How to Climate Proof Water and Sanitation Services in the Peri-Urban Areas in Naivasha

WSUP
Water & Sanitation for the Urban Poor

Cranfield University

How to Climate Proof the Water and Sanitation Services in the Peri-Urban Areas in Naivasha

Authors: Tom Heath, Alison Parker, Keith Weatherhead
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Correspondence: k.weatherhead@cranfield.ac.uk
a.parker@cranfield.ac.uk

Work based on field visit to Naivasha undertaken in July - August 2010

Cover Photo: Alison Parker 2009

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Reference
Heath, T., Parker, A., & Weatherhead, E. K. (2010). How to climate proof water and sanitation services in the peri-urban areas in Naivasha. Report prepared by Cranfield University. WSUP, London.

Executive Summary

This report evaluates the impacts of climate change on water and sanitation technologies in the peri-urban areas around Lake Naivasha, reviews the water resources in Lake Naivasha and considers the potential adaptations required to mitigate the impacts. Under current forecasts of climate change, the mean temperature in Kenya is predicted to increase while precipitation is expected to decrease in volume and increase in intensity, increasing the frequency and severity of droughts. The impacts of climate change were assessed using two scenarios (to account for the uncertainties associated with climate change): Decreasing lake and ground water levels and Increasing lake and ground water levels. The main impacts are as follows:

- **Decreasing lake and ground waters:** will have a significant impact as there will be higher domestic demand whilst surface water availability decreases. During droughts there are longer queues, water from vendors is more expensive and it takes longer to collect. As a result, water use decreases, hygiene deteriorates and disease increases. The lake area reduces and there is increased conflict between pastoralists and farmers; tourism and fishing suffers, there is reduced employment (in particular from the flowers and vegetable farms as they are less profitable to run) and the lake's quality deteriorates. The main problems cited by the community during previous drought were a decrease in income and the increased cost of food and water. There was little impact on the borehole supply (as it is a confined aquifer) and latrines

- **Increasing lake and groundwater levels** is largely positive for Naivasha as there is more water for domestic and irrigation use. The main problem is an increase in the number and intensity of flash floods. This increases the amount of solid waste and silt washed into the lake, causes latrines to collapse and overflow, exposes pipes, damages houses and crops and inundates roads which disrupt local business. However, flash floods are only an inconvenience to the community as they are able to harvest the increase in rainwater, but there is an observable increase in disease

Potential short, medium and long term adaptations are identified for WSUP (or the local provider), NAIVAWASS and the City Council. The adaptations were determined based upon a field visit, a vulnerability assessment and a literature review. The key recommendations (some are already being undertaken) are as follows and should be implemented within a Water Safety Plan:

WSUP

- Ensure affordable and accessible water supply
- Support catchment management plan
- Latrine construction and education to prevent collapse and overflowing
- Protect boreholes ensuring well head properly sealed and fenced
- Educate community on flood prevention and mitigation strategies
- Replace high lift pump at borehole in Kamere
- Education on the need to site latrine away from drainage channel, ensure proper seal when constructing pit latrines and build latrines with doors facing down slope
- All construction below ground from stone/bricks, possibly use properly compacted sand blocks
- Monitor water level in boreholes during droughts and floods

NAIVAWASS

- Incorporate kiosks system into distribution network
- Adapt the system to increase the resilience to flash floods, in particular the sewage system

COUNCIL

- Maintain, improve and develop drainage systems
- Terracing and tree planting in the upper catchment
- Support Water Allocation Plan when it is updated

Contents

Introduction

"Observational evidence from all continents and most oceans shows that many natural systems are being affected by climate change, particularly temperature increases" (IPCC, 2007). This report outlines the impacts (both direct and indirect) associated with the climate changes predicted for three peri-urban areas around Lake Naivasha.

It starts by reviewing the water resources in Lake Naivasha, the regulations, hydrology, hydrogeology and pollution of the lake. It then reviews the impacts of the climate scenarios predicted for Kenya; the indirect impacts of climate change and the impact upon Lake Naivasha. It then synthesises how the climate scenarios will affect the existing vulnerabilities, problems and technology in the peri-urban areas in Lake Naivasha. The report concludes by outlining the main adaptations required in the peri-urban areas by WSUP, NAIVAWASS and the local council, dividing them between short, medium and long-term adaptations. The key climate studies and researchers for Lake Naivasha are also listed.

The report aims to provide pragmatic recommendations for adaptation; focusing upon what is known rather than the uncertainties. The document should be read alongside the Kenya Climate Briefing (Heath, 2010).

Method

The research started by identifying literature on the impacts of climate change on water and sanitation technologies. The key document was a review completed by the WHO and DFID in 2010 (Charles *et al*., 2010). This describes the vulnerabilities of various water and sanitation technologies to climate change, and proposes adaptations. This was followed by a field visit which identified which technologies are being used in Lake Naivasha and hence identified the vulnerabilities of the water and sanitation system to climate change. The adaptations required to mitigate these vulnerabilities were selected from Charles et al (2010) and are listed in the appendix.

The field visit to Lake Naivasha, was completed in July 2010 and entailed 27 semi-structured interviews with members of the community and representatives from the local service provider, water utility, local Council, regional government, scientific community and NGOs (Table 3 in the appendix lists the interviewees). The interviews and observations assessed the impact of flooding and droughts on the existing environmental, social and economic vulnerabilities and the impact on technologies. The interviews also assessed the institutional awareness of climate risks. Further climate vulnerabilities were identified from the literature review. Two focus groups were undertaken with the community, to do a cause and effect analysis (i.e. what are the problems, what causes them and what impacts do they have).

The information gathered from the interviews was used to prepare a vulnerability assessment. This involved listing the problems identified in the peri-urban areas and identifying the linkages between them in a flow chart (e.g. flash floods can lead to buildings collapsing). Once the linkages between all of the problems had been identified, the expected changes in climate were added (e.g. decreasing rainfall) and the factors they impacted (directly and indirectly) were identified. In addition, the indirect impacts of climate change (e.g. food insecurity) were incorporated assessing which factors they affected. This made it possible to assess how climate change will affect the existing vulnerabilities in the peri-urban areas (see Appendix – Figure 4). This diagram was then used to determine the adaptations required to mitigate the problems.

The adaptations from both the fieldwork and the literature review were then amalgamated and assigned to the WSUP, NAIVAWASS and local Council, dividing them into short medium and long term adaptations.

Lake Naivasha

The lake is the basis of the economy in Naivasha. It provides freshwater for flower and vegetable farms (4000 ha), fishing and tourism opportunities. The horticulture and floriculture industries in Naivasha are highly profitable and expanding, which attracts new populations looking for employment and typically leads to poor housing, social friction and exploitation (Becht, 2007). The local populations are quite hostile towards the flower farms, blaming them for over abstraction, pollution and exploitation of workers. In reality the majority of pollution comes from the small farms in the upper catchment. *"80% of the reduced lake levels can be attributed to the irrigated horticulture around the lake while 80% of the inflow of pollutants and nutrients can be attributed to the farmers in the upper catchment"* (Becht, 2007, p24).

There are a large number of stakeholders working around the lake. In recent years there has been improved cooperation between them and they are now working towards better management of the catchment. An abundance of scientific research has been undertaken on the lake (more details in references) –especially from the ITC[1] lead by Robert Becht. The lake was designated a RAMSAR site (wetland of international importance) in 1995 as it is the largest freshwater reservoir in the Rift Valley, acting as a refuge for wildlife and it contains the largest number of water birds in Kenya (more than 20,000) (RAMSAR, 1995). A Water Allocation Plan (WAP) was developed in 2010 for Naivasha Basin by the Water Resource Management Authority in collaboration with the major stakeholders. The WAP establishes a framework for the allocation and abstraction of water resources for the entire basin; attempting to balance consumptive use with environmental and human rights. The WAP is based on the limited hydrology data available for the lake and recognises its accuracy is a major constraint to the plan. It recommends future editions are made on the basis of more accurate and comprehensive data (WRMA are investing in gauging stations and local gauge readers). The WAP links water allocation to the availability of the resource, restricting abstractions based on the lake, river and groundwater river levels (classifying the resource as satisfactory, stressed, scarce or reserved - Table 1). The WAP runs to 2012, when the plan will be evaluated and updated by a process described in the WAP. The WAP does not incorporate climate change and this should be amended in future versions. The WAP should

[1] ITC - Faculty of Geo-Information Science and Earth Observation, University of Twenty, Netherlands

improve the sustainability of the resource, particularly important as many of the majority of stakeholders fail to recognise the link between the groundwater and lake level assuming an abundant supply of groundwater.

