Strategies to increase water use efficiency of irrigated farm (South of Lake Naivasha, Kenya)

Gebremichael Gebrekirstos Hagos

February, 2008

Strategies to increase water use efficiency of irrigated farm (South of Lake Naivasha, Kenya)

by

Gebremichael Gebrekirstos Hagos

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: (Groundwater Assessment and Modelling)

Thesis Assessment Board

Chairman	Prof. Dr. Ir. Z. Su	WRS Head, ITC, Enschede
External examiner	Prof. Dr. Okke Batelaan	Vrije Universteit, Brussel
First supervisor	Drs. R. Becht	WRS, ITC, Enschede
Second supervisor	Dr. Ir. M. W. Lubczynski	WRS, ITC, Enschede

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

Dedication

To my parents, especially to Birnesh Weldegerima and Kidan Hagos,
who played a great role in my whole education time without which my participation in any course I had in my career including this would be impossible.

Abstract

Feasibility study on strategies to increase water use efficiency of irrigated farm was conducted in the horticultural area south of Lake Naivasha, confirmed as groundwater outflow zone of the area. Unlike to the other part of the lake, almost all flower farms of the area are using the lake water, which adds to the factor of declining the lake water level. With this continuous demand for water, the lake might not be able to sustain the needs of various users and may eventually threaten its existence. This study is targeted to assess the possibility of conjunctive use of shallow and deep groundwater, and lake water in combination with artificial groundwater recharge and possibility of improving the existing low quality of deep groundwater by mixing fresh lake water and artificial recharges generated from the greenhouses.

During field study, Injection and pumping test was carried out to determine the intake capacity and hydraulic property of the aquifer. In addition soil and ground water samples were taken for hydraulic conductivity and water quality analysis respectively. A spreadsheet model developed to analyze the recharge efficiency and cost per cubic meter of recharge water for 46 years duration of daily rainfall. Finally after modelling the two aquifers in MODFLOW, MT3DMS was used in the deep aquifer to trace the concentration of the mixed water at different interval of time and distance and therefore locating of abstraction wells.

The water budget of the steady state model reveals that the inflow through the constant head boundaries to the shallow and deep aquifer decreases by 12% and 3% respectively after the artificial recharge was implemented and the groundwater model of the shallow aquifer indicates a possibility of 100% water abstraction from the shallow aquifer.

Injecting the runoff collected from the greenhouse area and shifting abstraction of water from lake to the shallow groundwater results in saving 39% of the net abstraction as compared to without artificial recharge.

The groundwater quality of the deep aquifer was assessed after applying a daily artificial recharge generated from the existing and future expansion of greenhouse areas: it was found that, it can be used for 3 to 4 years with an abstraction of 400 to 500m^{3}d^{-1} after applying a recharge of 120m^{3}d^{-1} for 5 years before abstraction starts, and with a future expansion of greenhouse area up to 38ha, which can generate runoff 700m^{3}d^{-1}, groundwater can be used with out mixing with lake water with an abstraction rate of 1690m^{3}d^{-1} for 5 years after the starting of abstraction, but with abstraction value below two-third of the total value is possible atleast for 25 years after continues injection of 700m^{3}d^{-1} for 5 years while abstraction is not implemented.

Key words: artificial recharge, groundwater modelling, groundwater quality.

Acknowledgements

Above all I thank the living, almighty and ever-loving God for all what He has done and for giving me this opportunity and strength to do this program.

I am grateful to the Netherlands Government for providing me the financial support under the Netherlands Fellowships Programme without which my participation in the course would be impossible.

The support from Panda Flowers Ltd. has been instrumental for this study: the provided drilling rig and crew for free of charge was used to drill up to 7 boreholes without which undertaking of this study would be impossible.

I am immensely indebted to my first supervisor Drs. Robert Becht, for enabling me carry out a virtually new study and diligently guiding me through it all. I am grateful for all the support he provided right from the outset, through the fieldwork and subsequent analyses, to the final write-ups. I greatly thank to my second supervisor Dr. Lubczynski for his insightful help during the office work. I acknowledge the support during my laboratory work to Boudewijn de Smeth and Ir. Remco Dost. Many thanks go to all my lecturers for their willingness to patiently reveal their knowledge, and their friendly attitudes they displayed.

I would like to register special thanks with Mr. Jan Hendrikse for all the help during Leica GPS training and his fatherly advice.

I do acknowledge and appreciate the invaluable help of the water resources management authority personnel and the field assistants during fieldwork. The assistance of Mr. Walter Tanui and Dominik Wambua has been instrumental. Special thanks are extended to all the local farms and communities who were so co-operative when approached and contacted.

I would like to express my special thanks to my family, especially to my adored Kidan Hagos for all the full support I received in my career. I love you all so much.

Furthermore, I am thankful to Sunita Sarkar executive Officer of LNGG, for her immense support and willingness to co-operate during the fieldwork and providing of important data for my thesis.

Table of contents

List of figures

List of tables

1. Introduction

The term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated (Freeze and Cherry, 1979). Groundwater inevitably occurs in geological formation. Knowledge of these heterogeneous earth materials formed and the changes they have undergone is vital to understand the distribution of geological materials of varying hydraulic conductivity and porosity (Fetter, 2001). The increase demand for water in many regions has led to the implementation of more intensive water management measures to achieve more efficient utilization of limited available water supplies. The natural replenishment of ground water occurs very slowly. If water bodies are exploited at a rate greater than that of their natural replenishment this will result in declining water levels and hydraulically connected subsurface water system. Lake Naivasha is one of the fresh water bodies with large amount of abstraction and hydraulically connected with the surrounding groundwater system. Many studies on the area indicate that lake and groundwater level is declining with time. In the long term, it can cause destruction of the available water resources. For better management of groundwater, formulating a correct conceptual model, selecting parameter values to describe spatial variability within the groundwater flow system, as well as spatial and temporal trends in hydrologic stresses and past and future trends in water levels is most important (Anderson and Woessner, 1992). This study focuses on the underground out flow, southern side of the lake.

1.1. Research problem

Lake Naivasha has been considered as a highly significant national fresh water resource in Kenya by several authors. Its water is not only being utilized for domestic water supply and recreation but also sustains important economic activities such as flower and vegetable growing, geothermal power generation, tourism and fishing.

The importance of the lake in the socio-economic development of the area is growing fast and also abstraction of water around the lake.

Unlike to the other part, the southern part of the lake almost all flower farms are using the lake water, which adds to the factor of declining the lake water level. With this continuous demand for water, the lake might not be able to sustain the needs of various users and may eventually threaten its very existence.

In addition to this, many studies on the area show that, the general groundwater flow direction of the southern part of the lake is away from the lake. The supposed outflow plays a crucial role in the water use efficiency of the irrigated farms and the fate of the agrochemicals: if water flows away from the lake the irrigation return flow (seepage) will be lost from the system and so will the agrochemicals. Whether this outflow exists over the full southern sector has to be investigated.

Groundwater of the area is considered to be not suitable for flower farming, which needs detail investigation on how it can be used by mixing fresh lake water and artificial recharges generated from the greenhouses.

1.2. Research objective

The main objective of the study is to increase the water use efficiency of the flower farm of the area. In order to achieve the above major objective, the following specific objectives have been considered during the study.

- To study the existing hydraulic interaction between the lake and aquifers of the target area and its response after the recharge.
- To study the detailed direction of groundwater flow in the study area
- To evaluate the quantity of the available runoff from the greenhouse
- To assess the quality of groundwater (shallow and deep).
- To assess the possibility of conjunctive use of shallow, deep groundwater and lake water in combination with artificial groundwater recharge generated from greenhouse runoff.
- To develop an optimum exploitation strategy considering both water use-efficiency and water quality.

1.3. Research question

- What is the direction of groundwater flow in relation to the lake (in, out or stagnant)?
- What is the quality of shallow and deep groundwater in the study area?
- How water use efficiencies can be increased in the area by using a combination of shallow, deep aquifer exploitation and lake water in combination with artificial recharge?
- How can conjunctive use of lake and groundwater provide water with a quality designed for the horticulture/ flower farming?
- What is the optimum exploitation strategy considering the exploitation of lake water, very shallow (bank storage) and deeper groundwater in combination with artificial recharge?
- How can artificial groundwater recharge from farm effluents and storm runoff mainly, from greenhouses, minimize the lake water use and increases the potential use of groundwater?
- How enough amount runoff is generated from the greenhouses to be recharged to the groundwater and what is its effect on the quantity and quality of the groundwater?

1.4. Methodology

In order to achieve and answer the above research objectives and questions respectively, the following methods were applied.

1.4.1. Pre field work

- Literature review of previous work on the area and others related to the study.
- Acquisition of necessary equipments for field work
- Starting preliminary survey on the images and maps of the study area.

1.4.2. Field work

- Visiting the site for identifying the study area and over all observation.
- Describing the geology and geomorphology of the area
- Collection of meteorological data for further analysis like runoff generation.
- Collection of data on lake and groundwater level.
- Drilling test boreholes

- Collection of data on existing and recently drilled boreholes, such as hydraulic head and geological logs.
- Conducting pumping and injection test on the existing and recent boreholes.
- Collection of disturbed and core soil samples from the drilled boreholes for laboratory analysis.
- Collection of lake and groundwater sample for chemical constituents and isotope analysis

1.4.3. Post field work

- Organizing and analyzing of the data obtained from the field tests
- Soil and water sample analysis such as hydraulic conductivity and chemical constituents.
- Groundwater modeling of the area using MODFLOW and MT3DMS.
- Compiling and report writing based on the result of the analysis.

1.5. Previous work/study

Water resource evaluation and management of Lake Naivasha basin was studied by many Authors for many years to determine and understand the surface and subsurface water resource occurrence, distribution and potential of the basin. The basin is closed system with no surface out flow. The water input to the lake includes rainfall, inflow from rivers and the output are evapotranspiration, underground seepage and abstraction. The surface inflows to the lake come via three main river systems: the Gilgil, the Malewa and the Karati through a papyrus dominated fringe in the northern part of the lake. The Malewa system is the largest with an estimated annual flow of 153MCM (about 90% of the river discharge to the lake), the Gilgil has an estimated average annual flow of 24MCM, whereas the Karati river, which drains portion of the rift escarpment directly east of lake Naivasha, seasonal and its intermittent flow commonly does not reach the lake (Everard et al., 2002).

Nabide (2002), in his isotopic concentration analysis, mainly concentrated to the northern part of the lake, shows $\delta 18O$ value range of -5.75 to 6.5 ‰. As Owor (2000) noted, Nilson(1932) was the first to suggest that water entered and left the lake via underground seepage. Darling et.al (1996) modeled the direction, quantity and character of underground flow in and out of the lake tracing the outflows up to 30kms south. The northern flow is confined to the lake. Clarke, et.al (1990), using water balance studies and application of Darcy's law on groundwater estimated a total of 50MCM/year outflow representing about 20% of total recharge. Ojiambo (1996) indicates Lake Naivasha has a subsurface outflow of 40MCM/year along its eastern and south western shores. The flow to the south may account 50-90% of the total outflow. The long term yearly groundwater storage change around the lake was estimated to be 0.15MCM which is 0.1% of the lake storage change (Behar Hussein, 1999).

Studies dealing with the chemistry of the lake and groundwater have been done on the area. Morgan (1998) indicated that the composition and abundance of plagioclase as well as sodic amphiboles is the primary influence on Na^+ and Ca^+ in the area. As the water moves in to the shallow groundwater, sodium increases more rapidly indicating continued weathering (Ojiambo, 1996). Clarke et al., (1990) indicated that the groundwater in the area was of sodium-bicarbonate type with high silica content. Boreholes in the lake basin have different characteristics from lake water, and probably reflect several different streams of subterranean water flowing from higher parts of the catchment surrounding the lake, where no permanent streams are present.

1.6. Artificial groundwater recharge and its importance

The artificial recharge to ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques.
Artificial recharge techniques normally address to following issues:

- To enhance the sustainable yield in areas where over-development has depleted the aquifer.
- Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period.
- To improve the quality of existing ground water through dilution.
- To remove bacteriological and other impurities from sewage and waste water so that water is suitable for re-use.

The basic requirements for recharging the ground water reservoir are:
a) Availability and quality of non-committed surplus monsoon runoff in space and time.
The source of water needs careful consideration of the quantity and quality of alternative sources. The source should be evaluated as the average flow available; variability (daily to very long periods) in both flow rate and quality
b) Identification of suitable hydrogeological environment and sites for creating subsurface reservoir through cost effective artificial recharge techniques.
The geology and hydrogeology study determines the selection of suitable storage zones, recharge water sources as well as the location and type of recharge facilities. The general hydro geologic evaluation of the groundwater basin should consider the Surface soil and unsaturated zone characteristics, Aquifer characteristics: lithology, areal extent and depth, hydrologic boundaries, subsurface geologic structures.
Generally, there are two methods of artificial recharge (ASCE, 2001): surface infiltration and recharge through wells.

Surface infiltration system

Surface infiltration system spreads or impounds water to promote infiltration and percolation into and through the soil. They can only be used for recharging unconfined aquifers. Surface recharge system constructed at the outcropping of a confined aquifer, or at the location where the confined becomes unconfined, are used to recharge a confined aquifer.
This type of artificial recharge method consists:

1. In-channel system includes dams, weirs, canals, finger dikes or other structures in the stream bed or flood plain to impound and spread the water over as large a wetted area as possible, increasing infiltration volume.
2. Off-channel system consists of recharge basins, ponds or ditches specially constructed by excavation, by construction of berms (or both) or by using of old gravel pits, borrow areas, or similar excavations. The amount of water entering the aquifer depends on three factors: the infiltration rate, the percolation rate, and the aquifer's capacity for horizontal water movement.

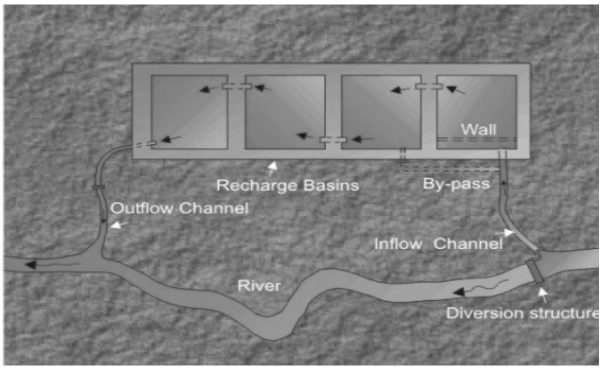


Figure 1-1 Infiltration basin (adopted EOLSS)

Recharge through wells

When conditions required for surface recharge can not be met, groundwater can also be recharged by putting water directly into aquifers through wells. Such wells are typically constructed similar to production wells (screens, gravel envelopes, grouting etc.), although greater screen lengths and diameters may be provided to increase recharge rate and reduce clogging.

The significance of an artificial recharge is not only increasing the potential of groundwater but also to prevent from direct evaporation of the water.

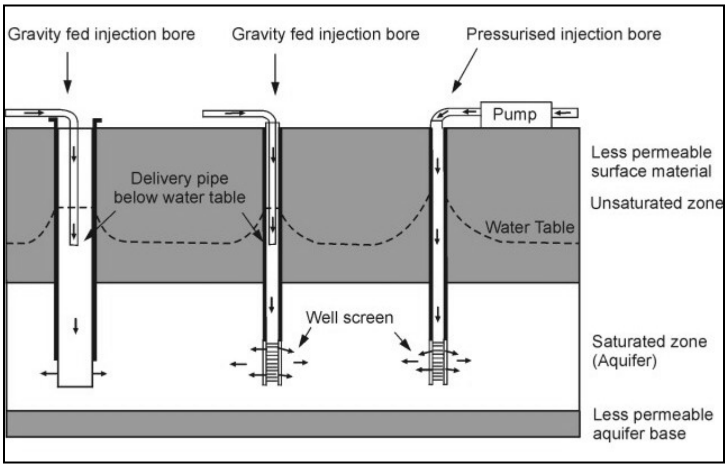


Figure 1-2 Injection through wells (adopted EOLSS)

Other recharge methods

Some times ground water recharge is by trenches, pits, adits, shafts, vadose zone well (dry well), similar systems excavated into the unsaturated zone. These systems are technically between surface infiltration and well injection systems. Their main disadvantage is the difficulty of the difficulty of cleaning them (removing clogging layers) to maintain satisfactory long term infiltration rates.

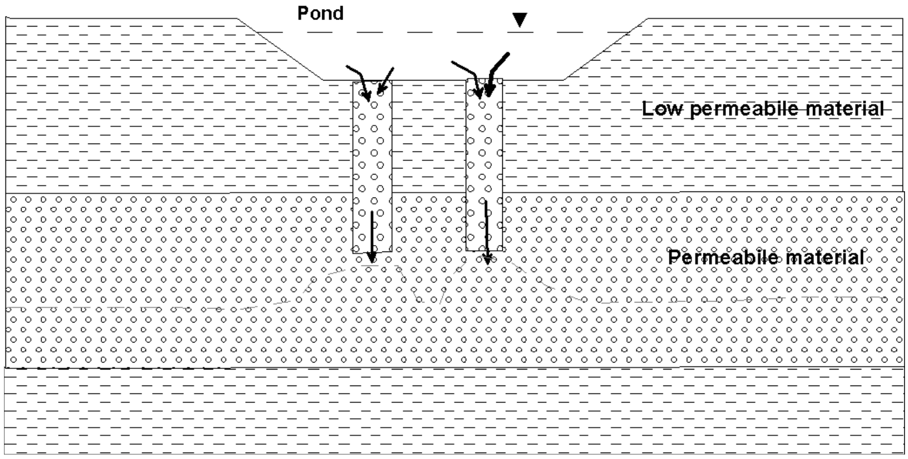


Figure 1-3 Combination of injection well and basin (adopted Mohammedjemal (2006)

2. General overview of the study area

2.1. The study area

Lake Naivasha is located at latitude $0^{o}5$’ South and Longitude $36^{o}20$’East in the semiarid central rift valley region. It is at an altitude of 1890m making it the highest of the rift valley lakes and unique in many ways. It lies on the floor of Africa’s eastern rift valley and is the second largest fresh water lake in Kenya (Everard et al., 2003). The study area is located approximately 80kms far from Nairobi, mainly south of lake Naivasha. It is accessible by all weather roads within the area.

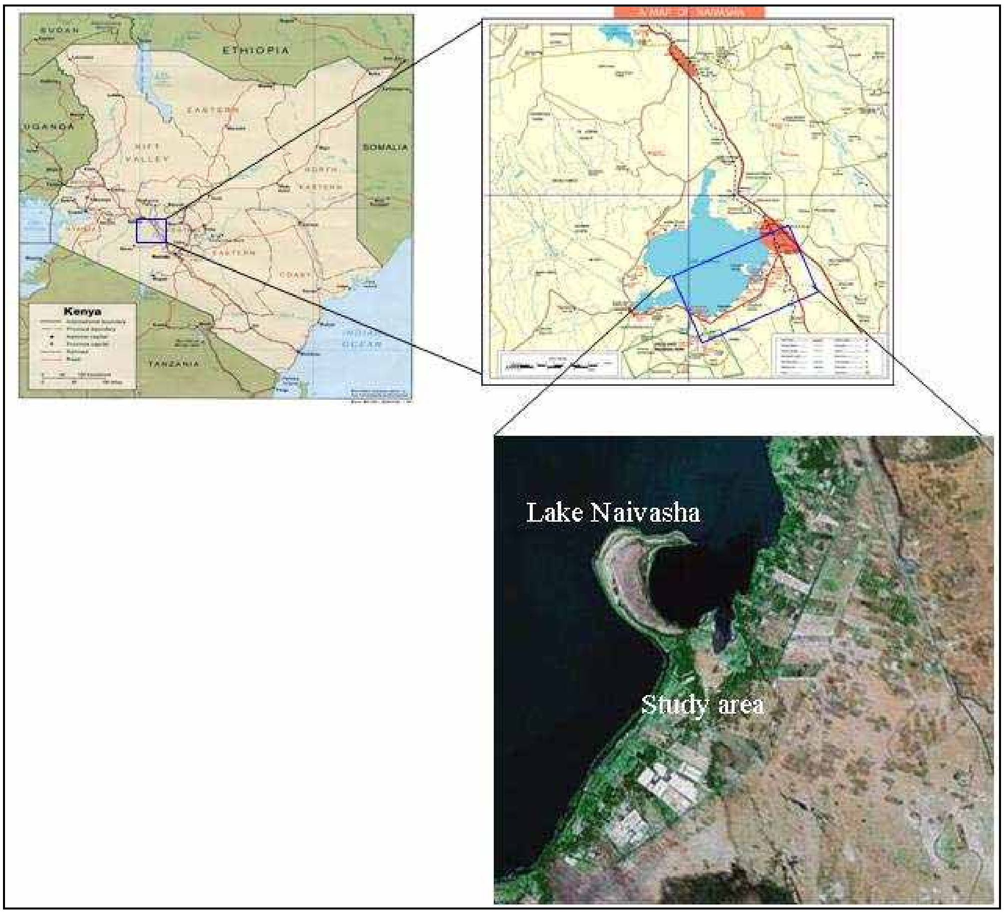


Figure 2-1 Location map of the study area

2.2. Physiography, Land use and climate

Lake Naivasha dominates the central part of the Naivasha basin. It has a mean surface area of 145 km^2 at an average altitude of 1890m above mean sea level (Yihdego, 2005). The Mau escarpment on the western fringe rises up to a maximum of 3080m.a.m.s.l with a N-NNW orientation. The escarpment is rugged and deeply incised with numerous faults and scarps that are prevalent. To the east is the broad Kinangop plateau that rises to a maximum altitude of 2740 m. The NNW- trending south Kinanagop fault scarp (100-240m; separates the plateau from the plain in a series of down throw fault steps (Clarke et al., 1990).

The principal land use is agriculture which includes crop farming (horticulture, vegetables and fruits) around the lake and a mixing farming on the rainfed slopes of the escarpment. The Eburru hills, Mau, and Longonot escarpments are all hosts to indigenous hard wood forests that form the main water shed of the lake basin.

The Naivasha basin lies with in the semi-arid belt of Kenya with average annual precipitation of 700m. The rainfall pattern is bimodal with the main rainy period in April-may and the shorter one from October-November. It is greater along the Mau and Aberare escarpments where it averages from 1250-1500 mm annually and is lower in valley areas where it averages about 650 mm at lake Naivasha being noticeably as a function of topography. There is an annual potential evaporation estimated at about 1700 mm (Mcann, 1974). Mean daily temperatures vary between 9 ^oc at night to 25 ^oc during the day.

2.3. Hydrology and drainage features

The Naivasha catchment is separated from the Nakuru-Elementata catchments by the Eburru Volcanic pile which is linked to the Mau Escarpment by a ridge at an altitude of around 2600m above mean sea level. Between the Eburru and Bahati escarpment, the surface drainage divide runs via Gilgil along a culmination of the rift floor at an altitude of approximately 2000m above mean sea level. To the south of lake Naivasha the surface water divide runs from the Mau escarpment in the west ,via the Olkaria and Longonot to the Kinangop plateau (Yihdego, 2005).

Lake Naivasha occupies the bottom of the rift valley and is in the middle of three major centres of geothermal activity: the Eburru hills to the northwest, Mountain Longonot to the southeast, and Olkaria to the south. The lake is the highest and freshest of all the lakes in the rift valley system. The lake level has been fluctuating, thus affecting its area and volume and gradually declining over time.

Groundwater discharge from the weathered volcanic aquifers provides base flow to the Rivers. The Malewa river is one of the two main perennial rivers that drain the lake and flow in a graben at the foot of the kinanagop plateau. The Malewa and Turesha rivers have a combined drainage area of about 1,730 km^2. The Kinanagop rivers are captured by the main Malewa river in the north east of the basin. Further downstream the Malewa river is joined by the Turash a river and the two flows south wards. The Gilgil river flows in a narrow basin to the north of the basin and is the second major perennial river that drains the lake.

2.4. Regional Geology and structure

The tectonic and volcanic regimes that led to the formation of the Kenya Rift commenced in the early to mid-Miocene. The geology of the Naivasha basin is a succession of late teritiary and quaternary volcanics with inter-leafing lacustrine beds and alluvium of reworked volcanic debris. The volcanic rocks in the area consist of Tephrites, basalts, trachytes, phonloites, ashes, tuffs, agglomerates and acidic lavas (rhyolite, pumice, comendite and obsidian). The rift valley floor is largely covered with sediments that accumulated in the lakes during the Gamblian stage of the Pleistocene period. They contain a large proportion of their volcanic material, and a few diatomaceous beds are known to occur. The lake beds are mainly composed of reworked volcanic material which includes pumice pebbles, gravels, sand silt and clay.

The Mau escarpment is largely composed of the ignimbrite succession dominated by tuffs with only rare outcrops of agglomerates and lavas. The rifting has produced blocks down-faulted to the east along the escarpment. The maximum exposed thickness is about 100 m.

The structure of the area comprises faulting on the flanks and in the floor of the rift valley and slight presence of unconformities the lake beds, which can mostly be detected along the Malewa river drainage. The majority of the fault are short, and can be seen to die in one direction or another. Several of the fault scarps suggests slightly curved faults, with the downthrown blocks on the convex side (Yihdego, 2005).

Age	Archaeological Stages	Rock Types Approximate Thickness	Main Locality	Remarks
Holocene	Neolithic	Trachytes and ashes Obsidians	Longonot Southern slopes of Eburru and Cedar Hill	Climate as present day
		Basaltic ash cones Basaltic flows Silts 3.1 meter	Badlands Badlands Nderit River	Wetter than present
		Ashes	Longonot	Drier than present day
	Mesolithic	Gravels and silts 6.1 meter Trachytes	Nderit Longonot	Slightly wetter than present day Lake Naivasha 36.6 feet higher than present lake
Upper Pleistocene	Upper Paleolithic	Obsidians	Eburru	Drier that present day
		Lake beds 30.5 meter	Lake Naivasha	Lake Naivasha terraces
	Middle Paleolithic	Basaltic ash cones Rhyolites Phonolites Trachytes Basalts Comendites Phonolites Trachytes (Rhyolites to Trachytes: with intercalated pyroclastic)	Badlands Eburu & S.W. Naivasha Eburru Eburru Badlands Lower Eburru Lower Eburru East of Karterit	Drier than present day Faulting Much volcanic activity in the Rift floor
Middle Pleistocene	Lower Paleolithic	Swamp deposits Pyroclastics (minimum 15 meter)	Kinangop and Mau Escarpments (diatomite) of Kariandus	Intense rifting and faulting Wetter than present day Erosion
		Welded tuff 90 cm Pyroclastics & sediments 122 meter Trachytes 30.5 meter Pyroclastics & sediments w/ intercalated trachytes 122 meter	Rift Walls	Wetter than present day
Lower Pleistocene		Kijabe-type basalt 45.7 meter		

Table 2-1 Summary of geological successions in the Naivasha area (Thomson and Dodoson, 1958).

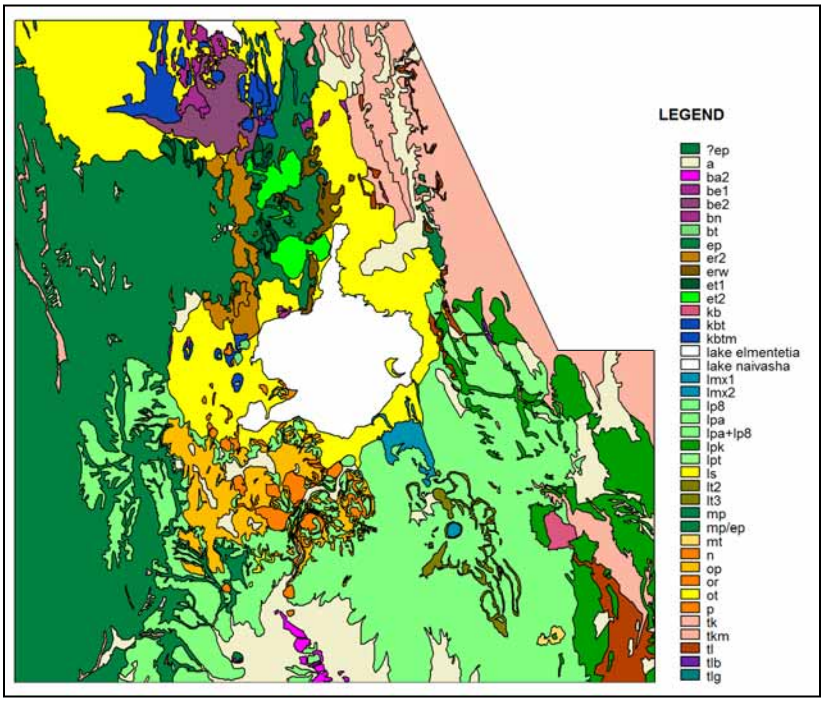


Figure 2-2 Geological map of the Naivasha area

Unit	Description
?ep	Eburru pumice, pantellerite, trachytic pumice, ash fall deposits
a	Alluvial deposit
ba2	Alkaria basalt, basalt and hawaiite lava flows, pyroclastic cones
be1	Older elementeita basalt, hawaiite lava flows, pyroclastic cones
be2	Younger elmenteita basalt, basalt, hawaiite and mugearite / benmoreite lava flows and pyroclastic cones
bn	Ndabibi basalt, hawaiite lava flows, pyroclastic cones
bt	Surtseyan / strombolian ash cones
ep	Eburru pumice, pantellerite, trachytic pumice, ash fall deposits
er2	Eastern eburru pantellerite and trachyte pumice, ash deposit
erw	Waterloo ridge pantellerite, welded and unwelded pyroclastics
et1	Older eburru trachyte, lava flows and pyroclastic
et2	Younger eburru trachyte, lava flows and pyroclastic cones
kb	Kijabe hill basalt
kbt	Surtseyan tuff cones
kbtm	Surtseyan tuff cones with laterally equivalent fall tuffs
lmx1	Lower longonot mixed basalt / trachyte lava flows and pyroclastic cones
lmx2	Upper longonot mixed basalt / trachyte lava flows and pyroclastic cones
lp8	Longonot ash
lpa	Longonot alkaria pumice
lpa+ip8	Longonot ash and alkaria pumice
lpk	Kedong valley tuff, trachyte ingimbrites and associated fall deposit
lpt	Longonot volcanic, pre-caldera welded pyroclastics and lava flows
ls	Lacustrine sediments
lt2	Lower longonot trachyte, lava flows and pyroclastic cones
lt3	Upper longonot trachyte, lava flows and pyroclastic cones
Mp	Maiella pumice, trachyte, pantellerite pumice and ash fall deposits
Mp/ep	Maiella pumice/trachyte pumice
Mt	Magaret trachyte, unwelded and welded pyroclastics
N	Ndabibi comedite lava flows, domes and pyroclastics
Op	Olkaria comendite, pyroclastics (include pre-lpk lacustrine sediments, reworked pyroclastics in ol Njorowa gorge
Or	Olkaria comendite, lava flows and domes (includeNjorowa pantellerite lava and welded pyroclastics
Ot	Olkaria trachyte, lava flows
P	Ndabibi pantellerite lava flows
Tk	Kinangop tuff (eastern rift margin)
Tkm	Mau tuff (western rift valley)
Tl	Limuru trachyte
Tlb	Karati and ol mogogo basalt
Tlg	Gilgil trachyte

Table 2-2 Description of the legend of the geological map of Naivasha basin

2.5. Hydrogeological setting

The lake Naivasha catchment is hydro-geologically complex due to the rift valley geometry and tectonics (Clarke et al., 1990). The hydrogeology of an area is determined mainly by the nature of the geology, topography and climate; these aspects are related to characteristics such as the parent rock, structural features, weathering and patterns of precipitation and finally the human activity.

The relief, creating two different hydrogeological environments markedly affects the hydrogeology of the region. The first is localized in highland areas, characterized by deep groundwater tables and steep groundwater gradients. This type of environment is also described by its larger rainfall values as compared with the valley, approximately 1200 mm versus 500 mm a year.

The second type of environment is localized in the valleys and is characterized by a shallow water table, which gently slopes to the lake, low values of precipitation as compared with mountains and low values of recharge.

The floor of the Rift Valley forms a topographical shoulder in the Naivasha area, with the general elevation decreasing to the south. Consequently, there is a hydraulic gradient along the axis of the Rift, which accounts for the outflow of groundwater from Lake Naivasha.

The main aquifer is found in sediments covering parts of the rift floor. Ground water is encountered at depths of 3-35m below ground level in the lake bed aquifer. These aquifers usually have relatively high permeability and are often unconfined to semi confined with high specific yield (Stuttard, 1995). Aquifers with high permeability found in sediments covering areas around the lake are also parts of the rift floor. They are often unconfined to semi confined and have relatively high specific yields. Mcann (1974) and Ojiambo (1996) also noted that the wells near the lake Naivasha shore yield water from lacustrine deposit aquifers and usually have higher specific discharge and transmissivities than wells further away from the lake. Clarke A.C.G., (1990) also noted that in addition to the these sediments, aquifers are normally found in fractured volcanics or along weathered contacts between different lithiological units. These aquifers are often confined or semi confined and storage coefficients are likely to be low.

Around Lake Naivasha the ground water level is between approximately 1884 and 1888m, with a slight difference with the lake water level. East and west of the lake the ground water contour rises ,indicating flow towards the lake, while to the south a fall in the contour of groundwater level is observed, indicating flow away from the lake. South of this region the pieziometric surface must drop by several hundreds of metres because the few boreholes drilled between Longonot and Suswa have all proved to be dry ,or have produced steam (Yihdego, 2005).

Mcann,(1974) in the hydro-geological study of ground water level changes in the Naivasha catchments noted that seasonal water level changes ranged from 0.5 to 0.25 m in response to ground water recharges. Changes were greater in the high land areas and less in lowland areas surrounding lake Naivasha. Clarke A.C.G., (1990) in his study, found that the highest values of permeability (12-148m/d) are found in reworked volcanics composing the sediments of Naivasha area, where the specific capacities of wells often exceeds 3 l/s/m. Clarke A.C.G., (1990) used stable isotope technique to show that lake water appeared to be detectable at least 30 km to the south direction. They showed that the reservoir fluid could be explained by a 2:1 mixture of lake water with unmodified meteoric recharge from the rift wall area.

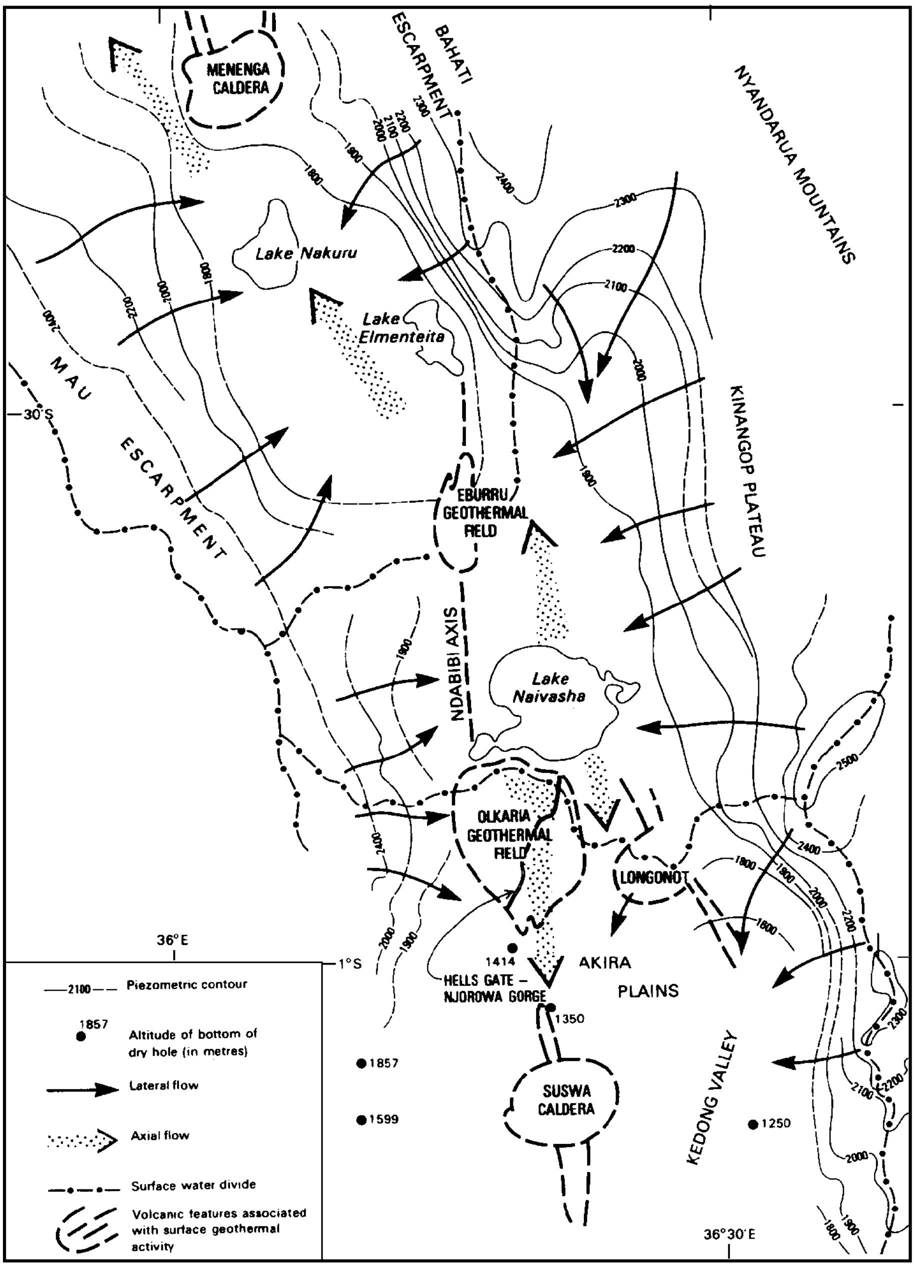


Figure 2-3 Pieziometric map of Lake Naivasha & vicinities taken from (Clarke et al., 1990)

3. Hydrology

Hydrology is broadly defined as the geoscience that describes and predicts the occurrence, circulation, and distribution the water of the earth and its atmosphere (Dingman, 2002).

3.1. Catchment Characteristics

The main catchment which generates runoff to be used as a source of water for the artificial recharge is the nearby greenhouse areas. All the greenhouse farms have access to the lake from which they use water for their farm. The total area of the catchment (greenhouse) is 115.21 ha.

Most of the green houses are supported with concrete and earth canal, collecting rain water draining from the greenhouses, which finally drains to the nearby open area. Depending on the design of the greenhouses the rain water is collected from the roof into the canals in two ways. In the old designed greenhouses the water is collected from the roof through open plastics. In the lately designed greenhouses the water is collected through PVC pipes to the surface canal. The recently implemented greenhouses are more efficient in collecting and delivering the water to the surface canals.

Figure 3-1 Greenhouses of the area

3.2. Rainfall Analysis

In order to calculate the amount of runoff generated from the greenhouses, selecting appropriate rainfall gauging station is very important. Naivasha Longonot Farm is one of the selected stations based on the distance to the site, distribution, data availability and general suitability for the site. The station is situated on Naivasha Longonot Farm at a distance of 1.5km and elevation of 1881m above sea level. It has daily rainfall data for the duration of 1957 to 1981 with some gap. In addition to this, local rainfall station owned by the flower farms were used to fill some gaps and also for the period of 1982 to 2006. All the local rainfall stations were plotted with the selected rainfall station to see their correlation, which found to be highly correlated.

