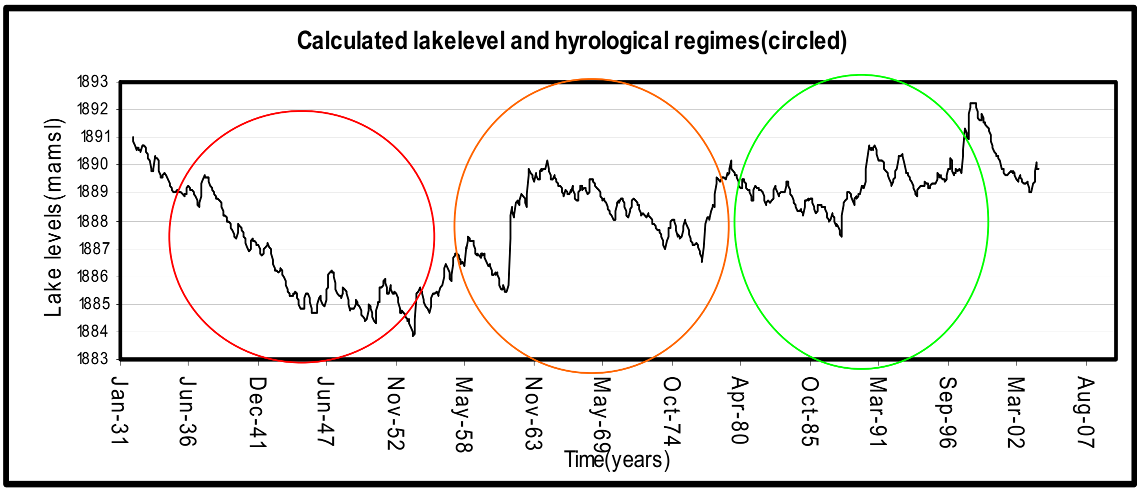

Figure 7-1: calculated lake level and hydrological flow regimes used to determine the time scale.

7.2. Scenario tree and scenarios

The scenario tree summarises the logical setting or flow of scenarios. Some scenarios will depend on others and in the tree they are indicated as branches or sub branches depending on the level of dependency, figure7-2. It should however be noted the placement of the scenarios in the scenario tree is dynamic depending on the scenario design.

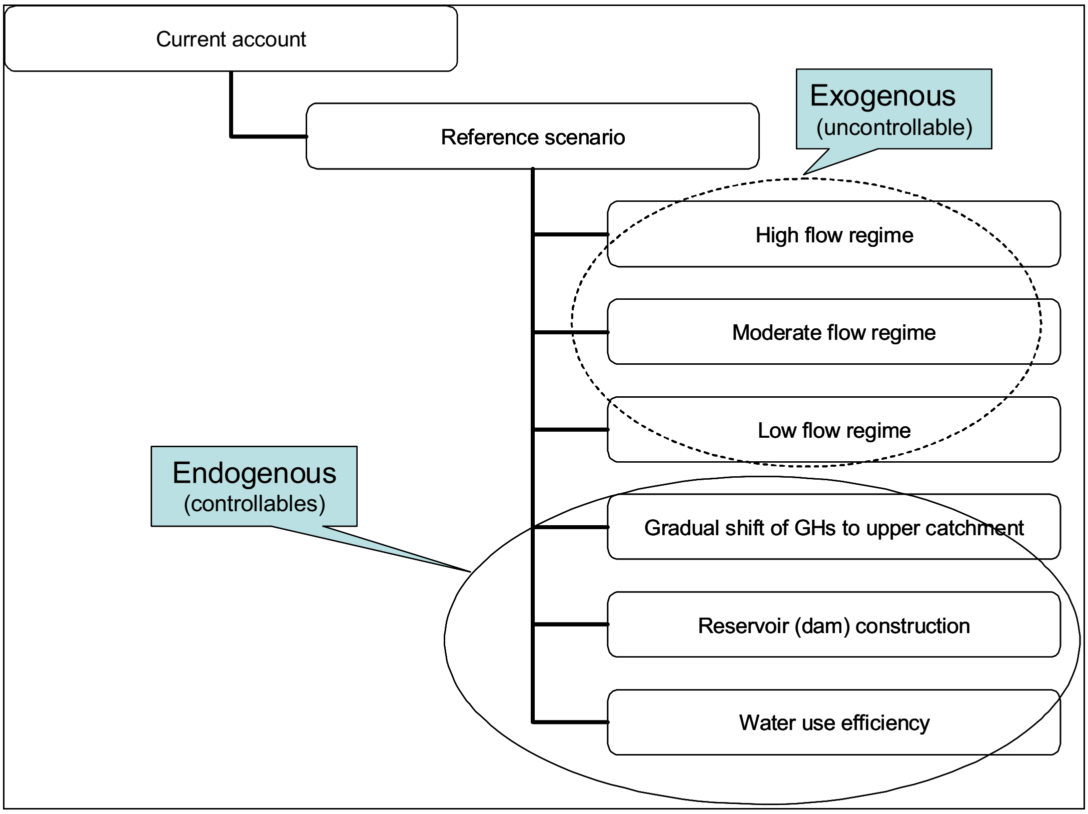

Figure: 7-2 scenario tree

7.2.1. Reference scenario

The reference or baseline scenario represents the ideal conditions for the modelling period. It is created based on a variety of economic, demographic, hydrological, and technological trends. All other scenarios are evaluated based on the reference scenario, therefore it should be as accurate as possible in mimicking the scenario modeling period. The hydrological component of the reference scenario has been modelled using the 1981-2000 meteorological series because it thought to offer the best predictor for the coming 20years (green circle in figure 7-1). Demand has been assumed not to change over the modeling period except for population that has a growth of 1.7% per year. This is due to the fact that irrigated agriculture, the main driver in water use, did not increase much between 2000 and 2006.

7.2.2. Climate change scenario

This scenario investigates the effect of the different hydrological regime on SWM and use. The scenario works on the assumption that the different hydrological regimes are solely governed by changes in climate. Analysis of discharge data into the lake and the resultant lake level data has been made to enable identification of the flow regime. Three different hydrological regimes, low flow (1939-1958), moderate flow (1965-19840 and high flow (1981-2000) each of 20years are identified, figure 7-1. Precipitation and lake evaporation for these windows are then used as meteorological series for the period 2001-2020 to model the hydrology for the different regimes. The demand side is modelled under the actual water abstraction conditions and its strength will be derived from how much it is able to inform sustainability of water management under the different climatical stress conditions.

7.2.3. Water use efficiency scenario

This scenario investigates the effect of water use practices on the sustainability of water use and management in the basin. The main focus is put on water used for irrigation because irrigation the biggest user of available water(80%), also due to the fact that irrigation requirements can easily be quantified and above all water abstraction data for irrigation is available. Data analysis was based on water abstraction records by the irrigated farms that subscribe to LNGG (Appendix.3). The abstraction figures per crop type were then assumed to be abstraction amounts for the entire catchment. Comparison of the abstraction amounts per crop type with crop water requirements calculated from different studies(Mekonnen Gebremichael, 1999; Mpusia, 2006) is then made table7-1& fig 5-5. This is aimed at revealing the hidden picture in water use management.

Table 7-1: Computation and comparison of crop water requirement and applied irrigation

Crops	Irrigation	Crops/Yr	ETact	ETact	ETact	Rainfall	Rainfall	H_2o Required	H_2o Applied
	Days/yr		mm/day	mm/Yr	m3/ha.yr	m3/ha.yr	m3/ha.yr	m3/ha.yr	m3/ha.yr
Indoor Flowers	365		3.5	1278	12775	0	0	12775	26467
Open Flowers	365		5.4	1971	19710	9390	9390	10320	21468
Grass/Fodder	330		2.9	957	9570	9390	8490	1080	
Vegetables	330	3	3.2	1056	10560	9390	8490	2070	16116

Scenario assumptions:

- All abstraction amount is used for irrigation
- Computed crop water requirements are allowed for a 10% increment to cater for losses during transmission.

7.2.4. Dam (Reservoir) construction in the upper catchment scenario

Construction of a reservoir that has a lesser potential for evaporation and that will regulate the lake area has been proposed by some stakeholders as a decision variable (cf. section 5.2.4.4). This scenario therefore assesses the impact of this decision variable will be on SWM and use. This vision is therefore here under investigated to un-conceal the complexity and uncertainties.

The biggest consumer of water from the lake is evaporation from the lake surface itself, estimated at 260MCM per year as opposed to the main input components into the lake which are, river discharge (220MCM) and direct rainfall (95MCM)(Becht & Harper, 2002). Annual values of precipitation in the hilly areas (upper catchment) are high, ranging from 1250mm to 1500mm with similar or lower rates of evapo-transpiration while the lower catchment experiences mean annual rainfall of between 667mm and 650mm with evapotranspiration rates of approximately 1800mm (Clarke.A.C.G, Allen .D, & Darling .G, 1990). Over the long term, the difference between precipitation and evapotranspiration is the water available for direct human use and management (Dingman, 2002), this therefore makes assessment of evaporation from the lake a crucial factor in SWM.