Table 1 Rules for Water Abstraction Restriction (there are additional restrictions for River flows (WRMA 2010)

Abstraction Restrictions and Reserve Water	Lake Naivasha level (mAOD)	Lake Water Abstractions	Groundwater Abstractions
Green i.e. Satisfactory: *Abstractions allowed up to permit limits*	> 1885.3	- Domestic and public water supplies - Others draw 75% of their licence	
Amber i.e. Stress: *Slight abstraction restrictions imposed*	1885.3 to 1884.6	- Domestic and public water supplies. - Others draw 75% of their licence	
Red i.e. Scarcity: *Severe abstraction restrictions imposed*	1884.5 to 1882.5	- Domestic and public water supplies draw 75% of licence - Others draw 50% of their licence	
Black i.e. Reserve: *Full protection; surface water uses restricted to basic human / livestock needs and nature (ecosystem) only*	< 1882.5	- Domestic and public water supplies draw amounts for basic body needs only i.e. 25 litres per person / livestock unit per day	- Domestic and public water supplies draw 75% of licence - Others draw 50% of their licence

Water Resources

This section draws heavily on work by Robert Becht (ITC) and the Lake Naivasha Riparian Association (Becht, 2005 et al. & 2007)

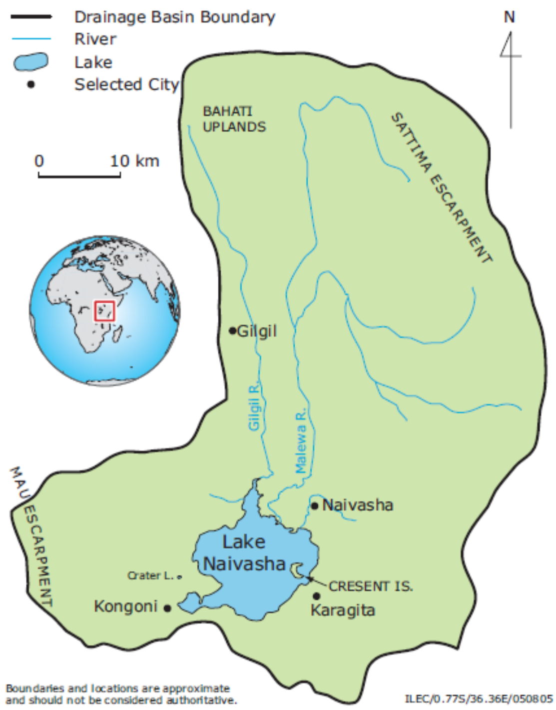


Figure 1 Map of Lake Naivasha catchment (Becht et al., 2005)

Lake Naivasha's water level has varied 12 m in the last century. The lake is fed by two perennial rivers (Figure 1), the Malewa and the Gilgil, providing 80% and 20% of the total inflow respectively (the areas south and west of the lake do not produce much runoff that reaches the lake lake). The rivers have good water quality with a low level of total dissolved solids, but the level of sodium in the water is relatively high. The lake's catchment receives an average rainfall of 600 mm/year the majority falling in the upper catchment. The lake fills a shallow depression (the main lake has a maximum depth of 8m), therefore its area and evaporation loss increases with rising lake levels (Becht, 2007). The lake has no surface outflow and the largest loss is from evaporation (approximately 1700 mm/year). The lake does not become saline as there is ground water flow to the shallow aquifer (recharging a deep geothermal aquifer system and other lakes in the region – taking around 1000 years to reach them). A water balance was developed for the period 1934-2006 by the ITC and Lake Naivasha Riparian Association (LNRA) (Table 2). It modelled the lake level accurately up to 1983 (95% of levels differed by no more than 0.52 m), but beyond this the modelled flow was 3 meters higher than the observed level (Figure 2). The discrepancy coincided with the commencement of horticulture in the basin and the estimated abstractions from surface and ground water closely matched the annual modelled deficit (60 million m^3)(Becht (2007) provides a review of the impact of the flower farms on the Lake). When the abstractions were incorporated into the model it matched the observed level. The model indicates that if a drought similar to 1940 occurred the lake's area would reduce from the present 120 km^2 to 30 km^2.

Table 2 Lake Naivasha water balance in M m^3 (10^6 m^3/Month) 1934-1983 (LNRA, 2006)

Rain	Surface water inflow	Evaporation	Groundwater outflow
95	220	260	55

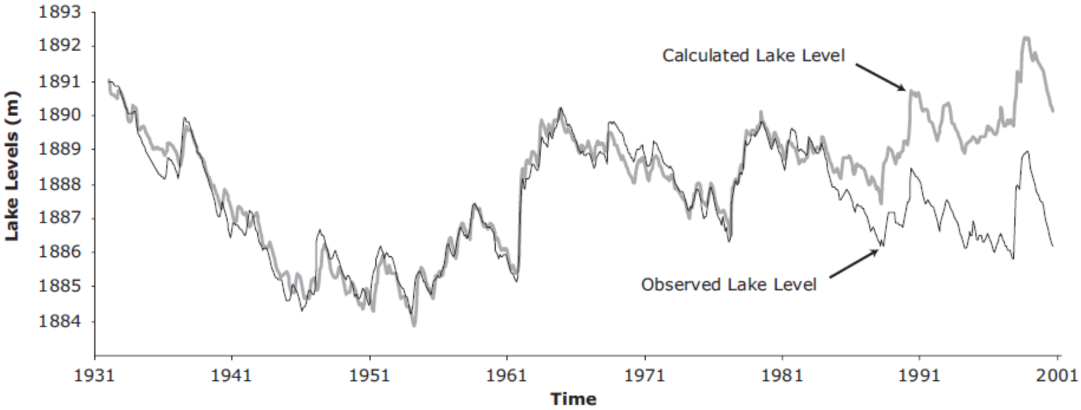


Figure 2 Long-term water change in Lake Naivasha, observed and modelled lake level (LNRA, 2006)

Groundwater has an important effect on the water balance for the lake - when the lake levels are high the lake recharges the surrounding aquifer and when low, the aquifer discharges into the lake. This interaction means there is a delay between meteorological stresses and changes in lake levels (LNRA, 2006). The groundwater acts as an extra reservoir, absorbing water during wet periods and releasing water during droughts. The aquifer has a very high transmissivity (pumping tests have yielded more than 10,000 m^2/day and the specific yield is 0.15 (Betch and Nyaoro, 2006). Due to the high transmissivity the gradient of the water table is low and the water table extends almost horizontally into the aquifer (Figure 4). There are some inflows from the flanks of the Rift Valley and major groundwater flows to the north and south drain away from the lake (Figure 3). There are significant groundwater abstractions north of the Lake, these have caused the natural gradient to inverse and a ground water depression to form – reaching a depth 6m below the lake (i.e. water flows from the lake towards the pumped zone - Figure 4). Groundwater movement is important in the area as it's used for supplying drinking water, transports pollutants and affects the levels.

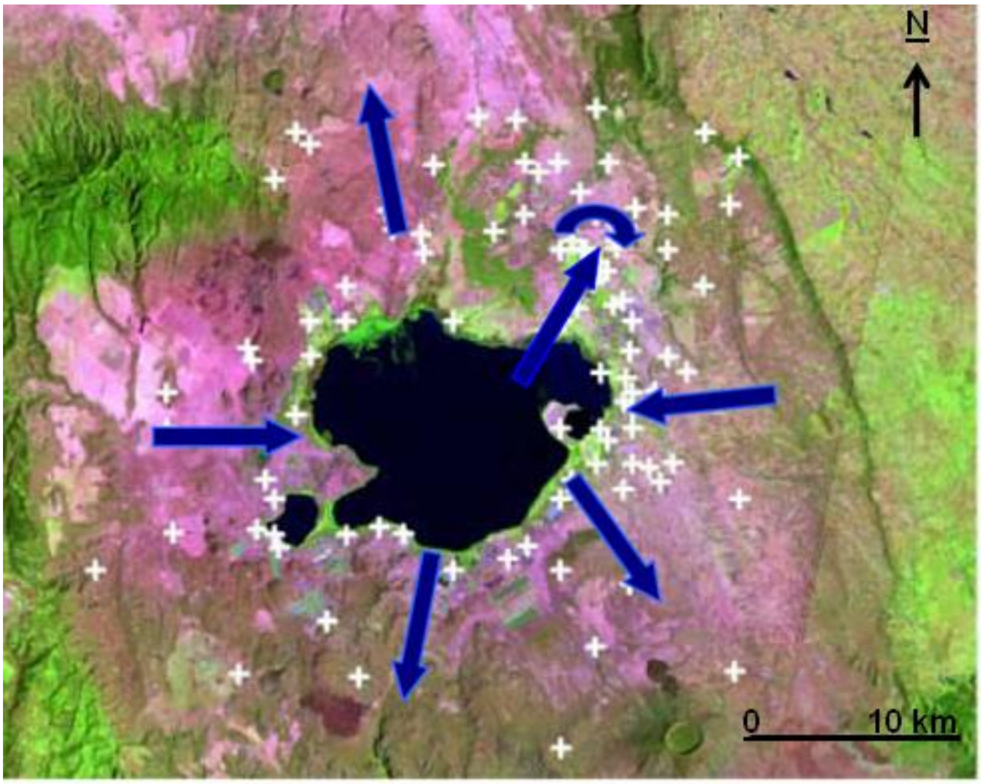


Figure 3 Lake Naivasha with wells (+) and general direction groundwater flow, reverse arrow represents return flow (figure 4c) (adapted from Becht & Nyaoro, 2006)

