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Water efficiency and its effects in Lake Naivasha, Kenya

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Preface

In Naivasha, Kenya, most hydrologic data about water abstractions is already known. It was my task to figure out what happens after these abstractions. The aim of this research is to provide further insight in water efficiency on a local scale, while not forgetting the overall picture. It turned out to be difficult to get all necessary local data from businesses, but the report gives an example on how to evaluate the local data. Furthermore enough data has been collected to compare different farming systems and their efficiencies in Naivasha. This research has helped me gain knowledge in local water flows and understanding on how to increase water efficiency in the agricultural business. I had a great introduction to some new techniques that I would not have thought to be possible.

I would like to thank the people that cooperated in the fieldwork during my time in Naivasha, especially Philip Kuria and Chakravarthi Kuppusamy for their openness in providing the data. A special thanks to WRMA for hosting me during my stay, and to Dominic Wambua for the great time together and the received help. Further thanks to Robert Becht, Abebe Chukalla and John Munyao for the supervision of my thesis and their quick responses on questions.

Summary

Water is interconnected with society, economy and ecology; this is not any different in the case of Lake Naivasha. The interconnection between commercial water abstractions, the economy of water, the domestic water usage and the ecology of Lake Naivasha were assessed.

Through three different surveys, one of them focussing on water efficiency on commercial farms, two of them focussing on domestic water efficiency were developed. These surveys were conducted on several places around Lake Naivasha and were later analysed. The analysis of commercial abstraction focusses on the water footprint of a crop and the irrigation system performance efficiency (ISPE). Domestic water efficiency focusses itself on the current water infrastructure in the settlements around Lake Naivasha.

The Blue water footprint was found to be about 1200 m^3/kg for a crop in a hydroponic, a 1600 m^3/kg for a crop in a greenhouse and 1900 m^3/kg for a crop in an open-field based farming system. The green water footprint was only assessed for the open-field based farming system and was calculated to be around 1700 m^3/kg.

The Irrigation System Performance Efficiency (ISPE) was calculated for the different scenarios and it was found to be that the only notable loss form abstraction to irrigation is the reservoir evaporation. Therefore the area of the reservoir is important, as a bigger reservoir means a bigger evaporation. The water application rates were found to be around 90% for hydroponics, which means 90% of the applied water is actually used by the crop and about 20-40% for greenhouse based farms. Another advantage of the hydroponic is the 40-50% recycling efficiency, which means that 40% of the total used water is actually recycled from the previous cycle.

The results of the surveys were also analysed for non-water parameters, including economy, human rights and biodiversity. Every water efficiency improving measurement was researched for costs and benefits. These include the investment costs, maintenance costs, chemical costs and improved yields. It was found that in the ideal situation farms would transfer to Hydroponics, as the next step, aeroponics, is not possible in the current Kenyan infrastructure.

For domestic water usage it was found that not all UN-guidelines are met. Furthermore water infrastructure seems to lacking in most areas around Lake Naivasha. The current situation is that people often have to drink water from boreholes, which is high in fluorides. This causes dental fluorosis amongst most of the population around Lake Naivasha.

The biodiversity and water quality were analysed through the help of experts and were mainly focussing on the linkage between water hyacinth coverage, Chlorophyll ‘a’ and nutrients. Furthermore the Water Quality Index for Biodiversity was calculated which proofed that the water quality between 1967-2002 was marginal for Lake Naivasha.

The best investment, both economically and based on water usage, would be for farms to invest in a hydroponic. For the domestic water usage it is recommended to developed water infrastructure in the settlements around Lake Naivasha.

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Acronyms

BOD – Biochemical Oxygen Demand
CG – County Government
COD – Chemical Oxygen Demand
DO – Dissolved Oxygen
EC – Electrical Conductivity
FLO – Fairtrade Labelling Organisation
GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit
ISPE – Irrigation System Performance Efficiency
ITC – Faculty of Geo-Information Science and Earth Observation
IWRAP – Integrated Water Resource Action Plan Programme
KenGen – Kenya Electricity Generating Company
KFC – Kenya Flower Council
KWS – Kenya Wildlife Service
LaNaWRUA – Lake Naivasha Water Resource Users Association
LNGG – Lake Naivasha Growers Group
LNRA – Lake Naivasha Riparian Association
MCN – Municipal Council of Naivasha
NAIVAWASS – Naivasha Water supply and Sewerage Company
NBSI – Naivasha Basin Sustainability Initiative
NEMA – Natural Environment Management Authority
PPP – Private Power Producers
RVWSB – Rift Valley Water Services Board
TDS – Total dissolved Solids
TSS – Total Suspended Solids
UN – United Nations
UNDP – United Nations Development Programme
WAP – Water Allocation Plan
WAS – Water Abstraction Survey
WHO – World Health Organization
WQIB – Water Quality Index for Biodiversity
WRMA – Water Resources Management Authority
WSUP – Water and Sanitation for the Urban Poor
WWF – Worldwide Fund for Nature

1. Introduction

1.1 General

There has been a lot of research around Lake Naivasha in Kenya. This is because Lake Naivasha is an important resource to the local ecology, local economy and international horticulture. Furthermore Lake Naivasha has been classified as a Ramsar site on the 10th of April 1995. The Ramsar convention on wetlands is an international treaty that acts to ensure the commitment of member countries to maintain the ecological character of the wetland. A site will only get the classifications of Ramsar Site if it is an important wetland with a fragile ecosystem (Kenya Wetlands Forum, sd ; The Annotated Ramsar List: Kenya, 2012).
There is an important role for water management in a wetland. The Water Resources Management Authority (WRMA) is responsible for the regulation and conservation of water resources to enhance environmental sustainability. This includes involving all stakeholders around the lake.

WRMA has developed a Water Allocation Plan (WAP) together with the stakeholders to address the shortcomings around the lake. The WAP was developed in a reaction to the increasing concerns on siltation and over-abstraction of ground and surface water (Water Resources Management Authority, 2009). It should provide a legal status to all water abstractions around Lake Naivasha. A Water Abstraction survey (WAS) has been done to support the WAP. The results of WAS have been incorporated in WAP. The WAP is seen as a general success, except for some of its shortcomings in methodology.

The research by de Jong (2011a) showed that the permit coverage of water abstraction in 2011 was poor as only 50% of all abstraction points in the basin have a legal status, but only 8% of all abstractions had a valid permit at that time. Since 2011 huge efforts have been made to increase permit coverage around Lake Naivasha, but there are still illegal abstractions. The biggest problem is that WRMA does not even have an estimate on what the coverage of permits is or how many illegal abstractions remain, because not all abstraction points are monitored. To help with the monitoring water gauges have been installed in nearly all of the big horticulture farms, which have proven to be the biggest abstractor of water around the lake. However small scale illegal abstractions still occur around Lake Naivasha and permits are not always renewed due to several reasons.

Another important factor is that the current WAP regulations during low flow have a severe effect on the abstractors. Current WAP regulations would allow the abstraction of water for irrigation for about 30-90% of the time in a year, although the WAP report indicates 20% as an average. Abstraction with domestic purposes would have been limited to 4-84% per year compared to an average of 5% indicated in the WAP report (2011b).

Both reports describe the problematic situation around Lake Naivasha for the lake itself and for the people depending on the lake as a natural resource. At this time there is no data on what happens behind each water inlet and therefore it is impossible to conclude adequate findings on water efficiency of each farm. Therefore it is important to know how the abstracted water is actually used within a farm. Naturally, this will include the process of adding chemicals to the water, which might address the further deterioration of the water quality in Lake Naivasha (Becht, Environmental Effects of the Floricultural Industry on the Lake Naivasha Basin, 2007).

The Water Efficiency of the irrigation can be linked to the water abstraction that is measured by the water intake points. This is an important step in understanding which water is used where and what for. With this new information a more detailed analysis can be made to increase the knowledge on how the natural resources in Lake Naivasha should be managed by all involved parties.

To get a basic understanding of the impacts of farms around Lake Naivasha water quality should also be assessed. It will be important to know whether the farms around Lake Naivasha cause the water quality deterioration or the farms upstream do so.

Naturally farms also impact other aspects around Lake Naivasha, which, in most cases can be linked to water again. These aspects include, but do not limit to, biodiversity, socio-economics and working and living conditions of employees. The links between these aspects and water are necessary to be able to understand the real problems of excessive water abstraction and deterioration involving the big flower farms around Lake Naivasha (Mekonnen, Hoekstra, & Becht, 2012).

1.2 Problem statement

As already mentioned in chapter 1.1 the biggest problem is the excessive water abstraction (domestic and irrigation) and the water quality deterioration in Lake Naivasha. The excessive water abstraction and water quality deterioration impose effects on different aspects of life around Lake Naivasha. It is however unclear what the effects are of the whole system around Lake Naivasha. Several studies have been done into specified fields around Lake Naivasha but there is a lack of integral approach that covers lake Naivasha and the effects of the horticulture industry around it.

It is important to do a broad an integral study around Lake Naivasha to understand the real effects, although basic, of the horticulture industry around Lake Naivasha. Different effects of the horticulture industry are already known, but these were all specified studies in a specified field. An integral approach, done with the help of monitoring officers of different organisations in Kenya, will help to address the ongoing problems in Lake Naivasha and create a database for further studies.

1.3 Research objectives

The basic objective is to understand the hydraulic processes from water abstractions in Lake Naivasha and there corresponding influences in society. This means including economical, biological and legal aspects of the water usage and efficiency around Lake Naivasha. On basis of the results recommendations are made with the goal to improve the efficiency of water use around Lake Naivasha. These goals are set by ITC and WRMA as a part of IWRAP. The idea is to end up with an integral survey and to collect a broad set of data so that issues involving big flower farms (more than just water issues) can be addressed.

1.4 Research questions

This Research will continue on the work of WRMA (2009) and WAS (de Jong, 2011a) for the water parameters. It will focus on what happens after each water intake point. This includes the process of return flows back in the lake. Furthermore extra non-water parameters are introduced so that the effects of excessive water abstraction and water quality deterioration can be shown. Research questions have been developed to meet the objectives in a structured way. These research questions are limited to the Lake Naivasha Area including the Business Flower Park, which can be seen in Figure 1.

1. What are the hydraulic processes that occur after each water inlet point and what are their corresponding quantitative values?
2. What is the water efficiency around Lake Naivasha?

3. What are the economic effects of increasing the water efficiency around Lake Naivasha and how can the water efficiency be increased?
4. What legal status should water abstractions get so that the human right to water and sanitation (Resolution 64/292) can be achieved and how can an increasing water efficiency help in addressing this issue?
5. What are the results of water quality deterioration on the biodiversity around Lake Naivasha and what can be done to prevent further water quality deterioration?

Some of these questions are follow up questions to different researches, namely de Jong's WAS (2011a), de Jong's review on legal status (2011b), the collection of papers in the book development in Hydrobiology (Boar, Everard, Hickley, & Harper, 2002), the report "Lake Naivasha, Kenya: Ecology, Society and Future" (Harper, Morrison, Macharia, Mavuti, & Upton, 2011) and the report "flowering economy of Naivasha" (Ghawana, 2008).

1.5 Organisations involved

This chapter is used to give a basic insight in the complexity of the IWRAP project. The list of stakeholders involving IWRAP around Lake Naivasha is not complete, but the main stakeholders are described in Appendix I.

1.6 Review of previous work

In this chapter the previous works, on which this research is a follow up, will briefly be described. This description is necessary to get an insight in the already known situation and the follow up research questions.

Thomas de Jong's "Water Abstraction Survey in Lake Naivasha Basin, Kenya" is a review of the legal coverage of the water abstractions in Lake Naivasha Basin. This research learns that around Lake Naivasha measurement devices are installed, but providing the data of abstraction records in WRMA is still lacking. LaNawrua has the most abstraction points and that 74% of the abstraction points have a legal status. Furthermore the report shows that for the region around Lake Naivasha shows that in 2011 584 legal actions should be taken in the LaNaWRUA and 1700 in the whole Lake Naivasha Basin (de Jong, 2011a). This is important for the legal question as it shows that there were still a lot of necessary actions to be taken at that time. As mentioned in chapter 1.1, most actions however have taken place by now, but there is still work that remains to be done. Legal actions might also provide solutions for increased Water Efficiency.

Thomas de Jong's "review Review on riverwater resource monitoring and allocation planning in the Lake Naivasha Basin, Kenya" is a comparison between the real situation and the situation proposed in WAP. This has already slightly been discussed in chapter 1.1, but further explanation is given below. He compared the WAP Flow Duration Curves with the newly composed Flow Duration Curves over the last years. The results show that if WAP regulation had already been applied in the years 2005-2009, abstraction for domestic purposes would have been restricted between 4-84% of the time and irrigation purposes 30-90% compared to the values of 5% and 20% as indicated in WAP. However, the research method is, as in WAP itself, very uncertain as stated by de Jong. The question arises if the current model is suitable for the water allocation planning (de Jong, 2011b). This report is important for the legal questions, because the report states that although there is an allocation planning and therefore a legal status, the method it is based on is very uncertain.

Most of the early ecological history has been summarized in the book "Developments in Hydrobiology; Lake Naivasha, Kenya". It consists of several papers that were written on Lake Naivasha that are all centered on Hydrobiology (Boar, Everard, Hickley, & Harper, 2002). This book is used as a reference for Biodiversity during a certain period around Lake Naivasha.

"Lake Naivasha, Kenya: Ecology, Society and Future" describes the past and current ecosystem of Lake Naivasha. It describes the changes in ecology at Lake Naivasha and tries to describe the cause of these changes. It links the water abstraction of the farms with the changes in ecology. It also provides a description of the different management approaches used to tackle the problem of the changing ecology, but also aspects that actually caused even more changes (Harper, Morrison, Macharia, Mavuti, & Upton, 2011). The paper acts as a reference for biodiversity during a certain period. Furthermore water quality data can be linked to the biodiversity described in Harper's work.

Tarun Ghawana's "Flowering economy of Naivasha" is too broad to describe, but it mainly consists of the economic review of a few sampling farms. It also provides a basic idea of the economic difference between small and big farms. Furthermore it gives a basic insight in what farms provide for their workers besides loan, for example housing, transport, food and water (Ghawana, 2008). The most important aspect of Ghawana's research is his method of collecting the data from the farms and the workers.

Viller's "spatial water quality monitorin and assessment in Malewa River and Lake Naivasha" describes the water quality in Lake Naivasha based on measurements of specific chemicals (2002). These measurements are shown in Appendix II and are used in this research.

Xu's "Water Quality Assessment and Pesticide Fate Modeling in the Lake Naivasha area, Kenya' describes the water quality of effluent points in certain areas around Lake Naivasha. These results are mainly used in chapter 5.6 as a comparison between effluent water and lake water quality (1999).

2 Study area

This chapter will briefly describe the current situation around Lake Naivasha in regards to location, water balance, water quality, land use, economy and ecology.

2.1 Location and description of Lake Naivasha

Lake Naivasha (0. 45^{o}S, 36.26^{o}E) is a lake in Africa's Eastern Rift Valley, covering about 140km^2. Lake Naivasha is the second largest freshwater lake in Kenya and has an altitude of 1890m above sea level. The Malawa River, a perennial river, covers about 80% of the total inflow and the Gilgil Rivers, another Perennial river, covers the other 18%. The Karati River drains the area east of the lake but only flows for about 2 months per year and is responsible for about 2% of the lake's inflow. The area south of the lake does not produce a major runoff reaching the lake. The drainage from Mau Hill and Ebaru infiltrates before it reaches the lake and therefore does not have a major impact on the lake. About 25% of the inflow from both rivers recharges the aquifers and flows to the south and the north of the lake, this is what causes the lake to be fresh (Becht, 2007 ; Thomas, 2011 ; Becht & Higgins, 2003).

West of the lake is Lake Sonachi. Sonachi (also known as Crater Lake) is in the caldera of a small volcano with its own microclimate. A forest covers the walls of the crater. Lake Oloiden is a smaller lake to the south of the lake and is, depending on the lake levels, separated or connected to the main lake. The lake consist of an area of 5,5 km^2 with a volume of 31 million m^3 of water (Lake Naivasha Riparian Owners Association, 1996 ; Becht & Higgins, 2003).

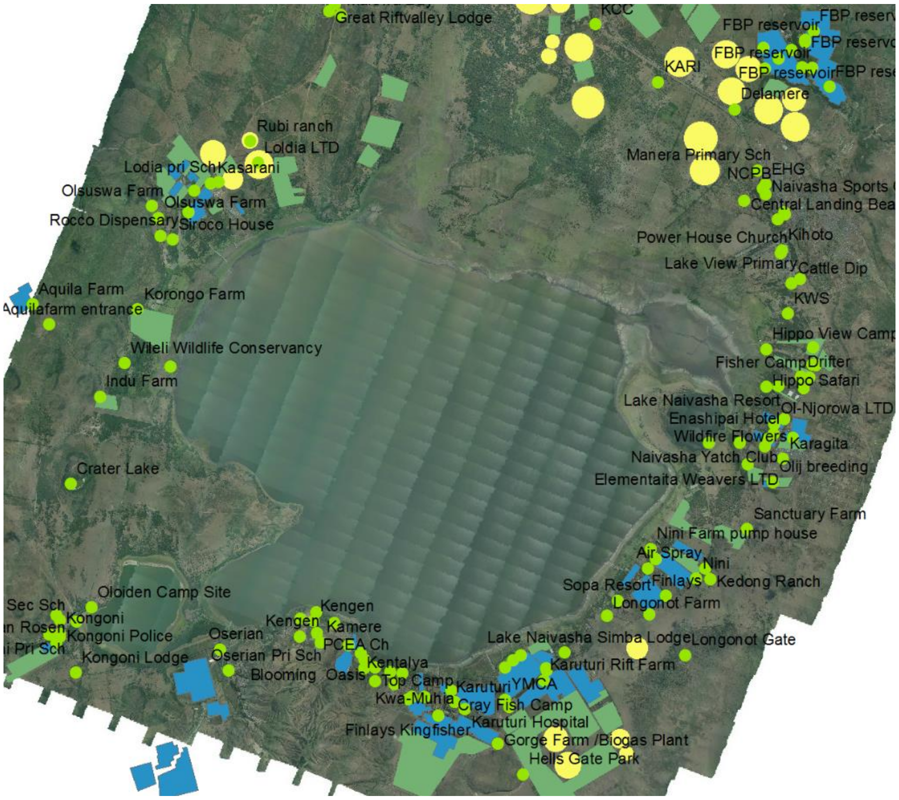

Figure 1- Study area

2.2 Climate

Lake Naivasha basin lies in the Intertropical Convergence zone. Because of the Mount Kenya and Nyandarau range the monsoon winds cast a significant rain shadow over Lake Naivasha during the monsoon season. There are two rainy seasons (bimodal), the first rainy season is from March to May and is called the "long rain", the second rainy season is called "short rains" and occurs from October to November. The latter one brings lesser precipitation than the first one. The dry seasons are from December to February and from June to September.

