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Groundwater – Surface Water Interactions of Papyrus Wetlands in the Lake Kyoga Basin of Uganda

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Masters of Natural Resource Management

Abstract

Natural resources play an important role to the livelihoods of rural communities. Dependency on resources as a source of food and water means that poor usage and management of these resources can potentially impact many lives. Understanding of system processes of natural resources can aid in development of management plans and education of stakeholders. The purpose of the study was to simulate the dynamic relationship of groundwater and surface waters of the study area and investigate how the natural system behaved under seasonal changes. Modelling program Modelmuse, developed by the United States Geological Survey (USGS), was used for developing a simulation of a section of the Naigombwa wetland, located in the Kyoga basin of Uganda.

Collected field data from January 2016 was used to assist in the creation of the model, as was previous data, which was collected as part of an associated project. Precipitation data collected from an established weather station showed that the region experienced four seasons per year, two rainy seasons and two dry seasons. Soil analysis was conducted on the study area by collecting samples from 4 zones on each side of the wetland. Textural analysis on collected soil samples showed high percentages of clay throughout the study area.

Simulation of the study area using Modelmuse found that groundwater was the dominating process within the hydrogeological processes of the study area. Sensitivity analysis on models showed that groundwater levels were more sensitive to changes of hydraulic conductivity than precipitation. Although Calibration of the model was conducted by assigning observation wells groundwater and wetland regions of the model.

A simulation period of a year was chosen so that changes to the system as a response to seasonality changes could be simulated. Creation of the simulation model required substantial correlation from other data, as collected data was not enough to cover a simulation period of an entire year. Because of missing data many of the results obtained from the studies results are accompanied with a higher margin of error.

Numerical modelling of hydrogeological processes is a important tool for understanding system processes and also simulating changes to systems from anthropogenic influences. Development of accurate models can be complicated and require large amounts of data. It is hoped that the findings of this thesis can aid in further studies conducted within the region.

Preface and acknowledgements

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Firstly, I would like to acknowledge and thank my supervisors Dr Helen French and Ellen Kayendeke at the Department Environmental Sciences at NMBU, for all their guidance and assistance throughout thesis writing and fieldwork. Without their support and guidance throughout this process I'm sure the results would not have been as conclusive. I would also like to extend my gratitude to those who assist with fieldwork; the Professors and Specialists at Makerere University and the residents of Butangole village, Bussembatia village and Nawangisa Village.

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Teresa Maxine Southwell, 13.05.2016

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1. Introduction

1.1 Background

Natural resources such as ground water and wetlands play an important role within rural African livelihoods. (MacDonald, et al., 2011). In many rural areas, communities depend on communal wells as sources of drinking water. Within the last decade, global pushes for safer drinking water has ensured that most of these wells and water sources, which provide drinking water for rural areas, are clean and potable. (Rickert, Schmoll, Rinehold , & Barrenberg , 2014). Increased demand for food security has also seen a mobilisation of increased agricultural production within many African countries including Uganda. With increased food demand the demand for arable land and water has also increased. This push has often been at the expenditure of natural resources. With poor environmental management these resources can become depleted and irreparable. (MacDonald, et al., 2011)

Uganda is a landlocked country located in Eastern Africa. As of the 2015 census, Uganda has a population of over 39 million people. (AQUASTAT, 2016). With projected population increases and development it is necessary that the current systems in place for agriculture and food production become more sustainable and sufficient for the growing demand. As of 2013 it is estimated that over 14 million hectares of land within Uganda is used for agriculture. (FAO, 2014). As such a large percentage of Uganda's land is used for agriculture, a large amount of water is also required. The country receives, annually, approximately 285km^3/year of rain. (AQUASTAT, 2016) FAO statistics show that approximately 95% of the Ugandan population farms on small-scale farms, which provide food and income. (Kaizzi, 2011).

For regions of Africa, such as Uganda, that experience dry and wet seasons throughout the year, groundwater is essential for the maintenance of this agricultural land and for general livelihood sustenance. (Mwebaze, 2002 & MacDonald, et al., 2011). As approximately 30% of the population lives below the poverty line and are vulnerable to food insecurity, small scale farming plays an important role in ensuring food security, especially in rural communities. (Kaizzi, 2011). The 2010 National Development plan, which strives to improve Uganda's economic situation, strives to build upon the agricultural sector, access and sustainability of resources, creating environments for investment in agriculture and institutional development of the agricultural sector. (Kaizzi, 2011).

To be able to successfully improve productivity within the country it is important that availability of current resources is understood and a sustainable management plan for the utilisation of these resources is created. Without proper management plans for future usages of groundwater, there is the risk of unsustainable resource usage. Most of the current groundwater usages for Uganda are from shallow aquifers, little is known about the availability and existence of deeper water sources. (MacDonald, et al., 2011). The groundwater map of Africa (fig 1) shows that for Uganda most groundwater storage has a depth of 1000mm-25000mm. (MacDonald, et al., 2011)

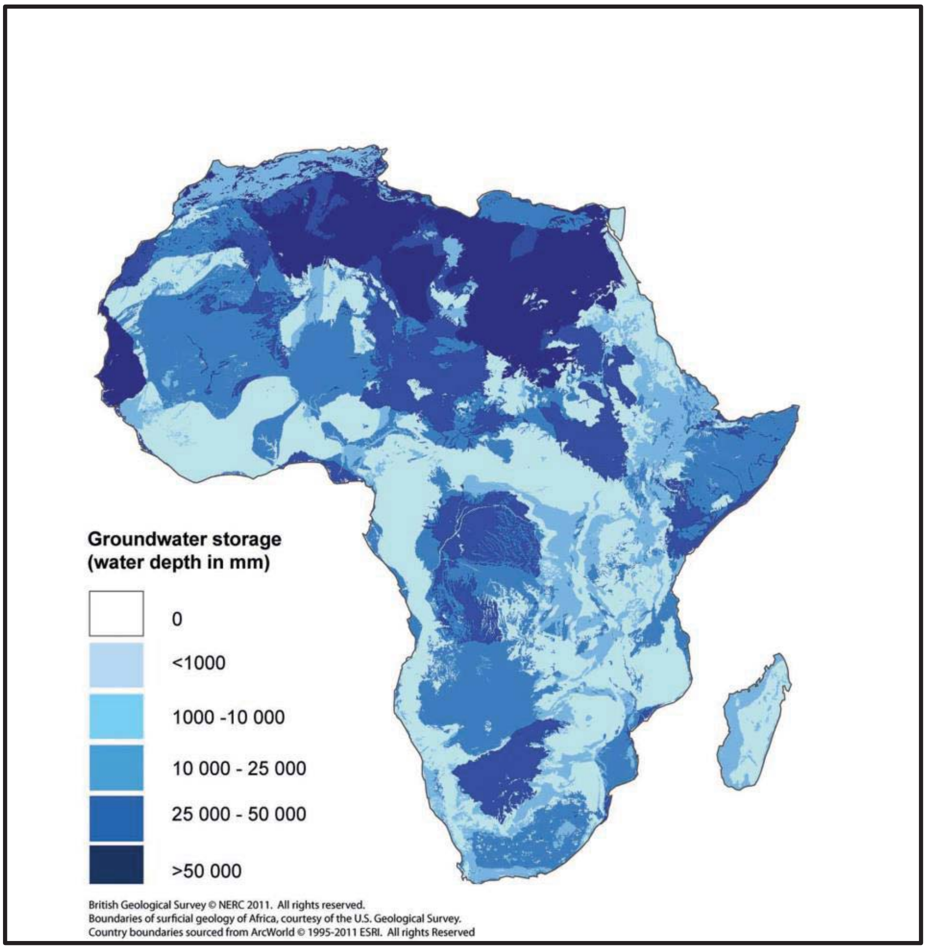


Figure 1: Map of estimated ground water storability of African countries. (MacDonald, et al., 2011)

Without accessibility to multiple drinking water sources the reliance of multiple communities to one aquifer makes these communities vulnerable to changes in aquifer water levels. It is because of these vulnerabilities that resources must be well managed. (Hunt, Strand, & Walker, 2006)

Other natural resources, which many rural communities are dependant on as a source of water are wetlands. Approximately 13% of the countries total area is wetland area. Wetlands are seen as a vital resource both economically and ecologically.
As wetlands are such a stable source of income, small-scale farmers, large-scale farmers and developers are constantly encroaching upon them. (Ugandan Ministry for Natural Resources, 1995).
Many regions of Uganda have extensive areas of natural resources such as rainforests and wetlands. With the increase of intensive farming and population pressures, these natural resources begin to become encroached upon. (FAO, 1997). For years wetlands have been viewed as an income source for both investors and the local community. Along with their ecosystem benefits, the importance of wetlands for local people is extremely high as they are a source of food, water and income generation. Increased awareness on the importance of wetlands has lead to global changes in wetland protection. (Ugandan Ministry for Natural Resources, 1995). Although

Some permanently flooded wetlands have been found to be a recharge and discharge point for groundwater. (Jaros, 2015, USGS, 2013). The interconnection of these two systems indicates that changes to one system can greatly influence the other. Understanding the relationship between groundwater and surface waters is important for managing the usage of the two sources. Interactions between wetlands and groundwater can be sensitive to changes, these interactions are important for the water balance of each system. (Hunt, Strand, & Walker, 2006). Hydrological relationships between the two systems can often times be dynamic relationships depending on the availability of water input to the two sources. (Hunt, Strand, & Walker, 2006). The dominating process can change seasonally depending on precipitation and temperatures.

1.2 Purpose of study

Much study has been conducted on wetlands and ground water systems. In recent years there has been increased awareness on wetland system services and how agriculture has impacted wetlands. Although there is much research conducted on ecological importance of wetlands there is little data available on how wetlands influence the hydrological cycle. As the importance of wetlands to the hydrological system is unique for each region it can be difficult to apply findings of one area to another. Groundwater surface water interactions can be difficult to quantify, as they are usually dynamic relationships, which are also dependent on other hydrological factors. In some instances wetlands are a recharge and/or discharge point for groundwater.

The main purpose of the study is to simulate the current natural process of the area, with regards to the relationship between surface water and groundwater processes, using hydrological modeling programs. The importance of understanding how local communities rely on natural resources and their vulnerability to change is also an important factor to consider alongside the environmental impacts. By creating a simulated model of the study area predicted future climate forecasts can also be applied to models and make educated assumptions on how this will change the relationship between the groundwater and the wetland and the impact on the community.

The chosen study area is a segment of the Nawangisa wetland found in the Iganga district of Uganda. The area was chosen, as there were clear boundaries to the wetland and groundwater in that area. Data collected for the study included long term data and also data collected from fieldwork conducted in January 2016. Simulation of the wetland aims to show the hydrological processes of a wetland over a period of a year.

There is currently little data available on the hydrogeological processes of the study area. This research along with the CAPSNAC project has allowed for the region to receive better information with regards to the natural processes occurring in the area. As an example, a weather station has now been installed within the study area. It is hoped that this weather station can continue to provide data for future projects within the region. It is hoped that the findings of this projects can assist others in similar studies and provide data for studies in the same region.

It is hypothesised that results will show a dynamic hydraulic relationship between the groundwater and wetland with regards to recharge and discharge. It is also hypothesised that the main driver for these changes in water exchange between the groundwater and wetland interactions is from seasonal changes in precipitation.

2. Theory

2.1 Soil and groundwater interaction

The study of soil properties is crucial in the understanding of water flow and the transport of solutes within the groundwater system. (Alvarez-Acosta et al, 2012). Groundwater is defined as the water, which is found within the saturated zone of soils. The understanding of soil directly relates to ground water characteristics such as how; water infiltrates from the surface to aquifers, runoff of water from the surface, aquifer depth, flow of water within aquifers and aquifer boundaries. Soils can be defined by their textural class, which in turn can assist in identifying which regions groundwater is most likely present. (Schwartz & Zhang, 2002). The three main soil classifiers are sand, silt and clay; soils are classified based on their content of these three identifiers. (Schwartz & Zhang, 2002). Characteristics of soil can indicate how easily soil will infiltrate to aquifers and also the amount of runoff that is likely to occur in the area. Soil characteristics not only highly influence aquifer quality but also the way that land is used. (Schwartz & Zhang, 2002). Land usage for agricultural purposes is highly dependent on the quality of soils and also the type of soils, which are present.

The geomorphic makeup of the Uganda mostly consists of Precambrian crystalline rocks with some sedimentary igneous rocks also present in some areas. (British Geologicla survey, 2001). Soil mapping allows for the estimation of where aquifers may be found and their size. Remote sensing, terrain analysis and environmental assessment techniques are used to develop soil maps.

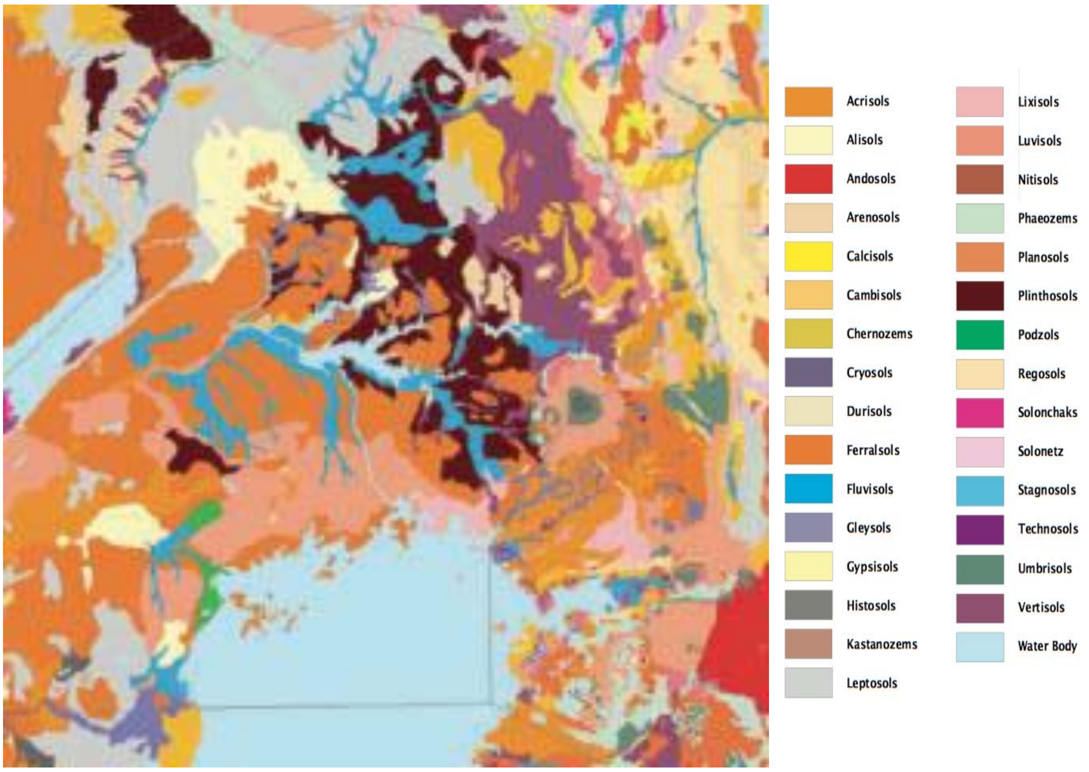


Figure 2 Uganda's section of the European Commission's African Soil Atlas at 1:5,000,000 scale. (Jones, et al., 2013)

The African soil atlas shows that within the Iganga district of Uganda, the major soil types are luvisols and fluvisols. Luvisols are soils with higher clay content and are suitable for agriculture usage due to their water storing capabilities. (Jones, et al., 2013). Fluvisols are characterized as soils, which occur in areas that are periodically flooded, such as those surrounding water bodies that have fluctuation water levels. (Jones, et al., 2013). The texture of these soils is dependent on the velocity of the surrounding water bodies. (Jones, et al., 2013). The vicinity of the soils to a water source also means that the soils are usually high in organic matter. (Jones, et al., 2013). For soils surrounding the wetland, that has a low flow velocity, it can be assumed that the soil is fine in grain size.

Research on aquifer properties is heavily focused on soils. Without understanding of the soils it is impossible to quantify the processes of an aquifer.
Soils have a large influence on groundwater quality, as they are able to act as barriers for pollutants. According to the Environmental Protection Agency (EPA), agricultural

non-point source pollutants are the biggest source of groundwater contamination. (EPA, 2008).

Unconfined aquifers of shallow or intermediate depth are usually dominated by horizontal flow of water within the aquifer. Whilst soil characteristics such as hydraulic conductivity and porosity of soils influence the speed at which water flows the hydraulic head of the aquifer determines the direction of flow of groundwater. The movement of water in aquifers is caused by changes of energy within the aquifer. The hydraulic head determines the amount of energy that is available for groundwater flow (Schwartz & Zhang, 2002). Flow occurs by water moving from areas of high hydraulic head to areas of low hydraulic head.

2.1.1 Groundwater storage and movement

The ability for an aquifer to store water is defined as the storativity of an aquifer. (Schwartz & Zhang, 2002). Understanding of the water storage of aquifers is important for developing groundwater management plans. The storativity of unconfined aquifers is given by the formula:

$$S = S_y + bS_s$$

Where:
S = storativity
S_y = specific yield
b =aquifer thickness
S_s = Specific storage

The specific yield of an aquifer is defined as the amount of water that can be drained from the aquifer by gravity. (Schwartz & Zhang, 2002). The storativity of unconfined aquifers is therefore equal to the specific yield.

Transmissivity of an aquifer is defined as “the ease at which water moves through an aquifer.” (Schwartz & Zhang, 2002). It is given by the formula:

$$T=bK$$

Where:
T= transmissivity
b= aquifer thickness
K = hydraulic conductivity

2.1.2 Hydraulic conductivity

Hydraulic conductivity of soils is a characteristic of how soils are able to retain water and allow water flow through soils, either vertically or horizontally. (Stibinger, 2014). Understanding the hydraulic conductivity of soils allows for the calculation of how pollutants will be transported within groundwater systems. Within scientific literature, hydraulic conductivity is represented by the letter K or the K-value. The K- value is measured as a function of velocity, distance (M) and time (T). (Stibinger, 2014). Soil characteristics such as, grain size, porosity and permeability all influence the K-value of the soils. Soils of high hydraulic conductivities, such as sand, have higher permeability and allow for less restricted water flow. Soils of low hydraulic conductivity and low permeability such as soils of high clay content restrict flow and act as confining layers within aquifers.

There are many methods for calculating hydraulic conductivity; they can be conducted either in field or within a laboratory. All methods for determining hydraulic conductivity have their pros and cons. In many instances of laboratory analysis it can be assumed that the calculated hydraulic conductivities are not true measurements of soil origin as the samples have been disturbed and do not retain the original structure. (Mahmoodinobar, 2014)

Field measurements for determining hydraulic conductivity include slug tests, Permeameter tests, single-ring infiltration tests and double-ring infiltration tests. (Stibinger, 2014). Benefits of conducting field tests for determining hydraulic conductivity include that soil structure is not disturbed and can usually be conducted quickly and cheaply. (Johnson, 1991)

Infiltration tests, such as double ring infiltration tests, measure the rate at which water passes through soil. For the calculation of saturated hydraulic conductivity it can be assumed that the infiltration rate is equal to the value of the soils saturated hydraulic conductivity. (Stibinger, 2014).

Hvorlev's method is one such method, which can be employed for the calculation of hydraulic conductivity from slug tests.

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

Where:
R = filter radius
R = Radius of the pipe
L= length of the filter

(Fabbri , Ortombina, & Piccinini, 2012)

2.1.3 Darcy's Law

For laboratory measurement of hydraulic conductivity within a homogenous soil sample, the Darcy experiment can be conducted and the hydraulic conductivity measured using Darcy's law. Darcy's law was developed in 1978 by French hydrologist Henry Darcy. (Schwartz & Zhang, 2002). By using a cylindrical apparatus with a known cross-sectional area, filled with sand water could be applied

$$Q = KiA \qquad \text{or} \qquad q = Ki$$

Where
Q = water flow in quantity of time
q = specific discharge
K= Hydraulic conductivity
A = Area

i = Hydraulic gradient

The Darcy equation can be rearranged so the K value is the unknown.

$$K = \frac{q}{i}$$

(Darcy, 1856)

Darcy's apparatus that was used to develop the Darcy law has also been used to develop other formulas with regards to water storage and movement within soils.

2.1.4 Recharge

Recharge of aquifers is defined as the amount of water, which enters the aquifer either from precipitation or surface waters as a measure of volume (L^3) over area (m^3). (Nimmo, Healy , & Stonestrom, 2005). Recharge of groundwater can occur through multiple processes. The dominant process for recharge is usually precipitation but recharge from surface waters, such as rivers and streams, and agricultural irrigation can also occur. In areas where potential evapotranspiration exceeds the rate of surface water infiltration there is no recharge. (Kinzelbach, et al., 2002). To understand the hydraulic processes occurring within certain regions, the recharge of the area must be well understood. (Nimmo, Healy , & Stonestrom, 2005).

Groundwater recharge can be irregular and difficult to estimate, as there is multiple factors in determining recharge rates. (Kinzelbach, et al., 2002). Seasonal fluctuations in precipitation influences recharge rates throughout the year. For areas that are dominated by recharge through precipitation in periods of low rainfall the recharge rate of aquifers can dramatically decrease. In areas that have aquifer recharge occurring through both precipitation and water bodies, the fluctuation in groundwater can be

Two empirical methods for calculating groundwater recharge are explained.

