Environmental Effects of the Floricultural Industry on the Lake Naivasha Basin

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January 2007

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Acronyms

CAAC	Catchment Area Advisory Committee
DGIS	Netherlands Agency for International Cooperation
EC	Electrical Conductivity
GIS	Geographical Information System
GoK	Government of Kenya
HEEIS	Hydrological Environmental Economic Information System
HOA_REN	Horn of Africa Regional Environmental Network
ITC	International Institute for Geoinformation Science and Earth Observation
IWRM	Integrated Water Resources Management
KFC	Kenya Flower Counsel
KWS	Kenya Wildlife Services
LNGG	Lake Naivasha Growers Group
LNMIC	Lake Naivasha Management Implementation Committee
LNMP	Lake Naivasha Management Plan
LNRA	Lake Naivasha Riparian Association
LNROA	Lake Naivasha Riparian Owners Association (now LNRA)
LNWBM	lake Naivasha Water Balance Model
MCM	Million cubic meter
MODFLOW	Modular Flow, USGS groundwater flow model
NEMA	National Environmental Management Agency
NGO	Non Governmental Organization
SWAT	Soil Water Assessment Tool
SWD	Specific Water Demand
TDS	Total Dissolved Solids
USDA	United States Department for Agriculture
USGS	United States Geological Survey
WEAP	Water Evaluation And Planning system
WRMA	Water Resources Management Authority
WRUA	Water Resources Users Association
WWF	World Wide Fund for Nature

Objectives

To determine whether current levels of water use, abstraction, and pollution in the Lake Naivasha basin are sustainable or not.

General Setting

Lake Naivasha (0.45° S, 36.26° E), altitude 1,890 m above sea level, lies on the floor of Africa's Eastern Rift Valley, covering approximately 140 km^2. It is the second-largest freshwater lake in Kenya, and one of a series of 23 major lakes in the East Rift Valley—8 in central Ethiopia, 8 in Kenya, and 7 in Tanzania—spanning latitudes from approximately 7° N to 5° S. The overall climate of the Eastern Rift Valley is semi-arid. The lake is fed by two perennial rivers, the Malewa and the Gilgil Rivers, discharging 80% and 20%, respectively, of the total inflow. The Karati River drains the area east of the lake, being ephemeral and flowing approximately 2 months per year. The area south of Lake Naivasha does not produce much runoff reaching the lake. The drainage from the Mau Hills and Eburu to the west infiltrates before it reaches the lake. About 25% of the surface water inflow recharges the aquifers and flows to the south and north. This outflow causes the lake to be fresh.

Concerns, issues, challenges, problems, misconceptions, and general consensus

Lake Naivasha receives a lot of local, national and international attention. This attention has lead to stakeholders expressing justified and substantiated concerns on the health of the lake as well as emotional speculations.

The main issues are:

- Reduction of lake levels
- Deterioration of water quality / Increase of nutrient inflow into the lake (eutrophication)
- Reduction of biodiversity
- Deforestation in the upper basin and the effect on the lake. (both in terms of water and sediment yield)
- Reduction of the area under papyrus
- Decrease in fish yield
- Increase in population and unplanned settlements
- Waste disposal from agriculture and settlements
- Access to the lake by fishermen and Masai. (Most of the riparian land his privately held)
- Effect of the geothermal plant on the lake
- Human rights, health, working conditions, salary of the farm workers.

Interestingly, the scope of concern has shifted over time. In the 1990's the main concern was the lowering of the lake levels. At the end of the 1990's and early 21st century fishing received a lot of attention. Lately, the land access issue is high on the agenda.

The general consensus of the local population is rather negative and the national media play an important role feeding these negative sentiments.
In a nutshell: *"the large flower farms empty the lake, pollute the water and environment, destroy the papyrus, and thus there is no fish left in the lake, and biodiversity is seriously affected. They also block access to the lake and exploit their workers who will die from working with toxic chemicals".*

Reality is less negative and above all much more complex.
The reduction in lake levels can definitely to a large extent be attributed to the large scale irrigation around the lake. However, the increased inflow of sediments and nutrients are mainly caused by the population in the upper catchment.

The reduction in biodiversity is a very complex issue. The large areas of irrigated agriculture and greenhouses do affect the biodiversity and the beauty of the area. However, reduction in biodiversity in the lake is mainly attributed to the introduction of alien species and increased nutrient loads from the upper catchment causing some eutrophication. The benthic flora (macrophytes) is reduced to zero through the combined affect of the crayfish and the reduced light penetration. The reduced light penetration is caused by the eutrophication and increased sediment inflow, the dredging of the common carp in the unprotected lake bottom. The absence of macrophytes reduces the hiding places for the fry.

The main reduction of the papyrus took place decades ago. Definitely, a few farms have destroyed the papyrus but the main cause of destruction can not be attributed to the flower farms. The main destruction took place in colonial days when the papyrus swamp was converted to agricultural land. More recently, the area has been relatively constant and pressure on papyrus is a combination of natural (lake level variation, hippopotamus) and human effect. The reduced fish yields are mainly attributed to over fishing and a changing aquatic habitat. Birds surviving on fish are affected because there is less fish to catch and the reduced transparency of the makes it more difficult to spot and catch the fish.

A booming economy always attracts people looking for employments and usually goes together with bad housing conditions, exploitation, and social friction. Here Kenya is no exception from Europe.

The organizations involved in the management of the lake had the tendency to concentrate on non-issues like pumice quarries, power lines over open roses, a small dike retaining water, the conservation of Eburru forest with no runoff to the lake, the access to the lake, the ban on crayfish fishing (crayfish caused a lot of ecological damage), instead of concentrating on the important issues like water abstraction and agrochemical loads.

History of stakeholder involvements around Lake Naivasha

In colonial days, large cattle ranches occupied the bottom of the Rift Valley. There was a large sisal plantation located south of Lake Naivasha. The lake water was used only to irrigate small acreages of fodder crops, provide water for cattle, and grow vegetables. Large areas of papyrus were cleared and converted into agricultural land.

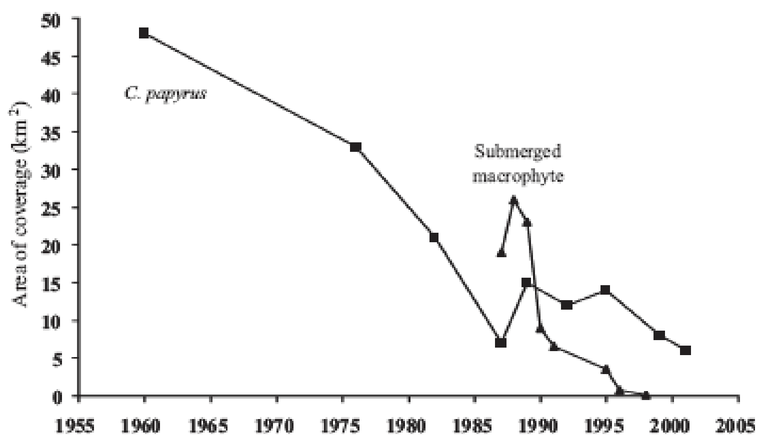


Figure 1 Papyrus and submerged macrophytes (Hickley, 2004)

Water levels receded between the 1930s and 1950s, when the Colonial Government was reluctant to approve water abstraction permits. In 1929, Naivasha landowners organized themselves into the Lake Naivasha Riparian Owners Association (LNROA). The land below the arbitrary chosen lake level of 6,210 ft above sea level (1, 892.8 m above sea level) was put into the custody of the landowners in 1933, under the LNROA, although no permanent structures were allowed to be built on this land. This proved to be a wise move, since it has protected the riparian/shore line from degradation. In the late 1950s, when the lake water levels started to rise, after a couple of decades of falling levels, the Administration began designing complex diversion schemes. Water was to be transferred to Lake Elmenteita to the north, and to Kedong valley to the south. Fortunately, these plans never came to fruition. Around 1990, the LNROA became more proactive and, in 1998, changed its name to the Lake Naivasha Riparian Association (LNRA) and opened itself to a wider membership by instituting associate membership. In 1999, the LNRA's 70th anniversary, the organization received the prestigious Ramsar Wetland Conservation Award in the NGO category for its conservation work on the lake.

The first large abstraction of the lake occurred when a pipeline from the Naivasha basin to Gilgil and Nakuru Town became operational in 1992. During the 1970s, there was little irrigation, and mainly fodder crops. In the early 1980s, however, one vegetable grower decided to switch crops to the production of cut flowers. This decision has profoundly changed the rules of the game. The permeable and fertile soils, low rainfall, reliable supply of good quality water, good climatic conditions, availability of cheap labor, and easy access to Nairobi Airport, are the ingredients of a booming flower-dominated horticultural industry around the shores of the lake. Since the first flower farms started in the early 1980s, there has been a fairly constant increase in the area under flowers. In the late-1990s, the flower farms started to mushroom; this process is still continuing, causing considerable concern regarding whether or not the lake can sustain this increase.

The horticultural developments caused a shift in the landownership and population around the lake. Before the horticultural developments, the population was comprised mainly of people born along the lake shores, or who were attracted by its peace and beauty. Since the 1980s, entrepreneurs have moved in, bought or rented land, and started growing commercial flowers for export. Those who had lived all or most of their lives in Naivasha however, realized that the paradise might be lost if the lake was not properly managed. The LNRA became the vehicle that started the lake management process in the late 1980s. The energy, diplomacy and stamina of two LNRA members and the Chairman and Honorary Secretary have been instrumental in starting and continuing this process. During this period, a rather dormant stakeholder organization with a long colonial history was transformed into an active organization interested in the sustainable development of the lake. The LNRA started sensitizing their members and others on environmental issues, compiled and summarized research that had been carried out over the years into one document (Goldson, 1993), encouraged researchers to investigate the lake, started to develop a management plan and sectoral codes of conduct, and started to network and lobby in order to achieve their goals, with the old riparian agreement becoming a powerful instrument for protecting the government-owned riparian zone.