The annual temperature around Lake Naivasha ranges from 8 ^{o}C to 30^{o}C (Al Sabbagh, 2001). The mean maximum monthly temperature is about 29^{o}C and the mean minimum temperature is about 9^{o}C. The warmest months are generally January, February and March (dry season and start of "long rain" season), where the coldest months are July and August, which are in both in dry season (Mulenga, Analysis of the leaching process in the intensive flower farms around Lake Naivasha, SULMAC Farm case study Naivasha Basin, Kenya, 2002). The average monthly temperature is given in Figure 2.

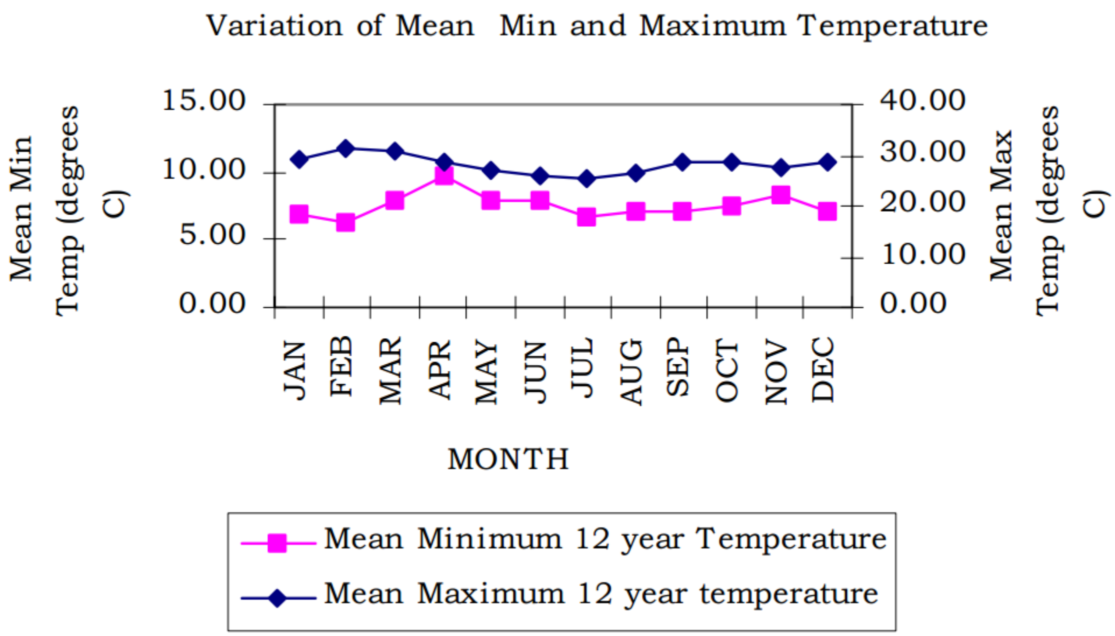

Figure 2 - Minimum and Maximum temperature (Mulenga, 2002)

2.3 Water balance

The water balance has been calculated several times in the last few years (Reta, 2011 ; Becht & Higgins, 2003 ; Pegasys, 2011). The newest version of Reta is further explained, because this version is the upgraded version from the one used in Pegasys (Wambua, *Personal Communication*).

The long term (1932 to 2010) water balance results in a net lake level fall of 5,4 meter over this period. The flow components are given in Table 1.

Table 1 – Long term water budget 1932-2010 (Reta, 2011)

Flow components	Inflow(Mm3/month)	Outflow(Mm3/month)
Precipitation	7.722	0.000
Evaporation	0.000	21.414
Surface inflow	19.366	0.000
Lake water withdrawal	0.000	1.921
Groundwater inflow (Lake seepage in)	1.137	0.000
Groundwater outflow (Lake seepage out)	0.000	5.563
Total	28.225	28.898
In-Out		-0.673

The difference in In-Out indicates that the long term net lake level fall of 5,4m resulted in a lake storage loss of 6,73 * 10^8 m^3 over the period 1932 to 2010 (Reta, 2011).

Interesting to see is the long term water budget before the large-scale abstraction. This water balance is calculated for the period 1934-1983 and is given in Table 2.

Table 2 - Long term water budget 1934-1983 (Gitonga, 1999)

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

As can be seen, there is no big difference in this period, but the lake water level is lower than the calculated lake level as showed in Figure 3.

Figure 3 - Difference between calculated Lake Level and actual Lake Level (Reta, 2011)

The lower lake level and information from R. Becht and S. Higgins (2003) indicates that the biggest change took place in the amount of water abstractions around Lake Naivasha Basin. Results also show that when an abstraction of 60 million m^3 per year is assumed, the actual lake level and the calculated lake level are similar in June 2000. After the year 2000 however, the calculate lake level is again higher than the measured lake level, which might indicate a higher abstraction than 60 Mm^3 per year during that period.

2.4 Water quality

Some studies have been done around the lake to analyse the water quality and some models have been developed to predict the effect of different activities in the catchment on the water quality. Furthermore chemical assessments have been done and their spatial distribution over the lake has been analysed (de Silva, 1998 ; Trinh, 2000 ; Donia, 1998 ; Tiruneh, 2003 ; Villers, 2002 ; Mclean, 2001).

Data regarding water quality at different points in Lake Naivasha in 2002 can be found in Appendix II.

2.5 Land use

The land use around Lake Naivasha has changed dramatically during the last years, as can be seen in Figure 4. The change of bushland to grassland and the increasing amount of farms (including horticulture) is most notable.

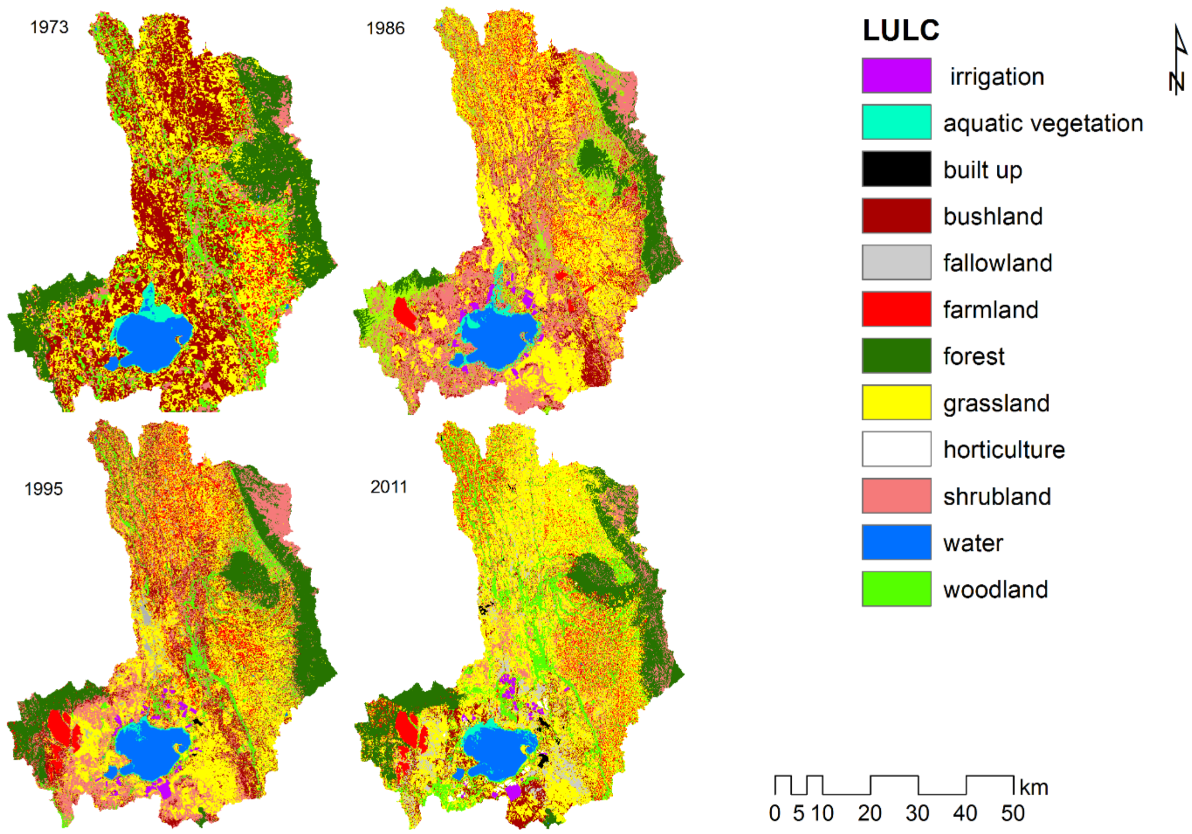

Figure 4 - Land use (Odongo, 2014)

2.6 Economy

The economy of Lake Naivasha has been described in Ghawana's "Flowering Economy of Naivasha" (2008) and Ahammad's "Economy versus Environment: How a system RS & GIS can assist in decisions for water resource management" (2001).

The horticulture industry is responsible for a big share of the local economy in Naivasha. The most prominent effect of the farms is through direct and indirect employment, because a great deal of the wages paid to the employees is spent in Naivasha.

For the larger farms revenue is ranging from 4,5 million Ksh per year to 765 million Ksh per year and a total of 61535 million Ksh. Smaller farms have a revenue of 40 thousand Ksh to 2,4 million Ksh per year. This means the inequality between the big farms and the smaller farms is quite big. The inequality around Lake Naivasha becomes even bigger when looking at the employee's wage, ranging between 100 Ksh per day to 185 Ksh per day (Ghawana, 2008).

As mentioned, the inequality between the revenue of the large farms (and profit) and the wages of the workers on these farms is high. Therefore some farms have made arrangements for the workers (e.g. housing, free transport and food). However, not all farms have made these arrangements and sometimes the arrangements are poorly executed.

2.7 Ecology

The ecology of Lake Naivasha has been broadly described in the book "Developments in Hydrobiology, Lake Naivasha, Kenya" (Boar, Everard, Hickley, & Harper, 2002) and in "Lake Naivasha, Kenya: ecology, society and future" (Harper, Morrison, Macharia, Mavuti, & Upton, 2011).

The currents lake ecosystem is highly influenced by the physical degradation of the papyrus tree during the last century. The papyrus tree acts as a biophysical filter, but due to the lack of this filter, nitrates and phosphates have made the lake highly eutrophic since the 1990s (Kitaka, Harper, & Mavuti, 2002 ; Harper, Morrison, Macharia, Mavuti, & Upton, 2011).

The fish population in Lake Naivasha mainly consists of *Cyprinus carpio* (common carp), *Micropterus salmoides* (large-mouthed bass) and *Procambarus clarkii* (Louisiana crayfish). These species are all alien species to Lake Naivasha and have been introduced in the last century for different reasons (accidentally or for fishing purposes) (Harper, Morrison, Macharia, Mavuti, & Upton, 2011).

In the wetlands and riparian zones a variety of animals can be found, which includes, but is not limited to, buffaloes, water bucks, giraffes, hippos, impala and zebra's (Urassa, 1999).

All the biodiversity around the lake is linked internally (e.g. the *E. crassipes* and the *P. clarkii*) and is linked to the water quality and the water level in Lake Naivasha (Harper, Morrison, Macharia, Mavuti, & Upton, 2011).

3 Methodology

The several concepts and theories that are being used need some clarification and explanation. Some of these concepts are fairly simple, while others are more complex. This chapter only contains the essentials behind each concept, which can be used as a built-up to the survey in chapter 4.1.

Water efficiency as mentioned in the research questions in chapter 1.4 is defined as the water footprint of a crop within a farm and the ISPE.

3.1 Water footprint

The water footprint consists of three components, namely a blue, a green and a grey water footprint. The blue and the green water footprint are based on the water use, while the grey water footprint is based on the pollution.

3.1.1 Blue water footprint

The blue water footprint is based on the fresh surface or groundwater use of a crop. The blue water footprint of a crop is defined as:

$$WF_{Blue} = \frac{CWU_{Blue}}{Y}$$

CWU_{blue} is considered to be the total blue crop use over the whole growing period. While the blue crop evaporation is difficult to calculate, because data of total crop evaporation is normally estimated, an effort can be made to estimate the blue water footprint. In chapter 5.1.2 the different estimations of crop evaporation are given. These are used when measured data is not available.

For greenhouses the whole crop evaporation will be blue when rainwater is not being collected. If rainwater is being harvested, the amount should be considered in the blue water footprint except when the method increases the soil water holding capacity. If the method of harvesting rainwater is increasing the soil water holding capacity, it should be considered in the green water footprint.

Water recycling and reuse should be considered when calculating the blue water footprint. The final CWU should be the consumptive use of the crop minus the recycled water for that crop. When such data is available on-site the blue water can more accurately be calculated (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011).

3.1.2 Green water footprint

The green water footprint is an indicator of the use of precipitation water. It is the amount of precipitation that does not run off or recharge the groundwater, but is used for the crop growth. The green water footprint is defined as:

$$WF_{Green} = \frac{CWU_{Green}}{Y}$$

CWU_{green} is the total green crop water use over the whole growing period. Y is the crop yield, which should be calculated the same way as in the blue water footprint.

Differentiating the blue and green water footprint is primarily an estimation and not always gives reliable information. However, the distinction between these water footprints is very important, because the hydrological environmental and social impacts are different for the use of groundwater and surface water or the use of rainwater. Due to the nature of the study area, in most of the bigger farms the calculations will pose no problem (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011).

3.1.3 Grey water footprint

The grey water footprint is a degree of fresh water pollution. The grey water footprint is defined as “the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards” (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011). The grey water footprint for a crop is defined as:

$$WF_{Grey} = \frac{(\alpha \times AR)/(c_{max} - c_{nat})}{Y}$$

Where AR is the chemical application rate per hectare, C_{max} is the maximum acceptable concentration and C_{nat} I the natural concentration of the pollutant. α is the leaching-run-off fraction which can either be a fixed fraction (tier 1), a standardized and simplified model (tier 2) or a sophisticated regional model (tier 3). In this study the tier 1 calculation is used where α is a fixed fraction. For an estimation of α the report “Grey Water Footprint Accounting, Tier 1 Supporting Guidelines” (Franke, Boyacioglu, & Hoekstra, 2013) is used.

3.2 Irrigation System Performance Efficiency

The ISPE can be seperated into different efficiencies namely the Water Conveyance Efficiency, Application Efficiency, Storage Efficiency and Seasonal Irrigation Efficiency (Howell, 2003).

3.2.1 Water Conveyance Efficiency

The Water Conveyance Efficiency is defined as the ratio between the water that reaches a farm and the amount of water that is diverted from the water source. It is typically noted as

$$E_C = 100\frac{V_f}{V_t}`$$

where V_f is the amount of water that reaches the farm and V_t is the amount of water that is withdrawn from the source, hence the water abstraction (Howell, 2003).

The main water losses that occur between the abstraction point and the actual irrigation happens in the reservoirs. Water from these reservoirs evaporates and is lost from the water system in the far. Apart from evaporation occasional spillages occur, but they are not significant and are usually the result of breakdowns. These breakdowns are fixed quickly, as the broken machines have a major impact on the farm at those times. These spillages are not taken into account for the Water conveyance efficiency as they are incidental and usually very small.

The water evaporation rate from an open-water (lake) in Naivasha is 6,43 mm/day (Reta, 2011). It is assumed that this rate is the same for smaller open-water storage reservoirs, even though there is some evidence that these evaporation rates are different, it is not covered in this report (Finch & Hall, 2001). The water conveyance efficiency formula would then become:

$$E_c = 100\frac{v_f - \frac{6{,}43}{1000} \times A_s - IS}{v_f} = 100 * \left(1 - \frac{0{,}00643 \times A_s - IS}{v_f}\right)$$

Where,

v_f	Abstracted amount of water (m^3/day)
A_s	Area of reservoirs (m^2)
IS	Incidental spillages (assumed 0) (m^3/day)

3.2.2 Application Efficiency

The Application Efficiency is defined as the ratio between the amount of water that the crop needs (crop evapotranspiration) and the amount of water that reaches the farm typically noted as

$$E_a = 100\frac{V_s}{V_f}.$$

Where V_s is the amount of water that is needed by the crop, hence the crop evapotranspiration (Howell, 2003).

The crop evaporation rates used are 2,174 for indoor crops, as found by the Stanghellini model using the FAO's average data. For open-field evaporations of 3,344 are used, as found by multiplying the evaporation rates in greenhouses by $\frac{1}{0{,}65}$, which coincides with the average data found in the FAO database (Mpusia, 2006). In some occasions and years crop evaporation might be higher or lower, but the equation is based on an average year. The application efficiency formula becomes:

$$E_{a,Greenhouse} = 100 \times \frac{0{,}002174 \times A}{v_f}$$

$$E_{a,Open-field} = 100 \times \frac{0{,}003344 \times A}{v_f}$$

where,

v_f	Abstracted amount of water (m^3/day)
A	Crop area (m^2)
E_a	Application efficiency

3.2.3 Water Recycling Efficiency

If farms reuse water (for example in hydroponics) then the water recycling efficiency should also be taken into consideration for the irrigation efficiencies. Therefore an efficiency is introduced as:

$$E_{recycling} = \frac{Recycled\ water}{Abstracted\ water + Recycled\ water}$$

This recycling efficiency is taken into account per farm to indicate the irrigation performance. This can only be done when the recycled/reused water quantity is known by the farm.

3.3 Evapotranspiration

In both water footprint and irrigation system performance efficiency the crop evapotranspiration has a central role. Because methods of measuring evaporation are often tedious and data around Lake Naivasha on measured evapotranspiration is limited, the estimation are discussed in this chapter.

Because the main part of the study is based on farms with greenhouses, appropriate evaporation models should be chosen, based on greenhouses. The models used in the greenhouses are based on Wan Fazilah Fazlil Ilahi's research on "Evapotranspiration Models in Greenhouses" (2009). It is suggested to base the evaporation model on the greenhouse technology and the available information.

Through the evapotranspiration models given in "Evapotranspiration Models in Greenhouses" the reference evapotranspiration can be calculated. The reference evapotranspiration should be multiplied with a crop coefficient based on the type of crop. Due to the limited data on crop coefficients for very specific crops only a few of the models mentioned in Ilahi's research can be used. The crop coefficients for most of the crops are given in "Crop coefficient of 40 varieties" (Irrigation Water Management Research Group).

Because of the limited data on crop coefficients Ilahi's research is used as a guideline, but the actual models will be limited to the FAO Penman model, the FAO Penman-Monteith Model, the FAO Radiation model, the Hargreaves model and the Stanghellini model. The models are briefly explained in Appendix III.

3.4 Link with non-water parameters

Water has all kinds of links in society and Lake Naivasha is no different. In order to fully understand the problem behind over abstraction and the measurements that can be taken one should consider non-water parameters with a link to the water usage. Furthermore a better assessment of Irrigation Efficiency can be made using these parameters.