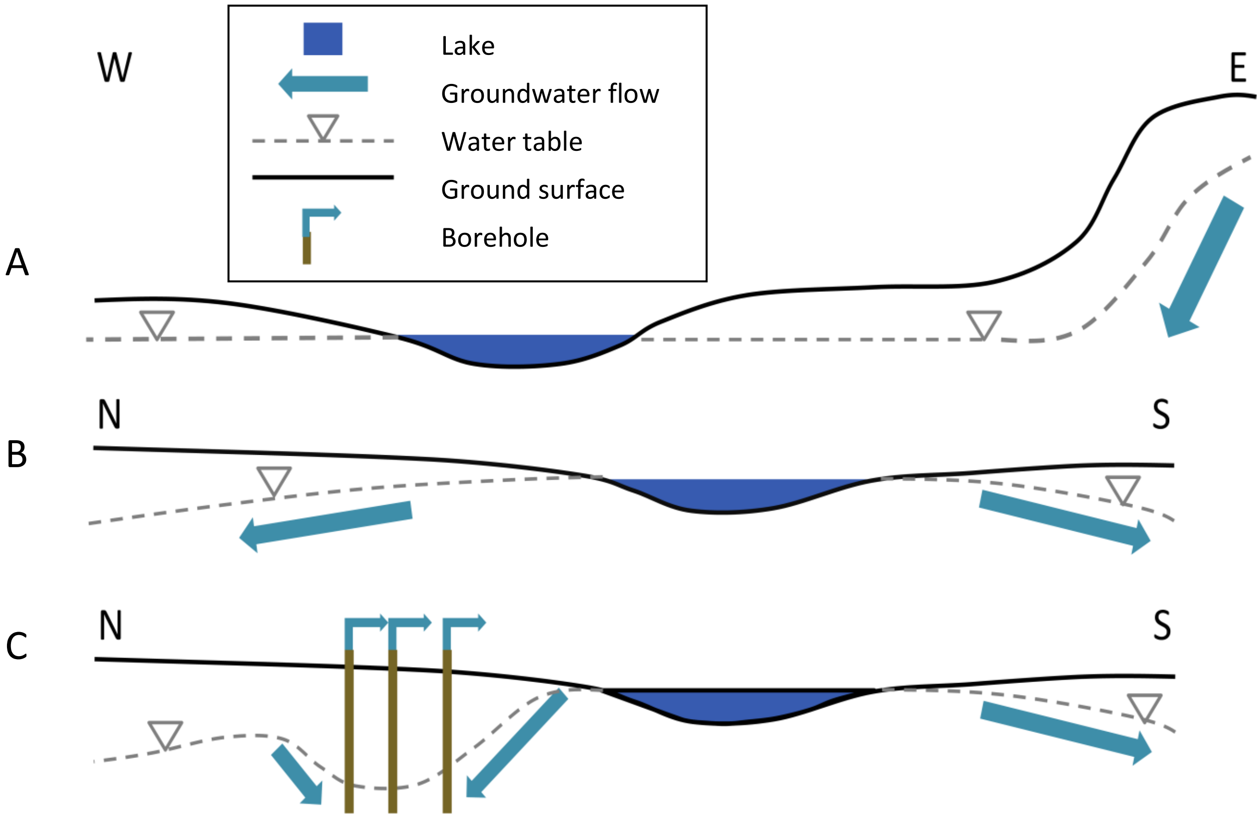


Figure 4 Cross Sections of Lake Naivasha showing water table West to East (A) and North to South before (B) and after pumping (C) (not to scale)

Pollution of the Lake

The lake environment has been severely degraded due to pollution, eutrophication, siltation and invasive species. Pollution is primarily from excess chemicals and manure applied in the upper catchments (steep slopes, high rainfall and impermeable soils) and sewage from around the town (Becht, 2007). Little pollution enters the lake from the floriculture and horticulture surrounding it, as there are permeable soils, gentle slopes and it is semi arid[2] (little direct runoff), however, agrochemicals are constantly transported downwards into the groundwater. Due to the groundwater flow paths if water is abstracted in the north it will return to the lake (as well as any pollutants) and be reused. In the south there is greater reliance on surface water (groundwater is more saline as the aquifer is deeper) and over irrigation leads to a net water loss as groundwater moves away from the lake. A review by Harper (2004) found that the ecology of the lake had been most severely disrupted by invasion of alien species – particularly the *Louisiana* crayfish and destruction of the papyrus vegetation (filters nutrients and sediment, provides a nursery and habitat). The destruction is most prevalent in the north of the catchment, where the main tributary enters; the area used to function as swamp, but now silt and nutrients run straight into the lake. Deforestation is a very significant issue in the catchment and is the cause of a lot of the eutrophication and siltation – the Naivasha council has a large tree planting programme to try and remediate the impacts.

[2] In addition as the flower and vegetable farms supply Europe they are regulated by EU standards, which have strict environmental requirements

Impacts of Climate Change on the Peri-Urban Areas

Kenya is classified as a chronically water-scarce country and has one of the world's lowest water replenishment rates per capita (World Bank, 2009). Agriculture is the basis of the economy and it is very vulnerable to increasing temperatures, droughts and floods, which reduce maize yields, the number of livestock and the output of every major sector of the economy. The arid and semi-arid lands (80% of the country) are particularly vulnerable as their economy is almost entirely dependent on livestock. The changes to climate expected are as follows (refer to the Kenya Climate Briefing - Heath, 2010 - for a more in depth overview):

CLIMATE CHANGES

Based on UNDP (2008), NAPA (2003), UNFCCC (2003) and discussions with Kenya Meteorological Organisation (2010):

- Temperature: the mean temperature is predicted to increase in Kenya with a greater frequency of 'Hot' days[3] and nights and very few 'Cold'[4] days or nights
- Rainfall: changes in rainfall are less certain, rainfall is anticipated to decrease in volume, increase in intensity and become increasingly irregular (observable in recent years)
- The climate is affected by strong ENSO event - El Niño is associated with increased rains throughout the year and La Niña is associated with a drier seasons – while a weak ENSO event has little influence on the climate
- Extreme events: anticipated increase in the frequency and intensity of extreme events, primarily droughts and floods. Extreme events are expected to expand their range of influence and there will be a shorter growing season in some regions

[3] Hot' day or 'Hot' night is defined by the temperature exceeded on 10% of days or nights in the current climate of that region (average)
[4] 'Cold' days or 'Cold' nights are defined as the temperature for the coldest 10% of days or nights (average)