The large commercial growers felt that the direction the LNRA had taken was not consistent with their commercial interests. As a result, a small group of large flower farms established the Lake Naivasha Growers Group (LNGG). Conflicts between LNRA and LNGG arose and were subsequently reconciled, which is all part of the consensus-building process and movement toward a more institutionalized form of management, with the result being that both groups are now working together for the benefit of the lake and the economy. The first important achievement in this process was the designation of Lake Naivasha as a Ramsar site in 1995. As a result, the Kenya Wildlife Services (KWS), the custodian of Kenyan Ramsar sites, became an important and influential partner with the LNRA. In 1996, the stakeholders agreed on the Management Plan, with the Government of Kenya officially approving it. This was the start of the implementation phase of the Plan. The Lake Naivasha Management Implementation Committee (LNMIC) was then formed, being the body to execute the plan, drawing its members from various relevant government and non-government stakeholder organizations[1]. The LNMIC has no executive powers, and no budget allocated to it. It has to work through, and with, official government institutions with some limited support of wetlands-oriented projects and NGOs. The Management Plan was approved by the District Environment Committee in April 2002 and forwarded to NEMA for gazettement. In 2004 The Lake Naivasha Management Plan (LNMP) was approved by a stakeholder's forum convened by the National Environment Management Authority and the Public Complaints Committee. However, some

[1] Membership list in annex 5

stakeholders raised objections particularly stating their exclusion in the implementation process and challenged the Plan in court. The case is still in court inhibiting the implementation of the Plan.

The Lake Naivasha Management Plan and the LNMIC who are to implement the plan are closely linked to NEMA. NEMA is a compliance agency with no executing powers. The factors mentioned above weaken the present status of the Management Plan developed by the LNRA.

In the meantime the water sector (reform) was heavily supported by several donors and the WRMA have become operational. Lake Naivasha falls under the Rift Valley-WRMA, the Rift Valley Catchment Area Advisory Committee (CAAC) and the Naivasha Water Resources Users Association (WRUA). The LNGG is likely to become a member of the LN-WRUA looking after the interest of the large flower producers.

The Netherlands Government (NG), for several reasons, has an interest to support management of the basin. The Naivasha-Elementeita-Nakuru (NEN) basin would serve as a pilot basin of IWRM under the WRMA with strong links to research and educational institutes. The Netherlands Government is not impressed by the progress in fighting corruption and increasing transparency by the GoK, and has therefore shelved all (direct) assistance to Kenya in April 2006.

Some Netherlands funds are still flowing towards the Naivasha Basin. The WWF-NL Naivasha projects receive a considerable amount of funding through the Dutch Agency of International Assistance (DGIS) and Naivasha is also a focal area under the NL-financed Horn of Africa Regional Environmental Network (HoA-REN). In this final stage of the developments around Lake Naivasha, the East Africa Regional Office of WWF proposed an ambitious programme to start implementing IWRM principles.

Hydrology

The total available amount of water is determined by the rainfall over the whole catchment. The bulk of the water falls in the higher parts of the catchment. A large part of this water is used by vegetation (evapotranspiration) and the excess flows into Lake Naivasha. During very intense storms some direct run-off from the area surrounding the lake flows 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 water (again) to the deep (geothermal) aquifer system. This deep groundwater can not disappear. The water escapes from the deep aquifer in the form of steam (fumaroles) and recharges lakes Magadi, Elementeita and Bogoria. Of course by far the largest water consumer is the lake itself (evaporation).

The lake is fed by two perennial rivers, the Malewa and the Gilgil, discharging 80% and 20%, of the total inflow. The Karati, drains the area east of the Lake is ephemeral and flows approximately 2 months per year. The area South of lake Naivasha does not produce much runoff reaching the lake. To the west the drainage from the Mau Hills and Eburu infiltrates before it reaches the lake. Both the Malewa and the Gilgil yield water of excellent quality. The Electric Conductivity (EC), a proxy for Total Dissolved Solids (TDS), may change very rapidly in a few hours but the mean EC for both rivers is around 100 μS/cm. Like all natural water in the area the sodium content is relatively high. The lake fills a shallow depression with gentle slopes. Therefore the area and the evaporation increases with rising lake levels. The lake shows a very dynamic behaviour that is shown in the figure 2 as well as water levels calculated from hydro-meteorological data. The variation of the lake levels over the last 100 years was some 12 meters.. Figure 2 shows clearly that rainfall is the driving force behind the variation of lake levels.

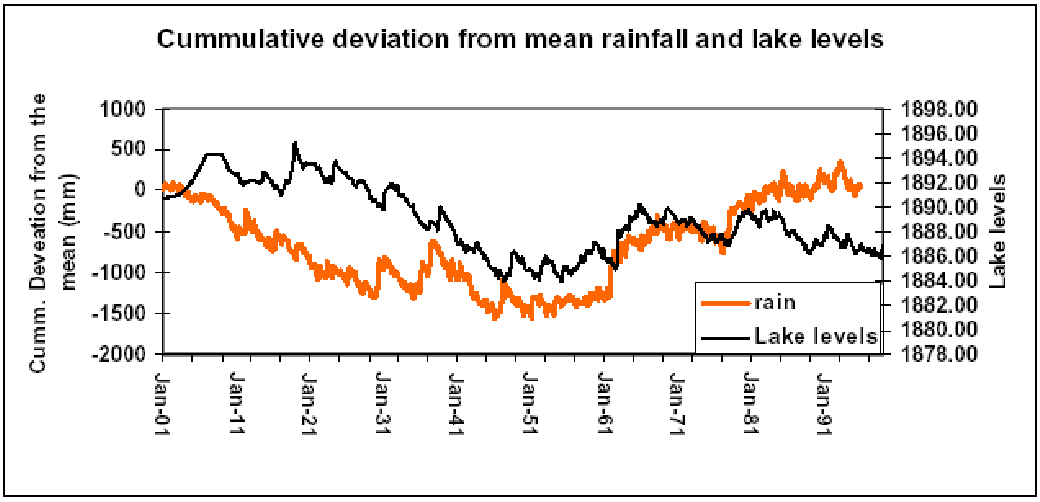


Figure 2 Cumulative deviation of the mean rainfall and lake levels (1900-2000)

The fluctuations of the lake levels have attracted the interest of both scientists and water managers. In 1948, Mr. Tetley, an Hydraulic Engineer in Nairobi wrote: " The lake reached its next highest peak in 1917 and since that year (1917) to April 1946 the level had a drop of about 37 feet; its area shrank from say 86 square miles to less than 33 square miles and it lost about fifteen sixteenth of the volume of water all in 29 years". Verschuren (2000) has studied the lake levels over the past 1000 years and has identified 4 periods where the lake went (almost) dry but also periods with higher levels than present.

Lake Naivasha actually consists of three lakes. The Crescent Lake which is the deepest part of the lake (18m depth) can be connected to the main lake depending on lake levels. Oloiden is a smaller lake at the south end of the Lake and depending on lake levels can be distinct from the main lake. The Crater Lake or Sonachi is located on the southwestern part of the lake and is independent from the main lake. The main lake is shallow (max 8m). The lake has no surface outlet and still has good water quality with an EC of approximately 300 µS/cm. For a long time it has been recognized that only an underground outflow can explain the freshness of the lake. The groundwater levels and the isotopic composition of groundwater indicate that this flow is both to the North and to the South. A small part of the groundwater evaporates and will escape in the form of fumaroles in the geothermal areas; the remainder of the water is flowing into Lake Magadi and Lake Elementeita, or probably even further north to Baringo (Becht, 2005). One should realize that it takes 1000's of years before the water arrives at these lakes. The lake itself can be considered as a groundwater outcrop of a very good shallow aquifer that is draining into a deeper aquifer system, which is carrying the water towards the terminal lakes. In general the water flows away from the lake with the exception of the West where an inflow from the Ndabi plains exits.

A model simulating the monthly lake levels based on inflow, rain and evaporation records is operational for the period 1934 - 2000. The model is used to calculate the water balance for the period before the large-scale abstraction began (1934 – 1983).

Lake Naivasha water balance in MCM (10^6 m^3/month) 1934-1983			
Rain	Surface water inflow	Evaporation	Groundwater outflow
95	220	260	55

Table 1 The long-term water balance (without irrigation from 1934-1983.

The model shows the effect of the abstractions during the period 1980 - 2000 (Figure 3). The model is also used to estimate the total abstraction from the lake basin (60 million m^3)

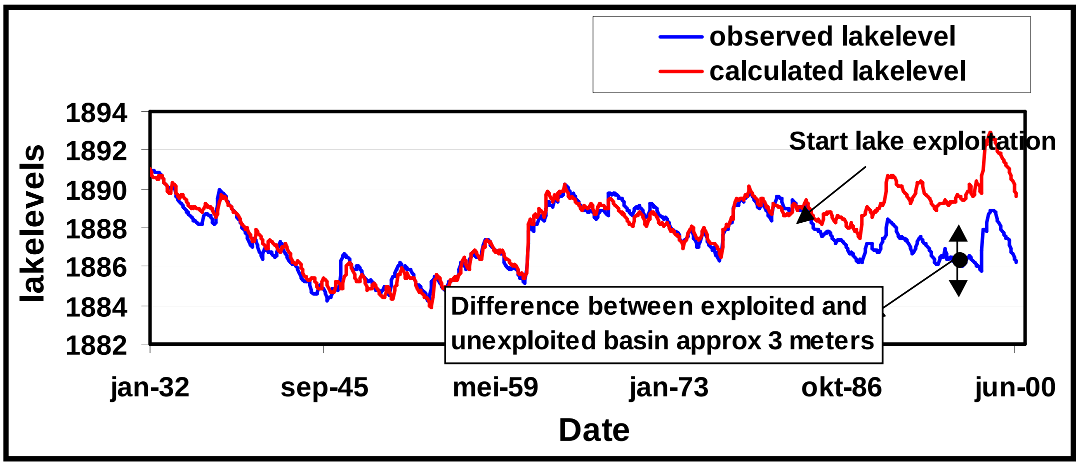


Figure 3 Simulated and measured lake levels

Figure 4 shows the result of a scenario: the total abstraction 60 $Mm^3$is imposed on the model since 1934. It is evident that the lakes goes almost dry As shown in figure 2 and 3 we have been experiencing a rather wet period over the last 40 years. If a prolonged draught like in the period 1930-1950 would occur again the water resources of the basin would become critically low.