Groundwater measurements

$$R = Sy \frac{\Delta h}{\Delta t}$$

Where

R = recharge

S_y = specific yield

Δh = change in head

Δt = change in time

Groundwater measurements can also be used for determining the recharge of an aquifer. Although this method is relatively simple it does not differentiate whether recharge is occurring via infiltration from precipitation or as discharge from connected water bodies.

Recharge calculations based can also be conducted based on precipitation data. In 1973 Senghal developed a method for measuring recharge using precipitation data, called the Amritsar formula (Rawat, Mishra, Paul, & Kumar, 2012).

$$R = 2.5(P - 0.6)^{0.5}$$

Where

R = recharge

P = precipitation in inches (annual rainfall).

Empirical methods for the calculation of recharge can be lengthy and complicated. For crude estimated values of recharge rates it can be estimated that 5% of total precipitation is equal to recharge. (Schwartz & Zhang, 2002)

2.1.5 Evapotranspiration

Evapotranspiration is defined as "the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants". (Oxford University, 2010). The measurement of evapotranspiration can be difficult as land cover usage influences the rate of evapotranspiration. Evapotranspiration greatly influences the amount of precipitation that is available as recharge to aquifers. (Schwartz & Zhang, 2002), There are multiple empirical methods for calculating the rate of evapotranspiration. One of the more widely used methods is the Thornthwaite equation.

The Thornthwaite equation can be used to estimate potential evapotranspiration. (Schwartz & Zhang, 2002).

$$E_T = 1.62(\frac{10T_{ai}}{I})^a$$

Where:

E_T = Evapotranspiration (cm/month)

T_{ai} = Mean monthly air temperature in °c for the month i

I = Annual heat index

a = Exponential constant

The annual heat index can be found using the formula

$$I = \sum_{i=1}^{12}(\frac{10T_{ai}}{5})^{1.5}$$

The exponential constant a can be found using the formula

$$a = 0.492 + 0.0179I - 0.0000771I^2 + 0.000000675I^3$$

2.1.6 Groundwater management in Uganda

Uganda's current groundwater usage is at relatively moderate levels. With projected development increases in the country's economy the demand for water is projected to far higher levels from industry demands. Currently the major usage of Ugandan groundwater is for drinking. According to Uganda's ministry of water and environment the total amount of available freshwater as of 2009 is 2170m^3 per capita. (Tindimugaya, 2010). Currently there at 20,000 protected wells and 12,000 protected springs within Uganda. (Tindimugaya, 2010)

Monitoring of groundwater involves the management of resources, management of quantity and use and also management of quality. (Chevalking, Knoop, & van Steenbergen, 2008)
Management of resources involves the understanding of where groundwater can be found, the accessibility of the groundwater and also groundwater quality. Resource management also includes the management of man-made resources such as wells and boreholes. (Chevalking, Knoop, & van Steenbergen, 2008).
Management of quantity involves quantifying the amount of groundwater, which is available and understanding how much groundwater can be used without rapidly depleting the resource. The main objective of groundwater management is to avoid point pollution and also prevent unsustainable usage. (Chevalking, Knoop, & van Steenbergen, 2008).
Management of groundwater quality includes ensuring that groundwater is safe for people to drink. Pollution from point sources and also pollution of connected systems such as wetlands can make groundwater unsafe for drinking. (Chevalking, Knoop, & van Steenbergen, 2008)

Groundwater modelling is a useful tool for simulating aquifer processes such as movement of groundwater, water source and discharge point. (Chevalking, Knoop, & van Steenbergen, 2008). With a comprehensive understanding of aquifers properties a simulation can be created. Using simulations predictions for increased pumping or decreased recharge rates can be applied to observe changes to the groundwater table.

2.1.7 Groundwater usage by the community

For many for many of the rural communities of Uganda, groundwater is the main source of fresh water. For the two townships adjacent to the Nawangisa wetland groundwater is also the main source of fresh water used in everyday life. The groundwater is used for drinking and is usually not boiled before consumption.

Figure 3 **Children collect water from communal wells in Nawangisa township (image taken by author).**

Townspeople take daily trips to communal wells where they pay a small fee to fill jerry cans with water. Water is manually pumped from these wells. In many families it is the younger children who are given this task of water collection.
Installation of pumps for running water is too expensive for most of the community as the major income for the village is through small-scale agriculture.

The Iganga district government installs the communal wells. The district authority is also responsible for the maintenance of these wells. The high reliance of the two communities on groundwater shows the vulnerability of the townships to changes in availability of groundwater.

2.2 Wetlands

2.2.1 Theory

Around the globe wetlands can be found, varying in characteristics from shape, size, water source and quality. It is estimated that approximately 6% of the total area of the earth is comprised of wetlands. This number is often changing due to anthropogenic influences such as wetland degradation and climate change.
As part of the Ramsar convention in 1971, a definition for wetlands was developed and agreed upon as “areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres.” (Barbier, Acreman, & Knowler, 1997).

Wetlands can be split into two main types, coastal or terrestrial, coastal wetlands occur as marshes in areas that are constantly or periodically inundated by seawater, whereas terrestrial wetlands occur inland and can have multiple sources of water. Wetlands can be further categorised based on their hydrological features such as their water source, wether it be from groundwater, surface water or precipitation, and where water is released. For some wetlands, seasonal changes influence these hydrological relationships. Wetlands are dynamic and play an important role in the hydrological cycle as both a receiver and contributor of water to both groundwater and surface waters.

The biggest causes of wetland degradation are from the increasing demand for soils and water. Soil types found within wetlands are dependant on the geology of the area and the water source of the wetland. For wetlands mostly fed from precipitation and surface runoff, soils found at the base are characterised by the soils around the wetland. Wetlands fed from upstream currents usually have soils characterised by the geology of the region where the water source originates.

A study conducted on the economic value of wetlands found that the 63 million hectares of wetlands around the world had an approximate economic value of $3.4 billion per year. (Russi, et al., 2013). The application of economic value to natural resources can be difficult as many variables are not included. The value of wetlands to the environment, such as with regards to biodiversity, is often not considered. (Russi, et al., 2013). Previously the common view of wetlands was that they were unusable areas and more productive if drained and used as agricultural land. The costs of wetland destruction were viewed to be more economically viable than to allow them to remain. This approach to wetland management is extremely short sighted.

Approximately 10 of Uganda's total land area are identified as wetlands. Ugandan wetlands are used traditionally for fishing areas and vegetation within the area can be used for crafts. Areas surrounding the wetlands are also used for agriculture and cattle grazing. (Ugandan Ministry for Natural Resources, 1995). Currently, all wetlands within the country are protected under the Country's government ministry of Environmental Protection. In 1995 the ministry developed a policy in response to continued wetland degradation within the country. (Ugandan Ministry for Natural Resources, 1995).

It has been found that wetland destruction has multitudes of negative impacts including increased area flooding. Wetlands have been proven to act as storage basins of water especially during rapid downpours in regions with soils that have poor infiltration rates. Farming within wetlands and along wetland edges usually entail creating canals so that water is diverted from areas of the wetland to expose

The high sensitivity of wetlands to changing hydraulic conditions makes them vulnerable to the predicted changing climatic conditions and also loss of groundwater by poor management. (Kazezyılmaz-Alhan, 2011)

The residence time and flow rate of water within a wetland plays an important role in the deposition of sediments into the wetland. Wetland flow rate is defined as the time it takes a unit of water to pass from the point of input to the point of output.

$$Q_{flow} = VA$$

Where:
Q = flow rate
V = velocity
A = area

Factors such as vegetation density can greatly influence the flow rate of wetlands by altering the hydraulic conductivity of the water. The diffusion wave theory equation can be modified to one, which considers the reduction of flow rate due to vegetation within the wetland. (Kazezyılmaz-Alhan, 2011). The theory can be used on wetlands with low slope gradients. (Kazezyılmaz-Alhan, 2011). Kadlec and Knight developed a law in 1996 based on this equation. The law comprises of two equations based on wetland density.

$$Q = \begin{cases} K_d W y^3 S_0 & \textit{Dense vegetation} \\ K_s W y^3 S_0 & \textit{Sparse vegetation} \end{cases}$$

Where:

Q = flow rate

Wy = cross sectional area

S_0 = bottom slope

K_d = dense vegetation coefficient $1x10^7$ m/d

K_s =sparse vegetation coefficient $5x10^7$ m/d

(Kazezyılmaz-Alhan, 2011)

For some wetlands vegetation can be extremely dense within the wetland. The density of vegetation within wetlands can be seasonal and also impacted by cultivation of these plants.

Papyrus wetlands such as that of the study area are common to Central, Eastern and Southern Africa. (van Dam, Kipkemboi, Zaal, & Okeyo-Owuor, 2011). *Cyperus Papyrus* is a type of sedge that grows on and around fresh water bodies such as wetlands and lakes. (van Dam, Kipkemboi, Zaal, & Okeyo-Owuor, 2011). Papyrus plants are extremely important for many ecosystem functions within wetlands and many African communities also rely on the as a source of crafting material. Papyrus plants can grow extremely densely to a height of 5m under optimal conditions. (van Dam, Kipkemboi, Zaal, & Okeyo-Owuor, 2011). The density at which papyrus can grow on water surfaces and their root systems can impact the flow rate at which the water moves through the wetland. A study conducted by Kadlec and Wallace (2009) found that many popular crop types used in wetlands are unable to remove nitrogen as efficiently as Papyrus.

Ugandan wetlands are all owned and protected by the government but increasingly adjacent landowners and also landless people have encroached upon them. Wetland destruction has also been caused due to development especially in areas nearby the capital city of Kampala. By altering the natural ecosystem of the wetland many ecosystem benefits such as nitrogen removal are also reduced.

By improving the understanding of wetland functions and their ecosystem benefits better strategy plans can be developed for ensuring sustainable usage of wetlands.

2.2.2 Usage by the community

Wetlands are a major source of income and food for many rural communities. Within the study area, both communities living on either side of the wetland utilise the area for both farming and fishing. The wetland is also a major source of water for villagers, with people using it for washing clothes and vehicles. As collecting groundwater from the communal wells requires a fee, many people use wetland water for non-consumption related purposes. Image 4 shows two local boys who have caught fish from the wetland.

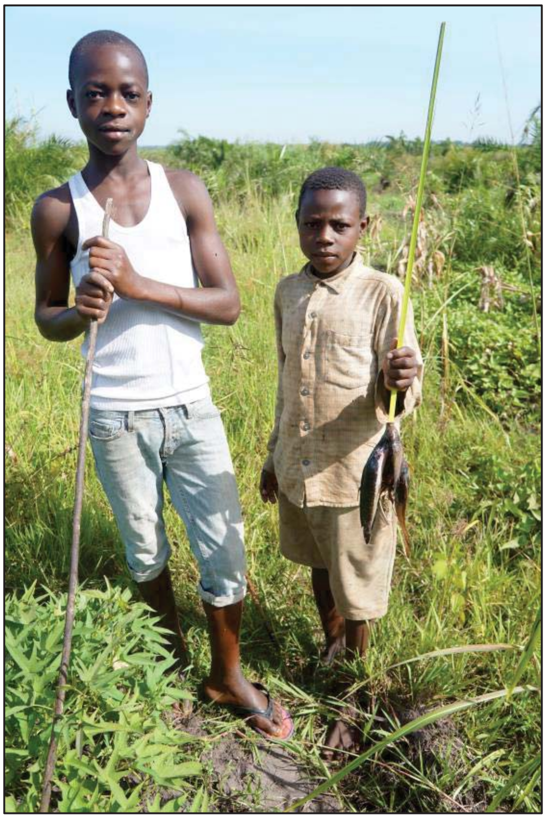


Figure 4 **Children showing their fish, which have been caught in the wetland (image taken by author)**

Many landowners with land adjacent to the wetland also believe that parts of the wetland are part of their ownership area.

On both the eastern and western edges of the wetland rice was being grown within the transition zone of the wetland. Just like in many other wetland regions within Uganda, each year the edges of these rice patties encroach further and further into the wetland. The creation of these patties can influence wetland flow as water is usually diverted from these areas.

The local people also used the papyrus plants found within the wetland for multiple purposes. The stems of the papyrus are hollow making them extremely light yet strong. Traditional mats, which are dyed to display geometric patterns, are a popular craft item made from the papyrus stems. Larger items, such as fences and huts can also be made from the papyrus plant.
These craft usages of the papyrus is a source of income for many women living in rural areas such as Butangole and Nawangisa

The Nawangisa wetland plays an important role in the livelihoods of both the Butangole and Nawangisa township residence. It is not only those who live on the wetland edge who benefit from the wetland but everyone within the community.

2.3 Groundwater Wetland interactions

2.3.1 Theory

Water resource management can only be affectively developed and applied when there is a holistic understanding of the water resources of a region.
Depending on the features of an areas landscape the relationship between surface waters and ground water can be significantly different. (Kazezyılmaz-Alhan, 2011). Whether wetlands gain water from above or below surface sources can change directly based on topography, climate and geology. Quantifying relationships between groundwater and surface water systems is important when monitoring contamination of either system. Connection of the two systems implies that contamination of one can potentially lead to the contamination of the other. (Hunt, Strand, & Walker, 2006). As surface waters can also receive recharge through runoff from the surrounding landscape it is at a higher risk of contamination than that of the groundwater. (USGS, 2013). By understanding how the surface water interacts with the wetland better management plans can be developed to prevent the contamination of groundwater from surface water infiltration and also for restoration. (Jaros, 2015).

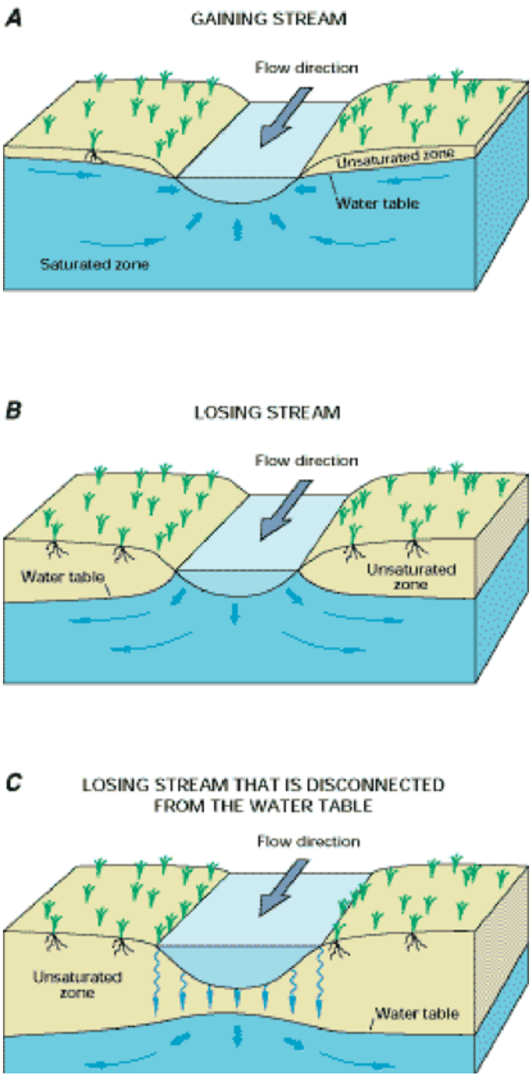


Figure 5 Differing types of hydraulic relationships between groundwater and surface water (USGS, 2013)

Figure 5 displays the 3 different ways, which groundwater and surface waters can interact with each other. (USGS, 2013),
The determining factor in whether a stream is either gaining or losing is from the height of the water table. For some systems the relationship between the surface water

and groundwater does not change throughout the year. This is usually observed in locations with steady precipitation rates throughout the year. For other locations the relationship between groundwater and surfacewater is dynamic and changes with the rate of recharge via precipitation. These types of relationships are usually observed in regions of low gradient and fluctuations in seasonal recharge rates. (USGS, 2013)

Losing streams occur from two major processes, firstly they can occur when there is an influx of water to the surface water body causing the elevation of the surface to higher than that of the groundwater table. (USGS, 2013). The other cause for a losing stream to occur is when wells are connected to the groundwater and the pumping rate is high enough to reduce the groundwater table to such an extent that it is below the elevation of the surface water body. (USGS, 2013). It is common for a surface water body to be gaining in some areas whilst losing in others.

Gaining streams occur when groundwater is infiltrating into the surface water. In locations where the elevation of the streambed is below that of the water table a gaining stream occurs. The hydraulic head determines the direction of exchange flow between groundwater and surface water. (USGS, 2013).

Discharge of surface waters to groundwater can create problems with groundwater quality. Measurements of water exchange between the two systems allows for clear understanding of the processes occurring within an aquifer. (Changnon , Huff, & Hsu, 1988). There are multiple methods, which can be employed for measuring the change in water flux between the two systems. Soil texture and classification play an important role in the exchange of water between groundwater and wetlands. The basins of surface water bodies are usually comprised of fine sediments the grain sixe of these sediments and their porosity determines how easily water will flow through the medium. (USGS, 2013). Core samples of surface water basins can be taken to measure the hydraulic conductivity of the soil. The depth of the surface water basin also plays an important role in the exchange of water between the two systems.

Empirical methods can be used for determining whether there is groundwater recharge or discharge occurring. Groundwater interaction with surface water can often

be dynamic, ranging from periods of discharge and periods or recharge.
(Kazezyılmaz-Alhan, 2011)

$$q_{drch} = -K_x \frac{\partial_h}{\partial_x} \begin{cases} < 0 & Groundwater\ recharge \\ > 0 & Groundwater\ discharge \end{cases}$$

Where:
h = total head
K_x= horizontal hydraulic conductivity
X = length of aquifer.

(Kazezyılmaz-Alhan, 2011)

As both groundwater and surface water processes are so closely interconnected changes to one system will inturn impact the other. It is because of this close relationship between the two systems that studying the processes involved between the two is crucial for management of both resources. Destruction of surface water sources such as streams and wetlands will inturn impact the water table when the surface water is a source of recharge for groundwater. (Kazezyılmaz-Alhan, 2011) In turn the lowering of the water table through over pumping of water could in turn cause surface water sources to dry out in cases where the groundwater is the main source of water.

Modelling can be used to predict how much precipitation must change to be cause a change in the relationship. The objective of transient simulation is generally to predict head distributions at successive times, given the initial head distribution, the boundary condition, the hydraulic parameters, and the external stresses. (Jaros, 2015). By understanding the head distributions of a system the flow of water within the system can also be obtained.

3. Study area

Figure 6 **Google map image of the study area**

(Image acquired from Google Earth)

Data collection occurred in Eastern Uganda between the two communities of Nawangisa and Butangole that surround the Naigombwa wetlands. The study area is located in the Iganga district of Uganda. The district is comprised of 12 sub counties, 66 parishes and 371 villages. (UBOS, 2009). Nawangisa and Butangole are two small villages of the district. The region was selected as it provided a section of the Naigombwa wetland that was enclosed by a railroad and road. The benefit of using an enclosed area was that boundaries were easily defined and a smaller area could be studied as a representation of the hydraulic system of the wetland. The two townships are identified as rural townships with low-income rates for most families. (UBOS, 2009)

The region of Iganga receives an average annual rainfall of approximately 1140mm per annum. (FAO, 1997). This precipitation rate is important as the cropland is not well irrigated and is dependent on rainwater for sustenance. Agriculture for the region is extremely important for ensuring livelihood wellbeing for the communities, as small-scale farming is the major source of income and food. (UBOS, 2009).

Groundwater and water from the wetland are the two main sources of water for the two communities. There are multiple, district built and managed, community wells throughout the two communities. The Ugandan government owns the Naigombwa wetland but there is little regulation on the wetland usage and encroachment from agriculture. (British Geologicla survey, 2001)

The major source of income to both communities is through agriculture with multiple farms growing sweet potatoes maize and cassava. (UBOS, 2009). Land surrounding the wetland edge is fairly intensively farmed with variations in crops along the edge. Cattle grazing also occurs in the along the wetland edge.

As both communities are so reliant of both the groundwater and the wetland for livelihoods it is important to understand the processes of the two systems to develop and implement sustainable management plans for the system.

Currently there is little quantified data for the hydraulic processes of the community. Knowledge of system processes is mainly compiled from observations from the local townspeople. As part of the project there was also brief dialog with the community and its leaders on the usage of the wetland and groundwater and the general observations of changes between periods of wet and dry seasons. This information was incorporated into the study to aid in result analysis.

4. Modelling

4.1 ModelMuse program description

For the simulation of the study area, USGS's developed modelling program, Modelmuse was selected as the modelling software. ModelMuse is a relatively new and free program. It was first released in 2006, developed as a graphical user interface for the pre-existing programs, MODFLOW- 2005 and PHAST. (Winston, 2009). The current version is now a revision that was released August 2015. The program allows for the creation of 3-D models of varying groundwater systems. The program itself is relatively user friendly; users are able to define many features of their selected study area. Multiple aquifer systems both confined and unconfined, either steady or transient can be created using the program. The main window of the program allows the user to view the model from multiple angles including top, side, front and a 3-D view.

ModelMuse is based on the concept of a grid system for defining area and layers allowing users to define the grid sizing and layer number at the beginning of the modelling process. Users are able to define the spatial and temporal data independent of the grid area and stress periods, respectively. The ability for the user to create objects within the program and (Winston, 2009)

The modelmuse program includes multiple package add-ons. These packages allow for the user to determine which add-ons are relevant for their study and adjust the program accordingly. One such package available within the program is the CHD program; it allows the user to apply a time variant head for transient study areas; for studies on steady state systems the package does not need to be activated.