Uncertainty

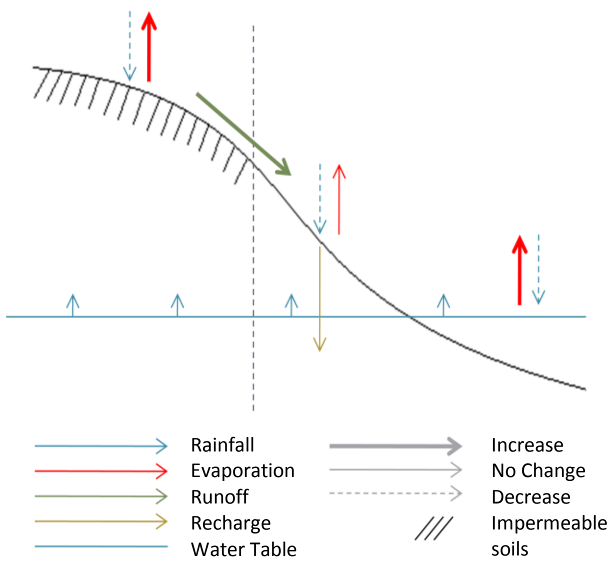
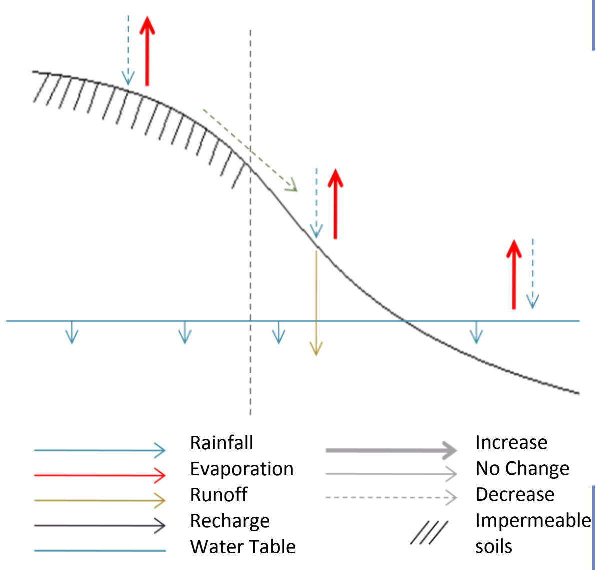
"One thing is certain; under climate change uncertainty will increase" UNWATER, 2009. When making climate change impact assessments, a 'cascade' of uncertainty arises (e.g. uncertainty with modelling, scenarios and data) making it difficult to make reliable predictions. The impacts predicted need to be considered alongside current population pressures and existing vulnerabilities - even without anthropogenic climate change, climate variability undermines food security, negatively affects the environment and significantly affects livelihoods. Therefore the most pragmatic adaptation is to develop the resilience of water and sanitation systems– managing risks, building their capacity to deal with unpredictable events and prioritising no-regret measures (UNWATER, 2009).

Climate Scenarios

To assess the impacts of climate change on the peri-urban areas surrounding Lake Naivasha, the impacts of increasing temperature, decreasing rainfall and increasing rainfall intensity were reviewed using two scenarios: increasing lake and groundwater levels and decreasing lake and groundwater levels. The differences in the scenarios are due to uncertainties with rainfall and evaporation (from soil and the lake). As it is not known how much rainfall intensity will increase or how much the total volume will decrease. This will affect the infiltration dynamics (in particular when the soil becomes saturated and rainfall can no longer infiltrate. The hydrology of the scenarios are summarised below (also outlined in Table 3 outlines how the hydrology would change for each and the key issues arising for water and sanitation technologies):

- **Increased Lake Levels:** Increase in rainfall intensity in the upper catchment results in increased runoff and river flow, offsetting the increase in evaporation at the lake and maintaining the lake level
- **Decreased Lake Levels:** Significant increases in evaporation from the lake (and irrigation demand); rainfall decreases and is more sporadic offsetting the increase in intensity and runoff

Table 3: Predicted changes to hydrology resulting from climate change (dashed arrows indicate a decrease, thick arrows an increase) and the key issues resulting from climate changes (the appendix summarises the impacts of the key issues on the technologies)

Increased Lake and Groundwater Level (increase in flash floods)	Decreased Lake and Groundwater Level (increase in droughts)
	
Impact on Water Supply • Increase in extreme rainfall events • Groundwater recharge increases • Run-off increases	**Impact on Water Supply** • Increase in extreme rainfall events • Water availability decreases

Sanitation	Sanitation
• Flooding increases; increase in extreme rainfall events	• Water availability decreases

IMPACTS OF CLIMATE CHANGE NOT DIRECTLY RELATED TO WATER AND SANITATION

The following summarises the impacts of climate change on Kenya not directly related to water and sanitation; refer to the climate change briefing (Heath, 2010) for a comprehensive overview:

- **Food insecurity – principally maize and livestock**: Increasing temperatures and the unpredictability of rainfall will increase crop failure, significantly increasing the cost of food – the drought in 2009 considerably increased the cost of food items in the peri-urban areas and was cited by the community as one of the main problems during the drought;
- **Employment –** the majority of employment in Lake Naivasha is from the flower and vegetable farms around the lake. If the lake is low the farms may reduce production and lay off workers (depending on the extent of the shortages and when the shortages occur in the growing season);
- **Electricity**: droughts and reduced rainfall decrease the availability of water for hydroelectric increasing the price of electricity and the cost of pumping water.

IMPACT OF CLIMATE CHANGE ON LAKE NAIVASHA

To assess the impact of climate change on Lake Naivasha the data used in the water balance model was modified to evaluate the sensitivity of the lake to changes in surface inflow, evaporation and rainfall and assess how the WAP abstractions would have differed calculated (The method and figures are presented in the appendix). The analysis indicated that the lake is more sensitive to changes in surface water inflows and evaporation than rainfall. Either a 10% increase in evaporation or a 10% percentage decrease in surface water reduces the lake level by a metre and significantly increases the number of months it is classed as scarce – from 5.2% of months to around 25%. If surface water inflows increase the lake level will increase and be classed 'satisfactory' for most months. This analysis indicated that surface water inflows have a significant effect on lake levels; therefore further studies should clarify how changing land use impacts inflows. Changes in rainfall have half the impact of changes in evaporation with a 10% reduction reducing the lake level by under a meter. Rainfall has less influence on the lake as it inputs half the volume inputted by surface water and removed by evaporation (95 M m^3 compared to 220 M m^3 and 260 M m^3, Table 2). If evaporation increases or surface water decrease coincided with a drought similar to the one of 1940 and current abstractions continue the lake would dry up - the new WAP limits should prevent this, but it highlights the significance of climate change and the need for sustainable management of the lake.

IMPACT OF CLIMATE CHANGE ON PERI-URBAN AREAS

Climate change is likely to exacerbate [or reduce] existing vulnerabilities rather than create new problems. Figure 4 synthesises how climate change will impact the existing vulnerabilities). The following outlines the impact of climate change on water and sanitation in the peri-urban areas around Lake Naivasha.

DECREASE IN LAKE AND GROUND WATERS

Decreasing lake levels and drought will have significant impacts on the peri-urban areas in Naivasha. During droughts there is higher domestic demand (laundry and washing), but water availability decreases. At the kiosks and the free borehole 4 km from Kamere there are long queues, while in the unserved areas it takes longer to collect water from the lake, it is more expensive from vendors and there is increased use of low quality water direct from the lake. As a result water use decreases, hygiene deteriorates, there is an increase in diseases, it is more difficult to irrigate domestic gardens and women have to spend more time cleaning, washing and collecting water (in Kamere men also collect water). In addition, children are often sent looking for work instead of going to school (especially water vendoring which is quite profitable). If the whole country is suffering from drought then food and consumables are more expensive and hydroelectric sources have insufficient supply increasing the cost of electricity and the cost of pumping water. During interviews the community almost exclusively cited the increased cost of food and water, combined with unemployment as the most significant issue during droughts. The boreholes supplying the kiosks in Karagaita are in a confined aquifer and the yield was not significantly affected by the 2009 drought. The water level in NAIVAWASS boreholes (3 next to the lake) was lower and volcanic soil was deposited in the tanks. In Mirera the borehole level was not significantly affected during the drought.

Impact on Employment

Decreasing lake levels create a large number of problems for the flower and vegetable farms:

- The concentration of pollutants in the lake increases, making alga blooms more likely, increasing the cost of filtering the water;
- The lake's shallowness means as the level lowers its area contracts and abstractions are no longer at the lake edge; to adapt the flower farms dig trenches to access the water, which act as barriers to wildlife and livestock;
- If the groundwater is lower it is more expensive to pump and becomes increasingly saline;
- As there is less water in lakes the farms abstract less as they feel it's not sustainable. The result is the financial viability of the farms decreases (especially the south side) and they reduce production and employment, significantly affecting the peri-urban areas.

The WAP will limit abstractions when the lake is low, therefore the farms need to increase the water efficiency or they will be forced to reduce production. The flower farms are investing in hydroponics[5] and more efficient water use, reducing their vulnerability, while the vegetable farms still have a high water demands.

Impact on Livelihoods

Fishing, livestock and tourism will also be affected by declining lake levels. Fisheries would be severely affected, as algal blooms reduce oxygen levels in the water leading to fish deaths, the fish nurseries are in the shallower parts of the lake which are exposed during droughts and the lakes' smaller area results in overfishing damaging future yields. Pastoralists are impacted by the declining lake edge and it becomes more difficult to reach water as the exposed riparian land is used for farming or trenches and wildlife corridors are not maintained, excluding livestock and creating conflict. During severe droughts Lake Naivasha is the only water

[5] Growing plants using mineral nutrient solutions, in water, without soil

point for livestock pastoralists. This leads to overgrazing and siltation which reduces future grass supplies. Tourism can also be affected as the lake reduces reducing the RAMSAR species habitats. During droughts the soil is very dry and low pressure develops over the lake increasing the wind strength, which causes erosion, damages crops and can blow off roofs.