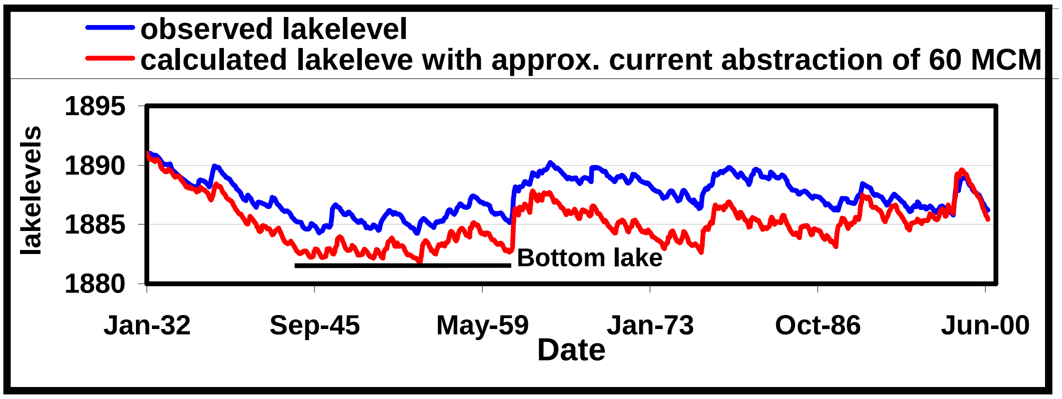


Figure 4: Simulated lake levels with 60 Mm^3abstraction

The long term simulation presented in figure 3 shows that the sustainable exploitation of the lake in terms of quantity is rather more a societal and political issue than a hydrological issue. The water balance of the lake is well established. It is relatively easy to calculate the drop in the water table due to a certain amount of abstraction. With a certain constant rate of abstraction the lake will establish a new equilibrium lake level, which as such is sustainable. In the case discussed above, this equilibrium is 3 meters lower than a natural (no abstraction) level (see fig 3). It is to the Kenyan decision-makers, society, and politicians to decide how much a drop in the water level is acceptable.

The more fundamental question, and in analogy with "environmental flow", is how large is the "environmental volume" can not be answered (yet). In other words, what is the minimum mean volume of the ecological poor lake to function as a life support system for the riparian (Ramsar) zone.

The overall basin water balance

A water balance describes water fluxes. In the case of a steady-state system (no time and storage considered), the average Naivasha basin water balance for a time interval can be formulated as:

> Vrain - Vevapotranspiration - Vlake_evaporation – Vgroundwater – Vnet_abstraction+Vstorage_change=0

Where,

> Vrain: Volume of rain=basin area * average basin average rainfall (m^3)
> Vevapotranspiration: volume of evapotranspired water from land surface= (basin area – average lake area)* average lake evaporation (m^3)
> Vlake_evaporation= Volume of evaporated lake water=average lake area* average rainfall on lake (m^3)
> Vgroundwater: groundwater outflow from the basin towards the North and the South (m^3).
> Vnet_abstraction: the volume abstracted minus the return flow (m^3)
> Vstorage_change: the change in storage (lake, soilmoisture, groundwater) (m^3) is assumed to be zero.

Table 2 gives the overall basin budget based on Salah (1999) and Becht & Harper (2002)

	m^3*10^6	**fraction**
Basin Rainfall	2790	100.0%
Evapotranspiration from land	2573	92.2%
Lake evaporation	256	7.8%
Groundwater outflow	56	2.0%
Net abstraction	60	2.2%
Closing error**	-155	-5.6%

Table 2: Water balance of the Lake Naivasha Basin

*** the closing error may seem considerable but is due to the inaccuracy of the estimate of the basin rainfall and the change in storage; an increase of the rainfall estimate of 5.6% (2950) would be enough to reduce the closing error to zero.*

The overall water balance quantifies the long term fluxes that can be related to man-made stresses on the system. In this case the abstractions constitute 2% of the total inputs.

Water accounting

To refine the rough overall water balance, Salah (1999) follows the IWMI procedure of water accounting (Molden, et al, 1999). The definitions are taken from the IWMI website ((see Annex 1). The values are derived for the hydrological year 1996 (March 1996-March 1997).

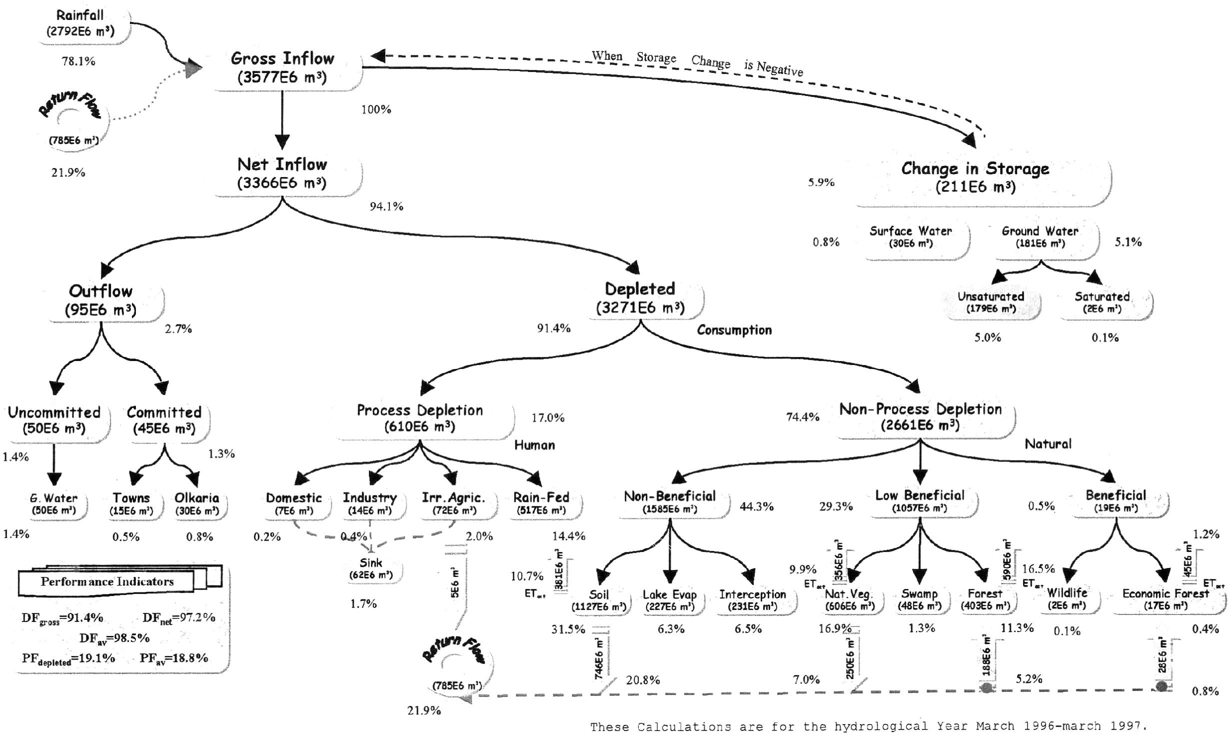


Figure 5: Water accounting framework based on IWMI

This water accounting framework (figure 5) may contain erroneous figures or assumptions (e.g the 30 Mm^3 committed to Olkaria is wrong) but gives a good overall picture of how the water is flowing through the system and how it is used.

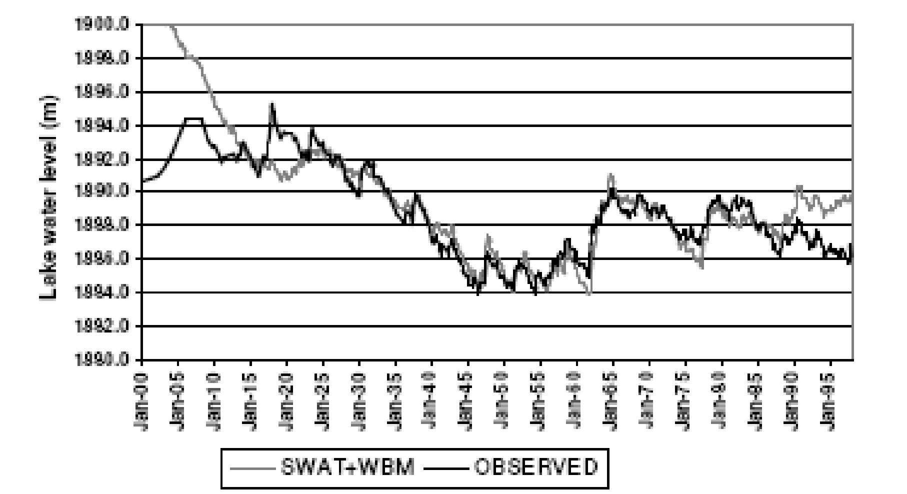
Detailed (sub) water balances and modeling

The overall water balances and water accounting schemes give a good overall picture. However, the large variability of fluxes in time and space are filtered out. Several more detailed water balances were made using surface water and groundwater models and water allocation models. The most important model results are discussed below.

1. The Lake Naivasha Water Balance Model (LNWBM) (Mmbuie,1999; Becht & Harper,2002). The LNWBM is discussed in detail in the references above. It models the lake levels based on river inflow, lake precipitation and evaporation. The LNBWM predicts lake levels very well as shown in the figure 3. The deviation between the modeled and measured water levels is attributed to the basin wide water abstractions. The LNWBM is very simple to use and can be used by a trained technician to run scenarios.