Based on the above facts, a brief review of the factors that influence evaporation has been carried out to establish how they relate. Evaporation is a diffusive process that follows Fick's first law represented by the equation

$$E = K_E * v_a(e_s - e_a) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5.1$$

Where E is the evaporation rate (LT^{-1}), e_s & e_a are vapour pressures of the evaporating surface and the overlying air respectively ($LL^{-1}T^{-2}$), v_a is the wind speed (LT^{-1}), and K_E is a coefficient that reflects the efficiency of vertical transport of water vapour by turbulent eddies of the wind (LT^2M^{-1}).

e_s on the other hand is given to a good approximation by the equation,

$$e_s = 0.611 * \exp\left(\frac{17.3T_s}{T_s + 237.3}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.2$$

e_s therefore increases exponentially with temperature which implies that rate of evaporation will increase with increasing temperature.
The vapour pressure in the air, e_a, depends on the relative humidity.
It can therefore be concluded that temperature has a direct relationship with rate of evaporation relative humidity has an inverse relationship with the evaporation rate.
Other factors that affect Open water evaporation are surface area of the water body (direct relationship) and rainfall over the water body (inverse relationship).

. Assessment of temperature, humidity and precipitation for lower and upper catchment of Naivasha has therefore been made with the intention of establishing the factor by which open water evaporation would reduce if a reservoir were constructed in the upper catchment.

A comparison of monthly average temperature for two stations one in the upper catchment (Mutuboi) and another in the lower catchment (Olkaria) has been made, figure7-3. Temperatures in upper catchment (8.54oC) are half the temperatures in lower catchment (17.93oC). Monthly precipitation for the upper catchment is found to be approximately twice that in the lower catchment and relative humidity is higher in the upper catchment as opposed to the lower catchment. Based on these factors, an assumption of the evaporation rate for the proposed reservoir to be constructed in the upper catchment is made as half that of the lake.
Expectation: Reduction in net evaporation through regulation of the lake size resulting in an increase in available water. Qualitatively, the reservoir will act as a sediment trap.

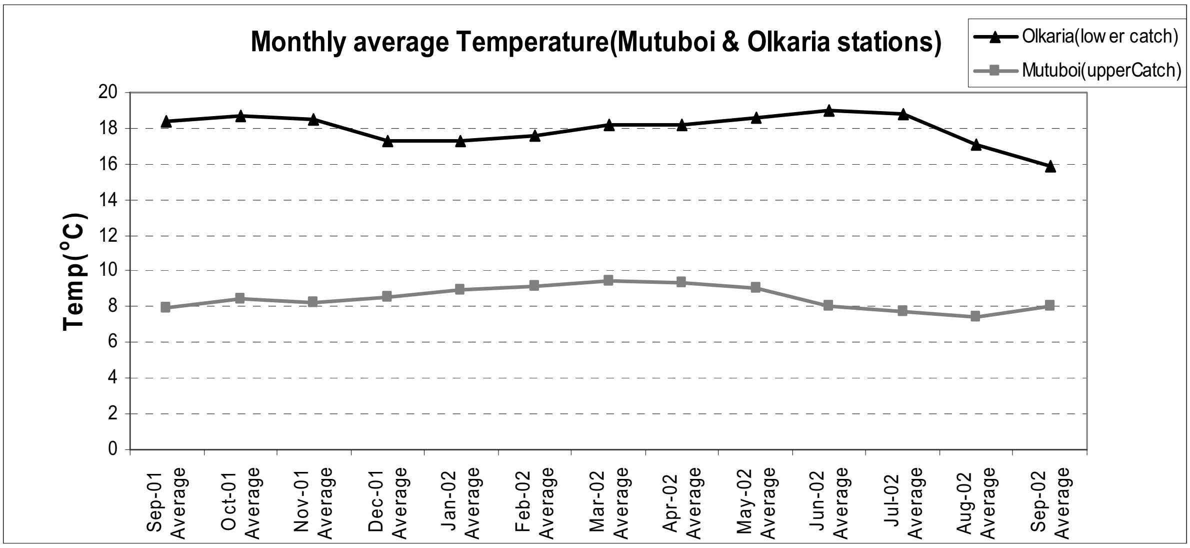

Figure 7-3: comparison of temperature variations for upper and lower catchment over a period of one year

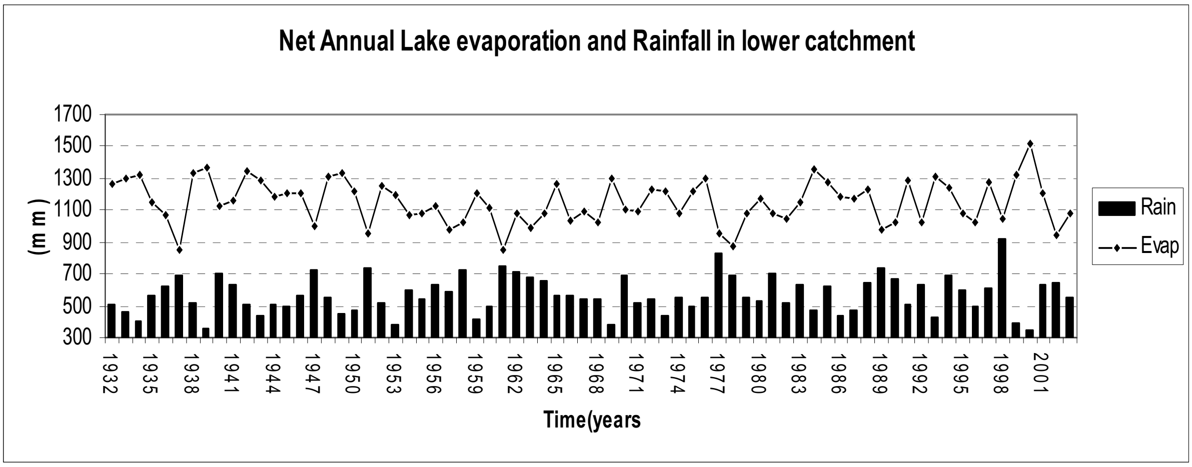

Figure 7-4: Influence of precipitation on evaporation over Lake Naivasha

Scenario design and assumptions
Dam dimensions: 5km length by 4 km width by 10m depth

- Area 20km2
- Volume 200MCM
- Placement, upper catchment
- Evaporation rate, 70% that of the lake

Operation rules:

- No losses to groundwater
- Top of buffer zone (dam volume below which releases are constrained)=100MCM
- Top of inactive zone (dam volume below which water is not available for allocation)=20MCM
- Buffer coefficient(fraction of water in the buffer zone available for allocation every month)=0.1

7.2.5. Gradual development of greenhouses in the upper catchment scenario

This scenario investigates the effect of development of green houses in the upper catchment. Two issue are investigated,

1) Management of runoff from the plastic greenhouses. Currently, all runoff from the green houses finds its self into groundwater figure 6-1. The total area under green houses is approximated at 1200hectares (12km2), table 5-3 with approximately 70% located south of the lake and 30% north of the lake. If annual around the lake precipitation is assumed to be 650mm and a runoff coefficient of 0.9 is assumed, then the total annual runoff from green houses would 7MCM per year. For the greenhouses north of the lake, there is a likely hood that runoff recharges the aquifers within their vicinity and it's probably re-pumped. However, for the green houses south of the lake, the runoff is lost to shallow groundwater and then to the deeper groundwater aquifer system that is thought to recharge the geothermal fumaroles, this water is completely lost from the catchment. The question therefore is, what if runoff found its way into the lake?

2) The scenario also seeks to assess the impact of return flow from greenhouse irrigated crops. Table 7-1 shows the crop water requirement and the abstracted water per hectare, the water abstracted for greenhouses (indoor flowers) is more than twice the crop water requirement. The scenario therefore also seeks to understand, what if all the return flow found its way back to the river streams.

The overall assumption of the scenario is that if the green houses were placed in the upper catchment, all rainfall runoff from the plastic greenhouses and the return flow would end up in the river stream and finally into the lake reservoir for use by stakeholders in the lower catchment.

Scenario design:

Initial conditions (2000)

- No greenhouses in upper catchment (0 hectares)
- Area of green houses in lower catchment=1200hectares
- Annual rainfall in lower catchment=650mm and upper catchment=1200mm

Other conditions:

- Runoff coefficient in upper catchment=0.9, lower catchment=0
- 80% of return flow is recycled or it finds its way in the river streams.
- Gradual development of green houses in upper catchment and similar rate of decay in lower catchment.
- Satellite town develops in upper catchment at rate of growth of greenhouses to meet demand for labour in the green houses.

8. Results and discussions

This chapter presents and discusses results accruing from model calibration and scenario modelling. Results from stakeholder analysis, demand data analysis and hydrological data processing have already been presented and used in chapters that have yielded to the presentation and discussion of this chapter. However, where deemed necessary, a discussion of the earlier presented results is also done in this chapter.