3.4.1 Economic

Economic effects can easily be linked to the water footprint and the ISPE. Revenue and profit is linked to water usage per hectare. Furthermore costs for investing in more efficient irrigation systems are analysed and linked to water usage, to see whether it is economically interesting to invest in water conservation measures.
The economic calculations are mainly based on previous researches combined with economic data acquired from two farms. Through recalculation of the data gotten by several farms to a 20 hectare farm (assuming that the costs per hectare are equal) and by recalculating the data gotten from researches considering soil-based, greenhouse, hydroponic and aeroponic farms to a general 20 hectare farm an overall assessment is made.

3.4.2 Legal and Human Rights

Legal issues regarding water and Human Rights are closely related. In this report the human right to water and sanitation (Resolution 64/292) by the UN is used. The UN has developed a set of standard rules regarding water. These rules should apply for any person in the world, disregarding ethnics or geographical location. The UN states that drinking water and sanitation water should be:

- Sufficient: according to the WHO, 50 to 100 litres of water per person per day are needed.
- Safe: water required for domestic use must be safe, which means free from micro-organisms, chemical substances and radiological hazards. The standard used in this report is the World Health Organization Guidelines for drinking-water quality.
- Acceptable: water should be of an acceptable colour, odour and taste. All water facilities and services must be culturally appropriate and sensitive to gender, lifecycle and privacy.
- Physically accessible: According to WHO, the water source should be within 1000 meters and collection time should not exceed 30 minutes.
- Affordable: the costs for clean water and water facilities must not exceed 3 percent of the household income, as suggested by the UNDP.

(United Nations General Assembly, 2010 ; UN Committee on Economic, Social and Cultural Rights, 2002 ; United Nations, sd)

Furthermore the available water infrastructure is analysed, as there is a big difference of available water infrastructure around Lake Naivasha. This is important as the main improvements can be made in the technical aspects (with a legal background).

3.4.3 Biodiversity

The link to biodiversity and water abstraction has already broadly been described in “Lake Naivasha, Kenya: Ecology, Society and Future” (Harper, Morrison, Macharia, Mavuti, & Upton, 2011). The link to water quality will mainly be done by calculating the WQIB and by a broad description of the current situation in Lake Naivasha, which can also be seen as a discussion for the using the WQIB. The WQIB is an index which is calculated on a global scale, based on the most basic chemicals in the water. The WQIB can be calculated for the different years that the Dissolved Oxygen, Electrical Conductivity, pH, Temperature, Nitrogen and Phosphorus levels are known. These parameters have been proven to have good correlations to biodiversity and are often measured (Carr & Rickwoord, 2008).

The WQIB is calculated as a proximity to target index, by using the expected parameters compared to the actual parameters. The expected parameters can be found in Table 3.

Table 3 - Targets WQIB (Carr & Rickwoord, 2008)

Parameter	Target	Details
Dissolved oxygen	6 mg L^{-1}	DO must not be less than target when average water temperatures are > 20 °C
	9.5 mg L^{-1}	DO must not be less than target when average water temperatures are ≤ 20 °C
pH	6.5 – 8.5	pH must fall within target range
Conductivity	500 µS cm^{-1}	Conductivity must not exceed target
Total Nitrogen	1 mg L^{-1}	Total nitrogen must not exceed target
Total Phosphorus	0.05 mg L^{-1}	Total phosphorus must not exceed target
Temperature	Latitude dependent	Temperature must not exceed modeled temperature

Data for this analysis is not collected during the survey because of limited time and analysis possibilities, instead historical data and data given in Appendix II is used.

4 Data collection

Gathering the necessary data for the analysis given in chapter 3 is done through available data and three types of surveys. These methods are necessary for analysis and answering the research questions.

This chapter will provide an overview on the types of surveys and the strategy used for gathering the data. The results of these surveys and measurements are given in chapter 5.

4.1 Survey

Because of the complexity of the necessary data and the focus on different aspects four surveys have been compiled. The first three surveys consist of surveys for farms, surveys for schools and surveys for people working on a farm. The last survey is actually a set of parameters to measure the riparian land quality around Lake Naivasha. The reason for conducting each survey is given in their corresponding chapters (4.1.1, 4.1.2, 4.1.3, 4.1.4).

4.1.1 Farm survey

The farms provide important information on their water usage and their water efficiency. Furthermore farms can provide information on the situation of their workers, which, in combination with the survey for the workers provided in chapter 4.1.2, will help to understand the situation the workers live in and detect any biases. These biases can be filtered out because farms might give different information about their workers than the information that the workers give about their situation. Therefore it is important to consult both parties about that matter.

Apart from the above, farms around Lake Naivasha usually measure other parameters (e.g. water quality and salinity) as well, which can be used to determine both the water footprint and the irrigation efficiency.

The actual survey and the necessary explanations for some of the questions are given in Appendix IV.

4.1.2 Worker survey

The workers of farms provide important information on their living conditions in relation to the human right for drinking and sanitation water. In combination with the farm survey given in chapter 4.1.1 an idea on the availability and quality of water for farm workers is created.

The actual survey and the necessary explanations for some of the questions are given in Appendix V.

4.1.3. School Survey

The schools provide important information on the living conditions for the children around Lake Naivasha. Children spend most of their days in the school, so it is necessary to get an idea of the water supply within schools when you are considering water usage per day for a household of workers.

The actual survey and the necessary explanations for some of the questions are given in Appendix VI.

4.2 Strategy

The actual farm survey consists of two parts. The first part are general question asked in relation to the whole farm, the second part are question based on location within each farm. Furthermore there are two types of collection methods used during the survey. For almost all open questions the traditional paper method is used, while for closed questions, or questions that can be coded, the ESRI Collector for ArcGIS is used (ESRI, 2014). The questions are read by the interviewer and the interviewee answers them, while the interviewer writes, this means the interviewee does not receive the interview (on paper or in the software) during the interview.

5 Results

5.1 Hydraulic processes during irrigation

Around Lake Naivasha there are three types of systems with their own corresponding hydraulic processes. The first system is open-field farming with pivot irrigations, the second system is a soil-based greenhouse farming and the third system is the hydroponic. Each system has some similar hydraulic flows, but because the systems are completely different they are described per system. The quantities of most of these flows are described in chapter 5.1.2.

5.1.1 Hydraulic flows

The hydraulic flows that occur in a system depend on the type of hydraulic system. This the types of hydraulic systems also determine the means of recycling water. The three types of systems (hydroponic, greenhouse soil-based and open-field farming) and their flows are shown in Figure 5.

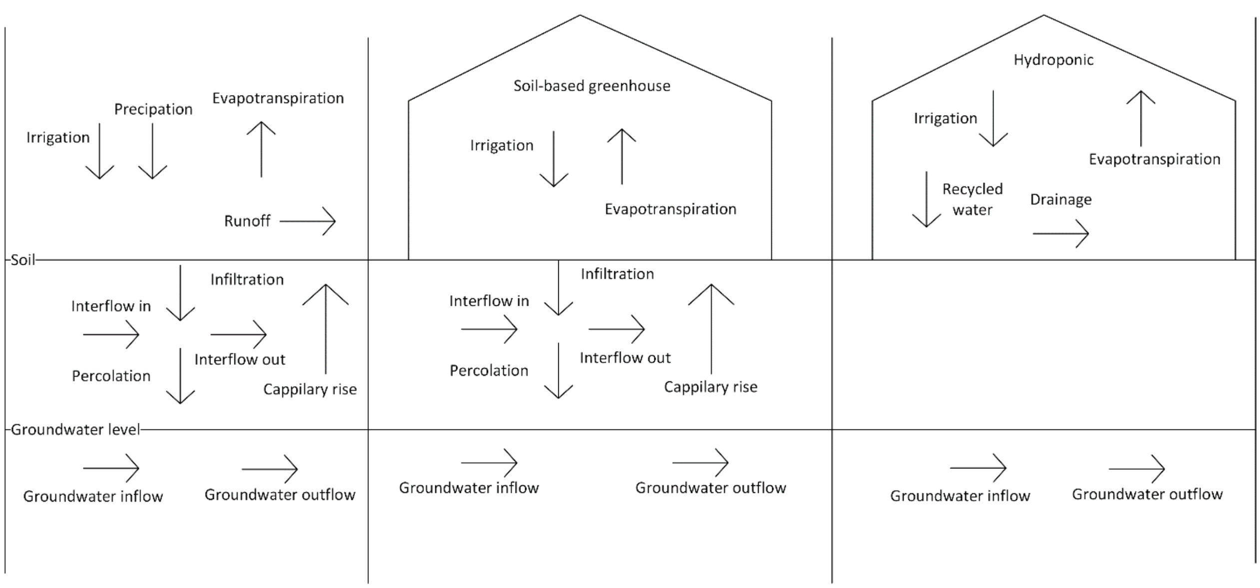

Figure 5 - Different systems and their flows

5.1.2 Quantities of Hydraulic flows

In this chapter the quantities of the hydraulic flows are described based on previous research and current data. Some of these quantities are used for the calculation of the crop evapotranspiration, the water footprint and the ISPE. They are described per water flow, but different water systems are mentioned within each flow.

Infiltration

Infiltration is primarily based on measurements done in Finlays Kingfisher in the report "Soil Investigation on the Sulmac Farm, Naivasha, Kenya" (Girma & Rossiter, 2001). The report shows a big difference in soil infiltration, but all infiltration rates high to very high. Infiltration is only important in a soil-based greenhouse or in open-field farming as it is usually the only constant outflow for a farm.

Precipitation

Rainfall is primarily measured by the farms themselves, therefore most rainfall measurements are based on the local conditions. Furthermore the average rainfall is given in the FAO ClimWat database. Rainfall provides an important flow for open-field farming and is strongly linked to the runoff within a certain area. For the purpose of calculating the green water footprint and the estimation of ET_c, the FAO ClimWat database is used if there is no, or insufficient, local data. The climate measurements of the FAO ClimWat database can be found in Appendix VII. Rainfall flows are only important when rainwater is harvested or in the situation of open-field farming as rainwater is often redirected to the wetland in the case of greenhouse cultivation.

Capillary rise

Because the groundwater level is generally very deep and capillary rise is relatively small it is neglected in the evapotranspiration calculation. Both FAO's AquaCROP and the paper "soil-water-plant Relations" show a near to zero capillary rise speed and amount. The program AquaCROP predicts the rise to be near zero due to the porous ground and the deep groundwater level (Ritzema, 1994 ; Food and Agriculture Organization of the United Nations, 2012).

Interflow

As the soil is very porous and the infiltration rates are high (and therefore almost vertical), interflow can be neglected as most of the infiltrated water will reach the groundwater level relatively quickly. Furthermore over small areas the inflow and outflow can be assumed equal.

Runoff

Runoff is only important for the open-field farms, because rainwater runoff does not reach a crop in a greenhouse system. Most farms divert the rainwater directly to a point outside the farm by using trenches, so most rainwater will become runoff in a greenhouse based farm. Direct runoff from a farm is generally small, because of the high infiltration rates, even in the steady state. Therefore runoff will be neglected when assessing on the individual farm level. Furthermore on a small area the runoff inflow and outflow can be assumed equal.

Groundwater flows

On small areas the inflow and outflow of groundwater can be assumed equal which means the groundwater flow will have no effect on the Evapotranspiration calculation or the irrigation efficiency. An indication of the flow speeds can be given through previous studies. The flow rates on the north side of Lake Naivasha is 0,97 $m^3\ s^{-1}$, while the flow rate on the south side of the lakes are about 2,58 $m^3\ s^{-1}$ (Reta, 2011 ; Hernandez, 1999).

Irrigation

Irrigation around Lake Naivasha mainly consists of drip-irrigation, although some forms pivot irrigations still exist. Drip irrigation is more efficient than pivot irrigation in terms of water usage and as most farms are placed in greenhouses, there is no option for pivot irrigation. An example of the water usage for irrigation of a farm is given in Appendix VIII.

Evapotranspiration

Evapotranspiration can be calculated in several ways, including local direct measurements, using different types of models or through the use of a water balance. As not all data is always known some assumptions have to be made or general data is used. The assumptions of the Evapotranspiration calculations are shown in Appendix IX, while the results are shown in Table 4.

Table 4 - Crop evapotranspiration

ID	FAO Penman (mm/crop cycle)	Stanghellin (mm/crop cycle)	Water balance (mm/crop cycle)	FAO Penman-Monteith (mm/crop cycle)	65% assumption (mm/crop cycle)	Measured outside (mm/crop cycle)
1	210,22	171,47	192,87	330,15	263,81	
2	130,97	119,57		218,34	183,95	214,39
3	192,83	160,16		298,11	246,41	177,15
AVG	178,01	150,40	192,87	282,20	231,39	195,77

The calculations show big differences in crop evapotranspiration. These differences are mainly caused by the combined use of local and average data. Especially the solar radiation varied a lot between the local and average data, which is shown in the variety in crop evaporation on the 3 samples. For outside samples the average is about 200 mm/crop cycle measured, while the modelled value is 250 mm/crop cycle. The outside model focuses heavy on average data however, and the measured data is local. The modelled crop evaporation per crop cycle is about 150-175 mm inside the greenhouse.

5.2 Water Footprint

The water footprint that is assessed in this report is based on the water footprint of a crop given in the report "the water footprint assessment manual" (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011). This means the crop evaporation will account for the footprints. For open-field farms the blue and green water footprint is combined, as they are difficult to split. For greenhouses, all irrigation water will be considered the blue water footprint.

5.2.1 Blue water footprint

The blue water footprint is described as the freshwater and groundwater use for irrigation. The irrigation consists of either open-field irrigation, drip irrigation in greenhouses or drip irrigation in hydroponics. The latter one recycles water and this should be assessed when the blue water footprint is calculated. The water footprint is calculated by dividing the total water use per year by the yield per year.

The input parameters for crop water use are given in Table 5. Farm 1 and 3B are hydroponic based arms, farm 2A, 3 and 4 and 5 are greenhouse farms. For all farms the open-field situation is also calculated. The yield statistics of each farm are shown in Table 6.

Table 5 - Evaporation Input

ID	Design	FAO Penman (mm/crop cycle)	Stanghellin (mm/crop cycle)i	Water balance (mm/crop cycle)	FAO Penman-Monteith (mm/crop cycle)	65% assumption (mm/crop cycle)	Measured outside (mm/crop cycle)
1	Hydroponic	210,22	171,47	192,87			
2	Greenhouse	130,97	119,57				
3A	Greenhouse	130,97	119,57				
3B	Hydroponic	130,97	119,57				
4	Greenhouse	192,83	160,16				
5	Greenhouse	130,97	119,57				
Open-Field	Open-Field				250*	220*	190*

*Average calculated on all 5 farms

Table 6 - Yield statistics

ID	Yield (stems/m²/year)	Weight (kg)	Yield (kg/m²/year)
1	200	38	7,6
2	210	25	5,25
3A	200	25	5
3B	240	38	9,12
4	200	25	5
5	180	25	4,5
Open-field	160	25	4

The resulting blue water footprint is given in Table 7 in m^3/kg. The blue water footprint for the open-field situation was calculated by calculating the total water footprint minus the green water footprint.

Table 7 - Blue water footprint

ID	$WF_{Blue,}$ Penman (m^3/ton)	$WF_{blue,}$ Stanghellini (m^3/ton)	$WF_{blue,}$ Water balance (m^3/ton)	$WF_{blue,}$ Penman-Monteith (m^3/ton)	$WF_{Blue,}$ 65% assumption (m^3/ton)	$WF_{blue,}$ measured ET (m^3/ton)
1	1835,7	1497,3	1684,1			
2	1655,6	1511,4				
3A	1738,4	1587,0				
3B	953,1	870,1				
4	2559,4	2125,8				
5	1931,5	1763,3				
open-field				2151,7	1893,5	1635,3

The water footprint of the two hydroponic farms are very different from each other. This is mainly the effect of different data usage. The data of the 3B farm is an average of the FAO CLIMWAT database, while the data from farm 1 is local data, where temperatures and solar radiation (and therefore Evapotranspiration) were higher than an average year. It can be concluded that based on average data, the water footprint of a hydroponic is lower than that of a soil-based greenhouse or an open-field based farm.

The differences between farm number 4 and the other soil-based systems is that this farm has a high water use compared to the other farms. The reason for this high water use could be that the farm consists of partly open-field cultivation and drainage is high in this farm.

5.2.2 Green water footprint

The green water footprint only applies to open field farming, because it consists of the rainwater use of a crop. The rainwater on greenhouse areas is not collected in the way of increasing the soil-holding capacity and is therefore not considered in the green water footprint.

The assumptions made in chapter 5.1.2 results in the a green water footprint for 1996 m^3/kg in the FAO Penman-Monteith situation, 1756 m^3/kg in the 65% assumption situation and 1516 m^3/kg in the measured situation.

5.2.3 Grey water footprint

The grey water footprint is calculated using the standards that are shown in Appendix X. The differences are calculated for Phosphorous and Nitrates. This is done by using the applied rates of 2 weeks collected from a hydroponic farm. All other data was lacking and far from sufficient. The data is somewhat flawed as the hydroponic farm does not have effluent water from the irrigation process as it is a closed system. It will be used as a reference for a soil-based greenhouse system however, as no actual data was collected from these farms regarding the fertilizer and pesticide use.

Table 8 - Grey water footprint

	Avg. Fert applic rate	Area	Total fertilizer applied	Leaching runoff	Leaching	Max conc.	Total WF roses	production	Wf_{grey}
Units	kg/ha	ha	ton/year		ton/year	mg/l	m3/year	ton	m^3/ton
Nitrate	2716,29	1	2,72	0,10	0,27	10,00	27162,92	76,00	357,41
Phosphorous	503,95	1	0,50	0,03	0,02	1,00	15118,60	76,00	198,93

The Leaching runoff fraction was retrieved from the report "grey water footprint accounting tier 1 supporting guidelines" (Franke, Boyacioglu, & Hoekstra, 2013). The guidelines were retrieved from Villers report and "the environmental management and co-ordination regulations of 2006 (Villers, 2002 ; Kibwana, 2006).

The water footprint of a 20 hectare farm with a given yield are given in Table 9.

Table 9 - Total grey water footprint

	Yield (stems/m^2/year)	Weight (gram)	Yield (kg/m2/year)	Production (kg/year)	Production (ton/year)	$Cwu_{grey,}$ Nitrate (m^3/ton)	$Cwu_{grey,}$ Phosphorous (m^3/ton)
Hydro ponic	200	38	7,6	1520000	1520	543263,2	302373,6
Green house	200	25	5	1000000	1000	357410	198930
Soil	180	25	4,5	900000	900	321669	179037

This data however is based on a hydroponic farm, so the water footprint that is given is low, because the hydroponic uses less fertilizers. If calculated for the actual hydroponic, the water footprint would be 0 as it is a closed system.