4.2 Conceptual Models

A conceptual model acts as a basic guide for the creation of a simulated study area. It uses basic knowledge of the study area to create a simple representation of the system, which can be further built upon as more data is collected. The creation of conceptual models can aid in reducing problems during the modelling process due to poor design and preparation. (Kupfersberger, 2008). Conceptual models can allow the designer to see problems within their model design early in the process, especially with regards to the spatial definition of the model. (Kupfersberger, 2008).

For this study two concept models were created as a guide for the creation of the study models, cross- sectional and overview.

4.2.1 Cross Sectional

The cross sectional concept model gives a cross sectional image of the study area. The design of the model does not give a real representation of the shape of the wetland basin, as the purpose of this model design is to be simple depiction of the study area. The purpose of designing a model in such a way is so that the interaction of water from the groundwater to the wetland or visa versa can be easily observed.

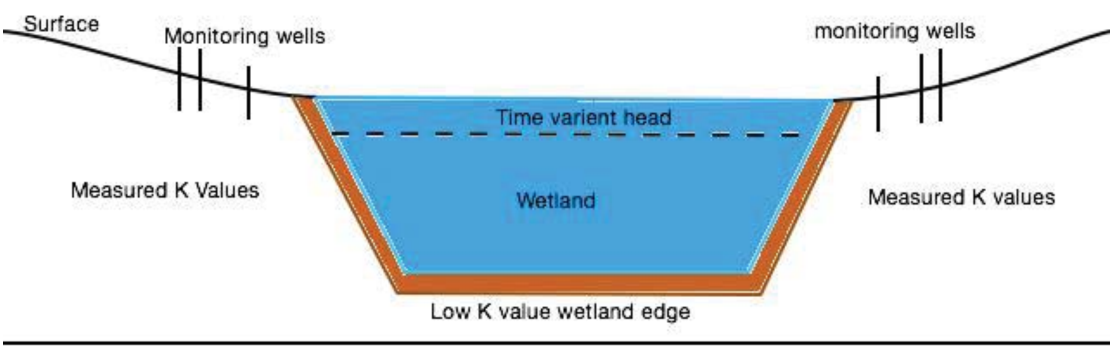


Figure 7 Cross sectional concept map of the study area

4.2.2 Top view

The top view concept model is a top view of the planned model, which will include the entirety of the study area as per boundaries (both natural and man-made). Surface elevation from topography data and wetland depth from collected survey data. This model was designed to show a true representation of the study area, unlike the cross sectional model, which is a basic interpretation.

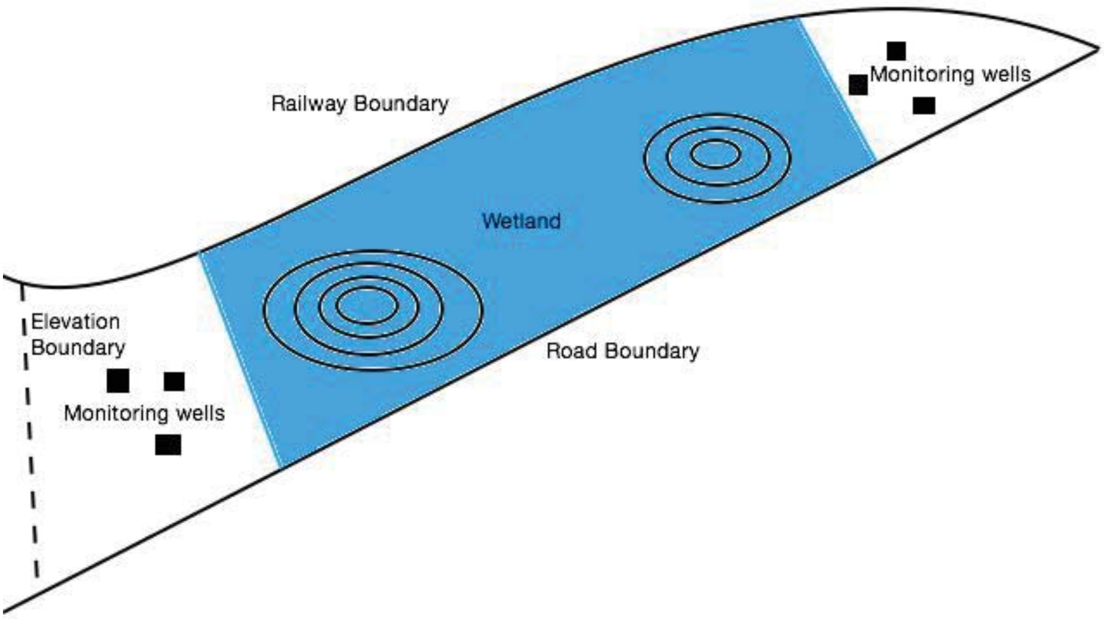


Figure 8 Concept map for the simulation of the study area and it's hydrogeological processes.

5. Methods

5.2 Long term data collection

For long-term data collection, the local community of both Nawangisa and Butangole assisted. The CAPSNAC project funded long-term data collection as part of Ellen Kayandeke's PhD research. People from the surrounding villages were employed to assist in data collection from July 2015 to present.

5.2.1 Weather monitoring

For weather monitoring a weather station was constructed in the village of Nawangisa. The weather station produces monthly reports on the temperature (°c) rainfall (mm) and wind speed and direction (km/hr). An example of the monthly reports from the weather station can be found in the appendix. As the weather station is located on a local villagers land a small rental price is paid to the landowner for rental and also protection and maintenance.
Data from the weather station, which was used in this study, came from the period of July 2015 – February 2016. This data does not give a representation of the climatic conditions of the region, as the period of data collection is too short.

5.2.2 Groundwater monitoring

For the monitoring of groundwater levels in the vicinity of the wetland, daily reading of water levels within the six boreholes was conducted. Readings were taken twice a day using tape measures. Discrepancy in data was altered as an average of previous readings and future readings.

5.2.3 Wetland level monitoring

Two staff gauges within the wetland were used in measuring the change in the water level. Measurement of these gauges were completed twice daily at approximately the same time that groundwater measurements were taken.

5.3 Field work

5.3.1 Hydraulic Conductivity

For the analysis of hydraulic conductivity both slug tests and double ring infiltration tests were conducted. The purpose for having multiple methods for conducting hydraulic conductivity is to ensure that results can be compared from each method to improve accuracy. Each method includes a certain margin of error, which can be reduced from conducting multiple tests.

5.3.2 Slug tests

Slug tests were conducted from the six existing boreholes within the study area, on the Western and Eastern side of the wetland. The tests were conducted on the 7th and 8th of January 2016. The boreholes were constructed as monitoring wells as part of the CAPSNAC project. Each borehole included pipes of varying depth with a width of 5.08 cm. Each pipe was fitted with a filter material at the base to avoid debris from entering the pipe and causing blockages. The rising head slug test method was used for this study. To conduct slug tests the water level within the boreholes were measured and then the boreholes were manually pumped empty of water with records of the time taken to reach steady state was noted. Steady state is defined as three consecutive measurements of the same infiltration rate. Measurements for infiltration of water were taken at time intervals:

Once per minute for the first 5 minutes

Once every 5 minutes from 5-30 minutes

Once every 10 minutes from 30-60 minutes

Once every 20 minutes from 60 – 120 minutes

Once every 60 minutes until steady state was reached.

Measurements can be found within the appendix.

Hydraulic conductivity was conducted using the Hvorslev’s method.

(h-H)/(h0-H)

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

Where:

R = filter radius

r = Radius of the pipe

L= length of the filter

Figure 9 Slug test analysis on borehole 2 during fieldwork. (image taken by author)

As there were some uncertainties about the collected measurements during the slug tests, measurements from July 2015 were also used to provide additional accuracy to the hydraulic conductivity calculation. Medium values of 2015 and 2016 results were used as final values. Results from the 2015 slug tests can be found in the appendix.

5.3.3 Infiltration tests

Double ring infiltration tests were conducted at two locations in the study area, on either side of the wetland. The purpose of using double ring tests is to determine how long it takes for water to infiltrate through the soil before it reaches steady state. To conduct a double ring infiltration test two rings of different sizes were hammered evenly into the ground, with the smaller ring within the larger ring. All loose debris was removed from the area before the test began. A ruler was placed above the centre ring. (Image 10 shows the correct setup of a double ring infiltration test)

Figure 10 Double ring infiltration test conducted on the Eastern side of the aquifer during fieldwork (image taken by author)

Water was added to both enclosures of the two rings. For the inner ring water was added until the 220 mark of the ruler. A timer was started and water was refilled in the inner ring to 220 each time the water dropped to 9.5 on the ruler. It was always ensured that there was water within each ring. Measurements of the water level within the inner ring were recorded at the rate of once a minute for the first 5 min, once every 5 min until 30 min was reached, once every 10 min until 60 min was reached, once every 20 min until 120 min then once every 60 min until steady state was reached.

5.3 Soil Analysis

5.3.1 Collection

Soil sampling was conducted over 3 days starting on the 13/01/2016. For the collection of soil samples the study area was categorised into sections. The study area was split into two areas the east and the west each area was then sectioned into the 5 zones based on distance from the wetland edge. The first zone was defined as the transition zone and was contained as a 3m band around the wetland edge. The second zone included the area of 100m distance away from the wetland. Zone number 3 included the area of 100-200m away from the wetland. Zone 4 included the area of 200-300m away from the wetland. Zone 5 included the area of 300-400m from the wetland. It was planned to include a sixth zone but the area was found to be settlement area.

Once zones were developed the method for soil sample collection was developed. Within each zone land use types were identified. Within the study area the surrounding land around the wetland was mostly comprised of agricultural land. Within the zones when a new land use area was found a sample was taken.

Figure 11 Image of soil sample collection using an auger during fieldwork (image taken by author)

An auger was used for the collection of soil samples. The augur was used to collect samples of soil at 0-15cm depths and 15-30cm depths. To ensure that the soil samples gave a good representation of the area, 3 samples were taken at each land use area in each zone.

The image above displays how the auger was used to collect soil samples. The three samples collected at the soil depth of 0-15 cm from each land use area in each zone were mixed together in a collection tray. Of the mixed sample a small portion was taken and tagged for lab analysis. The same technique was used for soil samples taken at the 15-30cm depths. In total 90 soil samples were collected from the study area.

5.3.2 Lab analysis

For soil analysis the samples were taken to the Soil Science faculty at Makerere University in Kampala, Uganda. The samples were analysed for the following properties:

- Texture
- CEC
- Chemical Properties
    - Calcium
    - Magnesium
    - Potassium
    - Nitrogen
    - Phosphorous
- Bulk Density
- Classification
- Organic matter content
- Pore size
- Particle size

For some samples it was found that there was not enough material for a complete analysis.

5.4 Surveying

Surveying of the wetland was conducted by a local Survey company from Mbale to determine the shape of the wetland base through elevation data. To complete the survey five transects were created within the wetland. Transects were created by cutting papyrus stems and making a path across the wetland by laying the plants across each other. As the papyrus is a buoyant plant, by placing multiple layers across each other it was possible to walk across the wetland. Local people were hired to assist in the creation of transects. Each transect was placed 100m in distance from each other. Image 12 shows the creation of one of the transects within the wetland.

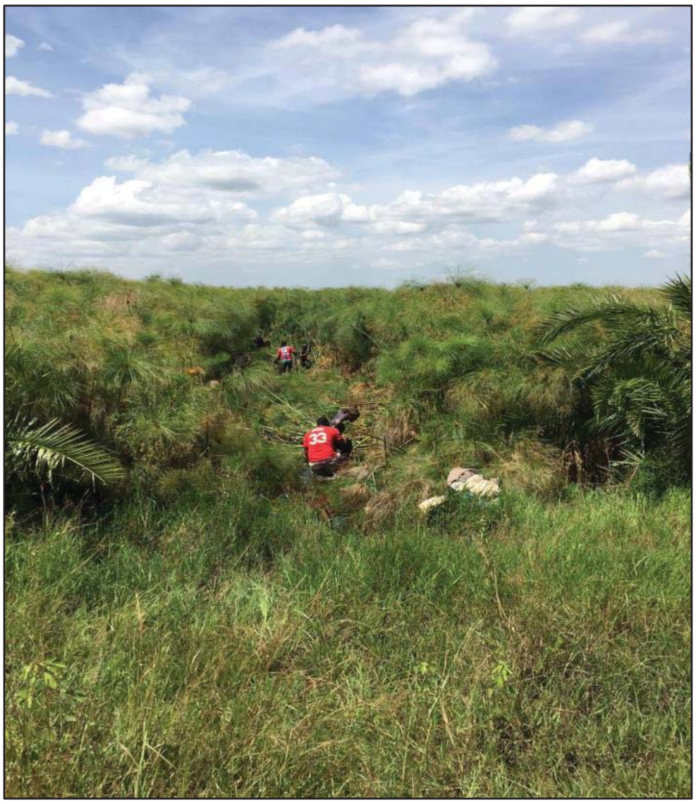


Figure 12 Creation of a transect within the Naigombwa wetland for the purpose of surveying. (image taken by author)

5.5 Model creation

Modelmuse was used to be able to simulate the hydrological relationship between groundwater and surfacewater within the study area. To be able to thoroughly understand the functions of each system a cross sectional model and area model were created of the area. The main purpose of the cross sectional model was to firstly determine the dominating system between the surface and groundwater and whether this changed between seasons.

5.5.1 Cross sectional model

For the creation of a cross sectional model of the study area, the initial grid was first defined. For the creation of a cross sectional grid, the row number was set as 0 and the column value was set to 30. The width for both the columns and rows were set to 1000. The numbers of layers assigned were 4 and labelled as; wet season, dry season, wetland basin and aquifer. The bottom elevations for the layers were set as 1070, 1060, 1055 and 1040 respectively.

The next step in the model was to assign elevations to various areas of the model. A polygon was drawn over the area representing the wetland and used to set the elevation of the model top in that section to 1063. The elevation of the bottom of the second layer was then set to model top. Over the area of the wetland the elevation was set to 1060 using the polygon tool. These elevation values are a simplification of collected elevation data. For the wetland base a polygon tool was used to set the bottom layer elevation of the wetland base to -0.5 that of the wetland bottom. The polygon tool was also used to show a staggering of elevation on the surface to represent the slope of the study area. Figure 13 displays the design of the cross sectional model after completing the layer elevation set up.

For this model four transient stress periods were used with a period of 91.25 days each (2884000sec) with 3 time steps each. The first stress period represents July – September, the second October – December, the third January – March and the fourth April – June. The total time of the model was 1 year as collected data only covered a period of less than a year.

ModFlow-2005 packages were then activated, 2 packages were activated in total. The recharge package and observation well packages were activated. The wetting function was also activated.

A recharge value was required for the model. Using precipitation data from fieldwork a 5% value of the total seasonal precipitation was used. A polygon over the study area was used to set recharge. A polygon over the entire area was used to set recharge based on the time steps.

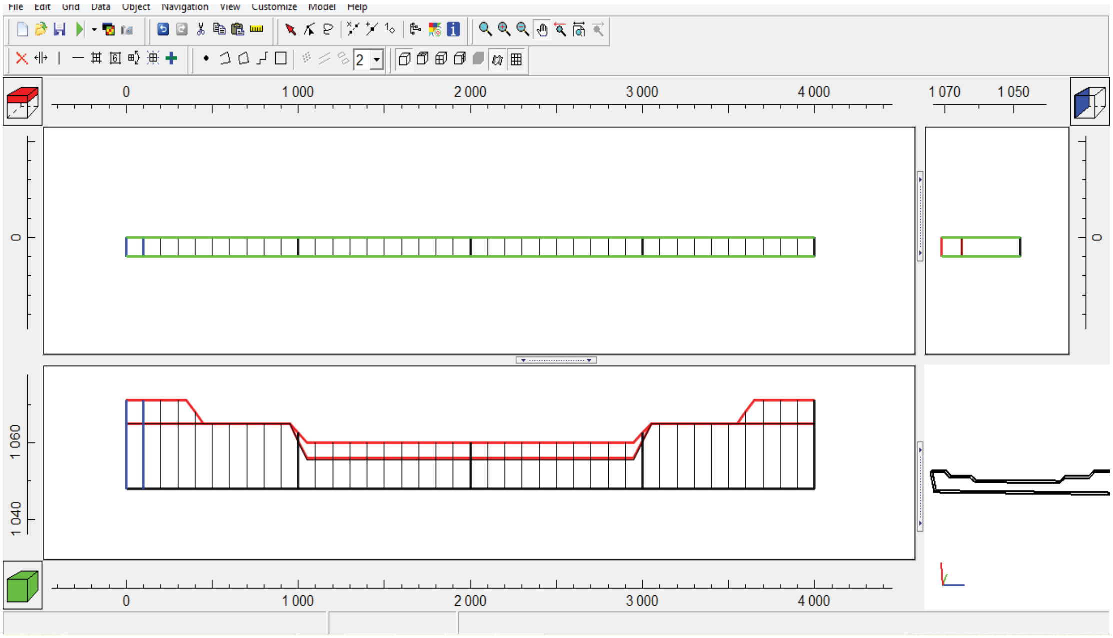


Figure 13 Output from modelmuse displaying the model setup for the cross sectional model.

Three observation wells were used for the model, one on either side of the wetland and also one within the wetland. Values for the observation wells were derived from averages of the observed levels from collected data. Groundwater observations were derived from borehole data. Wetland water levels were taken from averages of the wetland water level measurements.

Hydraulic conductivity was also set for the layers of the study area. The eastern and western side of the aquifer were assigned differing hydraulic conductivities. The western aquifer was given a Kx value of averages from slug tests conducted on the western boreholes. The eastern side of the aquifer was given a Kx value of averages taken from the results of slug tests conducted on the eastern boreholes.

Default values were used to set the Ky and Kz values. Hydraulic conductivity of the area representing the wetland was given a high hydraulic conductivity of 0.1m/s. The wetland base was assigned a low hydraulic conductivity of 0.0007, which represent literature findings for hydraulic conductivity of hydric soils found at wetland bases.

The model was then run and results imported.
Sensitivity analysis was conducted on the model to observe which process was dominating within the system.

5.5.2 Area model

Using ModelMuse a model of the entirety of the study area was created. For the creation of the model topography points and wetland survey data was merged together using Arcmap and Excel. Data was then converted to a shapefile and imported into ModelMuse. The initial set up of the model was with 2 layers and no grid. Heights for each layer were derived with heights from the elevation map. A boundary shapefile of the study area, created in Arcmap, was imported to ModelMuse to set the grid area and also define the areas of active and inactive cells. To set the bottom boundary for the first layer, which represents the confining soil layer of the wetland, the default formula for the bottom elevation was set as the model top. A polygon was used to assign 0.5m deep layer confining the wetland base. The second layer, which represents the aquifer, was assigned a bottom elevation of 1048. Figure 14 displays how the model should look after applying the elevation data to set the modeltop. The colour gradient represents changes in elevation.

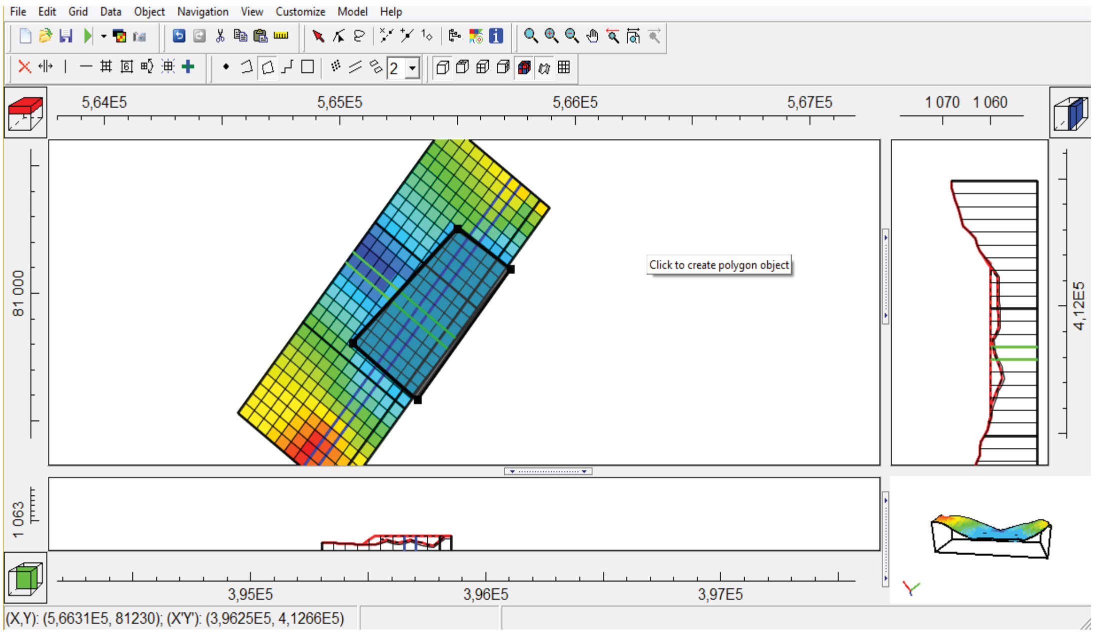


Figure 14 **Output from modelmuse of the area model with assigned layer elevations.**

The packages, which were used in the model included: recharge, head observations and time variant head. For this model four transient stress periods were used with a period of 91.25 days each (2884000sec) with 3 time steps each. The first stress period represents July – September, the second October – December, the third January –

March and the fourth April – June. The total time of the model was 1 year as collected data only covered a period of less than a year. The recharge was set with the same object used for defining the study area boundaries. The recharge value was derived from collected precipitation data as an average for each stress period. For the wetland area a polygon was created around the wetland boundary and the "upper Z value" was set as the same height of the land at the edge of the wetland and the "lower Z value" was set as the model top. Hydraulic conductivity for the wetland was set as 0.1m/s. The CHD package was used for the wetland. Head values were set as an average of the observed wetland levels for each stress period. Using the point object observation wells were placed on either side of the wetland. Average head values of well observations were placed for the four stress periods.