8.1. Model calibration

8.1.1. Hydrology (supply) component calibration

Calibration results show a root mean square error (RMSE) of 0.405m over the calibration period of 1932-1975, figure 8-1. Deviations are observed during peak water levels, similar deviations have been reported by(Muthuwatta, 2004) and (Mmbui Samuel, 1999). The deviation of the simulated levels from the observed levels could be attributed to the poor estimation of groundwater exchange between the aquifers and the lake. The lake is coupled with groundwater and it is likely that during wet periods there is a lot of groundwater flow into the lake. Modelling of lakes (reservoir)-groundwater interaction in WEAP is still weak, only entered as a seepage value (negative for a gain from groundwater) rather than being a head dependant value.

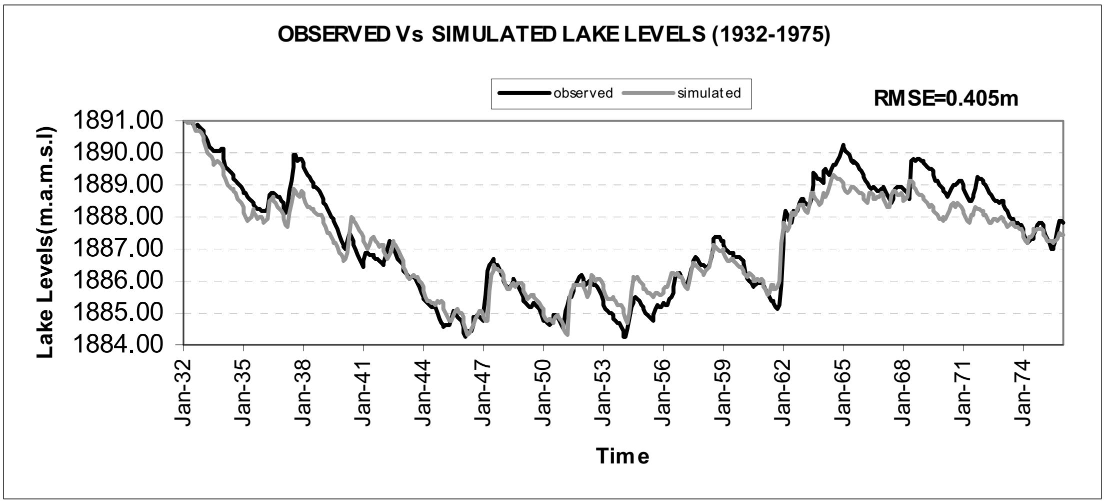

Figure 8-1: calibration results for observed and WEAP simulated lake level for the perion 1932-75

8.1.2. Demand component calibration

This was first modelled based on declared abstraction records for irrigated farms and standard water requirements for humans and animals. However as shown in figure 8-2A, deviation are observed for the period 2000 to 2004 between observed lake levels and simulated lake levels. Optimisation of abstraction had therefore to be made to fit the simulated levels with the observed figure 8-2B, this required a multiplication factor of 1.1 or an increment in abstraction of 10%. The implication is that water abstraction rates declared by LNGG irrigated farms are to a good extent very much reliable as they give only a 10% deviation and it therefore means that there is little concealment of the amount of water being abstracted by the irrigated farms. Secondly, it shows that the abstraction rates by LNGG members are very much representative of overall abstraction rates in the catchment and can there be applied for estimation irrigated agriculture in the entire catchment.

The other important information that can be derived from optimized demand is the actual water abstraction rates in the catchment per sector for the current account year 2000, table 8-1. This is on e of the strength of WEAP software, quick computation and keeping accounts of water use in a user friendly manner. Results of water use for 2000, table 8-1 are compared with results of water use based on WRAP inventory, table 5-3. Whereas the time difference between the two is 2years, the difference in water use is 36.7MCM (46.5%). I therefore argue here that revelation of this big difference in water use is attributed to stakeholder consultation and a deeper investigation of the uncertainties in the major drivers.

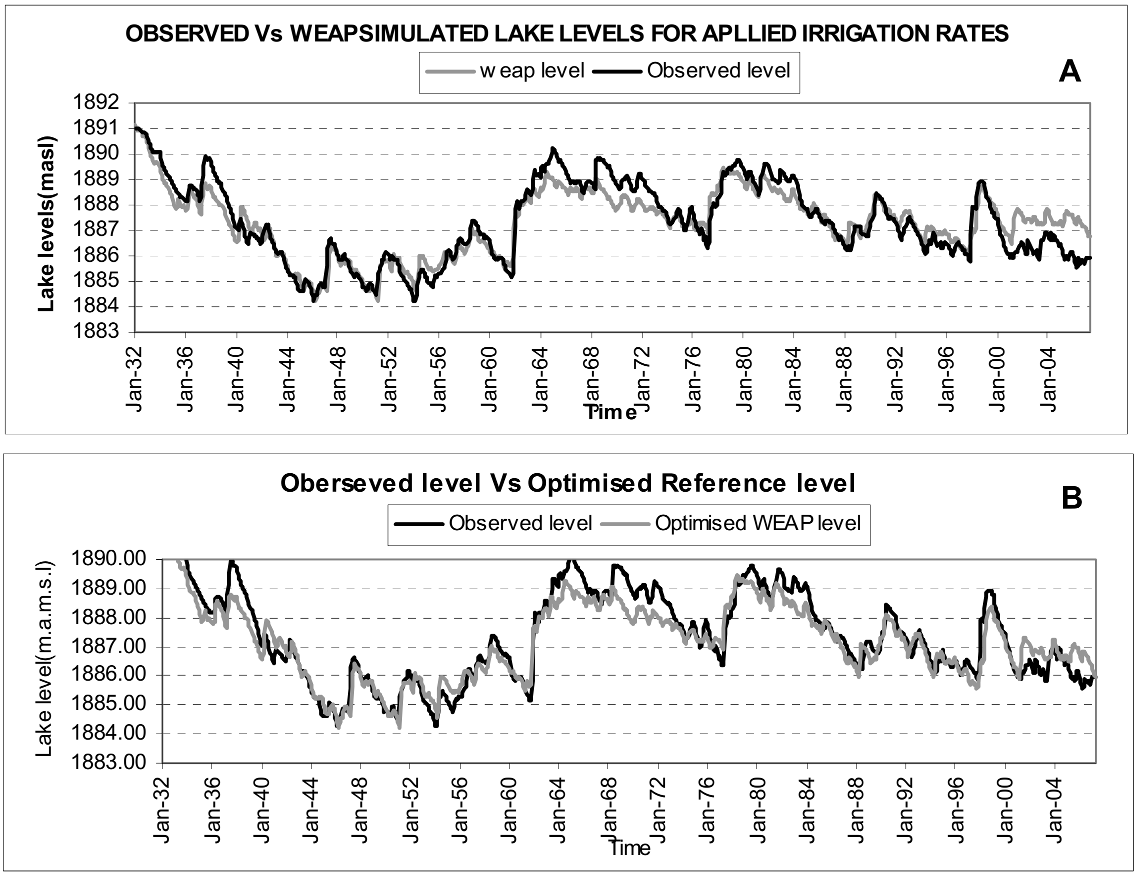

Figure 8-2: A&B optimization of demand to suit observed lake levels, (A) lake levels before optimization of demand (B) Lake levels after optimization

Table 8-1: water use per sector for the year 2000

Demand site	Quantity	Units	Annual water use(m3) per unit	Total water use(MCM)	%
Greenhouses upper catchment	0	ha	29126	0	0
Greenhouses North lake	288.4	ha	29126	8.4	7.3
Green houses south lake	832.6	ha	29126	29.1	25.2
Outdoor flowers North lake	310	ha	23615	7.3	6.3
Outdoor flowers south lake	465	ha	23615	11.0	9.5
Vegetables	1815	ha	17728	32.2	27.8
Grass/Fodder	1383	ha	10527	14.6	12.7
Nakuru and Gilgil town	0.232	m3s-1	7300000	7.3	6.3
Naivasha urban	58000	people	36	2.0	1.7
Naivasha Rural	750000	people	16.61	2.1	1.7
Olkaria geothermal	1		712430	0.7	0.6
Livestock/wildlife	61018	LU	16.61	1.0	0.9
			TOTAL	**115.7**	**100**

8.2. Reference scenario

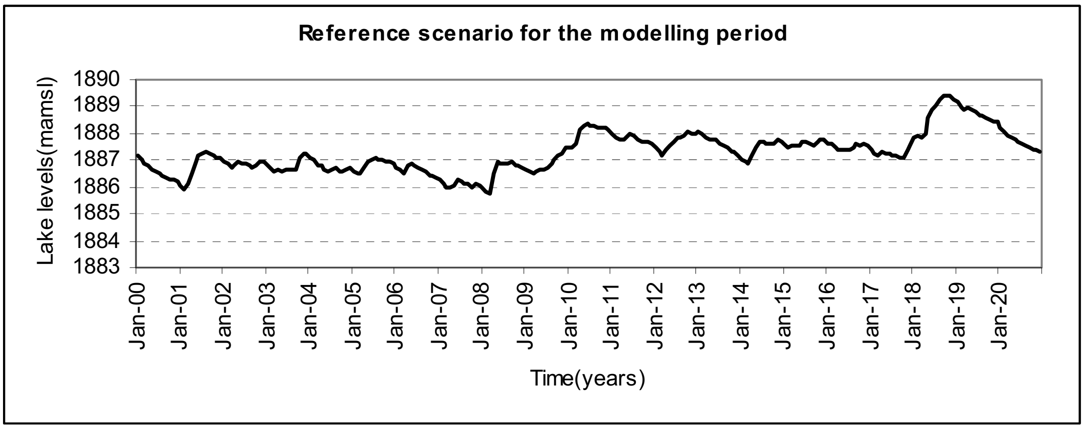

Figure 8-3:State of the lake levels under the reference scenario

The reference scenario will be used as a reference point for comparison with other scenarios that have been modelled.