2. SWAT (Soil & Water Assessment Tool, developed by USDA)is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds http://www.brc.tamus.edu/swat/). The model has been calibrated for the period 1900-2000 (Muthawata, 2004). The output of the model is used as input to the LNWBM. The result is shown in fig 5. The reason to model rainfall runoff relationships is that the streamflow data are of poor quality during the period 1975-1995. This model runs on meteorological input data only. It clearly shows the errors in the rainfall data before 1920. It could also be used for various scenarios. The model is highly complex and can

only be used by a specialist hydrologist. The model has also been calibrated for nutrient transport (Behirun, 2004). It confirms that the main nutrient load comes from the uppercatchment.



Graph 6-18: Observed and calculated lake levels after increasing the initial lake volume

Figure 6: Simulated based on rainfall only by combining a hydrological model with the lake water balance model.

3. The lake and groundwater interactions are complicated. Several hydrogeological models (ModFlow of the USGS) have been calibrated (Owor, 2000). The models are complex and can only be operated by a trained hydro-geologist. For the results and management implications I refer to Becht, 2007 (in press).

4. A GIS linked farm production model. (Hydrological Environmental & Economic System-HEES) Saheed (2000) and Pereira (2002) developed a farm production model linked to a GIS. This model allows the calculation of many important figures such as total water use, total production, profit/cubic meter of water used, employment, capital investment, pollution loads etc. Unfortunately, the models are outdated due to the rapid developments around the lake. However, together with LNWBM, *I consider this model the most important management tool for the management of the lake and the model deserves to be perfected and updated. Eg the present study could almost be carried out with "one mouse click".*

The most relevant output of this model is the extreme contrast in water productivity around the lake, displayed in figure 7.

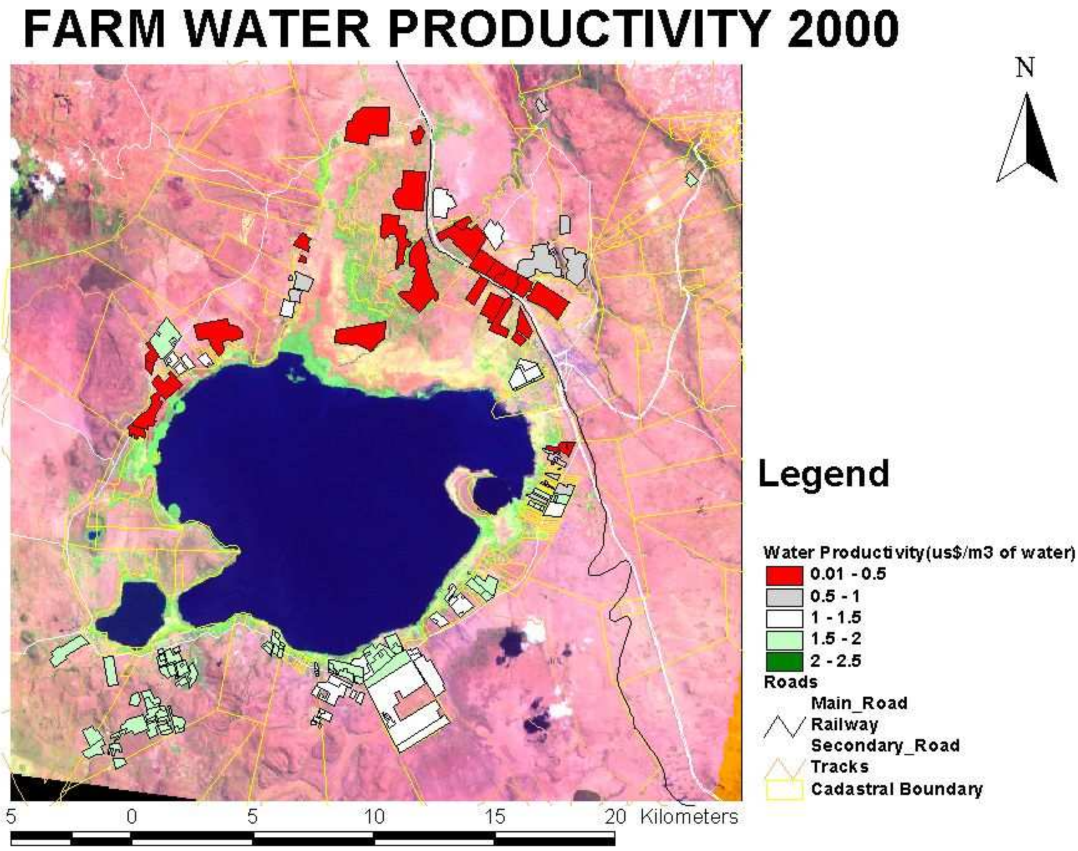


Figure 7: Water productivity map produced with HEEIS (Hydrological Environmental Economic Information System)

5. Water allocation and planning. WEAP (Water Evaluation and Planning system) is a user-friendly software tool that takes an integrated approach to water resources planning). Unfortunately, this study is not what we expected. The WEAP software has added a lot of functionality recently. The model can not be used as it is and should be rebuilt. The software is of average complexity.

Water use of irrigated agriculture

The irrigated area around Lake Naivasha shows a dynamic pattern of shifting between different types of agriculture. The classification, presented in figure 5, is based on April and June 2006 satellite images. Due to the frequent rotations of the open irrigation fields it is not always possible to distinguish between rainfed and irrigated agriculture, and irrigated vegetables or flowers. Therefore the images have been sent to the WRMA hydrologist based in Naivasha who knows this area very well. He has been asked to provide the following information for the 105 distinguished irrigated areas.

The following information was requested:

- farm Name, main crop (fodder, flowers, vegetables)
- specified crop (roses, grass, babycorn etc)
- irrigation (sprinkler, drip, hydroponics etc.)
- export (% exported)
- rotation (% used during year)
- water source (groundwater, lake, river)

Figure 8 shows the satellite image with the irrigated area that is differentiated in 8 classes.

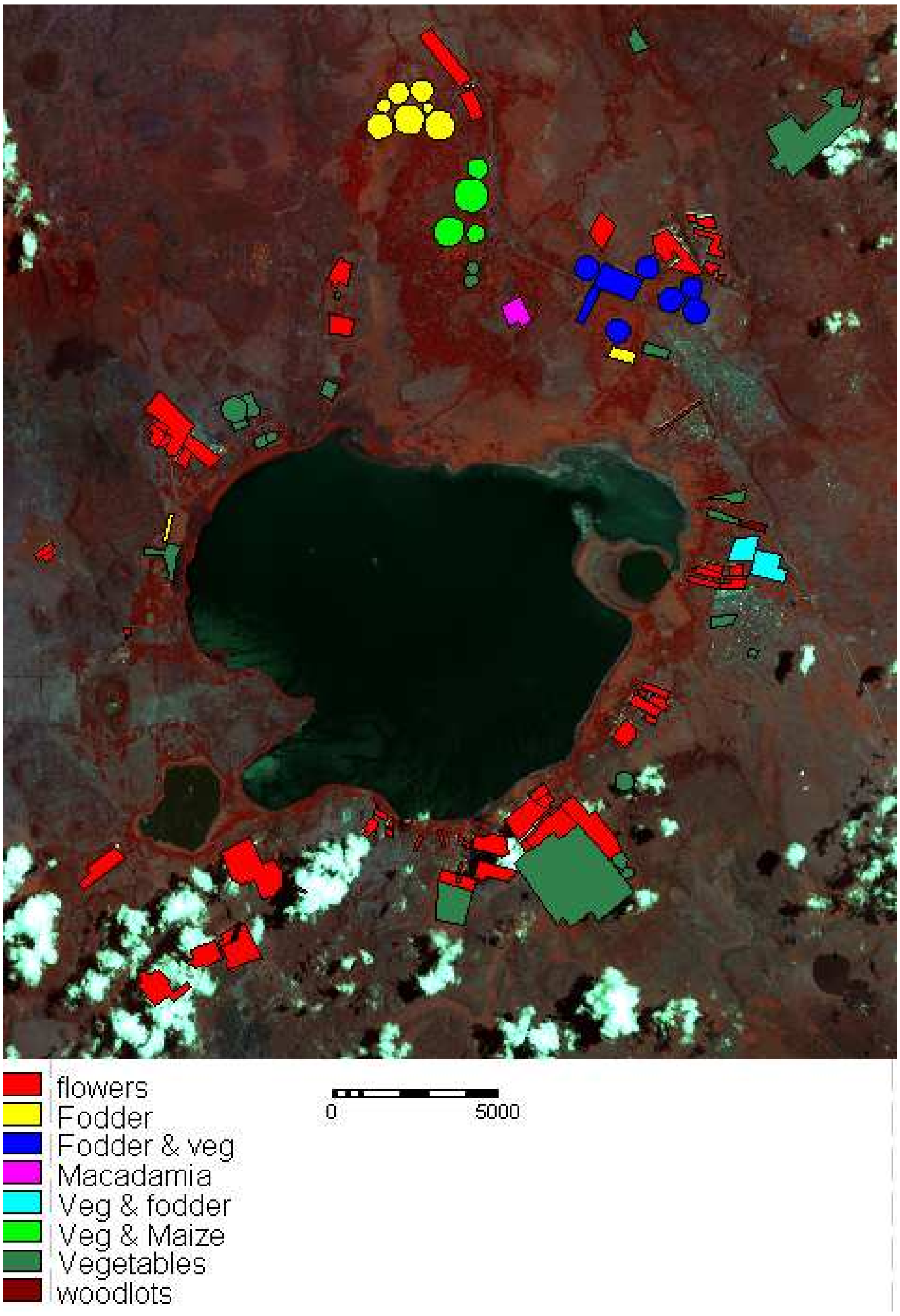


Figure 8: Irrigated Crops

Table 3 gives a more detailed breakdown of the different crops irrigated around Lake Naivasha.

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**

Table 3: Areas of irrigated crops

What does the above tell us?

Table 4 shows the irrigated areas with their water source.