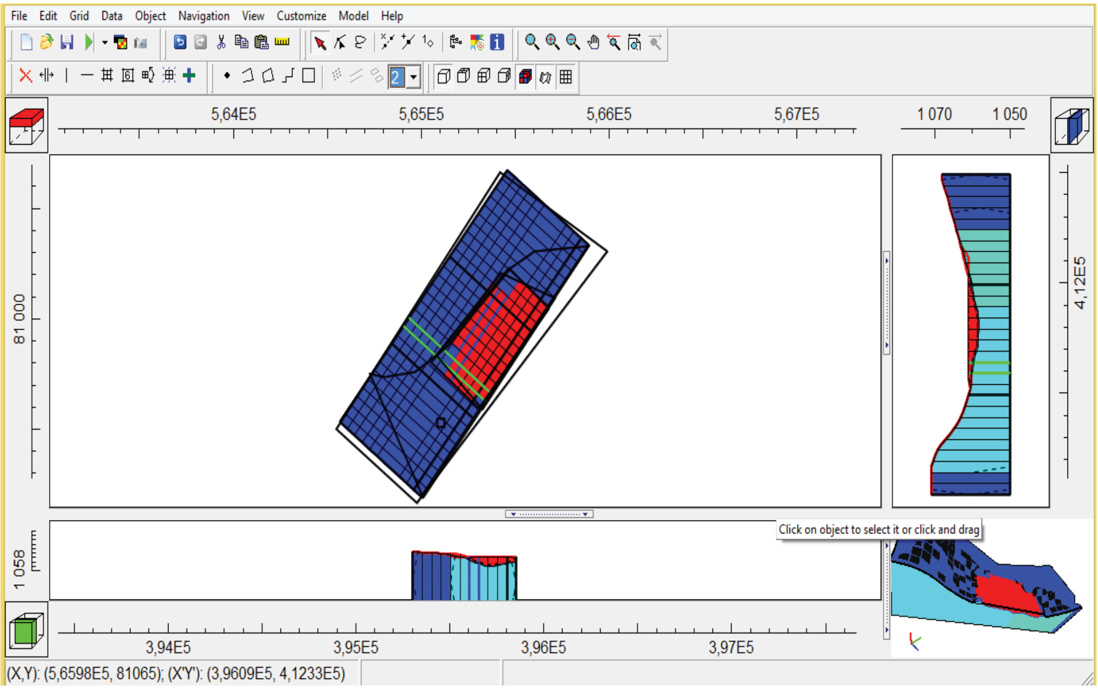


Figure 15 **Output from modelmuse of the model, coloured using the Kx values.**

Hydraulic conductivity was then assigned to all areas of the study area. For the aquifer the area was split into two areas of differing hydraulic conductivities the western side of the study area was assigned a hydraulic conductivity using averages calculated from the slug tests on the first 3 boreholes and the eastern side was assigned averages from the last 3 boreholes.

Layers of the model were set as unconfined and wettable.

The model was then run and results imported.

Calibration of the model included altering recharge and hydraulic conductivity of the model features until observed values and simulated values of the water table correlated.

Sensitivity analysis of the model was conducted by showing model reactions to changes in hydraulic conductivity and also recharge rate.

6. Results and Discussion

6.1 Hydraulic Conductivity.

Two methods were selected for conducting tests on hydraulic conductivities for the study area. Firstly the slug test method was used to calculate the hydraulic conductivities from the boreholes. The table below shows the calculated hydraulic conductivity of the slug tests conducted during fieldwork. The T_0 value for each borehole for use in the Hvorslev's method is also included in the table.

Table 1 slug test data from each borehole within the study area. Boreholes 4, 5 and 6 on the eastern side of the wetland displayed higher hydraulic conductivity values than that of the western side.

K values from slug tests						
	Borehole 1 (m/s)	Borehole 2 (m/s)	Borehole 3 (m/s)	Borehole 4 (m/s)	Borehole 5 (m/s)	Borehole 6 (m/s)
K 2015	$8.19x10^{-4}$	$8.19x10^{-4}$	0.080645	0.001255	0.01536	0.018975
K 2016	$4.85x10^{-3}$	$1.4x10^{-3}$	0.073	0.00398617	0.073	0.073
Medium	**$2.8x10^{-3}$**	**1.1x**10^{-3}	**$7.7x10^{-2}$**	**$2.6x10^{-3}$**	**0.04418**	**0.0459875**
	Borehole 1	Borehole 2	Borehole 3	Borehole 4	Borehole 5	Borehole 6
T0 2015	3940	488	40	2570	210	170
T0 2016	666	2268	44	810	44	44

To increase confidence with the calculated values, data collected from slug tests conducted the previous year (2015) were also used. An average was then made from the two values. Differences within values could be caused by the fact that different methods were used and also the different seasons of measurement. The difference between the calculated values from the two years was ignored, as they were so low. In the Appendix, section IV the graphs from using the Hvorslev's method to calculate T_0 can be found.

Double ring infiltration analysis on the eastern side of the wetland gave a hydraulic conductivity of 2.91667e-5 m/s whilst on the western side the hydraulic conductivity was found to be 9.02778e-5 m/s. On the day that the double ring infiltration analysis was conducted on the eastern side, there was heavy rainfall. This can influence the rate of infiltration as the soil is already saturated. (Stibinger, 2014)

There are disadvantages to using both these values for assigning hydraulic conductivity. Slug tests are able to provide reliable data for the hydraulic conductivity of an aquifer but they only calculate the values for the placement of the boreholes. (Stibinger, 2014). Whilst double ring infiltration tests can be conducted at multiple locations around the study area, for this study there was only one test conducted on each side of the wetland. When multiple infiltration tests are conducted a more holistic analysis of the areas

The value that will be used as the hydraulic conductivity of the aquifer for the model simulation was that of the slug tests as there was more data available. Values for hydraulic conductivity acquired from the double-ring infiltration test was also considered when calibrating the model.

6.2 Soil Analysis

Soil analysis data was conducted by the staff at the faculty of Environmental Sciences at Makerere University Kampala, Uganda. Two samples were taken at each location the top soil 0-15cm and the subsoil 15-30cm. Almost 100 soil samples were collected from the study area. Whilst chemical property analysis was also conducted on the soil samples, this data was not used as it was considered unnecessary for this research.

Table 2 Soil data from the transition zones around the wetland. It was found that for most samples the soil texture was dominated by clay and sand particles.

Soil classification - Transition zones

Lab No.	Client's		pH	OM	N	P	Ca	Mg	K	CEC	Sand	Clay	Silt	Textural class
	ref		'---------%---------			ppm	'------------cmol(+)/kg soil-------%-------------------							
S/15/8105	Transition zone 1st part nxt to road	Top	5.4	6.82	0.33	trace	19.29	9.08	0.07	30.11	40.4	37.8	21.8	Clay loam
S/15/8072	Transition zone 1st part nxt to road	Sub	5.6	5.75	0.26	1.05	24.08	11.38	0.09	40.16	40.4	45.8	13.8	Clay
S/15/8091	Transition zone part two	Top	5.7	6.12	0.27	trace	14.37	7.59	0.07	28.04	60.4	25.8	13.8	sandy clay loam
S/15/8074	Transition zone part two	Sub	5.7	3.65	0.19	1.39	17.97	8.02	0.09	32.08	56.4	35.8	7.8	sandy clay
S/15/8094	transition zone A 825ft	Top	5.4	5.25	0.24	12.10	18.96	10.92	0.23	31.77	50.4	33.8	15.8	sandy clay loam
S/15/8049	Transition zone A	Sub	5.6	4.01	0.19	4.11	25.57	11.86	0.26	44.04	40.4	41.8	17.8	Clay
S/15/8095	Transition zone part B	Top	5.6	3.20	0.16	8.70	21.52	8.98	0.13	35.23	54.4	33.8	11.8	sandy clay loam
S/15/8040	Zone transition part B	sub	5.7	4.30	0.19	2.58	21.43	10.09	0.14	37.66	46.4	41.8	11.8	Clay
Mean			**5.59**	**4.89**	**0.23**	**4.99**	**20.40**	**9.74**	**0.14**	**34.89**	**48.7**	**37.0**	**14.3**	
SD			**0.12**	**1.29**	**0.06**	**4.455**	**3.5484**	**1.57**	**0.07**	**5.435**	**7.96**	**6.228**	**4.243**	

The transition zone is defined the area of soil along the wetland edge that is occasionally also inundated by water. The lowest percentage of clay content was found in soil samples collected from the transition zone.

For zone one there was a correlation coefficient of -0.43 between topsoils, sub soils and soil texture class. This number represents a low to negative correlation between the soil texture and whether the sample was taken at 0-15cm or 15-30cm. Results of soil texture for zone one was well mixed. Mean percentages of the zone 1 soils showed a 43.6% sand content, 41.7% clay and 14.67% silt.

Zone 1

	pH	OM	N	P	Ca	Mg	K	CEC	Sand	Clay	Silt
		%	%	ppm	cmol(+)/kg soil			%	%	%	%
Mean	5.63	4.62	0.22	15.87	18.02	7.73	0.27	31.61	43.63	41.7	14.67
SD	0.44	1.21	0.05	37.17	4.59	1.31	0.18	9.24	5.52	7.67	3.67

Zone 2 represented the area at 100-200m distance away from the wetland. Zone 2 showed the highest average percentage of clay content, in comparison to the other zones, within its soils yet the sand content is also high.

Zone 2

	pH	OM	N	P	Ca	Mg	K	CEC	Sand	Clay	Silt
		%	%	ppm	cmol(+)/kg soil			%	%	%	%
Mean	5.56	4.67	0.22	4.21	14.91	6.35	0.27	25.75	45.46	42.57	11.97
SD	0.37	1.00	0.04	3.56	3.14	1.24	0.17	7.86	8.03	7.09	3.72

Zone 3

	pH	OM	N	P	Ca	Mg	K	CEC	Sand	Clay	Silt
		%	%	ppm	cmol(+)/kg soil			%	%	%	%
Mean	5.63	4.12	0.20	5.09	14.25	6.27	0.21	26.41	49.41	39.10	11.50
SD	0.34	0.67	0.02	8.84	3.64	1.37	0.12	7.90	7.76	8.39	3.62

Zone 4

	pH	OM	N	P	Ca	Mg	K	CEC	Sand	Clay	Silt
		%	%	ppm	cmol(+)/kg soil			%	%	%	%
Mean	5.68	3.95	0.19	11.25	13.21	5.16	0.22	24.16	48.05	40.39	11.56
SD	0.42	0.93	0.04	17.05	5.60	1.86	0.18	11.89	6.98	4.73	3.38

The entirety of the study area was found to mostly be comprised of 4 different soil texture classifications clay, clay loam, sandy clay loam and sandy clay.
Based on values given by the United States Natural Resources Conservation (NRC) services there are estimated values for the hydraulic conductivity of soils based on their soil classification.

Texture class	Ksat class	Hydraulic conductivity m/s
Clay	slow	4.2E-7 --> 9E-7
Sandy Clay	slow	9E-7 --> 1.4E-5
Sandy Silt Clay	mod. Slow	1.4E-5 --> 2.5E-5
Clay loam	mod. Slow	2.5E-5 --> 4.3E-5

(NRCS, 2013)

Based on these guidelines given by the NRCs the soils within the study area are mainly fine grained with low hydraulic conductivities.

For each zone the dominating soil textural type was found to be sand whilst clay was second and present in all soil samples. Variability in soil texture throughout the study area also indicates changes in soil porosity within the area. Sandy silt clay with poor sorting and porosity can increase permeability. (Johnson, 1991)

Land usage from zone 1 to zone 4 was agricultural mostly for growing crops but also grazing in some areas. Similar crops were found along all zones on both sides of the wetland. Discourse with local farmers from the townships found that the choice in crop was based on market value of crops at the time of purchase rather than which type of crop grew best. The high percentage of clay within the soils indicates that water retention within the soils is also high. It is possibly because of this soil characteristic that crops grown close the wetland edge are also found in zone 4. Having soils with good water storability is important for the region, as there is a lack of irrigation.

Soil samples of the wetland basin were not collected. It is predicted that because of the low incline of the surrounding area and low velocity of the water within the wetland that soils found at the base will be of fine grain size with a low hydraulic conductivity. The fine particle size of the surface soils within the study area indicates that there is a slow rate of infiltration of surface water to groundwater.

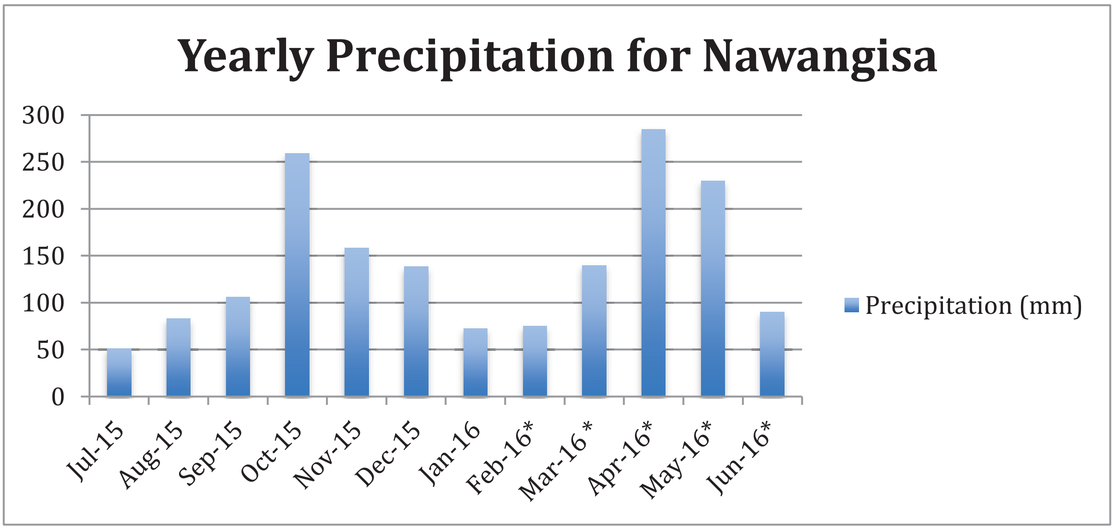
Including the location points for each soil sample would have been beneficial as it could aid in visualising whether similarities in soil texture were based on elevation at either side of the wetland. For tests on hydraulic conductivity the value was lower on the eastern side of the wetland than on the western side. It could have been beneficial to see if textural analysis supported these other findings.

6.3 Precipitation and recharge

The yearly precipitation data acquired from the weather station, which was constructed on the western side of the Wetland. Precipitation data was taken twice daily. Monthly averages were made of

Month	Precipitation (mm)
Jun-15*	90
Jul-15	51.2
Aug-15	82.8
Sep-15	105.8
Oct-15	258.8
Nov-15	158.44
Dec-15	138.4
Jan-16	72.8
Feb-16*	75
Mar-16 *	140
Apr-16*	285
May-16*	230
Total	**1688.24**
* Values taken from Uganda's Meteorological website	

Missing data for the months of June 2015, February 2016, March 2016, April 2016 and May 2016 was filled in by using data acquired by the Uganda Bureau of Meteorology (UBOS) and their precipitation data for the district of Iganga. Statistics for Iganga precipitation shows that on average 1313mm of rain falls in the district every year. (UBOS, 2009). The calculated annual total precipitation for the study area was 1688.24. Collected precipitation data displayed two periods of wet seasons and two periods of dry season, which matched the UBOS average annual precipitation data for the region.



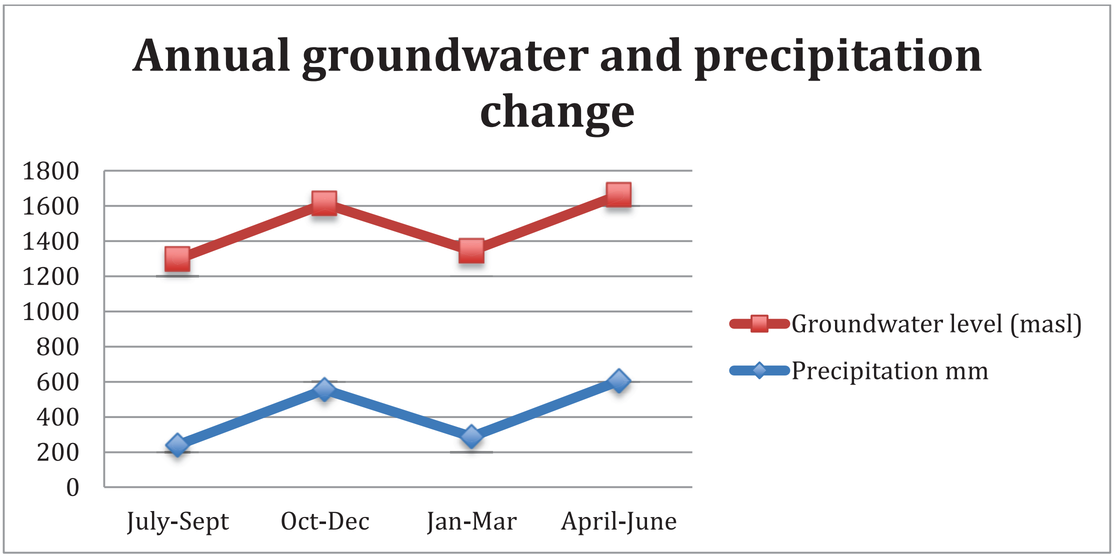
As the collected precipitation data for the study area was for a period of less than a year, usage of this data can only be for the simulation of the time period when the data was collected. Such small amounts of data cannot be used as an average climate representation of the area. Usually with literature the minimum period of data for climate representation is 30 years.

Recharge was calculated as a 5% value of the total precipitation, as recommended by Schwartz and Zhang (2003) when evapotranspiration and runoff values are unknown. As evapotranspiration formulas are dependent on many variables such as vegetation type and their respective transpiration rates it was not possible to calculate the evapotranspiration rate for the study area. Data was collected on the land usage in general but coordinates for data collection location were not also included.

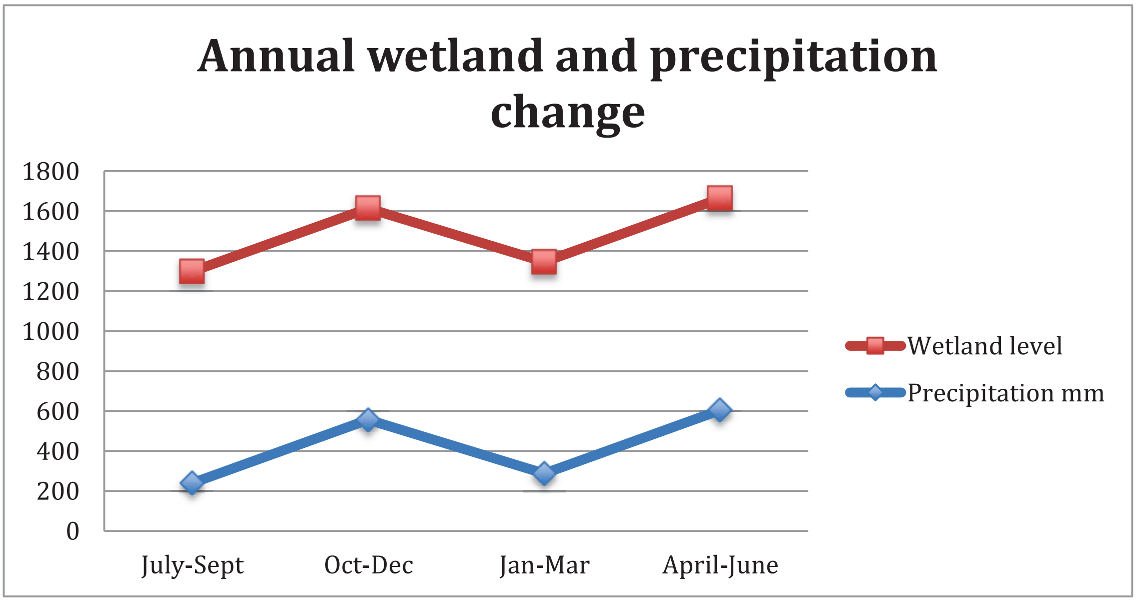
Months	Seasonal precipitation (mm)	Seasonal recharge (mm)
July- Sept (dry)	239.8	**11.99**
Oct-Dec (wet)	555.64	**27.782**
Jan-March (dry)	287.8	**14.39**
April-June wet)	605	**30.25**

Total yearly precipitation (mm)	Approximate yearly recharge (mm)
1688.24	84.412

Correlation analysis on precipitation and groundwater levels showed a value of 0.93 indicating a strong positive correlation between precipitation and groundwater levels. This correlation could indicate a strong influence of precipitation on groundwater levels. Studies conducted by Changnon, Huff and Hsu (1988) of the relation between precipitation and shallow groundwater in Illinois. Findings in the study showed most regions had no lag difference between groundwater and precipitation correlations whilst some areas showed up to 2 months lag. These differences in lag times was identified to be cause from changes in soil type across the region.