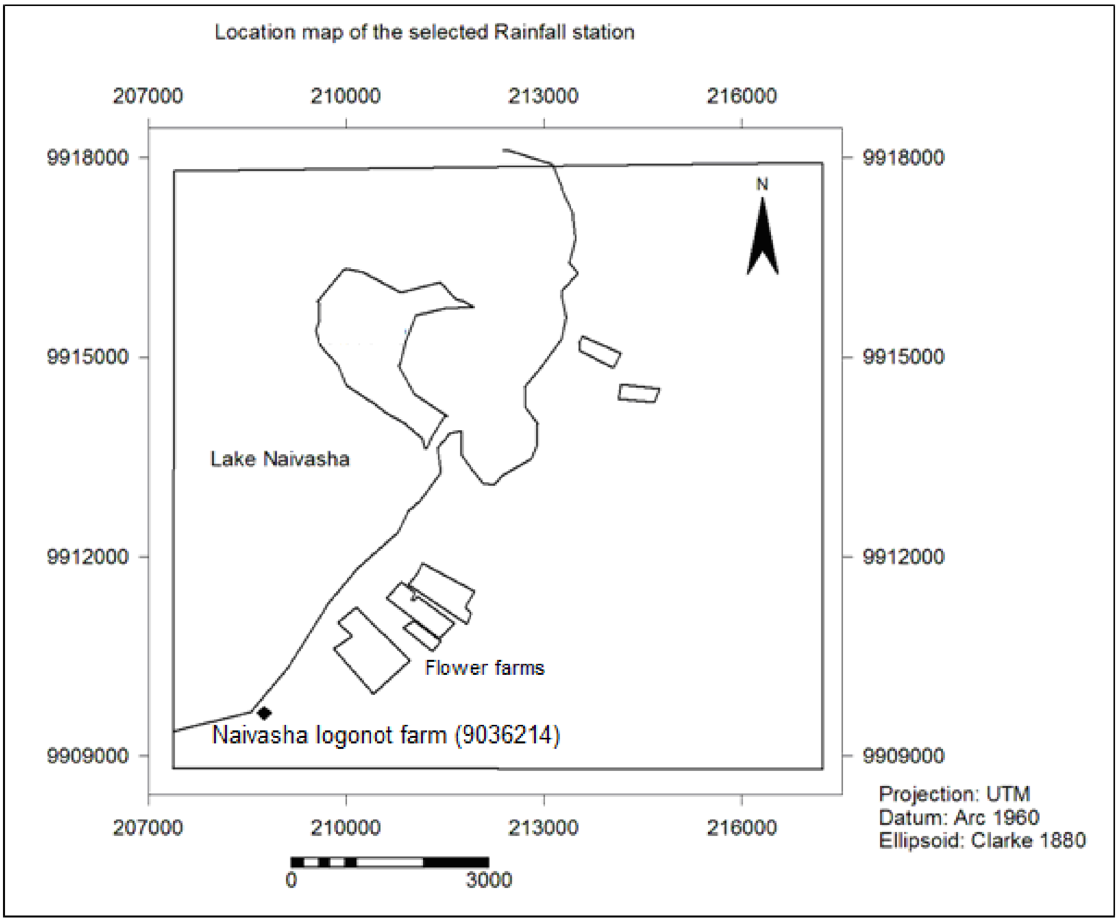


Figure 3-2 Location Map of the selected rainfall gauging station (9036214)

The analyzed rainfall of the selected gauging station shows a bimodal pattern of rainfall. The minimum rainfall recorded in the month of July is 31.86mm and the maximum rainfall of 119.91mm recorded in the month of April.

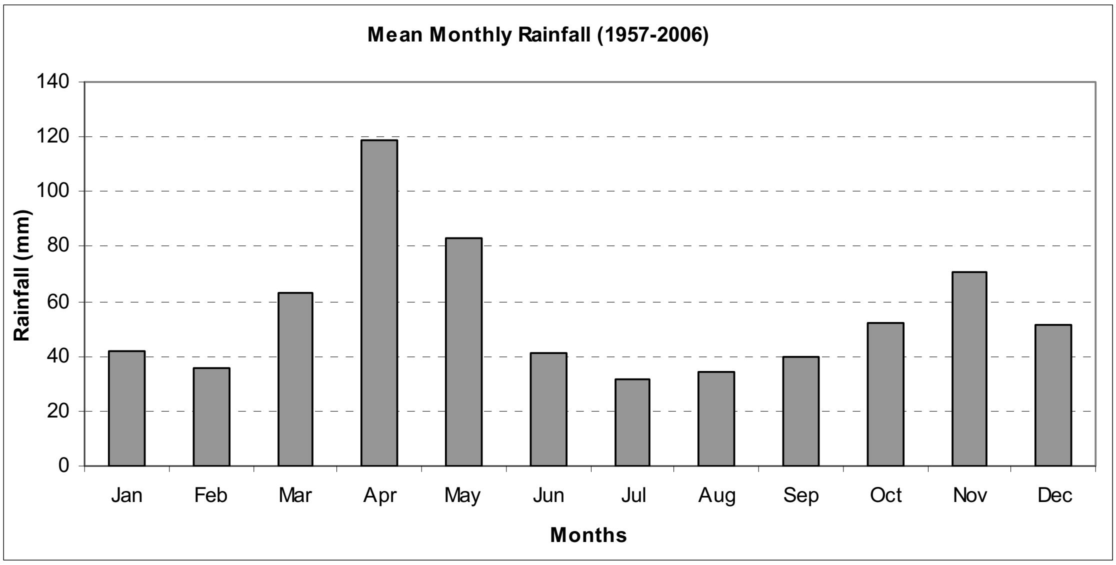


Figure 3-3 Mean Monthly rainfall of Longonot Farm (9036214)

Daily rainfall

Analyzing daily rainfall of the area is important for the generation of runoff from the greenhouse areas used as a source for the artificial recharge. As it is shown below (Figure 3-4), the mean daily rainfall of the recorded years vary from 1 to 2.8mm.

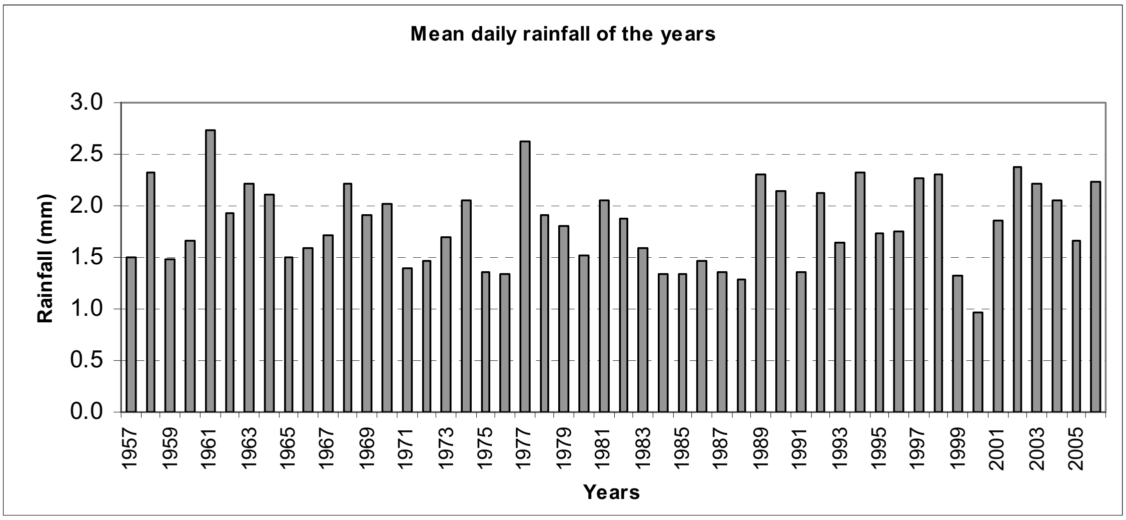


Figure 3-4 Mean daily rainfall for Naivasha Longonot Farm station (9036214)

3.3. Runoff calculation

Surface runoff is a term used to describe the flow of water over the land surface, and is a major component of the water cycle. Catchment characteristics and precipitation parameters are the main factors that can affect runoff generation. For this study, the main source of runoff is from the greenhouse areas of the site. Rational empirical formula was used to estimate the total amount of runoff generated from these greenhouses.

Runoff estimation using empirical formula

The rational formula, which states that if it rains long enough, the peak discharge from the drainage basin will be the average rate of rainfall times the drainage basin area, reduced by a factor to account for infiltration, represents a simple way of assessing the runoff of a watershed. It considers the entire basin area as a single unit (lumped model), estimates the flow at the most downstream point and makes the assumption that the rainfall is uniformly distributed over the drainage area and the runoff coefficient (C) is constant during the rain storm (Dingman, 2002).

$$Q = C \times P \times A \tag{3-1}$$

Where:

C = Runoff Coefficient
P = Daily rainfall of the area (m day^{-1})
A = Area of the contributing catchment (m^2).
Q = Runoff rate ($m^3 day^{-1}$)

Runoff coefficient

Runoff coefficient C, dimensionless, is defined as the ratio of peak runoff rate per unit area to rainfall intensity. The value of runoff coefficient for a concrete street and roofs ranges from 0.8 to 0.95 (R.H.McCuen, 2004). This value can be taken for this study, as the runoff collected from the greenhouse area to be drained through a lined concrete canal.
The annual computed runoff for the 49 years monthly rainfall is shown below (Figure 3-5).

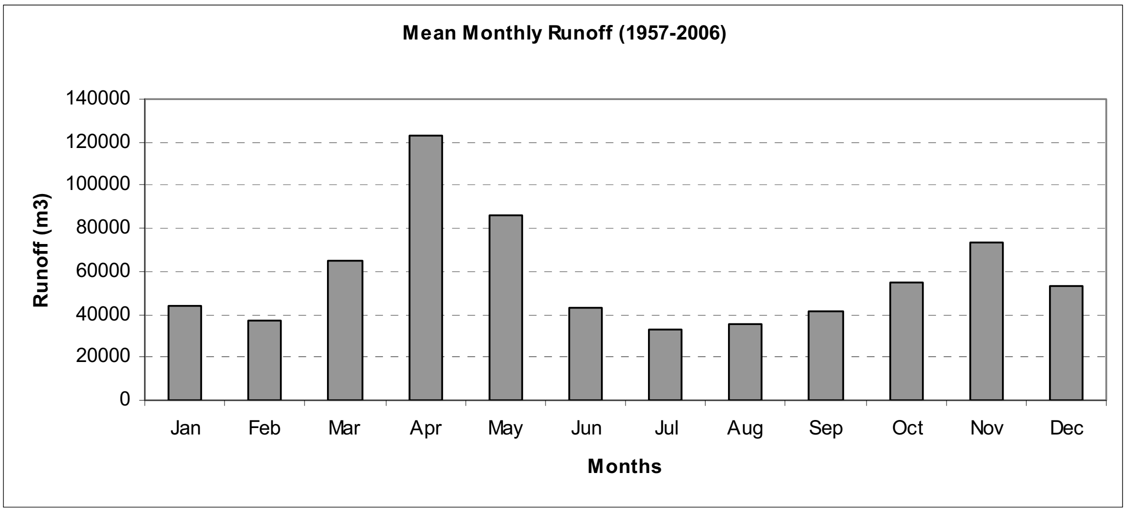


Figure 3-5 Mean monthly runoff generated from the greenhouse areas

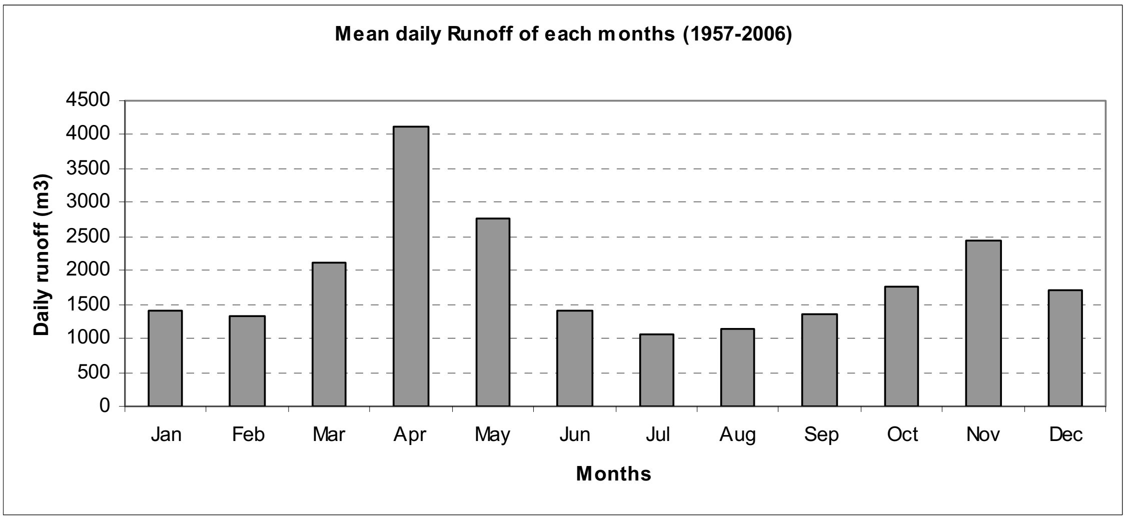


Figure 3-6 Mean daily runoff generated from the greenhouses.

4. Data Analysis

This chapter include collection and analysis of existing and recently drilled test borehole logs, pump tests, and hydraulic conductivity measurements. Test-holes were drilled and logged to collect core samples for laboratory analysis of hydraulic conductivity, which helps in evaluating potential recharge rates through the unsaturated sediments. Infiltration tests and injection tests were conducted at the selected test boreholes.

4.1. Subsurface investigation

The layering of subsurface materials and their extent is important in determining the path recharged water will flow, the possibility for mounding above an impermeable or semi-permeable layer, and the layout of recharge ponds and wells, as well as their spacing. Selecting the type and number of tests depend on the property of the existing geological material of the area, where formations and subsurface layers are known to be fairly continuous, a relatively small number of tests may suffice. Where the formations and layers are known or suspected to be discontinuous, a number of tests would be necessary.

Analysing of existing trenches, geological cross section and recently drilled test boreholes was used for the subsurface study carried out in the area.

4.1.1. Trenches and cross section

The top 1.8m is dominated by loose volcanic ash and pebbles of pumice of light grey to dark colour. It is overlying the moderately weathered, less compacted and reddish colour pumice layer. It is fine to medium grained and its thickness ranges from 1.8 to 2.1m. Completely weathered product (paleosol) exists as a continuous layer overlying medium rounded to rounded lacustrine deposit with some mixing of pumice pebbles. Its depth ranges from 2.1 to 2.6m, while the depth of the poorly sorted lake deposit ranges from 2.6 to 3.2m. The fine to medium grained lacustrine deposit overlies horizontally over on poorly sorted pumice pebbles. It is slightly weathered and its depth ranges from 3.2 to 6.4m. Static water level remains at 4.8m below the ground surface. Below the depth of 6.4m, underlying thin layer of silty clay is fully saturated fine grained sand and gravel served as a pass way of water from the lake. The descriptions of the cross section of the cross section are shown in Appendix 1.

4.1.2. Drilling test boreholes

A thorough understanding of the geology and hydrology of the subsurface formations is a prerequisite to obtaining result for recharge project. Aquifer properties should be obtained by analysis of samples, and if possible cores, taken from test holes and by test pumping of wells.

The drilling method is cable tool with a standard well drilling rig, percussion tools, and a bailer. The drilling is accomplished by regular lifting and dropping of a string of tools. On the lower end, a bit with a relatively sharp chisel edge breaks the formation by impact. From top to the bottom, string of tool consists of a swivel socket, a set of jars, a drill stem and drilling bit. Drill cuttings are removed from the well by a bailer. The method is less effective when it encounters the unconsolidated fine sand because the loose material slumps and caves around the bit (Walton, 1970). Disturbed and core samples were taken at different depths, used to establish the lithology and other physical characteristics of the unsaturated and the aquifer.

Figure 4-1 Core samples taken from the borehole

4.1.3. Geological logs

Seven representative test boreholes have been drilled to study the subsurface geology of the study area. Geological log of each drilled boreholes during the field work and existing cross sections was constructed and examined. The sampling depth interval was determined depending on the geology and results of infiltration tests of the area. The logs furnish a description of the geologic character and thickness of each stratum encountered as a function of depth in meter. Table 4-1 shows description for the TB7 from the core and disturbed samples obtained during drilling at different depth intervals.

The top layer is covered with fine volcanic ash. It is loose and dry. It is underlain by the light reddish, poorly sorted, sand and pumice pebbles. The next layer underlying thin layer of completely weathered product of the surrounding volcanic rocks named as paleosol, is medium rounded to rounded lacustrine deposit lying on poorly sorted pumice. It has some silty mixing. The next layer which is found in between two pumice layer is fine to medium grained sand deposit. As it was observed from the sand grains, the source could be from the surrounding volcanic rocks. The next layer below the relatively thin layer of pumice rock covering large area is trachyte rock. According to the depth of investigation during the field work, the bottom layer, extending from the depth of 53 to 60 meters is angular to rounded grains of lake deposit. The angularity of the deposit increases with depth. Toward the bottom of this lake deposit, shows some mixing of pumice pebbles, which could be an indication of contact with pumice layer.

The detail geological log of all the test boreholes is given in appendix 1.

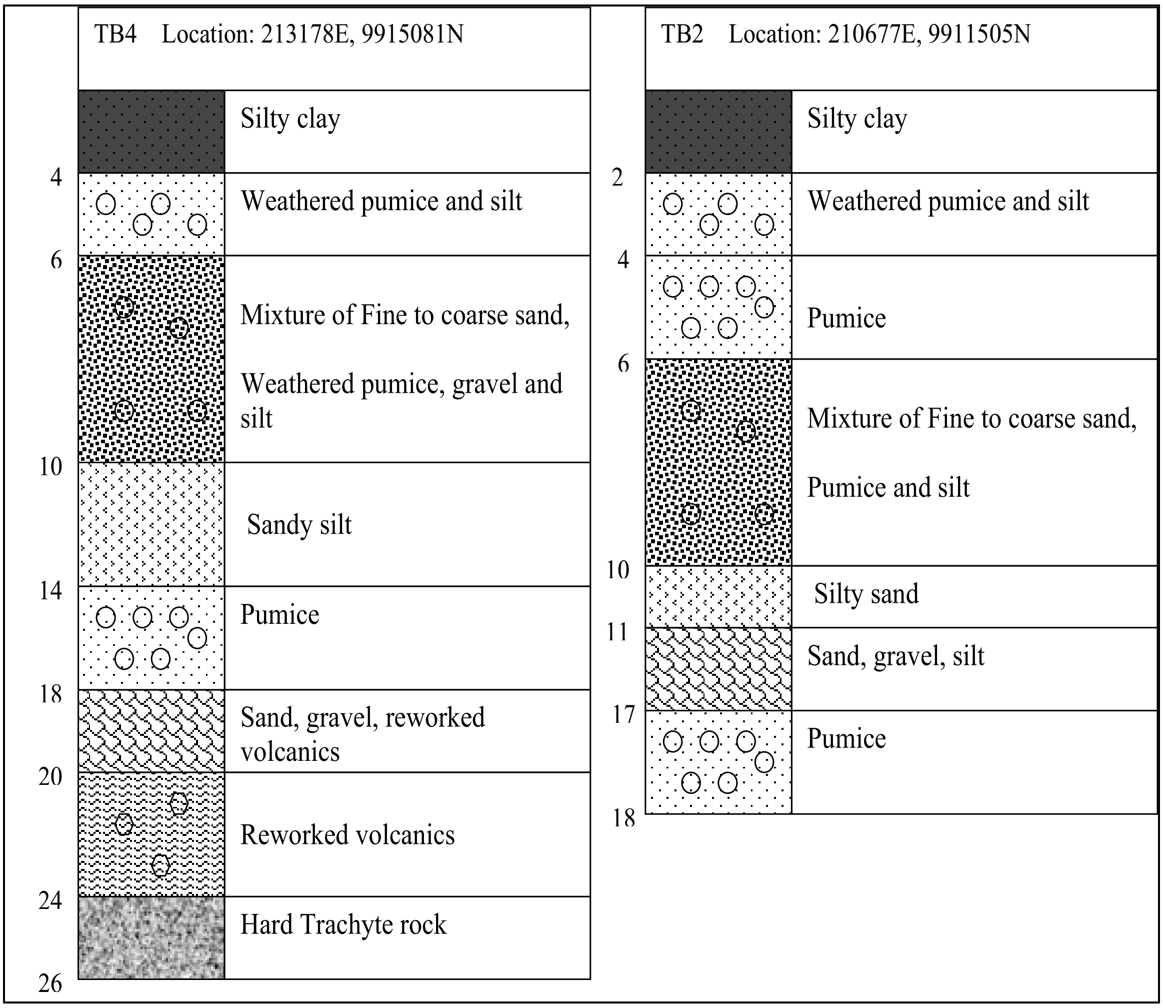


Figure 4-2 Geological log of boreholes, Shallow aquifer

Code: TB7	Location: 214206.58E, 9914650.422N
Depth (m)	Description
0-0.5	Top soil, dark, fine grained
0.5-2	sand and Pumice pebbles, fine to medium grained sand dominating
2-8	fining down ward pumice crushed in to dominating fine grained
8-32	The same Pumice but relative coarser graine, brownish color
32-38	Light dark to brown color, mixing of trachyte and Pumice grains, Pumice dominating
38-40	Hard layer and compacted Pumice layer with small inclusion of Trachyte, light grey to light brown color.
40-53	Hard Trachyte rock, black color, fining upward.
53-58	Moderately rounded to rounded lake deposit, fine to medium grained resulted from the weathering of the volcanic rock. Dominated by sand grained (approximately 90%), mixing brown to dark color. The dark color are more rouned, while the others have a mixing of angular grains. Some mixing of pumice grains with fine and dark volcanic grains.
58-59	the same as the above depth (53-58) but the angularity of the grains increase downward, more brown color (Pumice) dominant.

Table 4-1 Geological log of the test borehole, central part of the study area.

4.2. Soil sample analysis

Soil samples have been collected from the test boreholes. Nine core samples were collected from the selected representative test borehole in every one meter. In addition to the core samples, another five disturbed samples were taken at different depth intervals. The purpose is to analyse the soil samples, used as an alternative method to estimate the hydraulic conductivity, specific capacity, porosity and volumetric water content of the geological formation of the site.

4.2.1. Laboratory test

A representative core samples, using sampling ring of 100cm3 volume, were taken in to the laboratory. After fully saturating the samples slowly, hydraulic conductivity was calculated using the principle of constant head test. A soil water permeameter was used for measuring the saturated hydraulic conductivity of the undisturbed sample taken. Saturation of the sample was done in the container of the permeameter. The analysis result is attached in appendix 4.

4.3. Hydraulic conductivity measurement

Hydraulic conductivity is a soil property that describes the ease with which the soil pores permit water movement. It depends on the type of soil, porosity, and the configuration of the soil pores. Test or hydraulic conductivity of the site geological materials was carried out at field and lab. Field test includes pumping, injection and infiltration test at different depth interval depending on the heterogeneity of the geological formations with depth. Representative soil was taken for further laboratory analysis using the instrument soil permeameter.

4.3.1. Infiltration (Inverse Auger hole method) test

Seven bores were drilled along the selected representative area of the study site.

At each site, the depth of the bore was selected based on the variability of the geological formation of the site; a known volume (slug) of water was injected; the initial water level (ht) was measured immediately and then repeatedly over time as the water level dropped; and the falling water level was plotted against time (Appendix 3). As the material being tested becomes saturated, the curve gradually flattens out and becomes linear.

The hydraulic conductivity (K) of the material can be calculated using the relationship:

$$K = \frac{1.15 * \left[\log(h(t_i) + \frac{r}{2}) - \log(h(t_n) + \frac{r}{2}) \right]}{t_n - t_i} \qquad \textbf{4-1}$$

Where:

K = the hydraulic conductivity (m/day),

r = the radius of test hole (m),

$h(t_i)$ = the initial wetting depth (m), h(tn) the final wetting depth (m),

t_i = the initial time (s), and t_n is the final time (s)

And t_i and $h(t_i)$ are taken at the point where the test material surrounding the hole has been saturated. Saturation point is judged by plotting [log(h(t_i) + r/2) _ log (h(t_n) + r/2)] against t and noting the point where the curve becomes linear. From the tests performed at each site for the different stratigraphic units, representative values of hydraulic conductivity (K) were developed (Table 4-2).

Hydraulic conductivity test was done in all the seven test bores. The test was done at interval depth of 1 to 6m, depending on the pre-results obtained and geologic formation of the site.

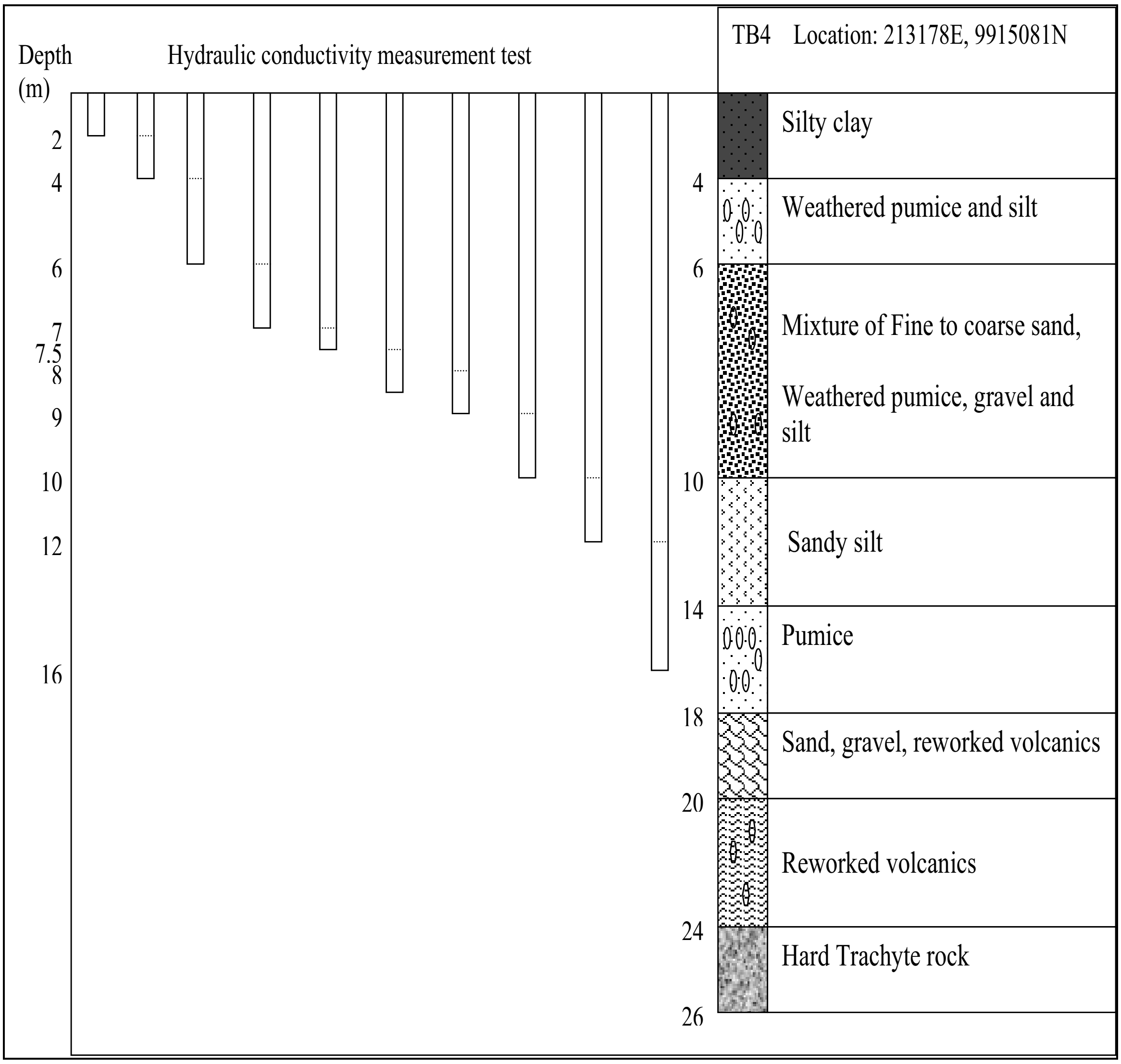


Figure 4-3 Infiltration test at different depth interval and corresponding geological log

Depth	K (m/d)	Geology
2	0.40	Silt and clay
4	0.01	
6	3.03	Pumice pebbles and silt
7	24.23	Pumice dominating
7.5	7.07	
8	5.05	Sand, gravel and silt
9	11.10	
10	6.06	Pumice and gravel
12	5.05	Sand dominating lake deposit
16	4.20	Silt, Sand and fine gravel
52	2.01	Sand, rounded reworked volcanics, gravel size
60	1.01	

Table 4-2 Calculated hydraulic conductivity and geological log

The infiltration test reveals the hydraulic conductivity of the first top 4m of the formation ranges from 0.1 to 0.4mday^{-1}. Formations with medium to high values of hydraulic conductivity are found between the depths of 6 to 12 m, ranging from 1 to 24mday^{-1}. The maximum value was recorded at the depth of 7m in the mixed deposit of fine grained sand and pumice pebbles; dominated by sand.

4.3.2. Soil water permeameter test method

A representative core samples, using sampling ring of 100cm^3 volume, was taken in to the laboratory. Core samples taken were more concentrated on the boreholes which are found to be difficult to undertake site tests like infiltration. This is because of collapsing the walls of the boreholes drilled at different depth. After fully saturating the 10 core samples slowly in the container of the permeameter, saturated vertical hydraulic conductivity was calculated using the principle of constant head test. The following Darcy equation was used to calculate the vertical saturated hydraulic conductivity.

$$K = \frac{V * L}{A * t * h} \qquad \textbf{4-2}$$

Where:

K = saturated hydraulic conductivity
V = volume of water flowing through the sample
L = length of the soil sample
A = cross section surface of the sample
t = time used for flow through of the water volume
h = water level difference inside and outside ring holder or sample cylinder.

The results of the test with corresponding depth are presented as follow (Table 4-3):

Depth (m)	Ks (m/d)	Geological log
4	0.09	Silty clay
5	4.57	Pumice
6	2.64	
7	1.14	Weathered pumice and silt
7.5	169.69	Mixture of Fine to coarse sand, Pumice and silt
8	329.4	
9	0.23	Silty sand
10	0.11	
17	19.85	Sand, gravel, silt

Table 4-3 Result of soil permeameter test at different depths and corresponding geological log

As it is shown in the above table, the upper top soil of 4m depth is characterized by low hydraulic conductivity geological formation. The highest hydraulic conductivity of the area corresponds to the depth dominated by the poorly sorted sand deposit and vesicular pumice pebbles. In addition medium rounded to rounded lake deposit of the site, underlying the pumice pebbles is also grouped among the formations of the site with high hydraulic conductivity.

4.3.3. Pumping and Injection test

The principle of pumping test is that if we pump water from a well and measure the discharge of the well and the drawdown in the well and in piezometers at a known distance from the well, we can substitute these measurements into an appropriate well-flow equation and can evaluate the hydraulic characteristics of the aquifer (Kruseman and de Ridder, 1983).

Pumping test at NINI flower farm (NT)

Pumping test was conducted during the field work inside the flower farm of dug trench used to pump water for the flower farm, found with in the shallow groundwater of the area. The trench has a length of 15m, width of 5m and saturation depth of 6m. The well to be tested was stopped pumping for about 11 hours and the static water level was measured 4.8m from surface during the test. The test duration was 10 hours, which results a drawdown of about 27cm. A well controlled constant volume of discharge was pumped from the well, which is $250m^3hr^{-1}$. The water pumped was used for the flower farms found nearby the well.

The drawdown was measured in the pumped well at frequent short intervals at the first since the water level drops fast then gradually decreased as pumping continuous.

The time–drawdown data, analysed using Aquifer Test for windows with the Walton analysis method for unsteady leaky aquifer resulted in transmissivity of $10640m^2day^{-1}$. These tests are included in the package AQUITEST 3.5. This value was used for the estimation of the hydraulic conductivity of the shallow aquifer. The pumping test result is presented in appendix 2.

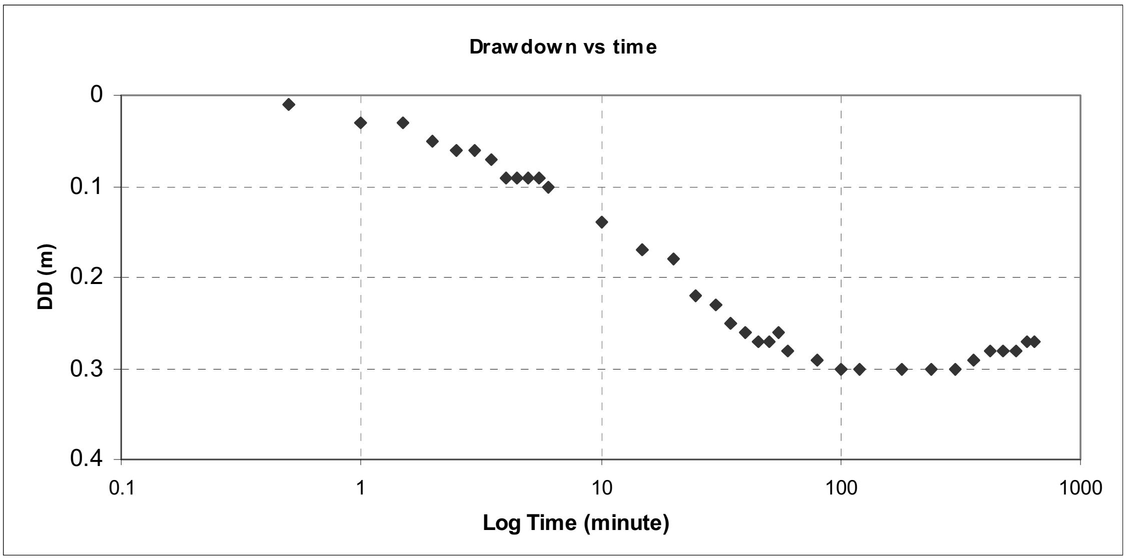


Figure 4-4 pumping test result of the site

The information found from the owners of the flower farm during the field work indicates the groundwater level of the pond drops and also some times it becomes dry when the lake level drops. Due to this, they shift the pumping of water to the second pond drilled near to the bank of the lake. This shifting of groundwater level with the change in lake level can be an indication to the direct link between the lake and the shallow groundwater of the area. The geological log of the site shows existence of thin layer of low permeable silty clay below the highly conductive pumice layer. Below this low permeable thin layer, pervious pumice and gravel with small mixture of silt is found (Figure 4-5). The drop in water level of the pond could be due to the existence of thin impervious layer between highly conductive layers of the aquifer and therefore penetrating up to the depth of second highly pervious layer is could be one solution.

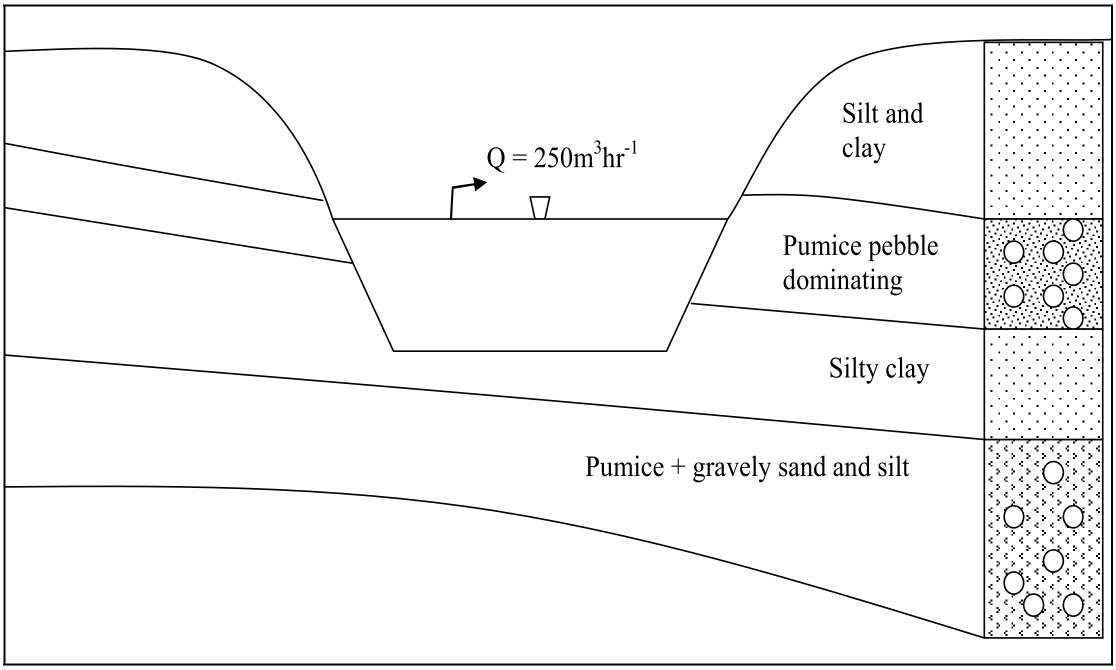


Figure 4-5 Geological cross section of the pumping site (not too scale)

4.3.4. Injection test

Injection test was done through the drilled boreholes during the filed work. The test was done by using a known volume of water directed into the aquifer through the injection wells, creating a cone of recharge which finally used to determine the intake capacity and hydraulic parameter of the aquifer. The raised groundwater level in the injection well was measured using electrical dipper at different time interval depending on the response of the well to the injected water. Injection test was done in all the seven drilled boreholes at different depth and time interval. Some of the analysis result and plot are presented in appendix 4.

Injection test at NINI Farm (TB2)

Three boreholes were drilled inside the farm used for the comparison of the injection test result and geological cross section of the shallow groundwater area. Test borehole2 (TB2) is one of the three boreholes at which the test was done by conveying water from the existing trench water supply for the flower farm. The rate of water directed to the borehole, measured on site by noting the time taken to container of known volume was $24m^3hr^{-1}$. The rate of water used was kept constant through out the test and measurement. The duration of the test varies from 20minutes to 2hours depending on the response of the well to the injected water. For the plot of the tests done, the minimum time duration of the test was used to show the variation and compare the results obtained at different interval of depth.
The injection test results were analyzed in two approaches. The first approach is to plot the recharge head rise and fall with time and interpreting the curves. The second, most important is computing the injection rate of each depth interval assuming the linearity relationship of injection rate and average pressure.
The first and second tests were conducted at 2m and 4m depth, after injection of $24m^3hr^{-1}$, it over flows within 20 and 25seconds respectively. The maximum fall down of water level after 90 minutes

is only 0.7 and 0.78m respectively, which implies that the lithology from the top to 4m depth is not permeable.