Source	**Area (ha)**	**%**
Groundwater	1739	39
Lake	2453	55
River	274	6
Total	4467	100

Table 4: Sources of irrigation water

The data concerning the irrigation type (drip, sprinkler) do not seems trustworthy. Assuming that all flowers are drip irrigated and all vegetables and fodder sprinkler irrigated. Table 5 shows the areas for different irrigation systems.

Irrigation	Area (ha)	%
drip	721	16
greenhouse	1190	27
pivot	958	21
sprinkler	1598	36
Total	4467	100

Table 5: Areas of different irrigation systems

Based on the updated information on irrigation around the lake the most important trends are:

- The area under irrigation has not changed significantly since 2000 (see figure.7 & 8)
- the expansion of pivot irrigation (from zero Ha in 1998 to 822 Ha in 2006)
- the increase of hydroponic irrigation systems and the increase of greenhouses.
- The large increase in groundwater based irrigation
- the shifts from open irrigation to greenhouses and from traditional greenhouses to hydroponics greenhouses.
- Based on the estimate of the export percentage the area used for export crop is calculated (percentage * area). The estimated area for export crops is 2756 ha (62%).

On water use and irrigation efficiencies

A discussion on the field level water balances is necessary to understand the water use for irrigation in the Naivasha basin. A simple sketch with the water balance components is shown in Figure 9. Note the influence of groundwater that exits the basin in the low end.

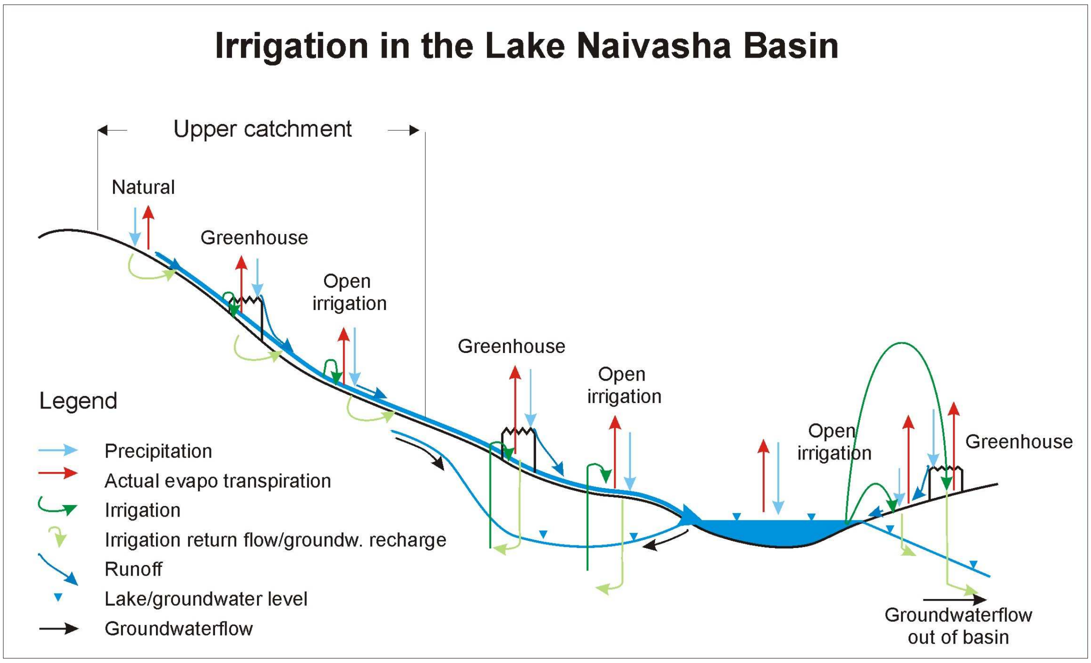


Figure 9: Schematic representation of the irrigation and hydrology

A simple water balance in Excel calculated the net abstraction based on water balance and hydrological positions (setting). The input data is given in table 6.

Around lake			
Rain	600	mm/year	
irrigation depth outdoor	6	mm/day	during dry periods
irrigation depth indoor	5	mm/day	
Actual ET outdoor (used by vegetation/crop)	4	mm/day	
Actual ET indoor (used by vegetation/crop)	3	mm/day	
Runoff coeff south	0.02		
Runoff coef north	0		
runoff coeff greenhouse	0.9		
Upper Catchment			
Rain	1200	mm/year	
irrigation depth outdoor	0.5	mm/day	
irrigation depth indoor	3	mm/day	
Actual ET outdoor (used by vegetation/crop)	3.5	mm/day	
Actual ET indoor (used by vegetation/crop)	2.5	mm/day	
Runoff coeff	0.06		

Table 6: Input parameters for the water balance calculations

Setting	Net abstraction from lake
South of lake, natural	12
South of lake, vegetables/flowers, sprinkler, lake water	-1578
South of lake, greenhouse, lake water	-1249
South of lake, greenhouse hydroponics, lake water	-500
North or West of lake, natural	0
North of lake, vegetables/flowers, sprinkler, groundwater	-860
North of lake, greenhouse, groundwater	-555
North of lake, greenhouse hydroponics, groundwater	-500
Upper Catchment, natural or rainfed crops	72
Upper Catchment, open irrigation vegetables, river water	-78
Upper Catchment, greenhouse, river water	168

Table 7: Water abstraction on basin level

**all numbers in mm year^{-1}. ** no rotation of crops is considered.*

Table 7 illustrates how efficient the water is used on a basin level. For the complete table of the water balance components see annex 3. The figures are generalized and many local deviations from the figures based on irrigation management and setting occurs. However, the general message is clear: a striking difference exists between the areas north of the lake and south of the lake considering the effect on the overall water balance. This difference is due to the groundwater outflow south of Lake Naivasha, causing all excess irrigation to leave the basin. This groundwater has only two exit points: geothermal steam (fumaroles) and Lake Magadi at the Tanzanian border. If we compare the two extreme cases with the natural situation than the worse case in terms of water use efficiency are the vegetables south of the lake where 1578+12=1590 mm is lost. The other extreme are greenhouses in the upper catchment, where the reduced evapotranspiration of greenhouse crops, result in positive net effect of 168-72= 96 mm on the water resources in the lake**. In other words, the lake may receive more water than in the natural situation!**

These results are one of the keys to rational water management in the basin. Greenhouses in the upper catchment have only a very small effect on the water availability in the lake (slightly positive, neutral, slightly negative), and thus give room for further expansion.

Panda farm, the greenhouse complex north of Naivasha, plans to inject storm runoff from greenhouses back into the aquifer. The advantage of this is the stored water can not evaporate as is the case in the lake, even more improving the water use efficiency.

Water abstraction by the flower industry

The abstraction can be defined in two ways.

1. The amount of water that the producers pump from the lake, rivers or groundwater to irrigate the flowers.
2. Taking the water balance principles as discussed earlier in consideration, determining the net abstraction from the system.

Based on the data in tables 6 & 7 the amount of water applied to crops can easily be calculated. We assume that the yearly application is equal to the 365*daily application minus rainfall for flowers. For vegetables we assume 75% and for fodder production we assume that 50% is applied.

Around lake	Depth (mm/yr)	Flower application (mm)
Rain	600	
irrigation depth outdoor	6	1590
irrigation depth indoor	5	1825

Table 8: Irrigation depth for in and outdoor irrigation around the lake

Crop	Area (ha)	Application (Mm3/yr)	%
roses	1028	18.76	31.4
roses & carnations	730	11.607	19.4
roses, hypericum	21	0.3339	0.6
flowers	132	2.0988	3.5
Total flowers	**1911**	**32.8**	**54.8**
			0.0
babycorn	**205**	2.444625	4.1
babycorn & beans	**143**	1.705275	2.9
babycorn & beans &cabbage	**45**	0.536625	0.9
babycorn & beans & cabbage	**124**	1.4787	2.5
babycorn, beans, onions	**905**	10.792125	18.0
Beans/tomatoes	**21**	0.250425	0.4
cabbage	**373**	4.448025	7.4
cabbage and beans	**6**	0.07155	0.1
Total vegetables	**1822**	**21.7**	**36.3**
			0.0
grass	286	2.2737	3.8
grass & lucerne	26	0.2067	0.3
grass,lucerne	14	0.1113	0.2
Lucerne	163	1.29585	2.2
Lucerne,babycorn,beans	176	1.3992	2.3
Total fodder	**665**	**5.3**	**8.8**
			0.0
macadamia	50		0.0
Eucalyptus	17		0.0
			0.0
TOTAL	**4467**	**59.8**	**100.0**

Table 9: Water use by different crops

The total comes close to the 60 Mm^3yr^{-1} that is generally accepted as the total abstraction from the lake. (Becht and Harper, 2002)

This estimate is too high since it does not consider the irrigation return flow. Also it does not calculate to other consumers in the basin such as humans, animals, industry, the inter-basin transfer to Nakuru town (7 Mm^3yr^{-1}) or irrigation in the upper basin etc.

2. The net abstraction from the system (lake).
This quantity is more difficult to calculate since it also depends of the **location** of the farm. Using GIS, the net abstractions are evaluated in table 7.

	Net abstraction (m3/year)
Flowers	19891621
Fodder	1401293
Fodder & vegetables	1599645
Vegetables	16838025
Total	39730584

Table 10: Location dependent net abstraction for irrigation

The total net abstraction by irrigated agriculture around the lake is 40 Mm^3yr^{-1}. Fifty percent (50%) is consumed by flowers, all exported to foreign markets. Part of the vegetables, like baby corn and French beans are also exported.

The effect of rose cultivation on the lake levels

The effect of abstractions from the lake can be represented as a simple relationship between abstraction and mean lake level. Unfortunately the relationship is not linear.