INCREASE IN LAKE AND GROUNDWATER LEVELS

An increase in river flows, lake levels and the resultant groundwater recharge would be largely positive for Naivasha as there will be more water for domestic and irrigation usage. Evaporation and abstractions are likely to limit significant increases, but the lake would maintain its current levels. The negative impact of this scenario is an increase in the number and intensity of flash floods, increasing the amount of solid waste and silt washed into the lake. The heavy rain can cause the following:

- Latrines collapse (principally due to slabs not being properly sealed) and overflow
- Mud building subside
- Pipes are exposed due to soil erosion
- Water gets in houses
- Wastewater mixes with the flood water
- Crops are damaged
- There is an increase in water borne diseases

Flash floods make road impassable and severely eroded, forming large pot holes and damaging their structure, this is compounded by the heavy rainfall which further degrades the road. This leads to disruption of business, increased transport costs, difficulties transporting food, increases in charcoal prices and children can have trouble getting to school. The advantage of the flood is it clears the streets of solid waste – although it ends up in the lake. The impacts are most severe in Kamere where the land is steepest and there are very fast flows, there are also severe problems in Karigaita; however in both areas the soils are volcanic so the water quickly drains and most homes are unaffected. In Mirera the floods only affect the roads and crops as it is relatively flat and there is more space between houses. During the rains prior to the floods the community is able to harvest rainwater (reducing takings at the kiosks), there is increased employment on local farms and food is cheaper.

The community felt that flash floods are only an inconvenience and not a major threat (although the health clinic observed increases in water borne diseases - diarrhoea, typhoid and amebaebic dysentry) and the benefits associated with the rains outweigh the costs. However; it’s important to recognise that rainfall intensity is predicted to increase, which may increase the severity and frequency of flash floods, making the impacts more severe.

CLIMATE CHANGE AWARENESS

As well as increasing the resilience of water supply and sanitation systems, working with other organizations to build capacity and share knowledge is key for successful adaptation to climate change. Therefore an understanding of the current climate awareness and actions of the different stakeholders is needed. Table 3 gives an assessment of this information based on stakeholder interviews.

Table 4: Climate change awareness and actions of organizations in Naivasha

Stakeholder	Awareness	Plans/Actions	No. Interviews
Community	Limited	None	10
WSUP	Medium	Not assessed in work or in water demand projections in Master Plan	2
NAIVAWASS	Limited	Not assessed in their work	2
Local Council	Medium	No direct plans	2
Farmers	Medium	Not aware of any plans	1
Government	Mixed	- Each ministry must have a climate change focal point - Involved in UNFCCC dialogue - Little regional or district work being completed, seen as issue for central government	7
Research	High	- Studies being undertaken and advocacy work	1
NGOs	High, involved in awareness raising	- WWF completing study looking at the impact of climate change on the catchment	4

Recommendations

Adapting to climate change requires a combination of technological and structural measures, risk sharing and capacity building to increase the robustness of systems. Coping with climate change does not involve many entirely new processes or techniques. It should, however, be made clear that this is not an argument for 'business as usual'. Existing instruments, methods and measures may need to be introduced at a faster pace, and applied in different locations, at different scales, within different socio-economic contexts and in new combinations (CAPNET, 2009). Developing water safety plans should be a priority, to reduce the risks to water supply by establishing a framework for managing the risks to drinking water from catchment to consumer (Bartram 2009).

This section reviews the key adaptations for WSUP (or a subsequent operator, NAIVAWASS and the local Council. The adaptations were determined based on a field visit, a vulnerability assessment and a literature review . Some recommendations will be part of existing maintenance programmes; however, the priority of these actions may need increasing. The adaptations have been divided into three timescales (based on Venton, 2010), four categories and three priorities: high priority, significant threat and actions that will improve resilience of the system. References in brackets provide further information about each recommendation.

- **Short term:** contingency adaptation for extreme events – e.g. Drought management/ flood forecasting, focussed on disaster management experience;
- **Medium term:** tactical adaptations regarding climate variability, linked with disaster risk reduction;
- **Long term:** adaptations necessary to respond to a predicted different climate.

The adaptations categories (based on Charles *et al*., 2010):

- **Capital expenditure**, which includes new investments and projects;
- **Operational expenditure**, which includes adaptations that can be made to existing systems;
- **Monitoring**, which includes programmes that can be implemented immediately to support planning decisions, or implemented in the long term to support continuing decisions;
- **Socioeconomic,** tools such as community education, training and public awareness.

SUMMARY OF ADAPTATIONS IN THE PERI-URBAN AREAS

The main impacts of climate change in the peri-urban areas around Lake Naivasha are a lack of access to affordable water during droughts, flash floods from the upper catchments causing latrines to overflow and heavy rain making latrines unstable. The main adaptations to each of these issues are outlined below:

- **Ensure affordable and accessible water supply:** during droughts there is increased unemployment, and higher living costs. Maintaining cheap water at the kiosks will ensure all households can still afford water and have enough for the increased domestic demand, avoiding a deterioration of hygiene and health and women spending large amounts of time collecting water. In Kamere installing a pump needs to be addressed as soon as possible in the interim there should be community education on source selection and treatment. In Mirera there should be management capacity building of the owners of the borehole system. In addition, water levels should be monitored during droughts and the data given to the WRMA so they can ensure the WAP designations adequately protect domestic supply

- **Continue to Support Catchment Management Plan:** deforestation and poor catchment management impact the peri-urban areas through erosion, high winds and flash floods. The peri-urban areas impact the catchment through their abstractions and solidwaste and wastewater which pollutes the lake. Damage to the lake impacts the flower farms which affects livelihoods. The solidwaste collection should be addressed, latrines promoted and education on open defecation needs to be advocated by WSUP. The direct impact of the peri-urban areas on the catchment is small; but the impacts on the peri-urban areas are significant. WSUP should continue to support WWF and the LNRA catchment management plan when requested (possibly installing drainage and terraces or providing land for afforestation) – the exception is subsidising payments for environmental services through the water tariffs, this should be avoided as it would impact the poorest households.

- **Latrine Construction and Education:** damage to latrines and overflowing sludge present the largest risks from flash floods and although few overflow, it is significant when they do. When building new latrines the soil should be compacted, a good seal installed, bricks used below ground level and 300m above ground rather than mud and the drainage paths accounted for (when necessary face latrine doors down slope). However, the priority should be educating the community on construction methods as WSUP sponsored latrines are of high quality and the main risks are from poorly constructed household latrines (detail on construction: ITDG, 2007)

- **Protecting Boreholes:** Rainfall is predicted to become more intense, so it is important to ensure the well head on the supply boreholes are properly sealed and no water can get into the borehole (e.g. make sure no cracks on the plinth, check cover clean, proximity to latrines, check 1m radius of concrete, put up fence to keep livestock out; WHO 2.1, 1996 and Lloyd and Helmer 1991)

WSUP/ Local Service Provider

Immediate/ Short term (0 – 6 months)

Capital Expenditure

- Ensure proper compaction of soil around the latrine and presence of adequate base and earth filling to protect pits, pit covers and slabs
- Replace pump at borehole in Kamere
- Ensure the use of durable materials in construction of latrines and raise the level

Operation Expenditure

- After flooding assess and address infrastructure damage (Reed, 2006 &WHO, 2003)
- Investigate the source of flash floods (is it from the catchment or local rain)
- Hygiene education on source selection and treatment in Kamere (Appleton and Sijbensema, 2005)
- Pipe maintenance programme to reduce leaks (DOH, 2008, EPD, 2007 & WHO, 2001)
- Regular maintenance of soil around pipes to protect against collapse (WHO, 2003, Chp 7)

Monitoring

- Sanitary inspection of latrines, storage and hygiene (Appleton and Sijbensema, 2005)
- Water use surveys to identify demand
- Carry out regular inspection and vulnerability assessments of kiosks

Social Economic

- Hygiene education on the importance of first flush when rainwater harvesting
- If pipes are exposed to water develop communication procedures to notify the community when the water is safe (Curtis, 2005)

Medium Term (6 Months – 1 year)

Capital Expenditure

- Ensure that well heads are properly designed to prevent erosion damage that may increase infiltration (WHO, 2003)
- Build bunds (banks, dykes or levees) to divert flow away from system
- Education on the need to site latrine away from drainage channel, ensure proper seal when constructing pit latrines and build latrines with doors facing down slope
- All construction below ground from stone/bricks, possibly use properly compacted sand blocks (method in ITDG, 2007)
- After flooding disinfect pipes (WHO 2.27, 1996)
- Develop borehole protection zones, ensure no risk from contaminants (WHO 2.1, 1996)
- Adopt higher design standards for infrastructure to take more frequent extreme weather events into consideration
- Use compaction of soils and planting around infrastructure to increase durability of structures