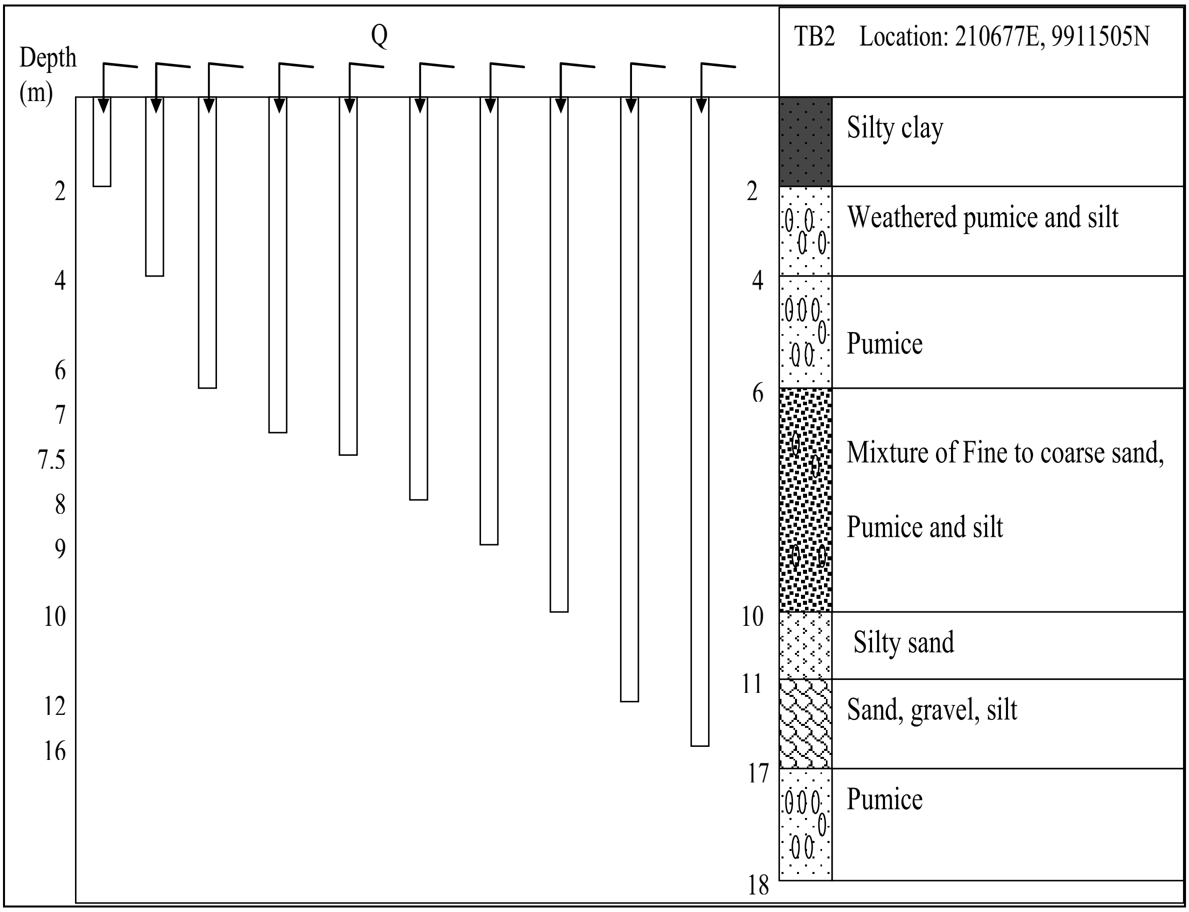


Figure 4-6 Injection test at different depths

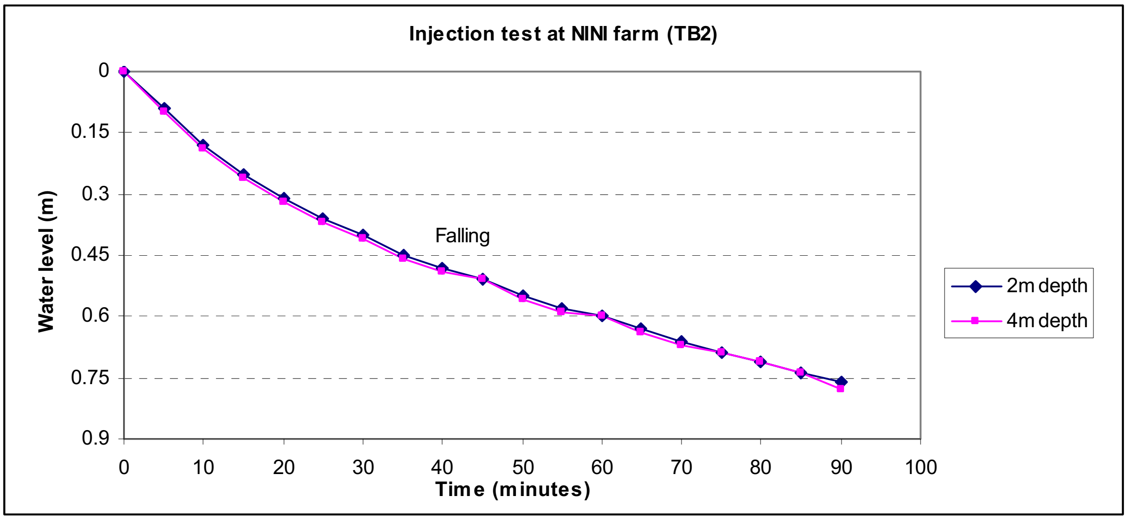


Figure 4-7 Injection test showing water level changes at the upper 4m depth

The next test was at 6m, the time of filling the borehole is relatively higher than the first two tests, but it is not as high as for the high permeability formation. The falling trend of the water level after filling of the borehole shows relatively less gentle, indicating relatively more change within short interval of time. The test done at 7 and 8m depth show full range of raising up and falling down of the water level. The two raising curves show similar trend up to 2 minutes, after which relatively steady state is observed at 3m in the 8m depth test, indicating variation in hydraulic conductivity. Because of the collapsing of loose geological formation encountered at this depth, after the fast falling of water level shows some sudden decrease of the trend. The response of the last three tests shows similar trend except the sudden changes observed as a result of the collapsing of wall of the well.

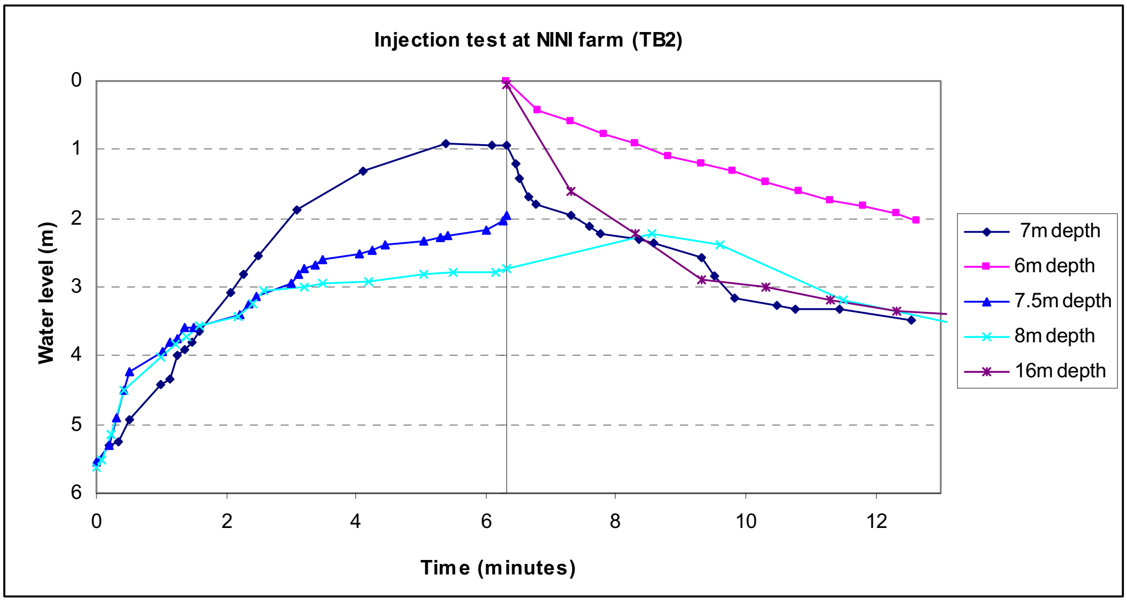


Figure 4-8 Injection test showing water level changes at different interval of depth

Injection Test at Wildfire farm (TB7)

The other test done among the seven boreholes is at the deep borehole newly drilled during the field work inside the wildfire farm. The total depth penetration was 60m with static water level of 30.45m from the surface and 0.15m diameter of borehole. Five tests were done at different interval of depth, but due to the collapsing of the wall of the well only the three relatively better done are presented below. The tests done are at depths of 30, 40 and 50m, showing almost similar trend of falling water level after applying of constant rate of discharge. A drop of about 25m in 5 minutes was observed in all the tests done, which show more stable near to the static water table. Except the first test, the test duration of the last two depth of interval was 37 minutes. The test at 30m was stopped after 8 minutes due to collapsing problem. The geological log of the whole depth of the borehole is presented in Table 4-1.

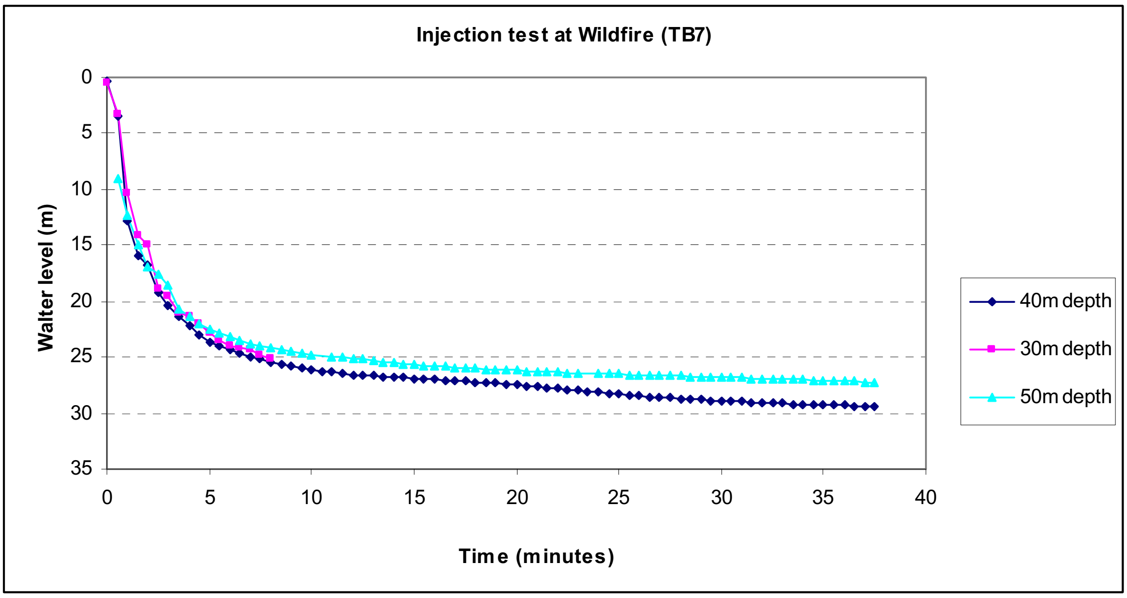


Figure 4-9 Injection test showing water level changes at different interval of depth (deep aquifer)

Injection rate and pressure

This method was applied to determine the infiltration potential of each depth of interest. Assuming the linear relationship of injection rate and average pressure, the amount of water and the specific injection rate per the thickness of each zone was calculated. The injection rate was about $24m^3day^{-1}$ and it was kept constant in all tests. By considering the same thickness for each test done at different interval of depth, the average pressure developed was different depending on the hydrogeologic characteristics of the formation at different depth. Accordingly, the average computed amount of injected water is in each group of depth is 1.04, 38.60, 51.97and $28.71m^3hr^{-1}$ respectively. From the obtained result, 51.97 m^3hr^{-1} is considered as the aquifer part with the highest intake of water as compared to the others, while the depth group part with the value of $1.04m^3hr^{-1}$ is expressed as impervious layer. In addition the above shallow depth, the amount of intake water obtained at depths 30, 40 and 50m is 18.48, 46.30 and 21.09 respectively. This relatively high amount of water in the deep borehole could be due to the presence of volcanic primary structures like lava tube or secondary structures such as fractures and contacts developed due to the formation of paleosols. As it was observed during the field test, collapsing of the wall of drilled wells was main problem. This could be one cause for the reduction of the amount of water intake of the aquifer at different depth. This can be supported by the result of pumping test performed on existing borehole about 100m away from drilled borehole at which injection test was done. The pumping test results in a transmissivity of $10640m^2day^{-1}$ considered as high value and expected to have high intake of water.

5. Hydrogeology

Hydrogeology is the part of hydrology that deals with the occurrence, movement and quality of water beneath the Earth's surface.

Geological and hydrogeological study plays a critical role in determining the suitability of a site for artificial recharge. A detailed geological and hydrological feature of the specific area was assessed for adequately selecting the site and the type of recharge structure. In particular, the features, parameters and data considered are: Geological boundaries, storage potential, hydraulic conductivity, transmissivity and lithology. The sediments at and below the infiltrative surface has been characterized to evaluate the artificial recharge methods.

5.1. Aquifer Hydrostratigraphy

The aquifer characteristics were studied based on the existing well records, pumping and injection tests. The water level of the shallow aquifer of the study area is encountered at depths of 8 to 10m below the surface, while that of the deep aquifer is at depth of 50m below surface. Geological cross section of the study area which is drawn based on the well logs of the drilled shallow and deep boreholes is shown in (Figure 5-1). The aquifer is complex due to the sedimentation, which took place concurrently with tectonic history and associated volcanism. The hydrostratigraphic unit is composed of two aquifer system named shallow and deep aquifer. The shallow aquifer consists of unconsolidated lake sediment, medium to rounded reworked materials and pumice pebbles. It is composed of fine to medium grained sand, with mixing of pumice pebbles and fine to medium grained medium to rounded gravel deposits overlying by 2 to 4m layer of silt and clay. The thickness of this aquifer ranges from 20 to 25m, occurred as confined to semi confined by the exposed thin layer of silt and clay.

The deeper aquifer is confined and composed of medium to rounded reworked volcanic materials, gravely sand with minor mixing of silty material. The aquifer is bounded in the top and bottom by hard volcanic rocks, such as trachyte and cemented pumice layer. The thickness ranges from 10 to 15m, the total thickness may reach up to 30m including the fractured aquifer.

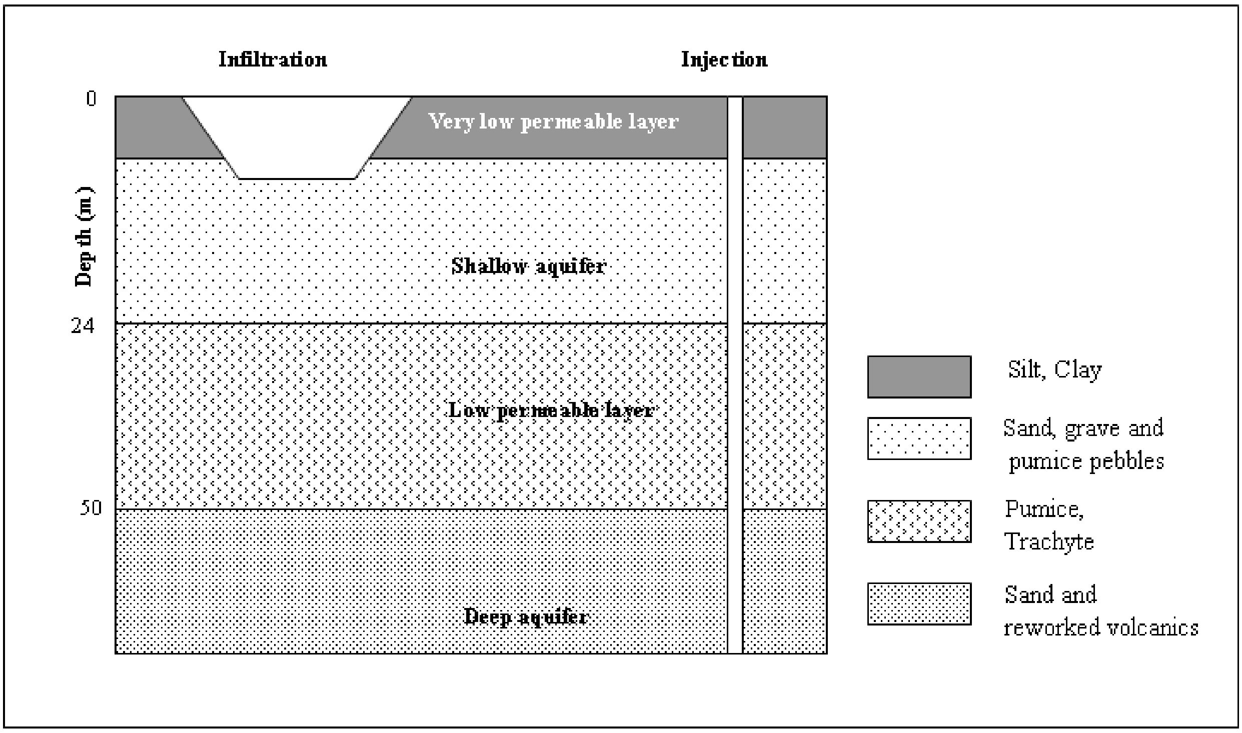


Figure 5-1 Hydrostratigraphy of the area and the injection scheme

5.2. Aquifer storage

Aquifer storage potential and retention characteristics are determined largely by geological conditions at the site, such as the nature of the aquifer material, extent of the strata, storage of coefficient, and existence of fractures and faults. The storage potential of the groundwater must be adequate to accommodate the anticipated volume of recharge. Aquifers best suited for artificial recharge are those having a low value of the T/C coefficients where, T=Transmissivity and S=Storage coefficient, that is aquifers which absorb large quantities of water and do not release them quickly, these two conditions are not often encountered in nature (United Nations, 1975).

The hydraulic effect generated by the artificial recharge is a result of the increased head which is applied in the recharge area and the mass of the water which is introduced into the aquifer through the recharge area. These are: the piezometric effect and the volumetric effects.

The piezometric effect results in a rise of piezometric surface in the unconfined aquifer and/or a rise of the artesian pressure in the confined aquifer. The effect is related to factors which create a damping reaction. This damping effect is related to the shape of the piezometric surface, to the geological and hydraulic boundaries of the aquifer and to the type and location of the recharge device. Secondly, it is related to the quotient T/C; thirdly, it is related to the artificial recharge yield and duration of the operation. The volumetric effect is related to the storage coefficient, transmissivity and boundary coefficients. Transmissivity is important for two reasons: (a) water must be transmitted from the area of recharge to points of extraction with a minimum gradient; (b) economic extraction requires large-capacity wells with small drawdown. Because specific capacity of wells is directly related to the transmissivity, a higher transmissivity is desirable.

The injection test conducted at different depth interval of shallow and deep aquifer, show variation in the ability of lateral spreading of the injected water. In addition to the response, the variation in the thickness of the overlying layer of the two aquifers is high. That is, for the shallow aquifer it is only 4 to 6m while for that of the deep aquifer, it is 40 to 50m thick. The total water abstraction from the lake and the amount of runoff generated from the greenhouse show significant variation between the flower farms near to the shallow and deep aquifer. The runoff generated from the greenhouses near to the shallow aquifer is 7 times of the greenhouses found near to the deep groundwater and also 4 times of the abstraction rate. The water level of the study area also has a large variation: 5 to 6m in the shallow aquifer and 30 to 50m below the surface in the deep aquifer. The injection test conducted at different depth interval indicates that lateral spreading of the injected water was observed in depth range of 6 to 8m in the shallow aquifer and 50 to 55m in the deep aquifer. Most of the water was infiltrated at the depth range of 38 to 40m. From the previous pumping test and current analysis results in a transmissivity in the range of 2500 to 10640m^2day^{-1} was found. The porosity of the formation is estimated from the laboratory core sample analysis and is found to be about 0.35. The test done on both types of aquifer indicates sufficient storage space and hydraulic build of water in the deep aquifer is easily possible. In the shallow aquifer, the relatively large amount of abstraction of water of the flower farms and high hydraulic conductivity of the aquifer formation could be one of the possibilities that can compensate the large volume of recharge generated by the flower farms. The total amount of water needed for the flower farms found near to the shallow aquifer is 4.5 times the runoff generated by the farms.

5.3. Groundwater flow direction

To understand the hydro-geological behaviour of the rift lake Naivasha it is essential to gain a good conceptual view of the geological and palae-hydrolgical processes. Extensive volcanism formed a thick volcanic rock sequence of mainly ignimbrite, tuff, rhyolite, trachyte and basalts. These volcanic rocks have been intensely faulted in the course of rift evolution. This has resulted in large difference in the transmissivity and hydraulic conductivity of the various rocks, the variation strongly controlling the ground water flow system in the rift valley and mutually subsurface hydraulic links of the lakes(Yihdego, 2005).

In general faulting has an effect on groundwater flow. It causes it to flow from the sides of the Rift towards the centre where it follows longer flow paths reaching greater depths, and it aligns the flows within the Rift along its axis. The structure of the rift valley, especially the major rift faults have a substantial effect on the groundwater flow systems of the area. Generally Faults have two effects on the fluid flow; they can provide channels of high permeability or barriers to the flow by offsetting zones of relatively high permeability.

With little evidence it is thought that in areas where horizontal flow predominates, faults are thought of as hydraulic boundaries in groundwater flow systems whereas in areas predominated by vertical flows, they are considered to provide conduit for flow (Clarke et al., 1990).

In the lake Naivasha basin, groundwater generally flows towards the lake from the Mau and Aberdare escarpments, although it is diverted locally by the presence of faults that form either barriers or conduits (Mcann, 1974). The historic contour map indicates that the regional groundwater flow direction is laterally from the eastern and western escarpments towards the Lake, and axially from Lake Naivasha northwards towards Lake Elmenteita and southwards from the lake towards the Longonot area Figure 5-3.

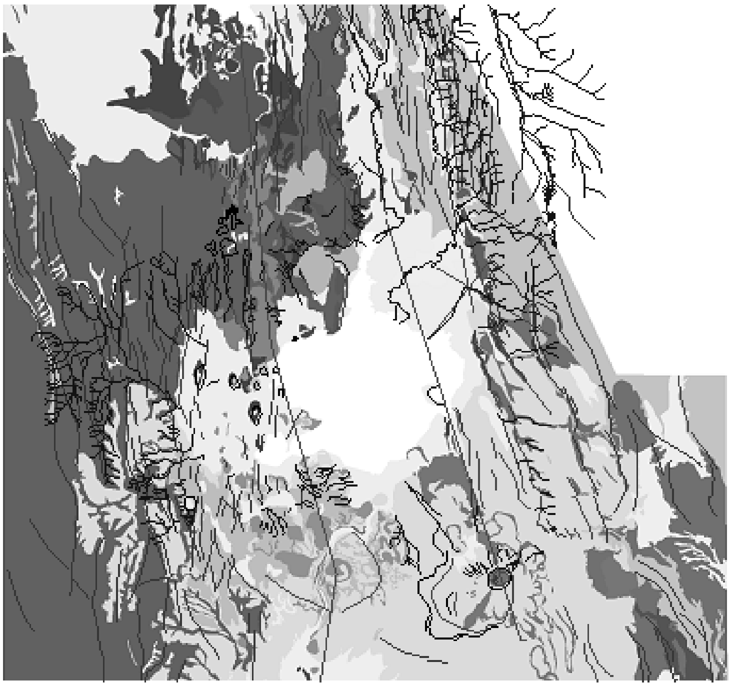


Figure 5-2 Fractures/faults shown on the geological map (Yihdego, 2005)

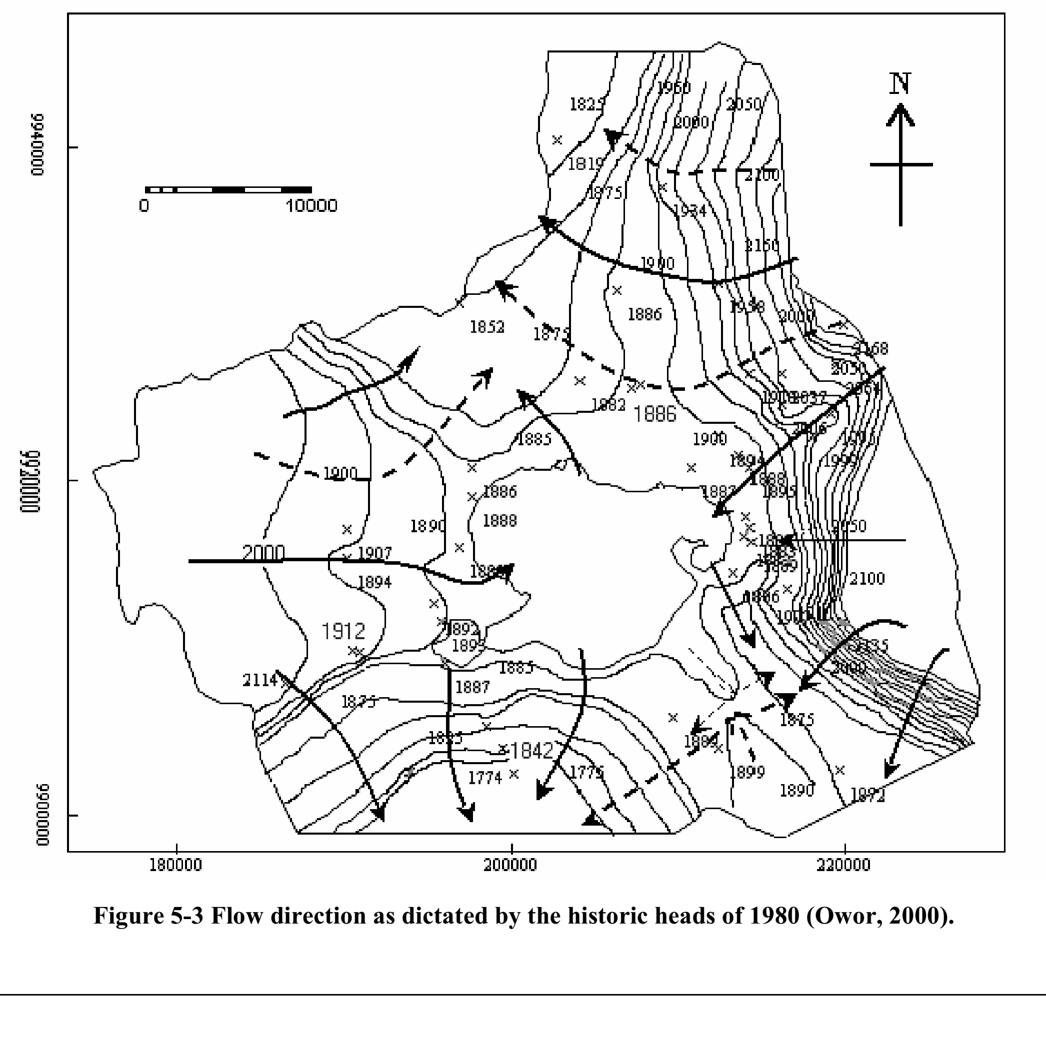


Figure 5-3 Flow direction as dictated by the historic heads of 1980 (Owor, 2000).

In addition to the previously recorded lake and groundwater levels, collecting of water levels of the site was done during the field work. Leica 2000 series GPS was used for the boreholes which are accessible of measuring the water level below ground surface and isotope samples for boreholes difficult to measure water level below ground surface. From the measurements taken during the field work, the water level of all shallow to deep boreholes was found to be below the lake level. This result matches with the previously dictated groundwater flow direction. The general flow direction is away from the lake toward the southern and south eastern direction of the lake. The minimum and maximum water level variation found between the lake and the surrounding boreholes was 20cm and 4.8m respectively. The lowest variation of the water level (6-20cm) was recorded between the lake and shallow boreholes of the area, while the maximum variation was recorded in the deep boreholes (>40m depth) found relatively at distant from the lake. Generally, the variation of the water level between the lake and the boreholes increases with distance away form the lake.
The contour of the water levels recorded during the field work is shown in Figure 5-5.

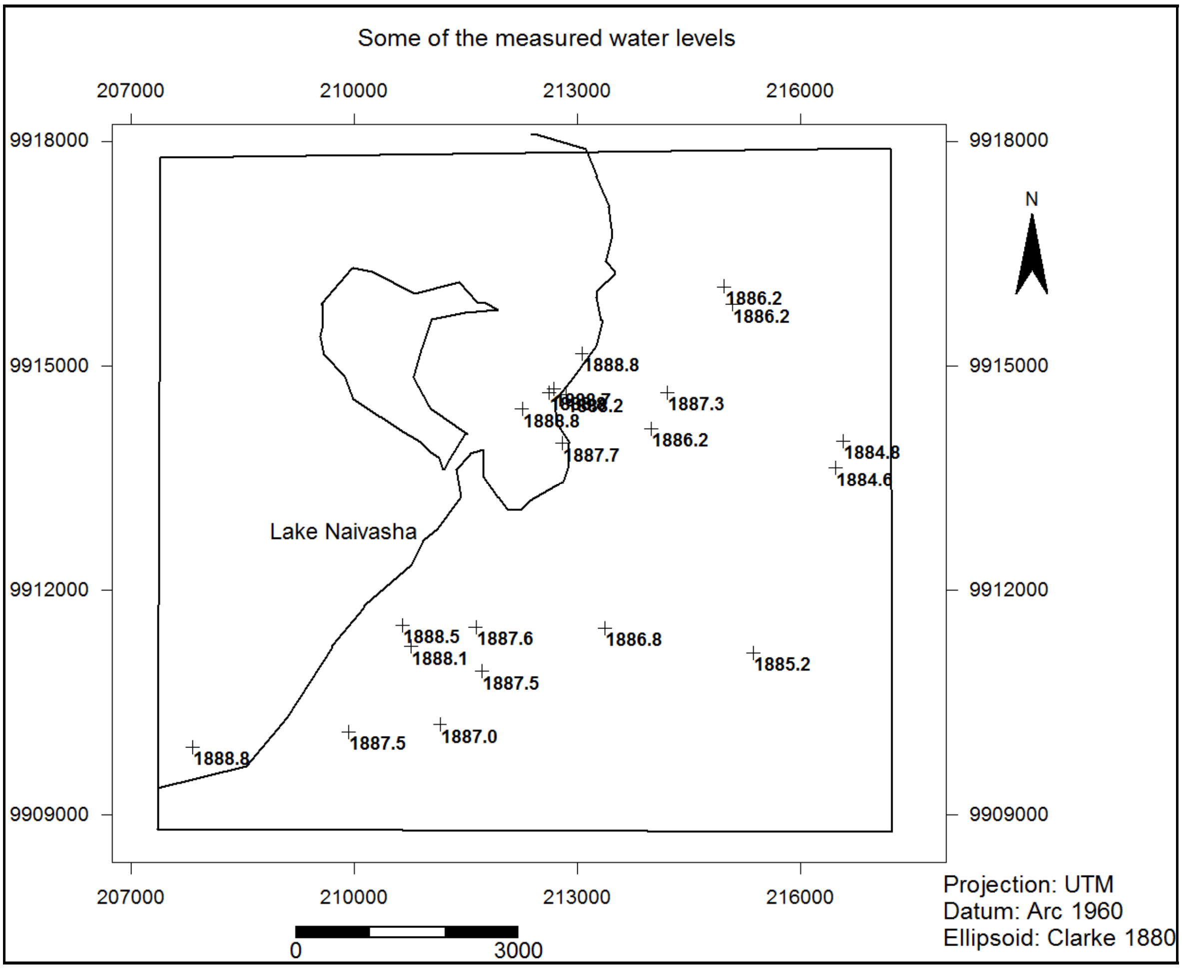


Figure 5-4 Location and water level map of the measured GPS points

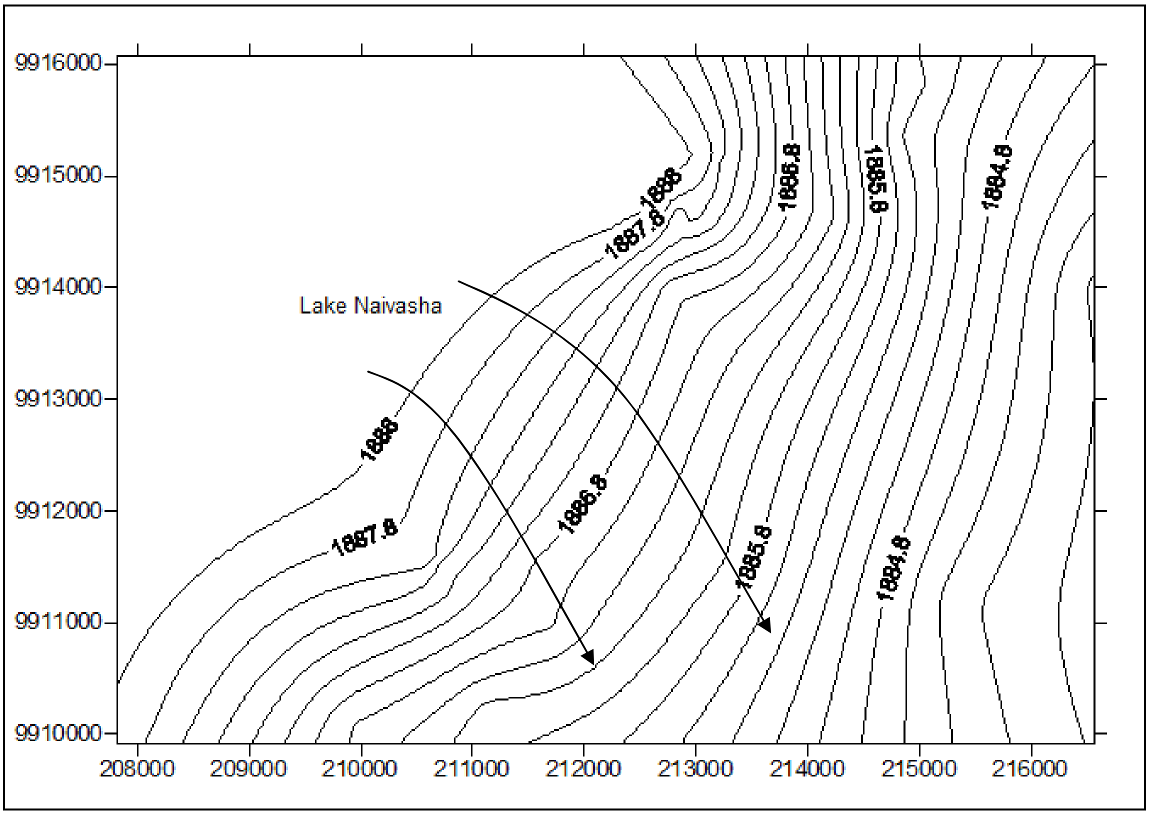


Figure 5-5 Groundwater level contour and flow direction (2007)

5.3.1. Isotopic analysis

Stable isotopes ratios of oxygen and hydrogen are routinely used to study the origin of water in aquifers and the dynamics between surface water and groundwater. 12 samples for isotope analysis from the lake and shallow to deep groundwater were taken. Most of the samples taken from the groundwater of the area concentrated on the wells which are difficult to measure their static water level. This is because all the accessible existing and wells drilled during the field work campaign, were surveyed their water level using differential GPS.

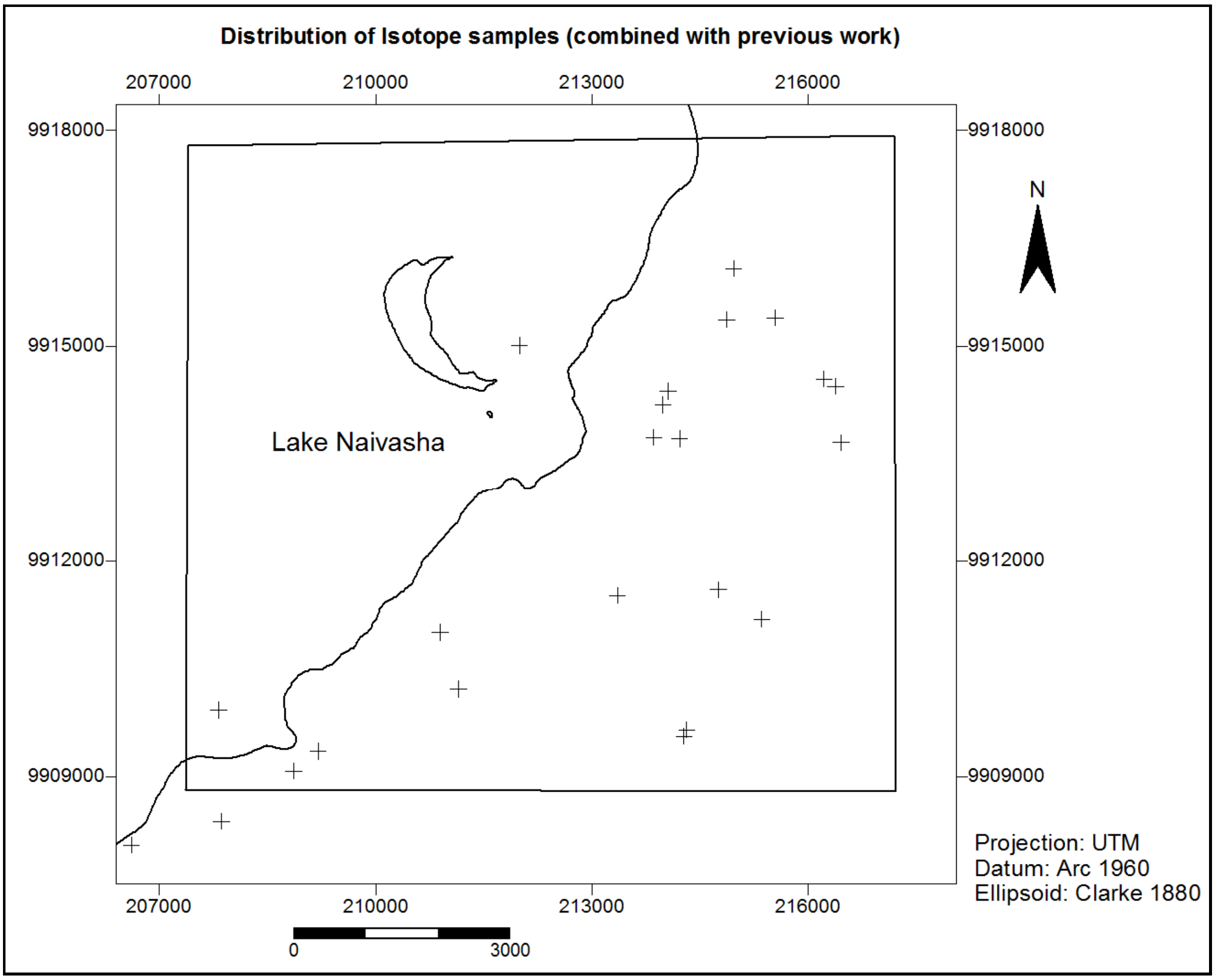


Figure 5-6 Distribution map of isotope samples combined with previous analyses

The collected isotope samples during the field work together with the previous isotope data (Nabide, 2002), were analysed to determine the significance of ground water out flow from the lake, which is important in conforming the groundwater flow of the area. The isotopic signatures of the water in the sampled wells and lake ascertain the assumptions that the groundwater flow is away from the lake toward the aquifers of the study area. From the analysis results water samples taken during the field work, the mean $\delta 18O$ of lake Naivasha water was found to be 4.3‰. From the previous work results, the mean $\delta 18O$ of lake Naivasha water was 6.5‰ and that for direct recharge from rainwater was –5.75‰ (Oppong-Boateng, 2001). The value obtained previously, mean of more samples analyzed was taken. The isotope analysis used for the study was stable isotopes of hydrogen and oxygen.

Location	Year	X_utm	Y_utm	dH-2 [‰]	dO-18 [‰]	d [‰]
Rubiri	2007	215357.8	9911181	9.9	1.11	1
Lake Naivasha	2007	211998.76	9914997.81	22.1	3.12	-2.9
Lake Naivasha	2007	207626	9909920	32.8	5.53	-11.4
Muita Karagita	2007	213861.5	9913728	27.8	4.57	-8.8
George Karagita	2007	214869.1	9915363	13.6	2.13	-3.4
Kedong ranch	2007	213360.4	9911513	30.2	4.91	-9.1
Infront of Flamingo	2007	211149.4	9910217	22.2	3.55	-6.2
Stephen karagita	2007	214218.8	9913705	22.2	3.57	-6.4
Masharia	2007	214762.7	9911595	30.1	5.05	-10.3
Fischers Tower	2007	214966.5	9916072	-10.4	-2.19	7.1
Migaa	2007	216223.9	9914534	-25.3	-4.51	10.8
Kiffmeir	2007	216463.7	9913647	-28.4	-5.22	13.4
Heather BH	2000	214281	9909564	29.2	4.19	-4.32
Sulmac farms	2000	207857	9908376	19.1	2.9	-4.1
3 Point farms BHM	2000	213065	9924682	-17.6	-4.33	17.04
Olsuswa water supply	2000	204888	9908150	23.9	3.53	-4.34
C562	1996	210900	9911000	25	4.3	-9.4
C567	1996	214318	9909647	23	4.2	-10.6
C7829	1996	206610	9908050	26	3.9	-5.2
C4397	1996	204750	9908600	21	4.2	-12.6
C4420	1996	204800	9908250	22	3.7	-7.6

Table 5-1 Isotope analysis result of water samples combined with previous work

Deuterium and Oxygen 18 isotopic composition in water are defined in a two-dimensional space vector by plotting the isotopic signatures of δD vs. $\delta^{18}O$ diagrams and compared with the different local signatures of rainfall, lake and groundwater.

From the samples analyzed the values of $\delta^{18}O$ and δD in groundwater samples vary from -5.22‰ to 5.05‰ and -28.4‰ to 30.2‰ respectively. The three most depleted groundwater from the collected samples during the fieldwork are from wells Fischers Tower, Migaa and Kiffmeir located in the eastern periphery of the site. The most enriched groundwater samples were those from the deep wells such as Kedong Ranch, Masharia and Muita Karagita. The groundwater samples plotted on a line of regression defined by the equation $\delta D=5.7708\delta 18O+1.7289$ ($r^2=0.9988$).