5.3 Irrigation System Performance Efficiency

The irrigation System Performance Efficiency can be divided in several equations, as can be seen in chapter 3.2. These measurements are important to address current issues and discuss improvements to reduce spillages and water losses in farms.

Water conveyance efficiency

Because data on area of the storage reservoirs is not known for most farms, only two examples will be given on the Water Conveyance Efficiency. For a farm that abstracts 30000 m^3 water per month and has an average of 600m^2 of storage, the Water Conveyance Efficiency is 99,6%, due to a loss of 119 m^3 water. For the Flower Business Park the storage area is about 13100 m^2 (based on remote sensing) and their water abstraction in 2010 was 12525 m^3/day. This means their Water Conveyance Efficiency was 99,3%.

Even for farm (or place) with a huge reservoir size, the relative loss is extremely small. It would be simple to reduce this loss by placing a sheet on top of the water. This will reduce the evaporation from the reservoirs and therefore increase the Water Conveyance Efficiency as the losses between irrigation and pumping decrease.

Application Efficiency

The application efficiencies of the different farms are given in Table 10. It is assumed that 70% of the water abstracted is used for irrigational purposes. The open-field rates could not be given as it is based on a theoretical farm and no water abstraction data was collected.

Table 10 - Application Efficiency

ID	Size (HA)	Water use (m3/day)	Application efficiency (%)
1	21,0	719,9	90,7
2	23,0	1341,7	37,3
3	72,0	4517,8	34,6
4	100,5	17269,7	14,7
5	22,0	2115,4	22,6

The high efficiency of farm 3 can be described due to the fact that this was measured on a hydroponic, without using the recycled water, the expected value of application efficiency would be 100%, as hydroponics are closed systems, due to spillages and errors in the measurements the 90% is explained. Generally the efficiency for greenhouses appears to be between 20-40%. The biggest loss in water application efficiency in the infiltration, which in high in Naivasha. However, the efficiency appears to be on the low side, which can be explained by the fact that the FAO database weather is a bit colder than the average weather found in the measurement stations during the last years. The warmer weather would increase crop evapotranspiration and therefore application efficiency. The last farm has a low application efficiency as it is partly based on open-field and partly on greenhouse, furthermore older data was used for that farm. Data from “Mpusia” shows that the application efficiency for that farm is around 40-50% (2006).
The best way to increase application efficiency is to go to hydroponics, whether this is economically also interesting is shown in chapter 5.4.

Water Recycling Efficiency

The water recycling efficiency is the ratio between the total amount of water used and the recycled water. Recycling is a difficult definition, as it could be argued that farms that let their water infiltrate in the groundwater are also recycling, but in a slower way. Recycling is considered the direct re-usage of wastewater within the farms. Because open-field farms and greenhouse based farms let their water infiltrate, only hydroponics recycle water according to this definition. The recycling rate of a full hydroponic farm was about 36,5% on average. Of course not only the water gets recycled but also the fertilizers. The recycled water already had an EC of 1,2, while for irrigation only 1,8 was necessary in that farm.

The Irrigation performance efficiency does not differ a lot per farm. It does differ a lot per farming system however, as can mainly been seen in the Application Efficiency. Furthermore the hydroponics that have a high application efficiency also have a significant water recycling efficiency, while other systems have no wastewater recycling. The water conveyance efficiency is generally small, but could easily be prevented by covering up reservoirs with a sheet, no matter what system the farm is on.

5.4 Economic effects

There are several methods of increasing the water efficiency around Lake Naivasha, most of them are based on technology or simple adaptions in water use. These technologic adaptions often have its effects on other aspects of the farm as well, besides purely water usage. These aspects (for example fertilizer use) are also considered as economic effects of increasing water efficiency around Lake Naivasha. This chapter solely focuses on the farms around Naivasha, domestic water efficiency is described in chapter 5.5. The technical methods have a big range in terms of implementations, some being very costly and probably not suited for Kenya, others are relatively easy to implement. However, for farms it is the case to gain profit, and since water is extremely cheap in Kenya, it is difficult to invest in water saving measures. The best techniques are the ones that safe fertilizers and pesticides, as they are a much bigger cost for farms. Several water saving techniques and their costs and benefits are shown in this chapter. In the economic calculations data from Nini farm, van den berg farm and Panda flower farm is used as reference and recalculated to a soil-based greenhouse farm of 20 hectare.

The results found from several studies are shown in Table 11. These results are based on an increase of costs/income in Ksh based on the previous technology. As can be seen a lot of data is missing because it proved to be difficult to acquire adequate financial information of the farms. A broader assessment, including the references and further explanation is given in Appendix XI.

Table 11 - Cost Breakdown

Costs	Pivot	Drip irrigation	Greenhouse	Hydroponic	Aeroponic
Water usage (Ksh/year)	0,00	60.000,00	108.000,00	300.000,00	
Investments (Ksh)	0,00	-176.000,00	-300.000.000,00	-35.000.000,00	
Yield increase (Ksh/year)	0,00			150.000.000,00	150.000.000,00
Fertilizer cost (Ksh/year)	0,00			-40.000,00	
Production costs (%)	0,00				-28,00%
Profit (%)	0,00				90,00%

It should be noted that greenhouse cultivation does increase yield, but the exact amount is unknown. Several reports show that the increase in technology also increases profit. However, as shown in Appendix XI, it was not always clear in Naivasha whether increase in technology also increases profit. Furthermore Aeroponics seem not realistically achievable at this time.

Rainwater harvesting

Rainwater harvesting is a far simpler method of saving water and increasing water efficiency than the hydroponics or aeroponics. It can mainly be implemented on the greenhouse farms as they already collect the rainwater, but let it runoff through the wetland and back into the lake, together with their effluent water. Only rainwater will not be sufficient for the daily operations, but it will lower the amount of abstracted water. Especially when the WAP regulations apply (so when the lake level is low), rainwater can help farms to reduce water shortage for irrigation purposes, as rainwater harvesting does not require a permit.

One reason the farms do not harvest rainwater is the large area that is needed for storage. Because land is expensive and the area is regarded as a loss (because water is cheap in Naivasha). It would be really easy for greenhouse farms to collect the rainwater, but because it is more profitable to use the area for greenhouse cultivation, it is not done at this time. If water prices go up it might become profitable as the investment is really small, but farms will not use rainwater unless they have the extra space or the area that is needed for storage is worth more than using that same area for greenhouse cultivation.

Not all these water saving measurements are easily implementable and economically interesting at this time. Individual farms can have some improvements on the water efficiency, but there is general not a huge spillage or loss of water. Generally the best and easiest improvement would be to focus on rainwater harvesting, the transitions from pivots into drip-irrigated greenhouses and for some farms the transitions into soil-based hydroponics. At this time Naivasha is not ready for a full hydroponic (with no medium) or an aeroponic and economically it is not interesting either.

5.5 Human rights and legal issues

Increasing water efficiency around Lake Naivasha includes increasing water efficiency for domestic usage and water availability for domestic usage. Before assessing how to increase the water efficiency for domestic usage the current water availability must be assessed. Furthermore water abstractions of the farms also have its influence on domestic abstractions, as can be seen in the legal rules of the WAS. The UN guidelines given in chapter 3.4.2 will be used as the criteria for water availability for domestic availability. Because of the limited amount of time only 11 work surveys have been conducted, however looking at the current status of water infrastructure in the poor areas around Lake Naivasha recommendation can be made. Furthermore surveys in schools have been conducted as the children of the workers spend a significant time in the schools. The results of the school and worker survey are shown in Appendix XII. Apart from the surveys the current water infrastructure in the different settlements around the lake are discussed.

The locations where the surveys have been conducted are shown in Figure 6, where the red houses are workers and the black houses are schools.

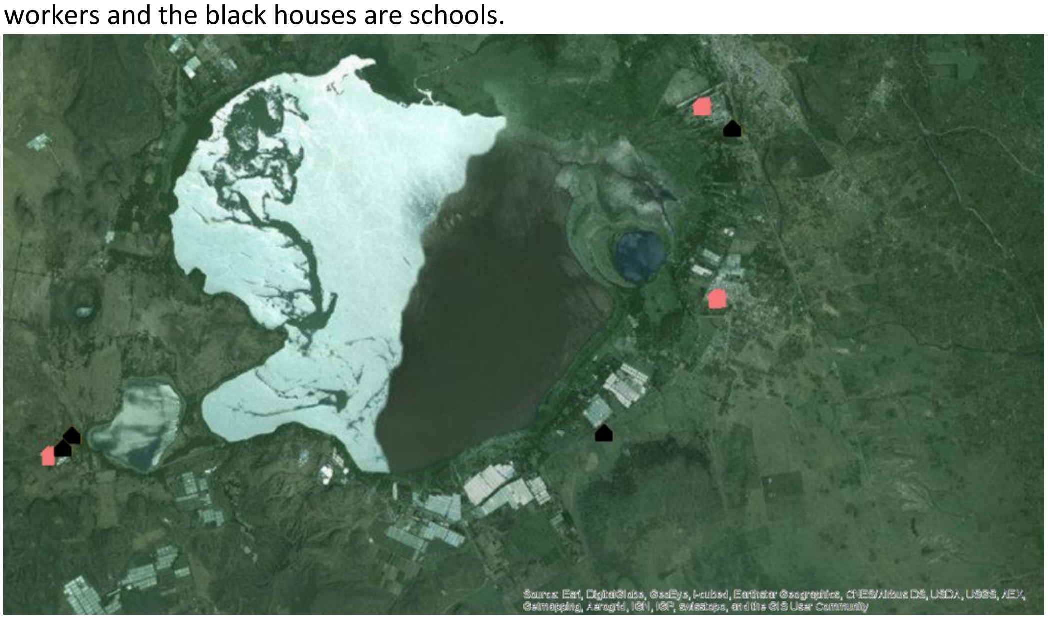

Figure 6 - Survey Location

As can be seen in the results of appendix XII that not all UN guidelines are always met. Especially the economic guideline, that water should not cost more than 3% of the household income, is often not met. Furthermore drinking water quality outside the farm compounds is often doubtful.

For the schools water abstractions seem to be generally small for the amount of students. It was found that the abstractions were only 1-8 litre per day per student. This means that most students should have access to sufficient water in their homes, but as can be seen from the worker surveys, this is not always the case. Furthermore water quality within the schools seems to be poor, with high fluoride levels because the water comes directly from the borehole.

In relation to the UN guidelines it could be said that on average, people have access to 50 litres of water per day. This water is reachable within 30 minutes and is within 1000 meters from the settlements.

The quality of the water is sometimes very doubtful. As fluoride levels are high, the provided water is not suitable for drinking according to the UN and WHO guidelines. N.E. Morgan shows that for Naivasha fluoride levels in the groundwater are between 4,5 and 10,3 mg/l (1998). The WHO shows that drinking-water concentrations between 0,9 and 1,2 mg/litre may give mild dental fluorosis, which can be seen around the Lake. Furthermore, an intake of 3-6 mg per litre may cause skeletal fluorosis (World Health Organization, 2008). The three best techniques to filter are either filtering at the source through reverse osmosis, using activated alumina defluoridation filters in people's houses or using defluoridation filters based on a local bone char technology. Bones (calcium) have the ability to soak up fluoride, but because of religious reasons this technique cannot always be used (Water & Sanitation for the Urban Poor, sd). Legal support should be given in this matter as the inhabitants will then be able to drink water coming from the tap or from a borehole.

Because the found water infrastructure is really different in each settlement around Lake Naivasha, the current water infrastructure is briefly described. This also helps to tackle the problems of improving water efficiency as the situations are very diverse around Lake Naivasha.

Naivasha Town:
Although there was no time to conduct the survey inside Naivasha town, the water infrastructure seems to be sufficient for the supply of drinking and sanitation water. The supplied drinking water is salty due to the high fluoride level, but bottled water is available throughout the city. Wastewater treatment through the sewer system is not sufficient, as can be seen in chapter 5.6.1.

Kihoto Village:
The interviewees in Kihoto village all had some kind of borehole nearby. The water from the borehole is high in Fluoride levels, so the drinking water quality is poor. Most people choose to buy drinking water from private vendors, while borehole water is used for sanitation water. Wastewater is often stored in pits. Since Kihoto village sometimes floods, these pits, together with the small farms, provide some form of pollution. Furthermore the sewer treatment plant of Naivasha discharges its water next to Kihoto village.

Karangita
The interviewees in Karangita all had a station from the "water and sanitation for the urban poor" (WSUP) nearby. These stations provide filtered or borehole water for cost price and are therefore a good option for the people living in Karangita. Some interviewees had their doubts with the quality of the filtered water and still buy bottled water from the private vendors. Wastewater is usually stored in pits.

Kwa-Muhia
This village also has the WSUP project so is equivalent to Karangita.

Kamere
Due to time constraints Kamere village was not visited and the water infrastructure is not assessed in this report.

Kongoni
Kongoni itself does not have a lot of farm workers and is mainly inhabited by small shop owners. They get their water from private borehole. The quality of the drinking water in relation to the fluoride levels is poor. Wastewater is mainly stored in pits.

Oserian worker village
Oserian provides their workers with housing and water. The water provided for sanitation is different than the water provided for drinking, but both are of good quality. Furthermore sanitation water is cleaned adequately and is stored in pits.

Other farm owned houses
There are a lot of farms that provide housing and water for their workers. It depends on the farm whether they also supply drinking water, or only limit supply to sanitation water. Quality of the water is often adequate, as can be seen from measurements done in Appendix XIII. The wastewater treatment is often limited to pits that are cleaned when they are full or are passed through artificial wetlands into the lake.

Because of the nature of each water system different recommendations on the systems in Naivasha town, the WSUP programme, the situation in Kongoni and the situation in the workers village are made on how to improve domestic water efficiency. These recommendations are often purely technical, as legal change in water abstractions does not seem realistically achievable. Furthermore often the abstractions are done by a supplying company/person and not by the end-users. This means that changes in the legality of water abstractions will not have positive effects, as water form these abstraction points is extremely cheap already.

Naivasha town
For Naivasha town legal and technical improvements can be made to reduce spillage when providing drinking water or discharging effluent water. Furthermore the legal prices of providing drinking water are a bit on the high side. NAIVAWASS provides drinking water for 92 Ksh/m^3 while they buy drinking water from WRMA for 0,5 to 0,75 ksh/m^3. The price has to be this high however due to the high loss of water during the water provision and the fact that NAIVAWASS also handles the wastewater treatment. It would be better if the wastewater treatment would be handled by the government, to ensure adequate treatment. Furthermore if the losses are looked into the price could drop, while maintaining the same amount of profit. The issues around wastewater treatment in Naivasha are further described in chapter 5.6.
At the moment only the wastewater treatment seems to be of a real issue to WRMA (see chapter 5.6), but the quality of the provided water should also be looked into.

Villages with WSUP
The WSUP programme has kiosks around the villages (about 100 meter apart from each other) and provide both RO-water (groundwater) and filtered RO water, through the use of defluoridation filters

with a local bone char technology. For some reason most locals buy their drinking water through private vendors or use the fluoridised water. There seems to be a lack of understanding and trust that the filtered water is safe and cultural ideas certainly influence the programme. Because the source of the bones is often unknown and people in these areas are generally religious, they do not take the defluoridised water from the WSUP programme. It is a good idea to trace the source of the bones and adequately inform the people in the villages about the source, so that they might take the defluoridised water from the WSUP programme, instead of relying on more expensive private vendors, which links with the non-compliance of the UN guideline that not more than 3% of a household income should be spent on water.

Kongoni village

In the situation that there is no actual water supplying company and the WSUP programme is not available the inhabitants only have the option to drink water with high fluoride levels (especially high in Kongoni area) or buy the more expensive bottled water. Because it is by no means doable to filter fluoride from the borehole, because the methods are too expensive, the only option is to provide filters or set up a company similar to WSUP. It must be noted however that Kongoni has few inhabitants compared with the other villages.

Farm owned houses

Generally the situation in the houses owned by the farms is farm. Most farms provide RO water for sanitation and supply bottled water for drinking. The situation regarding the water supply could be better but is not a necessity, because people never live more than 50 meters away from a collection point. Wastewater is often stored in pits, which currently is the best situation possible on the south side of the lake.

Overall, purely legal there is not a lot that can realistically be done at this time except in Naivasha town. Enforcement on water supply and wastewater treatment should however be of bigger importance. Furthermore water losses in the domestic water system should be evaluated. Most improvements can be made by implementing technical solutions to the current water infrastructure, although financial support is likely to be necessary. Especially in the rural areas water infrastructure should first be build up either through a water supply company or further support from WSUP. These actions will allow further compliance with the UN guidelines, as the survey shows that the main problems are related to water quality and the relative costs of water. Improvements have been made already latter problem, mainly due to increasing wages on farms, even when corrected for inflation (Ghawana, 2008). Further explanations for the water quality and biodiversity are given in chapter 5.6.

5.6 Biodiversity and water quality

Increasing water efficiency around Lake Naivasha also implies decreasing the grey water footprint and the chemical and nutritional wastewater amount. The direct linkage between wastewater output, lake water quality and biodiversity are split up into the categories linkage wastewater and water quality and the linkage between water quality and biodiversity. This prevents over-complications as the link between water quality and biodiversity has already been broadly described. Furthermore the prevention of further quality deterioration will be described in chapter 5.6.3.

5.6.1 Wastewater and lake water quality

For comparison of wastewater outlets the effluent sample measurements (mandatory measurements for NEMA each three months) of three wetlands are compared with the raw data of Villers given in Appendix II (2002). Furthermore measurements done by Xu are compared with the current effluent samples and the lake waters state to see whether improvements have been made (1999).

The raw effluent measurements that are conducted by the farms for NEMA can be found in Appendix VII. Unfortunately there is not enough information to describe a direct linkage between the effluent samples, but it does give an indication of the water that is discharged by farms that have a relatively high standard.

As can be seen in Appendix X there is a big difference between the measurements according to their place and time. This point is also shown in Xu's research, the effluent samples are not really uniform. Furthermore the levels depend on the situation of that day, the measurement method used, the type of crops and the type of irrigation system.

When compared with the guidelines the Chemical Oxygen Demand is very high, indicating there is a high amount of organic waste in the wastewater. The same result is shown in the measurements done in 1999. Furthermore phosphate (PO_4^{2-}) levels in the wastewater are high compared to the research done by Xu (1999), but are below the guideline set in the water quality act of 2006 (Minister for Environment and Natural Resources).