Operation Expenditure

- Develop Water Safety Plan (Bartram 2010)
- Capacity build management of private borehole operators in operation and distribution in Mirera
- Adapt maintenance programme to identify breakages (DOH, 2008 & (EPD 2007)
- Ensure high levels of maintenance on boreholes to avoid unnecessary losses of water at the point of use
- Plan for emergency supplies of drinking water to be available in the event of system failure
- Provide assistance emptying old latrines (Scott and Reed, 2006)
- Reduce non-revenue water (Parker, 2010)

Monitoring

- Monitor microbial quality of water in boreholes during droughts and floods
- Monitor the water levels in boreholes during droughts
- Monitor water use at kiosks during droughts
- Investigate the development of plot soakaways to reduce household flooding

SOCIAL ECONOMIC

- Educate communities about reliable water sources: how to select them, what makes them reliable, (Appleton and Sijbensema, 2005)
- Raise awareness among the public of the risk of contamination during and after extreme rainfall events (Reed, 2006)
- Community education/empowerment on need to maintain drains and build basic structures to minimise flooding – e.g trenches with rubble steps (Cairncross *et al.,* 1991 & Parkinson 2010)
- Education on latrine construction: soil compacted, good seal installed, bricks used rather than mud and the drainage paths accounted for
- Educate schools on dangers of mixing the water brought from pupils (in droughts some schools require pupils to bring in water which is then mixed together)
- Disseminate health advisory notices to the public with advice about dealing with the risks in droughts
- Develop and explain benefits of ECOSAN in areas with agricultural use (Smet and Sugden 2006)
- Raise awareness among water engineers of risks from water quality changes during extreme rainfall events, and how to manage the risk
- Raise awareness about risks from water quality changes during flooding and the need for household water treatment

LONG TERM (1 YEAR+)

- Maintain low price for water
- Assist WWF in catchment management plan
- Investigate methods to increase the artificial recharge of groundwater (BGR, 2009)
- Raise awareness among the community about the damage that erosion can cause to infrastructure, and the potential effect on the water supply system
- Raise awareness among the community about the damage that erosion can cause to wells and boreholes
- Consider deepening boreholes
- Determine the degree of vulnerability through investigating linkages between climate and groundwater, e.g. residence times, recharge rates and water level monitoring

Other Stakeholders

Adaptation to climate change requires an integrated approach from all stakeholders. Alongside WSUP, NAIVAWASS and Naivasha council are central for providing water and sanitation in the peri-urban areas. NAIVAWASS' priority needs to be incorporating the kiosks system into their distribution network, as larger systems are more resistant and better able to adapt to climate vulnerability (Bartram and Howard, 2010). In addition NAIVAWASS should adapt their system to better cope with flash floods, in particular their sewage network and treatment systems. The council have a central role within the catchment management plan. Maintaining, improving and developing new drainage is a key part of their role; combined with terracing and tree planting in the upper catchment. This will reduce flash floods, siltation, erosion and improve the quality of the lake. In addition, It is important that the council work in close collaboration with WRMA when Water Abstraction Plan is updated. The following identifies focused recommendations for NAVIAWASS and Naivasha council, on how they can help support the peri-urban areas in adapting to climate change. The adaptations for both are split into short, medium and long term adaptation and divided by priority (high priority, significant threat and action that will improve resilience of systems).

NAIVAWASS

Short term (0 – 6 months)

- Monitor water quality during droughts and floods
- Carry out regular inspection and vulnerability assessments of structures (WHO 2.1, 1996)

Medium term (6 months – 1 year)

- Build bunds (banks, dykes or levees) to divert flow away from system
- Adopt higher design standards for infrastructure to take more frequent extreme weather events into consideration (WHO, 2003)
- Concentrate water quality monitoring during periods of extended droughts
- Enhanced inspection of infrastructure after flash floods
- After flooding disinfect pipes (WHO 2.27, 1996)
- Monitor water quality and adapt treatment processes to ensure that water quality is not compromised (e.g. increasing sedimentation time and improving filtration systems)
- Install hydrological monitoring stations; rain gauges and access earth observation data
- Introduce additional more robust barriers and treatment stages
- Select appropriate water treatment stages to suit water quality
- Increase attention to construction quality and setting out of sewers, more rodding eyes, steeper falls, consider low-flush toilets (Gate, 2001)

Long term (1 year+)

- Develop emergency water plan for times of extreme scarcity, such as linkages to other sources or emergency tank supplies
- If supply from the borehole is already variable, consider that the current boreholes may need to be extended or new deeper boreholes may need to be installed

Municipality – Naivasha Council

Short term (0 – 6 months)

- Maintain drainage and culverts, ensure clear (Cairncross *et al.,* 1991 & Parkinson 2010)
- Maintain conditions which mitigate erosion e.g. compaction of soils and planting in buffer strips
- Maintain roads to reduce standing water and erosion

Medium term (6 months – 1 year)

- Improve drainage (Reed, 2006 & Parkinson 2010)
- Educate community on need to maintain drains
- Divert water from upper catchment away from town, tree planting
- Develop communication procedures to notify the community when the water is safe
- Improve legislation for allocation of riparian land, ensure wildlife and livestock access, establish processes to address conflict
- Land management – minimize erosion with planting schemes, buffer strips and storm water management
- Work with WRMA to incorporate climate change into work and expand hydrological network of monitoring stations – rain and lake gauges
- Provide assistance emptying old latrines (Scott and Reed, 2006)
- Install basic sand pump at Kamera at lake edge to filter pollutants from Lake (WHO, 2.5, 1996)

Long term (1 year+)

- Expand upstream terraces to reduce runoff
- Afforestation
- Garbage collection
- Provide free meal in schools during droughts to improve attendance
- Investigate methods for the artificial recharge of groundwater/Investigate catchment management practices to promote infiltration (BGR, 2009)
- Work with WRMA to quantify the reserve water levels in lake
- Establish more efficient charcoal production (burning in kilns rather than covering with soil)
- Reward farm forestry

Response to Recommendations

A response to the following questions will be included from WSUP, NAIVAWASS and the Council:

1. How will [stakeholder] respond to the climate proofing recommendations?
    a. How will the adaptations be implemented?
    b. How do they impact long term plans?
2. What additional information do you require to apply the adaptations?

Further Information

Climate modelling and climate change adaptation are both areas of continuing research. It is important to be aware of the ongoing work being undertaken which will inform future investments and adaptations. Table 4 illustrates that although climate change is recognised at the policy level, there is little work being implemented regionally. As policy filters down it will have a greater impact on resource management and it is important to stay aware of changes to policy.

Current Research

- **WWF** are completing a study of the impact of climate change on the Lake Naivasha basin
- **Water Abstraction Plan:** The Water Resource Management Authority will be updating the Water Abstraction Plan and reviewing the new abstraction levels applied to the lake and each river and assessing how climate change is incorporated to revisions will be important

Key Researchers

- **Dr. Robert Becht:** Assistant Professor: Department of Water Resources, ITC, Netherlands. Supervised over 60 MSc projects around Lake Naivasha and one PhD. Focus on modeling the lake: water balance, surface water, groundwater, water management and allocation) www.itc.nl/about_itc/resumes/becht.aspx
- **Dr David Harper**. Senior Lecturer. Department of Biology. University of Leicester, UK. Investigation of sustainable management of water resources and ecology of Lake Naivasha www2.le.ac.uk/departments/biology/people/harper
- **Dr Daniel Olago**: Senior Lecturer in Geology: Department of Geology, University of Nairobi, Kenya. Assessing sustainable management of water resources and assessing climate change vulnerability www.uon.ac.ke/profiles/?id=165900
- **Dr William Shivoga**: Senior Lecturer/ Head of Department of Environmental Science, Egerton University, Kenya. Studied the lithology of Lake Naivasha www.uwyo.edu/SUMAWA/bios/principalinvestigators/shivoga.htm

CLIMATE CHANGE DONORS IN KENYA

The following is a list of donor who are known to be supporting climate change adaptation in Kenya. It was noted that at present the Government has not secured much funding allocated for regional environmental and natural resource issues

- Danish Development Agency (DANIDA)
- Heinrich Böll - Foundation
- Christian Aid
- CORD Africa
- Carbon credit Scheme
- Reducing Emission from Deforestation and Forested Degradation (REDD+)
- UNDP
- World Bank