A strong correlation was also found between seasonal precipitation and seasonal wetland water levels, with a slightly higher value of 0.98, which is an almost perfect positive correlation. These findings could indicate that the main driver for fluctuations in wetland water levels is from precipitation. This does not necessarily mean that there is no exchange of water between the groundwater and wetland water.



6.4 Groundwater level

Groundwater data was collected over a period of 8 months, June 2015 – January 2016. The missing data for the 5 other months was

Western Boreholes							
	Borehole1		Borehole 2		Borehole 3		**Average**
	Gw depth(m)	Elevation (m.a.s.l)	Gw depth(m)	Elevation (m.a.s.l)	Gw depth(m)	Elevation (m.a.s.l)	
July-Sept	0.82	1059.18	0.76	1057.24	1.48	1056.52	**1056.88**
Oct-Dec	0.71	1059.29	0.57	1057.43	0.79	1057.21	**1057.32**
Jan-Mar	N/A	N/A	0.69	1057.31	1.54	1056.46	**1056.885**
April-June	N/A	N/A	0.47	1057.53	1.14	1056.86	**1057.195**

For borehole one, in January a diver was inserted so manual measurements were no longer taken.

Eastern Boreholes							
	Borehole 4		Borehole 5		Borehole 6		**Average**
	Gw depth(m)	Elevation (m.a.s.l)	Gw depth(m)	Elevation (m.a.s.l)	Gw depth(m)	Elevation (m.a.s.l)	
July-Sept	0.6	1058.4	1.29	1057.71	1.23	1057.77	**1058.085**
Oct-Dec	0.19	1058.81	0.875	1058.125	0.84	1058.16	**1058.485**
Jan-Mar	0.52	1058.48	N/A	N/A	1.19	1057.81	**1058.145**
April-June	0.28	1058.72	N/A	N/A	0.96	1058.04	**1058.38**

For Borehole 5 a diver was inserted in January so manual measurements were no longer taken.

Higher groundwater level in the eastern side of the wetland does not match the elevation data. This could be caused by inputs from the wetland. Correlation with change in precipitation

6.5 Wetland data

Data collected from the wetland only covered changes in the water level within the wetland over a period of 4 months. It is difficult to use other literature to estimate the wetland water levels for the other months as elevation and surface runoff play such an important role in determining how much water is entering the wetland. Using data It was observed within the wetland that the outflow points for the wetland water at the road were often blocked by vegetation. It is possible that it is because of the outlet blockages that such low water level differences are observed between wet and dry seasons. Missing data was interpolated by existing data and precipitation rates.
Based on the following equation flow rate within a wetland is directly relational to the detention time of water and nutrients within wetlands

Wetland water level measurements were taken from 3 gauges within the wetland. Mean values of the gauge measurements were used to define the starting level and ending levels of the wetland water levels for each season. Data showed the highest fluctuation of wetland level from the period of July to September.

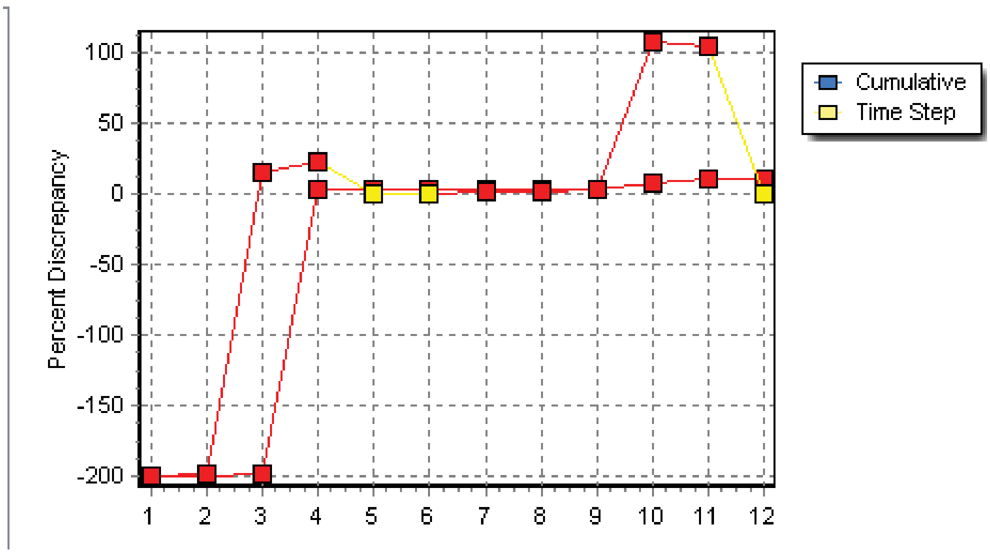
Period	Precipitation mm	Wetland level
July-Sept	239.8	1058.05
Oct-Dec	555.64	1058.75
Jan-Mar	287.8	1058.32
April-June	605	1058.84

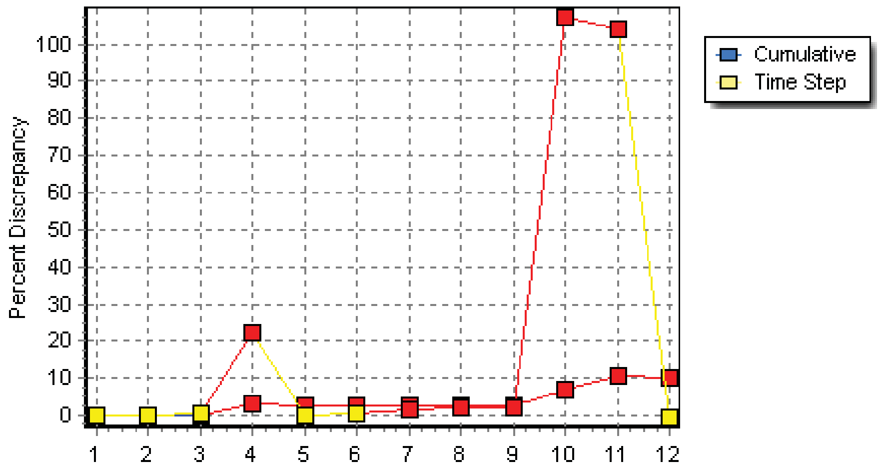
6.6 ModelMuse simulation of the study area

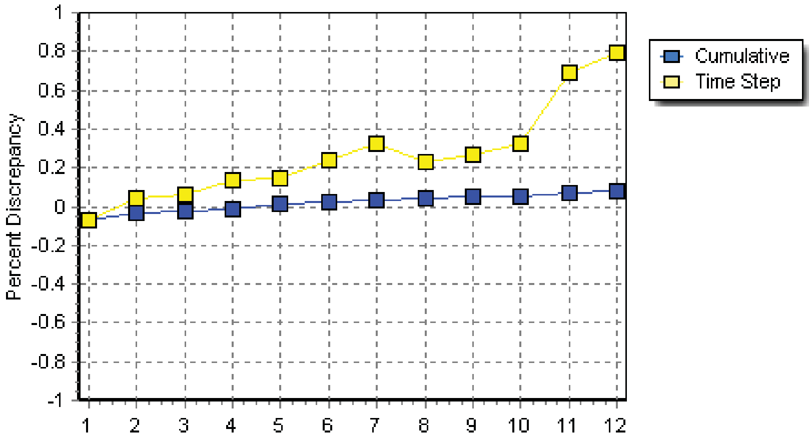
The cross sectional model was created as a simplified version of the study area to aid in the design process of the final model. The cross sectional model showed with sensitivity tests hydraulic conductivity had the greatest impact on the head values of the water table. Changes to hydraulic conductivity were made at small increments until there was a low percentage of disrepency between the observations and the simulated head values. The resulting hydraulic conductivity for the model was 3.6E-5. Changes to precipitation also impacted the head values but not at the same extent as with hydraulic conductivity. These results showed that the processes of the study are most sensitive to changes in the aquifer hydraulic conductivity.

When the model was first run the model monitor showed an error stating that the simulation was aborted because a constant head cell became dry. This occurred because the area marked as the wetland would become dry at the edges and upper cells during the dry season as the head level went below the elevation level of the cell. ModelMuse does not convert dry cells to inactive cells, which is why this error occurs. Application of the Newton method solves systems of nonlinear equations such as systems of surface water to groundwater interactions. (Niswonger, 2011).

Initial runs of the model showed high disrepency between observed data and simulated data when using slug test calculated values for the hydraulic conductivity.



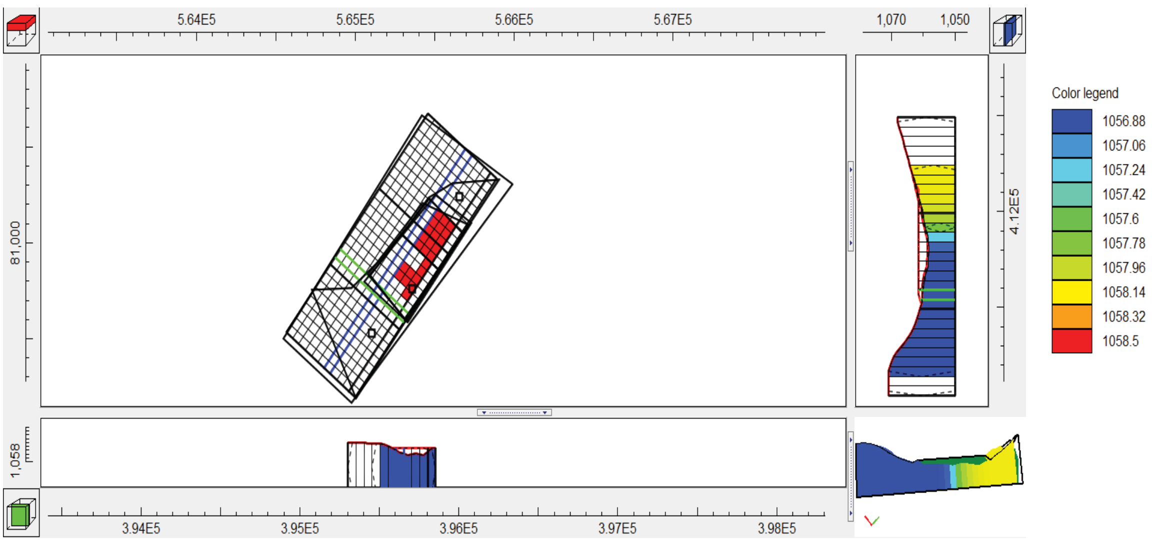




Calibration so that the model showed a discrepancy of less than 1% by altering the hydraulic conductivity of the soils so that the simulated water table matched that of the observed water table. Hydraulic conductivities calculated from infiltration tests and estimations from soil texture were used to calibrate the model from the slug test data. Using the values of the hydraulic conductivities from the infiltration tests, which were lower than that of the slug tests, showed lower values of disreprency between simulate data and observations.

Listing errors from the model were caused by the usage of the NWT solution. As the NWT solution changes cell formation due to wetting and drying to create a smooth storage change, cells are converted. For dry cells within the simulation the NWT solution creates values through interpolation. It is the NWT solution processes, which cause errors in the listing. These errors can be ignored, as they do not alter the model run.

Results from the model showed that throughout the seasons the groundwater was a constant source of water to the wetland. This was shown as the water table level followed elevation of the surface and never dropped below that of the wetland basin. For the wetland, the highest elevations found were 1061.34 m.a.s.l whilst the lower section was 1057.39. Head values of the simulation showed decreasing head values for the water table progressing towards the wetland. Whilst the aquifer displayed fluctuating head values, which correlated with precipitation, at no point in the simulation did the water table drop below the surface elevation of the wetland basin. Water table fluctuations had no lag with regards to precipitation correlation. Head values on the eastern side of the wetland were found to be lower than that of the western aquifer. This is probably because the surface elevation on the eastern side was found to be lower than that of the west. The storage of the aquifer was calculated to be 1.95E-04



For the simulation of the study area only saturated areas were considered. Modelling of the unsaturated zone was not conducted, as there was not enough data.

A study conducted by Anna Jaros (2015) on “Integrated groundwater-surface water model to manage springs, streams, lakes and fens: conditions in Kälväsvaara case, Finland” also found a study area with a groundwater system, which contributed water to the wetland. Conclusions made on the management of that system included regulation of infrastructure so that it did not interfere with processes with the groundwater and regulation of groundwater usage so that drawdown did not exceed recharge, therefore reducing the level of the groundwater table. (Jaros, 2015). Within the same study it was found that in cases where there is a large interference to the groundwater and the water table changes to a depth lower than the wetland the hydrogeological relationship could change, as there is no longer an availability of water for wetland recharge. In some cases the wetland can then also begin discharging water into the aquifer. (Jaros, 2015)

No flow was assigned for the wetland, although there was flow observed in field. Hydraulic conductivity of both the wetland and its confining layer were estimated values. The dense growth of papyrus has been found, in other papers, to influence flow of water through wetlands especially for surface flow. (van Dam, Kipkemboi, Zaal, & Okeyo-Owuor, 2011).

Error margins within the model may come from several sections where data is missing and had to be interpolated from examples found online. These errors can make the findings of the model inaccurate yet the processes of development of this type of groundwater – wetland interaction model could be used in future studies where more data is available.

7. Recommendations

The time limitations of the study impacted much of the data collection process. Climate data for the study only included a range of 10 months. Data for other hydraulic characteristics such as groundwater table and wetland level fluctuations only covered a period of 7 months. Literature studies show that for accurate representation of regional climate data sets of a 30-year period, minimum should be used. (Rawat, Mishra, Paul, & Kumar, 2012)

A more holistic analysis on the reliance the community has upon the wetland and groundwater system could also aid in developing management strategies. Understanding needs of the community allows them to be included in the decision process of

Multiple infiltration tests within the study area will allow for a better understanding of the aquifer processes. As soil characteristics influence groundwater flow so heavily, hydraulic conductivity calculations should be of high importance. In similar studies researchers conducted 25 infiltration tests for a study area. (Jaros, 2015).

Incorporating vegetiation data and inflow outflow rates of the wetland would allow for a more accurate representation of wetland processes. It has been found that Depth of wetland seepage soil and K value of the wetland water were derived from findings of similar studies. Having true values for the hydraulic conductivity of the wetland basin is important as this is the medium, which is allowing for water exchange. (Kazezyılmaz-Alhan, 2011)

As water movement within the wetland can impact the soil dynamics within the wetland it could be beneficial in further studies to measure the flow of water within the wetland and how papyrus does or may impact this flow.

It is hoped that the data collected for this research and the continual data collection from the installed weather station and boreholes will id with future research projects within the region.

8. Conclusion

For the study area of Naigombwa wetlands in Uganda, the supply of water given by the natural resources, groundwater and wetlands, is essential for community livelihoods. The wetlands are a source of money and food to many of the rural families living near the wetland. Groundwater is the main source of drinking water to the two townships. Fieldwork and numerical modelling techniques were conducted on the study area to simulate the hydrogeological processes.

Groundwater modelling is a useful method for creating simulations of hydrogeological processes. Simple representations of areas can be made with little data but large margins of error are also expected in these cases.

Empirical methods and field methods can be used to understand many hydrogeological processes. Empirical methods require large amount of known vairiables whereas the use of modelling programs such as Modelmuse allows the analysis of hydrogeological data and processes to be much more simple.

Little availability of data was the greatest restrictive factor to this study. Further studies into the area on land usage and hydrogeological processes are necessary for developing successful management plans for the region.

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10. Appendix

Appendix I: Groundwater level

Appendix II: Wetland level

Appendix III: Slug tests

Appendix IV: Double ring infiltration

Appendix V: Soil data

I. Groundwater levels

Western Boreholes

	Borehole 1		Borehole 2		Bore Hole 3	
day	9am	3pm	9am	3pm	9am	3pm
21/06/2015	1.07	1.08	1.014	1.013	1.55	1.54
22	1.012	1.013	1.012	1.012	1.58	1.56
23	1.014	0.95	1.013	1.01	1.57	1.38
24	1.03	1.05	1.01	1.03	1.4	1.45
25	1.06	1.06	1.07	1.07	1.48	1.49
26	1.06	1.07	1.06	1.08	1.49	1.5
27	1.06	1.08	1.09	1.1	1.52	1.53
28	1.09	1.09	1.11	1.11	1.55	1.54
29	1.08	1.08	1.11	1.12	1.53	1.54
30	1.07	1.09	1.11	1.12	1.52	1.54
7/01/15	1.09	1.09	1.12	1.12	1.55	1.55
2	1.09	1.1	1.12	1.13	1.56	1.56
3	1.11	1.12	1.13	1.14	1.58	1.58
4	1.12	1.14	1.14	1.15	1.59	1.59
5	1.15	1.16	1.16	1.17	1.59	1.63
6	1.17	1.17	1.17	1.18	1.61	1.63
7	1.17	1.18	1.19	1.19	1.63	1.63
8	1.2	1.2	1.2	1.21	1.64	1.65
9	1.21	1.22	1.22	1.23	1.67	1.67
10	1.23	1.24	1.24	1.25	1.68	1.68
11	1.24	1.14	1.25	1.21	1.7	1.71
12	1.15	1.15	1.22	1.22	1.72	1.71
13	1.15	1.16	1.22	1.23	1.72	1.73
14	1.16	1.17	1.23	1.24	1.73	1.72
15	1.18	1.18	1.25	1.25	1.74	1.74
16	1.19	1.19	1.26	1.27	1.75	1.75
17	1.2	1.21	1.26	1.27	1.77	1.77
18	1.22	1.22	1.28	1.28	1.78	1.785
19	1.23	1.24	1.29	1.29	1.79	1.79
20	1.24	1.24	1.29	1.3	1.79	1.8
21	1.24	1.25	1.32	1.345	1.82	1.82
22	1.265	1.27	1.34	1.34	1.83	1.83
23	1.28	1.295	1.34	1.34	1.84	1.84
24	1.295	1.295	1.345	1.35	1.845	1.85
25	1.3	1.3	1.35	1.36	1.855	1.86
26	1.3	1.3	1.36	1.36	1.86	1.855
27	1.305	1.31	1.36	1.36	1.855	1.86
28	1.31	1.315	1.36	1.365	1.87	1.87
29	1.26	1.26	1.34	1.35	1.85	1.855
30	1.3	1.28	1.36	1.345	1.86	1.86
31/07/15	1.24	1.25	1.315	1.32	1.82	1.83

8/01/15	1.215	1.22	1.27	1.285	1.78	1.785
2	1.25	1.25	1.305	1.3	1.8	1.79
3	1.27	1.27	1.325	1.33	1.82	1.83
4	1.28	1.28	1.34	1.35	1.84	1.845
5	1.305	1.26	1.36	1.32	1.85	1.81
6	1.23	1.24	1.27	1.28	1.78	1.79
7	1.17	1.18	1.22	1.23	1.72	1.71
8	1.22	1.23	1.25	1.26	1.78	1.76
9	1.24	1.25	1.27	1.3	1.77	1.78
10	1.27	1.28	1.31	1.32	1.8	1.8
11	1.3	1.3	1.33	1.35	1.81	1.83
12	1.32	1.32	1.36	1.36	1.84	1.85
13	1.32	1.29	1.37	1.375	1.86	1.87
14	1.305	1.31	1.36	1.37	1.85	1.86
15	1.31	1.29	1.37	1.38	1.87	1.88
16	1.29	1.3	1.36	1.36	1.86	1.86
17	1.3	1.3	1.37	1.37	1.87	1.87
18	1.3	1.3	1.37	1.35	1.87	1.86
19	1.29	1.29	1.36	1.365	1.87	1.875
20	1.3	1.3	1.37	1.37	1.88	1.88
21	1.29	1.29	1.36	1.36	1.87	1.87
22	1.29	1.295	1.36	1.37	1.87	1.88
23	1.29	1.29	1.36	1.365	1.87	1.875
24	1.3	1.31	1.38	1.39	1.88	1.88
25	1.32	1.32	1.4	1.38	1.89	1.89
26	1.32	1.32	1.39	1.39	1.9	1.9
27	1.32	1.33	1.4	1.4	1.91	1.91
28	1.34	1.34	1.41	1.41	1.92	1.92
29	1.34	1.34	1.41	1.42	1.93	1.93
30	1.35	1.35	1.42	1.43	1.93	1.94
31	1.36	1.37	1.44	1.45	1.95	1.95
9/01/15	1.38	1.38	1.44	1.45	1.95	1.955
2	1.38	1.39	1.45	1.46	1.96	1.96
3	1.4	1.4	1.47	1.47	1.97	1.97
4	1.4	1.26	1.47	1.26	1.97	1.82
5	1.21	1.22	1.265	1.285	1.79	1.8
6	1.265	1.275	1.33	1.34	1.82	1.83
7	1.275	1.285	1.355	1.355	1.845	1.855
8	1.295	1.3	1.36	1.475	1.86	1.875
9	1.315	1.32	1.38	1.385	1.88	1.885
10	1.33	1.33	1.4	1.4	1.89	1.89
11	1.345	1.35	1.405	1.415	1.905	1.915
12	1.355	1.36	1.425	1.43	1.925	1.93
13	1.375	1.38	1.44	1.44	1.94	1.945
14	1.385	1.39	1.445	1.45	1.95	1.95
15	1.395	1.4	1.46	1.46	1.965	1.96
16	1.4	1.405	1.47	1.495	1.96	1.97
17	1.41	1.415	1.48	1.48	1.97	1.975