8.3. Climate scenario

This is an extreme case scenario depicting both the best case and worse case scenarios. The results show that under current abstraction conditions, the water resources would be sustainable under high and moderate flow regimes. However, under low flow regime, the lake just runs dry in mid 2007 and totally fails to recover figure 8-3. The implications of this scenario to the stakeholders in the basin are that should the low flow conditions of 1930s to 1950s recur, then there is an eminent economic and environmental collapse for aquatic species. The lake will shrink to an approximate surface area of $10km^2$ the fisher men will no longer have a lake to fish from let alone the fish perishing in the mud left, KWS will have to relocate the hippopotamus, irrigation farms abstracting water from the lake will have to lay their pipes for a longer period increasing the abstraction costs. The scenario can therefore be used as a strong water management tool for example on assessing what the impact of a long drought would cause if it occurred. The scenario would also be important in setting limits to water abstraction during low flow regimes and it could also stimulate thinking for alternative sources of water as well as prioritisation in the use of water.

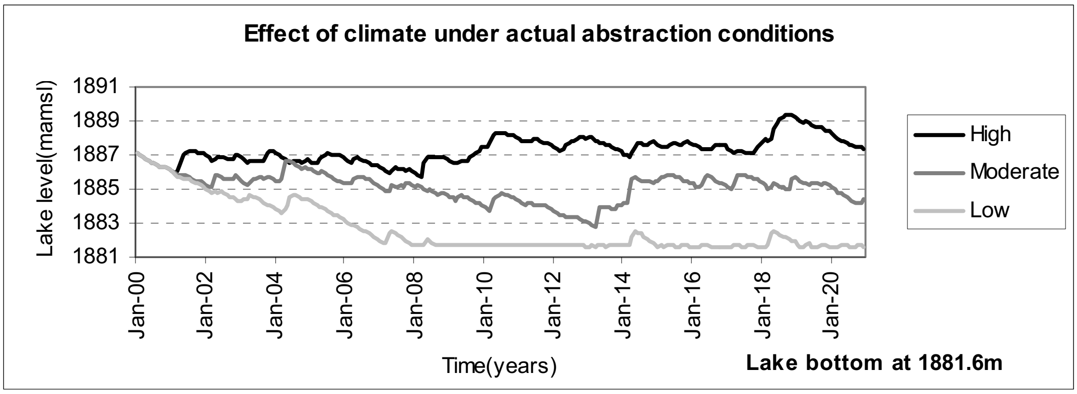

Figure 8-4: Effect of climate under lowflow, moderate flow and high flow conditions

The positive aspect in the worst case scenario (low flow), is that the riparian land will greatly increase to about 210km2 providing vast grassland for fauna and flora, biodiversity will most likely increase figure 8-5. The polluted lake will be gone, the area under papyrus will enormously increase and the vast stretch of grassland will provide grazing ground for the masai pastoralists as well as sanctuary to much of the wildlife.

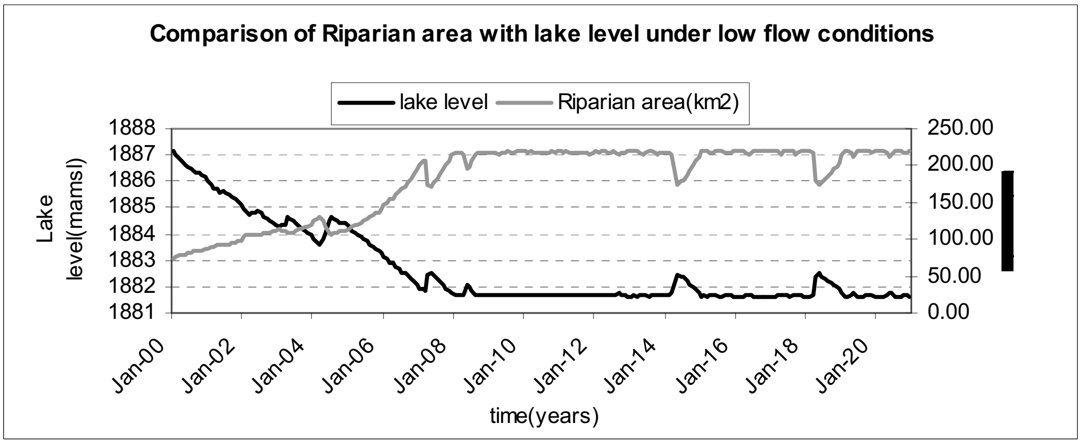

Figure 8-5:Variation of riparian land with lake level

8.4. Water use efficiency scenario

This scenario investigated what the effect of water use efficiency would be on the availability of water in the catchment. Results presented in figure 8-6 show that overall, there is an average rise in the lake level of about 1.5m if irrigated agriculture used water saving methods. The scenario shows the importance proper resource management on the demand side. When combined with the climate scenario (low flow condition), it further stresses the need for a shift from traditional water management methods where increased demand for water is satisfied by increasing supply rather than managing demand

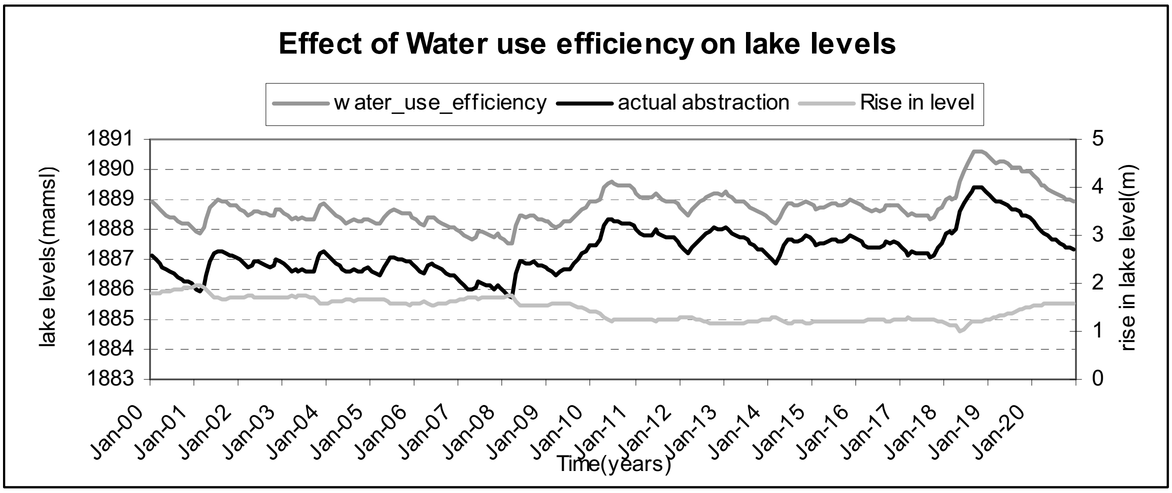

Figure 8-6:Effect of water use efficiency on lake levels

8.5. Dam (Reservoir) construction in the upper catchment scenario

This scenario investigated what the effect of construction of a reservoir in the upper catchment would be on the availability of water in the catchment.

Overall there is a decline in the lake level, it is drastic in the first year dropping by up to 0.6m which is due to the fact that the dam begins empty and also in the first year (2000), was a period for general lake level decline even without the dam probably due to low rainfall. However, the lake level starts gaining slowly and by 2020 it has regained by about 50%, figure 8-7A. However, in figure 8-7B, the corresponding change in total volume is much positive, in the first ten years, there is a net loss in total volume of 2.5MCM per month, however, in the subsequent 10years, the system gains an average of 25MCM of water per month which is more than enough of the total water requirement in the catchment.

Qualitatively, the dam acts as a sediment trap for much of the sediments from the upper catchment there by improving the quality of water in lake Naivasha located in the lower catchment. Overall therefore, the dam increases available water.

The negative aspect is the initial cost required to construct the dam as this is an enormously expensive project and it also initially involves a lot of environmental concerns and displacement of many people.