When comparing the effluent samples (I to IV and F1-F12 from Xu) with the measurements done by Villers (2002) the following observations are made:

- .The pH of the water measured in the artificial wetland is considerably lower than the pH in the Lake in 2002 but still meets the standards.
- The conductivity of the wastewater is higher than the measured conductivity in the Lake in 2002, but still meets the standards.
- The total dissolved solids (TDS) are considerably higher than the measured TDS in the Lake, but still meets the wastewater standards.
- The chemical oxygen demand (COD) is occasionally higher than the average in the lake in 2002, and does not always meet the wastewater standards. The lake itself sometimes exceeds the wastewater standards as well.
- Sodium (Na^+) levels are very high in samples I and II, but Xu shows that in 1999 the Na^+ levels were not considerably higher than the lake Na^+ level.
- Aluminium levels in sample III and IV are considerably lower than those measured in the lake.
- Chloride levels in sample III and IV are extremely high compared to the chloride levels in the lake.
- Ammonium (NH_4^+) levels in the samples from 1999 and the samples III and IV are considerably lower than those of the lake.
- Nitrates of samples I and II are higher than those measured in the lake, they do comply with the standards however.
- Phosphate (PO_4^{2-}) are higher in the samples of Xu and samples I and II than those measured in the lake. Furthermore Phosphate levels do not always comply with the wastewater standard.

(Xu, 1999 ; Villers, 2002)

The differences in lake water quality and effluent water quality can be caused by several reasons. These reason include a change of fertilizer and pesticide use over the years (not only in quantity, but in type as well). Furthermore the measured parameters in the lake are already spread out and less concentrated.

It must be said that the measured effluent sources are sometimes measured before the artificial wetland that most farms now have. The constructed wetlands filter the water before it actually reaches the lake. The results of a study in Finlays Kingfisher farm shows that the water temperature (23,1 to 18,3 ^{o}C), the conductivity (29% reduction), TDS (28% reduction), TSS (90% reduction), BOD (48% reduction), COD (68% reduction), total nitrogen (61% reduction) and total phosporus (53% reduction) are significantly reduced in the artificial wetland. Heavy metal concentration were already low in that study when measured before the wetland. The concentration does slightly decline throughout the wetland, but it is not significant (Kimani, Mwangi, & Gichuki, 2012).

Another potential source of wastewater runoff is that of the wastewater treatment plant. There have been reports of daily fish deaths in the particular area where the wastewater reaches the lake. Measurements there show low DO, extremely high measurements of nutrients, a high EC and an high COD. The water that does reaches the lake looks unhealthy and is also slightly affected by the solid waste that lies on route to the lake, as the last part of the sewer system is open. Furthermore the pipeline to the lake is broken on some places and diversions occur, allowing for additional pollution (Xu, 1999 ; Becht, *Personal Communication* ; Pacini, *Personal Communication*).

Each of these parameters or combination of parameters has is own influence on the lake water quality and the lake it's biodiveristy. These linkages are described in chapter 5.6.2.

5.6.2. Lake water quality and biodiversity

There seems to be a trend in the high COD measurements. High COD measurements often correlate with treats to human health, including toxic algae blooms. Furthermore high COD levels decrease the amount of dissolved oxygen (DO). When DO gets low, "hypoxia" can cause reduced cell functioning, disruptions in circulatory fluid balance in aquatic species and can result in the death of organisms. In 2013 a case of massive fish deaths was reported in Naivasha, probably due to the low levels of DO (Ndanyi, 2013). Hypoxic water can also cause the sediments to release additional pollutants, which in Lake Naivasha would mean an extra input of sediment-bound phosphorus into the Lake which results in further eutrophication of Lake Naivasha (Kitaka, Harper, & Mavuti, 2002 ; StormwateRx, sd).

As mentioned around the wastewater plant low DO gets measured and fish kills occur daily because of this fact. Furthermore there is a general consensus that a large amount of the pollution is coming from the wastewater plant and that insufficient wastewater treatment takes place before releasing the water back into the environment.

A good link between the chemical part and the algae bloom is the measurements of Chlorophyll 'a'. Because nutrients in Lake Naivasha are used by the algae and the *eichhornia crassipes* (water hyacinth) there will be a generally low level of nutrients in the lake. An indication of the amount of algae can be made through the Chlorophyll 'a' measurements. Because of the reason given earlier, the chlorophyll 'a' levels are also an indication of the nutrient concentrations in Lake Naivasha (Pacini, *Personal Communication*). Chlorophyll 'a' concentrations increased from 0,03 mgm^{-3} to 0,178 mgm^{-3} from 1982 to 1995, but decreased from 0,06 to 0,01 mgm^{-3} in the last 4 years, which might be related to the lake level rise (Majozi, Salama, Bernard, & Harper, 2012). Although chlorophyll 'a' measurements can be linked to phytoplankton, the direct relation is difficult to determine, because the linkage depends on the types of phytoplankton and algae (Felip & Catalan, 1999). Another indication for the types of phytoplankton is the sudden decrease in Silica in Lake Naivasha. This decrease is caused by the growth of the genera *Aulocoseira* and *Achnantes*. These two planktonic diatoms also give an indication for the high inflow of nutrient concentration in Lake Naivasha (and the low actual level of nutrients in the lake) (Pacini, *Personal Communication* ; Lee, et al., 2009 ; Poister, Kurth, Farrel, & Gray, 2012).

For *eichhornia crassipes* the optimum growth conditions are between 28^{o}C and 30^{o}C, with an abundance of Nitrogen, Phosphorus and Potassium. This means the climatic and nutritional conditions in Lake Naivasha are optimal for the growth of the *Eichhornia crassipes* after they first appeared in 1988 (Harper, Morrison, Macharia, Mavuti, & Upton, 2011). Because of their invasive nature, the mats can destroy natural wetlands, reduce infiltration of sunlight and block irrigation channels and rivers. As Naivasha has many irrigation channels leading to pump houses, the blockage of *Eichhornia crassipes* leads to lower flow rates in these channels and therefore lower pumping capacity. Furthermore they can lower DO, increase water loss through transpiration and change the temperature and pH of the lake water. Under favourable conditions it can double its mass every 6-18 days (Burton, Oosterhout, Ensbey, & Julien, 2012 ; IUCN/SSC Invasive Species Specialist Group, 2006).

Several methods have been developed to remove the *eichhornia crassipes* including the mechanical removal and the removal by water hyacinth weevils. The water hyacinth weevils (*Neochetina)* have been introduced into Lake Naivasha in the past as a biological control agent against the water hyacinth infestation. The weevils have had some effect on the water hyacinth infestation in Lake Victoria and are held responsible for the reduction of weed cover by up to 80%. Because conditions in Naivasha are slightly different, exact numbers cannot be given, but overall the weevils introduction will have had its effect in Lake Naivasha as well (Ochiel, Njoka, Mailu, & GItonga, 2001). Besides the biological control, the manual removal by the fishers seem to be the norm, but this is on a small scale. Mechanical control in Lake Naivasha is not very common and often consists of chopping the pieces of weed. However, regrowth of this chopped weed is likely to take place. In Lake Naivasha ecological succession has made a significant contribution to control the mats of *eichhornia crassipes*. In the lake the mats of hyacinth were invaded by papyrus, often to be followed by hippo grass. Hippo grass is expected to die once the nutrients from water hyacinths are depleted (Mironga, 2006).

A further link between the nutrient runoff and siltation of the lake is the removal of the *Cyperus Papyrus* around Lake Naivasha, already mentioned in chapter 2.7. The lack of papyrus trees results in the lack of a natural filter around Lake Naivasha. This lack of filtering partly resulted in the high coverage of phytoplankton and *eichhornia crassipes* in Lake Naivasha, which then resulted in a lower DO, which infects aquatic life (both native and exotic species).

Another way of assessing the quality of the lake water for biodiversity was given in chapter 3.4.3. Because of the limited data on water quality, the calculation procedure for the WQIB has been altered slightly. Instead of using a proximity to target calculation for a whole year, the proximity to target was calculated for the period 1961-2002 and one final WQIB is given. The proximity to target calculation is done by dividing the observed value minus the target level by the worst value minus the target value. The target values were calculated through the guidelines given in the report “Water Quality Index for Biodiversity Technical Development Document” (Carr & Rickwoord, 2008). The calculated values are shown in Table 12.

Table 12 - Targets for WQIB

Parameter	Targets	Unit
Dissolved Oxygen	6	mg L^{-1}
Electrical Conductivity	500	µS cm^{-1}
pH	6,5-8,5	
Temperature	27,5	^oC
Total nitrogen	1	mg L^{-1}
Total phosphorus	0,05	mg L^{-1}

The total WQIB scores that were calculated from the data given in Appendix II and the WRMA database data given in Table 13 (Villers, 2002).

Table 13 - WRMA database data

Year	1961	1965	1984	1988	1989	1990	1997
Conductivity (µS cm^{-1})	372		350	415	480	280	
Nitrogen (mg L^{-1})	32		400-600	100-475	300-675		
Phosphorus (mg L^{-1})	58	90	50-90	50-73	50-200	8-64	55
pH		8,9	8,5				

Table 14 - WQIB scores

Parameter	WQIB
Temp	100,0
Conductivity	100,0
DO	83,6
Nitrogen	100,0
Phosphorus	75,0
pH	48,1
Total	84,4

The water would qualify as a marginal water over the years 1961-2002 according to the WQIB scores. Because the pH samples were only taken in 2002 the score might be lower, as pH might have been lower in the past, and thus meeting the requirement more often. Even though, the current pH does not meet the requirement in most places inside the lake. The Nitrogen and Phosphorus levels are not exceeding the target, but as mentioned earlier in this chapter the nitrogen and phosphorus levels are kept low due to algae blooms and water hyacinth growth. The WQIB score would probably be lower is these situations did not occur and this might result in a WQIB with a poor indication. Since there is a relationship between these water quality parameters and biodiversity, the WQIB score can be used as a simple quantification for Lake Naivasha. For a more accurate assessment there is a need for monthly or even daily water quality data inside the lake. The score does however give an impression of the current state of the lake, which is marginal for biodiversity.

5.6.3 Water quality improvements

There are several methods to improve water quality, they should focus on the wastewater source and not on the current Lake status. It is still unknown however where exactly the pollution comes from, but one target should be the wastewater treatment plant. Furthermore technical adaptions can be made inside the farms so that less nutrients are used and effluent water is less polluted. Most of these technical adaptions have been described in chapter 5.4. Because the report only focusses on the area around Lake Naivasha, no results for the upper catchment can be made. However, it is believed that the biggest pollution comes from the small farmholders in the upper catchment, therefore some recommendations for small farmholders are also shown.

In the case of legal adaptions, the farmers should be supported to build their own artificial wetland. At this moment farmers don't pay a fee for effluent water if there is no point source of effluent water. When they construct a wetland they have to get a permit for effluent water from both NEMA and WRMA. This means farmers are not at all supported to build artificial wetlands at this time. Furthermore stronger enforcement should take place as there are no real consequences for having effluent water exceeding standards.

For the lake water hyacinth harvesting (biological or mechanical) should be considered carefully. As nutrient levels are kept low due the filtering. It be better to restore the Riparian land with papyrus trees, as they offer an ability to filter before reaching water hyacinths. If the hyacinths are harvested the nutrient levels in the lake will rise which will cause different infestations.

6 Discussion

In this chapter every result will shortly be described and shortcomings will be addressed. Furthermore the results of these shortcomings will briefly be discussed

The hydraulic processes are mainly based on local data, measured by other people. Because the data is not used on the local basis but on the whole Lake Naivasha area is slightly inaccurate for the use on a local scale. Furthermore the assumptions that capillary rise is 0 is not accurate, but due to lack of accurate data this is assumed. Capillary rise actually plays an important role in plant water uptake and should therefore be investigated further for the Naivasha area. Furthermore the average data used in the FAO climwat database is lower than the average recorded in the WRMA database over the last 15 years, but because the source and quality of the data in the WRMA database is unknown, the FAO climwat database is used. The different climate data explains the big differences in ET_o as explained in chapter 5.1.2. It would be best to use local data that is available over an average year, but as that data is currently unavailable all local data was scaled with the FAO climwat database.

The water footprints are based on the water footprints of a crop, while it might be better to use the water footprint of a business. The water footprint of a business does require the knowledge of the water footprints of all processes within a business and their responding water usage and virtual water trade. Because this is unknown for most chemicals that are used in the farm, it is difficult to assess at this time. It would be good to investigate the water footprint of the chemicals used and all other processes done in the farms, so that an accurate assessment of the water footprint of a business can be made. The green water footprint should be recalculated using a rainwater-runoff model so that the runoff is accounted for and not all rainwater is used by the crop. Furthermore the calculation of the grey water footprint is based on a very limited set of data and is therefore not accurate, it would be good to collect more chemical usage schedules and effluent water samples so that the grey water footprint can assessed on basis of a broader dataset.

The irrigation System Performance Efficiency should include incidental spillages in further research. As they are difficult to measure and time was limited they were not assessed in this report. Furthermore the seasonal efficiency should be reassessed. As it is unknown what the exact amount of drainage water is that should be applied for maintaining the salinity balance is the soil. Therefore the assessment could not be made in this report and it was assumed that the seasonal efficiency is 100%. In the recycling efficiency a parameter for recycling of chemicals should be made, as this is an important step for the economic effects of starting a hydroponic.

The economic effects of starting up a greenhouse, a hydroponic or an aeroponic seem to be on the positive side and are often not based on rose cultivation. While greenhouses do increase yield, this is not so sure for hydroponics. The farms reported different yields per m^2 and the hydroponic area seemed to have a lower yield than some of the soil-based greenhouses. Furthermore hydroponics require a more intensive monitoring system which is very unpractical in Kenya at this time. Therefore the choice of going from a greenhouse to a hydroponic should be carefully considered and maybe even tested (like the green farming project) to see if it actually increased yield, as it only increases yield under very specific conditions. The choice for aeroponics will not be made anytime soon as nobody has really tested in a commercial system and the investment is very expensive to Kenyan standards. Furthermore savings are lower than projected due to the cheap labour costs in Kenya.

Human rights should be investigated further to a spatial scale, as the situation seems to be lacking in some areas, while in other areas water supply seems adequate. The situation in different towns was only assessed based on the inhabitants of that area, while it might be better to investigate the actual infrastructure and do water quality tests if time permits so that the actual water quality can be assessed. Furthermore it will be interesting to see if the situation changes with the new water bill of Kenya that will be implemented somewhere this year.

Biodiversity and water quality were difficult to link as there is an important role for the riparian land, which was only partially assessed during the study period. The data of the riparian land is insufficient at this time to make a big scale assessment on areas where pollution might occur more easily. Furthermore measures from 1999 were used, which might be a bit outdated. The water quality from the sewer area is still poor however. The WQIB should be reassessed with data form before the water hyacinth infestation and data from after the water hyacinth infestation, as the nutrients have a big effect in the WQIB index. Furthermore for an actual WQIB index there is the need of daily or monthly data, which is not there at this time, it would be good to develop a water quality monitoring plan that covers the basic parameters of water quality which are assessed monthly, so that a better idea can be given of the water quality within Lake Naivasha.

7 Conclusions and recommendations

The objective of this study was to understand the relationships between water abstractions, their efficiency and their social, legal, economic and ecologic counterparts. This was approached mainly by using data given from farms, inhabitants and experts on their respective fields.

The analysis from the water efficiency include the water footprint and the ISPE. These measurements show a big difference between the open-field based farming, the soil-based greenhouse and the hydroponic system. They show that farms can increase their irrigation efficiency by up to 60% by transferring to a hydroponic system. Furthermore their water footprint decreases by 0-40% when on a hydroponic system, because yield increases and water usage decreases. The grey water footprint that is found based on the fertilizer use in an hydroponic over 2 weeks is 357 m^3/ton for nitrate and 199 m^3/ton for phosphorous per hectare. The hydroponic farm however as 0 m^3/ton as it is a closed system and therefore the grey water footprint will strongly decrease when farms transfer to hydroponic farming.

Economically investing in the techniques of greenhouses and hydroponics (or even aeroponics) is considered to be profitable in most cases, but it is advised that it is first tested locally. Some farms reported lower yields because the hydroponics were not designed properly. If designed properly however, economically it would be interesting to make the step. Aeroponics might be worth the investment but have not been tested commercially and therefore involve taking a big risk. For the areas where open-field cultivation still takes place it is interesting to invest in a greenhouse, despite the high investment costs. Yield will increase drastically and water usage will go down by up to 25% compared to an open-field drip irrigation system (Harmato, Babel, & Tantau, 2004). It is recommended that farms at least transfer to greenhouse drip irrigation on a soil basis as this is known to be profitable in the Naivasha area. Further data from the greenfarming project will also give results on whether it is profitable to make a transition to a full hydroponic system for a farm at this time.

Domestic water usage does not always reach the UN guidelines and is considered to be inefficient in some areas around Lake Naivasha, mainly in Kihoto village and Kongoni village. Furthermore due to religious believes the water from the WSUP programme provided in other areas is not always used, as the bone source used for filtering of the fluoride is often unknown. Furthermore legally there is not a lot to be done at this time except for the Naivasha town area, where enforcement should increase as the wastewater treatment is far from sufficient at this time. It is recommended that legal enforcement takes place in Naivasha town and water infrastructure is built in the settlements around Lake Naivasha.

The water quality of Lake Naivasha still seems to be a problem, but due to biologic influences it cannot be assessed directly through chemical measurements. The biologic parameters, such as the water hyacinth coverage and Chlorophyll ‘a’ levels, should be considered for an accurate indication of the current lake water quality. Even though these parameters were not included in the WQIB, the index still gave a score 84,4 over the period 1961-2002, which is an indication for a marginal lake level water quality. If the biological parameters were included in the WQIB, it is likely that the water quality for biodiversity would be rated as poor (lower than 75). The main problem seems to be the enforcement on water quality, as it does not seem to matter if farms have a high concentration of a certain chemical in their effluent water.