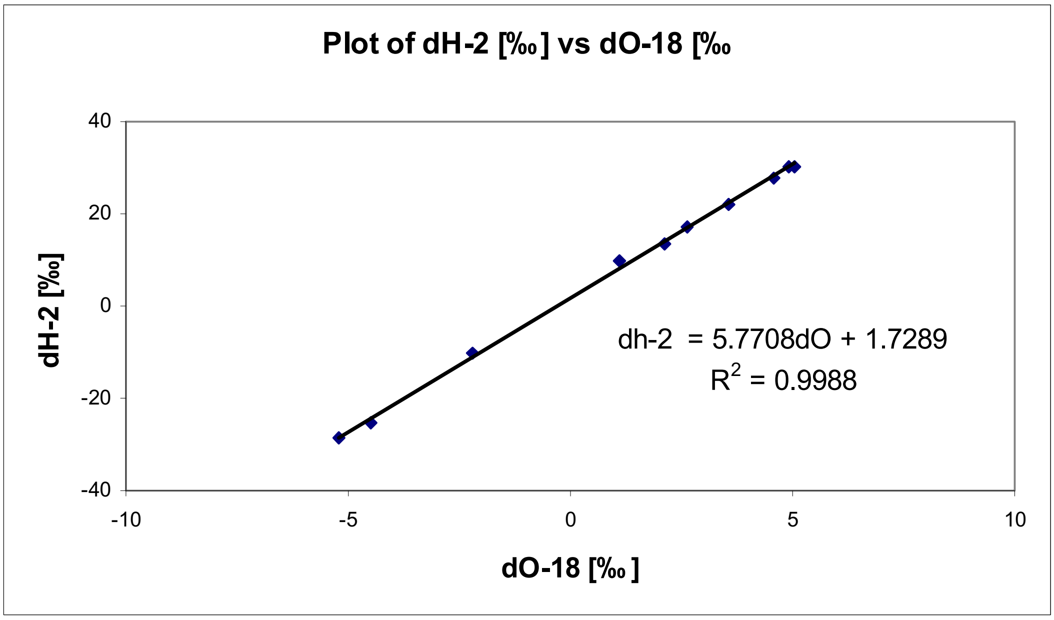


Figure 5-7 Plot of δD against δ18O showing the regression lines of groundwater water.

As Oppong-Boateng, (2001) indicated, the $\delta^{18}O$ values of rainfall from regional and local locations were –5.1%o and –6.4‰ respectively whiles that of δD were -32.8‰ and –39‰ respectively.

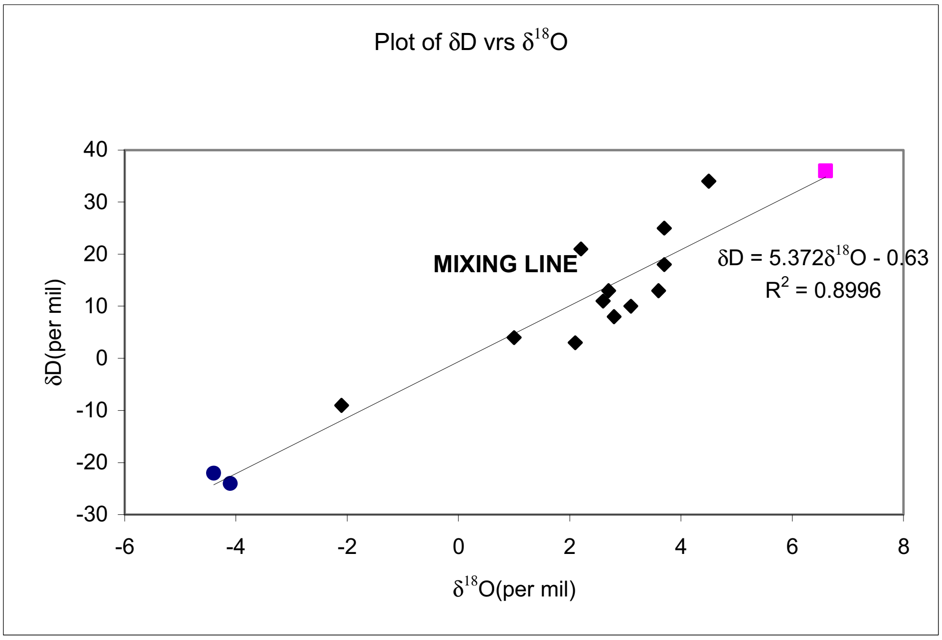


Figure 5-8 Plot of δD-δ18O showing the mixing line of Lake Naivasha and groundwater (Oppong-Boateng, 2001)

Interpretation of the Isotopic Signatures was based on the assumption that samples lie along the Direct Recharge-Lake Water Mixing line. Consequently, all samples are a mixture of these two end members, which are Direct Recharge water and Lake Water with $\delta^{18}O$ values of –5.75‰ and 6.5‰

respectively (Nabide, 2002). For a sample with $\delta^{18}O$ value v, its ratio of composition can arithmetically be delivered as shown below:

If L is the ratio of lake water in the sample, then the ratio of rain water will be (1-L)

$$V = \delta^{18}O_{sample} = (L * \delta^{18}O_{lake}) + ((1-L) * \delta^{18}O_{rain}) \quad \textbf{5-1}$$

$$= (\delta^{18}O_{lake}L + \delta^{18}O_{rain} - \delta^{18}O_{rain}L$$

From which,

$$L = (\delta^{18}O_{sample} - \delta^{18}O_{rain}) / (\delta^{18}O_{lake} - \delta^{18}O_{rain})$$

The results obtained using the above equation 5-1 is presented in Table 5-2.

Location	Year	dH-2 [‰]	dO-18 [‰]	L (percentage of lake water)
Rubiri	2007	9.9	1.11	56
Muita Karagita	2007	27.8	4.57	84.24
George Karagita	2007	13.6	2.13	64.33
Kedong ranch	2007	30.2	4.91	87.02
Infront of Flamingo	2007	22.2	3.55	75.92
Stephen karagita	2007	22.2	3.57	76.08
Masharia	2007	30.1	5.05	88.16
Fischers Tower	2007	-10.4	-2.19	29.06
Migaa	2007	-25.3	-4.51	10.12
Kiffmeir	2007	-28.4	-5.22	4.33
KSPCA	2007	17.2	2.64	68.49
Heather BH	2000	29.2	4.19	81.14
Sulmac farms	2000	19.1	2.9	70.61
3 Point farms BHM	2000	-17.6	-4.33	11.59
Olsuswa water supply	2000	23.9	3.53	75.75
C562	1996	25	4.3	82.04
C567	1996	23	4.2	81.22
C7829	1996	26	3.9	78.77
C4397	1996	21	4.2	81.22
C4420	1996	22	3.7	77.14

Table 5-2 The percentage of lake water in boreholes

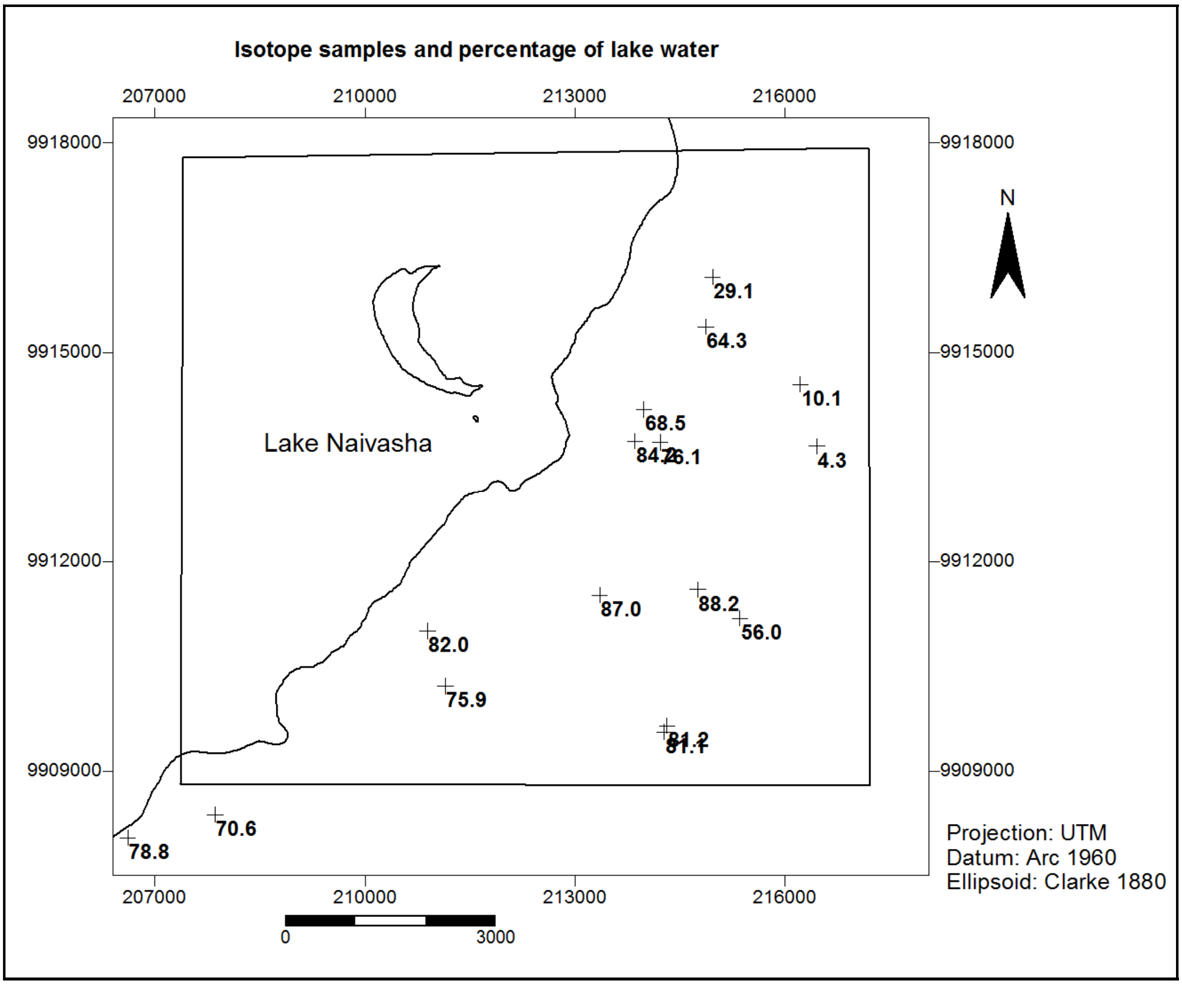


Figure 5-9 Boreholes and percentage of lake water

As it can be seen from Table 5-2, the percentage of lake water in the boreholes varies from 10.12 to 88.16. Except the three aforementioned depleted boreholes, all the boreholes of the area are dominated by lake water, indicating groundwater flow away from the lake.

The higher the percentage of lake water in any borehole may either mean a stronger flow of lake water in that direction, or close vicinity of that borehole to that lake. As it shown in the location map of the isotope sample distribution, most of the boreholes are located far away from the lake. These boreholes with high percentage of lake water are a good indication of the groundwater flow direction. Two good borehole examples are Masharia and Kedong Ranch which have 88.16% and 87.02% of lake water.
The isotope signatures obtained from the three most depleted boreholes do not show mixing with the lake water; this could be due to direct mixing of rain water with the well water. Some of the boreholes of the site are open and during raining time, direct fall on the wells and runoff from the surrounding area can make the value small. The other reason could be probably due to a groundwater intercepted by the large fault nearby trending N-S.

6. Hydro-Chemical assessment

The chemical composition of groundwater is the combined result of the composition of water that enters the groundwater reservoir and reactions with minerals present in the rock that may modify the water composition (Appelo and Postma, 1993). As water infiltrates and moves through the subsurface geological formation, the composition changes gradually. This is because of the interaction between the slowly moving water and the geology in contact, resulting in increasing of the saturation of some ions or some end product of some weathered rocks.

6.1. Field data

Representative samples of lake and groundwater were taken for the analysis of major and minor ions. In addition, alkalinity (bicarbonate) and other physical parameters: Electrical conductivity, PH and total dissolved solid were measured at the site. Samples taken from the lake, shallow and deep groundwater were analyzed in the ITC geochemical laboratory. The result of the analysis was used for tracing the chemical signature and interaction of the lake and groundwater of the site.

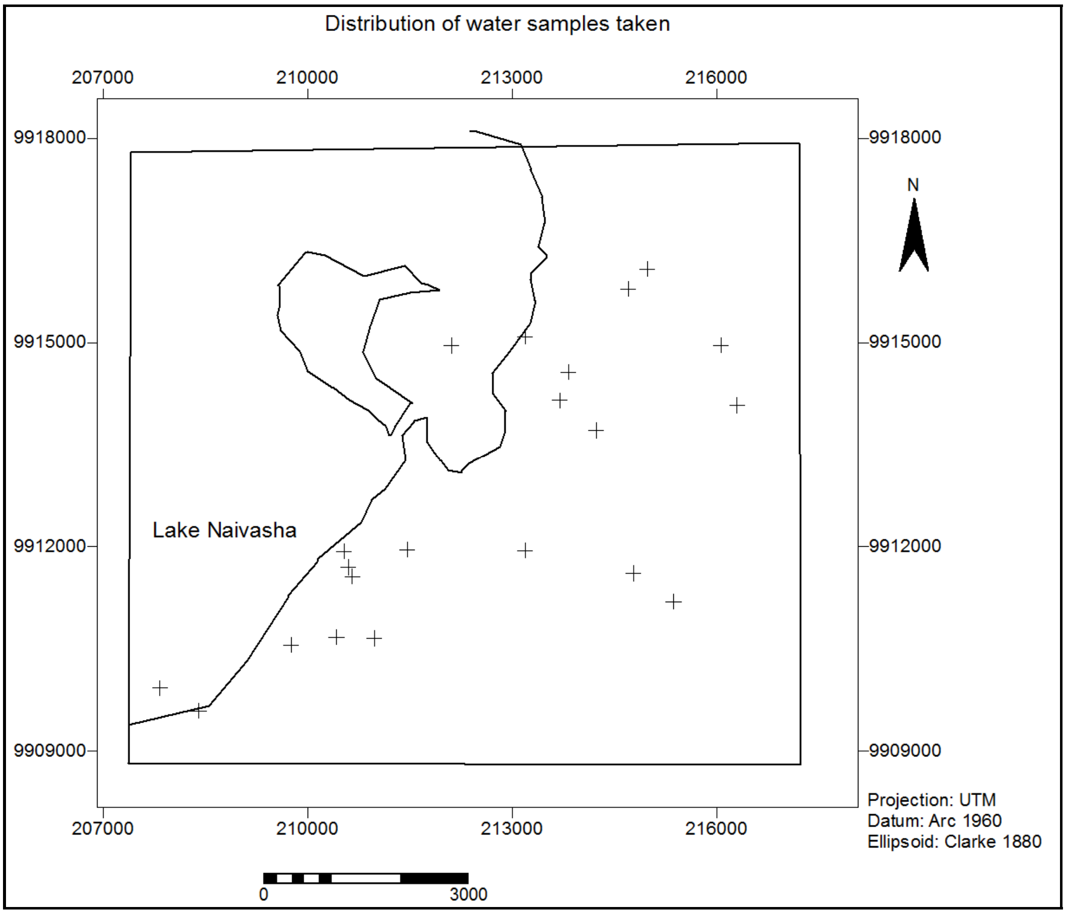


Figure 6-1 Location and distribution map of water samples taken

6.2. Analysis and Interpretation

Water quality assessment can be divided into two categories: use-orientated and impact-orientated. Use orientated assessment test whether water quality is satisfactory for specific purposes, such as drinking water supply, irrigation, and industrial use. Impact oriented assessment examines the effects of specific activities on water quality (Chapman, 1992). This chapter deals with use-oriented water analysis and interpretation. The analysis result of all samples collected from the lake and groundwater were used for the reliability checking of the water use for the flower irrigation of the site. The minimum and maximum analysis result of the ions is presented in Table 6-1. The analyses result of all samples is presented in appendix 5.

Ions analyzed	Minimum Value and boreholes		Maximum Value and boreholes		Lake (mg/l)
	(mg/l)	Boreholes (BH)	(mg/l)	Boreholes (BH)	
Ca	10.33	Rubiri water project	65.01	Infront of Flamingo	13.48
K	12.09	Stephen Karagita	88.195	TB1 (NINI)	13.69
Mg	0.32	Masharia	15.98	Infront of Flamingo	3.79
Na	22.79	TB4	352.72	KSPCA	22.79
Cl	4.2	TB1 (NINI)	143	KSPCA	9
F	1.13	TB4	15.29	George residence	1.13
PO4	0.07	Stephen Karagita	0.94	Simba Lodge Naivasha	0.08
P	0.02	Stephen Karagita	0.31	Simba Lodge Naivasha	0.03
P2O5	0.05	Stephen Karagita	0.71	Simba Lodge Naivasha	0.06
SO4	4	TB4	170	Simba Lodge Naivasha	4
NO3	2.4	Karagita	24.7	TB1 (NINI)	4.8
NO3-N	0.5	Karagita	5.6	TB1 (NINI)	1.1
HCO3(mmol/l)	0.5	NINI	10	Infront of Flamingo	2.6
pH	2.86	Rubiri water project	7.39	Masharia	7.19
EC(us/cm)	226	Masharia	2267	Stephen Karagita	221.14
TDS(mg/l)	107.1	TB4	1098	Stephen Karagita	107.1

Table 6-1 Minimum and maximum value of the analyzed groundwater chemistry of the site

6.2.1. Source rock deduction

The purpose of this technique is to gain insight into the possible origin of water analysis. Applying this method for water samples with pH value of less than about 5-6 may cause an interpretation problem because significant quantities of clay minerals may dissolve and release anomalously high silica (and alumina) to the water (Hounslow, 1995). Therefore all the discussion mentioned in this part will refer to the samples with pH value of greater than 6.

Sodium and Chloride

The assumption here is that the primary source of chloride in water is from sodium chloride (directly from halite dissolution or indirectly from the ocean via rainfall). On the other hand if sodium is greater than chloride, sodium can be derived from sources other than halite, such as dissolution of albite-plagioclase and salt sources such as Soda. The analysis results of all water samples of the site indicate sodium is by far greater than chloride. From the geology of the site and the chemical analysis results, the source rock can be concluded as Soda.

Calcium and Sulphate

The primary assumption is that sulphate is generally the result of direct dissolution of gypsum (or anhydrite) or the neutralization of acid waters by limestone or dolomite.

$Ca^{2+} = SO4^{2-}$ indicates gypsum

$Ca^{2+} < SO4^{2-}$ indicates pyrite oxidation, or Ca^{2+} removal, such as by calcite precipitation, or natural softening.

$Ca^{2+} > SO4^{2-}$ indicates Ca^{2+} source other than gypsum, such as calcite/dolomite or silicates.

The analysis results of boreholes around karagita and near some farms show concentration of sulphate greater than calcium, which could be the effect of fertilizers or presence of the aforementioned sources. More than half of the samples show higher concentration of calcium than sulphate, with a favourite source of silicates.

Sodium and Calcium

The Na/Ca ratio can be used as a way of distinguishing between silicate and carbonate weathering. Because the ratio of all the samples is not low, the source rock can not be carbonate, and there fore the favourite source may be silicate or plagioclase.

6.2.2. Graphical illustration of the analysis result

Graphical methods of illustrating water analyses have two main objectives: the first is to be able to plot analyses on a map and the second is to detect chemical trends (Hounslow, 1995).

Piper diagram

Piper diagrams are a combination of anion and cation triangles that lie on a common base line. Four basic conclusions can derived from multiple analyses plotted on piper diagrams. These are water type, precipitation or solution, mixing and ion exchange.

The trend of the water type is from fresh to saline type of water. Most of the samples taken from deep groundwater (depth greater than 30m) are grouped under the saline part of the piper plot, which matches with the amount of electrical conductivity measured at site. Analyses results obtained from the lake and shallow groundwater show alkali bicarbonate type of water, with a dominant cation of sodium and potassium. Analysis results of borehole found along the North eastern periphery of the study area (around Fischers' Tower and Migaa) show $Na\text{-}SO_4^{2-}$ and $Na\text{-}Ca\text{-}SO_4^{2-}$ type of water.

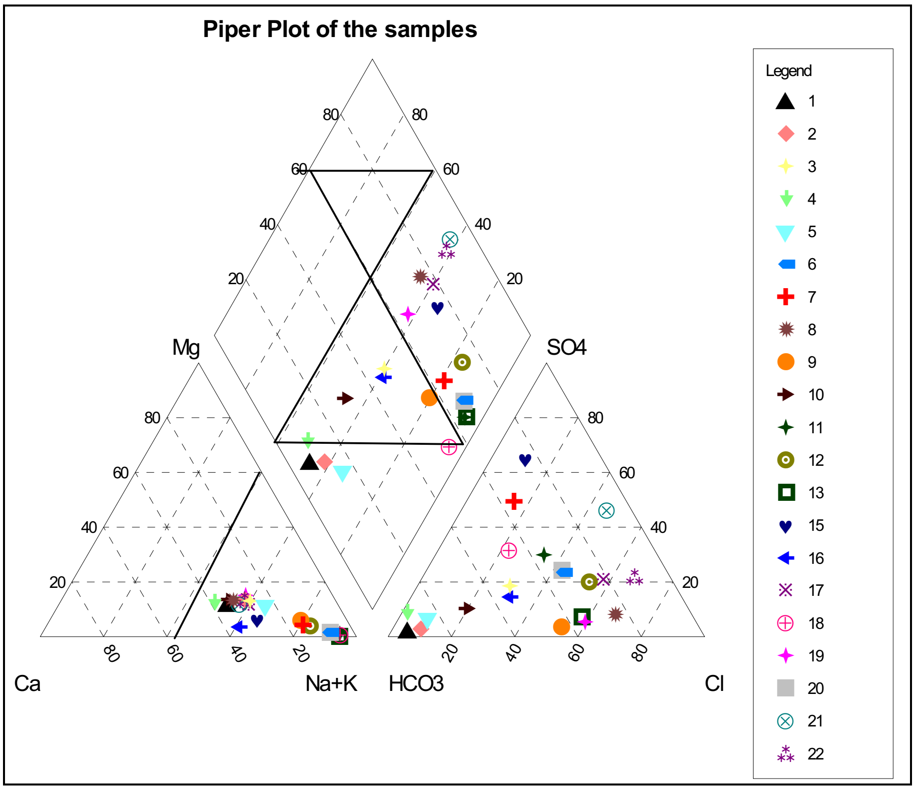


Figure 6-2 Piper plot of the hydrochemical analysis results of the samples

6.3. Water quality assessment for irrigation

Quality of groundwater is of paramount importance for irrigation in arid regions.

Natural waters are never pure; they always contain varying amounts of dissolved gases and solids. The major ionic species in most natural waters are Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, and SO_4^{2-} (Shaki and Adeloye, 2006). To evaluate ground water quality and suitability for irrigation, samples were collected from the lake and groundwater of the site. From the analyses results of the borehole samples, Sodium, expressed by salinity was found to be the most problem of the site (Figure 6-3). This is more prominent in the deeper groundwater of the site. Almost all the analyses result of the samples taken from the shallow groundwater (near to the lake) and the lake itself indicate suitable quality of water for the irrigation of the surrounding farms. With a special emphasis on salinity analysis, the following four criteria were used for the assessment of water quality suitability for the irrigation of the flower farms of the area.

6.3.1. Salinity hazard (total soluble salt content)

The total concentration of salts in irrigation water is measured by the electrical current conducted by the ions in solution. This measurement is expressed as electrical conductivity (EC) and its value increases with increasing of salt concentration in water. The electrical conductivity of the groundwater of the area shows a wide variation: low in the shallow groundwater near to the banks of the lake and higher in the medium to deeper (>30m) groundwater of the area. The variation of the value with in the shallow groundwater is very small, ranging from 293 to 300µs/cm. On the other hand, the electrical conductivity value variation of medium to deeper groundwater is 438 to

2267µs/cm. Most of the boreholes with the highest value of electrical conductivity are concentrated along the local name of Karagita area. Other boreholes (depth of 30 to 50m) found with in the flower farms, which are not yet being used have a value of 510 to 750µs/cm. Due to this variation of electrical conductivity value, the salinity trend of the groundwater of the area varies from low to high salinity water. Most of the samples taken from medium to deep groundwater (depth greater than 30m) are grouped under medium to high saline water, which matches with the amount of electrical conductivity measured at site. Shallow boreholes drilled near to the bank of the lake and with in the flower farms are grouped under low salinity water (Figure 6-2 and 6-3).

6.3.2. Relative proportion of sodium cations (Na+) to other cations (Sodium hazard)

The sodium hazard of irrigation water usually is expressed as the sodium adsorption ratio (SAR). This is the proportion of Na^{+} to Ca^{2+} plus Mg^{2+} in the water. The following formula was used to calculate SAR:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \qquad \textbf{6-1}$$

where, ions in the equation are expressed in milliequivalents per liter (meq/l).
Although sodium contributes directly to the total salinity and may be toxic to sensitive crops, the main problem with a high sodium concentration is its effect on the physical properties of soil. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidally absorbed sodium. This breakdown results in the dispersion of soil clay that causes the soil to become hard and compact when dry and increasingly impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action.

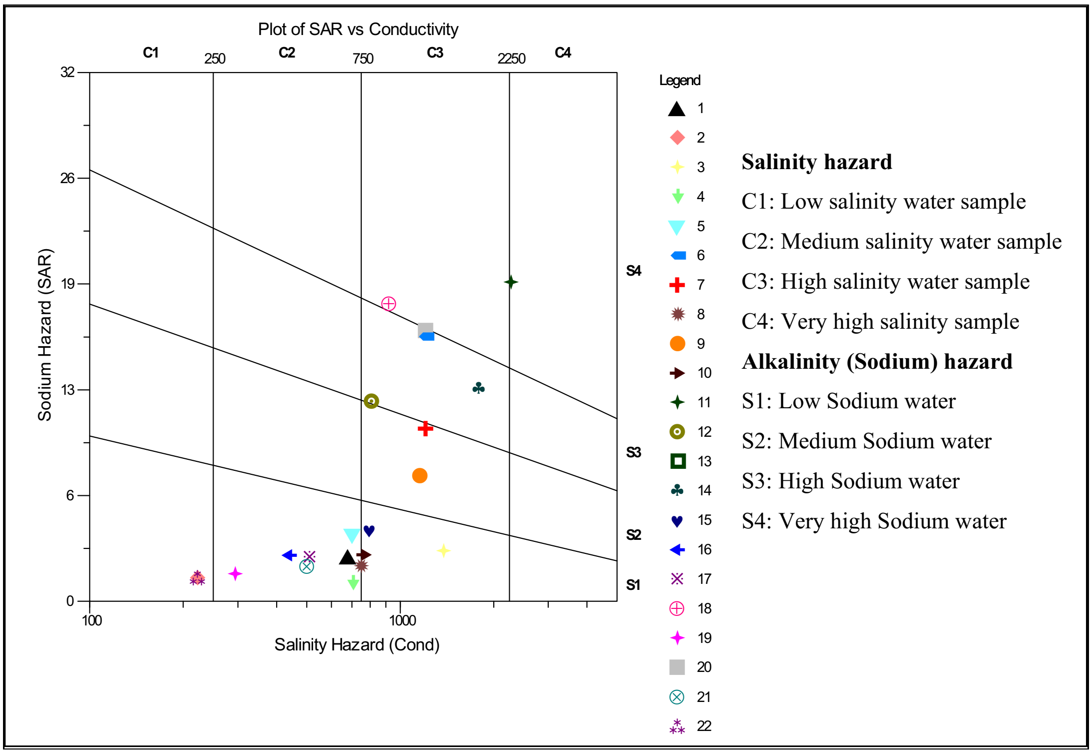


Figure 6-3 Sodium Absorption Ratio Vs Conductivity

About 50% of the samples lie between C2 and S1, characterized by medium salinity and low sodium water. Most of the shallow groundwater samples taken around the flower farms are grouped under this category. Samples analysed from the lake water fall in the low salinity and sodium part of the plot. The other water samples taken from the deep boreholes around karagita area are grouped under the graph of C3, S2 and C3, S3, dominated by high salinity and sodium water. Results of two water samples of deep borehole (>50m) around the flower farms (near to Flamingo) show high salinity and low sodium water.

According to the concentration limit of sodium, calcium and magnesium given by the flower farms, the maximum allowable SAR value calculated using equation 6-1 was 4.93. The SAR value of all water samples of the shallow boreholes around the flower farms is below this limit. Other water samples exceed the limit value by far. The SAR value calculated for each sample is given in Table 6-2.

Samples	SAR value	Samples	SAR value
1	3.78	12	17.09
2	2	13	25.29
3	4.32	14	18.17
4	1.53	15	6.08
5	5.7	16	3.89
6	22.62	17	3.79
7	14.75	18	25.45
8	3.02	19	2.34
9	10.71	20	23.12
10	3.99	21	2.99
11	27.25	22	2

Table 6-2 Calculated SAR value of each samples

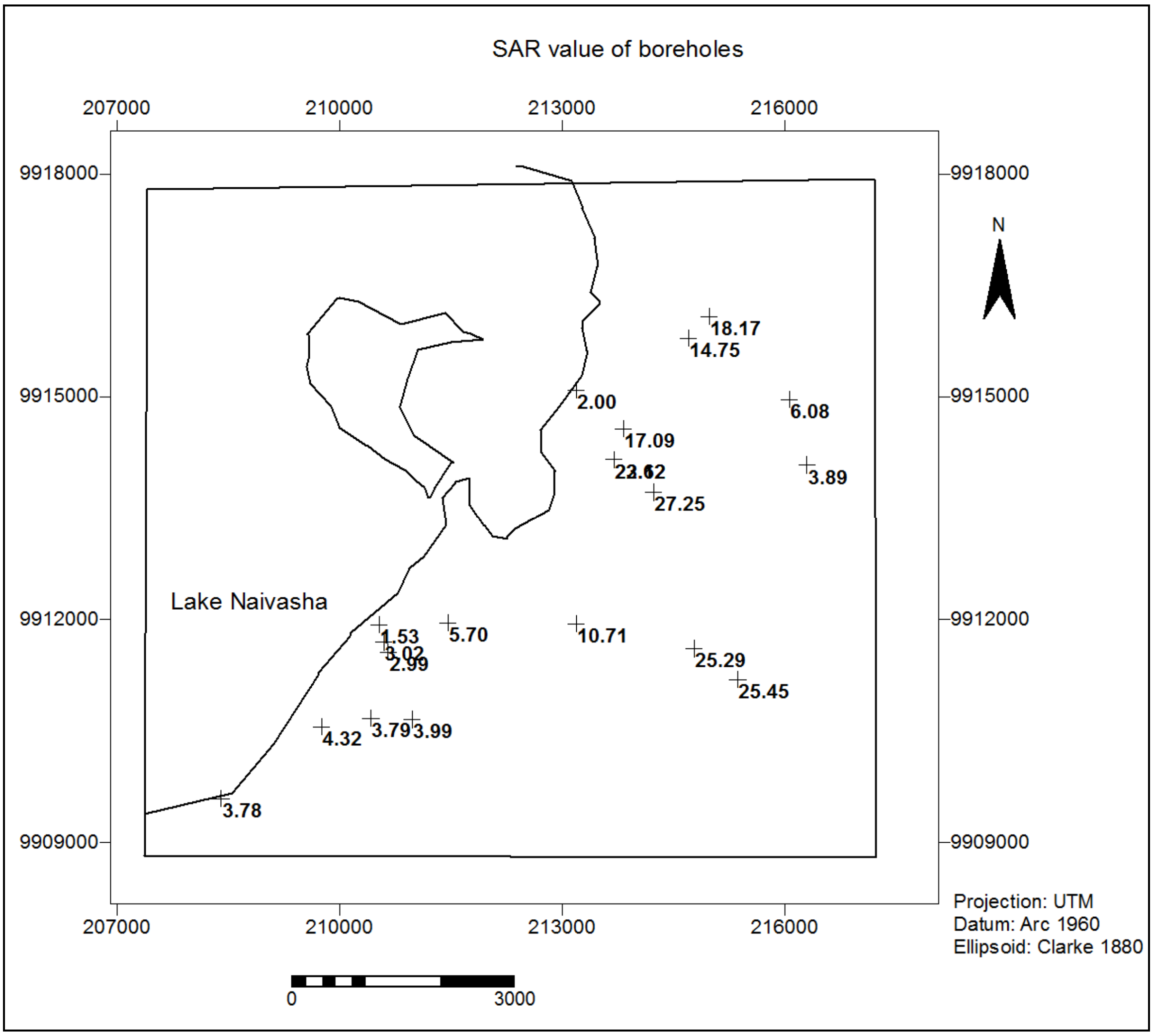


Figure 6-4 SAR value distribution of boreholes

6.3.3. pH of the water

The pH of water is a measure of the acidity or basicity. It is reported as the negative log of the H^+ ion concentration, so acidic water (high concentration of H^+ ions) has a low pH and basic water (low concentration of H^+ ions) has a high pH value. Most plants grow best when the media solution pH is 5.6 to 6.2. The main effect of water pH on plant growth is through control of nutrient availability. A low pH may be responsible for excess iron and manganese availability leading to toxicity, or calcium and magnesium deficiencies. A high pH may cause iron and manganese and other minor nutrients to become unavailable to plants, leading to deficiencies.
The allowable value of pH value for the flowers, obtained from the flower farmers is 5.5 to 7.5. A total of 6 water samples taken from the deep boreholes of Karagita area and with in the flower farms (around flamingo) are with the pH value below 5.5, expressed as acidic water. The pH value of the rest samples, taken from the shallow boreholes of the flower farm areas is with in the allowable range (appendix 5).

6.3.4. Specific ions

Specific ions include chloride (Cl^-), sulfate (SO_4^{2-}) and Nitrate-nitrogen (NO_3-N), Bicarbonate concentration (HCO_3^-). Irrigation water high in chloride (Cl^-) and/or sulfate (SO_4^{2-}) ions reduce phosphorus availability to plants and reduce the concentration of organic acids in plants to suboptimal levels (Hem, 1989).
Wells and surface water sources may contain high chloride levels in association with sodium. The concern with chloride is the possibility of excessive foliar absorption under overhead irrigation or leaf edge burn caused by excessive root uptake in sensitive plants. If concentrations are less than about 100 ppm, there is no concern from excessive foliar absorption. If concentrations are less than about 150 ppm, there is no concern about toxicity resulting from root uptake. The maximum limit and target value of chloride given by the flower farms is 160 and 71mg/l respectively. The analysis result of all samples analyzed is below this limit and target value.
Waters high in bicarbonate (HCO_3^-) will tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates through evapotranspiration. This means that the SAR value will increase and the relative proportion of sodium ions becoming greater. This, in turn, will increase the sodium hazard of the water to a level greater than indicated by the SAR value. The analysis result of all the samples fall below the maximum limit obtained from the flower farms (appendix 5).

6.4. Salinity problem and improvement of the water quality

Irrigation water contains a mixture of naturally occurring salts. Soils irrigated with this water will contain a similar mix but usually at a higher concentration than in the applied water. The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management and the adequacy of drainage (Ayers et al., 1985).

6.4.1. Build up of Soil Salinity and Leaching.

Added salts with irrigation water reduces crop yield if they accumulate in the rooting depth of plants to damaging concentrations. The planted crop removes much of the applied water from soil to meet its evapotranspiratiom demand but leaves most of the salt behind to concentrate in the shrinking volume of soil – water. A portion of the added salt in the irrigation water must be leached from the root zone before the concentration affects the yield. Over time, the salt removal by leaching must equal or

exceed the salt additions from the applied water or salts will build up and eventually reach damaging concentrations. This leaching is done by applying sufficient water so that a portion percolates through and below the entire root zone carrying with it a portion of the accumulated salts.
The fraction of applied water that passes through the entire rooting depth and percolates below, called Leaching fraction (LF), is calculated as follow (Ayers et al., 1985):

$$LF = \frac{\text{Depth of water leached below the root zone}}{\text{Depth of water applied at the surface}} \quad \textbf{6-2}$$

Or,

$$LF = \frac{EC_W}{5*(EC_e) - EC_W} \quad \textbf{6-3}$$

Where,
ECe = Average soil salinity tolerated by the crop as measured on a soil saturation extract, obtained from tabulated value based on the crop demand and irrigation water or soil salinity (Appendix 5).
A high leaching fraction results in less salt accumulation than a lower leaching fraction.
If the water salinity and the leaching fraction are known or can be estimated, both the salinity of the drainage water that percolates below the rooting depth and the average root zone salinity can be estimated form the equation:

$$EC_{dW} = \frac{EC_W}{LF} \quad \textbf{6-4}$$

Where,
EC_{dW} = Salinity of the drainage water percolating below the root zone (equal to salinity of soil-water).
EC_W = salinity of the applied irrigation water
LF = Leaching fraction
The total annual depth of water that needs to be applied to meet both the crop demand and leaching requirement (fraction) can be estimated as:

$$AW = \frac{ET}{1 - LF} \quad \textbf{6-5}$$

Where,

AW = Depth of applied water (mm/year)
ET = Total annual crop water demand (mm/year)
LF = Leaching fraction expressed as leaching requirement.

6.4.2. Blending or mixing of water supply

Using available water for the desired purpose like irrigation is an easy solution. This is only possible if a better quality supply is easily available. For example, a poor quality groundwater is usually abandoned if a better quality supply becomes available, but this is not necessary if there is still a water supply shortage. Under these conditions, consideration should be given to blending the poorer with the better quality supply, thus increasing the total quantity of usable water available.

Blending of the poor quality of the deep groundwater of the area with the runoff generated from the greenhouse is the main target of this part of study. For the flower farms near to the lake where the groundwater level is shallow, blending of this water is not the main concern. This is because of the quality of shallow groundwater is suitable for the flower farming.

For two water types: poor quality (a) and better quality (b), the quality of the blended water (c) can be found by using equation (6-6) (Ayers et al., 1985)

$$C = [C\,(a) * P\,(a)\,\text{used}] + [C\,(b) * P\,(b)\,\text{used}] \quad \textbf{6-6}$$

Where,

C = Concentration of blended water

C (a) = Concentration of the poor quality of groundwater

P (a) = Proportion of water used from the poor quality groundwater.

C (b) = Concentration of the better quality of runoff generated from the greenhouse areas.

P (b) = Proportion of water used from the runoff generated from the greenhouse areas.

The proportion of the two water types used for mixing were calculated based on the limit on chemical composition and some physical parameters given by the flower farms and the analyses result of the water samples taken from the deep groundwater of the area. The main quality problem of the groundwater of the area is salinity (section 6-3), reflected on the electrical conductivity (EC) value of the water samples and therefore used as the concentration of the two water types in equation (6-6). In addition to the main concern of salinity expressed by electrical conductivity, other chemical compositions like sodium, magnesium and potassium were used in the calculation, used to know the amount of rainwater needed for the mixing with the poor quality of groundwater and finally come up with the desired quality of water for the flower irrigation. The maximum and target value of electrical conductivity given by the flower farms is 1000 and 500µs/cm respectively, assigned as the concentration of the blended water in equation (6-6). From the result of the calculation, all the shallow groundwater found within the flower farms are found to be suitable for the flower farms with a possibility of 100% use. Taking 500µs/cm as maximum limit concentration of the blended water, the proportion of the groundwater needed ranges from 21 to 73% of water, which indicates 27 to 79% of rainwater is required to get the allowable value of electrical conductivity (Table 6-3). The minimum proportion of water for the blending is obtained from the deep boreholes found around Karakita area. The groundwater proportion range for these boreholes is 21 to 40% that is 60 to 79% of rainwater is required. The other deep boreholes found with in the flower farms, around Hamerkop have groundwater proportion range of 60 to 73%, in turn 40 to 23% of rainwater is needed for the mixing result of required concentration of water. The proportion of rain and groundwater required for the mixing at 500 and 1000µs/cm of electrical conductivity for different groundwater samples is given in Table 6-3.