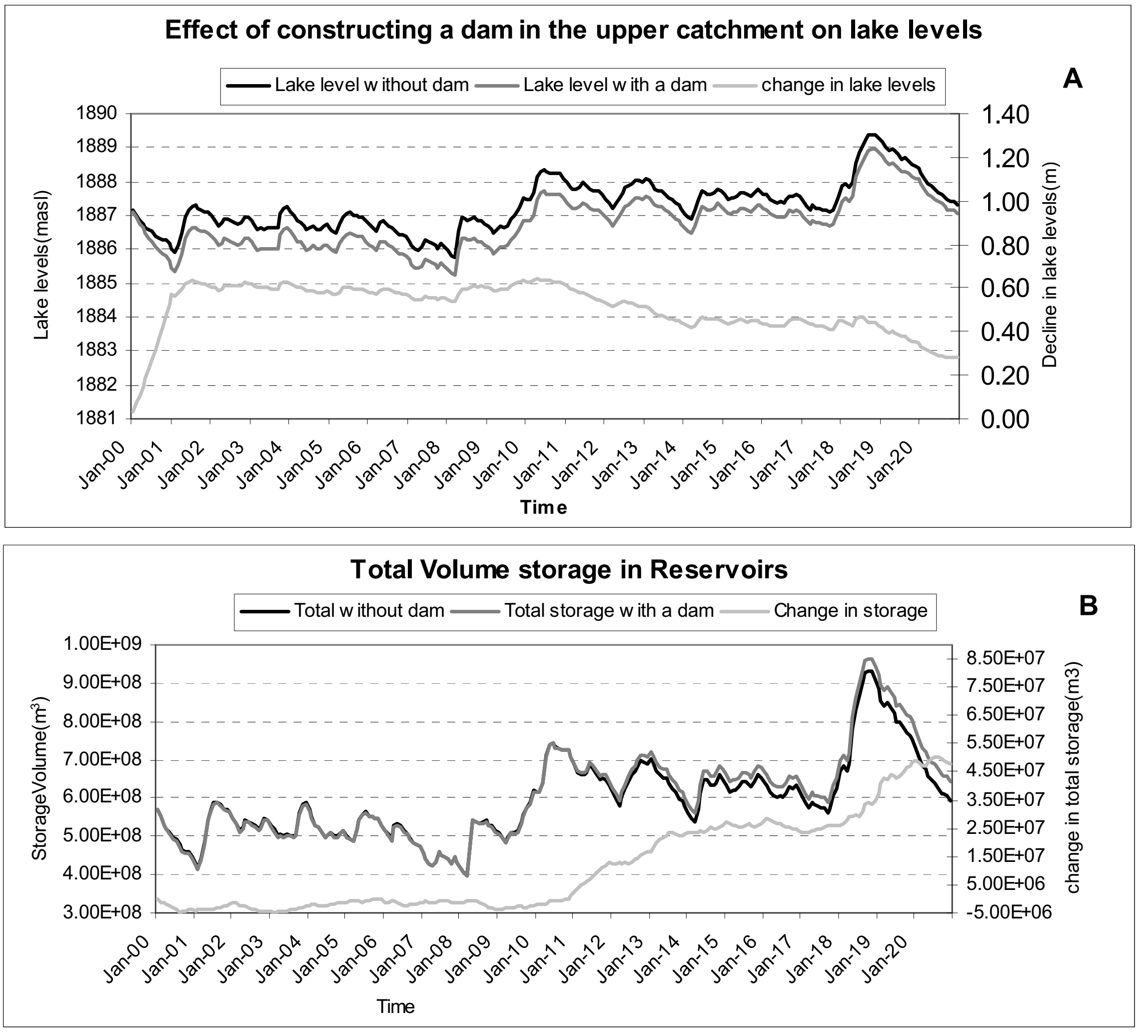

Figure 8-7:Effect of construction of a dam in the upper catchment on; A) lake levels & B) Total volume storage.

8.6. Gradual development of greenhouses in the upper catchment scenario

This scenario investigated the effect of gradual shift of green houses to the upper catchment with the aim of managing the rainfall runoff from plastic greenhouses and management of return flow due to over irrigation. The results are presented in figure 8-8.

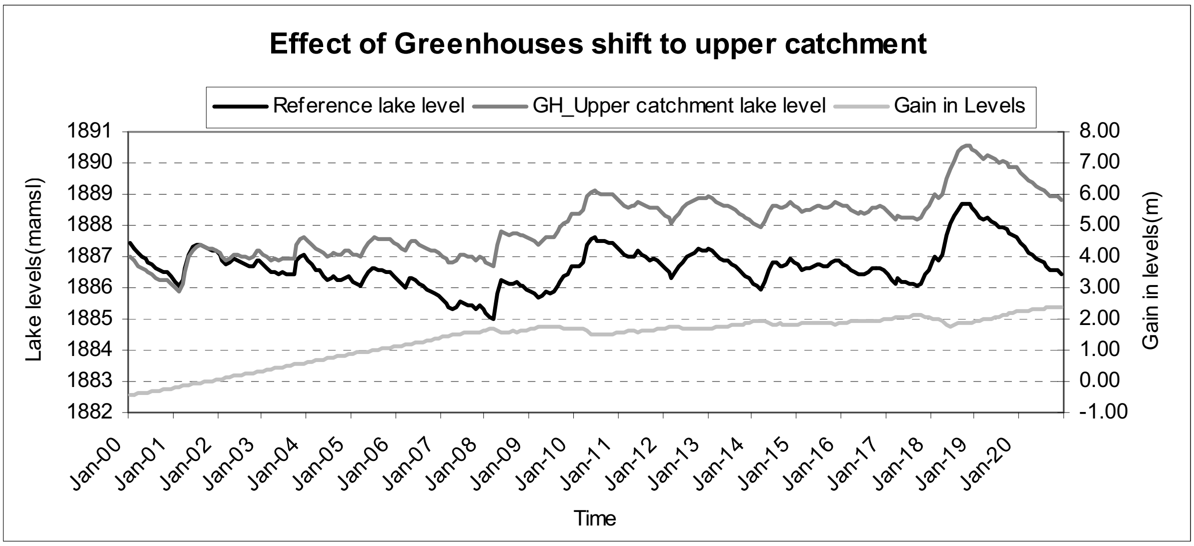

Figure 8-8 Effect of gradual shift of green houses to upper catchment

The result shows a general gradual rise in the lake level and therefore availability of water, figure (8-8), by the year 2020 when all greenhouses are assumed to have shifted to upper catchment, the lake level would have risen by approximately 2.4m. The decline in the lake levels observed in the first year of simulation is attributed to over estimation of the initial area under green houses in the year 2000.

The general gradual rise in the lake level highlights the impact of management of rainfall runoff from greenhouses and management of return flow. It also highlights the importance of placement or site selection for the green houses, because in the upper catchment there are very little losses to groundwater and also the rainfall is much higher than in the lower catchment.

What does this mean in terms of water quantity?

Based on the scenario assumptions and table 7-1, the water quantise saved are calculated:

Rainfall runoff = 0.9(runoff coefficient)*1.2(rainfall depth m)*12000000(area m2) =12.96MCM

Return flow=52%*12000000(area m2)*2.6467(irrigation depth, m)*80%(return flow coefficient) =13.21MCM

Overall total of water saved =26.17MCM. This amount is 77% of water being abstracted for use in the greenhouses. Therefore, if green houses were in the upper catchment, the lake would be approximately 2.4m higher. This would also free up space around the lake and allow for easier access to it by the Masai pastoralists and other interest groups who complain of denial of access to the lake by irrigated commercial farms.

However, the return flow has a negative effect of carrying all the agro chemicals into the river stream and the eventually the lake polluting the entire water system. This has a big risk of making much of the water un-useable and therefore its success only depends how best the return flow is treated.

9. Conclusions and recommendations

In this study a total of 18 stakeholders were identified. This group can be broken down in nine (9) primary stakeholders (water consumers) and nine (9) secondary stakeholders (non-water consumers, but involved in management, policy, public opinion, research, etc).

The analysis of the semi-structured interviews on shows a total of 8 interests. Two attributes are assigned to all interests: importance of interest and the potential impact of the interest on water availability and water quality. From a cross tabulation between stakeholders and interests/ impact the relative importance of the stakeholders and interests can be derived. The most important stakeholders are large commercial farmers, Naivasha municipality and kihoto village settlers and the overarching interests are water abstraction, access to the lake, land use and power generation.

The analysis also shows that in some cases there exists a strong disconnection between importance and influence. Fishermen have a low impact (very small group, low economic out put, hardly effect on water level/quality) but are influential because of political reasons. this is line with(Boix Fayos, 2002) findings of fishermen being a centre of conflict.

Majority of Stakeholders' visions show a preference for a high lake level and good water quality. Only the Masai pastoralists had no opinion here since access to the lake is their main interest.

Most of the stakeholders had no clear idea how the optimum status (high lake level and water of good quality) should be reached. This hampered one of the objectives of this study namely to model stakeholder perceptions of what is to be done to restore the lake using WEAP.