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Appendix I - Organizations involved

- WRMA: Both national WRMA, Nakuru Regional WRMA and Naivasha Sub-regional WRMA are involved in the management of the natural resource water. They are responsible for monitoring water resources and issuing permits for water abstraction.
- NEMA: Both national NEMA and NEMA Nakuru. NEMA is responsible for managing all natural resources, including some aspects of water management. As the new water bill of Kenya will be implemented, most of the aspects of water resources management will be under the control of WRMA.
- WWF: The Kenya branch of WWF has the final responsibility of the IWRAP project and it's financing. Furthermore WWF is interested in a sustainable environment, in which humans and nature can live together.
- LNRA: The LNRA is an organisation which has the goal to protect the environment around Lake Naivasha. The owners of the LNRA are the farmers, tour operators, the Kenyan Power Company, the local municipal council and land owners on the shore of the lake. It is an organisation that protects the environment "for the community, by the community". (Lake Naivasha Riparian Association, sd)
- Imarisha: Imarisha Naivasha is responsible for the coordination of stakeholders around the lake. They are supposed to bring all stakeholders together for an integrated planning in the basin. It is the coordinative organisation in Naivasha (Koyo).
- KFC: the KFC is a voluntary association of independent growers and exporters of cut-flowers and ornamentals in Kenya, with the aim to ensure safe production of cut flowers in Kenya. It focusses on the protection of workers and the protection of the environment (Kenya Flower Council, sd).
- ITC: ITC is participating in the IWRAP programme that focusses on water resource management. ITC is closely cooperating with Deltares. The specific task is to "increase knowledge and technical capacity for quantitative water resource management and monitoring in Lake Naivasha Basin" (Faculty of Geo-Information Science and Earth Observation, sd).
- Deltares: Deltares is a Dutch consultancy company that is responsible for the "increased knowledge and technical capacity for quantitative water resource management and monitoring in Lake Naivasha Basin", in cooperation with ITC
- Vitens Evides International: Vitens focusses mainly on water and wastewater management practices and service provision of drinking water to the lowest income areas of Naivasha (Global Water Operators Partnerships Alliance, sd).
- RVWSB: RVWSB is one of the eight water services Boards in Kenya, formed under the Water Act of 2002. The goal of the RVWSB is to ensure cost effective and sustainable provision of water and sanitation services in the area of its jurisdiction (Rift Valley Water Services Board, sd).
- NAIVAWASS: NAIVAWASS is represented in the RVWSB and is the supplier for drinking water and the sewerage company in Naivasha.
- MCN: The MCN is responsible for the politics in Naivasha, including water resources and sanitation. Naturally the MCN is interested in all projects that occur within its region. Of course the CG is also responsible for some of the projects within the MCN.
- KWS: Both KWS on the national level as KWS Naivasha are involved in managing the resources of Lake Naivasha. KWS conserves and manages all wildlife in Kenya. It is an organisation that is

particularly interested in ensuring biodiversity conservation, which means it is also interested in tackling issues around the deterioration of Lake Naivasha.

- KenGen: KenGen has two geothermal plants (45 MW and 70 MW) in Naivasha that use water from the lake. Furthermore it has a cooperative venture with the LNRA and ITC to research the hydrology of Lake Naivasha Basin (Kenya Electricity Generation Compan, sd).
- PPP: The PPP's abstract water for the same purpose as KenGen does, to generate electricity, which means they are interested in a sustainable lake land groundwater level of Lake Naivasha
- LaNaWRUA: The LaNaWRUA its main goal is to conserve the fresh water lake and its tributaries. The organisation is the users association of Lake Naivasha Basin, this means it is the representative association of all water users in Lake Naivasha.
- Water Governance Centre: This centre is involved in the IWRAP programme, together with the Dutch water bodies Stichtse Rijnlanden and Noorderzijlvest. They work together with WRMA to create a governance framework which can be implemented into an integral management plan for Lake Naivasha (Netwerkorganisatie voor de Maatschappelijke Inbedding van Waterbeheer, sd).
- LNGG: The LNGG is an organisation that represents the growers around Lake Naivasha. The want to ensure that the growers' interests are represented in the management of Lake Naivasha and its environment. The organisation helps to balance commercial interests and environmental sustainability around Lake Naivasha Basin (Oserian, sd).
- NBSI: The NBSI is an initiative funded by COOP and REWE to "create education initiatives and demonstration projects that advance sustainability of water in the Naivasha Basin" (Cory, 2010 Harper & Pacini, 2014).
- Flower Farms: Some flower farms are neither member of the LNGG or the KFC, but are indeed stakeholders around Lake Naivasha. They do subtract water and are a special group of users, because they do not have the strict environmental and legal obligations that members of the KFC and the LNGG have.
- GIZ: GIZ is funding some of the projects that are part of IWRAP through Imarisha Naivasha. They provide financial and logistical support for certain projects around Naivasha.
- Domestic water Users: All users of water for domestic purposes are of course stakeholders. The users are represented in the LANAWRUA, but themselves are stakeholders as well as they subtract water from the lake (either themselves or through NAIVAWASS)
- Small farm holders: most small farm holders are no members of LNGG or the KFC because they grow vegetables, which are not meant for export. They do however subtract water from Lake Naivasha.
- Fisheries: The fisheries around Lake Naivasha depend on the local fish population of Lake Naivasha for their income. They are mainly concerned about the water quality deterioration in perspective to the population of fish in Lake Naivasha.
- Hotels: hotels abstract an amount of water from Lake Naivasha for their guests. Furthermore hotels will be interested in retaining the Biodiversity (and a lake view), so that the guests can enjoy the huge variety of flora and fauna.
- Cattle ranges: The cattle uses the water from the lake as drinking water. This means the holders of cattle ranges are involved in the Lake Abstraction by introducing non-native to the Lake's surrounding, extracting an extra amount of water.

Appendix II – Raw Water Quality Data

The figures Figure 7, Figure 8 and Figure 9 describe the raw data that Villers (2002) collected.

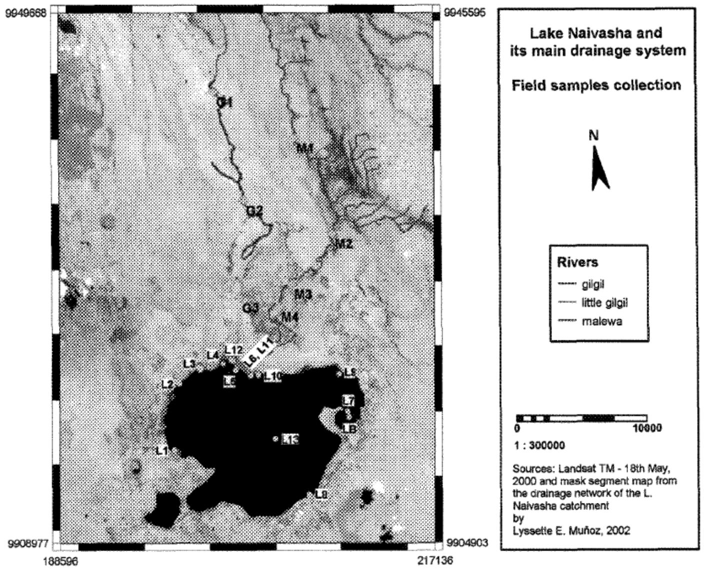


Figure 7 - Positions (Villers, 2002)

Parameters/Sample locations		LA	LB	L1	L2	L3	L4	L5	L6
Temperature	°C	25.0	20.6	23.9	26.6	24.1	25.2	21.4	21.0
pH		8.1	9.0	8.7	8.8	8.1	8.6	9.0	9.0
Conductivity	µS	247.05	402.21	326.84	324.19	321.86	285.01	310.24	287.67
TDS	mg/L	131.4	192.8	156.7	155.4	154.3	136.6	148.7	137.9
Turbidity	NTU	-	-	-	-	27.7	36.2	42.8	50.8
Dissolved oxygen	mg/L	-	-	6.70	6.49	4.35	6.27	5.82	6.40
Oxygen saturated	%	-	-	95.0	100.0	68.0	95.0	80.0	88.0
COD	mg/L	70	66	54	59	64	48	61	60
K^+	mg/L	15.83	-	16.90	17.37	16.96	15.56	16.09	15.40
Na^+	mg/L	27.06	-	27.43	27.80	27.35	25.49	26.44	25.84
Ca^{2+}	mg/L	13.79	-	14.29	20.10	14.94	13.76	14.07	14.54
Mg^{2+}	mg/L	6.08	-	6.57	6.80	6.71	6.08	6.56	6.12
Al^{3+}	mg/L	1.27	-	0.78	0.96	0.89	1.10	1.13	1.10
Fe^{3+}	mg/L	1.44	-	1.30	1.00	0.81	1.06	0.95	0.93
Mn^{2+}	mg/L	0.29	-	0.34	0.31	0.37	0.46	0.37	0.33
Li^+	mg/L	< 0.05	-	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Cl^-	mg/L	13.3	15.6	15.8	14.0	14.6	16.0	13.0	13.0
NH_4^+	mg/L	4.0	1.2	0.00	5.3	2.1	< LOD	1.4	0.5
NO_3^-	mg/L	0.8	0.6	0.8	0.5	0.7	0.6	0.8	0.9
SO_4^{2-}	mg/L	1	-	1	1	1	1	1	1
PO_4^{3-}	mg/L	0.28	-	0.18	0.19	0.26	0.34	0.22	0.73
Total alkalinity	mg/L	152.55	219.67	176.96	183.06	167.81	176.96	176.96	170.86
Total hardness as $CaCO_3$	mg/L	60.5	90.08	70.06	75.07	75.07	70.06	78.07	70.06
Σ Cations	meq/L	3.20	0.07	3.02	3.66	3.18	2.87	3.05	2.94
Σ Anions	meq/L	2.92	4.05	3.39	3.43	3.20	3.39	3.31	3.23

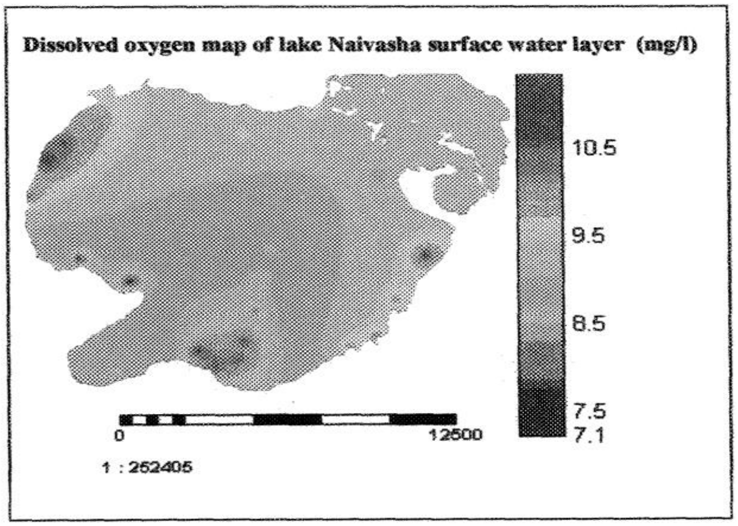
Parameters/Sample locations		L7	L8	L9	L10	L11	L12	L13	Kenya government guidelines
Temperature	°C	21.2	21.6	18.1	17.2	17.0	19.1	21.1	± 2 °C[1]
pH		9.1	8.7	9.1	9.1	-	9.0	8.3	6.0 – 9.0
Conductivity	µS	401.87	337.47	399.00	92.00	92.00	213.00	332.00	*
TDS	mg/L	192.7	161.8	191.3	44.1	44.1	102.1	159.1	1200
Turbidity	NTU	3.81	18.7	-	-	-	-	-	*
Dissolved oxygen	mg/L	7.07	4.13	7.40	7.05	-	6.0	6.03	*
Oxygen saturated	%	98.4	60.0	108.6	101.3	-	83.0	81.9-	*
COD	mg/L	55	66	66	19	12	59	65	50
K^+	mg/L	21.65	20.49	22.13	3.95	4.06	11.31	17.41	*
Na^+	mg/L	32.02	32.83	32.02	8.22	8.51	21.76	27.82	*
Ca^{2+}	mg/L	15.08	16.97	15.81	11.27	6.53	10.55	14.29	*
Mg^{2+}	mg/L	8.51	8.17	8.86	2.31	2.31	4.40	6.70	*
Al^{3+}	mg/L	0.25	0.53	1.57	1.33	1.35	1.53	0.58	*
Fe^{3+}	mg/L	0.19	0.74	1.13	1.93	1.80	1.85	0.83	*
Mn^{2+}	mg/L	0.07	0.45	0.43	0.35	0.32	1.23	0.35	1.0
Li^+	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	*
Cl^-	mg/L	15.3	15.2	19.6	8.3	7.2	12.8	20.7	1000
NH_4^+	mg/L	< LOD	1.1	1.3	0.9	0.4	0.9	3.2	0.2
NO_3^-	mg/L	0.9	0.6	0.6	1.1	1	0.8	0.8	*
SO_4^{2-}	mg/L	1	2	< LOD	1	1	< LOD	< LOD	500
PO_4^{3-}	mg/L	0.09	0.16	0.26	0.59	0.58	0.44	0.50	1.0
Total alkalinity	mg/L	234.93	200.15	231.88	67.12	48.82	103.73	259.34	*
Total hardness as $CaCO_3$	mg/L	79.07	75.07	85.08	28.03	29.03	42.04	80.07	*
Σ Cations	meq/L	3.44	3.63	3.78	1.49	1.24	2.42	3.21	
Σ Anions	meq/L	4.32	3.77	4.37	1.39	1.06	2.09	4.86	

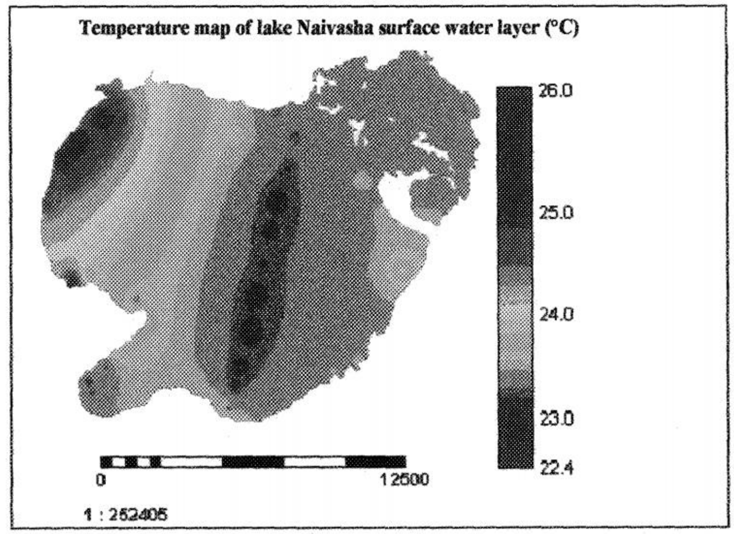
Figure 8 - Raw data (Villers, 2002)

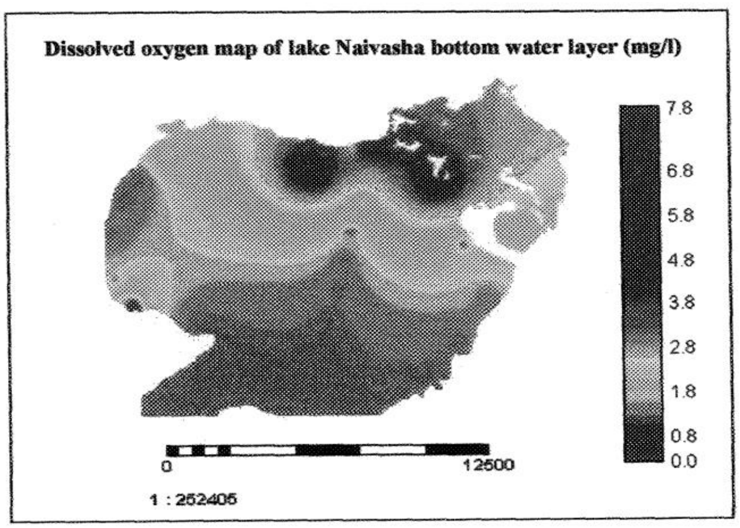
Parameters/Univariate statistics	Units	No. of observations	Maximum	Minimum	Mean	Median	Standard deviation	1st quartile	3rd quartile	1st percentile	Ninetieth percentile	Skew coefficient
Temperature	°C	507	26.80	17.00	20.80	20.80	1.80	19.50	21.60	18.70	22.84	0.76
pH		158	9.30	8.20	8.85	8.80	0.24	8.70	9.10	8.60	9.10	-0.22
Conductivity	μS	507	402.87	92.00	330.33	334.00	58.32	324.76	380.65	247.00	391.00	-1.75
TDS	mg/L	158	193.14	116.90	166.45	161.22	14.86	157.80	183.83	155.10	187.61	0.07
Turbidity	NTU	100	72.70	3.28	19.96	14.55	14.22	11.98	23.05	10.97	39.15	1.80
Dissolved oxygen	mg/L	153	7.93	4.01	6.34	6.33	0.70	5.87	6.77	5.60	7.27	-0.42
Oxygen saturated	%	153	115.00	58.40	91.21	90.30	10.76	83.10	99.70	80.12	106.64	-0.20
COD	mg/L	15	70.00	12.00	54.93	60.00	16.45	54.50	65.50	30.60	66.00	-1.94
K^+	mg/L	14	22.13	3.95	15.37	16.50	5.35	15.44	17.40	6.24	21.30	-1.20
Na^+	mg/L	14	32.83	8.22	25.04	27.02	7.36	25.58	27.82	12.49	32.02	-1.63
Ca^{2+}	mg/L	14	20.10	6.53	14.00	14.29	3.01	13.77	15.04	10.77	16.62	-0.63
Mg^{2+}	mg/L	14	8.86	2.31	6.16	6.57	1.91	6.08	6.78	2.94	8.41	-0.90
Al^{3+}	mg/L	14	1.57	0.25	1.03	1.10	0.38	0.80	1.32	0.54	1.48	-0.50
Fe^{3+}	mg/L	14	1.93	0.19	1.14	1.03	0.47	0.86	1.40	0.76	1.84	0.14
Mn^{2+}	mg/L	14	0.46	0.07	0.33	0.34	0.09	0.31	0.37	0.25	0.44	-1.38
Li^+	mg/L	14	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	-
Cl^-	mg/L	15	20.70	7.20	14.29	14.60	3.38	13.00	15.70	10.10	18.16	-0.30
NH_4^+	mg/L	15	5.30	0.00	1.49	1.10	1.50	0.45	1.75	0.00	3.68	1.40
NO_3^-	mg/L	15	1.10	0.50	0.79	0.80	0.17	0.65	0.90	0.62	1.01	0.19
SO_4^{2-}	mg/L	14	2.00	0.00	0.86	1.00	0.52	1.00	1.00	0.00	1.00	-0.22
PO_4^{3-}	mg/L	14	0.73	0.09	0.34	0.27	0.19	0.02	0.49	0.17	0.59	0.70
Total alkalinity	mg/L	15	259.34	48.82	171.38	176.96	57.54	160.18	209.91	81.77	233.71	-0.78
Total hardness as $CaCO_3$	mg/L	15	90.08	28.03	67.13	75.07	18.54	65.06	78.57	34.23	83.07	-1.24

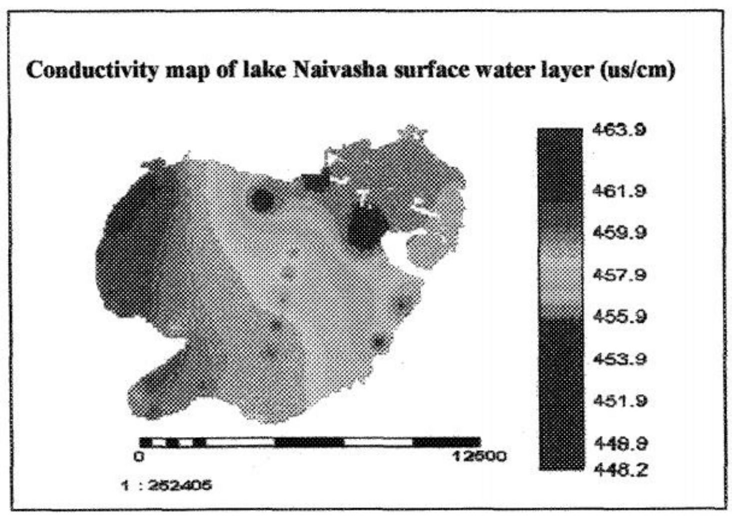
Figure 9 - Distribution (Villers, 2002)

To give a better insight in the spatial distribution the images of Donia (1998) are used. Note that Figure 10 is calculated with different values of the above parameters (and only for some of them). They do give an idea about the spatial distribution in Lake Naivasha.