18	1.425	1.43	1.485	1.495	1.975	1.98
19	1.43	1.43	1.495	1.49	1.985	1.99
20	1.435	1.445	1.495	1.505	1.99	2.1
21	1.45	1.45	1.5	1.5	2.1	2.1
22	1.385	1.4	1.455	1.47	1.97	1.96
23	1.41	1.42	1.48	1.48	1.97	1.975
24	1.42	1.43	1.485	1.49	1.98	1.985
25	1.43	1.435	1.495	1.505	1.995	2.1
26	1.445	1.45	1.505	1.51	1.995	2.1
27	1.45	1.45	1.52	1.52	1.995	2.1
28	1.45	1.455	1.525	1.525	1.995	2.1
29	1.47	1.47	1.525	1.53	1.995	2.1
30	1.47	1.47	1.435	1.44	1.995	2.1
10/01/15	1.46	1.475	1.44	1.55	1.021	1.022
2	1.48	1.485	1.55	1.55	1.023	1.024
3	1.49	1.49	1.56	1.56	1.035	1.031
4	1.495	1.5	1.565	1.57	1.033	1.04
5	1.51	1.52	1.57	1.57	1.035	1.031
6	1.505	1.51	1.575	1.575	1.031	1.023
7	1.51	1.51	1.58	1.58	1.051	1.061
8	1.51	1.51	1.58	1.58	1.071	1.073
9	1.51	1.51	1.58	1.58	1.02	1.0145
10	1.51	1.51	1.58	1.58	1.01	1.02
11	1.505	1.51	1.57	1.57	1.069	1.03
12	1.51	1.51	1.575	1.58	1.03	1.0125
13	1.51	1.51	1.58	1.58	1.0125	1.016
14	1.51	1.51	1.59	1.59	1.016	1
15	1.51	1.51	1.59	1.59	1.021	1.025
16	1.505	1.51	1.585	1.585	1.505	1.028
17	1.51	1.51	1.585	1.59	1.69	1.69
18	1.515	1.515	1.59	1.595	1.69	1.69
19	1.515	1.515	1.59	1.59	1.69	1.69
20	1.51	1.5	1.585	1.58	1.69	1.69
21	1.5	1.5	1.58	1.58	1.69	1.69
22	1.515	1.51	1.58	1.58	1.69	1.69
23	1.5	1.5	1.58	1.58	1.69	1.69
24	1.43	1.435	1.5	1.51	1.69	1.69
25	1.445	1.43	1.52	1.51	1.69	1.69
26	1.26	1.25	1.34	1.33	1.875	1.735
27	1.13	1.101	1.17	1.51	1.745	1.71
28	1.95	1.77	1.18	1.645	1.725	1.725
29	1.775	1.71	1.64	1.56	1.75	1.52
30	1.72	1.72	1.65	1.72	1.79	1.79
31	1.72	1.72	1.73	1.74	1.76	1.76
11/01/15	1.72	1.72	1.755	1.77	1.765	1.21
2	1.72	1.735	1.77	1.785	0.12	0.22
3	1.76	1.77	1.84	1.84	0.23	0.31
4	1.82	1.83	1.87	1.88	0.35	0.31

5	1.83	1.83	1.885	1.885	0.33	0.34
6	11.81	1.72	1.89	1.82	0.35	0.31
7	1.73	1.71	1.83	1.81	0.31	0.23
8	1.66	1.67	1.69	1.74	0.51	0.61
9	1.68	1.66	1.74	1.65	0.71	0.33
10	1.66	1.68	1.68	1.71	0.2	0.145
11	1.65	1.65	1.69	1.69	1.11	0.2
12	1.64	1.54	1.15	1.15	0.69	1.03
13	0.54	0.54	0.14	0.14	1.03	1.02
14	0.51	0.52	0.64	0.65	0.21	0.26
15	0.51	0.66	0.69	0.97	0.26	1.26
16	0.67	0.71	0.97	0.72	1.22	1.25
17	0.72	0.73	0.73	0.84	1.26	1.28
18	0.77	0.775	0.98	0.99	1.29	1.29
19	0.74	0.73	0.78	0.79	1.23	1.21
20	0.63	0.63	0.76	0.75	1.21	1.22
21	0.64	0.645	0.71	0.715	1.92	1.72
22	0.655	0.71	0.72	0.77	1.22	1.24
23	0.72	0.755	0.78	0.81	1.26	1.28
24	0.77	0.78	0.82	0.84	1.295	1.305
25	0.79	0.8	0.85	0.855	1.31	1.325
26	0.81	0.815	0.865	0.87	1.33	1.34
27	0.82	0.73	0.875	0.83	1.355	1.37
28	0.74	0.71	0.84	0.8	1.3	1.31
29	0.72	0.74	0.81	0.82	1.32	1.32
30	0.75	0.78	0.83	0.84	1.33	1.43
12/01/15	0.78	0.78	0.85	0.86	1.34	1.35
2	0.8	0.76	0.87	0.74	1.36	1.25
3	0.77	0.71	0.75	0.8	1.26	1.28
4	0.72	0.585	0.81	0.68	1.09	0.185
5	0.59	0.47	0.68	0.58	0.19	0.115
6	0.48	0.49	0.58	0.59	0.13	0.13
7	0.051	0.55	0.6	0.6	0.6	0.1
8	0.56	0.59	0.63	0.62	0.11	0.99
9	0.605	0.64	0.63	0.67	0.995	0.9
10	0.65	0.72	0.68	0.73	0.1	1.16
11	0.73	0.73	0.74	0.77	1.17	1.18
12	0.72	0.8	0.68	0.82	1.2	1.25
13	0.81	0.815	0.83	0.86	1.26	1.28
14	0.82	0.8	0.87	0.86	1.29	1.3
15	0.81	0.82	0.87	0.87	1.31	1.32
16	0.83	0.82	0.88	0.87	1.33	1.34
17	0.83	0.85	0.88	0.9	1.36	1.37
18	0.87	0.87	0.91	0.92	1.37	1.88
19	0.88	0.89	0.93	0.97	1.39	1.41
20	0.9	0.9	0.98	0.8	1.42	1.43
21	0.91	0.92	0.91	0.96	1.44	1.44
22	0.93	0.8	0.97	0.98	1.45	1.45

23	0.81	0.93	0.99	0.1	1.46	1.46
24	0.94	0.91	0.2	0.99	1.47	1.46
25	0.92	0.77	0.1	0.9	1.47	1.37
26	0.78	0.795	0.91	0.92	1.38	1.39
27	0.8	0.82	0.9	0.91	1.4	1.4
28	0.83	0.85	0.92	0.94	1.41	1.42
29	0.86	0.89	0.95	0.97	1.43	1.45
30	0.92	0.93	0.99	0.99	1.46	1.47
31	0.93	0.94	0.99	0.1	1.48	1.5
1/01/16	0.95	0.96	0.2	0.3	1.51	1.52
2	0.97	0.98	0.4	0.5	1.53	1.54
3	0.98	0.97	0.6	0.4	1.55	1.52
4	0.98	0.99	0.5	0.6	1.53	1.54
5	0.1	0.3	0.7	0.75	1.55	1.56
6	0.3	1.03	0.8	1.08	1.53	1.53
7	1.05	1.07	1.08	1.07	1.58	1.58
8	1.05	1.07	1.1	1.12	1.6	1.61
9	1.08	1.08	1.13	1.13	1.62	1.62
10	1.09	1.09	1.14	1.14	1.63	1.64
11	1.09	1.09	1.14	1.145	1.64	1.64
12	1.09	1.09	1.15	1.15	1.64	1.65
13	1.1	1.1	1.15	1.16	1.65	1.66
14	1.11	1.12	1.17	1.17	1.67	1.66
15			1.18	1.18	1.67	1.67
16			1.19	1.15	1.68	1.65
17			1.16	1.12	1.66	1.62
18			1.13	1.14	1.63	1.64
19			1.15	1.15	1.65	1.66
20			1.05	1.05	1.66	1.66
21			1.05	1.06	1.67	1.68
22			1.07	1.08	1.6	1.605
23			1.09	1.6	1.61	1.19
24			1.61	1.08	1.1	1.58
25			1.09	1.1	1.59	1.6
26			1.1	1.1	1.6	1.61
27			1.08	1.09	1.58	1.59
28			1.08	1.08	1.6	1.6
29			1.07	1.08	11.59	1.6
30			1.09	1.09	1.6	1.6
31			1.1	1.1	1.6	1.62
2/01/16			1.11	1.11	1.63	1.64
2			1.11	1.02	1.64	1.64
3			1.03	1.03	1.66	1.67
4			1.04	1.05	1.67	1.68
5			1.16	1.17	1.69	1.69
6			1.18	1.18	1.7	1.7
7			1.18	1.23	1.7	1.72
8			1.23	1.24	1.73	1.74

9			1.25	1.22	1.75	1.74
10			1.33	1.34	1.75	1.76
11			1.25	1.26	1.77	1.77
12			1.26	1.27	1.77	1.78
13			1.27	1.81	1.78	1.69
14			1.29	1.3	1.8	1.8
15			1.305	1.32	1.81	1.82
16			1.33	1.335	1.83	1.84
17			1.335	1.34	1.84	1.845
18			1.345	1.36	1.85	1.86
19			1.39	1.395	1.87	1.875
20			1.38	1.385	1.88	1.885
21			1.39	1.39	1.89	1.89
22			1.395	1.4	1.895	1.88
23			1.405	1.41	1.895	1.9
24			1.41	1.42	1.91	1.92
25			1.43	1.435	1.93	1.935
26			1.435	1.44	1.935	1.94
27			1.44	1.44	1.94	1.945
28			1.43	1.435	1.95	1.955
29			1.44	1.445	1.96	1.965
3/01/16			1.45	1.455	1.97	1.975
2			1.46	1.465	1.98	1.985
3			1.45	1.455	1.99	1.995
4			1.47	1.475	1.98	1.98
5			1.48	1.485	1.98	1.98
6			1.49	1.495	1.98	1.98
7			1.495	1.5	1.98	1.98
8			1.5	1.505	1.98	1.98
9			1.47	1.475	1.98	1.985
10			1.47	1.475	1.98	1.985
11			1.48	1.485	1.99	1.995
12			1.43	1.44	1.99	1.995
13			1.46	1.47	2.28	2.28
14			1.48	1.485	2.28	2.28
15			1.49	1.495	2.28	2.28
16			1.5	1.505	2.28	2.28
17			1.51	1.515	2.28	2.28
18			1.52	1.52	2.28	2.28
19			1.525	1.525	2.28	2.28
20			1.53	1.535	2.28	2.28
21			1.54	1.545	2.28	2.28
22			1.55	1.55	2.28	2.28
23			1.555	1.555	2.28	2.28
24			1.56	1.565	2.28	2.28
25			1.57	1.575	2.28	2.28
26			1.58	1.585	2.28	2.28
27			1.585	1.585	2.28	2.28

28			1.59	1.59	2.28	2.28
29			1.595	1.6	2.28	2.28
30			1.61	1.61	2.28	2.28
31			1.615	1.615	2.28	2.28
4/01/16			1.62	1.62	2.28	2.28
2			1.62	1.615	2.28	2.28
3			1.61	1.605	2.28	2.28
4			1.6	1.595	2.28	2.28
5			1.59	1.595	2.28	2.28
6			1.6	1.605	2.28	2.28
7			1.61	1.615	2.28	2.28
8			1.62	1.615	2.28	2.28
9			1.61	1.615	2.28	2.28
10			1.62	1.615	2.28	2.28
11			1.61	1.615	2.28	2.28
12			1.62	1.625	2.28	2.28
13			1.63	1.625	2.28	2.28
14			1.62	1.625	2.28	2.28
15			1.63	1.635	2.28	2.28
16			1.61	1.615	2.28	2.28
17			1.6	1.595	2.28	2.28
18			1.59	1.58	2.28	2.28
19			1.55	1.545	2.28	2.28
20			1.53	1.535	2.28	2.28
21			1.55	1.545	2.28	2.28
22			1.53	1.535	2.28	2.28
23			1.54		2.28	2.28

Eastern Boreholes

	Borehole 4		Borehole 5		Borehole 6	
day	9am	3pm	9am	3pm	9am	3pm
21/06/2015	0.83	0.89	1.09	1.06	1.63	1.59
22	0.95	0.96	1.09	1.091	1.59	1.62
23	0.91	0.93	1.078	1.056	1.61	1.65
24	0.87	0.89	1.01	1.01	1.49	1.52
25	0.89	0.92	0.99	1.01	1.53	1.52
26	0.85	0.88	0.96	0.98	1.45	1.52
27	0.89	0.88	0.97	0.97	1.51	1.51
28	0.88	0.87	0.96	0.97	1.49	1.52
29	0.89	0.87	0.99	0.93	1.54	1.48
30	0.92	0.93	0.95	0.96	1.53	1.49
7/01/15	0.89	0.92	0.95	0.97	1.51	1.52
2	1.089	0.92	0.95	0.97	1.54	1.51
3	0.93	0.94	1.01	1.02	1.55	1.56
4	0.95	0.96	1.03	1.04	1.59	1.57
5	0.98	0.96	1.05	1.05	1.59	1.59
6	0.99	0.97	1.08	1.09	1.61	1.59
7	1.01	1.02	1.11	1.12	1.63	1.64
8	1.03	1.04	1.13	1.15	1.65	1.66
9	1.05	1.07	1.14	1.16	1.67	1.69
10	1.08	1.08	1.17	1.17	1.7	1.71
11	1.08	1.09	1.18	1.18	1.72	1.73
12	1.1	1.12	1.19	1.17	1.74	1.75
13	1.13	1.14	1.18	1.2	1.73	1.74
14	1.15	1.15	1.21	1.22	1.75	1.76
15	1.16	1.16	1.23	1.23	1.78	1.78
16	1.17	1.12	1.24	1.25	1.79	1.76
17	1.13	1.14	1.25	1.25	1.76	1.76
18	1.15	1.15	1.26	1.26	1.77	1.78
19	1.16	1.16	1.27	1.27	1.78	1.19
20	1.17	1.18	1.28	1.28	1.79	1.8
21	1.19	1.19	1.29	1.29	1.82	1.82
22	1.2	1.22	1.31	1.31	1.83	1.83
23	1.22	1.22	1.31	1.31	1.84	1.84
24	1.23	1.23	1.32	1.32	1.85	1.85
25	1.24	1.24	1.33	1.33	1.86	1.86
26	1.25	1.25	1.34	1.34	1.87	1.86
27	1.25	1.25	1.35	1.35	1.86	1.86
28	1.26	1.26	1.36	1.36	1.87	1.87
29	1.16	1.12	1.29	1.26	1.82	1.78
30	1.15	1.17	**1.27**	**1.3**	1.81	1.79
31/07/15	**1.15**	**1.8**	1.21	1.23	1.73	1.73
8/01/15	**0.9**	**1.01**	1.18	1.195	1.67	1.68
2	**1.7**	**1.8**	1.23	1.23	1.7	1.71
3	**1.9**	**1.11**	1.25	1.25	1.73	1.74

4	1.12	1.14	1.27	1.28	1.78	1.77
5	1.15	1.16	1.29	1.29	1.78	1.79
6	**1.8**	**1.9**	1.24	1.25	1.74	1.74
7	0.94	0.99	1.15	1.19	1.64	1.66
8	1.4	1.7	1.22	1.24	1.68	1.69
9	1.9	1.11	1.26	1.27	1.72	1.73
10	1.12	1.13	1.27	1.28	1.76	1.76
11	1.15	1.15	1.28	1.29	1.77	1.78
12	1.18	1.16	1.3	1.3	1.79	1.8
13	1.17	1.17	1.31	1.31	1.8	1.81
14	1.18	1.18	1.32	1.3	1.81	1.815
15	1.185	1.17	1.28	1.28	1.82	1.8
16	1.18	1.185	1.29	1.295	1.81	1.815
17	1.18	1.185	1.3	1.305	1.82	1.825
18	1.19	1.19	1.305	1.305	1.825	1.83
19	1.195	1.195	1.31	1.31	1.835	1.835
20	1.2	1.2	1.315	1.315	1.84	1.84
21	1.18	1.18	1.28	1.285	1.83	1.835
22	1.19	1.18	1.29	1.28	1.84	1.83
23	1.17	1.18	1.27	1.29	1.82	1.825
24	1.19	1.95	1.3	1.305	1.83	1.84
25	1.2	1.205	1.31	1.31	1.85	1.85
26	1.21	1.815	1.32	1.32	1.855	1.855
27	1.22	1.225	1.33	1.335	1.86	1.865
28	1.23	1.235	1.34	1.345	1.87	1.875
29	1.24	1.265	1.35	1.355	1.88	1.885
30	1.25	1.255	1.36	1.365	1.89	1.895
31	1.26	1.265	1.37	1.37	1.9	1.905
9/01/15	1.27	1.275	1.375	1.375	1.91	1.915
2	1.28	1.285	1.38	1.385	1.92	1.925
3	1.29	1.295	1.39	1.395	1.93	1.935
4	1.3	1.3	1.395	1.4	1.94	1.945
5	0.99	1.3	1.16	1.2	1.7	1.72
6	1.8	1.11	1.24	1.26	1.74	1.76
7	1.14	1.15	1.28	1.29	1.78	1.79
8	1.16	1.165	1.3	1.3	1.8	1.805
9	1.17	1.18	1.3	1.305	1.81	1.82
10	1.19	1.195	1.31	1.315	1.83	1.835
11	1.2	1.21	1.32	1.34	1.84	1.85
12	1.22	1.225	1.35	1.355	1.86	1.865
13	1.23	1.235	1.36	1.365	1.87	1.875
14	1.24	1.245	1.37	1.375	1.88	1.885
15	1.25	1.255	1.38	1.385	1.89	1.895
16	1.26	1.265	1.39	1.395	1.9	1.905
17	1.27	1.275	1.4	1.405	1.91	1.915
18	1.28	1.285	1.41	1.415	1.92	1.925
19	1.29	1.295	1.42	1.42	1.93	1.935
20	1.3	1.305	1.425	1.425	1.94	1.945

21	1.31	1.315	1.43	1.435	1.95	1.95
22	1.2	1.22	1.36	1.365	1.88	1.885
23	1.23	1.24	1.35	1.36	1.89	1.895
24	1.25	1.26	1.37	1.375	1.9	1.91
25	1.27	1.275	1.38	1.385	1.92	1.925
26	1.28	1.285	1.39	1.395	1.93	1.935
27	1.29	1.295	1.4	1.405	1.94	1.945
28	1.3	1.305	1.41	1.415	1.95	1.955
29	1.31	1.315	1.42	1.425	1.96	1.965
30	1.32	1.325	1.43	1.435	1.97	1.975
10/01/15	1.3	1.3	1.4	1.405	1.93	1.45
2	1.315	1.315	1.43	1.435	1.965	1.97
3	1.32	1.325	1.44	1.445	1.97	1.975
4	1.33	1.335	1.45	1.455	1.98	1.985
5	1.34	1.345	1.46	1.465	1.99	1.995
6	1.35	1.355	1.47	1.475	2.1	2.1
7	1.36	1.365	1.48	1.485	2.1	2.1
8	1.37	1.375	1.49	1.49	2.1	2.1
9	1.38	1.385	1.495	1.495	2.1	2.1
10	1.39	1.395	1.5	1.505	2.1	2.1
11	1.4	1.405	1.505	1.505	2.1	2.1
12	1.33	1.335	1.43	1.435	1.98	1.985
13	1.34	1.345	1.44	1.445	1.99	1.995
14	1.35	1.355	1.45	1.455	2	2.1
15	1.36	1.365	1.46	1.465	2.1	2.1
16	1.37	1.375	1.47	1.475	2.1	2.1
17	1.35	1.355	1.45	1.455	1.99	1.995
18	1.36	1.365	1.46	1.465	2	2.1
19	1.37	1.375	1.47	1.475	2.1	2.1
20	1.3	1.305	1.4	1.405	1.95	1.955
21	1.31	1.315	1.41	1.415	1.96	1.965
22	1.32	1.325	1.42	1.425	1.97	1.975
23	1.33	1.34	1.43	1.44	1.98	1.99
24	1.15	1.16	1.28	1.29	1.83	1.84
25	1.17	1.18	1.3	1.31	1.85	1.86
26	0.8	0.76	1.05	0.99	1.69	1.59
27	0.71	0.78	0.91	0.93	1.45	1.45
28	0.85	0.73	0.95	0.81	1.44	1.22
29	0.63	0.62	0.64	0.63	0.99	0.84
30	0.61	0.58	0.62	0.61	0.88	0.93
31	0.56	0.55	0.58	0.55	0.99	1.02
11/01/15	0.54	0.545	0.54	0.545	1.06	1.07
2	0.56	0.6	0.56	0.6	1.09	1.11
3	0.64	0.645	0.68	0.67	1.14	1.16
4	0.66	0.665	0.7	0.705	1.2	1.205
5	0.67	0.675	0.71	0.715	1.22	1.225
6	0.68	0.66	0.73	0.7	1.24	1.22
7	0.55	0.54	0.57	0.55	1.17	1.12