Borehole Name	Code	% of rain water needed for blending the groundwater	
		<1000µs/cm	<500µs/cm
Simba Lodge Naivasha	1	0	27.5
Lake Naivasha sopa resort	3	28	65.1
TB1(NINI)	4	0	0
Hamerkop	5	0	29.9
Dr.Muita hause (Karagita)	6	17.4	60
George residence	7	17.4	60
Nini Borehole	8	0	34.2
Kedong Ranch	9	13.6	58.2
Infront of Flamingo	10	0	35.9
Stephen Karagita	11	56.7	79
KSPCA	12	0	63.1
Masharia	13	17.5	60.1
Fishers Tower	14	44.9	73.3
Migaa	15	0	38.5
Kiffmeir farm	16	0	0
Flamingo	17	0	2.1
Rubiri water project	18	0	47.1
Karagita	20	17.4	60
Nini Trench	22	0	0
TB4	23	0	0

Table 6-3 Percentage of rain water for blending the groundwater of the area

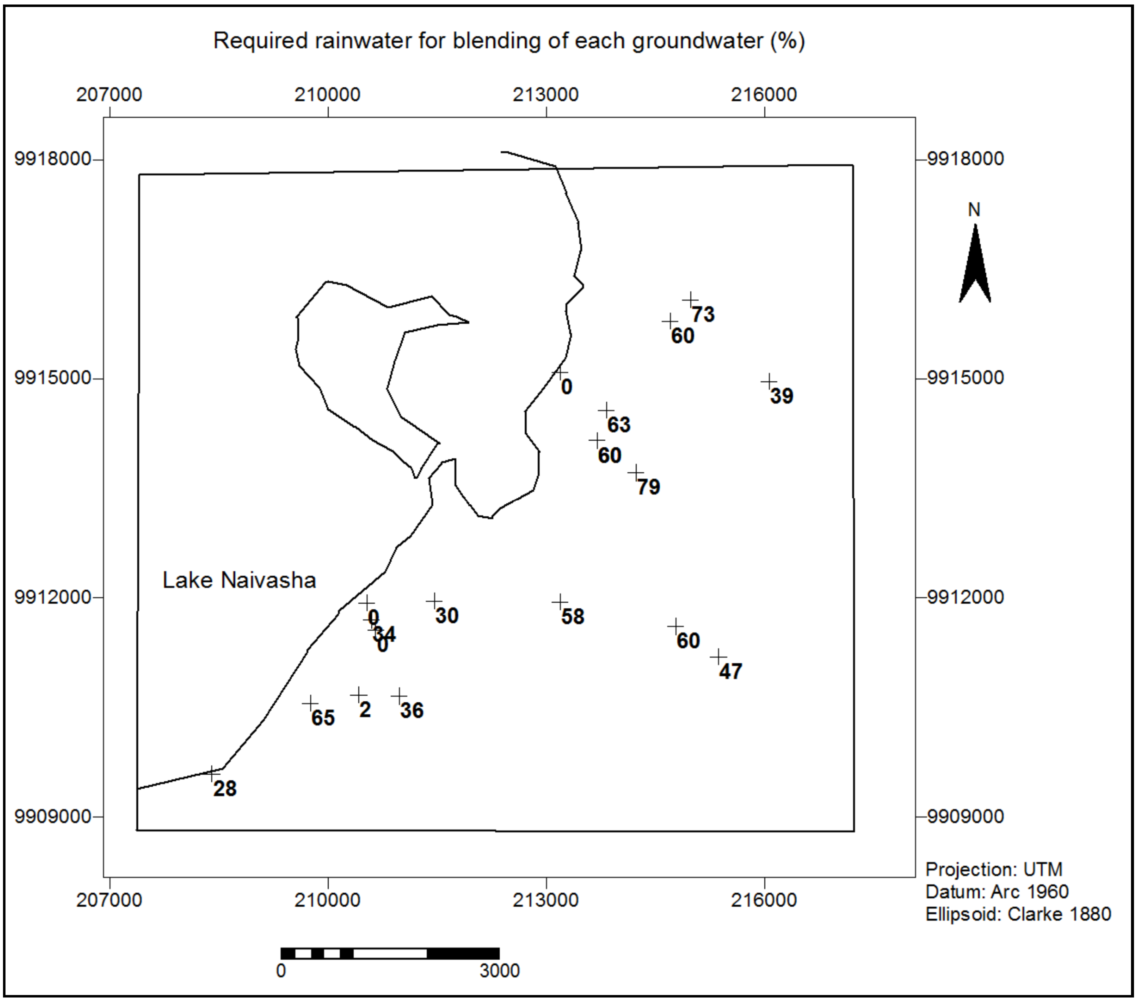


Figure 6-5 Percentage distribution of rainwater needed for the blending of the groundwater of the area

7. Options of artificial recharge

The proposed method of the artificial recharge should be based on the type and variability of the aquifer of the site to be recharged. The aquifer of the site varies as we move from near (bank) of the lake away toward the southern direction. Along this direction the depth of the aquifer increases, but the quality decreases. Shallow aquifers of the site are characterized by water suitable for the flower farming. They have a direct link with the lake water. Depending on the type and quality of the aquifer of the site, the suitability of an artificial recharge site was determined by field and laboratory measurement of soil properties, field experiments and modelling. The technical feasibility of artificial recharge methods have been discussed based on the source water availability and quality, site specific hydrogeological studies, land availability, the quality of the existing groundwater and overall objectives of the artificial recharge. Since the water source of the recharge is a direct runoff from the rainfall and free of contamination, the most important factors determining the feasibility of artificial recharge method is the hydrogeological conditions of the underlying area of interest and recharge objective. In addition, the existing quality of the groundwater plays a major part in selecting the recharge method and location of the recharging and abstraction wells to be selected.
The artificial recharge methods considered under this study are infiltration basin and recharge wells. A spreadsheet model was developed to analyse and compare the two artificial recharge methods based on their recharge efficiency, construction cost and space availability.

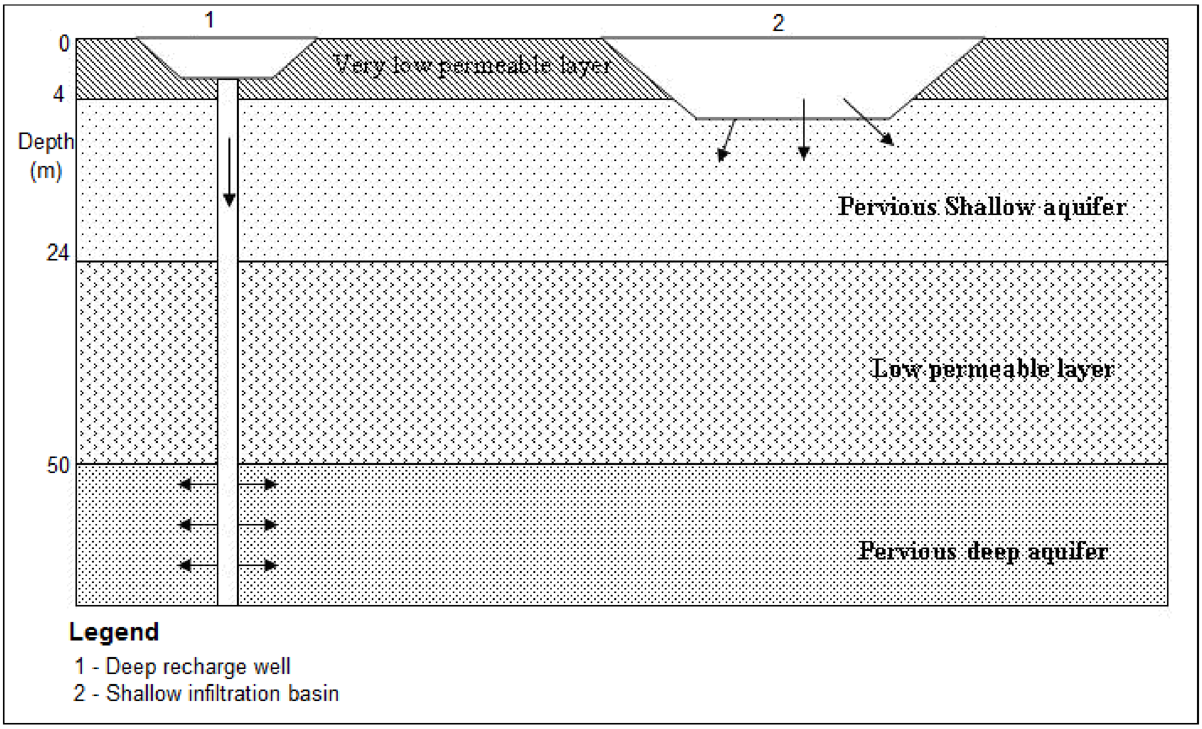


Figure 7-1 Artificial recharge method

7.1. Shallow infiltration basin

Surface recharge techniques are feasible where the aquifer to be recharged is unconfined, permeable and sufficiently thick to provide storage space. The shallow infiltration basin needs sufficient thick and permeable soils at or near the land surface.

There are two cases in the area regarding the overlying bed of the aquifer of the site. Shallow groundwater of the area are overlaid by thin layer (4 to 6m) of impervious to semi pervious layer, while the deep groundwater are overlaid by thick layer (38 to 50m) of impervious to semi pervious layer. The top 30m layer is separated by impervious and hard trachyte layer. From the infiltration test done at site and core sample analysis, the hydraulic conductivity of the top layers of the shallow aquifer is in the range of 0.02 to 0.4md^{-1}, while the top layers of the deep aquifer is 0.02 to 480md^{-1} separated by impervious layer of hard trachyte. The low permeability thick top layer of the deep aquifer limits the infiltration rate and found to be not feasible recharging option. In the shallow aquifer, to apply this method atleast the top 4m layer should be removed. In addition, the geological log of the shallow aquifer shows existence of relatively low permeable between medium to highly pervious layers at different depths (Figure 4-5). The existence of this thin layer can limit the infiltration of water from shallow infiltration basin.

7.2. Deep infiltration basin (DIB) in NINI flower farm

Discussing the option of deep infiltration basin inside NINI flower farm represents the flower farms near to the shallow groundwater area including Flamingo, Hamerkop and Lamorna. The DIB site proposed is located separately for each flower farm near to the site where abstraction well for each flower farm is selected. Collecting of all the runoff generated from each flower farm owned by different person in to one DIB is not easy and therefore need to use separate basin near to their proposed abstraction well. The location of the DIB should be aligned in the direction of the groundwater flow with the abstraction well.

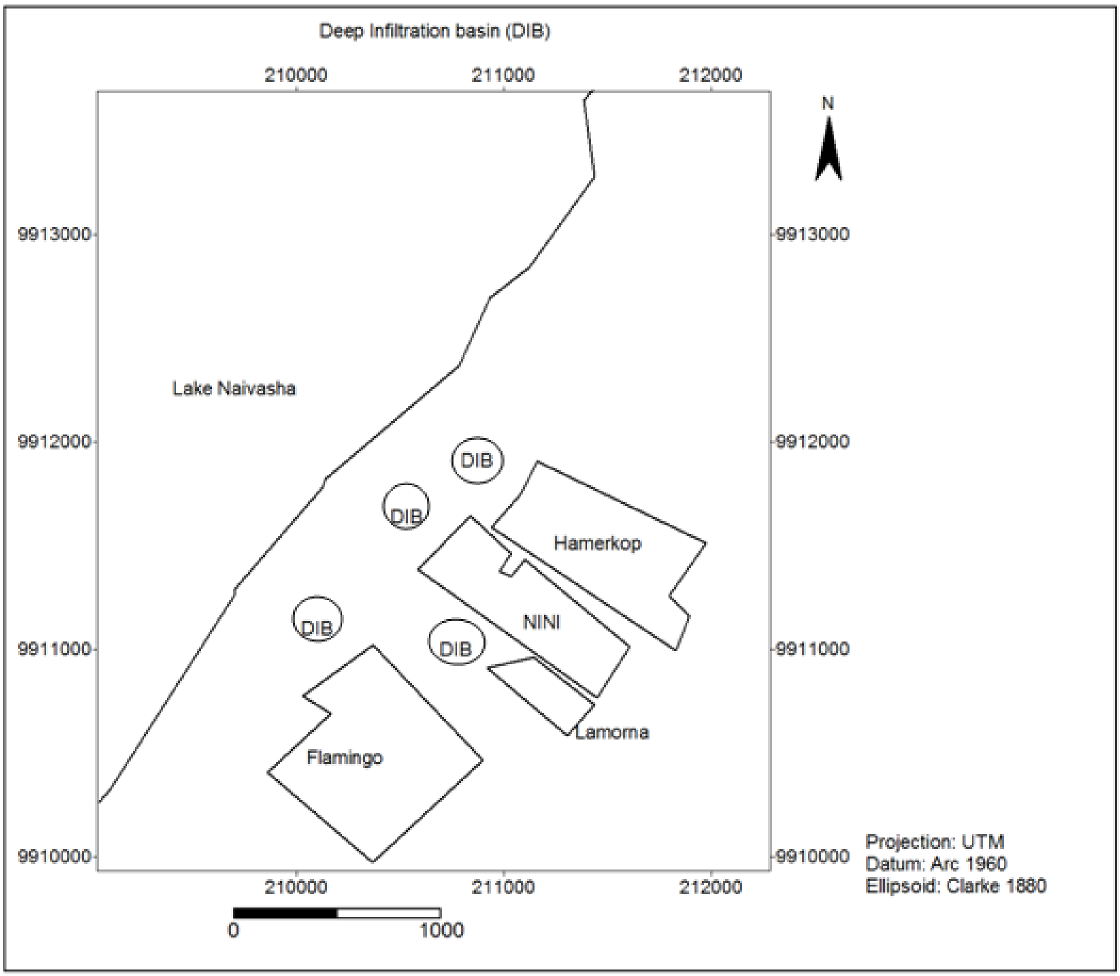


Figure 7-2 Location of Deep Infiltration Basin of the shallow aquifer (DIB)

Recharge efficiency and cost per cubic meter

The spreadsheet model developed by Mohammedjemal,(2006) was used by updating the input parameters and hydraulic characteristics of the area. The model compute the daily water balance of the storage, efficiency of the infiltration basin and cost of construction per cubic meter of recharged water for the duration of 46 years. The preliminary cost of construction includes the excavation and drilling costs. The model has components of daily rainfall, infiltration rate of the basin, inflow volume, spilled water and storage change. The daily runoff from the green houses was calculated from the long term daily rainfall (1957-2003), green houses area and runoff coefficient using the rational empirical formula here with. In addition to the daily rainfall, hourly event of storm rainfall was used for the approximation of the storage capacity of the basin. The daily infiltration rate of the basin was determined from the field test, found to be greater than the daily runoff generated from the greenhouse areas. This comparison excludes the storm events of rainfall expected after a certain interval of years with in short period of time.

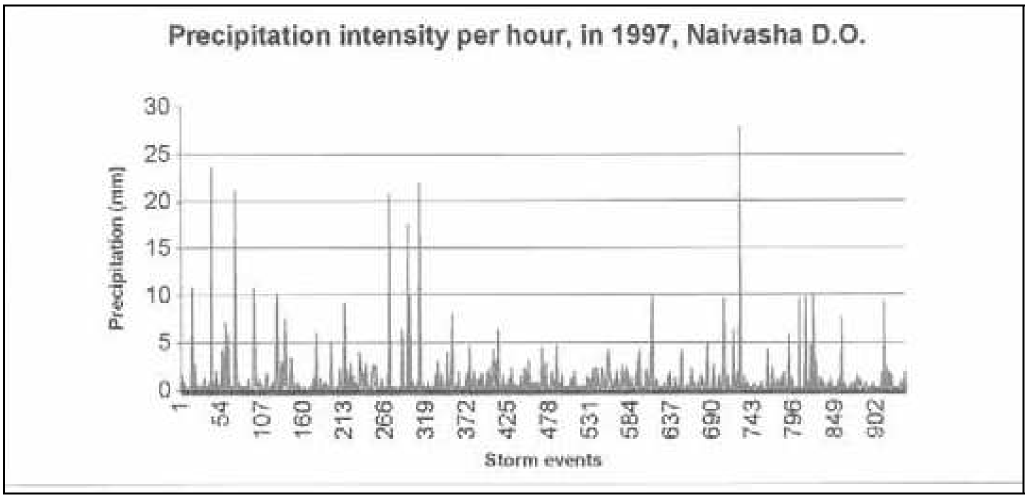


Figure 7-3 Precipitation intensity per hour (Gorrotxategi Gonzalez, 2001)

The water balance is expressed as:

Inflow - Outflow = Change Storage

$$R - (I_r+S_w) = \Delta S \qquad \textbf{7-1}$$

Where:

R = daily runoff from the green houses (m^3day^{-1})

I_r = daily infiltration rate of the recharge wells (m^3day^{-1})

S_w = daily spilled water (m^3day^{-1})

ΔS = the change in volume of the reservoir (m^3day^{-1})

The following assumptions were considered during the model development:

- The minimum depth of excavation should be 6m.
- The hydraulic conductivity of the basin is about 480$mday^{-1}$
- The unit cost of excavation is 300 and 500 KES (Kenyan shilling) per cubic meter.
- The model is computed from duration of 46 years of rainfall and the aforementioned events.

Based on these assumptions the model results an infiltration volume of 65000m^3day^{-1}. The optimum output efficiency and cost per cubic meter are 99.5% and 0.64KES (Kenyan shilling) respectively. The results of the model are summarized below in Table 7-1. It should be noted that the amount of cost calculated does not represent the total cost of construction of the deep infiltration basin.

Parameters	Amount	Unit
Storage capacity	45600	m3
Infiltration rate	65000	m3day-1
Unit excavation cost shallow	300	KES (Kenyan shilling)
Unit excavation cost deep	500	KES
Total excavation cost	13680000	KES
Cost per infiltration	0.64	KESm-3
Number of years	46	
Efficiency	99.58	%

Table 7-1 Summary of the output of the deep infiltration basin

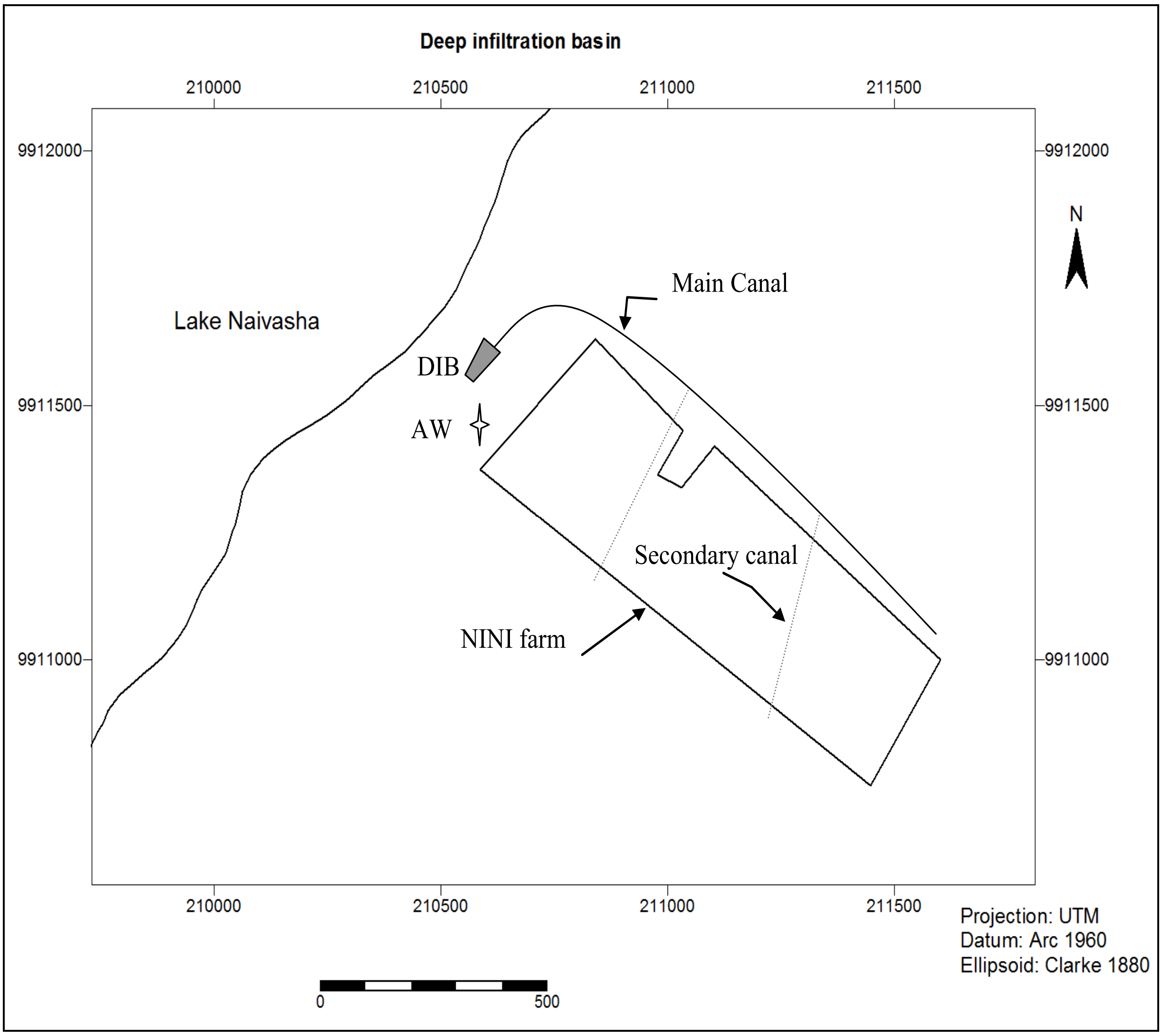


Figure 7-4 Location and layout of deep infiltration basin at NINI farm

7.3. Recharge well and shallow infiltration basin on the shallow aquifer area

The recharge well at each flower farm can be used to recharge water collected from the flower farms to the shallow aquifer. The shallow reservoir can be used as temporarily storage of the collected water from each greenhouse area. Recharge well can be drilled within each shallow infiltration basin to facilitate the recharging process to the underlying aquifer. As it was observed during the field work, the top layer of the area is covered by silt and clay, which can produce more suspended materials to the water flowing from the roof of the greenhouse area, and therefore canals of the area need to be lined. Lining of the canal minimizes clogging of the wells by suspended materials.

In order to explore recharge well potential for the possibility of the recharging method, analysis of aquifer characteristics based on the field injection test and modelling of the study area was done. From the analyses, the minimum recharge potential found was $90000 m^3 d^{-1}$. The layout of the recharge wells selected inside the flower farm is presented in Figure 7-5 below.

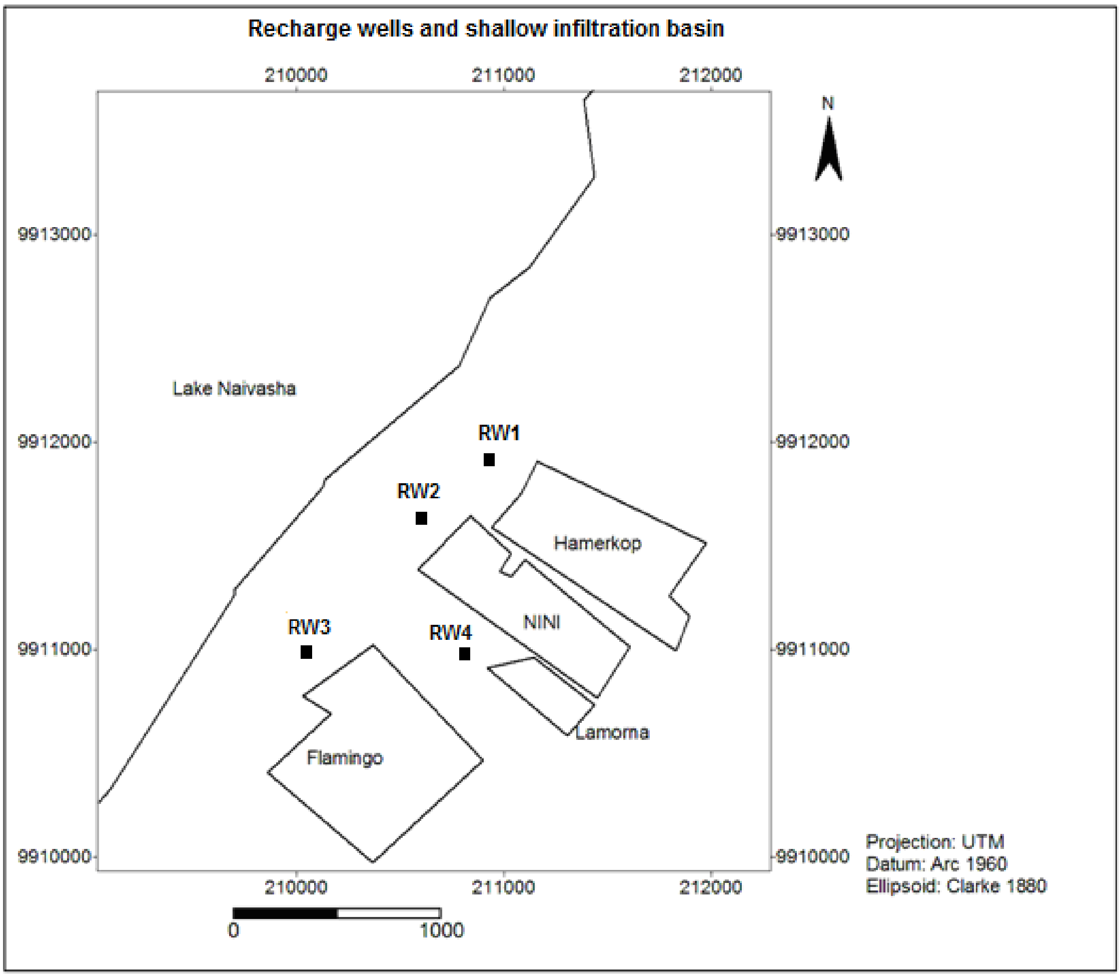


Figure 7-5 Location of the proposed recharge wells of the shallow aquifer

Recharge efficiency and cost per cubic meter

The same spreadsheet model as in the DIB of the shallow aquifer was used to analyse the efficiency and cost per m^3, with additional inputs of Borehole recharge rate. The observations and assumptions are outlined below:

- The recharge wells have a minimum potential of 90000m^3.
- Unit cost of excavation is 300 KES (Kenyan shilling) per cubic meter for shallow depth (up to 4m).
- Unit cost of excavation is 500 KES (Kenyan shilling) per cubic meter for deeper depth (> 4m).

The analysis of the model was done considering the total area of the flower farms found with in the shallow aquifer. The recharge potential of the basin is found to be higher than the amount of runoff generated from each flower farms. If the total amount of runoff generated from the flower farms need to be collected to one recharge well, storing the water temporarily will be required. The requirement of the storage area is by considering the storm events expected after a certain intervals of year and also considering the duration of rainfall and its corresponding intensity. It was found from the spread sheet model that the cost per m^3 is more sensitive to the amount of storage volume than the borehole recharge rate. The optimum recharge rate and storage capacity obtained by changing the two values are 70000m^3d^{-1} and 20000m^3 respectively. The corresponding recharge efficiency and cost per cubic meter are 99.65% and 0.31KES (Kenyan shilling) respectively. The additional cost incurred to increase the storage capacity above 20000m^3 results insignificant change on the efficiency of the recharge wells. The output of the model is summarized in Table 7-2.

Parameters	Amount	Unit
volume storage capacity	20000	m^3
Total infiltration rate	70000	m^3day^{-1}
Unit cost excavation (shallow)	300	KES (Kenyan shilling)
Unit cost BH	120000	KES
Expected infiltration rate	90000	m^3day^{-1}
Number of BH required	4	
Total excavation cost	6000000	KES
Total BH cost	480000	KES
Total cost	6480000	KES
Cost per infiltration	0.31	$KESm^{-3}$
Number of years	46	
Efficiency	99.65	%

Table 7-2 Summary of the optimized output of the recharge wells

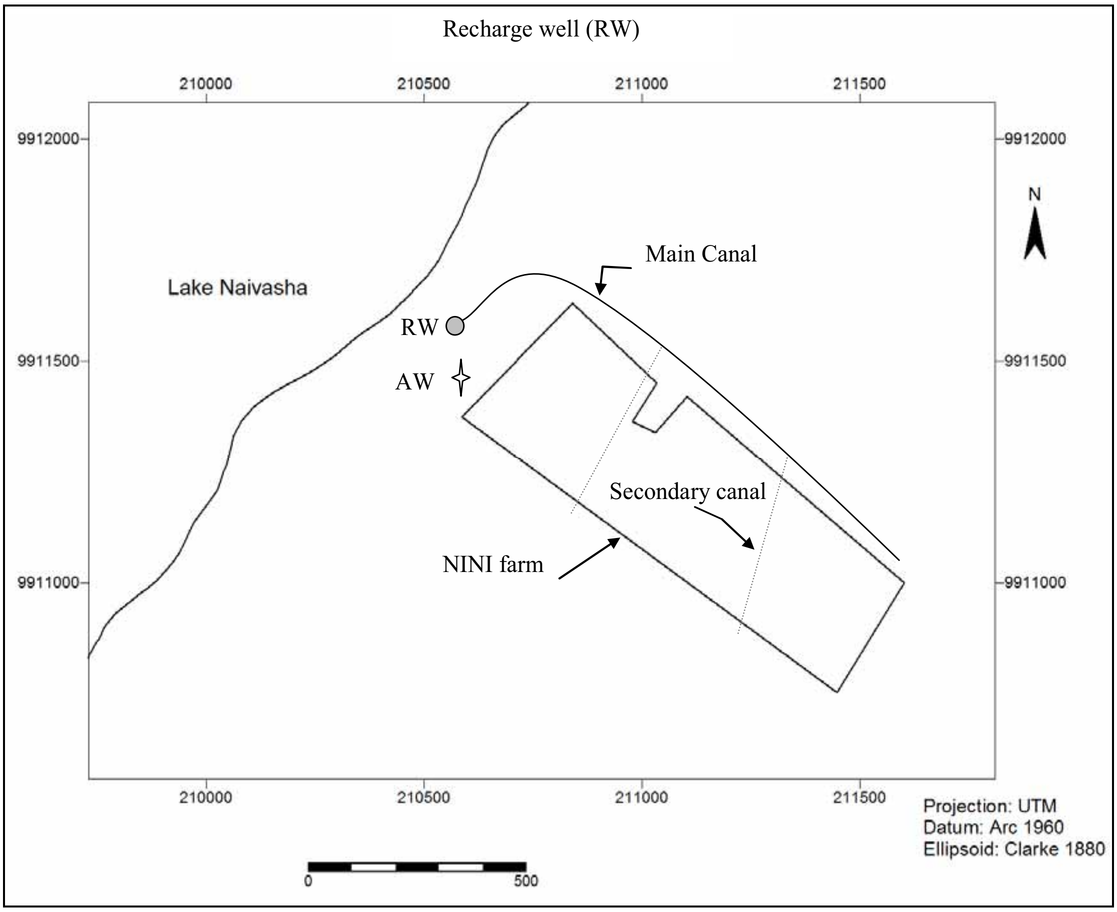


Figure 7-6 Location and layout of recharge and abstraction wells at NINI farm

7.4. Recharge well (RW) and shallow infiltration basin in Wildfire flower farm

Before recharging the runoff generated from the greenhouse area within the flower farm, reservoir should be provided, which will be used as a temporary storage of the runoff. The reservoir needs to be connected through concrete lined canal with the outlet of the PVC pipes connected to the roof of the greenhouse. The temporary reservoir should also be lined with an impervious material, in order to avoid the loss of water to the thick layer of unsaturated zone. This also helps in avoiding farther mixing of the clean water from the roof of the greenhouse with clay and silt products suspended materials, which may lead to an increase of EC value. Protecting the reservoir from the entrance of suspended material through surface runoff is important. In addition, the reservoir should be provided with shading in order to avoid the loss of water through evaporation. Avoiding loss of water before injection also improves the amount of water to be used for the improvement of existing groundwater quality.

Recharge using direct infiltration of well is important for the direct hydraulic connection of the aquifer to be recharged. In addition to the replenishment of the aquifer after the planned abstraction, the direct infiltration of water to the aquifer with out the contact of the overlying layer helps for the improvement of existing low quality groundwater. This is because from the core samples obtained during the field work, the source of the low quality water due to high salinity is not expected from the aquifer itself. The recharged water will have a direct dilution effect on the existing low quality groundwater. For this using recharging well for the direct injection of water to the target aquifer without contact with the overlying layers is important.

In order to explore recharge well potential for the possibility of the recharging method, analysis of aquifer characteristics based on the field injection test and modelling of the study area was done. In addition the data of pumping tests done by Water Resource Management Authority on the deep groundwater of the area was used for the estimation of the recharge potential of the well. The overall recharge potential of the aquifer is greater than $10000 m^3 d^{-1}$. Compared to the potential of the recharge well, the amount of runoff generated from the greenhouse is small for which only one recharge well is selected. The layout of the recharge well selected inside the flower farm is presented in Figure 7-7 below.

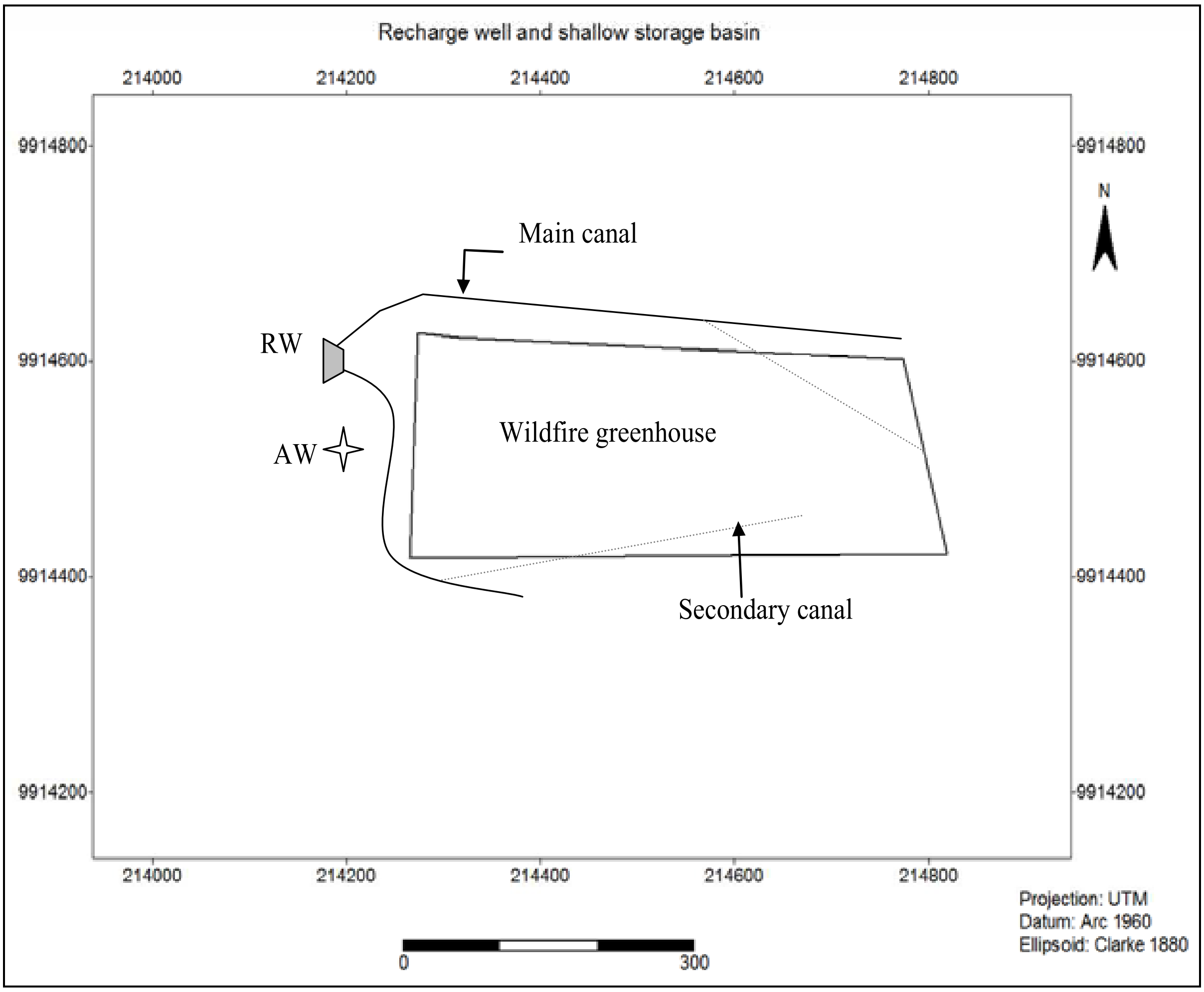


Figure 7-7 Location of the proposed recharge and abstraction well (AW and RW)

From the drilling, it was observed that the deep aquifer of the site is covered by heterogeneous low to high permeability formation separated by impervious hard trachyte rock. Collapsing of the wall of the drilled was observed as a result of unstable overlying geological formations. In order to avoid such collapsing, casing is important. The casing should be cemented from the bottom of the casing to ground surface to ensure an adequate seal against flow movement outside the casing through possible channels opened during construction. A screen or perforation is necessary to be placed at the bottom of the casing to allow water to infiltrate from the injection well into the saturated zone. A filter can be placed below the basin to eliminate any suspended sediments which can block the recharge well. The filter pack consists of coarse sand, gravel and pebbles with thickness of 0.55m, 0.95 and 1.5m respectively from the top to the bottom (Mohammedjemal, 2006). The proposed recharge well and filter design is shown in figure 7-8. Well cap is proposed on the well head so that to prevent the entry of suspended materials including sediment in to the well with the inflowing water.

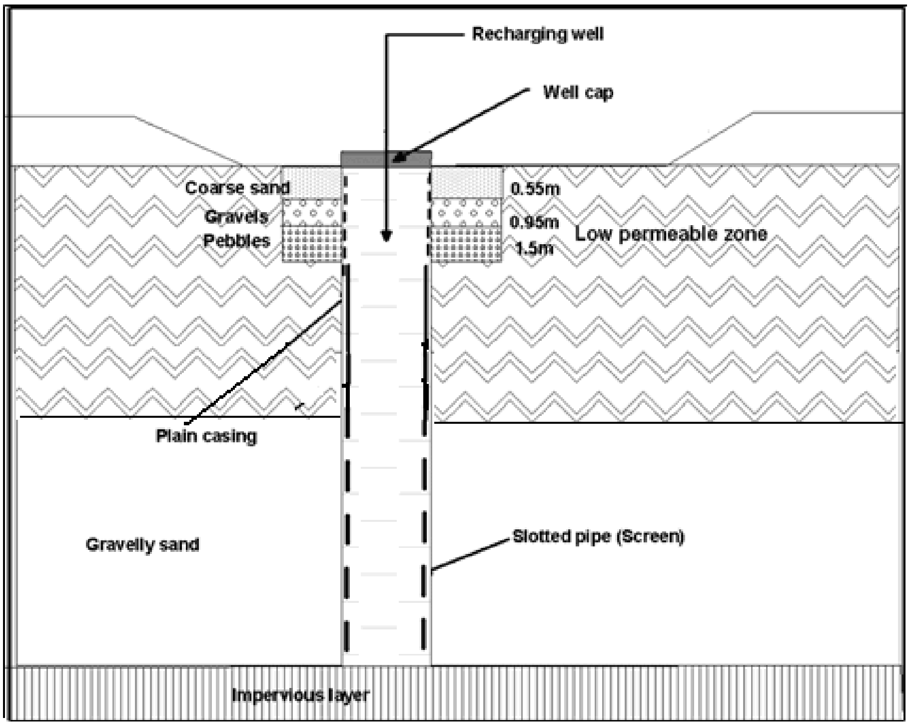


Figure 7-8 Design of recommended recharge well modified (Mohammedjemal, 2006)

Recharge efficiency and cost per cubic meter

The same spreadsheet model as in the DIB of the shallow aquifer was used to analyse the efficiency and cost per m^3, with additional inputs of Borehole recharge rate. The observations and assumptions are outlined below:

- The recharge wells have a minimum potential of 10000m^3.
- Unit cost of excavation is 300 KES (Kenyan shilling) per cubic meter for shallow depth (up to 4m).
- Unit cost of excavation is 500 KES (Kenyan shilling) per cubic meter for deeper depth (> 4m).
- Unit cost of drilling and complete construction for a well of 60m depth is 360000 KES (Mohammedjemal, 2006).

The model result obtained by changing borehole recharge and storage capacity was found from the spread sheet model that the cost per m^3 is more sensitive to the amount of storage volume than the borehole recharge rate. The optimum recharge rate and storage capacity obtained by changing the two values are 6000m^3d^{-1} and 8200m^3 respectively. The corresponding recharge efficiency and cost per cubic meter are 95.2% and 1.60KES (Kenyan shilling) respectively. The additional cost incurred to increase the storage capacity above 8200m^3 results insignificant change on the efficiency of the recharge wells. The output of the model is summarized in Table 7-3.

The preliminary cost calculated does not include the total cost which may be invested during the set up of the recharge well. Some of the costs may be compensated by indirect benefits like avoiding of some of the causes of declining lake level and hauling of water long distance.