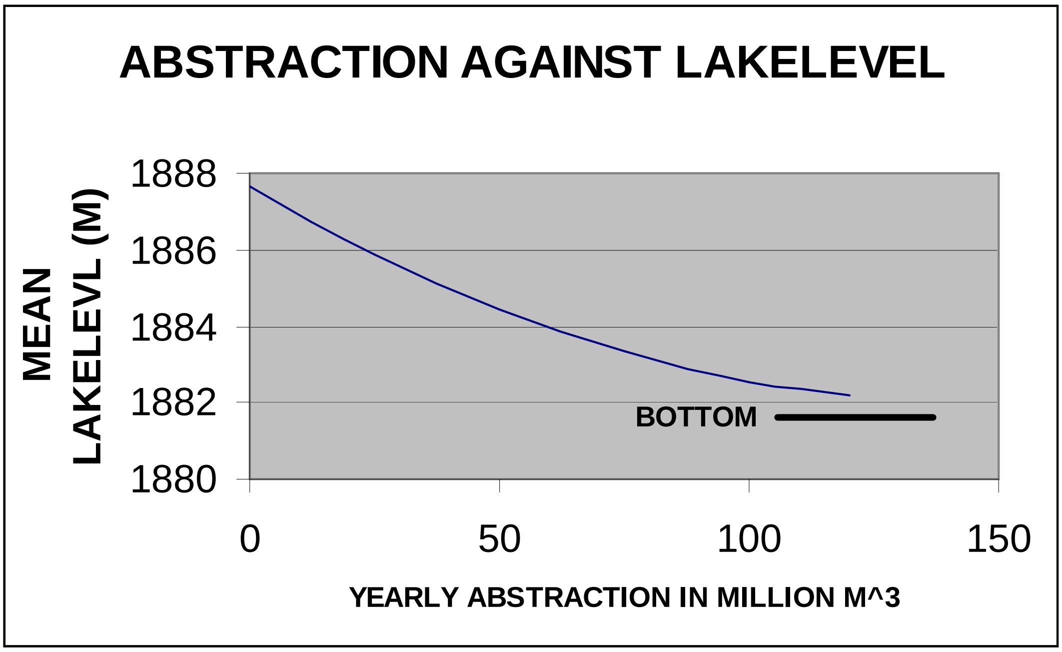


Figure 10 The relation between long-term abstraction rate and mean lake level

A linearized approximation gives a lowering of the long term mean water level of 0.5 meter for a long term constant abstraction of 10 Mm^3 yr^{-1}. The limit is where the abstraction is equal to the inflow from the rivers (220 Mm^3 yr^{-1}.)

The water consumption for flowers based on Table 10 is 2 Mm^3. Therefore the long-term drawdown caused by flower production on the Lake is approximately 1 meter.

The relationship can also be used for simple climate change scenarios.
Assume the following scenario: Rain reduces by 5%, stream flows by 10% and lake evaporation increases to 3%. This gives the following changes in the water balance components:

	Rain	surface water inflow	lake evaporation	Total
average	95	220	260	
%	-0.05	-0.1	0.025	
Change	-4.75	-22	6.5	33.25

Table 11 Climate change scenario using the relation in figure 10

The effect on the average lake level is some 1.7 meters. A serious warning is in place. Climate change scenarios are usually based on complex models taking into account the complex relationships between the atmosphere and the land. They can hardly be replaced by simple approximations like the one shown here.

Sustainable yield

Figure 7 shows the long term effect of abstractions on the average lake levels. The average lake level reaches this upper limit when no abstraction occurs (1888 m asl) and a lower level when all inflow is abstracted (1881.6 m asl).

At present the abstraction is estimated as some 60 /yr and the average lake level is approximately between the two limits.

In terms of water quantities the sustainable yield, this is rather a political and societal issue than a hydrological one. A constant rate of abstraction results in a lower average lake level and yearly dynamics. The higher dynamics are caused because the yearly flood has to be stored in a lake with a smaller surface area and therefore the rise of the flood will be larger. In the discussion on the sustainable level only negative factors are mentioned. However, the lower levels of the lake just before the 1997 El Niño, has definitely protected many homesteads from flooding.

It is to the stakeholders around the lake and Kenyan policy makers and politicians to decide what size of the lake acceptable.

Virtual Water

Hoekstra et al (2003) give a detailed discussion on virtual water. The virtual water content of a product is the volume of water used to produce the product, measured at the place where the product was actually produced (production site specific definition). The virtual water content of a product can also be defined as the volume of water that would have been required to produce the product in the place where the product is consumed (consumption site specific definition).

In this analysis the production site specific approach will be used. Hoekstra & Hung (2002) defined the Specific Water Demand, SWD:

SWD= CWR/CY

Here, SWD denotes the specific water demand ($m^3\ ton^{-1}$) of crop c in country n, CWR the crop water requirement ($m^3\ ha^{-1}$) and CY the crop yield ($ton\ ha^{-1}$).

The average production of roses based on 200 stems m^{-2} year and a weight of 35 g $stem^{-1}$. The average weight of the Kenyan roses is approximately 35 g $stem^{-1}$ (measured at the Albert Heijn Supermarkt). The crop yield, CY, is 7 kg $year^{-1}\ m^2$ (70 ton $ha^{-1}\ year^{-1}$). The crop water requirement for indoor roses, CWR, is 3 mm/day (10950 $m^3\ ha^{-1}\ year^{-1}$). The specific water demand, **SWD, is thus 156 $m^3\ ton^{-1}$.**

If we assume that the crop classed "roses and carnations" in table 3 (at Oserian) is 50% roses, then the total area under rose cultivation around Naivasha is approximate 1400 ha. The total production of roses is estimated as 70 ton/ha*1400ha= 98000 tons.. **The total virtual water export is thus 15.3** $Mm^3.year^{-1}$

Based on 2005 export figures from the Kenyan Flower Counsel (KFC) Kenya exported 81,217 tons in 2005, of which 73% is roses (see annex 2). This means that in 2005 59,000 tons of roses has been exported, with an virtual water content of 9.4 Mm^3. Note that this figure is much lower than the 98000 tons estimated for Naivasha.

KFC claims membership coverage of 70% and it is not clear whether these figures are national totals or only referring to KFC members.

The concept behind SWD is that the difference of the water used to produce the roses (applied water) and the water consumed by the plants, CWR, returns to the system and can be (re) used beneficially. The above approach is suitable to allow international comparison.

However, in the paragraph on the water balance it is shown that basin irrigation efficiency varies widely depending on production system and location in the basin.Table 12 show the results of an alternative calculation based on the quantity of water taken from the basin to produce roses. Note that greenhouse roses produced in the upper catchment have a positive effect on the water yield to the lake and therefore a negative SWD_modified.

Setting	Net abstraction from lake (mm)	SWD modified (m^3 ton^{-1})
South of lake open roses	1578	225
South of lake greenhouse roses	1249	178
South of lake greenhouse hydroponics roses	500	71
North of lake open roses	860	123
North of lake greenhouse roses	555	79
North of lake greenhouse hydroponics roses	500	71
Upper Carchment greenhouse roses	-168	-24

Table 12: Modified SWD and net abstractions from the lake

The pollution of Lake Naivasha

The physical conditions around the lake cause poor hydraulic connections between the (irrigated) farms and therefore the possibilities of agrochemicals to end up in the lake are small.

The area has very permeable soils with low water holding capacity and very gentle slopes. Agrochemicals are constantly transported downwards to groundwater by the irrigation return flow. In greenhouses this process is not affected by rainfall. Due to the very permeable soils and gentle slope and the semi-arid character of the lake surroundings direct runoff from the agricultural area is rare. Many areas around the lake never produce runoff. For above reasons the surface water transport mechanisms for agrochemicals are very limited. Most of the agrochemicals end up in groundwater systems. Furthermore, the runoff from plastic greenhouse roof is pure rainwater.

Figure 8 shows a satellite image of the lake with the known wells and the direction of groundwater flow.

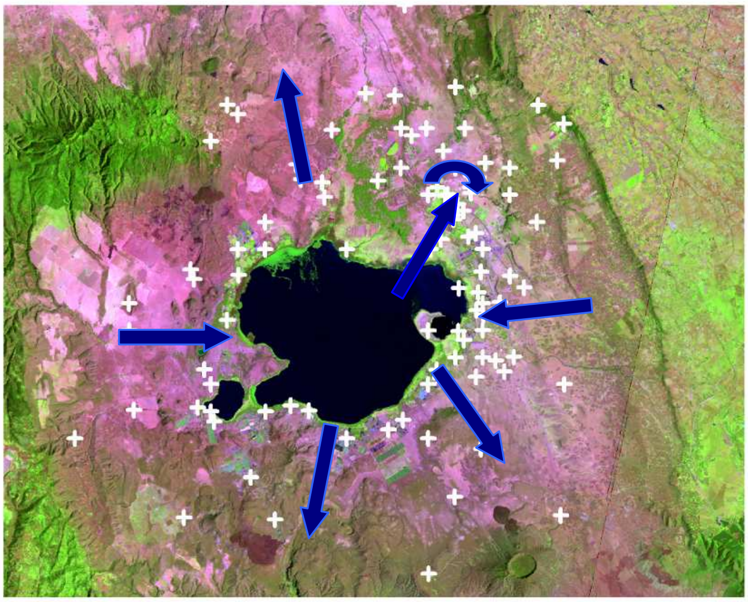


Figure 11: Lake Naivasha with wells (+) and general direction groundwater flow

The major flows are the outflow to the North and South draining the lake. Some ground water inflow occurs from the flanks of the Rift Valley towards the lake. North of the lake, in the area with important groundwater exploitation, the natural gradient is inversed and a groundwater depression has been formed. The water pumped from this area comes indirectly from the lake. The rather complicated flow pattern has implications for the management of the lake. The southern zone is an outflow zone with much lake water based irrigation. Over-irrigation in this zone will cause a net water loss since the excess water drains towards the shallow aquifer. Eventually, this water will re-appear in Lake Magadi after 10,000s of years. Agrochemical pollutants carried by the water will have the same fate. In outflow zones careful irrigation management preventing over irrigation is important, the risk that pollutants are carried to the lake by groundwater is small. Exactly the opposite is true for the inflow zones. In the case of over irrigation, the access water will find its way to the lake and can be reused. Of course the same holds true for pollutants, constituting a danger for the ecological quality of the lake: they flow away from the lake in outflow zones(south) and into the lake in groundwater inflow zones (west & east) and are recirculated North of the lake All irrigation in the zone north of the lake is based on groundwater. Irrigation return flows from over-irrigation will recharge the aquifer and the concentration of salts and pollutants is likely to increase.