8	0.52	0.525	0.51	0.52	0.98	1.2
9	0.53	0.54	0.54	0.545	1.6	1.3
10	0.56	0.54	0.56	0.55	0.99	1.01
11	0.51	0.49	0.52	0.5	1.03	1.035
12	0.46	0.42	0.47	0.45	1.05	1.02
13	0.35	0.355	0.35	0.355	0.98	0.975
14	0.36	0.385	0.36	0.39	0.97	0.98
15	0.43	0.425	0.44	0.475	1.01	1.03
16	0.53	0.56	0.53	0.57	1.06	1.085
17	0.62	0.625	0.63	0.645	1.13	1.145
18	0.64	0.645	0.67	0.66	1.17	1.175
19	0.62	0.59	0.66	0.62	1.17	1.165
20	0.54	0.51	0.55	0.525	1.15	1.13
21	0.47	0.48	0.48	0.49	1.09	1.095
22	0.5	0.53	0.51	0.54	1.1	1.115
23	0.58	0.6	0.59	0.615	1.14	1.155
24	0.63	0.64	0.65	0.67	1.18	1.19
25	0.66	0.655	0.7	0.68	1.22	1.225
26	0.64	0.63	0.65	0.64	1.24	1.225
27	0.6	0.605	0.61	0.605	1.2	1.195
28	0.61	0.605	0.61	0.605	1.18	1.175
29	0.59	0.595	0.59	0.595	1.195	1.195
30	0.6	0.61	0.6	0.68	1.18	1.18
12/01/15	0.63	0.64	0.64	0.66	1.2	1.21
2	0.66	0.65	0.69	0.68	1.23	1.2
3	0.62	0.625	0.65	0.655	1.14	1.15
4	0.63	0.56	0.63	0.57	1.17	1.15
5	0.44	0.4	0.45	0.4	1.1	0.99
6	0.32	0.32	0.32	0.32	0.83	0.9
7	0.31	0.34	0.32	0.355	0.93	0.945
8	0.38	0.405	0.4	0.425	0.97	0.98
9	0.45	0.48	0.46	0.49	1.01	1.03
10	0.54	0.57	0.54	0.58	1.08	1.09
11	0.61	0.63	0.63	0.66	1.13	1.15
12	0.66	0.67	0.7	0.72	1.2	1.205
13	0.69	0.695	0.75	0.755	1.22	1.23
14	0.7	0.705	0.76	0.765	1.25	1.255
15	0.72	0.73	0.77	0.775	1.27	1.275
16	0.75	0.71	0.78	0.77	1.29	1.295
17	0.65	0.69	0.75	0.77	1.295	1.31
18	0.75	0.755	0.81	0.82	1.33	1.34
19	0.77	0.785	0.85	0.885	1.36	1.365
20	0.81	0.815	0.88	0.895	1.39	1.395
21	0.83	0.835	0.93	0.935	1.42	1.425
22	0.79	0.805	0.92	0.935	1.41	1.415
23	0.85	0.855	0.96	0.97	1.43	1.44
24	0.86	0.865	0.98	0.985	1.45	1.455
25	0.87	0.84	0.98	0.94	1.46	1.42

26	0.77	0.75	0.78	0.76	1.34	1.33
27	0.7	0.705	0.72	0.73	1.3	1.29
28	0.7	0.725	0.75	0.77	1.3	1.32
29	0.76	0.77	0.8	0.83	1.35	1.37
30	0.8	0.825	0.86	0.88	1.4	1.45
31	0.86	0.875	0.88	0.92	1.44	1.45
1/01/16	0.9	0.91	0.97	0.975	1.47	1.48
2	0.93	0.935	0.995	1.02	1.51	1.52
3	0.93	0.935	1.02	1.04	1.54	1.55
4	0.97	0.98	1.07	1.08	1.57	1.58
5	0.93	0.95	1.03	1.05	1.54	1.545
6	0.98	0.99	1.08	1.09	1.57	1.585
7	1.01	1.02	1.11	1.12	1.61	1.62
8	1.04	0.99	1.14	1.08	1.61	1.56
9	0.98	1.01	1.1	1.12	1.57	1.59
10	1.03	1.035	1.13	1.14	1.61	1.615
11	1.01	0.97	1.15	1.12	1.63	1.59
12	1.01	0.98	1.14	1.1	1.61	1.6
13	0.97	0.98	1.13	1.14	1.59	1.6
14	1.01	1.015	1.15	1.15	1.62	1.625
15	1.02	1.025			1.63	1.635
16	1.04	0.99			1.65	1.63
17	0.97	0.975			1.61	1.615
18	0.98	0.975			1.62	1.615
19	0.97	0.975			1.61	1.615
20	0.99	0.995			1.62	1.625
21	1.01	0.98			1.61	1.59
22	0.94	0.92			1.57	1.55
23	0.88	0.9			1.52	1.55
24	0.93	0.935			1.55	1.555
25	0.91	0.9			1.53	1.52
26	0.89	0.885			1.51	1.505
27	0.88	0.89			1.5	1.49
28	0.87	0.875			1.48	1.485
29	0.88	0.885			1.49	1.495
30	0.89	0.9			1.5	1.51
31	0.91	0.915			1.52	1.53
2/01/16	0.93	0.94			1.54	1.55
2	0.95	0.96			1.56	1.57
3	0.97	0.98			1.58	1.59
4	0.99	0.995			1.6	1.61
5	1.01	1.02			1.62	1.625
6	1.03	1.04			1.64	1.65
7	1.05	1.06			1.67	1.67
8	1.07	1.08			1.68	1.69
9	1.09	1.09			1.69	1.7
10	1.09	1.1			1.72	1.73
11	1.11	1.11			1.73	1.73

12	1.11	1.12			1.74	1.745
13	1.13	1.135			1.74	1.745
14	1.14	1.145			1.75	1.755
15	1.15	1.155			1.76	1.765
16	1.16	1.165			1.77	1.78
17	1.17	1.175			1.79	1.795
18	1.18	1.185			1.8	1.805
19	1.19	1.195			1.815	1.815
20	1.2	1.205			1.82	1.825
21	1.21	1.21			1.83	1.835
22	1.215	1.215			1.84	1.845
23	1.225	1.225			1.85	1.855
24	1.23	1.255			1.86	1.86
25	1.24	1.245			1.865	1.865
26	1.25	1.255			1.87	1.875
27	1.26	1.26			1.88	1.885
28	1.25	1.255			1.87	1.875
29	1.26	1.265			1.88	1.885
3/01/16	1.27	1.275			1.89	1.895
2	1.28	1.285			1.9	1.905
3	1.29	1.29			1.91	1.915
4	1.295	1.295			1.92	1.925
5	1.3	1.305			1.93	1.935
6	1.31	1.31			1.94	1.94
7	1.315	1.315			1.945	1.945
8	1.32	1.325			1.955	1.955
9	1.25	1.255			1.9	1.895
10	1.25	1.255			1.89	1.895
11	1.26	1.265			1.9	1.905
12	1.24	1.245			1.89	1.895
13	1.25	1.255			1.9	1.91
14	1.26	1.27			1.92	1.925
15	1.28	1.285			1.93	1.935
16	1.29	1.3			1.94	1.945
17	1.31	1.315			1.95	1.955
18	1.32	1.325			1.96	1.96
19	1.33	1.335			1.965	1.965
20	1.34	1.34			1.97	1.97
21	1.345	1.345			1.975	1.975
22	1.35	1.355			1.98	1.98
23	1.36	1.365			1.98	1.985
24	1.37	1.37			1.99	1.99
25	1.375	1.375			1.995	1.995
26	1.38	1.38			2	2
27	1.385	1.385			2.1	2.1
28	1.4	1.4			2.1	2.1
29	1.41	1.415			2.1	2.1
30	1.42	1.42			2.1	2.1

31	1.42	1.425			2.1	2.1
4/01/16	1.43	1.435			2.1	2.1
2	1.39	1.385			2.1	2.1
3	1.38	1.395			2.1	2.1
4	1.37	1.365			2.1	2.1
5	1.36	1.365			2.1	2.1
6	1.37	1.375			2.1	2.1
7	1.38	1.375			2.1	2.1
8	1.37	1.365			2.1	2.1
9	1.36	1.365			2.1	2.1
10	1.37	1.375			2.1	2.1
11	1.38	1.385			2.1	2.1
12	1.39	1.385			2.1	2.1
13	1.38	1.385			2.1	2.1
14	1.39	1.385			2.1	2.1
15	1.38	1.385			2.1	2.1
16	1.35	1.34			1.99	1.98
17	1.32	1.31			1.96	1.955
18	1.3	1.26			1.95	1.93
19	1.2	1.205			1.89	1.885
20	1.22	1.23			1.88	1.89
21	1.25	1.255			1.91	1.915
22	1.27	1.275			1.93	1.935
23	1.28				1.94	

II. Wetland level

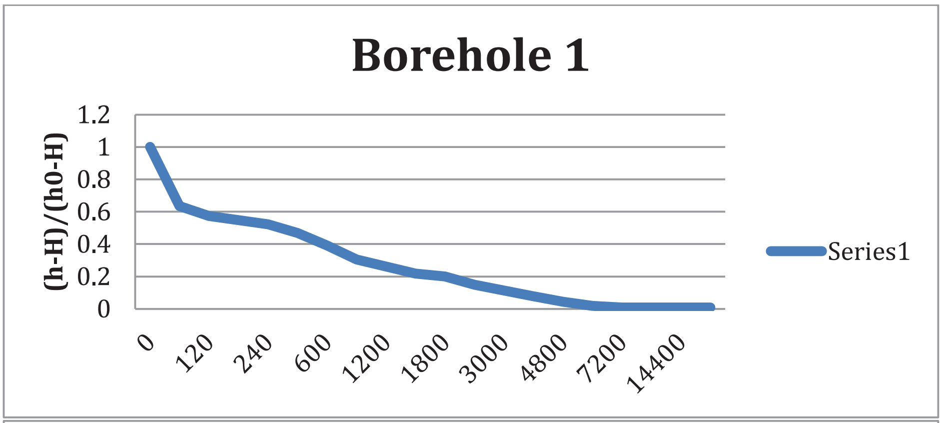
Day	Month	Year	Time	Hours	Gauge 1	Gauge 2	Gauge 3
11	5	2015	0.25	0	1059.23	1058.74	1058.84
11	5	2015	0.75	12	1059.24	1058.75	1058.85
12	5	2015	0.25	24	1059.24	1058.75	1058.85
12	5	2015	0.75	36	1059.2	1058.73	1058.82
13	5	2015	0.25	48	1059.16	1058.72	1058.81
13	5	2015	0.75	60	1059.15	1058.67	1058.76
14	5	2015	0.25	72	1059.09	1058.63	1058.73
14	5	2015	0.75	84	1059.06	1058.62	1058.74
15	5	2015	0.25	96	1059.05	1058.55	1058.61
15	5	2015	0.75	108	1059.01	1058.5	1058.6
16	5	2015	0.25	120	1058.97	1058.49	1058.58
16	5	2015	0.75	132	1058.94	1058.47	1058.57
17	5	2015	0.25	144	1058.94	1058.47	1058.57
17	5	2015	0.75	156	1058.94	1058.47	1058.57
18	5	2015	0.25	168	1058.94	1058.47	1058.57
18	5	2015	0.75	180	1058.94	1058.47	1058.57
19	5	2015	0.25	192	1058.91	1058.46	1058.56
19	5	2015	0.75	204	1058.91	1058.46	1058.56
20	5	2015	0.25	216	1058.9	1058.43	1058.4
20	5	2015	0.75	228	1058.9	1058.43	1058.4
21	5	2015	0.25	240	1058.92	1058.3	1058.47
21	5	2015	0.75	252	1058.91	1058.39	1058.46
22	5	2015	0.25	264	1058.88	1058.38	1058.43
22	5	2015	0.75	276	1058.87	1058.37	1058.42
23	5	2015	0.25	288	1058.86	1058.37	1058.42
23	5	2015	0.75	300	1058.86	1058.37	1058.42
24	5	2015	0.25	312	1058.86	1058.37	1058.42
24	5	2015	0.75	324	1058.86	1058.37	1058.42
25	5	2015	0.25	336	1058.7	1058.37	1058.42
25	5	2015	0.75	348	1058.79	1058.37	1058.42
26	5	2015	0.25	360	1058.78	1058.37	1058.42
26	5	2015	0.75	372	1058.78	1058.37	1058.42
27	5	2015	0.25	384	1058.75	1058.36	1058.41
27	5	2015	0.75	396	1058.75	1058.36	1058.41
28	5	2015	0.25	408	1058.75	1058.36	1058.41
28	5	2015	0.75	420	1058.75	1058.36	1058.41
29	5	2015	0.25	432	1058.76	1058.37	1058.42
29	5	2015	0.75	444	1058.76	1058.37	1058.42
30	5	2015	0.25	456	1058.75	1058.36	1058.41
30	5	2015	0.75	468	1058.75	1058.37	1058.41
31	5	2015	0.25	480	1058.75	1058.36	1058.41
31	5	2015	0.75	492	1058.75	1058.37	1058.41
1	6	2015	0.25	504	1058.75	1058.36	1058.41
1	6	2015	0.75	516	1058.75	1058.36	1058.41
2	6	2015	0.25	528	1058.75	1058.36	1058.41
2	6	2015	0.75	540	1058.75	1058.36	1058.41
3	6	2015	0.25	552	1058.75	1058.35	1058.3

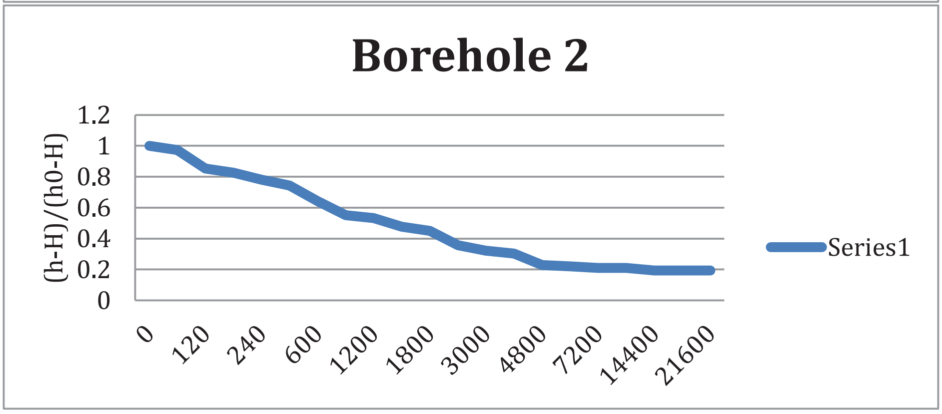
3	6	2015	0.75	564	1058.75	1058.35	1058.3
4	6	2015	0.25	576	1058.75	1058.35	1058.3
4	6	2015	0.75	588	1058.75	1058.35	1058.3
5	6	2015	0.25	600	1058.74	1058.34	1058.39
5	6	2015	0.75	612	1058.74	1058.34	1058.39
6	6	2015	0.25	624	1058.73	1058.33	1058.38
6	6	2015	0.75	636	1058.75	1058.33	1058.38
7	6	2015	0.25	648	1058.71	1058.32	1058.35
7	6	2015	0.75	660	1058.71	1058.32	1058.35
8	6	2015	0.25	672	1058.71	1058.32	1058.35
8	6	2015	0.75	684	1058.71	1058.32	1058.35
9	6	2015	0.25	696	1058.6	1058.31	1058.34
9	6	2015	0.75	708	1058.6	1058.31	1058.34
10	6	2015	0.25	720	1058.6	1058.31	1058.34
10	6	2015	0.75	732	1058.6	1058.31	1058.34
11	6	2015	0.25	744	1058.6	1058.31	1058.34
11	6	2015	0.75	756	1058.6	1058.31	1058.34
12	6	2015	0.25	768	1058.6	1058.31	1058.34
12	6	2015	0.75	780	1058.6	1058.31	1058.33
13	6	2015	0.25	792	1058.69	1058.31	1058.34
13	6	2015	0.75	804	1058.68	1058.2	1058.33
14	6	2015	0.25	816	1058.68	1058.2	1058.33
14	6	2015	0.75	828	1058.68	1058.2	1058.33
15	6	2015	0.25	840	1058.68	1058.2	1058.33
15	6	2015	0.75	852	1058.68	1058.2	1058.33
16	6	2015	0.25	864	1058.68	1058.2	1058.33
16	6	2015	0.75	876	1058.68	1058.2	1058.33
17	6	2015	0.25	888	1058.68	1058.2	1058.33
17	6	2015	0.75	900	1058.68	1058.2	1058.33
18	6	2015	0.25	912	1058.66	1058.22	1058.32
18	6	2015	0.75	924	1058.66	1058.22	1058.32
19	6	2015	0.25	936	1058.65	1058.22	1058.32
19	6	2015	0.75	948	1058.65	1058.22	1058.32
20	6	2015	0.25	960	1058.65	1058.22	1058.32
20	6	2015	0.75	972	1058.65	1058.22	1058.32
21	6	2015	0.25	984	1058.65	1058.22	1058.32
21	6	2015	0.75	996	1058.69	1058.2	1058.35
22	6	2015	0.25	1008	1058.6	1058.2	1058.36
22	6	2015	0.75	1020	1058.6	1058.2	1058.36
23	6	2015	0.25	1032	1058.6	1058.2	1058.36
23	6	2015	0.75	1044	1058.7	1058.22	1058.37
24	6	2015	0.25	1056	1058.7	1058.22	1058.37
24	6	2015	0.75	1068	1058.6	1058.22	1058.37
25	6	2015	0.25	1080	1058.71	1058.23	1058.38
25	6	2015	0.75	1092	1058.71	1058.23	1058.38
26	6	2015	0.25	1104	1058.72	1058.24	1058.39
26	6	2015	0.75	1116	1058.72	1058.24	1058.39
27	6	2015	0.25	1128	1058.85	1058.42	1058.5
27	6	2015	0.75	1140	1058.85	1058.42	1058.5
28	6	2015	0.25	1152	1058.85	1058.42	1058.5
28	6	2015	0.75	1164	1058.84	1058.42	1058.5
29	6	2015	0.25	1176	1058.84	1058.41	1058.5
29	6	2015	0.75	1188	1058.84	1058.41	1058.5
30	6	2015	0.25	1200	1058.84	1058.41	1058.5
30	6	2015	0.75	1212	1058.88	1058.44	1058.56

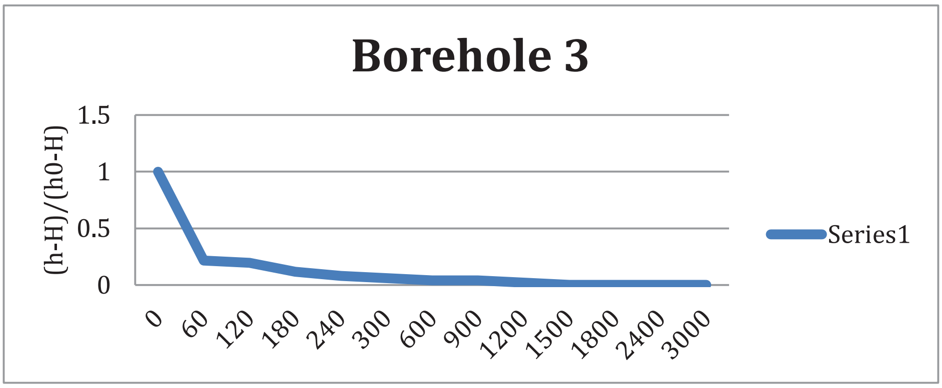
1	7	2015	0.25	1224	1058.88	1058.44	1058.56
1	7	2015	0.75	1236	1058.87	1058.4	1058.53
2	7	2015	0.25	1248	1058.87	1058.4	1058.53
2	7	2015	0.75	1260	1058.86	1058.4	1058.53
3	7	2015	0.25	1272	1058.85	1058.4	1058.5
3	7	2015	0.75	1284	1058.85	1058.4	1058.5
4	7	2015	0.25	1296	1058.85	1058.4	1058.5
4	7	2015	0.75	1308	1058.84	1058.4	1058.5
5	7	2015	0.25	1320	1058.75	1058.33	1058.39
5	7	2015	0.75	1332	1058.73	1058.32	1058.39
6	7	2015	0.25	1344	1058.73	1058.32	1058.39
6	7	2015	0.75	1356	1058.73	1058.32	1058.39
7	7	2015	0.25	1368	1058.73	1058.32	1058.39
7	7	2015	0.75	1380	1058.72	1058.31	1058.36
8	7	2015	0.25	1392	1058.62	1058.26	1058.32
8	7	2015	0.75	1404	1058.5	1058.24	1058.2
9	7	2015	0.25	1416	1058.59	1058.23	1058.29
9	7	2015	0.75	1428	1058.58	1058.22	1058.28
10	7	2015	0.25	1440	1058.57	1058.21	1058.27
10	7	2015	0.75	1452	1058.57	1058.21	1058.27
11	7	2015	0.25	1464	1058.56	1058.21	1058.27
11	7	2015	0.75	1476	1058.56	1058.21	1058.27
12	7	2015	0.25	1488	1058.56	1058.21	1058.26
12	7	2015	0.75	1500	1058.56	1058.21	1058.26
13	7	2015	0.25	1512	1058.55	1058.22	1058.26
13	7	2015	0.75	1524	1058.55	1058.22	1058.26
14	7	2015	0.25	1536	1058.55	1058.22	1058.25
14	7	2015	0.75	1548	1058.55	1058.1	1058.23
15	7	2015	0.25	1560	1058.54	1058.09	1058.22
15	7	2015	0.75	1572	1058.54	1058.09	1058.22
16	7	2015	0.25	1584	1058.54	1058.09	1058.21
16	7	2015	0.75	1596	1058.52	1058.18	1058.2
17	7	2015	0.25	1608	1058.51	1058.18	1058.19
17	7	2015	0.75	1620	1058.5	1058.17	1058.18
18	7	2015	0.25	1632	1058.48	1058.16	1058.18
18	7	2015	0.75	1644	1058.48	1058.16	1058.18
19	7	2015	0.25	1656	1058.45	1058.14	1058.16
19	7	2015	0.75	1668	1058.45	1058.14	1058.16
20	7	2015	0.25	1680	1058.45	1058.14	1058.16
20	7	2015	0.75	1692	1058.45	1058.14	1058.16
21	7	2015	0.25	1704	1058.44	1058.14	1058.16
21	7	2015	0.75	1716	1058.44	1058.14	1058.16
22	7	2015	0.25	1728	1058.44	1058.14	1058.16
22	7	2015	0.75	1740	1058.44	1058.14	1058.16
23	7	2015	0.25	1752	1058.3	1058.1	1058.12
23	7	2015	0.75	1764	1058.3	1058.1	1058.12
24	7	2015	0.25	1776	1058.39	1058.08	1058.1
24	7	2015	0.75	1788	1058.38	1058.06	1058.09
25	7	2015	0.25	1800	1058.38	1058.06	1058.09
25	7	2015	0.75	1812	1058.38	1058.06	1058.08
26	7	2015	0.25	1824	1058.35	1058.06	1058.08
26	7	2015	0.75	1836	1058.35	1058.06	1058.08
27	7	2015	0.25	1848	1058.35	1058.05	1058.08
27	7	2015	0.75	1860	1058.35	1058.04	1058.08
28	7	2015	0.25	1872	1058.34	1058.04	1058.07