Results from 4 years of monthly metered data from 20 farms were analysed show an average yearly water use of greenhouses as 26467 mm, open flowers 21468mm and vegetables 16116mm. No trend in water consumption could however be detected during the 4 years.

It was shown that the hydrological model integrated in WEAP could reliably reproduce the monthly discharges and thus lake levels over the calibration period from 1932 to 1975. In the present version of WEAP it is still not possible the model the aquifers linked to the lake. This is a serious limitation for modelling the Naivasha system.
WEAP as a software is strong in running different scenarios, however, it is weak in comparison of the different scenarios, comparison had to been done in excel.

Modelling the lake levels from 1975 to 2004 using the areas under irrigation derived from satellites images and analysed application rates showed a very good result. Calibration using application depth as a variable showed a value of only 10% higher than one derived from the analysis of the farm abstraction data, and thus we can conclude that the range 26467-29114 mmyear^{-1} is a reliable estimate for greenhouses application depth.
A comparison with previous research on consumptive use in greenhouses shows an over irrigation of approximately 120% for greenhouses, 108% for open flowers and over 600% for vegetable, table 7-1.

Through stakeholder analysis and assessment of the driving forces behind SWM managements and use can yield to very informative scenarios with applicable decision variables.

- Climate scenario warns of an economic and environmental collapse if a long drought occurred
- Water use efficiency scenario indicates that an approximate 60MCM would be saved. It also confirms that irrigation is over 100%
- Construction of a 200MCMdam (Reservoir) in the upper catchment saves water of up to 25MCM per month with very minimal decline in the lake level.
- Gradual shift of greenhouses to upper catchment would save water of about 26MCM per year by the year 2020. It would also free up space around the lake easing tensions over access to the lake.

The developed scenarios are only a first step to SWM, there is need to understand stakeholders' reactions over the developed scenarios and thereafter a re-modification and performance of a multi criteria evaluation for the scenarios.

Overall, WEAP is a strong tool for modelling multi disciplinary water aspects in a basin and it is still under development and it is therefore likely that in the near future, it will be a fully distributed modelling softer ware capable coupling physical modelling with social economics modelling.

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Appendices

Appendix I Field interview respondents

No.	Respondent	date
1	Mr. Dominic Wambua ; Hydrologist Naivasha district	12/09/07
2	Mr. John Mawolo , farmer-Kihoto village	13/09/07
3	Sarah Higgins, Hon. General secretary for LNRA	15/09/07
4	Mr. Mbogo, Monitoring officer for the association-LNRA	17/09/07
5	Mr. Gibson Gachanja, farmer-Kihoto village	16/09/07
6	Ms. Ndenga Nancy-Technical Assistant WWF	17/09/07
7	Mr. Gomeri Kombo – General manager Lake Naivasha country club	18/09/07
8	Mr. Naftali- General Manager , SOPA Resort Hotel	18/09/07
9	Mr. Machaga Elizaphan- Peasant farmer in Ndemi village upper catchment	20/09/07
10	Mr. Eric Doodman and Stuart: proprietor Laurel Investments (New Holland Flowers) –upper catchment	20/09/07
11	Mr. Ireri Kinyua Vicent:- Fisheries Officer –Naivasha district	21/09/07
12	Mr. Kennedy Abwao-Journalist Pan African News Agency	22/09/07
13	Mr. Nyaga Ndonga-Gen secretary 3M Water Association. –upper catchment	22/09/07
14	Mr. Mwaniki Joguna-Chariman; Mkungi/Kitiri WRUA.	23/09/07
15	Mr. Jack Kagwira Kamau-Member Mkungi/Kitiri WRUA.	23/09/07
16	Load Andrew Ennis Killen-Chairman LNMIC/LNRA	24/09/07
17	Ms. Sunita Sarkar Executive Officer LNGG	24/09/07
18	Mr. Mwirikia Jeffrey-Chairman Mr. Gadura M John-Vice Chairman Mr. Ewoyi Andrew-Secretary Mr. Chege Samuel-Member; Kamere landing site: Kamere beach management Unit (BMU)	28/09/07
19	Mr John Mwakamba, Head Naivasha WRMA	30/09/07
20	Mr. Olekwisamau Andrew:- Coordinator, Centre for Pastoralist Development.	04/10/07
21	Mr. Thuo Stephen:-Naivasha Municipal council	04/10/07

Appendix II Naivasha basin population data

	Sublocation	Location	Division	District	Area_km2	Density	Population (people)			
							1999	2006	2016	2031
1	Kamae	Kamae	Lari	Kiambu	0.02	109.63	2	2	3	4
2	Gilgil	Gilgil	Gilgil	Nakuru	21.06	780.15	16,430	20,045	24,645	31,381
3	Eburru	Gilgil	Gilgil	Nakuru	105.12	24.36	2,560	3,124	3,840	4,890
4	Olkaria	Hell's Gate	Naivasha	Nakuru	151.66	62.89	9,538	11,637	14,308	18,218
5	Mirera	Hell's Gate	Naivasha	Nakuru	95.64	209.85	20,070	24,486	30,106	38,335
6	Karunga	Karunga	Gilgil	Nakuru	135.93	107.22	14,574	17,781	21,862	27,837
7	Kiambogo	Kiambogo	Gilgil	Nakuru	7.44	102.04	759	926	1,139	1,450
8	Kongasis	Kiambogo	Gilgil	Nakuru	3.36	46.17	155	189	233	296
9	Longonot	Longonot	Naivasha	Nakuru	37.55	58.98	2,215	2,702	3,322	4,230
10	Kongoni	Maiella	Naivasha	Nakuru	76.08	34.62	2,634	3,213	3,951	5,030
11	Maiella	Maiella	Naivasha	Nakuru	28.83	196.75	5,672	6,920	8,508	10,834
12	Tarambete	Malewa	Naivasha	Nakuru	72.56	80.94	5,873	7,165	8,809	11,217
13	Karati	Malewa	Naivasha	Nakuru	141.53	198.89	28,149	34,341	42,223	53,764
14	Moindabi	Moindabi	Naivasha	Nakuru	34.22	91.94	3,146	3,838	4,719	6,009
15	Kipkonyo	Moindabi	Naivasha	Nakuru	66.72	28.34	1,891	2,307	2,836	3,611
16	Maraigushu	Naivasha Ea	Naivasha	Nakuru	59.55	196.83	11,721	14,300	17,582	22,388
17	Mununga	Naivasha Ea	Naivasha	Nakuru	58.43	170.72	9,975	12,170	14,963	19,052
18	Lake View	Naivasha To	Naivasha	Nakuru	18.15	430.6	7,815	9,535	11,723	14,928
19	Sokoni	Naivasha To	Naivasha	Nakuru	59.37	493.74	29,313	35,762	43,970	55,989
							172,494	**210,442**	**258,741**	**329,463**
20	Olkinyei	Entontol	Mau	Narok	0.08	43.38	3	4	5	7
21	Parkarara	Olchorro	Mau	Narok	1.08	43.89	47	58	71	90
22	Olchorro	Olchorro	Mau	Narok	5.62	42.51	239	291	356	454
23	Topoti	Olorropil	Olokurto	Narok	17.14	23.73	407	496	606	773
24	Sakutiek	Upper Meli	Mau	Narok	15.08	78.43	1,183	1,443	1,762	2,247
25	Enaibor Aji	Upper Meli	Mau	Narok	81.6	36.55	2,982	3,639	4,444	5,667
							4,862	**5,931**	**7,244**	**9,237**
26	Murungaru	Engineer	North Kinar	Nyandarua	72.62	159.72	11,599	13,803	15,775	17,863
27	Gathara	Engineer	North Kinar	Nyandarua	64.47	141.05	9,094	10,821	12,367	14,004
28	Kahuru/mur	Engineer	North Kinar	Nyandarua	95.39	158.01	15,073	17,936	20,499	23,212
29	Kiambogo	Geta	Kipipiri	Nyandarua	15.77	289.94	4,572	5,441	6,218	7,041
30	Makumbi	Geta	Kipipiri	Nyandarua	9.97	468.8	4,674	5,562	6,357	7,198
31	Geta	Geta	Kipipiri	Nyandarua	20.33	269.9	5,487	6,530	7,462	8,450
32	Mikeu	Geta	Kipipiri	Nyandarua	18.42	257.14	4,736	5,636	6,442	7,294
33	Gichungo	Kaimbaga	Ol Kalou	Nyandarua	47.56	184.37	8,769	10,435	11,925	13,504
34	Kandutura	Kiambaga	Ol Kalou	Nyandarua	64.24	84.02	5,397	6,423	7,340	8,312
36	Githioro	Kipipiri	Kipipiri	Nyandarua	85.01	105.61	8,978	10,684	12,210	13,826
37	Miharati	Kipipiri	Kipipiri	Nyandarua	58.21	160.48	9,342	11,116	12,705	14,386
38	Kiriko	Lereshwa	Kipipiri	Nyandarua	66.91	90.86	6,079	7,235	8,268	9,362
39	Lereshwa	Lereshwa	Kipipiri	Nyandarua	28.25	164.75	4,654	5,539	6,330	7,168
40	Bamboo	Magumu	South Kinar	Nyandarua	3.14	463.83	1,456	1,733	1,981	2,243
41	Malewa	Malewa	Kipipiri	Nyandarua	40.41	138.49	5,597	6,660	7,611	8,619
42	Ndemi	Malewa	Kipipiri	Nyandarua	52.56	122.64	6,446	7,671	8,767	9,927
43	Karati	Mugumo	South Kinar	Nyandarua	29.49	48.21	1,422	1,692	1,934	2,189
44	Matura	Mugumo	South Kinar	Nyandarua	13.94	281.49	3,924	4,670	5,337	6,043
46	Ndabibi	Ndabibi	Naivasha	Nyandarua	120.02	30.04	3,606	4,291	4,904	5,553
47	Matindiri	Ndundori	Ol Kalou	Nyandarua	27.02	110.04	2,973	3,538	4,044	4,579
48	Melangine	Ndundori	Ol Kalou	Nyandarua	17.61	261.13	4,598	5,472	6,254	7,082
49	Ruiru	Ndundori	Ol Kalou	Nyandarua	4.61	230	1,060	1,262	1,442	1,633
50	Sabugo	Ndundori	Ol Kalou	Nyandarua	3.58	407.62	1,459	1,737	1,985	2,247
51	Tulaga	Njabini	South Kinar	Nyandarua	19.37	108.49	2,101	2,501	2,858	3,236
52	Muruaki	Njabini	South Kinar	Nyandarua	22.98	247.02	5,677	6,755	7,720	8,742
53	Mekaro	North Kinar	North Kinar	Nyandarua	61.08	47.91	2,926	3,482	3,980	4,506
54	Nandarasi	North Kinar	North Kinar	Nyandarua	44.83	209.49	9,391	11,176	12,772	14,463
55	Kinja	North Kinar	North Kinar	Nyandarua	40.24	197.46	7,946	9,455	10,806	12,236
56	Mkungi	North Kinar	North Kinar	Nyandarua	30.51	204.51	6,240	7,425	8,486	9,609
57	Kitiri	North Kinar	North Kinar	Nyandarua	57.73	72.33	4,176	4,969	5,679	6,431
58	Koinange	Nyakio	South Kinar	Nyandarua	25.22	184.94	4,664	5,550	6,343	7,183
59	Karangathi	Nyakio	South Kinar	Nyandarua	0.29	537.21	156	185	212	240
60	Gathambi	Nyakio	South Kinar	Nyandarua	15.33	98.14	1,505	1,790	2,046	2,317
61	Mukeu	Nyakio	South Kinar	Nyandarua	0.28	296.1	83	99	113	128
62	Nyairoko	Ol Joro Oro	Ol Joro Oro	Nyandarua	4.66	80.05	373	444	507	574
63	Oraimutia	Ol Joro Oro	Ol Joro Oro	Nyandarua	0.02	79.38	2	2	2	2
64	Mawingo	Ol Kalou	Ol Kalou	Nyandarua	50.73	103.94	5,273	6,275	7,171	8,120
65	Munyeki	Ol Kalou	Ol Kalou	Nyandarua	51.41	155.53	7,996	9,515	10,874	12,313
66	Passenga	Rurii	Ol Kalou	Nyandarua	22.54	105.99	2,389	2,843	3,249	3,679
67	Matura	Rurii	Ol Kalou	Nyandarua	26.04	237.85	6,194	7,370	8,423	9,538
68	Rurii	Rurii	Ol Kalou	Nyandarua	46.22	130.02	6,009	7,151	8,173	9,254
71	Kanjuiri	Tumaini	Ol Kalou	Nyandarua	41.04	103.53	4,249	5,056	5,778	6,543
72	Upper Gilgi	Tumaini	Ol Kalou	Nyandarua	22.11	108.05	2,389	2,843	3,249	3,679
73	Gatondo	Wanjohi	Kipipiri	Nyandarua	49.42	71.52	3,534	4,206	4,807	5,443
74	Rironi	Wanjohi	Kipipiri	Nyandarua	30.34	98.36	2,984	3,551	4,058	4,596
75	Wanjohi	Wanjohi	Kipipiri	Nyandarua	66.62	173.83	11,581	13,781	15,750	17,834
76	Weru	Weru	Ol Joro Oro	Nyandarua	0.06	108.86	7	8	9	10
							228,839	**272,318**	**311,221**	**352,411**
77	Abergare Fo	Aberdare Fo	Aberdare Fo	Nyeri	1.22	0.17	0	0	0	0
Totals					**2983.64**	**272.28117**	**812,389**	**977,383**	**1,154,411**	**1,382,224**