Parameters	Quantity	Units
Storage capacity	8200	m^3
Unit excavation cost (shallow)	300	KES
Total recharge rate	6000	m^3day^{-1}
Unit cost BH (60m)	360000	KES (Kenyan shilling)
Expected infiltration rate	10000	m^3day^{-1}
Number of BH	1	
Total excavation cost	2460000	KES
Total BH cost	360000	KES
Total cost	2820000	KES
Cost per infiltration	1.6	$KESm^{-3}$
Number of years	46	
Efficiency	96.2	%

Table 7-3 Summary of the optimized output of the recharge well

7.5. Potential problems associated with the recharging process and possible solutions

7.5.1. Potential problems

One of the main problems with groundwater recharge systems is soil clogging. This occurs in both surface infiltration and well injection systems. The clogging of soil particles is directly associated with the quality of water as a function of suspended sediment load, chemical compatibility of surface water and soil matrix, and biological activity.

Clogging of surface infiltration systems is due to the accumulation of suspended solids contained in the source water on the bottom and sides of the basin or other infiltration facility. Clogging of recharge well is also due to the same causes and processes and can occur on the well screen, gravel envelope, or surrounding aquifer. The solids causing clogging can consist of fine inorganic particles like silt, fine sand, and clay, algal cells, decaying organic matter or other organic solids. Also, microorganisms can grow on the soil or the wetted perimeter and forms biofilms that clog the soil by the presence of the organisms themselves or by their metabolic products. Generally, it is caused by physical, chemical and biological processes acting as the recharge water enters and infiltrates the recharge medium. Because clogging layers have a low hydraulic conductivity and, hence, low infiltration rates, their formation should be prevented as much as possible and they should be periodically removed when the infiltration rates decline to unacceptably low values (ASCE, 2001).

Suspended materials

The accumulation of inorganic and organic suspended solids in the recharge water, such as clay and silt particles, within the recharge water can clog pore spaces in the recharge medium. Turbidity carried in the injected water may cause clogging at the interface between the filter pack and the wells casing, in the filter pack around the well, at the interface between the filter and aquifer formation, and within the aquifer itself.

Chemical reaction

The interaction between the recharge water, groundwater or the recharge medium may form a chemical precipitate that deposits in pore spaces. Clogging of the recharge well due to chemical reaction may occur at the screen or casing perforations, the formation face, or in the aquifer itself. Chemical clogging can be caused by (ASCE, 2001).

- Precipitated metabolic products of bacteria including iron oxide, ferrous bicarbonate, metallic sulfide (sulphur) or calcium carbonates
- Chemical interaction of the dissolved chemicals in the injected water and in the aquifer formation yielding precipitates, or solution and redeposit ion of soluble compounds such as gypsum.
- Reaction of high sodium water with soil particles causing deflocculating and swelling of the soil (clay) particles, decreasing the size of the interstitial openings and effectively clogging the formation. Expansion of clay materials may occur upon contact with water having different chemical characteristics than the native water. This typically happens when formation materials containing base exchange clays are flooded with waters containing high amounts of sodium.

Biological process

The growth of algal or bacterial material in pore spaces, the accumulation of by product resulting from the decomposition of biological growth causes clogging. The bacterial contamination of the aquifer by the injection water and biological change in the injection water and the groundwater may result clogging.

7.5.2. Possible solutions

The operational life of artificial recharge facility, recharge well, will be shortened due to the problems incurred in artificial recharge There are many methods that can be implemented before and during recharge to reduce most of the problems mentioned.

Suspended materials

To prevent physical clogging of the recharge medium or recharge wells, the water coming from the green houses should be low in suspended sediments. There are two possible options to minimize the suspended sediments. These are to implement stilling basin to settle sediments before reaching the reservoir or to line the canals. Especially, in the deep aquifer all the canals should be lined to have continuous flow of required volume of water.

Sand and gravel filters can be constructed next to recharge wells to reduce the level of turbidity in water before recharge.

The recharge well can be surged or pumped in order to dislodge fine sediments from the well or gravel pack.

Single injection wells are typically redeveloped by installing a vertical turbine pump, by air lift pumping or by swabbing and bailing with cable tool drilling equipment (Pyne, 1995).

Chemical reaction

It is difficult to predict the geo chemical reactions that can adversely affect the aquifer permeability. But if it happens the chemical clogging is usually confined to the immediate vicinity of the well gravel pack or surrounding rock matrix.

Pumping and surging can be trial tested to develop precipitates from around the well.

If pumping is not successful, a chemical solution can be added to the recharge water to dissolve the chemical precipitate in pores spaces.

Biological process

Surging or pumping the well may disturb organic matter and reduce clogging.

7.6. Artificial recharge and its effect on water use efficiency

Artificial recharge plays a great role on the groundwater management of the area by addressing the following issues:

- To enhance the sustainable yield in areas where over-development has depleted the aquifer.
- Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period, and reduces evaporation.
- To improve the quality of existing ground water through dilution

Comparison between the existing condition and after applying the expected artificial recharge was done. As the main loss of water in the area is through evapotranspiration, the main target during the comparison was how efficient artificial recharge can minimize evapotranspiration and decrease the amount of water use from the lake, which plays a major role on the water balance of the area.

Two main conditions were considered to overview the effect of artificial recharge on the major outflow of the area and therefore water balance of the area under different hydrological conditions:

1. Greenhouse catchment without applying artificial recharge
2. Greenhouse catchment and applying artificial recharge

In addition to the two aforementioned conditions, natural catchment condition without greenhouse and artificial recharge was also considered to see how change in land cover of the catchment can influence the amount of runoff the catchment produced. Covering the area by greenhouse can decrease the amount of water infiltrated to the groundwater and in turn increases the runoff produced by the catchment. This can also have an effect on the evapotranspiration of the area. As it was indicated by previous studies, the major components of the inflow in to the lake are the surface runoff from the surrounding catchment and groundwater inflow. The outflow components are evaporation, groundwater out flow, abstraction for irrigation and other purposes. The natural recharge is estimated as 4.38mmyear^{-1} (Nalugya, 2003).

7.6.1. Greenhouse catchments without applying artificial recharge

The change in land cover of the catchment in to green houses reduces the amount of water infiltrated to the groundwater and therefore increases the amount of runoff produced by the catchment. In this condition the dominant process will be the direct runoff to the lake. Lake water is also abstracted for the purpose of irrigation development. The abstraction rate calculated from the abstraction record collected during the field work is 4mmday^{-1}, which gives a net abstraction water of 1460mmyear^{-1}. Almost 90% (592mm) of the rain falling in the catchments will join the lake in the form of surface runoff. The water balance of lake indicates 92 percent of the water inflow from the lake is evaporated

(Mmbui Samuel, 1999), 545mm. Therefore the contribution to the lake is 8% of the runoff, 47mm. the net abstraction considering the catchment contribution to the lake and amount of water required for the irrigation will be 1413mm.

7.6.2. Greenhouse catchment and applying artificial recharges

In this condition the runoff from the green houses will recharge the groundwater storage through the recharge wells. Storing the water underground prevents the water from being lost through evapotranspiration in the catchment and direct evaporation from the lake. In this condition the abstraction of water for irrigation shifts to groundwater from lake. The same net abstraction water 1460mmyear^{-1} aforementioned was used. The recharge water can be computed as:

$$R_w = P \times R_c \times R_{eff} \qquad \textbf{7-2}$$

Where:

R_w is Recharge water in mmyear^{-1}
P is the precipitation in mm
R_c is Runoff coefficient, 0.9
R_{eff} is Recharge efficiency, 0.99

The recharge water is 592mm and the contribution to lake will be 8% of the spilled and/or seep water, which is 6mm. From this, the net water abstracted taking into consideration the amount of water required for irrigation and recharged to the groundwater will be 862mm. Therefore 39% (551mm) of the net abstraction as compared to without artificial recharge is saved by injecting the runoff generated from the greenhouses.

8. Modeling

In addition to predicting a consequence of a proposed action, groundwater models can be used in an interpretive sense to gain insight in to the controlling parameters in a site specific setting or as framework for assembling and organizing field data and formulating ideas about system dynamics (Anderson and Woessner, 1992). The model can also be used for tracing of the path of flowing water in a site specific and to estimate the lateral extent and movement of stored water. A reliable groundwater model based on accurate field data, which replicate the process of interest at the site, can be used to complement monitoring and laboratory bench-scale studies in evaluating and forecasting groundwater flow and transport (Spitz and Moreno, 1996).

Two separate groundwater models for the shallow and deep aquifer were developed. Modelling the two aquifers separately helps to meet the objective of the artificial recharge in both aquifers. In the deep aquifer, in addition to the development of the aquifer, the proposed artificial recharge helps to improve the low quality of existing water. After modelling the two aquifers in MODFLOW, MT3DMS model was used in the deep aquifer to trace path of the recharged water at different interval of time and distance, to analyze the concentration of the mixed water at different interval of time and distance and therefore locating of abstraction wells.

8.1. Model Setup

Two local groundwater models were developed separately for the shallow and deep aquifer of the study area. In the deep aquifer groundwater model MT3DMS was also used to trace the path of the flowing water at different intervals of time and distance, used for locating the abstraction well. The retardation factor for the transport model was assigned as 1 in order to keep the particle and groundwater flow velocity the same.

8.1.1. Hydrostratigraphy

Including the deep and shallow groundwater, the aquifer of the site is grouped as two layer system. The upper 20m layer is characterized by mixture of sand to rounded lake deposit and pumice pebbles. Due to the presence of rounded gravelly deposit and pumice pebbles, the layer is found to be highly permeable. The second layer, with an average thickness of 10m is composed of highly permeable reworked and weathering product of volcanic rocks. The two layers were modeled using confined aquifer.

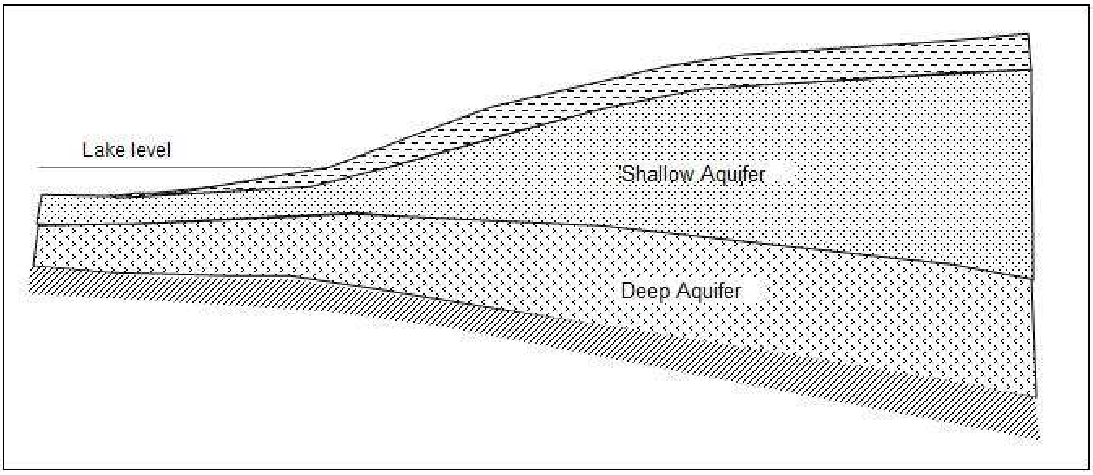
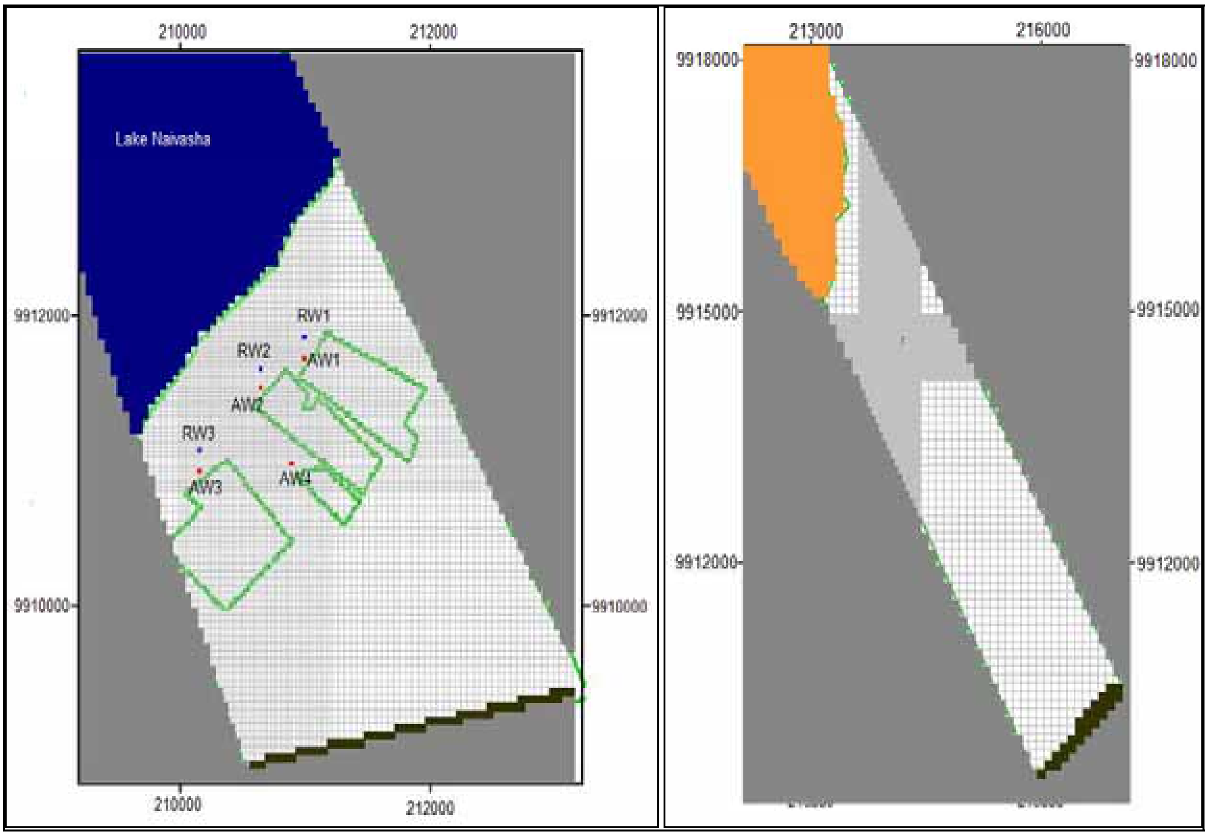


Figure 8-1 2D Schematization of the conceptual model

8.1.2. Grid geometry and model boundaries

The grid sizes of the two models vary based on the detailed requirement of the simulation. The grid size ranges from 100 to 10m refinement. The small size of grid (10m) was used along the recharge and abstraction wells to have detail representation of the hydrologic system. More refinement of the grid size was also done in the solute transport model of the deep aquifer. The boundary to the lake of the two aquifer models was taken as a constant head boundary, while the lower bottom SSE part of the model was used as a general head boundary by assigning measured groundwater head value. The average lake level assigned to the constant head was 1887.944m above sea level. The other two boundaries, parallel to the flow line were assigned as no flow boundary.



a) Shallow aquifer **b) Deep aquifer**

Figure 8-2 Grid design and boundary condition of the area

8.2. Model input parameters

8.2.1. Recharge

Two recharge types were considered during the two groundwater modeling: natural recharge obtained from precipitation which percolates through the overlying vadose zone in excess of soil moisture deficit and evaporation. The value, obtained from previous works is estimated as 4.38mm/year (Nalugya, 2003). The second recharge is the direct injection of artificial recharge generated from the nearby greenhouse area.

8.2.2. Well abstraction

Except one flower farm near to the bank of the lake, all flower farms of the study area use water from the lake it self. The feature use of water from the groundwater was calculated based on the collected daily water use of each flower farms of the area. Other possibility of calculating the daily water use can be using the formula:

Abstraction rate = area of irrigated farm X depth of irrigation, where the total area and depth of irrigation for the greenhouse and outdoor is known. The total area of greenhouses included within the shallow and deep groundwater area is 84.61 and 6.6 ha respectively. Based on the obtained records of daily water use of the farms, the total abstraction rate in the shallow and deep groundwater model area is 5918 and 1690m^3 respectively.

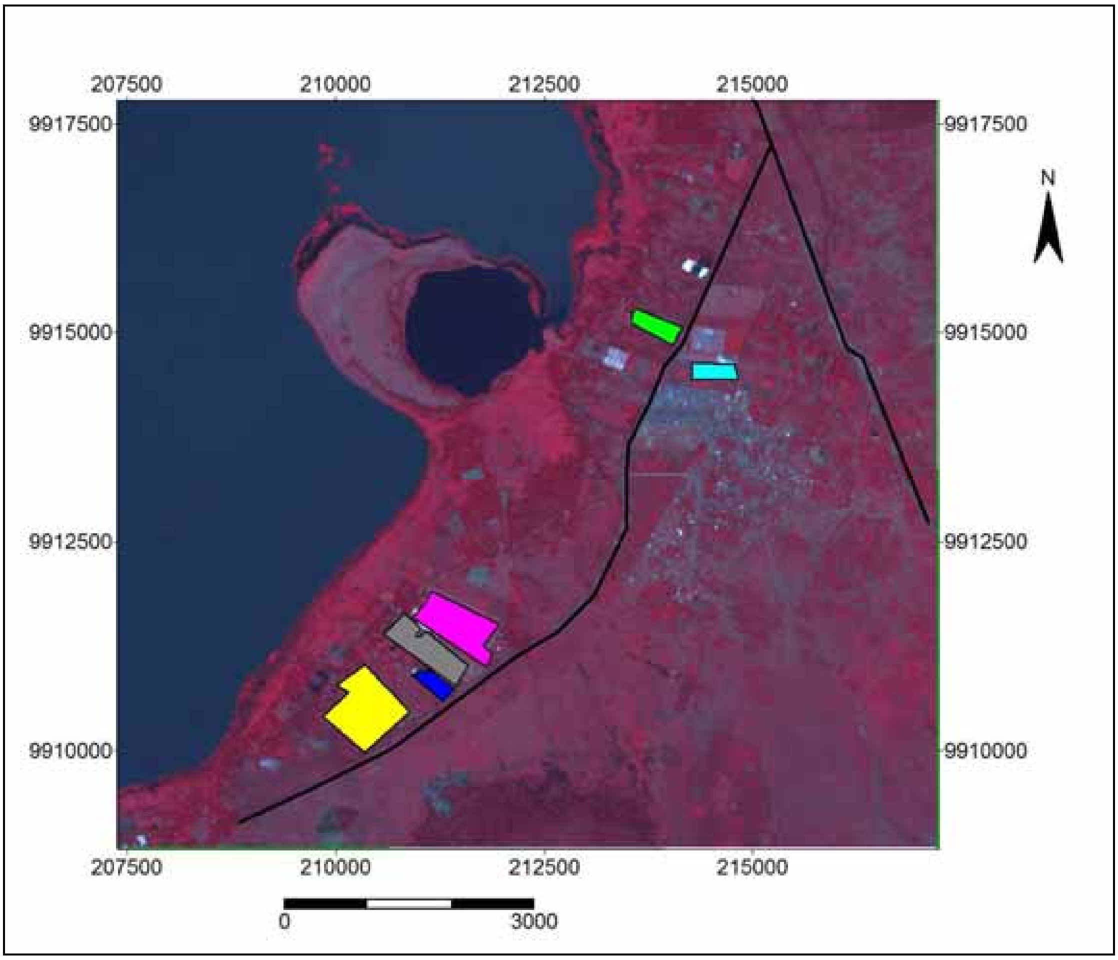


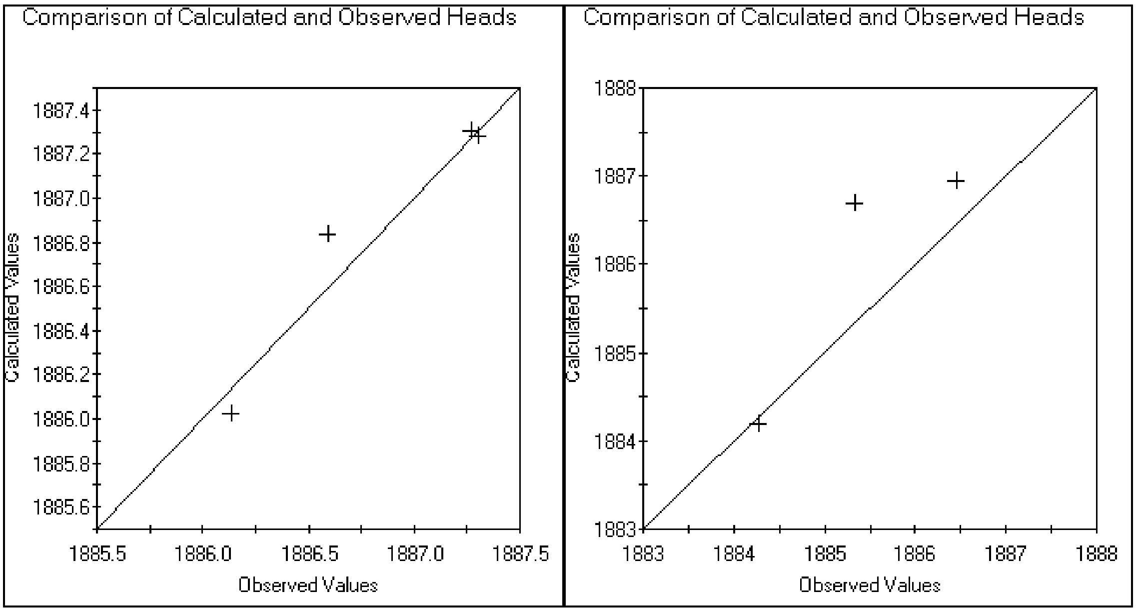
Figure 8-3 Digitized area of flower Farms

Flawer farms (Greenhouse)	Area (m2)
Flamingo	406100
NINI	210000
Hamerkop	230000
Oljorwa	160000
Wildfire	66000
Total area	1152100

Table 8-1 Greenhouse area

8.3. Calibration

Calibration was accomplished by selecting a set of parameters and boundary conditions that produces simulated ground water levels that match field by varying the model-input parameters within reasonable ranges to produce the best fit between simulated and observed hydraulic heads.
The objective of calibration in the steady state model was to match the observed head points with heads calculated by the model and therefore minimizing their difference. The calculated versus observed heads of the groundwater observation used in the calibration process is shown in Figure 8-4.



a) Shallow groundwater model **b) Deep groundwater model**

Figure 8-4 Scattered plot of the calibration result (m)

In the process of calibration of the model, the main three objective functions were used:
Mean error (mean difference between measured and calculated hydraulic heads):

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(h_{measured} - h_{calculated}\right)_i \qquad \textbf{8-1}$$

Mean absolute error (Mean absolute value of the difference between measured and calculated heads):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\left(h_{measured} - h_{calculated}\right)_i\right| \qquad \textbf{8-2}$$

The root mean squared error (Average of the squared difference differences between measured and calculated heads):

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(h_{measured} - h_{calculated}\right)_i^2\right]^{\frac{1}{2}} \qquad \textbf{8-3}$$

Considering the observed lake and groundwater level, the obtained difference between the observed and simulated groundwater was found to be in the acceptable range. The difference between the observed lake and groundwater level used in the calibration process, taking the average lake level as 1887.944m above sea level ranges from 0.689 (near to the recharge area) to 1.861m. The result of the difference between the observed and simulate heads of the observation boreholes is presented in Table 8-2.

Code_Shallow Aquifer	Easting	Northing	Observed value	Calculated value	Difference (m)
HK	211630.4	9911515	1886.596	1886.874	-0.278
IF	211149.4	9910217	1886.133	1886.032	0.101
TB1	210699.6	9911491	1887.305	1887.315	-0.01
TB2	210677.7	9911505	1887.271	1887.339	-0.068
Code_Deep Aquifer					
TB7	214206.6	9914650	1886.448	1886.939	-0.491
KS	213987.5	9914171	1885.337	1886.688	-1.351
RB	215357.8	9911181	1884.27	1884.195	0.075

Table 8-2 Difference between the observed and simulated heads of the observation points

The model accuracy based on the three main objective functions expressed by the equations 8-1, 8-2 and 8-3 is given in Table 8.3.

Parameters	Shallow groundwater model	Deep groundwater model
ME	-0.08	-0.59
MAE	0.15	0.64
RMSE	0.18	0.83

Table 8-3 Objective function value summary of the calibrated model

8.4. Artificial recharge and groundwater response

The groundwater level response was evaluated based on the steady state calibrated model before and after the injection of the proposed volume of artificial recharge on both groundwater models. The evaluation includes the impact of the proposed abstraction well on the existing groundwater level before and after the introduction of artificial recharge. The total amount of abstraction water was proposed based on the previously recorded daily water use of each flower farm from the lake.

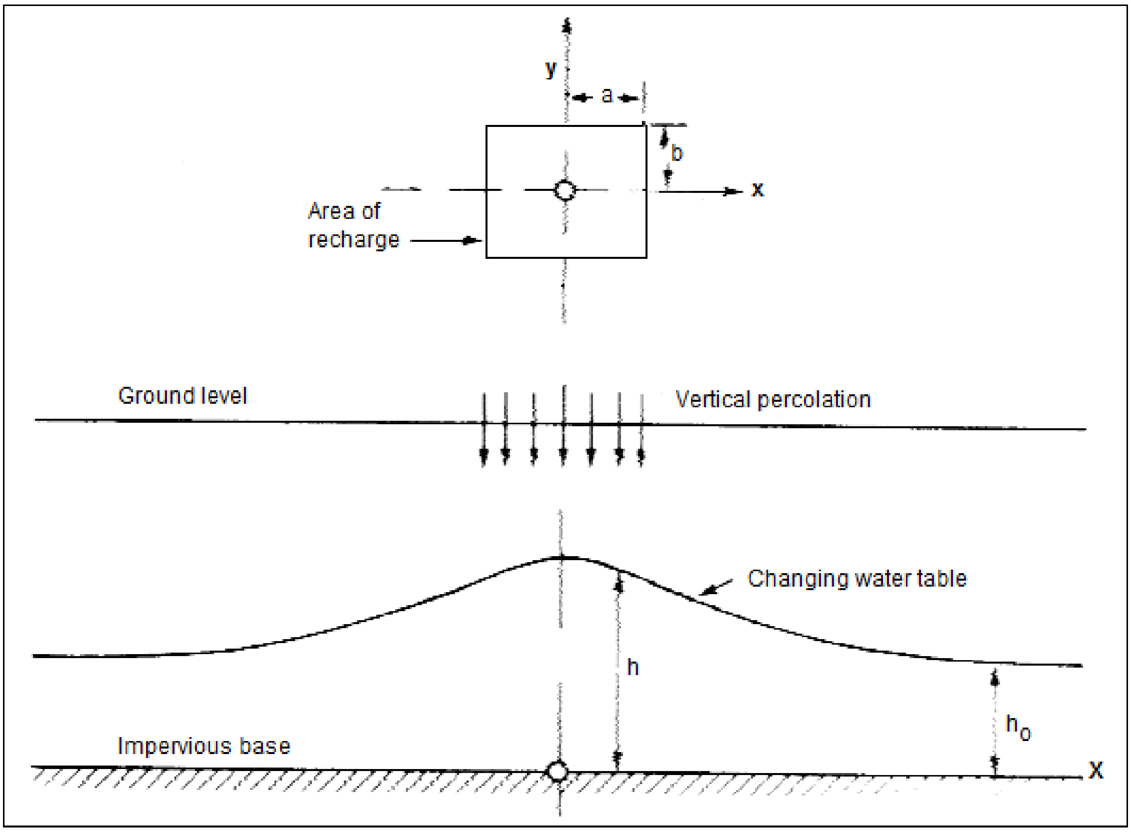


Figure 8-5 Diagrammatic representation of the rise of the water table beneath a recharging area

8.4.1. Shallow aquifer

The recharging and abstraction wells for each flower farms were proposed separately. The selection takes into account the amount of runoff generated by each flower farm compared to the intake capacity, the space availability to collect all the runoff generated in a reservoir, the distance between the flower farms. Considering all the conditions, each flower farms will have its recharging and abstraction well. The position of proposed recharge and abstraction wells are presented in Figure 8-6.

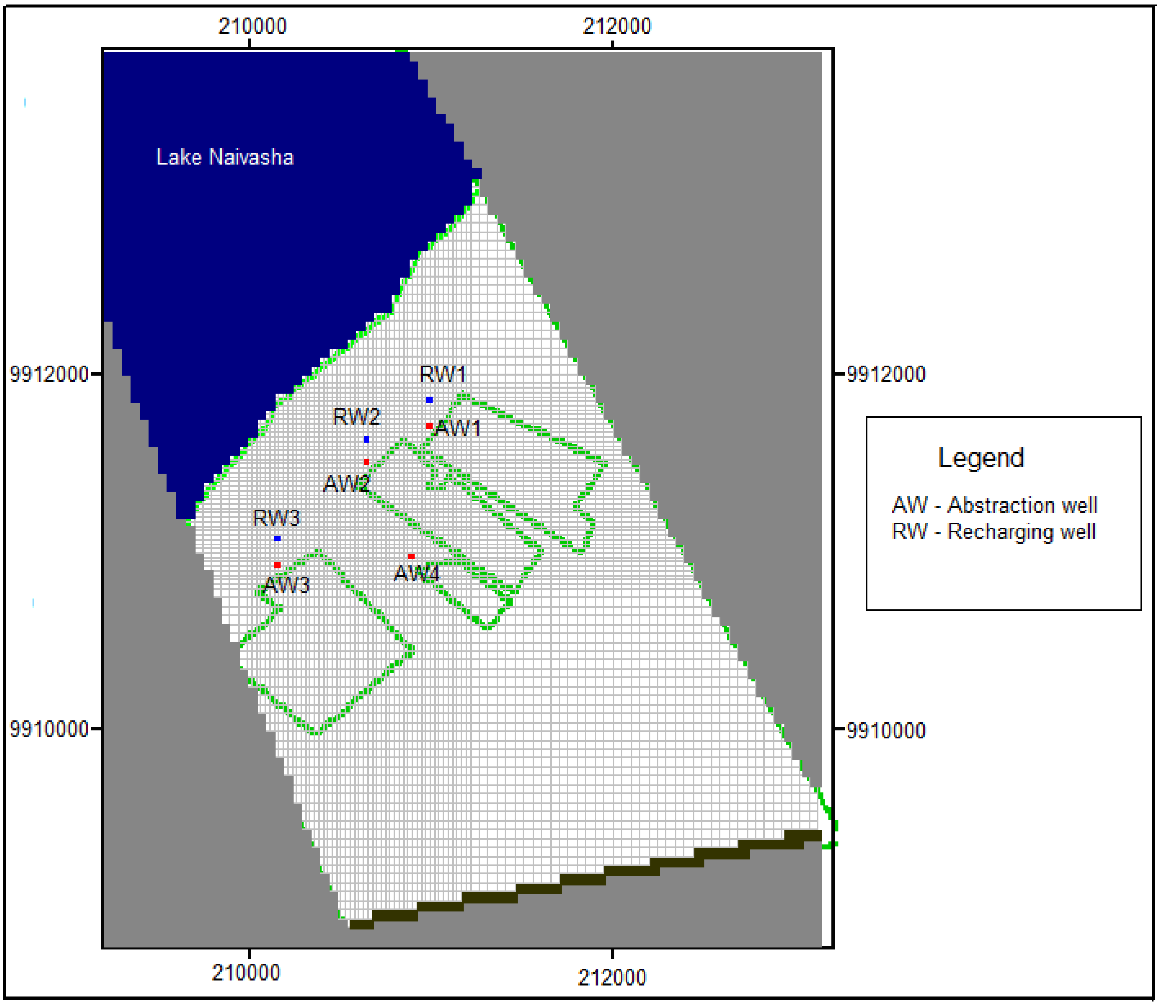


Figure 8-6 Location of the proposed Recharge and Abstraction wells of the shallow aquifer

The water level at the proposed recharging and abstraction wells was analysed for the two conditions:

1. Implementing of abstraction wells before the proposed artificial recharge.
2. Implementing of abstraction wells and artificial recharge.

By comparing the water levels simulated under the two aforementioned conditions, the water levels have been raised locally by the artificial recharge. The water level rise in the abstraction and injection wells created as a result of injecting 1540m^3d^{-1} of water shows variation with distance from the lake. The water level rise in the abstraction wells range from 9.6 to 11.9cm Table 8-4, while water level rise in the recharging wells is from 30.9 to 35cm Table 8-5.

Code	Easting	Northing	Simulated heads (m)		Head Difference (m)
			without recharge	with recharge	
AW1	211001.5	9911741	1887.126	1887.245	0.119
AW2	210648.7	9911542	1887.174	1887.29	0.116
AW3	210149.8	9910968	1886.849	1886.956	0.107
AW4	210898.7	9911016	1886.608	1886.704	0.096

Table 8-4 Summary of the hydraulic heads of the proposed abstraction wells

Code	Easting	Northing	Simulated heads (m)		Head Difference (m)
			without recharge	with recharge	
RW1	211000.6	9911892	1887.328	1887.637	0.309
RW2	210651.5	9911664	1887.343	1887.661	0.318
RW3	210149.1	9911118	1887.158	1887.508	0.35

Table 8-5 Summary of the hydraulic heads of the proposed recharge wells

The water level rise shown in both case is relatively lower as compared to the amount of water injected. This could be as a result of high hydraulic conductivity resulted in a fast flow of water from the injection well and also higher amount of proposed abstraction water compared to the runoff generated by each flower farm. Generally, it can be concluded as the overall result shows an increase in the groundwater level in the localized abstraction and recharge well.

8.4.2. Water balance of the entire model under the two conditions

Shallow aquifer

The water budget of the entire model of the shallow aquifer was simulated under the two conditions: one during abstraction of water before implementing the proposed artificial recharge, and second after implementing of both the proposed abstraction and artificial recharges. The model simulation result under the two conditions is presented in Table 8-6. In the first condition, more than 99% of the water coming to the aquifer is from the lake through the constant head boundary. While more than 53% of the outflow from the aquifer is through the head dependent boundary, with an assumption destination of the far deep aquifer. Only about 46% of the outflow from the aquifer goes to the proposed abstraction wells. In the second condition, the proportion of the inflow from the lake water through the constant head decreases by about 12% from the first condition due to the introduction of artificial recharge. But the proportion of outflow from the aquifer through the head dependent boundary increases by 0.2%, indicating the amount of water proposed for abstraction is not enough to keep the water before being lost through the boundary.

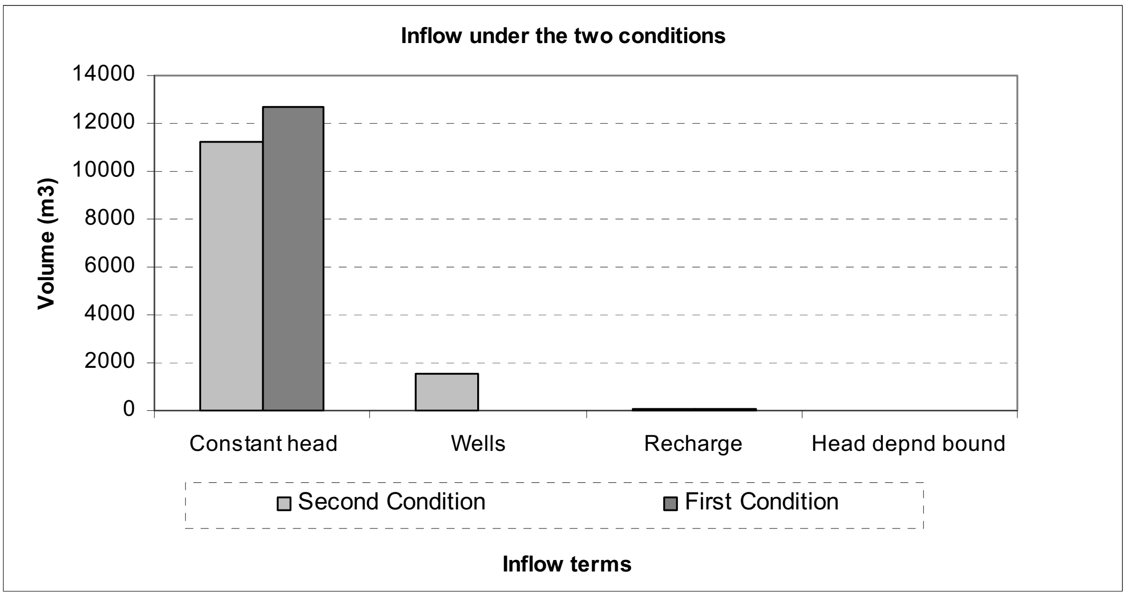


Figure 8-7 Inflow to the shallow aquifer under the two simulation conditions

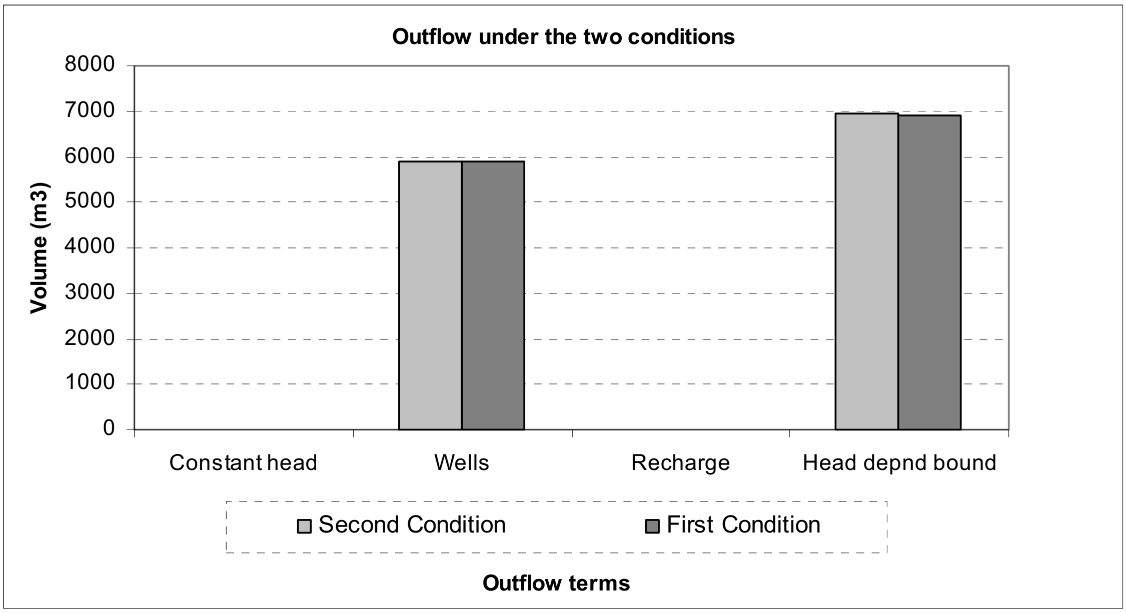


Figure 8-8 Outflow from the shallow aquifer under the two simulation conditions

Before implementing of Artificial recharge					
Flow Terms	Inflow	% of total inflow	Outflow	% of total outflow	Inflow-Outflow
Constant head	12725.86	99.22	0	0	12725.86
Wells	0	0	5918.82	46.15	-5918.82
Recharge	99.56	0.78	0	0	99.56
Head depend bound	0	0	6906.59	53.85	-6906.59
Sum	12825.432		12825.42		0.01
After implementing of Artificial Recharge					
Flow Terms	Inflow	% of total inflow	Outflow	% of total outflow	Inflow-Outflow
Constant head	11240.592	87.27	0	0	11240.59
Wells	1540	11.96	5918.82	45.95	-4378.82
Recharge	99.56	0.77	0	0	99.56
Head depend bound	0	0	6961.32	54.05	-6961.32
Sum	12880.158		12880.146		0.01

Table 8-6 Water budget of the shallow aquifer model simulation under the two conditions

Deep aquifer

Like to the shallow aquifer the water budget of the entire model of the deep aquifer was simulated under the two conditions mentioned. The model simulation result under the two conditions is presented in Table 8-7. In the first condition, 100% of the water coming to the aquifer is from the lake through the constant head boundary. While about 52% of the outflow from the aquifer is through the head dependent boundary. Only about 48% of the outflow from the aquifer goes to the proposed abstraction wells. In the second condition, the proportion of the inflow from the lake water through the constant head decreases by about 3.4% from the first condition due to the introduction of artificial recharge. But the increase in proportion of outflow from the aquifer through the head dependent boundary is significant.