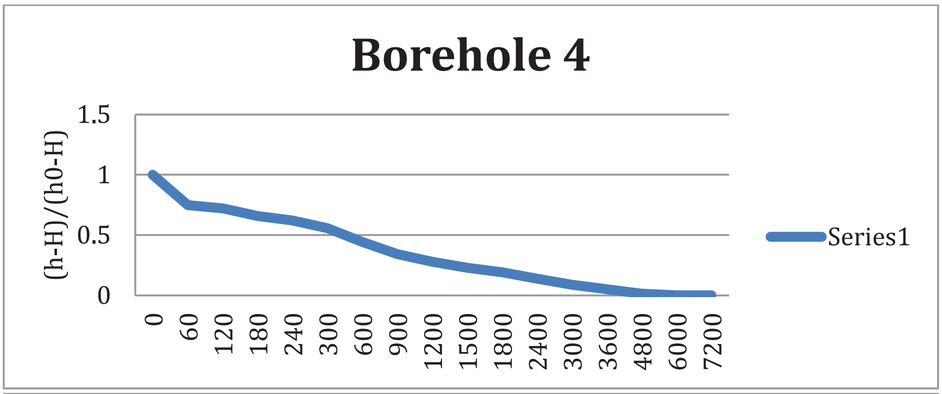
28	7	2015	0.75	1884	1058.34	1058.04	1058.07
29	7	2015	0.25	1896	1058.34	1058.04	1058.06
29	7	2015	0.75	1908	1058.33	1058.04	1058.06
30	7	2015	0.25	1920	1058.33	1058.04	1058.06
30	7	2015	0.75	1932	1058.33	1058.04	1058.06
31	7	2015	0.25	1944	1058.33	1058.04	1058.06
31	7	2015	0.75	1956	1058.33	1058.04	1058.06
1	8	2015	0.25	1968	1058.32	1058.04	1058.05
1	8	2015	0.75	1980	1058.32	1058.04	1058.05
2	8	2015	0.25	1992	1058.32	1058.04	1058.05
2	8	2015	0.75	2004	1058.32	1058.04	1058.05
3	8	2015	0.25	2016	1058.32	1058.04	1058.05
3	8	2015	0.75	2028	1058.32	1058.04	1058.05
4	8	2015	0.25	2040	1058.32	1058.04	1058.05
4	8	2015	0.75	2052	1058.32	1058.04	1058.05
5	8	2015	0.25	2064	1058.32	1058.04	1058.05
5	8	2015	0.75	2076	1058.32	1058.04	1058.05
6	8	2015	0.25	2088	1058.32	1058.06	1058.05
6	8	2015	0.75	2100	1058.32	1058.04	1058.05
7	8	2015	0.25	2112	1058.32	1058.04	1058.05
7	8	2015	0.75	2124	1058.31	1058.03	1058.05
8	8	2015	0.25	2136	1058.31	1058.03	1058.05
8	8	2015	0.75	2148	1058.31	1058.03	1058.05
9	8	2015	0.25	2160	1058.31	1058.03	1058.05
9	8	2015	0.75	2172	1058.31	1058.03	1058.05
10	8	2015	0.25	2184	1058.31	1058.03	1058.05
10	8	2015	0.75	2196	1058.31	1058.03	1058.05
11	8	2015	0.25	2208	1058.2	1058.01	1058.02
11	8	2015	0.75	2220	1058.2	1058.01	1058.02
12	8	2015	0.25	2232	1058.2	1058	1058.01
12	8	2015	0.75	2244	1058.2	1058	1058.01
13	8	2015	0.25	2256	1058.2	1058	1058.01
13	8	2015	0.75	2268	1058.28	1058	1058.01
14	8	2015	0.25	2280	1058.28	1058	1058.01
14	8	2015	0.75	2292	1058.26	1058	1058.01
15	8	2015	0.25	2304	1058.25	1058	1058.01
15	8	2015	0.75	2316	1058.25	1058	1058
16	8	2015	0.25	2328	1058.43	1058.09	1058.12
16	8	2015	0.75	2340	1058.43	1058.1	1058.13
17	8	2015	0.25	2352	1058.43	1058.1	1058.18
17	8	2015	0.75	2364	1058.43	1058.1	1058.13
18	8	2015	0.25	2376	1058.43	1058.1	1058.13
18	8	2015	0.75	2388	1058.43	1058.1	1058.13
19	8	2015	0.25	2400	1058.48	1058.1	1058.13

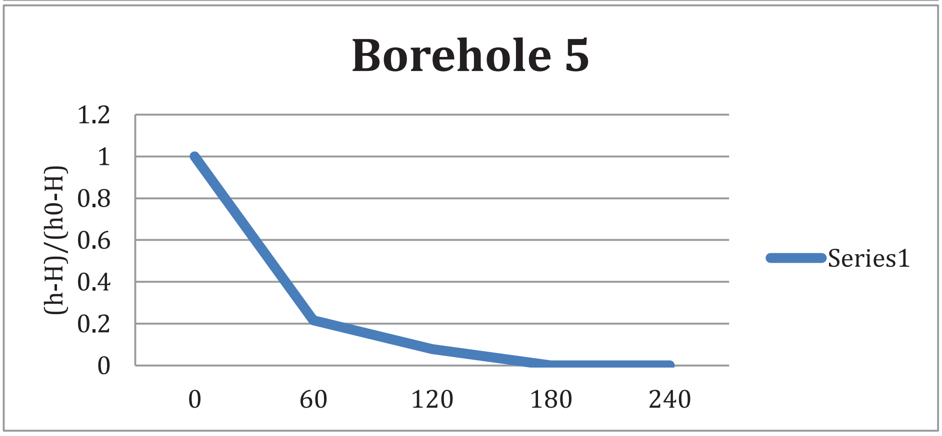
III. Slug tests

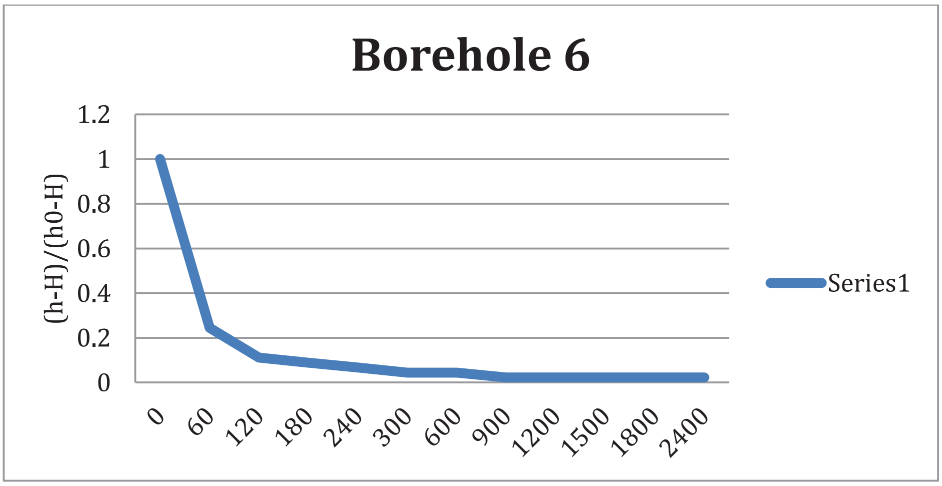







Borehole 4
(h-H)/(h0-H)
1.5
1
0.5
0
0
60
120
180
240
300
600
900
1200
1500
1800
2400
3000
3600
4800
6000
7200
Series1


Borehole 5
(h-H)/(h0-H)
1.2
1
0.8
0.6
0.4
0.2
0
0
60
120
180
240
Series1


Borehole 6
(h-H)/(h0-H)
1.2
1
0.8
0.6
0.4
0.2
0
0
60
120
180
240
300
600
900
1200
1500
1800
2400
Series1

IV. Double ring infiltration

Western side

Date: 09/01/16

Time (min	Measurement	Refill to 220
0	220	
1	1	
2	4	
3	6	
4	8	
5	9.5	Refill
10	7.5	Refill
15	3.5	
20	9.5	Refill
25	5.5	
30	9.7	Refill
40	8.4	Refill
50	6.4	Refill
60	2.6	Refill
80	5.2	Refill
100	6.6	Refill
120	6.6	Refill
180	2.2	Refill x3
240	5.9	Refill x2
300	7	Refill x2
260	5.6	Refill x2
420	3.4	Refill

Eastern side

Date: 10/01/16

Time	Measurement	Refill to 220
0	220	
1	0.8	
2	1.5	
3	2	
4	2.4	
5	2.7	
10	4	
15	5.1	
20	6.1	
25	7	
30	7.5	
40	8.5	
50	9.5	Refill
60	1	

V. Soil Data

Lab No.	Client's		pH	OM	CEC	Sand	Clay	Silt	Textural class
	ref		%	%	%	%	%	%	
S/15/8035	Zone one, swt potato	Top	5.7	3.44	31.50	46.4	37.8	15.8	Sandy loam
S/15/8036	Zone one, swt potato	Sub	5.4	3.07	26.37	42.4	45.8	11.8	Clay
S/15/8037	Zone one, maize fallow	Top	5.9	5.26	35.31	48.4	31.8	19.8	sandy clay loam
S/15/8038	Zone three, simsim&maize	sub	5.7	4.06	29.77	30.4	57.8	11.8	Clay
S/15/8039	Zone one maize&g.nuts	sub	5.1	4.26	25.40	40.4	49.8	9.8	Clay
S/15/8040	Zone transition part B	sub	5.7	4.30	37.66	46.4	41.8	11.8	Clay
S/15/8041	Zone four fallow(goat grazing	Sub	5.6	3.94	30.99	32.4	51.8	15.8	Clay
S/15/8042	Zone one potato	Top	5.2	6.12	22.20	40.4	41.8	17.8	Clay
S/15/8043	Zone one potato	Sub	5.3	1.86	15.40	46.4	37.8	15.8	sandy clay
S/15/8044	Zone two fallow	Sub	5.2	2.50	22.80	40.4	47.8	11.8	Clay
S/15/8045	Zone two maize	Sub	5.1	4.80	22.13	**Not enough**			
S/15/8046	Zone two potato	Sub	5.1	2.79	25.20	36.4	47.8	15.8	Clay
S/15/8047	Zone four banana	Sub	5.9	3.27	36.87	46.4	41.8	11.8	Clay
S/15/8048	Zone one sugarcane	Sub	5.8	3.43	39.81	44.4	41.8	13.8	Clay
S/15/8049	Transition zone A	Sub	5.6	4.01	44.04	40.4	41.8	17.8	Clay
S/15/8050	Zone one cassava wth mangoes	Top	5.3	3.77	21.83	46.4	31.8	21.8	sandy clay loam
S/15/8051	Zone one maize fallow	Top	5.5	3.40	30.00	48.4	37.8	13.8	sandy clay
S/15/8052	Zone one sugarcane	Top	5.8	6.28	41.26	46.4	35.8	17.8	sandy clay
S/15/8053	Zone one sweetpotato 2	Top	5.5	6.78	31.66	44.4	41.8	13.8	Clay
S/15/8054	Zone one maize	Sub	4.9	3.91	18.50	30.4	61.8	7.8	Clay
S/15/8055	Zone one maize&gnuts	Top	5.5	6.06	27.60	46.4	37.8	15.8	sandy clay
S/15/8056	Zone two potato	Top	5.7	6.09	34.02	42.4	41.8	15.8	Clay
S/15/8057	Zone one sweetpotato 2	Sub	5.8	3.55	31.94	36.4	51.8	11.8	Clay
S/15/8058	Zone one cassava wth mangoes		5.1	4.11	26.30	34.4	49.8	15.8	Clay
S/15/8059	Zone one cassava	Top	6.4	6.42	49.58	46.4	33.8	19.8	sandy clay loam
S/15/8060	Zone one cassava wth mangoes	sub	5.1	3.70	18.00	38.4	51.8	9.8	Clay
S/15/8061	Zone one cassava	Sub	5.2	5.59	28.00	34.4	53.8	11.8	Clay

S/15/8062	zone two maize&cassava	Top	5.3	5.75	17.42	54.4	35.8	9.8	sandy clay
S/15/8063	zone two maize&cassava	Sub	5.3	3.89	16.95	40.4	49.8	9.8	Clay
S/15/8064	Zone two potato 2	Top	5.3	5.95	23.09	48.4	41.8	9.8	Clay
S/15/8065	Zone two potato 1	Sub	5.5	3.53	21.74	48.4	41.8	9.8	Clay
S/15/8066	Zone one cassava	Sub	5.9	4.62	38.15	50.4	33.8	15.8	sandy clay loam
S/15/8067	Zone two maize	Top	5.5	5.38	25.22	46.4	37.8	15.8	sandy clay
S/15/8068	Zone one maize mixed with soyabeans	Top	6.3	5.76	55.41	40.4	41.8	17.8	Clay
S/15/8069	Zone one cassava wth maize	Top	5.7	5.79	32.23	48.4	37.8	13.8	sandy clay
S/15/8070	Zone four banana	Top	6.2	6.11	46.64	40.4	43.8	15.8	Clay
S/15/8071	Zone one maize&fallow	Sub	5.4	3.49	30.88	40.4	49.8	9.8	Clay
S/15/8072	Transition zone 1st part nxt to road	Sub	5.6	5.75	40.16	40.4	45.8	13.8	Clay
S/15/8073	Zone three,cassava& maize	Top	5.7	4.06	22.20	56.4	35.8	7.8	sandy clay
S/15/8074	Transition zone part two	Sub	5.7	3.65	32.08	56.4	35.8	7.8	sandy clay
S/15/8075	Zone four potato/banana/c assava	Top	5.6	3.51	18.92	50.4	41.8	7.8	Clay
S/15/8076	Zone three banana	Top	5.6	3.61	26.95	50.4	41.8	7.8	Clay
S/15/8077	Zone four maize	Top	5.3	4.40	12.55	56.4	35.8	7.8	sandy clay
S/15/8078	Zone three potato	Sub	5.1	3.78	14.20	48.4	45.8	5.8	Clay
S/15/8079	zone four maize	Sub	5.2	2.88	12.20	46.4	41.8	11.8	Clay
S/15/8080	Zone four potato/banana/c assava	Top	5.6	4.50	19.64	58.4	33.8	7.8	sandy clay loam
S/15/8081	Zone three potato	Sub	5.2	3.69	14.20	48.4	45.8	5.8	Clay
S/15/8082	zone three fallow/grazing	Sub	5.3	4.00	16.22	54.4	37.8	7.8	sandy clay
S/15/8083	zone three fallow/grazing	Top	6	4.76	32.11	60.4	29.8	9.8	sandy clay loam
S/15/8084	zone four potato	Sub	5.3	3.72	13.05	46.4	41.8	11.8	Clay
S/15/8085	zone four potato	Top	5.8	3.98	23.38	52.4	37.8	9.8	sandy clay
S/15/8086	zone four cassava sub	Sub	5.3	2.59	12.40	50.4	41.8	7.8	Clay
S/15/8087	zone two potato 1	Top	5.7	3.79	25.01	58.4	33.8	7.8	sandy clay loam
S/15/8088	zone two fallow	Top	5.6	5.41	18.17	58.4	31.8	9.8	sandy clay loam
S/15/8089	Zone one cassava	Top	5.5	5.15	27.35	46.4	35.8	17.8	sandy clay
S/15/8090	zone four	Top	5.4	4.45	14.95	54.4	33.8	11.8	sandy

	cassava								clay loam
S/15/8091	Transition zone part two	Top	5.7	6.12	28.04	60.4	25.8	13.8	sandy clay loam
S/15/8092	zone three cassava&maize	Sub	5.3	3.11	12.35	48.4	45.8	5.8	Clay
S/15/8093	Zone two potato 2	Sub	5.1	4.05	22.00	38.4	51.8	9.8	Clay
S/15/8094	transition zone A 825ft	Top	5.4	5.25	31.77	50.4	33.8	15.8	sandy clay loam
S/15/8095	Transition zone part B	Top	5.6	3.20	35.23	54.4	33.8	11.8	sandy clay loam
S/15/8096	Zone three potato	Top	6.1	4.80	37.89	50.4	37.8	11.8	sandy clay
S/15/8097	Zone two fallow	Top	5.3	4.20	15.55	58.4	35.8	5.8	sandy clay
S/15/8098	zone two fallow	Top	5.4	4.82	23.38	50.4	33.8	15.8	sandy clay loam
S/15/8099	zone three cassava	Sub	5.7	3.10	30.66	60.4	23.8	15.8	sandy clay loam
S/15/8100	Zone two cassava	Sub	5.8	4.50	31.32	32.4	53.8	13.8	Clay
S/15/8101	Zone two fallow	Sub	5.3	3.20	17.07	46.4	45.8	7.8	Clay
S/15/8102	Zone three potato	Top	5.2	4.52	14.20	54.4	35.8	9.8	sandy clay
S/15/8103	zone two maize&fallow	Sub	5.4	3.82	28.39	32.4	53.8	13.8	Clay
S/15/8104	Zone three banana	Sub	5.3	3.10	21.19	48.4	41.8	9.8	Clay
S/15/8105	Transition zone 1st part nxt to road	Top	5.4	6.82	30.11	40.4	37.8	21.8	Clay loam
S/15/8106	Zone four cassava	Top	6	3.80	32.55	50.4	35.8	13.8	sandy clay
S/15/8107	zone three sugarcane	Sub	5.3	4.00	25.61	42.4	43.8	13.8	Clay
S/15/8108	zone one sweetpotato 2	Sub	5.3	5.21	24.88	48.4	43.8	7.8	Clay
S/15/8109	zone three simsim &maize		5.8	5.40	33.05	44.4	41.8	13.8	Clay
S/15/8110	zone two sweet potato	Sub	6.2	5.62	38.92	40.4	49.8	9.8	Clay
S/15/8111	zone two sweet potato	Top	6.2	5.85	37.89	40.4	45.8	13.8	Clay
S/15/8112	zone one maize	Top	6.5	4.82	41.89	51.7	33.0	15.3	Sandy clay loam
S/15/8113	zone three cassava	Top	6	3.52	32.02	60.4	23.8	15.8	sandy clay loam
S/15/8114	zone one maize	Sub	6.1	3.50	32.28	45.1	38.9	16.0	Sandy clay
S/15/8115	zone two maize	Top	5.7	5.61	30.33	41.1	38.9	20.0	Clay loam
S/15/8116	Zone four fallow(goat grazing	Top	6.6	4.82	39.19	43.1	38.9	18.0	Clay loam
S/15/8117	zone three maize&sorghum	top	5.9	4.20	29.17	47.1	40.9	12.0	Clay
S/15/8118	Zone one sweet potato	Top	6	4.10	32.41	47.1	40.9	12.0	Clay
S/15/8119	zone two maize/fallow	Top	6.4	5.24	40.21	47.1	38.9	14.0	Clay loam

S/15/8120	zone one,maize mixed with soya beans	Sub	6	3.92	38.02	47.1	38.9	14.0	Sandy clay
S/15/8121	zone three sugarcane	Top	6	4.30	33.36	47.1	38.9	14.0	Sandy clay
S/15/8122	Zone two cassava	Top	5.8	5.45	37.37	41.1	40.9	18.0	Clay
S/15/8123	zone one maize fallow	Sub	6	3.90	39.59	41.1	42.9	16.0	Clay
S/15/8124	zone three maize&sorghum	sub	5.8	5.12	31.94	43.1	38.9	18.0	Clay loam
S/15/8125	zone four cassava	Sub	6.1	3.20	33.30	47.1	40.9	12.0	Clay