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Appendix

STAKEHOLDER INTERVIEWS

Table 5 Overview of interviews undertaken in Naivasha

Organisation	Number of Interviews	
Naivasha Council	**2**	
Community	**8**	
• Karagita		2
• Kamera		5
• Mirera		1
WSUP	**2**	
Government	**7**	
• WRMA – Naivasha		2
• Ministry of Agriculture – Naivasha		1
• Fisheries Officer– Naivasha		1
• Health Clinic– Naivasha		1
• Kenyan Meteorological Organisation		1
• National Environmental Management Authority – Naivasha		1
NAIVAWASS	**2**	
Farmers	**1**	
NGO	**4**	
• Lake Naivasha Riparian Associate		1
• Lake Naivasha Grower's Group		1
• WWF		2
Research	**1**	
• Institute for Environment and Water		1
Focus Groups	**2**	
• Karagita		2
Total	**29**	

Impact of climate change on Lake Naivasha

To assess the impact of climate change on Lake Naivasha the data used in the water balance model was modified to evaluate the sensitivity of the lake to changes in surface inflow, evaporation and rainfall and assess how the WAP abstractions would have differed calculated. 20 simulations were completed in total using the following method:

1. Monthly surface inflows were varied[6] by a fixed percentage (between -25% & 25%) and the monthly lake level modelled between 1932 and 2006
2. The value of monthly precipitation was decreased by a fixed percentage (-5%, -10%, -15%, -20%, -25%) and the monthly lake level modelled between 1932 and 2006
3. The value of monthly evaporation was increased by a fixed percentage (5%, 10%, 15%, 20% & 25%) and the monthly lake level modelled between 1932 and 2006
4. The WAP designation was calculated for each month between 1932 and 2006 for the original data
5. The WAP designation for the lake was calculated for each month between 1932 and 2006 for each model simulations
   NOTE: variables were not modified simultaneously

Figure 4 displays the result indicating how the lake level would have changed for each simulation and how on average the lake would have been classified for each scenario (e.g. If the evaporation was 10% higher between 1932-2006 what percentage of months would the lake have been scarce). The method is simplistic and has major limitations (principally the changes won't happen independently, past climate can't be relied on for predicting the future and the change in percentage would vary); however, it gives a rough indication of the significance of changes in runoff, evaporation and rainfall.

The analysis indicates the lake is more sensitive to changes in surface water inflows and evaporation than rainfall. Either a 10% increase in evaporation or a 10% percentage decrease in surface water reduces the lake level by a metre and significantly increases the number of months it is classed as scarce – from 5.2% of months to around 25%. If surface water inflows increase the lake level will increase and be classed 'satisfactory' for most months.

[6] Surface runoff values were both increased and decreased due to uncertainties with infiltration dynamics

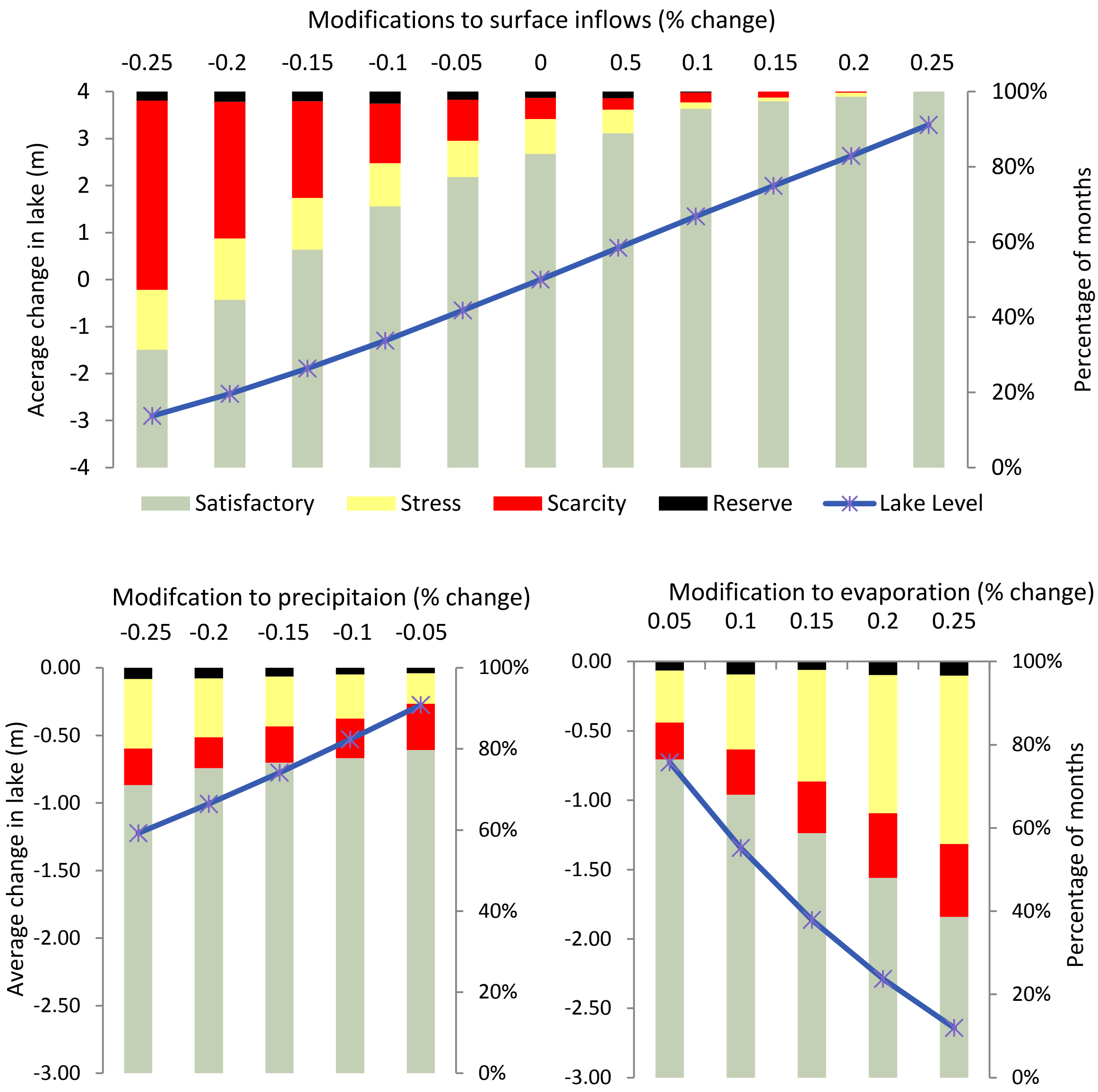

Figure 5: Impact of changing runoff, evaporation and rainfall on Lake Naivasha. The blue line indicates how the average height of lake would have differed if the monthly surface inflow, evaporation or precipitation were varied by a fixed percentage between 1932-2006. The bars indicate percentage of months the lake would have been each designation for each scenario (e.g. If evaporation had been 10% higher between 1932-2006 the lake would have been on average 1.34 m lower and for 25% of months it would have been classed 'Scarce').

This analysis indicates that surface water inflows have a significant effect on lake levels; therefore further studies should clarify how changing land use impacts inflows. Changes in rainfall have half the impact of changes in evaporation with a 10% reduction reducing the lake level by under a meter. Rainfall has less influence on the lake as it inputs half the volume inputted by surface water and removed by evaporation (95 M m^3 compared to 220 M m^3 and 260 M m^3, Table 2). If evaporation increases or surface water decrease coincided with a drought similar to the one of 1940 and current abstractions continue the lake would dry up - the new WAP limits should prevent this, but it highlights the significance of climate change and the need for sustainable management of the lake.

Vulnerability Assessment

Understanding the existing vulnerabilities is central to assessing the impacts of climate change. Figure 4 outline the environmental vulnerabilities and problems with the water supply systems in the peri-urban areas and impact of the climate scenarios predicted for Naivasha. Both scenarios (increasing and decreasing lake and groundwater levels) are represented on the diagram, as there would be overlap. The factors directly impacted are highlighted red and impacted factor in pink –the darker the colour, the greater the likelihood the problem will be affected by climate change, factors that are not affected are green.

Figure 4 Impact of climate change on the peri-urban areas in Lake Naivasha (red indicates direct impact of climate change, green no direct affect, dashed lines are for visual purposes)

LITERATURE REVIEW

In addition to identifying the impacts of climate change on the existing vulnerabilities and problems in the peri-urban areas in Lake Naivasha the literature was reviewed to assess the impact of climate change on water and sanitation technologies. The following tables overview how the technologies (current and planned) are vulnerable to the key issues and the resulting impacts. The tables are based on observations during the field visit and literature, which assesses the impact of climate change on technology – principally a review completed by the WHO and DFID in 2010 (Charles *et al.*, 2010).