Appendix 3: Monthly abstraction data

2003

Ha irrig	January	February	March	April	May	June	July	August	September	October	November	December	Total
19.3	13643	15349	16834	11981	8859	11065	13111	10390	12974	12814	11264	15066	153350
23.3	99722	100913	102110	103669	98762	92469	102295	84324	92927	90305	98182	90000	1155678
55	18311	38267	35978	21107	6948	33669	15974	13390	35890	21913	17565	20000	279012
100	363896	469140	568750	424810	234720	516229	524000	437100	537810	519740	376263	400000	5372458
3.7	5440	4550	4190	4710	3259	4620	1870	3110	5190	6640	4890	5730	54199
1.5	1195	2651	2249	1404	597	1194	2087	714	1160	1419	1799	2541	19010
23	46889	40023	43411	33593	39752	39357	39095	37331	50000	55591	44914	52265	522221
7	11927	10914	13330	10620	11000	10000	10414	9860	14018	14629	8560	10913	136185
10	3792	6290	8881	6723	1650	2798	4032	3217	6927	5588	2046	6409	58353
3	1163	1214	1356	1152	692	1015	1585	1467	1600	1945	1370	1648	16207
100	166746	179703	12134	124828	80307	145068	11992	132509	165175	178726	162090	202146	1561424
21	41932	47109	39277	38274	41241	41558	42929	38707	42000	37030	40628	46312	496997
7.3	6570	6570	6570	6570	6570	6570	6570	6570	6000	6000	6000	6000	76560
16	30712	25269	37126	22160	11066	25820	22999	21045	28095	27316	20053	50569	322230
160	206984	268614	336025	254377	203627	233291	124572	156670	148944	155802	127816	120000	2336722
2	683	1036	1287	988	747	973	719	293	951	958	1143	1769	11547
12	17634	15963	11596	5534	4432	6407	9162	12650	13501	13000	13000	13000	135879
136	20000	20000	20000	20000	20000	72370	96890	58080	126190	134060	182460	154750	924800
10	12562	14173	11860	8216	563	891	169	200	2284	862	1528	1205	54513
35.6	33095	34555	39420	28044	19151	33492	40890	24363	51153	41046	31367	41622	418198
745.7	**1E+06**	**1302303**	**1E+06**	**1E+06**	**793943**	**1E+06**	**1071355**	**1051990**	**1342789**	**1325384**	**1152938**	**1241945**	**1.4E+07**
460	370425	370425	370425	370425	370425	370425	370425	370425	370425	370425	370425	370425	4445100
1205.7	1473321	1672728	1682809	1499185	1164368	1649281	1441780	1422415	1713214	1695809	1523363	1612370	18550643
	59000	59000	59000	59000	59000	59000	59000	59000	59000	59000	59000	59000	708000

2004

Irrig. ha	January	February	March	April	May	June	July	August	September	October	November	December	Total
19.3	14,733	12,872	14,975	8,747	8,034	10,047	12,086	12,063	11,165	9,069	7,491	10,227	131509
4.4	5,580	6,210	5,160	2,740	2,340	2,240	3,140	4,510	4,850	4,500	3,940	4,290	49500
23.3	55,162	47,598	47,010	26,918	40,571	44,958	51,876	48,310	48,809	52,245	39,881	50,927	554265
19	50070	57390	53270	48990	47800	17,720	44,980	48,120	47,870	43,890	34,150	31,480	525730
55	24,946	24,721	33,159	6,303	20,158	15,073	27,853	23,524	15,955	23,634	18,399	18,656	252381
100	536,630	391,110	388,470	264,690	521,030	657,470	445,310	586,080	689,330	486,500	222,440	319,780	5508840
1.5	1,841	2,403	2,065	376	2,300	2,326	2,300	2,300	2,300	2,300	2,300	2,300	25111
23	2,967	2,161	2,272	1,253	1,666	2,092	2,686	3,318	2,608	1,910	1,697	2,156	26786
7	15,498	12,215	14,732	10,990	10,350	10,789	15,712	16,726	17,307	18,568	15,857	18,849	177593
12.8	7,205	66,648	2,199	2,149	2,491	4,422	35,288	5,255	4,969	6,360	8,664	7,118	152768
3	1,555	1,251	1,311	896	1,169	1,596	1,660	1,586	1,395	1,392	626	1,368	15805
100	177,795	236,200	140,890	45,580	164,810	221,190	228,310	222,460	108,270	45,750	133,290	182,880	1907425
21	52,138	49,012	49,585	37,082	46,320	48,634	45,630	47,221	40,960	42,045	48,590	48,590	555807
16	27,490	23,915	21,148	4,527	18,638	21,605	21,415	27,367	23,188	24,026	21,621	23,667	258607
160	241,539	305,559	271,595	237,582	259,592	230,427	300,335	295,391	314,270	332,972	248,260	340,469	3377991
3	2,239	2,153	2,136	1,455	2,015	1,707	2,300	2,086	1,668	2,345.91	2,152.30	1,948.50	24203.67
12	16,381	16,098	9,927	11,646	12,412	12,001	14,082	17,157	16,652	14,087	12,578	15,466	168487
136	281,710	189,320	201,360	132,800	135,020	244,610	257,310	235,780	222,710	255,120	222,710	270,420	2648870
10	893.5	3,144.60	4,384.90	20,966.60	3,995.60	4,552.30	4,677.40	4,581.50	2,409.80	2,160.20	1,455.90	1,443.80	54666.1
35.6	44,314	46,385	43,083	36,742	43,400	42,000	43,200	43,200.00	42,000.00	55,506.90	43,857.70	49,407	533095.6