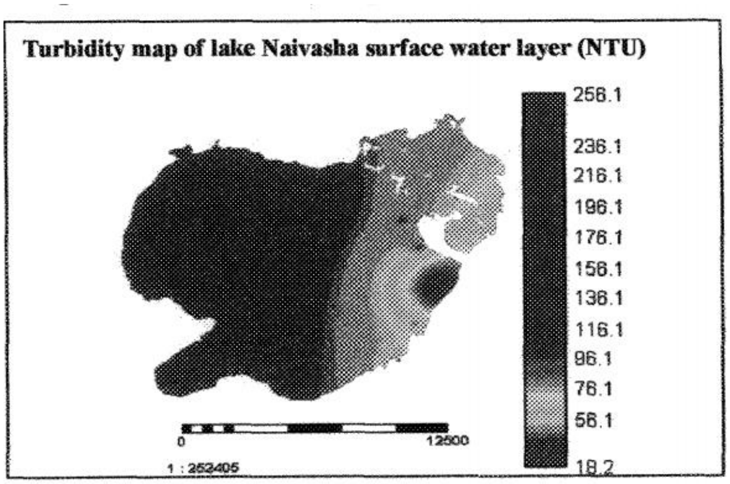


Figure 10 - Spatial Distribution maps (Donia, 1998)

Appendix III – Evapotranspiration models

All evaporation models that are possibly used are shortly explained in this chapter.

FAO Penman Model

As the name suggest, the FAO Penman model is an improved version of the regular Penman model. The equation is given as:

$$ET_o = \frac{1}{\lambda}\left(\left(\frac{\Delta}{\Delta+\gamma}\right)(R_n - G) + \left(\frac{\Delta}{\Delta+\gamma}\right)(6{,}43)(W_f)(VPD)\right)$$
$$W_f = 1 + 0{,}0536U_z$$

Where,

λ	Latent heat of vaporization (MJ kg^{-1})
R_n	Net radiation flux at the crop surface (MJ m^{-2} day^{-1})
G	Soil heat flux density (MJ m^{-2} day^{-1})
Δ	Slope Vapour pressure curve (kPA $^oC^{-1}$)
γ	Psychometric constant (kPa $^oC^{-1}$)
W_f	Wind function
VPD	Vapour pressure deficit (kPa)
U_z	wind speed at z (m) height

(Ilahi, 2009)

Because this data is difficult to acquire some steps and assumptions can be made so that the necessary data will be: Daily mean air temperature, daily mean water temperature, altitude of the area, mean relative humidity, wind speed and measured height, net radiation, number of the month, daytime wind speed and night-time wind speed. This is explained step by step in "A Computer System of Estimating Reference Crop Evapotranspiration Using the Modified Penman's (FAO – 24) Method" (Theocharis).

FAO Penman-Monteith

The FAO Penman-Monteith simulates a reference crop with a crop height of 0,12 meter, a fixed surface resistance of 70 s m^{-1} and an albedo value of 0,23. The equation of the FAO Penman-Monteith model is given below.

$$ET_O = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0{,}34u_2)}$$

Where,

T	Mean air temperature (^oC)
U_2	Wind speed at 2m above the ground (m s^{-1})
R_n	Net radiation flux (MJ m^{-2} d^{-1})
G	Sensible heat flux into soil (MJ m^{-2} d^{-1})
e_s-e_a	Saturation vapour pressure deficit, VPD (kPa)
Δ	Slope Vapour pressure curve (kPA $^oC^{-1}$)
γ	Psychometric constant (kPa $^oC^{-1}$)

Again, this model can be simplified using the "step by step calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method)" (Zotarelli, Dukes, Romero, Migliaccio, & Morgan, 2013).

FAO Radiation Model

The FAO radiation model was developed for areas where available climatic data, including air temperature and sunshine hours, cloudiness or radiation were available, but not wind speed and air humidity. This model proved to work better in a low-technology greenhouse, but as they were not found around Naivasha the model is not further explained.

Hargreaves model

The Hargreaves model is an empirical model and can be alternated in such a way that only temperature data and humidity data is needed to estimate the potential evapotranspiration. This model proved to work better when limited data was available but as this was not the case is not further explained.

Stanghellini model

The stanghellini model is a revised Penman-monteith model to represent conditions in a greenhouse. It is a more complicated model with more complex input parameters. For medium-tech greenhouses this model seems to work best (Ilahi, 2009). The formula is given below:

$$ET_o = 2LAI \times \frac{1}{\lambda} \times \frac{\Delta(Rn - G) + K_t \frac{VPD \times \rho \times C_p}{r_a}}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)}$$

$$R_n = 0{,}007R_{ns} - \frac{252\rho C_p(T - T_0)}{r_R}$$

$$\gamma = \frac{C_p P}{\varepsilon\lambda}$$

$$r_R = \frac{\rho C_p}{4\sigma(T + 273{,}15)^3}$$

Where,

LAI	Leaf area index (m^2m^{-2})
K_t	Time unit conversion (86400 for ET_o in mm day^{-1})
r_c	Canopy resistance (s m^{-1})
Rns	Net short wave radiation ($MJm^{-2}day^{-1}$)
T_0	leaf temperature (^oC)
r_a	aerodynamic resistance (s m^{-1})
Cp	specific of air (MJ kg^{-1} $^oC^{-1}$)
ρ	mean air density (kg m^{-3})
ε	water to dry molucar weight ratio
λ	latent heat of vapourization (MJ kg^{-1})
σ	Stefan-Boltzmann constant ($MJm^{-2}K^{-4}day^{-1}$)
r_R	radiative resistance (sm^{-1})

Because most of these parameters are difficult to measure and are unknown in the farms, the outcomes of the report "Comparison of Water Consumption between Greenhouse and Outdoor Cultivation" are used. This data was measured in Naivasha Panda Flower farm so it can be assumed that it is adequately accurate for similar systems in Naivasha (Mpusia, 2006).

Appendix IV – Farm Survey

All questions are marked in bold, while explanations are in italic.

Farm name
Date of today
Age of interviewee
Age of the farm
Kind of certification (e.g. KFC gold, KFC silver, Fairtrade, etc.)
It is important to know which kind of certification the farms have, because having certain certifications means that the farms adhere some kind of standard for their production regarding water use, environmental awareness and the rights of workers.
Revenue in Ksh per year
Production costs in Ksh per year
Pesticide costs in Ksh per year
It is important to know the pesticide costs because they are related to some of the irrigation systems around Lake Naivasha (for example the Hydroponics). The reduction is pesticide costs are also taken into account while searching for methods of increasing water efficiency.
Fertilizer costs in Ksh per year
Same as pesticide use.
Energy consumption in Kwh
Energy consumption is also taken into account when searching for methods of increasing water efficiency.
Energy costs in Ksh per year
Amount of male employees
Amount of female employees
Wages of managers
Amount of managers
Wages of skilled workers
Amount of skilled workers
Wages of casuals
Amount of casuals
Other rewards, besides wages, for employees
Some farms provide schooling, healthcare, housing, food and/or transport for their employees. These can also be considered rewards for their work, besides the normal wages.
Are union allowed?
Unions for workers are a representative unit and can therefore provide support for the workers when conflicts arise.
Is there a contact point for abuse?
Abuse still is an important aspect around Lake Naivasha (Ogodo & Vidal, 2007 ; Gachari, 2012 ; Food and Agriculture Organization of the United Nations, 2005 ; Brenya, 2006 ; Martín-Borregón, 2014)*. Mothers usually work on the farms, leaving their children alone with often poor, older woman. Because a part of the problems found in water issues can be indirectly linked to their living situations, abuse (both sexual as physical) is also addressed briefly. One example is the lack of toilets, about a quarter of the woman that*

have defecate an open field have had experiences with first or second-hand harassment (Frost, Byanyima, Woods, & Alipui, 2014).

Are there other abuse preventive measurements?

See Is there a contact point for abuse?

Do you supply your workers with protective gear against pesticides?

Another part of the workers living situation is the protection against the pesticides they use. It is important to understand the workers situation before recommendations on the water level can be made.

Which type of pesticides do you use?

The type of pesticides (names) is important because they can be linked to water quality, human health and biodiversity.

Which type of fertilizers do you use?

See Which type of pesticides do you use?

How much pesticides (and when) do you use?

Understanding when and where pesticides are used is important to address the spatial variability in lake pollution, as seen in Appendix II.

How much fertilizers (and when) do you use?

See How much pesticides (and when) do you use?

How much water (and when) do you use for irrigation?

The amount of water that is used is important to calculate their efficiency of water usage.

What is the conductivity of the irrigation water?

Salinity of the water is a problem around Lake Naivasha and is part of the water quality. If farms measure their conductivity the salinity of the water can be calculated (S. Wanjala, *Personal communication ; S.* Higgins, *Personal communication*).

What is your Irrigation Return Flow (or discharge)?

The amount of water that returns in the lake (could be point pollution) is important for the calculation of the grey water footprint.

What is the volume of your drainage water (if applicable)?

The type of drainage and the amount of drainage water are a part of the hydraulic flows within a farm and are therefore necessary to know.

Do you do any other water quality measurements, and if yes, can you share them?

The water quality measurements (preferably before the inlet and at their return flow) can be used to calculate the grey water footprint.

Is there a constructed wetland?

Wetlands provide a natural filter against the outflow of pesticides and nutrients and should therefore be considered when calculating the grey water footprint.

Do you use any other protection systems against pesticide and nutrition outflow?

Do you harvest rainwater, if yes, what is the amount?

Harvesting rainwater is considered in calculating the blue water footprint.

Do you recycle water, if yes, what is the amount?

*Recycled water is also considered in calculation the blue water footprint***.**

What were the costs of the already implemented water saving measures?

This information is necessary to get a basic understanding of the investments made for increasing the water efficiency.

Do you have any ideas of other water saving measures?
Do you have soil type and soil moisture data that you can share?
Soil type and soil moisture percentage can be used to estimate the infiltration and capillary rise in a water flow system.
What is the level of groundwater around the farm (if applicable)
Groundwater level is also necessary for estimating the infiltration and capillary rise.
Do you measure rainfall data and can you share it with me?
Rainfall data is needed for the calculation of the evapotranspiration, see chapter 5.1.2.
Do you measure evapotranspiration data and can you share it with me?
If farms measure evapotranspiration data directly, this is the preferred method of calculating the water footprint.
Do you measure temperature data and can you share it with me?
Temperature data is necessary for the calculation of evapotranspiration, see chapter 5.1.2.
Do you measure radiation data and can you share it with me?
Radiation data is necessary for the calculation of evapotranspiration, see chapter 5.1.2.
Do you measure humidity data and can you share it with me?
Humidity data is necessary for the calculation of evapotranspiration, see chapter 5.1.2.
On what height do you measure this data?
The height of the measured data is necessary for the calculation of evapotranspiration, see chapter 4.2.
Do you measure infiltration rate and capillary action rate and can you share it with me?
If infiltration rate and capillary action are measured within a farm, they can be used together with the estimation for a more accurate result.
Do you measure runoff data (if applicable) and can you share it with me?
If a farm is open-field, runoff data can be important as it may cause diffuse pollution in Lake Naivasha.
What other parameters, besides the ones already asked do you measure?
This question is an inventory of all parameters farms measure, it could be used for later analysis and recommendations.

In part two the interviewee will get a map with his property and is asked to draw certain parameters in the map.

What is where? (e.g. hydroponic, regular greenhouse, pivot irrigation etc.)
This is a basic lay-out question of the farm, it is necessary to understand the lay-out as otherwise the irrigation efficiency cannot be calculated (certain inlet points provide irrigation water for a certain area).
What type of drainage is used in each of this area?
The drainage type may provide important information on the water flows after irrigation inside the farm.
What type of greenhouse is in each area (e.g. aluminum with whitening sheets)?
The type of greenhouse will provide the best method of calculating the evapotranspiration, see chapter 5.1.2.
Could you draw which pump irrigates which area and how the pipelines go from the abstraction pump to the irrigated area?
To get a further understanding in the water flows, the pipelines from the abstraction point to the area that is irrigated should be drawn. This provides basic information of which inlet point irrigates which area.
What is type of crop do you use in each area, and what is the corresponding yield (and crop cycle)?
The type of crops and corresponding yield are necessary for calculating the water footprint. Furthermore they can provide information necessary for the calculation of the actual evapotranspiration, see chapter 5.1.2..

Appendix V – Worker survey

The actual questions are marked bold, while the explanations, if necessary, are written in italic.

Date of today
Gender of interviewee
Employer of Interviewee
Are you married?
It is important to understand a household for the UNDP guideline that not more than 3% of your household income should be spend on water.
What is the married person's job?
How many children do you have?
Are the children going to school?
Are the children working on a farm?
Who owns the house?
Some farms provide houses for their workers. It is important to see what other rewards employees get because in some cases it should be deducted on the household income.
What is the type of house?
How many m^2 is the house?
What is your income in Ksh/day?
What is your household income in Ksh/day
The household income is the direct parameter in the UNDP guideline of 3%.
How much water is available per day in litres?
The UN states that 50-100 litres per person should be available per day to each person.
How long do you take to collect this water (min)?
The UN states that no person should take more than 30 minutes for collecting water per day.
How far is the water collection place (meters)?
The UN states that no person should have to collect water from more than 1000 meters away.
Which type of drinking water collection do you use?
Their source of drinking water is important to know, are they getting tap water, are they buying from private vendors or are they using their own borehole.
What do you pay for your water per day in Ksh?|
Each method of collection has its own price. Furthermore the amount of spend on water should not be more than 3% of the household income.
Who collects the water?
The gender and age of the person who collects the water is important, see chapter 3.3.2.
Does the drinking water look clear?
Because drinking water tests are not always possible basic properties of the drinking water should be analysed, see chapter 3.3.2.
Does the drinking water smell?
What is the toilet type you use?
The toilet types might explain some points of pollution around Lake Naivasha, especially if no toilet is available.

Who owns the toilets?
The owner of the toilet is responsible for the toilet and should ensure that the toilets are adequately separated if they are community owned.
Are the toilets separated?
Are the toilets clean?
Is there basic sanitation for girls available?
Girls need a different form of sanitation than boys. Most toilets have been designed by men and sometimes the basic need for girls have been overlooked (bins, water to wash their hands etc.), see chapter 3.3.2.
Who owns the showers?
Same as Who owns the toilets?
Are the showers separated?
Which type of fuel do you use?
The type of fuel might give an indication for a cause of pollution.
How much fuel do you use per day?
Are you a union member?
It is important to see whether a worker is a union member, as unions might play a role in increasing water supplies, especially in farm owned houses.
How long is your average working day?
How many breaks do you have per day?
Do you have protective gear?
Have you ever been abused?
Abuse can be linked to water, see Appendix V: Is there a contact point for abuse?
Is there a contact point for abuse?
Have you ever seen someone else been abused?
Which gender is your manager?
If abuse takes place within a farm, the role of the manager (male or female) might be of importance, though not primarily related to water on this occasion, but more to working conditions.

Appendix VI – School survey

The actual questions are marked bold, the explanations are written in Italic.

Date of today
Name of the school
Age of the school
Gender of the Interviewee
Gender of kids in the school
Basic information on what type of school: Mixed, separated boys and girls or girls/boys school.
Owners of the school
Some schools are owned by farms, might be interesting to see whether they differ from public schools
Amount of students
Amount of teachers
Amount of male teachers
amount of female teachers
Average tuition fee in Ksh per year
Average teacher Salary in Ksh per year
Amount of water abstracted per day in litres
A part of the 50-100 litres of water that a person should have per day, according to the UNDP, is consumed in the schools.
Source for drinking water
The source of water gives an indication of the water quality that is consumed in the school.
What do you pay for water per day in Ksh?
Colour of the drinking water
See Appendix V and chapter 3.3.2.
Smell of the drinking water
Type of toilet system
See Appendix V
Are the toilets separated?
Toilets in schools should be adequately separated. Especially girls are prone to absence during their menstruation because toilets are not adequately separated. Of course shame plays a role in this problem.
Are the toilets clean?
Basic sanitation for girls available?
See Appendix V
Are the showers separated?
Which type of fuel do you use?
The type of fuel might provide information on the sources of pollution around Lake Naivasha.
How much fuel do you use?

Appendix VII – FAO climate database

This data will only be used if local data is not available.

Table 15 - FAO ClimWat data Naivasha (Food and Agriculture Organisation of the United Nations)

	Rain	Effective rain	min temp	avg temp	max temp	humidity	Wind speed	Sunshine hours	Solar radiation	P*	ETO
Units	mm	mm	°C	°C	°C	%	$M\ s^{-1}$	Hours	$Mj\ m^{-2}\ day^{-1}$	kPa	$Mm\ day^{-1}$
Jan	34,0	32,2	8,0	17,8	27,6	51,0	1,2	5,4	17,3	80,8	3,9
Feb	40,0	37,4	8,1	18,2	28,2	50,0	1,2	5,9	18,7	80,8	4,2
Mar	51,0	46,8	9,7	18,5	27,2	56,0	1,2	5,4	18,0	80,8	4,0
Apr	105,0	87,4	11,5	18,3	25,0	69,0	1,2	4,9	16,6	80,8	3,5
May	80,0	69,8	11,2	17,5	23,7	73,0	1,4	5,1	15,9	80,8	3,2
June	44,0	40,9	9,8	16,4	23,0	71,0	1,4	5,0	15,2	80,8	3,1
July	43,0	40,0	9,2	15,9	22,5	70,0	1,4	4,5	14,7	80,8	3,0
Aug	52,0	47,7	9,3	16,1	22,8	69,0	1,5	4,9	16,1	80,8	3,3
Sept	31,0	29,5	8,7	16,6	24,5	65,0	1,5	5,5	17,8	80,8	3,7
Oct	46,0	42,6	9,0	17,3	25,5	62,0	1,5	5,6	18,1	80,8	3,9
Nov	64,0	57,4	9,2	16,9	24,6	67,0	1,2	4,7	16,3	80,8	3,4
Dec	46,0	42,6	8,6	17,2	25,7	61,0	1,2	4,5	15,7	80,8	3,4
Avg	53,0	47,9	9,4	17,2	25,0	64,0	1,3	5,1	16,7	80,8	3,5
Total	636,0	574,3	112,3	206,3	300,3	764,0	15,9	61,4	200,4	80,8	42,5

*Atmospheric pressure (P) was estimated through the use of the following formula

$$P = 101{,}3\left(\frac{293 - 0{,}0065z}{293}\right)^{5{,}26}$$

Where,

Z elevation above sea level (m)

P Atmospheric pressure (kPa)

The elevation above sea level has been estimated to be about 1900 meter for the other data given in this table. Therefore z has been assumed to be 1900 meter (Allen, Pereira, Raes, & Smith, 1998).