Before implementing of Artificial recharge					
Flow Terms	Inflow	% of total inflow	Outflow	% of total outflow	Inflow-Outflow
Constant head	3521.57	100	0	0	3521.57
Wells	0	0	1690.32	48	-1690.32
Head depend bound	0	0	1831.25	52	-1831.25
Sum	3521.57		3521.57		0
After implementing of Artificial Recharge					
Flow Terms	Inflow	% of total inflow	Outflow	% of total outflow	Inflow-Outflow
Constant head	3411.79	96.6	0	0	3411.79
Wells	120	3.4	1690.32	39.28	-1570.32
Head depend bound	0	0	1841.47	60.72	-1841.47
Sum	3531.79		3531.79		0

Table 8-7 Water budget of the deep aquifer model simulation under the two conditions

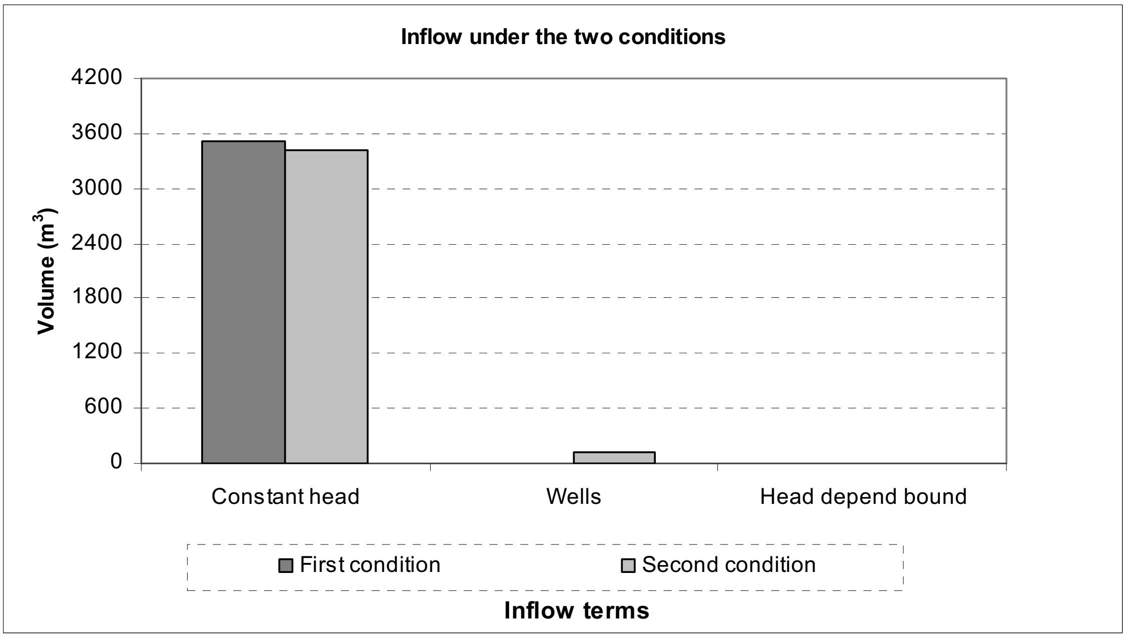


Figure 8-9 Inflow to the deep aquifer under the two simulation conditions

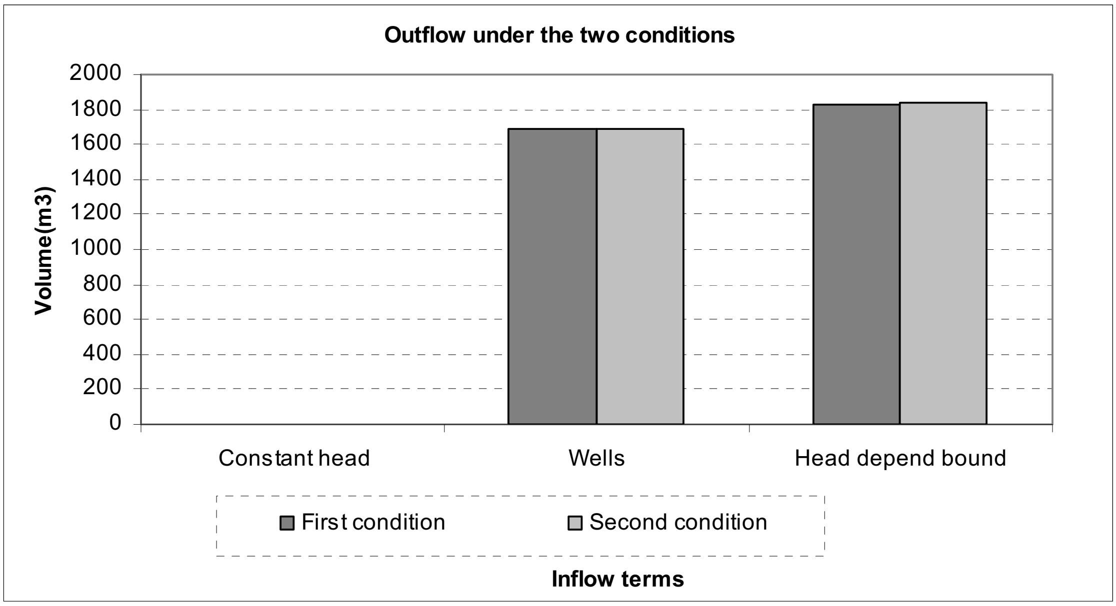


Figure 8-10 Outflow from the deep aquifer under the two simulation conditions

8.5. Deep Aquifer transport model

By applying the same methods as discussed in sections 8.4.1 and 8.4.2, the response of the aquifer before and after injection of the proposed artificial recharge was simulated.

As it was explained in the previous sections, the quality of the existing groundwater of this deep aquifer is not suitable for the flower farming. In the deep aquifer, in addition to the development of the aquifer, the proposed artificial recharge helps to improve the low quality of existing water. Analysing the flow of the aquifer after the injection of the water generated from the greenhouse of the area is important to see how the process of dilution can improve the quality of the existing water with distance from the recharging well and length of time since the injection of water. After performing the flow model of the deep aquifer in processing MODFLOW, MT3DMS model was used in the deep aquifer to trace the concentration of the mixed water at different interval of time and distance and therefore locating of abstraction wells with the desired concentration of water.

8.5.1. Additional inputs

Other than the common inputs for the two groundwater models discussed in section 8.2, additional inputs were used in MT3DMS interface for the transport modelling.

Initial concentration

At the beginning of a transport simulation, MT3DMS requires the initial concentration of each active species at each active concentration cell. As explained in chapter 6, the main quality problem of the groundwater of the area is salinity, reflected on the electrical conductivity (EC) value of the water samples and therefore used as an input for the concentration of the model. The electrical conductivity (EC) can be also related with the total dissolved solids (TDS) of the water by an expression previously obtained. In order to have a relation between TDS and EC value of the water, correlation analysis was done by scatter plotting of the two parameters (Figure 8-11). In addition to the obtained scattered plot result, other expressions obtained from literatures: TDS (mg/l) = 0.6 * EC (µs/cm) (http://www.dpi.vic.gov.au/dpi/index.htm) were used. The need to change the value of EC is to have the input value in concentration (mg/m^3), which finally converted back into EC (µs/cm).

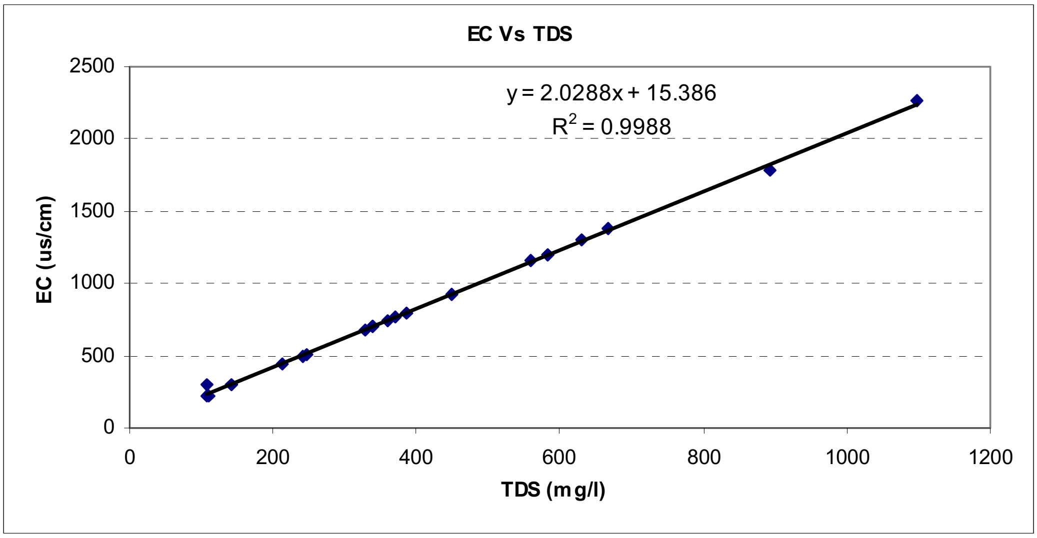


Figure 8-11 Scattered plot of EC and TDS

The average Electrical conductivity value of the lake and groundwater is 1200 and 220µs/cm respectively, used as an initial concentration by changing in to TDS (mg/m^3) value. The TDS value of the lake water was used as a constant concentration boundary. The initial concentration of the three water types is presented in Table 8-8.

water type	EC (µs/cm)	TDS	
		mg/l	mg/m^3
Lake	220	132	132000
Groundwater	1200	720	720000
Rainwater	31.4	18.84	18840

Table 8-8 Concentration of the three water types

Sink/ source concentration

A number of measurements on TDS and EC values were done during the field work campaign. The average obtained EC and TDS value of the lake water was 220 µs/cm and 132000mg/m^3 respectively. The measured concentration value of lake water was used as a constant head cell and the average TDS value (Table 8-8) was assigned to the rest cells of the groundwater. After assigning the initial value concentration of the lake and groundwater, runoff generated from the greenhouse was injected in the selected well. The concentration (TDS) of the rainwater used in the simulation was 18840mg/m^3.

8.5.2. Results and discussion

The importance of solute simulation model of the area was:

- To trace the path of the injected water along the flow direction of the groundwater
- To see how the injected water can be used to dilute the existing high concentration groundwater in to the desired concentration value
- To trace the improved concentration of mixed water with distance from the injection well
- To examine the resulting diluted concentration at different time of simulation
- To locate abstraction well with the desired concentration value for the flower farming and time of abstraction after the injection of the runoff generated from the flower farms.

In order to achieve the above mentioned objectives the model was run for different time of injection periods, from one to 10 years. The results obtained at each injection period were plotted against time and distance. The obtained concentration of the mixed water was converted back into EC (µs/cm) to analyze how the allowable value of EC can be achieved at different interval of time and distance since the injection starts and from the injection well respectively. The results obtained at different injections period were compared with the allowable (limits) values of concentration for the flower farming given by the local flower farmers (Chapter 6).

In the one year injection period, the EC value range found was 32.87 to 100µs/cm along 50m distance in the direction of groundwater flow. Unlike to the first 50m distance, the next 100 µs/cm increase of EC value covers only 10m distance, indicating relatively fast rise of concentration with short interval of distance. In other words the dilution capacity of the injected water after the distance of 50m away from the injection well is not the same as the first 50m. The maximum allowable limit of EC (500 µs/cm) was attained at a distance of 80m from the injection well, indicating locating of abstraction well beyond 80m distance is not feasible. The next injection period was 2 years. The concentration result of the mixed water shows no variation with the one year injection period up to the distance of 35m from the injection well. A decrease of 4 to 44µs/cm EC value was observed from the distance of 35 to 50m form the injection well. From 50 to 230m distance the gentleness of the slope increases, showing relatively a small rise of concentration over a large cover of distance. The distance from the well where the maximum limit of concentration (at 500µs/cm) was attained increase by a distance of 30m from the first injection period. The third injection period (5 years) done shows similar trend of the slope of the plot with that of 2 years injection period, relatively more slightly gentle slope. The increase in distance from the second injection period where the maximum concentration limit attained was only 10m, but afterwards the gap of the concentration value between the two injections period show a slight increase. It was observed that during the third injection period the concentration contour emerging from the constant concentration cell boundary (lake) extend toward the mixed water near to the recharging well. The concentration values obtained from the last injection period (10 years) almost coincides with the values of 5 years injection period. The maximum difference of the concentration result between 10 and 5 years injection period was 2.55µs/cm at a distance of 1710m, while the maximum difference within the distance of allowable value of concentration is 1.87µs/cm at a distance of 120m from the recharging well. The analysis result at different injection period is shown in Figure 8-12.

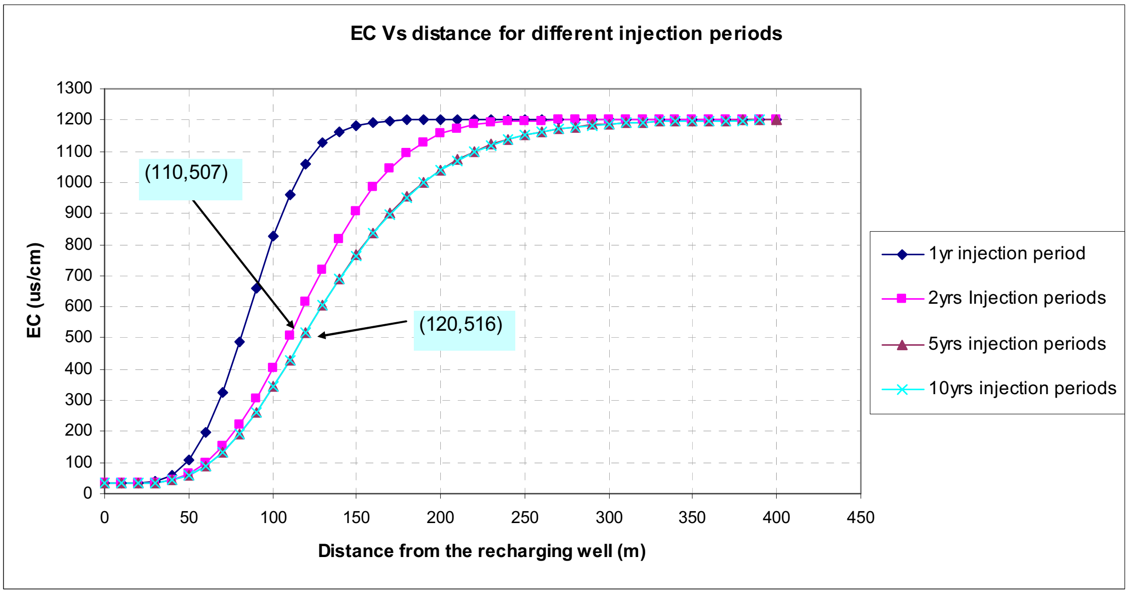


Figure 8-12 EC Vs distance from the recharging well at different simulation periods

It is also possible to work with relative concentrations. In that case, all concentrations entered into the model can be scaled according to the maximum concentration (Co) of either aquifer or fluid sources. Subsequently, the model simulates the changes in the relative concentration (C/Co). The break through curve obtained by inserting the concentration values (C) relative to the initial concentration (Co) of the groundwater is shown in Figure 8-13.

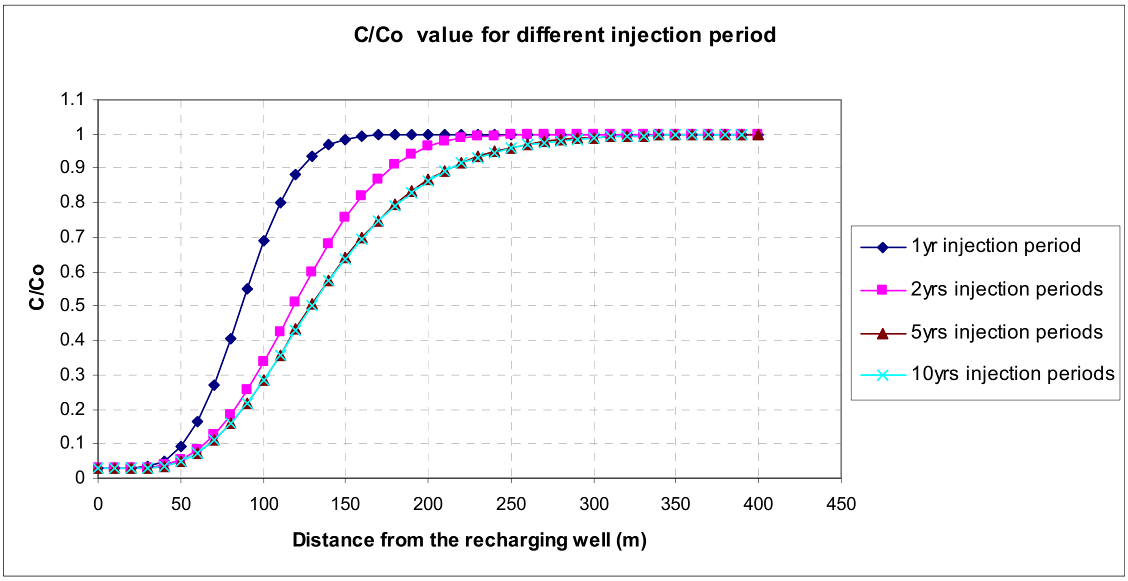


Figure 8-13 Relative concentration (mixing) of the mixed water at different simulation periods

Concentration and wells

A representative abstraction wells based on the pre simulated groundwater flow and the obtained concentration at different distance from the recharging well were selected for the analysis. The selected abstraction wells at different distance from the recharge well were tested at different intervals of injection and abstraction periods to see how the concentration values of the mixed water vary with time. Testing the concentration value for the different periods helps for the selection of optimum distance from the recharging well and time of abstraction after the implementing of the artificial recharge. The result of the analysis is plotted in Figure 8-14.

The first test was done at 20m from the recharging well. EC of the mixed water dropped from the initial value (1200µs/cm) to 509µs/cm after 40 days. The EC value stabilization was observed after 400 days at a value of 32.8µs/cm. The mixed water at a distance of 50m becomes 504µs/cm after 170 days. The value almost stabilizes at 63 to 60µs/cm after 900 days, which becomes 60µs/cm after 1200days onwards. The final test was at 100m from the recharging well, which resulted in 501µs/cm after 580 days. It stabilizes at 370µs/cm after 1350 days, relatively low possibility of selecting as a location for abstraction well. From the analysis results the selected location for the abstraction well, 50m away from the recharging well gives better results on the chemical composition and optimum hydraulic head. It has a long stabilized range of concentration and also the obtained concentration of the mixed groundwater can be used for farther mixing of the lake water before using it for the flower farm. The mixing process is explained in section 6.4.2 (Blending or mixing of water supply).

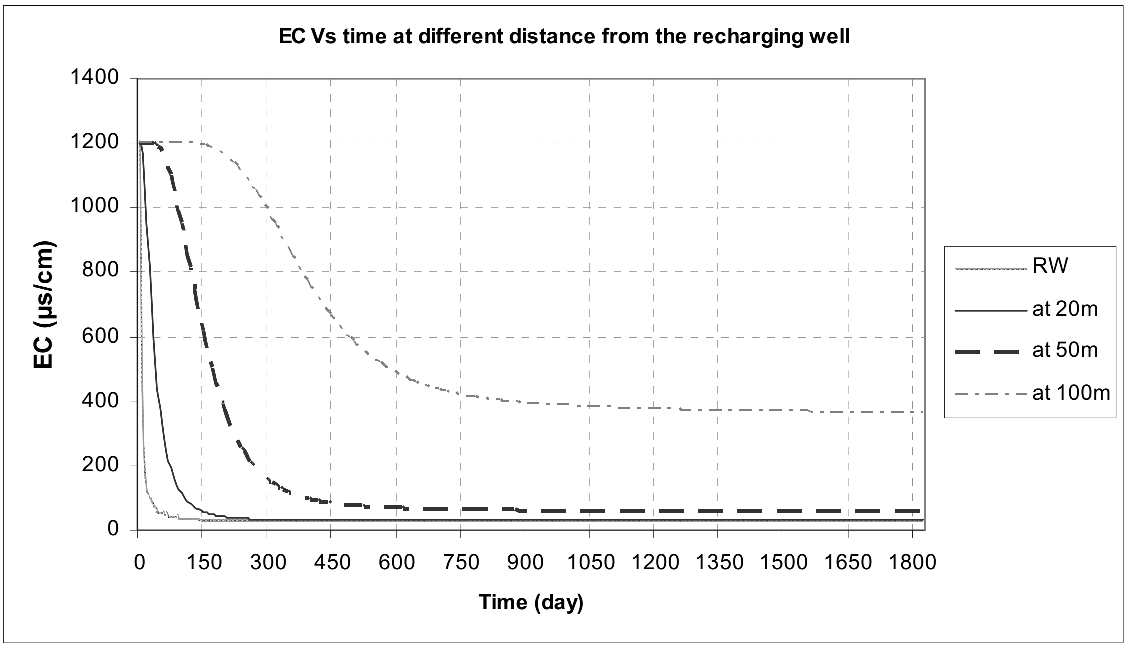


Figure 8-14 EC value at different distance from the recharging well

Abstraction and concentration at the selected well

After selecting the abstraction well at 50m from the recharging well, the concentration response of the well was tested by implementing the daily required abstraction water for the flower farming. The daily average amount of water needed for the flower farm around the interest area is 1690m^3, while the daily average runoff generated from the 6.6ha of greenhouse area is 120m^3, which is 7% of the abstraction water. The amount of the runoff is expected to be more than 700m^3 with the farther expansion of the greenhouse area from the existing more than 38ha of open land irrigation.

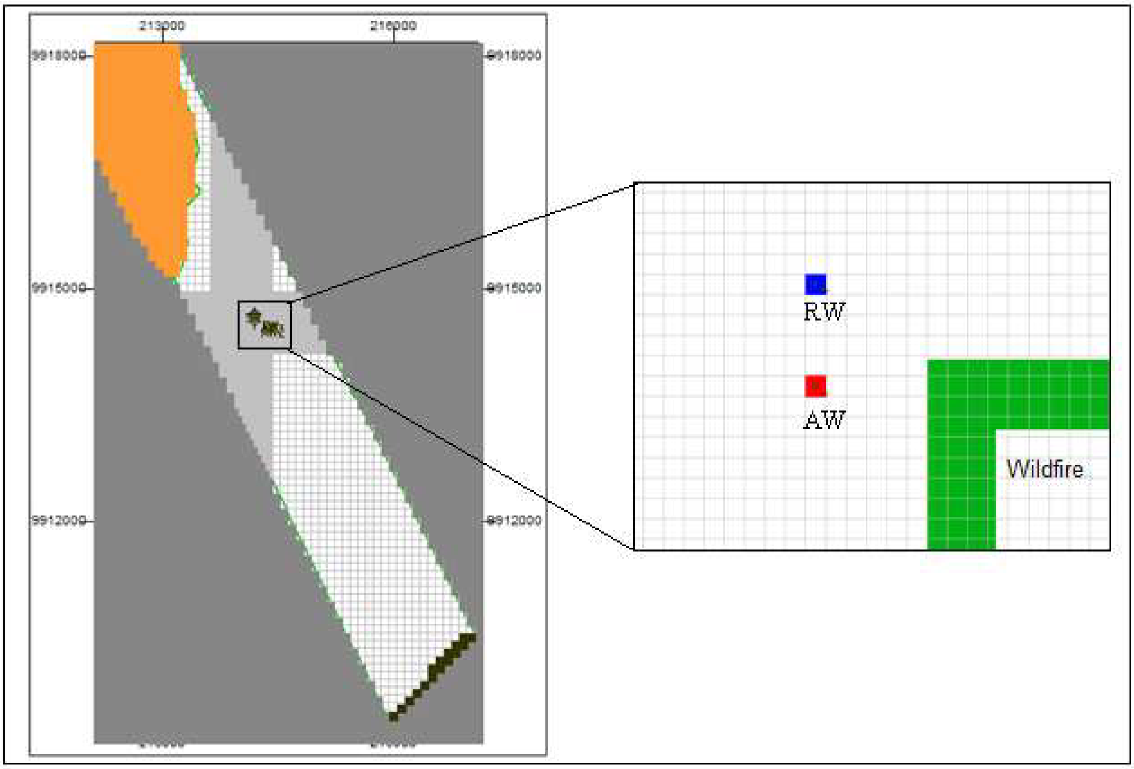


Figure 8-15 Location map of the recharging (RW) and abstraction (AW) wells

The simulation of the groundwater model was done by assigning different stress periods. Two stress periods were assigned: the first stress period starts with injection of the runoff without the implementation of the abstraction well. In the second stress period, both groundwater abstraction and injection of the runoff were implemented. The time assigned for the two stress periods was (5, 25), (10, 20) and (15, 15) years. The total simulation period was 30 years. It was found that difficult to use the water from the groundwater by implementing the total required amount of abstraction water. This is because the difference between the amount of generated runoff and required abstraction water is high. The initial concentration of the groundwater is also high compared to the required concentration value for the flower farm. In order to compensate this large difference, the amount of abstraction water used in the second stress period was assigned as total amount, half, two-third and one-third of the total amount. After simulation with different combination of time and amount of abstraction water, relatively better result was obtained in implementing the abstraction well after 5 years of injecting water. The maximum amount of abstraction water which gives better result of mixed water concentration was one-third of the total amount. The plot of the result is shown in Figure 8-16. After implementing the abstraction well at 5 years, the concentration of the mixed groundwater starts rising. It shows a gradual increase of concentration from 5 to 9 years, while from 9 to 15years constant fluctuation was observed. After 15 years a rise in EC value up to 1000µs/cm was observed, which makes difficult to use the water for irrigation.

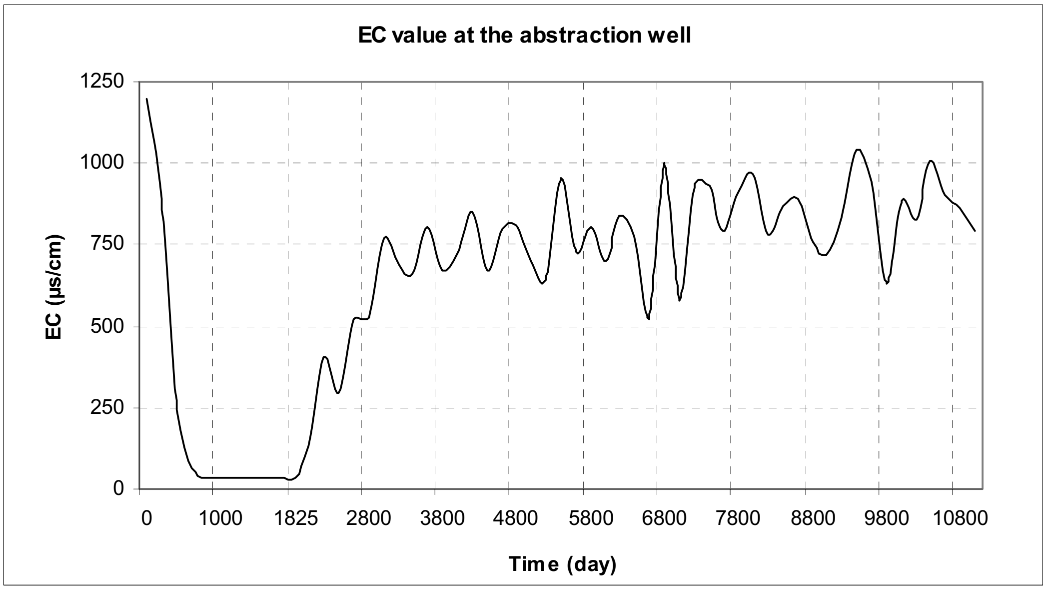


Figure 8-16 EC value at different time interval after the starting of abstraction of water

Conclusion on the abstraction and concentration of the mixed water

As it can be seen from Figure 8-16, the EC value is found to be below the maximum limit up to 8 to 9 years after abstraction starts at 5 years. This indicates abstraction of water from the groundwater is possible for about three to four years after the abstraction starts. The next intervals of years (9 to 15 years), the groundwater will have an average EC value of 750µs/cm. This indicates in order to use the groundwater in this interval of year; the relatively high amount of EC should be lowered by mixing the water with the two-third of total abstraction water from the lake. Without mixing the groundwater obtained after 4 years from the starting of abstraction can not be used for the flower farms. The detailed process of mixing (blending) water is shown in chapter 6 (6.4.2).

From this two possibilities can be proposed:

- The groundwater can be used without mixing with lake water for 3 to 4 years after the starting of abstraction, but after 4 years to use the groundwater for the next 5 years (9 to 15 years) mixing with two-third water expected from the lake is important. Finally, abstraction from the groundwater after 15 years should be stopped for 5 years in order to repeat the recharging process for 5 years.
- After using the groundwater for 3 to 4 years since the abstraction starts, injection of the generated runoff can be continued for 5 years while abstraction is abandoned in order to repeat the first step. That is abstraction of water from the groundwater is possible every 5 years, while runoff is continuously injected.

Years of recharging	Years of abstraction	Remarks
Continuous	5-9	Abstraction starts after 5 years since injection of runoff
	9-15	Needs mixing with the lake water before being used

Table 8-9 Injection and abstraction time

Prediction of abstraction and concentration with expansion of Greenhouse areas

In the area there are at least two types of irrigation system: open and greenhouse area irrigation systems. The runoff used in the groundwater modelling was only from areas where their irrigation system is under greenhouse; however, there are large areas where their irrigation system is under open system. As it was observed during the field work, some of the open area irrigation systems were developed into greenhouse system, which can produce more runoff during rainy season and hence the amount of runoff to be injected. Increasing runoff generated from the greenhouse increases the dilution volume of the existing groundwater and therefore an increase in the abstraction amount and time. The model was used for prediction of the abstraction volume and time considering the expansion of up to 38ha of open area irrigation system in to greenhouse areas. The 38ha of greenhouse area can generate atleast $700m^3d^{-1}$ volume of runoff. The prediction result after injecting the expected volume of runoff is shown in Figure 8-17. The abstraction amount considered during the model run were total amount ($1690m^3d^{-1}$), half ($850m^3d^{-1}$) and about two-third ($1100m^3d^{-1}$) of the total required abstraction. The different abstraction volumes considered during the prediction process were implemented after 5 years of injection period.

The result with the abstraction of $850m^3d^{-1}$ shows an EC value below the maximum limit throughout the simulation period. With this amount of abstraction, the groundwater can be used without mixing with the remaining half of the total abstraction water from the lake. With the abstraction amount of $1100m^3d^{-1}$, the groundwater can be used for the irrigation of the flower farm for the following 15 years since abstraction begins without mixing with the lake water, but mixing is needed afterwards.

With total amount of abstraction, the EC value of the groundwater is expected to remain below the maximum limit for only 5 years since abstraction begins. After 5 years of abstraction, repeating the injection process for the following 5 years is important to keep the EC value of the groundwater below the maximum limit (500µs/cm). That is abstraction will be possible after every 5 years of injection period.

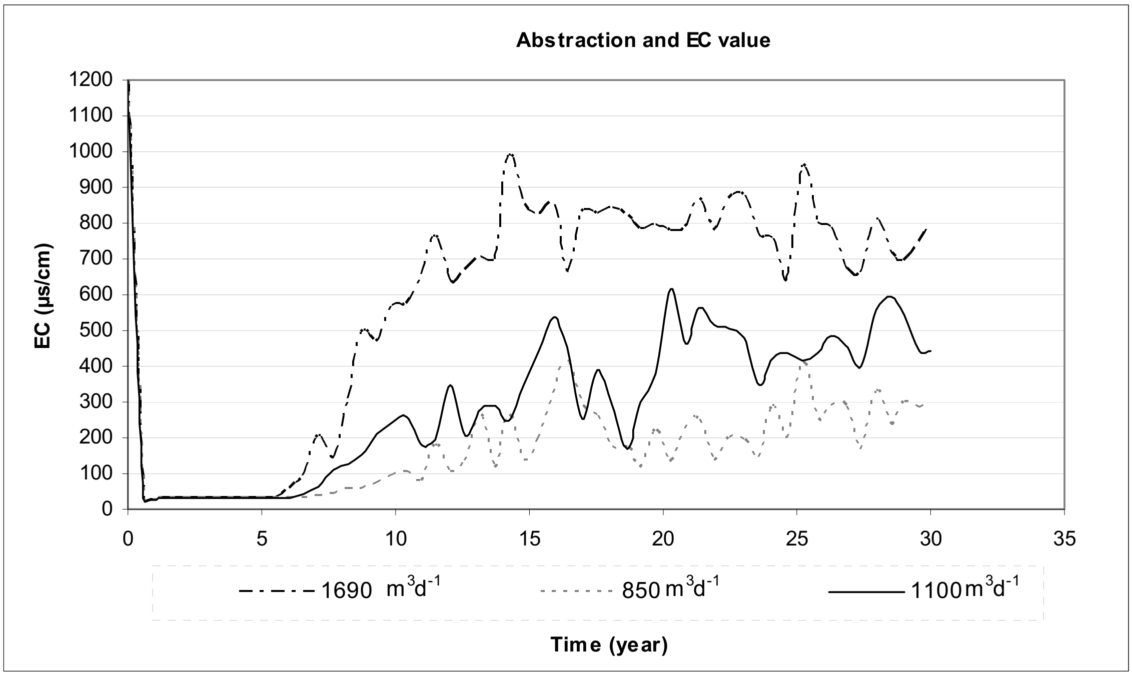


Figure 8-17 Predicted EC value at different amount of abstraction and time

9. Conclusion and recommendations

9.1. Conclusions

- The groundwater flow direction of the area confirmed as away from the lake can play a major role in feeding the shallow aquifer of the area during abstraction time.
- The maximum daily volume of runoff estimated from the long term data using rational empirical formula in the shallow and deep aquifer is 77000 and 6000m^3 respectively.
- The shallow aquifer of the area is mainly composed of loose to compacted pumice pebbles, sand and rounded gravely deposits, while the deep aquifer separated by hard trachyte rock from the overlying layers is dominated by sand and gravely reworked volcanic deposits.
- From the pumping test and laboratory soil sample analyses, the hydraulic conductivity of the two aquifers range from 200 to 480md^{-1}, while the overlying layers characterized by 0.1 to 0.4md^{-1}.
- The main quality problem of the deep groundwater of the area is salinity, reflected on the electrical conductivity (EC) value of the water samples, with a maximum value of 2267µs/cm, grouped under medium to high saline water.
- Taking 500µs/cm as maximum limit EC value of the irrigation water, the proportion of rainwater required for mixing with the existing groundwater ranges from 27 to 79% to get the allowable value of electrical conductivity. The maximum amount of rainwater needed goes to the deep groundwater of the area.
- A spreadsheet model was used to analyse the effective and cost effective method of artificial recharge. Recharge wells method combined with shallow infiltration basin in the deep aquifer is found to be feasible method with optimum solution of the model about 6000m^3day^{-1} of total recharge well potential, 95.2% recharge efficiency and estimated preliminary cost of 1.60KES (Kenyan shillings) per cubic meter of recharge water, while in the shallow aquifer both methods can be possible except with some disadvantages in the DIB method.
- The water budget of the steady state model reveals that the inflow through the constant head boundaries to the shallow and deep aquifer decreases by 12% and 3% respectively after the artificial recharge was implemented.
- The water from the green houses areas is found to be the first priority source of artificial recharge for the dilution of existing low quality of groundwater. This is due to the fact that it is free of contaminates and very low suspended sediments, which in turn plays a great role in the water quality of the recharge water and efficiency of the recharge facilities.
- Injecting the runoff collected from the greenhouse area and shifting abstraction of water from lake to the shallow groundwater results in saving 39% of the net abstraction as compared to without artificial recharge.
- The groundwater quality of the deep aquifer was assessed after applying a daily artificial recharge generated from the existing and future expansion of greenhouse areas: it was found that, it can be used for 3 to 4 years with an abstraction of 400 to 500m^3d^{-1} after applying a recharge of 120m^3d^{-1} for 5 years before abstraction starts, but with a future expansion of greenhouse area up to 38ha, which can generate runoff 700m^3d^{-1}, groundwater can be used with out mixing with lake water with an abstraction rate of 1690m^3d^{-1} for 5 years after the starting of abstraction, but with abstraction value below two-third of the total value is possible atleast for 25 years after continues injection of 700m^3d^{-1} for 5 years while abstraction is not implemented.

- The main potential problem of artificial recharge through recharge wells is clogging of the reservoir and/or the recharge well due to the suspended sediments and recharge water quality. Of these two factors, for the present situation suspended sediments are the main source of clogging since the recharge water is direct runoff, free from contaminates.

9.2. Recommendations

- The possible solution to mitigate clogging of the recharge wells and shallow infiltration basin is to design filter below the recharge wells and/or to line the canals collecting the runoff from the green houses or to design stilling basin upstream of the reservoir.
- The concentration of water samples taken from groundwater depths below 25m are found to be above the maximum limit of irrigation water required for the flower farm, and therefore groundwater drilling in the shallow aquifer should not be extended below 25m depth.
- Continuous monitoring of EC value of the deep groundwater is important before using it for the irrigation of the flower farms. This helps in monitoring whether the groundwater needs farther mixing with the remaining volume of water taken from the lake.
- The return flow from the irrigation farms may have high concentration and affect the mixing process of rain and existing groundwater, which needs detail investigation. Therefore care must be taken not to mix uncontrolled concentration return flow with the runoff generated from the roof of the greenhouse areas during injection process.

References

Anderson, M.P. and Woessner, W.W., 1992. Applied groundwater modeling : simulation of flow and advective transport. Academic Press, San Diego etc., 381 pp.

Appelo, C.A.J. and Postma, D., 1993. Geochemistry, groundwater and pollution. Balkema, Rotterdam etc., 536 pp.

ASCE, 2001. Standard guidelines for artificial recharge of groundwater. WERI / ASCE;34-01. American Society of Civil Engineers Reston, 106 pp.

Ayers, R.S., Westcot, D.W. and Fao, 1985. Water quality for agriculture. FAO irrigation and drainage paper;29Rev.1. FAO, Rome, 174 pp.

Behar Hussein, A., 1999. Surface water - groundwater interaction, near lake Naivasha, Kenya. MSc Thesis, ITC, Enschede, 98 pp.

Chapman, D.e., 1992. Water quality assessments : a guide to the use of biota, sediments and water in environmental monitoring. Chapman & Hall, London etc., 585 pp.

Clarke, M.C.G., Woodhall, D.G., Allen, D. and G.Darling, 1990. Geological, Volcanological and hydrogeological controls on the occurrence of geothermal activity in the area surrounding Lake Naivasha, Kenya, 138 pp.

Darling, W.G., Berhanu, G. and Arusei, M.K., 1996. Lake groundwater relationships and fluid rock interaction in the East African rift valley : isotopic evidence. Journal of African Earth Sciences, 22(1996)4, pp. 423-431.

Dingman, S.L., 2002. Physical hydrology. Prentice Hall, Upper Saddle River, 646 pp.

Everard, M., Vale, J.A., Harper, D.M. and Tarras-Wahlberg, H., 2002. The physical attributes of the Lake Naivasha catchment rivers. Hydrobiologia, 488(1-3): 13-25.

Everard, M.e., Harper, D.M.e., Boar, R.R.e. and Hickley, P.e., 2003. Lake Naivasha, Kenya : papers from the conference: Science and the sustainable managment of Shallow Tropical waters, Naivasha, Kenya, 11 - 16 April 1999 + additional studies on the lake. Developments in Hydrobiology;168. Kluwer Academic, Dordrecht etc., 203 pp.

Fetter, C.W., 2001. Applied hydrogeology and Visual Modflow, Flownet and Aqtesolv student version software on CD - ROM. Prentice Hall, Upper Saddle River, 597 pp.

Freeze, R.A. and Cherry, J.A., 1979. Groundwater. Prentice-Hall, Englewood Cliffs, 604 pp.

Gorrotxategi Gonzalez, I., 2001. Peak runoff estimation of the ungauged area in Naivasha basin using the slope area method and empirical formulas. MSc Thesis, ITC, Enschede, 45 pp.

Hem, J.D., 1989. Study and interpretation of the chemical characteristics of natural water. Geological survey USGS : water - supply paper;2254. UG United States Governement Printing Office, Washington, 263 pp.

Hounslow, A.W., 1995. Water quality data : analysis and interpretation. CRC Lewis, Boca Raton etc., 397 pp.

Kruseman, G.P. and de Ridder, N.A., 1983. Analysis and evaluation of pumping test data. ILRI Bulletin;11. International Institute for Land Reclamation and Improvement (ILRI), Wageningen, 200 pp.