761.9	**1,560,687**	**1,496,366**	**1,308,732**	**902,432**	**1,344,111**	**1,595,459**	**1,560,150**	**1,647,035**	**1,618,685**	**1,424,381**	**1,089,960**	**1,401,442**	**16,949,440**

2005

Irrig. ha	January	February	March	April	May	June	July	August	September	October	November	December	Total
19.3	12,652	12,916	13,595	11,861	8,794	8,968	12,211	12,531	9,587	8,226	7,224	10,805	129,370
4.4	3,290	2,720	2,250	2,720	2,710	2,890	2,720	2,470	3,500	4,690	3122.686567	4,910	37,993
23.3	57,625	61,159	63,397	54,696	44,637	51,200	51,193	60,705	57,472	53,829	65,348	68,145	689,406
19	50,070	57,390	53,270	48,990	47,800	46,470	42,320	47,750	59,190	65,330	64,970	73,760	657,310
55	31,319	19,212	32,650	21,971	17,389	21,677	32,628	22,070	9,807	25,610	18,670	39,439	292,442
100	379,940	426,100	487,300	411,180	413,500	318,660	299,840	272,830	187,680	155,960	142,900	138,670	3,634,560
1.5	1090.142857	1090.142857	133	326	1090.142857	1090.142857	1090.142857	1,094	988	1,673	1,461	1,956	13,082
23	2,374	2,492	3,367	3,305	2,118	3,829	4,621	4,209	3,584	3,976	3399.402985	4,085	41,359
7	20,356	21,465	14,341	14,105	11,426	11,168	9,538	13792.02985	10,199	14,057	13,632	13,724	167,803
12.75	9,783	11,332	6,827	4,993	2,913	4,732	3,690	3,668	4,085	4,807	4,617	7,820	69,267
3	1,516	1,683	1,346	1,132	1,205	1,205	1,472	1,546	1,352	4,481	1,339	1,700	19,977
100	175,420	184,040	144,340	143,580	108,930	152,210	164,900	119,390	137,790	131,600	148,680	162,570	1,773,450
21	58,191	49,774	51,870	49,162	47,550	45,560	49,409	57,678	56,842	59,021	51704.14925	52,306	629,067
16	30,163	33,395	32,557	24,675	21,688	25,768	28,284.50	28,926	20,601	31,271	26,439	31,274	335,042
160	381,807	382,071	403,058	383,916	301,569	392,967	417,016	410,206	372,279	364,604	353,609	452,804	4,615,906
3	1,170.79	997.27	1,014.01	742.7	746	715	827.6	829.7	805	2,390	1,241	1075.4	12,554
12	14,440	13,519	13,236	10,693	9,101	11,717	13,648	17,219	16,663	16,573	14,267	18,623	169,699
136	294,670.00	226,180	164,650	174,460	138,460	32,010	72,100	161,000	155,460	261,720	254,840	251,700	2,187,250
16.71	2,056	2,208.60	2,167.20	1,555	1,249	1,847	1,991.20	1,941	1,944	2,238	1,581.00	2091	22,869
35.6	64,816.60	62,814.10	61,352	60,419	49,436	67,035.70	55,752	60232.2	60232.2	60232.2	60232.2	60232.2	722,786
768.56	**1,592,750**	**1,572,558**	**1,552,720**	**1,424,482**	**1,232,311**	**1,201,719**	**1,265,251**	**1,300,087**	**1,170,060**	**1,272,288**	**1,239,276**	**1,397,690**	**16,221,192**

2006

Irrig. ha	January	February	March	April	May	June	July	August	September	October	November	December	Total
12.14	12,981.20	10,997.50	8,245.50	7,060.50	8,496.50	11,007.00	11,028.50	11,206.50	12,907.50	13,082.00	64,985.00	6,895.00	178,892.70
4.4	8,130.00	6,200.00	7,040.00	5,110.00	3,430.00	3,400.00	5,050.00	6,430.00	3,500.00	4,690.00	3,122.69	4910	61,012.69
23.3	121,147.00	97,228.00	105,317.00	93,716.00	113,204.00	114,814.00	103,671.00	106,738.00	104,818.00	106,561.00	73,894.00	84,100.00	1,225,208.00
19	69,440.00	51,640.00	51,710.00	38,740.00	38,290.00	40,740.00	35,620.00	40,750.00	43,270.00	43,420.00	31,650.00	34,610.00	519,880.00
55	38,759.00	44,536.00	24,401.00	18,693.00	10,260.00	50,614.00	30,868.00	30,318.00	29,865.00	34,127.00	33,448.00	10,996.00	356,885.00
100	163,900.00	170,700.00	120,000.00	127,900.00	128,500.00	169,800.00	141,500.00	159,000.00	152,800.00	166,000.00	86,500.00	106,300.00	1,692,900.00
1.5	1,499.00	1,904.00	154.00	777.22	250.00	554.00	973.00	1,081.00	933.00	1,116.00	77.00	138.00	9,456.22
23	4,542.00	3,665.00	2,181.00	2,022.00	2,164.00	3,649.00	3,963.00	3,361.00	3,488.00	3,676.00	2,006.00	1,608.00	36,325.00
7.2	11,464.00	10,957.00	9,582.00	8,243.00	8,388.00	8,743.00	7,059.00	7,806.00	9,382.00	9,073.00	6,471.00	6,056.00	103,224.00
12.75	5,330.00	3,818.00	2,314.00	893.00	2,771.00	6,034.00	5,538.00	6,631.00	4,079.00	8,778.00	2,636.00	2,478.00	51,300.00
2.43	1,758.00	1,493.00	1,079.00	1,038.00	1,163.00	1,607.00	1,812.00	1,575.00	1,472.00	1,496.00	1,191.00	1,190.00	16,874.00
120	161,290.00	167,170.00	75,510.00	64,770.00	101,060.00	138,240.00	146,580.00	142,390.00	125,880.00	163,070.00	66,580.00	92,570.00	1,445,110.00
21	55,104.00	47,802.00	51,551.00	49,567.00	48,915.00	44,800.00	46,895.00	45,360.00	47,299.00	51,021.00	46,291.00	43,759.00	578,364.00
16	31,869.00	25,134.00	18,498.00	11,851.00	13,798.00	28,107.00	23,078.00	19,265.00	28,794.00	31,624.00	15,340.00	16,135.00	263,493.00
160	487,443.00	470,379.00	412,516.00	360,249.00	371,627.00	352,310.00	453,818.00	438,617.00	477,401.00	509,792.00	291,661.00	303,873.00	4,929,686.00
3	1,035.00	1,147.00	1,001.50	539.20	489.50	502.25	558.60	795.20	564.80	812.80	258.70	464.70	8,169.25
10	16,336.00	37,714.00	33,218.00	10,693.00	9,101.00	11,717.00	13,648.00	17,219.00	16,663.00	16,573.00	14,267.00	12,923.00	210,072.00
115	249,800.00	170,440.00	115,250.00	55,510.00	72,360.00	157,560.00	95,330.00	117,010.00	92,670.00	91,620.00	130,440.00	69,420.00	1,417,410.00
16.71	1,929.50	2,049.60	1,390.80	1,030.40	1,156.60	1,596.50	1,738.20	1,591.70	1,931.00	2,286.30	1,177.30	1,501.00	19,378.90

38.6	64,816.00	92,853.10	48,208.60	45,993.50	49,339.00	78,276.10	71,302.10	86,482.20	79,188.00	90,945.20	44,334.20	49,223.60	800,961.60
761.03	**1508572.7**	**1,417,827.20**	**1,089,167.40**	**904,395.82**	**984,762.60**	**1,224,070.85**	**1,200,030.40**	**1,243,626.60**	**1,236,905.30**	**1,349,763.30**	**916,329.89**	**849,150.30**	**13,924,602.36**