Impact of Climate Change on Technology in Peri-Urban Areas

Borehole

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Water availability decreases	Insufficient water for demand	Water shortages and potential for water rationing. Public health risk from inappropriate water saving in the home	Investigate alternative and supplementary water sources and water harvesting methods, such as rainwater collection and water reuse. Prioritize water use for drinking. Investigate methods for the artificial recharge of groundwater Investigate catchment management practices to promote infiltration. Consider deepening the wells and boreholes	Ensure high levels of maintenance on wells to avoid unnecessary losses of water at the point of use	Monitor water use at well for user pays scheme, and assist in demand management. Monitor the ability of wells to cope with current droughts	Implement education programme to reduce water demand. Promote the importance of hygiene
	Increased use of viable wells causes increased wear and tear, and increased water demand	Damage to well or borehole increases the risk of contamination entering water source. Public health risk from consumption of the water	Determine the degree of vulnerability through investigating linkages between climate and groundwater, e.g. residence times	Ensure high levels of maintenance on in demand wells	Sanitary survey. Monitor the ability of wells to cope with current droughts	
	Less water available for hygiene and cleaning	Public health risk from inappropriate water saving in the home	Research cleaning and hygiene methods that have low-water usage		Water use surveys	Raise awareness of the importance of hygiene
	Groundwater levels dropping, especially during a dry period or season	Water shortages and potential for water rationing. Public health risk from inappropriate water saving in the home. Increased risk of contamination of the water at the end of the drought	If supply from the well is already variable, consider that the current well may need to be extended or new deeper wells may need to be installed. Install relief wells that can be uncapped for easy use in dry periods to supplement existing wells	Determine the degree of vulnerability	Concentrate water quality monitoring during periods of high risk at the end of the droughts	
Run-off increases	Erosion	Permanent loss of borehole or well. Damage to the structure of the borehole or well, leading to a temporary loss of supply. Public health risk from contaminants entering the standpipe	Ensure that well heads are properly designed to prevent erosion damage that may increase infiltration. Use compaction of soils and planting around infrastructure to increase durability of structures	Maintain conditions which mitigate erosion e.g. compaction of soils and plants in buffer strips.	Monitor microbial quality of water after the well or borehole has been renovated	Raise awareness among the community about the damage that erosion can cause to wells and boreholes. Develop communication procedures to notify the community when the water is safe
Increase in extreme rainfall events	none					

COMMUNITY-MANAGED DRINKING WATER SYSTEMS (DIRECT CONNECTIONS)

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Water availability decreases	Insufficient water for demand, or increased seasonality of water	Water shortages and potential for water rationing. Public health risk from inappropriate water saving in the home	Restrict water supplies and switch pipes off. Investigate alternative water sources and water harvesting methods. Develop emergency water plan for times of extreme scarcity, such as linkages to other sources or emergency tank supplies. Integration of systems may protect from water shortages	Pipe maintenance programme to reduce leaks. Prioritize allocation for domestic use. Establish centralized support unit to provide technical and administrative assistance	Monitor for microbial quality of water.	Educate communities about reliable water sources: how to select them, what makes them reliable, etc. Promote the importance of hygiene. Implement education programme to reduce water demand.
Run-off increases	Increased erosion leading to more polluted run-off, with silt and nutrients.	Increased suspended sediment loads may exceed the treatment capacity of the water treatment facilities. Public health risk from contaminants entering the water distribution system.	Land management – minimize erosion with planting schemes, buffer strips and storm water management.	Maintain vegetation in buffer strips next to rivers. Establish centralized support unit to provide technical and administrative assistance.	Monitor water quality and adapt treatment processes to ensure that water quality is not compromised, such as by increasing sedimentation time and improving filtration systems.	Raise awareness among the community of the risk of contamination during and after extreme rainfall events. Disseminate health advisory notices to the public with advice about dealing with the risks. Develop communication procedures to notify the community when the water is safe.
Increase in extreme rainfall events	Damage to infrastructure	Potential failure of the drinking-water supply system and loss of service. Public health risk from contaminants entering the water distribution system through damaged pipes.	Adopt higher design standards for infrastructure to take more frequent extreme weather events into consideration.	Response plan after flooding to assess and address infrastructure damage. Plan for emergency supplies of drinking water to be available in the event of system failure.	Hydrological monitoring stations. Rain gauging. Earth observation data. Enhanced inspection of infrastructure.	Raise awareness among the public of the risk of contamination during and after extreme rainfall events. Raise awareness among water engineers of risks from water quality changes during extreme rainfall events, and how to manage the risk. Disseminate health advisory notices to the public with advice about dealing with the risks.
	Surface water quality deterioration during floods.	Floodwater carries increase sediment load that may exceed the treatment capacity of any small-scale water treatment system that is part of the supply system. Run off water from upstream may carry higher concentrations of chemical and microbial contaminants. Risk to public health from consuming the water.	Adapt water treatment for flood conditions depending on water source and contamination. Introduce additional more robust barriers and treatment stages. Relocate abstraction points, where possible.	Select appropriate water treatment stages to suit water quality. Dig out buried intakes after the flood waters recede.	Sanitary inspection. Simple monitoring of raw water quality, e.g. turbidity.	Develop communication procedures for when water is safe. Raise awareness about risks from water quality changes during flooding and the need for household water treatment.
	Flooding causes damage to bridges that support mains or distribution pipes over rivers.	Localized or widespread disruption to water supplies.	Review risks and benefits of burying main under river or supporting from bridge over the river. Select least risk option. Install isolation valves at both sides of crossing.		Carry out regular inspection and vulnerability assessment of structures.	Develop monitoring, management and communication procedures with the bridge owners, if not owned by the community

Kiosk/ Standpipe

Issue	**Vulnerability**	**Impacts**	**Adaptations**			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Water availability decreases	Addressed in community managed supply					
Run-off increases	Erosion damaging standpipe.	Destruction of the standpipe and loss of service. Public health risk from contaminants entering the standpipe	Land management – minimize erosion with planting schemes, buffer strips and storm water management. Use durable materials in construction	Maintain conditions which mitigate erosion, e.g. compaction of soils and plants in buffer strips.	Sanitary survey.	Raise awareness among the community about the damage that erosion can cause to infrastructure, and the potential effect on the water supply system Disseminate health advisory notices to the public with advice about dealing with the risks.
Increase in extreme rainfall events	None					

IMPROVED PIT LATRINES

Issue	Vulnerability	Impacts	Adaptations			
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Increase in extreme rainfall events; run-off increases	Erosion	Collapse of latrine	Site latrine away from drainage channel. Use durable materials in construction to protect pit covers. Proper compaction of soil around the latrine and presence of adequate base and earth filling to protect pits, pit covers and slabs. Install robust upper foundations, collar and footing to protect from erosion and flooding	Regular maintenance essential to limit vulnerability to collapse		Hygiene promotion. Education on regular maintenance requirements
Water availability decreases	Increased distance to GW tables	Reduced risk of groundwater pollution	Pit latrines become more viable option			

FUTURE: SEPTIC TANKS

Issue	Vulnerability	Impacts	Adaptations	Issue	Vulnerability	Impacts
			Capital expenditure	Operational expenditure	Monitoring	Socioeconomic tools
Increase in extreme rainfall events; run-off increases	Erosion of soil around the tank and absorption field	Damage to infrastructure. Reduced efficacy of the absorption field	Planting of grasses and shrubs on the absorption area, and around the tank, to reduce erosion. Repair erosion damage and sod or reseed areas as necessary to provide turf grass cover. Build bunds (banks, dykes or levees) to divert flow away from system	Check the vegetation over the septic tank and soil absorption field after flooding.		
Water availability decreases	Less water available for flushing and cleaning	Toilet and discharge pipe becomes dirty or blocked	Examine lower-water use approaches (plastic seals rather than water seals, for example) and slabs that are easier to clean. Increase attention to construction quality and setting out of sewers. More rodding eyes. Steeper falls. Consider low-flush toilets. If no water available, septic tanks will not be a viable option. Investigate other systems for management of human excreta	Consider feasibility of households doing more regular cleaning, rodding etc. Improve solid waste management, especially for fat solids	Septic tank system inspections	Education and awareness of lower-water use latrine options
		Reduced risk of groundwater pollution	Septic tanks become more viable option			
	Changing moisture levels in soils	Movement and infrastructure damage	Design for movement.	Adapt maintenance programme to identify breakages	Monitor performance for blockages and breaks	