Mcann, D.L., 1974. Hydrogeolgic investigation of rift valley catchments, United nations-kenyan government geothermal exploration project.

Mmbui Samuel, G., 1999. Study of long term waterbalance of lake Naivasha, Kenya. MSc Thesis, ITC, Enschede, 98 pp.

Mohammedjemal, A., 2006. Assessment of artificial groundwater recharge using greenhouses runoff, North East Naivasha, Kenya. MSc Thesis, ITC, Enschede, 106 pp.

Morgan, N.E., 1998. Groundwater chemistry and quality assessment of the Lake Naivasha area, Kenya. MSc Thesis, ITC, Enschede, 65 pp.

Nabide, I.K., 2002. Development of 3 - D conceptual hydrogeological model for Lake naivasha area : based on the integration of geology, hydrochemistry, isotopic analysis and boundary conditions, ITC, Enschede, 122 pp.

Nalugya, E., 2003. Estimation of direct recharge of natural vegetations of the lake aquifer : a case study of Lake Naivasha basin, Kenya. MSc Thesis, ITC, Enschede, 94 pp.

Ojiambo, B.S., 1996. Characterization of subsurface outflow from a closed - basin freshwater tropical lake, rift valley, Kenya. PhD thesis Thesis, UMI dissertation services, Ann Arbor, 141 pp.

Oppong-Boateng, R., 2001. Assessment of the use of groundwater for irrigation in the southern part of lake Naivasha, Kenya. MSc Thesis, ITC, Enschede, 95 pp.

Owor, M., 2000. long term interaction of groundwater with lake Naivasha, Kenya : a numerical simulation of the relationship between groundwater and lake allowing for fluctuating lake levels. MSc Thesis, ITC, Enschede, 110 pp.

Pyne, R.D.G., 1995. Groundwater recharge and wells: A Guid to Aquifer storage and Recovery. Boca Raton, Fla., [etc.] : Lewis, 376 pp.

R.H.McCuen, 2004. Hydrologic Analysis and Design. Prentice Hall, New Jersey.

Shaki, A.A. and Adeloye, A.J., 2006. Evaluation of quantity and quality of irrigation water at Gadowa irrigation project in Murzuq basin, southwest Libya. Agricultural Water Management, 84(1-2): 193-201.

Spitz, K. and Moreno, J., 1996. practical guide to groundwater and solute transport modelling. Wiley & Sons, New York etc., 461 pp.

Stuttard, M.J., J.hayball,G.Narcos,M.Suppo,R.catani,L.Isavwa,J.baraza and A.,Oroda, 1995. Monitoring lakes in Kenya:An envirnomental Analysis Methodolgy for developing countries,Final report to European commision,Contract.

Thomson, A.O. and Dodoson, R.G., 1958. Geology of the Naivasha Area.

United Nations, 1975. Ground - water storage and artificial recharge : natural resources water series no. 2. United Nations : Department of Economic and Social Affairs, New York, 270 pp.

Viessman, W., Lewis, G.L. and Knapp, J.W., 1989. Introduction to hydrology. Harper & Row, New York etc., 780 pp.

Walton, W.C., 1970. Groundwater resource evaluation. McGraw-Hill Series in Water Resources and Environmental Engineering;. McGraw-Hill, New York etc., 664 pp.

Yihdego, Y., 2005. Three dimensional ground water model of the aquifer around lake Naivasha area, Kenya. MSc Thesis, ITC, Enschede, 89 pp.

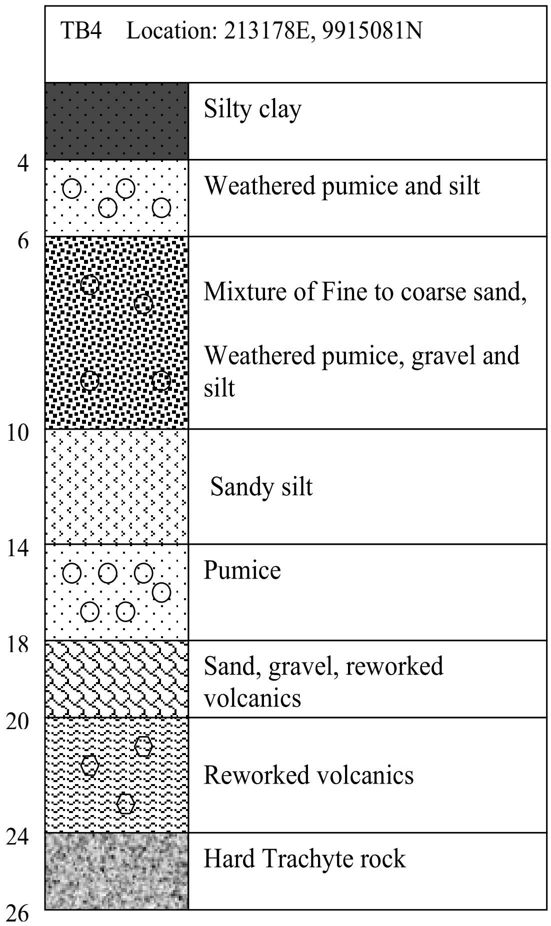
Appendices

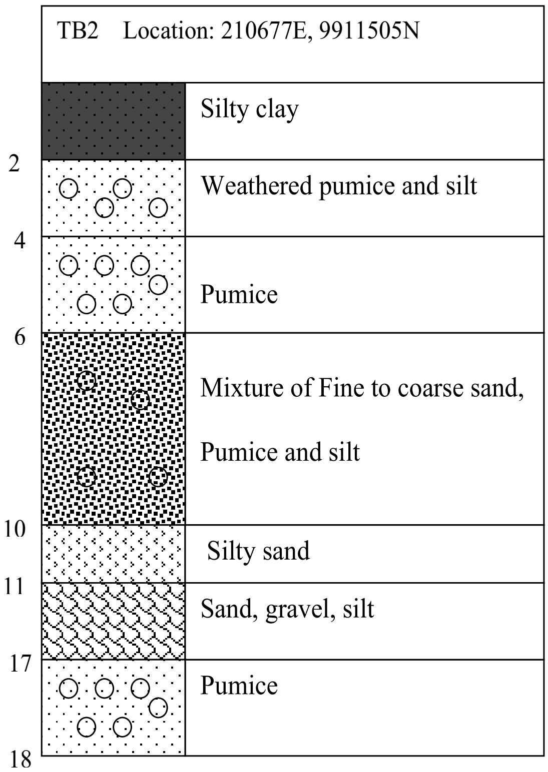
Appendix 1 Geological log of test boreholes

Code: TB1	Location: 210699.596E, 9911490.715N
Depth (m)	Description
0-2	Silty clay
2-4	Silt (dominated) and weathered Pumice, light grey color
4-6	Pumice, grey to dark color, pebble vessicles
6-10	Pumice, Sand and silt, greyish color, fining downward water strike at 10m
10-11	Silty sand and less gravel mixing, coarsening downward, light grey color,rounded
11-17	Sand and small fragment of pumice, fine to coarse grained sand and small silt mixing, light to dark color.
17-18	Pumice rock

Code: TB2	Location: 210677.723E, 9911505.212N
Depth (m)	Description
0-2	Silty clay
2-4	Silt (dominated) and weathered Pumice, light grey color
4-6	Pumice, grey to dark color, pebble vessicles
6-10	Pumice, Sand and silt, greyish color, fining downward water strike at 10m
10-11	Silty sand and less gravel mixing, coarsening downward, light grey color,rounded
11-17	Sand and small fragment of pumice, fine to coarse grained sand and small silt mixing, light to dark color.
17-18	Pumice rock

Code: TB3 Location: 210676.326E, 9911503.184N	
Depth (m)	Description
0-2	Silty clay
2-4	Silt (dominated) and weathered Pumice, light grey color
4-6	Pumice, grey to dark color, pebble vessicles
6-10	Pumice, Sand and silt, greyish color, fining downward water strike at 10m
10-11	Silty sand and less gravel mixing, coarsening downward, light grey color,rounded
11-17	Sand and small fragment of pumice, fine to coarse grained sand and small silt mixing, light to dark color.
17-18	Pumice rock





Code: TB4 Location: 213178.166E, 9915081.766N	
Depth (m)	Description
0-4	Weathering result top solil
2-4	Fine grained sand, light grey to dark color
4-4.3	Fine grained sand, weathered product of the volcanic rock
4.3-5	moderately weathered pumice, brownish color, overlying volcanic tuffs (interlayered) with some vessicles.
5-6	Weathered pumice and mixing of Tuff, brownish to light reddish color. Fine to some inclusion of Volcanic crystals.
6-8	Weathered sandy to fine gravel size, weathered product of pumice, brownish to light reddish color. Occurrence of hard fine grained gravel size volcanic grains. Water level strikes at 6m, generally fine fine sand to fine grained gravel size.
8-10	Similar to the 6-8m depth, with relatively high coarser grain volcanic inclusion. Light dark to brownish color.
10-14	Fining down ward weathering result of Pumice. The sand grains are similar to the above with relatively increasing finer grains of sand. Light brownish to light reddish color, with some weathering product of dark color volcanic rocks.
14-18	Weathered Pumice results, fining upward and dominated by coarse grained weathering products
18-20	Sand size resulted from the weathering product of the surrounding volcanic rocks, gravels and reworked volcanics
20-26	Hard trachyte rocks, hard to core.

Code: TB5 Location: 212955.632E, 9914618.489N	
Depth (m)	Description
0-1	Brown color top soil
1-2	Dark grey fine grained sand and Pumice, sand dominating
2-5	Brown coarse sand and pumice, changing in to dark sand from 4m.
5-7	fine grained sand, coarsening downward
7-8	Coarse grained sand, more greyish color.
8-17	Hard and very compacted Trachyte rock.

Code: TB7 Location: 214206.58E, 9914650.422N	
Depth (m)	Description
0-0.5	Top soil, dark, fine grained
0.5-2	Sand and Pumice pebbles, fine to medium grained sand dominating
2-8	Fining down ward pumice crushed in to dominating fine grained
8-32	The same Pumice but relative coarser graine, brownish color
32-38	Light dark to brown color, mixing of trachyte and Pumice grains, Pumice dominating
38-40	Hard layer and compacted Pumice layer with small inclusion of Trachyte, light grey to light brown color.
40-53	Hard Trachyte rock, black color, fining upward.
53-58	Moderately rounded to rounded lake deposit, fine to medium grained resulted from the weathering of the volcanic rock. Dominated by sand grained (approximately 90%), mixing brown to dark color. The dark color are more rouned, while the others have a mixing of angular grains. Some mixing of pumice grains with fine and dark volcanic grains.
58-59	The same as the above depth (53-58) but the angularity of the grains increase downward, more brown color (Pumice) dominant.

Code: NINI Trench Location: 210645.933E, 9911550.466N	
Depth (m)	Description
0-1.2	Loose silty and pebbles of pumice, dominated by loose volcanic ash, light grey color, fine to medium grained and moderately sorted.
1.2-1.8	Loose fine grained volcanic ash (dust), dark completely fine grained
1.8-2.1	Moderately wethered Pumice, reddish color, less compacted fine to medium grained
2.1-2.6	Completely weathered product (paleosol), light grey to dark color with some reddish.
2.6-3.2	Medium round to rounded lacustrine deposit and some mixing of Pumice pebble, fine to medium grained with less silty mixing, lying on poorly sorted pumice pebbles
3.2-6.4	Poorly sorted Pumice pebbles, with some vesicular structure, slightly weathered fine to medium grained (with medium grained dominating), static water level at 4.8m.

Appendix 2 Pumping test results

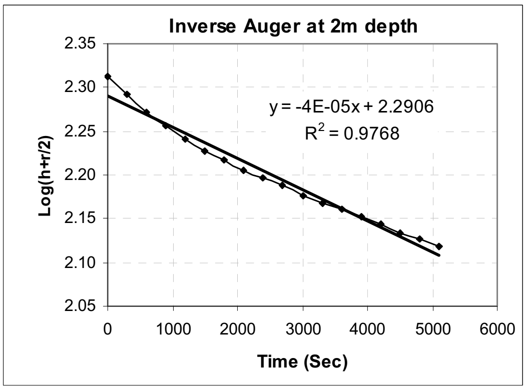
Pumping test at NINI farm Location: 210645.933E, 9911550.466N

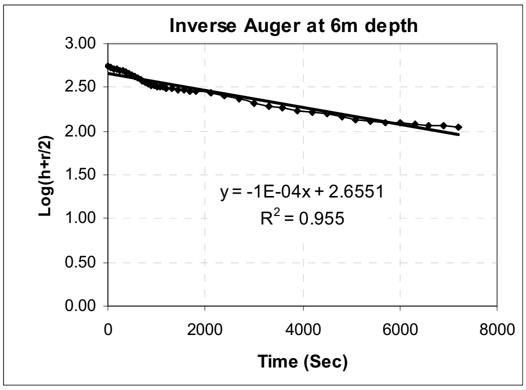
Time (minutes)	Water level (m)	Draw-down (m)	Time (minutes)	Water level (m)	Draw-down (m)
0	0.37	0	35	0.62	0.25
0.5	0.38	0.01	40	0.63	0.26
1	0.4	0.03	45	0.64	0.27
1.5	0.4	0.03	50	0.64	0.27
2	0.42	0.05	55	0.63	0.26
2.5	0.43	0.06	60	0.65	0.28
3	0.43	0.06	80	0.66	0.29
3.5	0.44	0.07	100	0.67	0.3
4	0.46	0.09	120	0.67	0.3
4.5	0.46	0.09	180	0.67	0.3
5	0.46	0.09	240	0.67	0.3
5.5	0.46	0.09	300	0.67	0.3
6	0.47	0.1	360	0.66	0.29
10	0.51	0.14	420	0.65	0.28
15	0.54	0.17	480	0.65	0.28
20	0.55	0.18	540	0.65	0.28
25	0.59	0.22	600	0.64	0.27
30	0.6	0.23	642	0.64	0.27

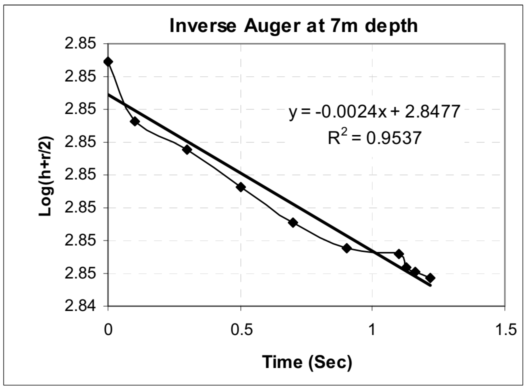
Pumping test at NINI farm Location: 210645.933E, 9911550.466N

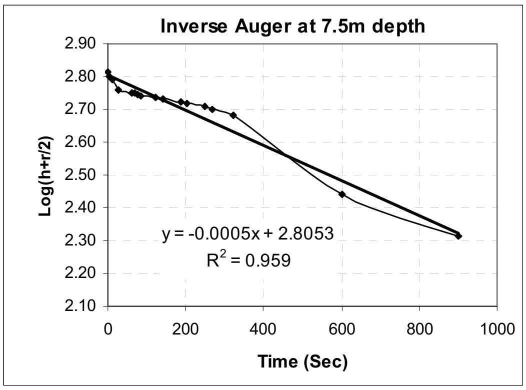
Time (minutes)	Water level (m)	Draw-down (m)	Time (minutes)	Water level (m)	Draw-down (m)
0	0.37	0	35	0.62	0.25
0.5	0.38	0.01	40	0.63	0.26
1	0.4	0.03	45	0.64	0.27
1.5	0.4	0.03	50	0.64	0.27
2	0.42	0.05	55	0.63	0.26
2.5	0.43	0.06	60	0.65	0.28
3	0.43	0.06	80	0.66	0.29
3.5	0.44	0.07	100	0.67	0.3
4	0.46	0.09	120	0.67	0.3
4.5	0.46	0.09	180	0.67	0.3
5	0.46	0.09	240	0.67	0.3
5.5	0.46	0.09	300	0.67	0.3
6	0.47	0.1	360	0.66	0.29
10	0.51	0.14	420	0.65	0.28
15	0.54	0.17	480	0.65	0.28
20	0.55	0.18	540	0.65	0.28
25	0.59	0.22	600	0.64	0.27
30	0.6	0.23	642	0.64	0.27

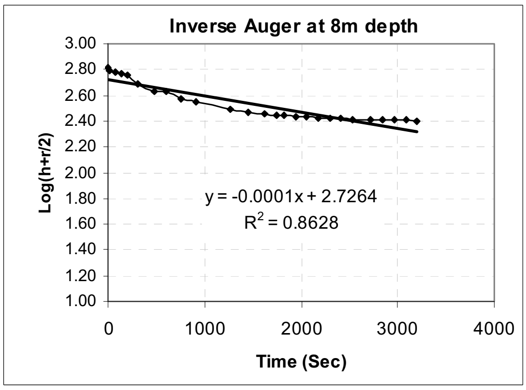
Appendix 3 Invers Auger hole test reslts

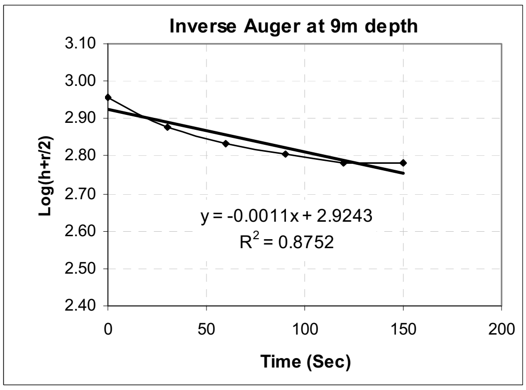


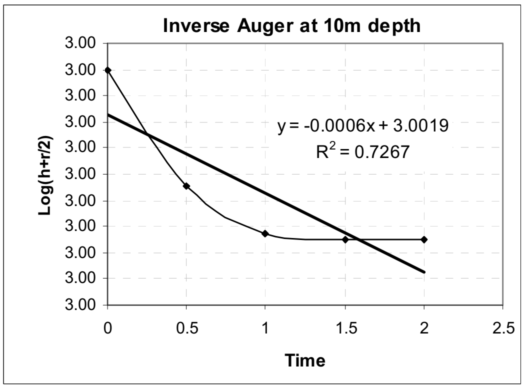


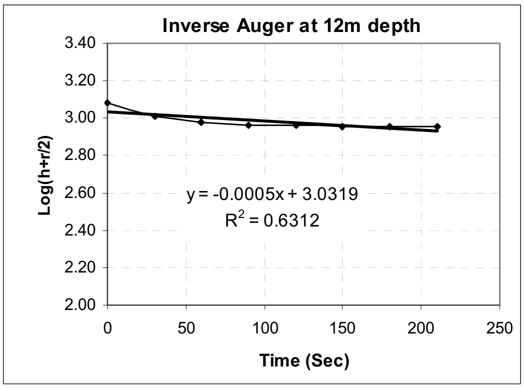


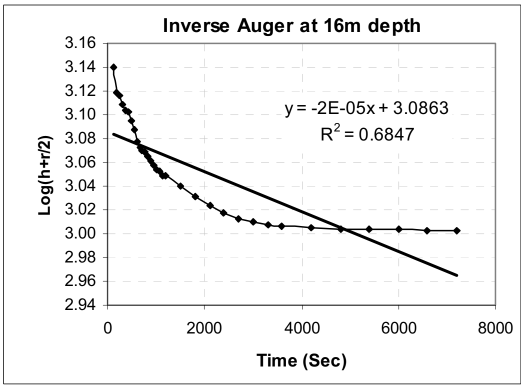


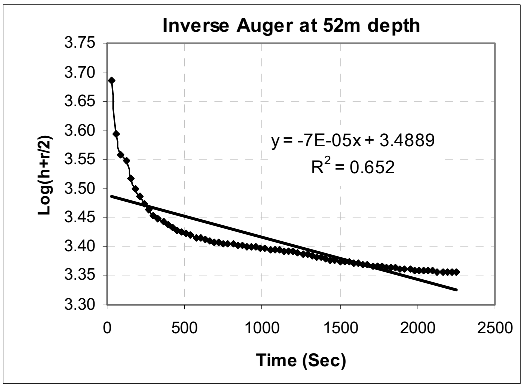


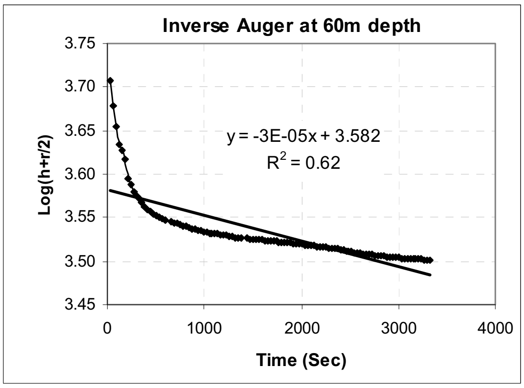



Inverse Auger at 10m depth
y = -0.0006x + 3.0019
R2 = 0.7267
Log(h+r/2)
Time
3.00
0
0.5
1
1.5
2
2.5

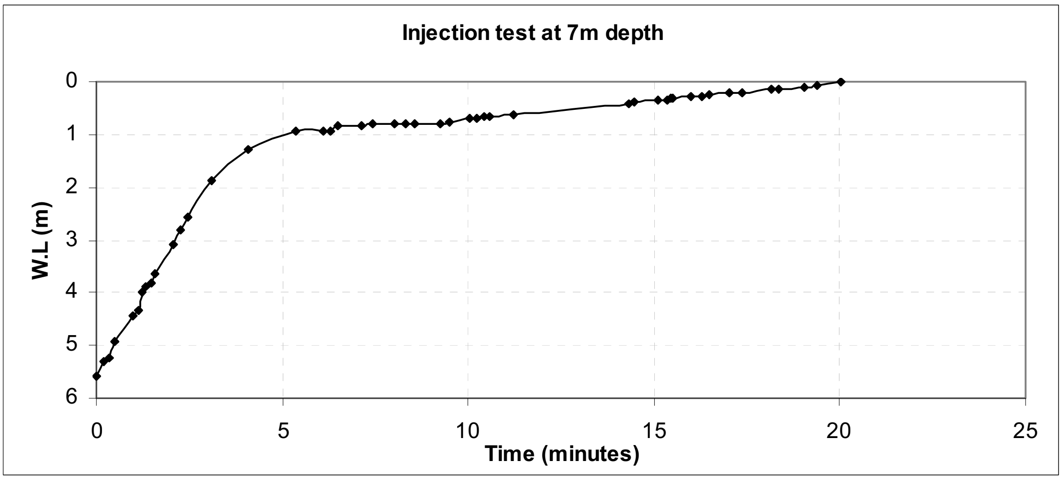

Inverse Auger at 12m depth
y = -0.0005x + 3.0319
R2 = 0.6312
Log(h+r/2)
Time (Sec)
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
0
50
100
150
200
250

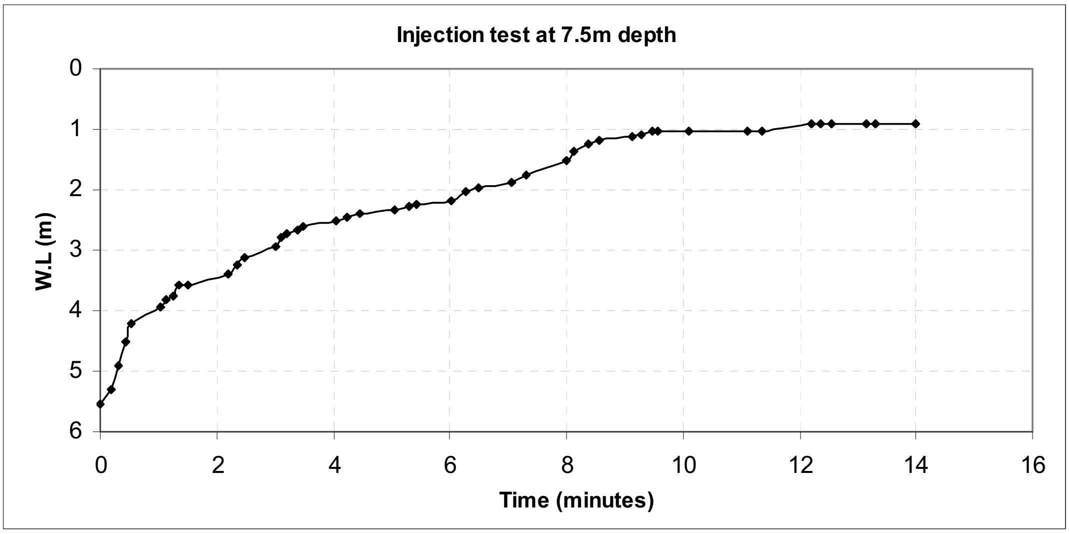

Inverse Auger at 16m depth
y = -2E-05x + 3.0863
R2 = 0.6847
Log(h+r/2)
Time (Sec)
3.16
3.14
3.12
3.10
3.08
3.06
3.04
3.02
3.00
2.98
2.96
2.94
0
2000
4000
6000
8000

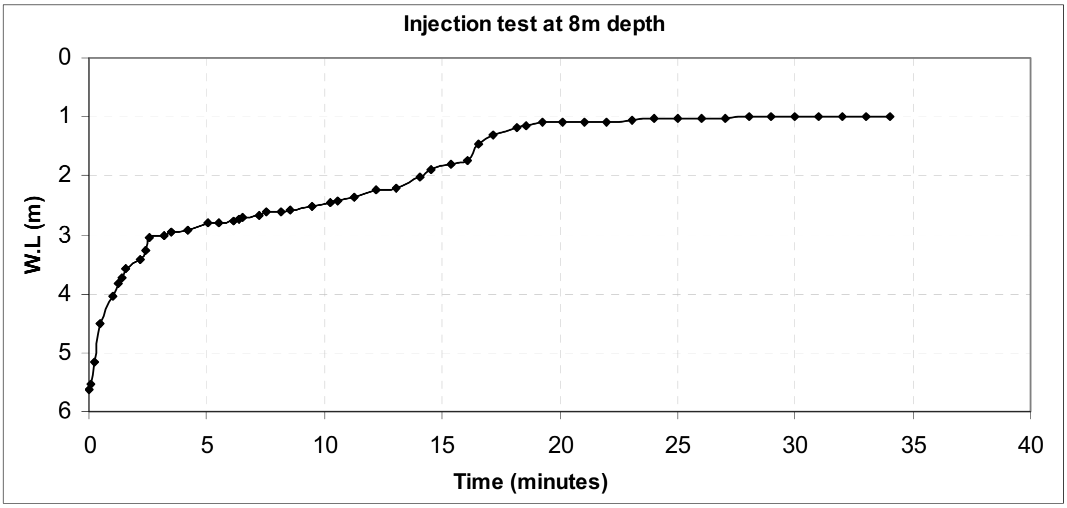

Inverse Auger at 52m depth
y = -7E-05x + 3.4889
R2 = 0.652
Log(h+r/2)
Time (Sec)
3.75
3.70
3.65
3.60
3.55
3.50
3.45
3.40
3.35
3.30
0
500
1000
1500
2000
2500


Inverse Auger at 60m depth
y = -3E-05x + 3.582
R2 = 0.62
Log(h+r/2)
Time (Sec)
3.75
3.70
3.65
3.60
3.55
3.50
3.45
0
1000
2000
3000
4000

Appendix 4 Selected injection and permeamter test results







Selected injection test results

Permeameter results							
Depth (m)	Bulk density (gm/cm3)	SAT Gravimetric water content (%)	SAT Volumetric water content (%)	FC Gravimetric water content (%)	FC Volumetric water content (%)	Ks (md)	Ks_corr (md)
4	1.21	0.44	0.53	0.4	0.49	0.07	0.09
5	0.67	0.87	0.58	0.77	0.52	3.67	4.57
6	1.09	0.46	0.51	0.37	0.4	2.12	2.64
7	1.38	0.31	0.43	0.24	0.33	0.91	1.14
7.5	0.89	0.48	0.43	0.43	0.38	136.01	169.69
8	0.74	0.52	0.38	0.46	0.34	264.02	329.4
9	0.98	0.57	0.56	0.47	0.46	0.18	0.23
10	1.47	0.26	0.38	0.22	0.33	0.08	0.11
17	1.19	0.4	0.47	0.35	0.42	15.91	19.85

Permeameter test results

Appendix 5 Water quality

Code	Location	X_Coord	Y_Coord	Ca	K	Mg	Na	Cl	F	PO_4	P	P_2O_5	SO_4	NO_3	NO_3-N	HCO_3 (mmol/l)	PH	EC (us/cm)	TDS (mg/l)
1	Simba Lodge Naivasha	208395	9909576	62.66	34.27	13.19	89.17	16.3	5.94	0.86	0.28	0.64	11	4.1	0.9	8.8	6.55	678	328
2	Lake water	207826	9909920	13.48	13.69	3.79	22.79	9	1.13	0.08	0.03	0.06	4	4.8	1.1	2.6	7.19	221.14	107.1
3	Lake Naivasha sopa resort	209742	9910548	40.04	25.45	11.83	85.72	19.6	4.07	0.94	0.31	0.71	17	4.4	1	1	7	1376	666
4	TB1	210522	9911916	61.04	88.195	12	35.36	4.2	2.14	0.2	0.06	0.15	39	24.7	5.6	8.3	7.11	700	339
5	Hamerkop	211447	9911940	37.71	20.59	11.05	109.53	31	4.51	0.81	0.27	0.61	30	7.5	1.7	8.1	5.57	700	339
6	Dr.Muita hause	213684	9914150	24.54	16.67	3.07	316.45	56	10.45	0.1	0.03	0.07	41	3	0.7	1.2	5.78	1204	583
7	George residence	214690	9915784	54.89	43.15	9.52	318.59	18	15.29	0.16	0.05	0.12	80	6.7	1.5	1.2	5.78	1204	583
8	Nini	210584	9911684	35.92	22.255	8.93	55.21	49	4.95	0.43	0.14	0.32	8	7.4	1.7	0.5	6.45	743	360
9	Kedong Ranch	213179	9911936	32.47	21.025	7.94	185.77	43	5.61	0.26	0.08	0.19	4	3.9	0.9	1	6.12	1153	558
10	Infront of Flamingo	210966	9910642	65.01	32.46	15.98	98.11	99	3.96	0.08	0.03	0.06	71	7	1.6	10	5.11	761.9	369
11	Stephen Karagita	214219	9913705	13.29	12.09	1.65	280.36	37	9.24	0.07	0.02	0.05	44	5.2	1.2	1.1	6.73	2267	1098
12	KSPCA	213811	9914562	49.39	24.49	9.12	352.72	143	9.13	0.23	0.08	0.17	72	3.4	0.8	2	6.26	1300	629
13	Masharia	214762	9911594	12.96	14.155	0.32	238.81	40	7.59	0.1	0.03	0.07	7	4.3	1	0.7	7.39	226	110
14	Fishers Tower	214966	9916071	32.73	46.93	6.19	306.15	55	9.24	0.39	0.13	0.29	170	6.6	1.5		6.86	1788	894
15	Migaa	216046	9914956	55.15	29.475	7.65	128.74	11	4.84	0.23	0.07	0.17	90	8.9	2	0.7	4.37	793	387
16	Kiffmeir farm	216282	9914072	37.68	17.025	2.3	64.4	14.2	2.75	0.17	0.06	0.13	9	14.1	3.2	0.7	4.16	438	212
17	Flamingo	210411	9910661	35.55	28.77	9.05	69.29	57	4.84	0.3	0.1	0.22	28	4.2	0.9	0.6	4.63	510	247
18	Rubiri water project	215357	9911181	10.33	14.785	0.92	225.22	12.1	7.37	0.23	0.08	0.17	23	5.9	1.3	0.7	2.86	918	450
20	Karagita	213684	9914150	23.75	16.815	3.12	319.53	55	9.57	0.11	0.04	0.08	42	2.4	0.5	1.2	5.78	1204	583
22	Nini Trench	210645	9911550	32	27	7.3	51	14	2.1	0.2	0.06	0.15	19	6.2	5.6	4.1	6.9	500	242
23	TB4	213178	9915081	13.48	13.69	3.79	22.79	9	1.13	0.08	0.03	0.06	4	4.8	1.1	2.6	7.19	293	107.1

Chemical analyses result of water samples

FIELD CROPS	100%		90%		75%		50%		0%	
	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw
Barley (Hordeum vulgare)4	8	5.3	10	6.7	13	8.7	18	12	28	19
Cotton (Gossypium hirsutum)	7.7	5.1	9.6	6.4	13	8.4	17	12	27	18
Sugarbeet (Beta vulgaris)5	7	4.7	8.7	5.8	11	7.5	15	10	24	16
Sorghum (Sorghum bicolor)	6.8	4.5	7.4	5	8.4	5.6	9.9	6.7	13	8.7
Wheat (Triticum aestivum)4,6	6	4	7.4	4.9	9.5	6.3	13	8.7	20	13
Wheat, durum (Triticum turgidum)	5.7	3.8	7.6	5	10	6.9	15	10	24	16
Soybean (Glycine max)	5	3.3	5.5	3.7	6.3	4.2	7.5	5	10	6.7
Cowpea (Vigna unguiculata)	4.9	3.3	5.7	3.8	7	4.7	9.1	6	13	8.8
Groundnut (Peanut) (Arachis hypogaea)	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Rice (paddy) (Oriza sativa)	3	2	3.8	2.6	5.1	3.4	7.2	4.8	11	7.6
Sugarcane (Saccharum officinarum)	1.7	1.1	3.4	2.3	5.9	4	10	6.8	19	12
Corn (maize) (Zea mays)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Flax (Linum usitatissimum)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Broadbean (Vicia faba)	1.5	1.1	2.6	1.8	4.2	2	6.8	4.5	12	8
Bean (Phaseolus vulgaris)	1	0.7	1.5	1	2.3	1.5	3.6	2.4	6.3	4.2
Squash, zucchini (courgette) (Cucurbita pepo melopepo)	4.7	3.1	5.8	3.8	7.4	4.9	10	6.7	15	10
Beet, red (Beta vulgaris)5	4	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15	10
Squash, scallop (Cucurbita pepo melopepo)	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Broccoli (Brassica oleracea botrytis)	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14	9.1
Tomato (Lycopersicon esculentum)	2.5	1.7	3.5	2.3	5	3.4	7.6	5	13	8.4
Cucumber (Cucumis sativus)	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Spinach (Spinacia oleracea)	2	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Celery (Apium graveolens)	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18	12
Cabbage (Brassica oleracea capitata)	1.8	1.2	2.8	1.9	4.4	2.9	7	4.6	12	8.1
Potato (Solanum tuberosum)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Corn, sweet (maize) (Zea mays)	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Sweet potato (Ipomoea batatas)	1.5	1	2.4	1.6	3.8	2.5	6	4	11	7.1
Pepper (Capsicum annuum)	1.5	1	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce (Lactuca sativa)	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9	6
Radish (Raphanus sativus)	1.2	0.8	2	1.3	3.1	2.1	5	3.4	8.9	5.9
Onion (Allium cepa)	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5
Carrot (Daucus carota)	1	0.7	1.7	1.1	2.8	1.9	4.6	3	8.1	5.4
Bean (Phaseolus vulgaris)	1	0.7	1.5	1	2.3	1.5	3.6	2.4	6.3	4.2
Turnip (Brassica rapa)	0.9	0.6	2	1.3	3.7	2.5	6.5	4.3	12	8
Wheatgrass, tall (Agropyron elongatum)	7.5	5	9.9	6.6	13	9	19	13	31	21
Wheatgrass, fairway crested (Agropyron cristatum)	7.5	5	9	6	11	7.4	15	9.8	22	15
Bermuda grass (Cynodon dactylon)7	6.9	4.6	8.5	5.6	11	7.2	15	9.8	23	15
Barley (forage) (Hordeum vulgare)4	6	4	7.4	4.9	9.5	6.4	13	8.7	20	13
Ryegrass, perennial (Lolium perenne)	5.6	3.7	6.9	4.6	8.9	5.9	12	8.1	19	13
Trefoil, narrowleaf birdsfoot8 (Lotus corniculatus tenuifolium)	5	3.3	6	4	7.5	5	10	6.7	15	10
Harding grass (Phalaris tuberosa)	4.6	3.1	5.9	3.9	7.9	5.3	11	7.4	18	12
Fescue, tall (Festuca elatior)	3.9	2.6	5.5	3.6	7.8	5.2	12	7.8	20	13
Wheatgrass, standard crested (Agropyron sibiricum)	3.5	2.3	6	4	9.8	6.5	16	11	28	19
Vetch, common (Vicia angustifolia)	3	2	3.9	2.6	5.3	3.5	7.6	5	12	8.1
Sudan grass (Sorghum sudanense)	2.8	1.9	5.1	3.4	8.6	5.7	14	9.6	26	17
Wildrye, beardless (Elymus triticoides)	2.7	1.8	4.4	2.9	6.9	4.6	11	7.4	19	13
Cowpea (forage) (Vigna unguiculata)	2.5	1.7	3.4	2.3	4.8	3.2	7.1	4.8	12	7.8
Trefoil, big (Lotus uliginosus)	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	7.6	5
Sesbania (Sesbania exaltata)	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	17	11
Sphaerophysa (Sphaerophysa salsula)	2.2	1.5	3.6	2.4	5.8	3.8	9.3	6.2	16	11
Alfalfa (Medicago sativa)	2	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	10
Lovegrass (Eragrostis sp.)9	2	1.3	3.2	2.1	5	3.3	8	5.3	14	9.3
Corn (forage) (maize) (Zea mays)	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15	10
Clover, berseem (Trifolium alexandrinum)	1.5	1	3.2	2.2	5.9	3.9	10	6.8	19	13
Orchard grass (Dactylis glomerata)	1.5	1	3.1	2.1	5.5	3.7	9.6	6.4	18	12
Foxtail, meadow (Alopecurus pratensis)	1.5	1	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Clover, red (Trifolium pratense)	1.5	1	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, alsike (Trifolium hybridum)	1.5	1	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, ladino (Trifolium repens)	1.5	1	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, strawberry (Trifolium fragiferum)	1.5	1	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Date palm (phoenix dactylifera)	4	2.7	6.8	4.5	11	7.3	18	12	32	21
Grapefruit (Citrus paradisi)11	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8	5.4
Orange (Citrus sinensis)	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8	5.3
Peach (Prunus persica)	1.7	1.1	2.2	1.5	2.9	1.9	4.1	2.7	6.5	4.3
Apricot (Prunus armeniaca)11	1.6	1.1	2	1.3	2.6	1.8	3.7	2.5	5.8	3.8
Grape (Vitus sp.)11	1.5	1	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Almond (Prunus dulcis)11	1.5	1	2	1.4	2.8	1.9	4.1	2.8	6.8	4.5
Plum, prune (Prunus domestica)11	1.5	1	2.1	1.4	2.9	1.9	4.3	2.9	7.1	4.7
Blackberry (Rubus sp.)	1.5	1	2	1.3	2.6	1.8	3.8	2.5	6	4
Boysenberry (Rubus ursinus)	1.5	1	2	1.3	2.6	1.8	3.8	2.5	6	4
Strawberry (Fragaria sp.)	1	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4	2.7

Crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (ECw) or soil salinity (ECe)

Appendix 6 Typical runoff coefficients for 5 to 10 years frequency design (Viessman et al., 1989).

s.n	Description of the area	Runoff coefficient
1	Business	
	Downtown	0.70-0.95
	Neighborhood areas	0.50-0.70
2	Residential	
	Single-family area	0.30-0.50
	Multiunit, detached	0.40-0.60
	Multiunit, attached	0.60-0.75
3	Residential (suburban)	0.25-0.40
4	Apartment dwelling areas	0.50-0.70
5	Industrial	
	Light areas	0.50-0.80
	Heavy rains	0.60-0.90
6	Parks, cemeteries	0.10-0.25
	Playground	0.20-0.35
	Railroad yard areas	0.20-0.40
	Unimproved areas	0.10-0.30
7	Streets	
	Asphalt	0.70-0.95
	Concrete	0.80-0.95
	Brick	0.70-0.85
8	Drives and walks	0.75-0.85
9	Roofs	0.75-0.95
10	Lawns; Sandy soil	
	Flat,2%	0.05-0.10
	Average,2-7%	0.10-0.15
	Steep,7%	0.15-0.20
	Lawns; Heavy soil	
	Flat,2%	0.13-0.17
	Average,2-7%	0.18-0.22
	Steep,7%	0.25-0.35

Appendix 7 Photo galleries


Lake and its user




Instruments used during the filed work

I like Naivasha