Appendix VIII – Irrigation schedule

This is an example of the water usage per day for a greenhouse based farm where irrigation is of the sub-surface drip type and humidity inside the greenhouse is controlled.

Table 16 - Water usage example

Date	Water usage m^3 day^{-1}	Humidity water usage m^3 day^{-1}
1-5-2014	1740,6	537
2-5-2014	1785,6	342
3-5-2014	1624,2	409
4-5-2014	1601,3	453
5-5-2014	1755,7	274
6-5-2014	1778,5	523
7-5-2014	1618,5	360
8-5-2014	928	605
9-5-2014	2326	283
10-5-2014	1369,6	376
11-5-2014	1526,3	496
12-5-2014	1530,5	308
13-5-2014	1526,8	557
14-5-2014	1761,2	362
15-5-2014	1680,7	654
16-5-2014	1782,4	416
17-5-2014	1680,6	330
18-5-2014	1578,9	0
19-5-2014	1191,6	849
20-5-2014	1418,4	340
21-5-2014	1215,5	447
22-5-2014	1638,4	476
23-5-2014	1542,3	428
24-5-2014	1527,4	457
25-5-2014	1490,7	447
26-5-2014	1433,9	480
27-5-2014	1425	408
28-5-2014	1452,4	393
29-5-2014	1548,5	376
30-5-2014	1560,1	549
31-5-2014	1521,2	326
Total	48560,8	13261

Appendix IX – Evapotranspiration calculations

For the different farms the evapotranspiration calculations were done based on three or four different methods, namely the measured evapotranspiration, the water balance model, the Stanghellini model and the best-fitted model based on greenhouse technology (Ilahi, 2009). For the different models, see chapter 5.1.2 and Appendix III.

For evapotranspiration the FAO penman, the Stanghellini were used for greenhouses. The FAO Penman-Monteith was used to calculate evapotranspiration on an open-field. If there was no local data available, the FAO climwat database was used. Otherwise the FAO data is scaled to the current measurements of 2014. It is assumed that the climates in regulated greenhouses are the same around Lake Naivasha, so crop evaporation will be nearly the same for each greenhouse.

The evaporation was calculated for 3 different farms with different data and models based on different systems. Most weather data is based on local weather measurements and is then scaled to the whole year by using the FAO database.

For the Stanghellini model the parameters in the report of Mpusia were used (LAI = 0,85, K_c = 0,4), for the FAO penman the assumptions in "A Computer System of Estimating Reference Crop Evapotranspiration Using the Modified Penman's (FAO - 24) Method" were used (Mpusia, 2006 ; Theocharis). Furthermore the 65% assumption is based on the fact that the evaporation within a greenhouse is about 65% of that outside the greenhouse, as suggested by various authors. For the FAO Penman-Monteith model a K_c of 1,4 was used, as this seemed to reflect the actual measurements the best.

Appendix X – Effluent samples

The raw measurements were performed by Cropnuts Laboratory Services and AgriQuest Limited. Because they use different parameters for their measurements, sample I and II have different parameters as samples III and IV. The guidelines are adapted from the CropNuts laboratory (samples III and IV). If no measurements were done by CropNuts the guidelines from AgriQuest are used. If the sample measurements are higher than the guidelines, they are marked.

Table 17 - Effluent Water Quality Samples

Chemical		Sample I	Sample II	Sampe III	Sample IV	**Guidelines**
pH		7,24	7,35	7,31	8,42	**6,5-8,4**
Electrical conductivity	mS/cm			<1,5	0,61	**<1,5**
Colour in Hazen Units		12	16	<10	20	**<15**
Biological Oxygen Demand (BOD)	mg/l	24,1	28,7	20	10	**<30**
Chemical Oxygen Demand (COD)	mg/l	65,3	80,5	600	70	**<50**
Total dissolved Solids (TDS)	mg/l	390	1110	727	292	**<1200**
Total Suspended Solits (TSS)	mg/l	28	14	9	40	**<30**
Oil and Grease	mg/l	NIL	NIL	0,056	0,04	**<0,05**
Ammonium	mg/l			0,29	0,01	**<100**
Total N	mg/l			1,18	0,01	**<16**
Nitrate N	mg/l			0,27	0,01	**<100**
Nitrite	mg/l			0,019	0,01	**<100**
Phosporus	mg/l			1,72	1,51	**<2**
Chlorides	mg/l			123	41,7	**<250**
Fluorides	mg/l			5,43	5,99	**<1,50**
Boron	mg/l			0,092	0,054	**<1**
Sulphur	mg/l			15,6	10,3	**<170**
Arsenic	mg/l			0,012	0,02	**<0,02**
Cadmium	mg/l			<0,002	0,01	**<0,01**
Chromium	mg/l			<0,004	0,01	**<0,1**
Nickel	mg/l			<0,003	0,01	**<0,3**
Mercury	mg/l			<0,001	0,01	**<0,05**
Selenium	mg/l			<0,02	0,02	**<0,02**
Aluminium	mg/l			<0,07	0,16	**<5**
Zinc as Zn	mg/l	0,09	0,06	<0,01	0,0095	**<0,5**
Lead as Pb	mg/l	<0,001	<0,001	<0,009	0,04	**<0,1**
Copper as Cu	mg/l	0,02	0,09	<0,01	0,0075	**<1**
Iron as Fe	mg/l	0,62	0,67			**<10**
Calcium as Ca	mg/l	14,5	18,9			**No guideline**
Manganese as Mn	mg/l	0,35	0,38			**<10**
Sodium as Na	mg/l	124	137			**No guideline**
Phosphates as Po42-	mg/l	18,3	20,4			**<20***
Nitrates as No3-	mg/l	2,78	5,21			**<10***

Microbiological						
Total coliforms	cfu/ml	1700	350			**<30***
Faecal Coliforms				<1	1	**<30**
Faeacal E. Coli				<1	1	**<1**

* Guideline adapted from “the environmental management and Co-ordination act” (Minister for Environment and Natural Resources, 2006)

Appendix XI – Economics explained

Drip irrigation and greenhouse cultivation

As can be seen in Figure 1, there are still some farms who use pivot irrigation in open-field farming. Water application for sub-surface drip irrigation is about 10% less than the water application needed for pivot irrigation. It must be noted however that the investment costs for sub-surface drip irrigation are slightly higher than those for pivot irrigation (about 8800 Ksh per hectare more). Studies shows that when solely dealing with pivot and drip irrigation, the pivot irrigation provides more revenue due to the lower maintenance costs (O'Brien, Rogers, Lamm, & Clark, 1998). However, because drip irrigation can be combined with greenhouse cultivation it has more potential. When upgrading from open field drip irrigation to greenhouse drip irrigation the farm can save an additional 20-25% of water (Harmato, Babel, & Tantau, 2004). For a 20 hectare farm this would imply a saving of about 12500 m^3/month of water, which is a saving of 108000 Ksh/year. Investment costs for a modern greenhouse are expensive, about 1500 Ksh/m^2, which means 300 million Ksh for a 20 hectare farm. Current greenhouses are of a lower technology, but are often replaced by modern greenhouses. It should be noted that yield in greenhouses increases, which means additional income (Mpusia, 2006 ; TNAU Agritech portal Horticulture, sd). An overall assessment by the TNAU Agritech portal for Horticulture shows that investing in a greenhouse with drip irrigation would be a simple way to improve water efficiency with increasing profits for the now pivot-irrigated areas, although it is difficult to finance the investment costs in the first year.

Hydroponics

Hydroponics are greenhouses where the water system is basically closed and the only loss is crop evapotranspiration. The hydroponics in Naivasha are all soil-based hydroponics. This means there is still a soil base where the plants grow in, but drainage is collected and recycled. The advantages of hydroponics is that the drainage water can be reused and is rich in chemicals that were not used by the plant. This means that besides water recycling, unused nutrients get recycled as well. Another option would be to grow the plants without a medium, so only in nutrient-rich water. A disadvantage of this technique is that it is prone to failure, as the plants will die faster than in the soil-based hydroponic. In a full hydroponic system all drainage water gets reused in the hydroponic system again, but the drainage water has to be treated against bacteria, because harmful bacteria can destroy all of the crops when the recycled water is used over and over.

Another thing that was seen at different farms is to have a part of soil-based hydroponics and a part soil-based greenhouse farming. The hydroponic water is then reused on the soil-based part and because the water is only recycled once, UV-filters for bacteria are not necessary.

Studies from the green farming project in V.d. Berg farm show that soil-based hydroponics use 65% less water, have an average of 20% more stems per m^2 and about 52% more production in terms of weight. Furthermore turnover on the soil-based hydroponic area of the farm is 28% higher than on a similar soil-based green house (Greenfarming, sd).

A water reduction of 65% would mean an additional saving of about 300000 ksh/year on a 20 hectare farm. The increase in yield (both amount of stems and weight of stems) will mean an increase of turnover of about 100-200 million ksh/year for a 20 hectare farm (The World Bank Group, 2009 ; Greenfarming, sd). Although fertilizer use is lower than in traditional systems, fertilizer costs are usually higher than a traditional soil-based system, because of the use of specialised fertilizers. On a yearly basis, hydroponic fertilizer costs would be around 40000 ksh more expensive than the traditional system. Total maintenance and operating costs (including water costs) are about 5-10% higher than the operating

costs for traditional soil systems, based on a gerbera crop and cucumbers (Grafiadellis, Mattas, Maloupa, Tzouramani, & Galanopoulos, 2000 ; Engindeniz & Gül, 2009) . However the reports also show that profit is higher with hydroponics than it is with traditional soil-based systems.
Hydroponic investment costs are extremely expensive however. When upgrading from a regular greenhouse to a hydroponic, expect to pay 35 million Ksh for a 20 hectare farm. Additional costs will be made if a full hydroponic is opted, because UV-filtering has to be adequate. Furthermore hydroponics require a constant monitoring of nutrients as the system is are far more volatile, which results in the higher operating costs.
Eventually hydroponics will take over the traditional greenhouses as they use less water and as water stress arises, water prices will go up. Furthermore when wages go up, the techniques that require less workers will become even more interesting. However, it might take a long time before hydroponics take over due to the high investment costs and not all results show a big increase in crop yield, sometimes even reporting lower crop yields in a hydroponic farm than in a soil-based greenhouse farm. Furthermore not all farms seem to have the knowledge and the ability to properly design a hydroponic and maintain it at this time, primarily lacking the nutrient monitoring units, which means an additional investment.

Aeroponics

Aeroponics are a form of hydroponics where instead of growing in a medium or water, the roots dangle in the air. The roots are sprayed with a rich nutrient solution, either by slightly larger particles of water (normal Aeroponics) or by applying small mist size particles (about 5 µm) of nutrient rich water (fogponics). Fogponics have the advantage that particles get absorbed quicker and more efficient, but the ultrasonic foggers tent to clog quickly due to the nutrient solutions and are therefore expensive in maintenance
Aeroponics generally require a high investment cost and are extremely vulnerable to system failures, making them at this time not really interesting as a water efficiency measure in Kenya. A short power failure will cause total loss of crops. Aeroponics however do increase crop yield and decrease fertilizer use based on the regular hydroponics. Despite the decrease in fertilizer use the fixed and production costs do increase. Fixed costs increase by about 90% over the current hydroponics in Naivasha. Production costs increase by about 28% over the current hydroponics. Income of the aeroponic farm is about 90% higher than the soil-based hydroponic farm, while profit is about the double of the semi-hydroponic farm, which is explained by the doubled yield of the crop (Mateus-Rodriguez, et al., 2013). Aeroponics will not take over anytime soon in Naivasha as they require expert knowledge, a huge investment and are very prone to breakdown. Furthermore the savings are based on a study in South-America where labour is more expensive than in Kenya, resulting in higher cost reductions when working with less labour-intensive techniques. As prices of labour will go up in the future, prices of water go up and infrastructure increase, aeroponic farming might become interesting for farms, at the moment however, the infrastructure is lacking and the risks in investing in these techniques are not worth the relative small benefits.

Appendix XII - Survey data

Table 18 - Results schools

School Name	1	2	3	4	5	6	7	8	9	10	11	12	13
Kongoni primary school	1927	500	14	22000	7	7	429	Tap	210	=	No facilitations	No electricity	Facilitations broken
Lake view primary school	1995	748	16		7	9		Other		=	Handwash	No electricity	Harvest rainwater + borehole
Longonot DEB primary school	1994	634	18		8	10	5000	Other	0	+	Wash or toilet	Solar	Finlays provide water for free
Rev Ghitirwa secondary school		42	7	8000	4	3		Tap		+	No facilitations	Electricity net	Own borehole

1 School started in
2 Amount of students in the school
3 Amount of teachers in the school
4 Average teacher salary
5 Amount of male teachers in the school
6 Amount of female teachers in the school
7 Water abstracted (liters/day)
8 Source of drinking water
9 Costs of water (Ksh/day)
10 Are the toilets separated to gender
11 Is there basic sanitation for girls available
12 Fuel Type
13 Other

Three other questions were asked but the answers were the same in every school, their results are shown below.

Type of toilet	All pit latrines
Gender of the children in the school	All mixed schools
Owner of the school	All public schools

Because of the size the table is split up into this page and the next page. Green colours indicate compliance with the UN guidelines, yellow colours indicate near compliance and red colours indicate a lower standard than the UN guidelines.

Table 19 - Results workers

Gender	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Male	500	1000	Yes	1	Yes		Rent	Stone	20	60	10	100	Shared drinking water	15	0,03	Woman	Toilets not seperated
Male			Yes	0			Farm	Stone	20	999	5	15	Shared drinking water				
Female	266	266	Yes	3	Yes	No	Rent	Stone	16	40	10	20	Private Vendor	15	0,06	Woman	Toilets adequatly seperated
Male	500	500	No	0			Rent	Stone	16	40	10	100	Shared drinking water	4	0,01	Men	
Male	200	400	Yes	2	Yes	No	Rent	Stone	16	20	10	100	Private Vendor			Children girl	
Female	130	130	No	3	Yes		Rent	Stone		70	0	1000	Shared drinking water	15	0,12	Woman	
Male	530	<Null>	Yes	5	Yes		Farm	Stone	20	999	5	10	Shared drinking water	0	0,00		
Male	2000	2000	Yes	2	Yes		Rent	Stone		999	5	20	Other	15	0,01		Toilets not seperated
Male	229	460	Yes	2	Yes	No	Rent	Stone	16	250	30	100	Private Vendor	25	0,11	Men	
Female	267	567	Yes	3	Yes		Rent	Iron sheet		999	10	10	Other	6	0,02		

18	19	20	21	22	23	24	25	26	27	28	29
Community owned	Electricity net		Yes	10	1	No	No	Yes - Within farm	No	Male	High Fluoride senior supervisor
Community owned	Electricity net		Yes	8	1	Yes - Avg. Shape	No	Yes - Within farm	Yes P	Male	manager good
	Electricity net		No	11	1		No	Yes - Within farm	Yes P	Male	manager abuse contact
Bucket shower	Electricity net		No	10	1	Yes - Bad Shape	No	Yes - Within farm	Yes P and S	Female	Verbally abbused
Bucket shower	Coal	50	Yes	10	1	Yes - Avg. Shape	No	Yes - Within farm	No	Male	
			Yes								
Bucket shower	Coal	50	Yes	8	2	Yes - Avg. Shape	No	Yes - Outside farm	Yes P and S	Male	
Bucket shower	Electricity net		No	8	1	No	No	Yes - Within farm	No	Male	used to work for shalimar
Community owned	Coal	50	No	10	1	Yes - Bad Shape	No	No	No	Male	Abusive language

1 Income (Ksh/day)
2 Household income (Ksh/day)
3 Married
4 Amount of children
5 Children going to school
6 Children working on a farm
7 House owned by
8 Type of house
9 house space (m^2)
10 Water available (litres/day)
11 Collection time of water (min/day)
12 Collection distance of water (metres)

16 Person to collect water
17 Are the toilets separated
18 Who owns the showers
19 What type of fuel is used
20 Amount of fuel used
21 Union member
22 Average working day (hours)
23 Amount of breaks per day
24 Protective gear available
25 Ever been abused
26 Contact point for abbuse
27 Ever seen people being abused (p=physical, s=sexual)

13 Type of drinking water collection
14 Water payment (Ksh/day)
15 Percentage of household income (Payment/income)

28 Gender of the manger
29 Other

Appendix XIII – Farm water quality measurement

This is a water sample from the drinking water provided in a farm. The drinking water measurements comply with the standards on all measured parameters. The measurements are an example of the drinking water's quality inside the farm.

Table 20 - Drinking water measurement

Parameters	Method	Results	Standard
Aesthetic Quality Requirements			
pH	KS 05 - 459	6,96	6,5-8,5
Turbidity in NTU	KS 05 - 459	0,24	5
Total Dissovled Solids (TD)S mg/l	KS 05 - 459	300	1000
Suspended Matter, mg/l	KS 05 - 459	NIL	NIL
Inorganic contaminants			
Fluoride as F, mg/l	KS 05 - 459	0,35	1,5
Nitrate as No3, mg/l	KS 05 - 459	0,41	50
Nitrites as No2-, mg/l	KS 05 - 459	<0,001	0,003
Sulphates as SO42-, mg/l	KS 05 - 459	1,38	400
Calcium as Ca, mg/l	KS 05 - 459	1,87	150
Sodium as Na, mg/l	KS 05 - 459	28,4	200
Iron as Fe, mg/l	KS 05 - 459	0,29	0,3
Manganese as Mn, mg/l	KS 05 - 459	0,44	0,5
Zinc as Zn, mg/l	KS 05 - 459	0,07	5
Magnesium as Mg/ mg/l	KS 05 - 459	3,27	100
Free chlorine, mg/l	KS 05 - 459	0,21	
Chloride as Cl-, mg/l	KS 05 - 459	14,7	250
Potassium as K, mg/l	KS 05 - 459	25,4	
Copper as Cu, mg/l	KS 05 - 459	<0,001	1
Lead as Pb, mg/l	KS 05 - 459	<0,001	,01
Microbiological			
Total Viable counts at 37C, cfu per ml	KS 05 - 459	6	100
Total Coliforms, cfu per 250ml	KS 05 - 459	NIL	NIL
E. Coli, cfu per 250ml	KS 05 - 459	NIL	NIL
Salmonella, cfu per 250ml	KS 05 - 459	NIL	NIL