Based on the physical conditions around the lake the risk of agrochemicals ending up in Lake Naivahsa is small. Where it does occurs, the hydraulic link is rather easily disconnected using infiltration pond/constructed wetlands or better irrigation management techniques.

This leads to the political somewhat difficult conclusion that the pollution and eutrophication of the lake is due to the upper catchment population and to a certain extent to the sewage of Naivasha town and not to the flower farms.

In the upper catchment the physical conditions are almost opposite to the lake area; high rainfall, steep slopes and impermeable soils. Therefore, all agrochemicals used by the farmers and not used by the plants will finally end up in the lake. Kitaka (2000), who carried out her PhD on Phosphorus loads in the rivers, concludes that these loads are enough to explain the phosphorus levels in Lake Naivasha.

Summary, conclusion, recommendations

The Naivasha case can be summarized as follows:

80% of the reduced lake levels can be attributed to the irrigated horticulture around the lake while 80% of the inflow of pollutants and nutrients can be attributed to the farmers in the upper catchment.

Flower production consumes some 50% of the total water abstractions (20 Mm^3). However, the economic returns and also the amount of labor needed for flower production are an order of magnitude higher for flowers as compared to vegetables. Fodder production is in economic terms a waste of water.

The virtual water exported with roses from Naivasha amounts to 15.3 $Mm^3\ yr^{-1}$
The irrigated flowers result in a lowering of the lake level of approximately 1 meter.

The estimated area for export crops is 2756 ha

Groundwater based irrigation is steadily increasing at now reaching 39% of the total abstraction. Groundwater management and artificial groundwater recharge will become paramount.

The effect of the total abstractions from the lake has resulted in a lowering of the average lake level of more than 3 meters. Under the climatic conditions of the last 50 years this is sustainable, but reaching the limit. No more expansion of irrigated agriculture around the lake. The upper catchment still has room for further expansion.

The environmental status of the lake is degraded and may well be irreversible. However, this is more related to the introduction of alien species (especially the crayfish and carp) and the nutrient loads coming from the upper catchment than to the irrigated agriculture around the lake.

Many tools exist to reduce the water consumption for irrigation:

- Stop issuing water abstraction permits.
- Mechanisms to encourage highly efficient irrigation through water charges and tradable water rights.
- Discourage (water charges) irrigation of low income crops like fodder
- Encourage fodder production for dairy cattle in the upper catchment (upstream-downstream economic links)
- Encourage greenhouses (+/- 30% reduction in evapotranspiration)
- Better irrigation management
- Hydroponics especially in groundwater outflow zones
- Encourage greenhouses in the upper catchment (zero or even slightly positive effect on the recharge of the lake); here very adequate measures to prevent the transport of agrochemicals to the lake is essential.
- Improve the water holding capacity of soil using locally available products like clay and zeolite.
- Encourage rainwater harvesting of greenhouse runoff. Especially north of the lake this water could be used to recharge the aquifer optimizing the water use efficiency.

Planning of further increase is essential. Only allow further expansion in the groundwater outflow zones (south of lake) for hydroponic greenhouses and greenhouses in the groundwater inflow/recirculation zones. With proper planning a water balance neutral expansion of the floricultural activities seems feasible.

The reduction of agrochemical loads are more complex to address. As explained, in general the hydraulic link between the irrigated farms around the lake and the lake is bad or absent. A series of rather simple measures such as recirculation basins and constructed wetlands can reduce the loads to the lake even further. The main management challenge in the basin is the reduction of agrochemical loads to the lake mainly caused by the 1000's of small farmers in the upper catchment.

Agrochemical and sediment loads to the lake may be reduced:

- Rehabilitating the sewage system of Naivasha town.
- Rehabilitation of the North Swamp possibly in combination with a dike
- Reduce hydraulic use of agrochemicals through better irrigation/ fertigation /pest management.
- The occurrence of zeolites in the Rift Valley and their application in the floriculture could be investigated.
- Reduce hydraulic link between farms and lake through retention/infiltration basins and/or artificial wetland.
- Promote/introduce Phosphor poor detergents
- Environmental education of the upper catchment populations in combination with watershed rehabilitation measures reducing direct run-off.
- Reduce the consumption of firewood (this will require a large number of parallel actions)

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Annex 1 How does Water Accounting work?

Water accounting uses a 'water balance' approach to quantify the amount of water entering a system (through precipitation and river and groundwater flows) and the amount leaving a system (through evaporation, plant transpiration and river and groundwater flows). The amounts depleted within the basin are then classified according to use, whether or not the use is intended and whether or not it is beneficial. The amount of unused water flowing out of the system is classified according to whether or not it is committed for downstream use. Non-committed outflows are further subdivided into water that is currently utilizable and water that is not utilizable without additional infrastructure.

Water accounting definitions

Water depletion is a use or removal of water from a water basin that renders it unavailable for further use.

Available water represents the amount of water available for use. Available water includes process and non-process depletion, plus utilizable outflows.

Net inflow is the gross inflow plus any changes in storage.

Non-process depletion occurs when water is depleted, but not by a human-intended process. Non-process depletion can be either beneficial, or non-beneficial-for example, evaporation from fallow land would generally be classified as non-beneficial, while evaporation from forests would generally be considered beneficial.
Classification as beneficial or non-beneficial requires a value judgment and is a good entry point for discussions with stakeholders.

Process depletion is that amount of water diverted for use that is depleted to produce a human-intended product.

Gross inflow is the total amount of water flowing into the river basin or defined area from precipitation, rivers and subsurface sources (groundwater).

Committed water is that part of outflow from the basin or defined domain that is committed to other uses such as downstream environmental requirements or downstream water rights.

Uncommitted outflow is water that is not depleted, nor committed and is therefore available for a use within the domain, but flows out of the basin due to lack of storage or sufficient operational measures. Uncommitted outflow can be classified as utilizable or non-utilizable. Outflow is utilizable if it could be used by improved management of existing facilities. **Once water is categorized, Water Accounting indicators refine the picture**

Depleted Fraction indicators reveal how much scope remains for water resources to be developed, how close they are to being fully committed, and how sustainable the system is. For example, the depleted fraction (amount of water depleted divided by gross inflow) for Pakistan's Chishtian sub basin was 1.09—meaning more water is being depleted than is flowing into the system. This indicates groundwater overdraft and therefore unsustainable water use.

Beneficial Utilization relates the amount of water depleted by all beneficial processes to the amount of water available for use. This indicator offers a more accurate view of basin efficiency than traditional indicators, because it takes into consideration the water consumed by valuable natural ecosystems as well as the water consumed by human activities (such as agriculture). For example, according to the classical definition, Kirindi Oya sub basin has an efficiency of 22 percent (counting only water used by crops), but its beneficial utilization is actually much higher-65 percent (counting water consumed by crops and beneficial natural vegetation).

Productivity of Water quantifies the value derived from the water used. In agriculture, it can be expressed as the yield (in kilograms) produced per cubic meter of water consumed by crops. More generally, it can be expressed as the economic value of production per unit of water consumed. These productivity values can also be related to the amount of water available, depleted or diverted.

Annex 2 Flower Industry

The rose is the top Kenyan flower variety, leading exports by 73 %. mixed bouquets (11%), carnations (5%), statice (3%), Alstromeria and Veronica (1 % each) while other varieties account for the remaining 6 %. The industry has maintained an average growth of 20% per annum. In 2003, Kenya exported over 60,000 tonnes of cut flowers compared with 52,000 tonnes in 2002. The year 2005 saw this figure move to a record high of 81,217 tonnes. In last year's figures, roses accounted for 61,072 tonnes up from 45,668, Carnations 2603 tonnes up from 1,476 tonnes, Statice 438 tonnes down from 563 tonnes, Alstromeria 949 tonnes, up from 767 tonnes with others at 16,155 tonnes.

The international market share in the flower markets shows Kenya is the largest supplier to the EU representing 31% of their imports. The major market for Kenyan flowers is Holland with 69% of all the Kenyan flower exports being the Dutch auctions. Other destinations include the UK accounting for about 19%, Germany 6% and a range of other smaller destinations (Fig 2). The floriculture sector in Kenya is the number two foreign exchange earner after tea bringing in more than $250million per annum and employing 100,000 people directly and more than 2 million indirectly.

The sub sector has also recorded the highest growth in volume and value of cut flowers exported every year. It has had a growth rate of 35% annually in the last 15 years. The area under roses is expected to keep increasing every year.

The current Kenya Flower Council membership represents more than 70% of the flowers exports. While Kenya was not exporting the products in 1970, it is currently the leading exporter to the European Union, contributing 31% of all flower sales, followed by Columbia with 17% and Israel 16%. The main European Union markets are Holland, Germany, Switzerland, France, and the United Kingdom.

The Kenyan flower industry has gone through a significant maturing since 1990. Kenya's export volume has continued to grow from 14,000 tons in 1990 to 39,000 tons in 2000 to 61,000 tons by 2003 and 81,217 tons in 2005, of which 73% is roses. This is depictive of a significant growth in the volume of flower exports. The value of flower exports has risen from about 1billion KSHS in 1990 to 7billion in 2000 to 16 billion Kshs in 2003 and to a record 22.8 billion shilling in 2005.
http://www.pathfastpublishing.com/ROSEBOOK/International%20Rose%20Scene.htm
(http://www.kenyaflowers.co.ke/industryinfo/kenyanf.php)

Annex 3 Detailed crop water balance

Setting	Dir. Grw	Rain	Irrig ation	drain	run off	grw rech	actual ET	net abstract ion from lake	irrigation return flows to lake
South of lake, natural	From lake	600	0	0	12	15	573	12	12
South of lake, vegetables/flowers, sprinkler,lakewater	From lake	600	1590	0	12	718	1460	-1578	12
South of lake,greenhouse,lakewater	From lake	600	1825	36.5	540	693.5	1095	-1248.5	36.5
South of lake,greenhouse hydroponics,lakewater	From lake	600	1825	784.8	540	0	1040.25	-500.25	784.75
North or West of lake, natural	To lake/recircul	600	0	0	0	30	570	0	0
North of lake, vegetables/flowers, sprinkler,lakewater	To lake/recircul	600	1590	0	0	730	1460	-860	0
North of lake,Greenhouse,lake water	To lake/recircul	600	1825	0	540	730	1095	-555	0
North of lake,greenhouse hydroponics,lakewater	To lake/recircul	600	1825	784.8	540	0	1040.25	-500.25	784.75
Upper Catchment, natural or rainfed crops	To river/lake	1200			72		1128	72	72
Upper Catchment, open irrigation vegetables	To river/lake	1200	182.5		72	33	1277.5	-77.5	105
Upper Carchment, greenhouse	To river/lake	1200	1095		1080	182.5	912.5	167.5	182.5

Note: The large drain flux for hydroponic greenhouses is recycles on farm. Some 20% is not recycled to prevent the built-up of Sodium (Na).

Annex 4 Scientific issues & further research

Below a list of some further research ideas/issues

1. In East Africa the effect of land use conversion has not been seriously studied since colonial days (1950-1960). With all attention going towards climate change the effect of land use changes on hydrology and ecology remain under-focused. The hydrology of the East African Water Towers, providing 80% of the surface water resources, is poorly understood. The last serious research was carried out in colonial days by the Institute of Hydrology, Wallingford: the famous East African Catchment Experiments.

A good hydro-meteorological monitoring system, in combination with satellite observations, could boost the understanding and knowledge on these systems. Satellite hydrology would assist in all components of the water cycle (rain, evaporation, soilmoisture, runoff, water levels, water quality)
This would be perfectly in line with ITC research interests. Naivasha has Ramsar status, is an UNESCO HELP basin (hydrological reference basin) and is a reference basin of the Worldbank/GEF/ILEC programme on lake management. The basin could evolve to a reference basin for the Unesco/ESA (European Space Agency) TIGER project.

Recognizing the utility of satellite data for water resource management elsewhere and the urgent need for action in Africa expressed at the WSSD, the European Space Agency in the context of the Committee of Earth Observation Satellites (CEOS) WSSD follow-on programme, launched in 2002 the TIGER initiative aimed at: "assisting African countries to overcome problems faced in the collection, analysis and dissemination of water related geo-information by exploiting the advantages of Earth Observation (EO) technology". (http://www.tiger.esa.int/about.asp).

2. The information under 1) forms the input to more accurate hydrological models than available at present and allows *climate change and land use change scenario's (re/de-forestation) as well as development scenarios.*

The information derived under 1) can also be linked to ecosystems in order to quantify the water demand. The ecosystem services become quantifiable in terms of water demand. Linking this with an economic (e)valuation of the ecosystem functions/services leads to "ecological water productivity"

3 The farm production systems (water productivity) of the traditional rural agricultural systems should be studied in the same detail as the commercial systems.

4. The items 2 & 3 lay down a basis of comparing and evaluating ecosystem functions with crops for export and crops for food.

5. An socio-economic analysis of the effect of the large-scale commercial farms on the well-being of the populations in the basin, linked with 4) further narrows down the effects of the development both on a international scale (virtual water trade) as to the local situation (benefit for the local situation). (People, Planet, Profit)

6. The issue of the sustainability of the lake, the "environmental volume" and the "environmental quality" should be taken up.
A remote sensing water quality monitoring study could be part of this item. Fragmentation of landscape probably plays an important role.

7. The influence of groundwater on the system is important. Further study of this is needed.

8. The relation between nutrient and sediment fluxes into the lake, the volume of water, water quality, transparency of the lake water, the energy balance of the lake, the relationship between the lake and the supported riparian zone, the fish-yield are not well understood.

9. Study of energy needs (cooking) and firewood production.

10. A number of zones with strong gradient in land use/ownership/protection status are very suitable to study land degradation effects in relation to population pressure.

11. Study of the relationship between land assets (climate, size, soil, and degradation level), biodiversity, socio-economy, and poverty.

12. The effect of commercial farms on the local economy; the effect on socio-economic indicators such as income, health, education, housing, etc as compared to people living in a comparable agro-climatic zone.

14. Comparison of large scale pivot vegetable production and small-scale vegetable production for local (NBI) market.

15. Information management, GIS, EO decision support systems for IWRM/"good governance". Optimalisation models.

16. Combining many components of above a rather complete description of matter (water, agrochemicals, nutrients, goods (flowers)), money, biomass (people, animals, vegetation) **FLUXES AND STATES** could be synthesized

17. Naivasha in relation to other flower/vegetable producing countries (in Africa/Asia/L. America) and the Western Markets. A field level farm production model linked to, or is association with GoogleEarth. Building on Virtual Water Trade concepts.

18. Nutrients/sediments uptake capacity of the (restored) Malewa/GilGil Paparus Swamp.

19. Water use of the Riparian Acacia Xantaphloea (Fever Tree) forest.

20. Population density estimates using high resolution satellite images.

21. Re-estimate of the lake evaporation using satellite images. Being by far the largest water consumer a small error is already a considerable amount of water.

22. Trophic state of the lake using satellite images.

23. Detailed land-use/land-cover classification of the whole basin using sophisticated image classification tools and high resolution images.

Annex 5 Full Membership of Lake Naivasha Management Implementation Committee (LNMIC)

Lake Naivasha Riparian Association (LNRA).
Kenya Wildlife Service (KWS).
World Conservation Union (IUCN).
Ministry of Water Development and Management (MoWD).
Ministry of Environment and Natural Resources. (MENR).
Fisheries Department (under Ministry of Livestock and Fisheries Development).
District Commissioner, Nakuru.
Naivasha Municipal Council.
Kenya Power Generating Company (KenGen).
Ministry of Lands and Settlement.
Ministry of Agriculture and Rural Development.
Lake Naivasha Fishermens' Co–operative Society.
Co-opted members: The Chairmen of the Sub-committees for: Tourism, Eburru Forest, Livestock, biodiversity Monitoring, Water.

Annex 6 WWF Project implementation

Points of attention

- In April 2007 a Lake Naivaha Management and Monitoring workshop was held in Naivasha with approximately 50 participants from various stakeholder groups. The workshop was organized by LNRA and moderated by Harper (Leicester University) and Becht (ITC). During this day it became clear that the development of a **common vision** is essential for WWF's mission.

- Scientific support
  It is advised to start the project with a workshop with participants from WRMA, WWF, and a few staff of local and/or foreign universities knowledgeable on Naivasha (Harper, Becht, Mavuti). A priority ranking of interventions based on scientific criteria should be made. (e.g. In which area do we start implementing watershed management measures).

- Information management.
  Transfer of data from ITC and Leicester University to Naivasha and a short course in GIS.

- Update of the Hydrological-Environmental Economic models.
  These models provide relevant information on production inputs (water, agrochemical, labour, capital), outputs (flowers, vegetables, etc) , loads on ecosystem, profits). This system allows precise monitoring of management. It could be further developed for the Naivasha case and than used in other project in the framework of the Virtual Water Trade studies.

- Water allocation models need to be updated.

- Define a monitoring network (both physical and socio-economic) supporting research and allowing monitoring the effectiveness of interventions after implementation.

Annex 7 Terms of Reference.

Draft TOR for Lake Naivasha Hydrology Consultancy

BACKGROUND

Reduced river flows, depleted groundwater aquifers, and deteriorating water quality are resulting in significant adverse ecological and social impacts and threaten to check economic growth and poverty reduction efforts in much of the world, including Kenya. WWF-UK has recently completed a report on the virtual water trade of a number of crops destined for the EU/UK. WWFs aim is to illustrate the role that water plays as an invisible and forgotten aspect of various commodities in our food economy and how water used for food and fibre production can significantly contribute to changes of regional water systems. Our overall objective for this study is to establish a concrete picture of the impacts directly attributable to the water used for producing export commodities in the Lake Naivasha basin.

We recognise from our work that to make meaningful comments as to the long term sustainability of any water system and to make links between production with negative effects on biodiversity, we need to have a better understanding of the local hydrological system of the case study areas. This is an essential step in our efforts to engage meaningfully with the stakeholders that we have identified as key in positively addressing this issue. We are therefore seeking to commission a study to fill in the knowledge gaps which currently exist in respect to the hydrology, water use and impacts on people and nature in Lake Naivasha.

OBJECTIVES

To determine whether current levels of water use, abstraction, and pollution in the Lake Naivasha basin are sustainable or not.

METHODS

We foresee this to be a desk study of between 4 to 8 days in length at an agreed day rate. This report will be a Word document, no more than 20 pages, figures and graphs in Microsoft office package and delivered to us as an electronic copy.

OUTPUTS

The report should contain the following information;

- Background history on attempts by government, riparian associations etc to address the problems facing Lake Naivasha. Comments on their effectiveness.
- estimates on water abstraction for export horticulture operations,
- the effects (quantity and quality) on water sources due to abstraction for agriculture
- links to biodiversity loss because of water quantity and/or quality issues where possible
- evolution over time of the pollution levels, their causes, consequences and components
- overall hydrology of the lake system, *i.e.* recharge rates, fluctuations, trends, natural variation, forecasts, climate change scenarios and water balance.
- estimates on environmental flows needed to maintain lake biodiversity levels and downstream users
- reference to the sustainability/non-sustainability of abstraction and pollution levels
- some indication as to the scientific consensus on Lake Naivasha as to the sustainability of this system under current usage patterns
- suggestions toward solutions for better managed abstraction/pollution issues

We recognise that Naivasha is impacted by a number of water users and this dynamic must be reflected in the findings. The report should be comprehensible by a non-hydrology specialist.