Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

GROUNDWATER MANAGEMENT PRACTICE:

THE CASE OF AKAKI PHASE II WELL FIELD

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Thesis Submitted to Addis Ababa Institute of Technology, in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering Water Supply and Environmental stream.

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I hereby declare to the Senate of Addis Ababa University that this thesis is entirely original work and all other materials are duly acknowledged. This work has not been submitted for academic degree award at any University.

Declaration

Lidiya Bekele

ACKNOWLEDGEMENT

“*God thank you for giving me the strength and encouragement especially during all the challenging moments in completing this thesis. I am truly grateful for your exceptional love and grace during this entire journey”*

I must express my very profound gratitude to my family especially for my mom for providing me with unfailing support and continuous encouragement though out my years of study, through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Furthermore, I would like to thank my father Bekele Moges for his backstopping whenever I ran into a problem or had a question about my research or writing. He consistently allowed this paper to be my own work but steered me in the right direction whenever he thought I needed it.

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Last but not least, a huge thank you to everyone who has been a part of my life directly or indirectly supported and prayed for me along the way.

ABSTRACT

Water is a precious natural resource vital for life, national development and the environment. Groundwater resource supports many urban and rural area of Ethiopia. In Addis Ababa city the shortage of portable water has not yet been solved even if Addis Ababa Water and Sewerage Authority have implemented different mechanism to solve the city's problem. This research is conducted in Addis Ababa city at Akaki Phase II groundwater well field located in the south East of Addis. The well field is currently one of the main sources of water supply to Addis Ababa City. The objective of this study is to assess the groundwater management practices of the Akaki Phase II well field and the effect of abstraction of water without proper groundwater monitoring system in place. According to the analysis of the pump test through different methods, the transmissivity and storativity values obtained in this research have great variation from the study report of WWDSE. Among the 15 wells analyzed 10 have underestimated transmissivity whereas the 5 wells are expected to have overestimated transmissivity. The groundwater sources of the Akaki Phase II has wrong assumptions in the design phase since there is not given a major stress to the well drawdown loss by considering either the well efficiency or the effect of partial penetration to the well. From the questionnaire response gathered; the result clearly showed in Akaki Phase II well field that the groundwater monitoring practice is not regular, inconsistent, and focused only on limited visible parameters. If the current monitoring practices continues it will lead to the failure of the wells and unable to meet the objectives of the project.

Key words: - Akaki Phase II, Monitoring, Transmissivity, Storativity, Partial Penetration and Well Efficiency

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Abbreviations

AA	Addis Ababa
AAWSA	Addis Ababa Water Supply and Sewerage Authority
CT	Collection Tank
DCI	Ductile Cast Iron
DD	Draw Down
DN	Diameter Nominal
ECDSWC-WEDSS	Ethiopian Construction Design & Supervision Works Corporation-Water and Energy Design and Supervision Sector
EPA	Environmental Protection Agency
EEPCO	Ethiopian Electric & Power Corporation
GW	Groundwater
KMs	Kilometers
KV	Kilo Volt
l/s	Liters per Second
m^3/day	Cubic meter per day
mAMSL	meters Above Mean Sea Level
MoEFCC	Ministry of Environmental, Forest and Climate Change
MoWE	Ministry of Water and Energy
MoWR	Ministry of Water Resources
SCADA	Supervisory Control and Data Acquisition
Sa	Observed Draw Down
Sc	Corrected Draw Down
WF-PW	Well Field- Project Well

1. Introduction

1.1 General

Water is one of the gifts of nature that exists on surface and below ground on Earth. Water is also a scares resources that may not be abundant as needed and the quality is also varies from acidic to alkaline in nature. The sea water is salty and some surface and groundwater are fresh for human consumption. Some water bodies on earth are also not potable in the due to different mineral contents. Its support to the existence of life makes it more valuable and vital for living things. Water is the basis of life. It is used for human and animal consumption to support life, domestic use for cooking, cleaning and washing, for food production as precipitation and irrigation. It facilitates the transportation of goods and people in rivers and larger water bodies like sea and ocean. It is also used for industrial production of electric power, steam engine, cooling of varies engines and related purposes.

Water exists in solid, liquid and gas forms on Earth. It has a hydrological cycle of continuous process where it evaporates as gas form from large water bodies like sea and ocean and then the evaporated water condenses and precipitates on the earth surface on land and water bodies. It flows in the river and as runoff on the land surfaces, infiltrates into the ground to recharge the groundwater and flow as a spring or seepage to flow forming a stream. It closes the cycle by being evaporated again by forming a cloud to condense and precipitate in a liquid form. Water gets solid after cooling below 0^0 centigrade on the surface to form ice and on sea surface on the poles of the earth (Todd, 2005).

The water need of metropolitan cities is growing as the urban population rapidly grows and the commercial centers expanding. Addis Ababa city was established in 1886, on those days the principal water sources were springs and hand dug wells from the foot of Entoto Mountain.

The first spring and surface water from Kechene River tapped in 1938. After six years Gefersa dam was built for town water supply and its capacity was raised and treatment plant built 1n 1960.

The growth of the town and the increase of water consumption per capita have necessitated additional new structure to be built in Legedadi river which is called Stage I Water Supply Project in 1970. During the first phase expansion of treatment plant, construction of a new transmission pipeline into the city, the rehabilitation of the Gefersa treatment plant and the construction or upgrading of several reservoirs and pumping stations was done. The second phase construction in 1980 was extensions of primary and secondary pipeline installations and improvements to the distribution network having a capacity of 150,000 and 30,000 m^3/day production of water which lasted until 1992. (Ijigeneh Sime, 1998)

The feasibility study of Stage III water supply system was done in 1991 but the implementation was delayed that required emergency response of fast-track for the development of two water supply projects. These are part of the Akaki well field and the implementation of Dire dam.

Groundwater sources are also used as a water supply source for the city of Addis Ababa. The major groundwater source developer of the City and its suburbs is Addis Ababa Water Supply & Sewerage Authority (AAWSA), however there are also thousands of private groundwater developers (factories, service providers, etc.) for their own consumption mostly with very low rate of abstraction except few companies such as brewery and water bottling factories, which have high groundwater abstraction rates. In general, the groundwater exploitation in the city and its suburb is anarchy (without any policy, regulation and management).

Currently AAWSA has drilled aggressively a total of 150 deep production and test wells at Addis Ababa Suburbs and in the city since 2009 and summary of the drilled wells is given in table 1.

Table 1: Total bore holes drilled for AAWSA since 2009 (Source: WWDSE)

No	Area	Location	Drilled no. of wells
1	Akaki	South of AA	82
2	Legedadi	East of AA	27
3	South Ayat	East of AA	21
4	AA city	Within the City	17
5	Sebeta-Tefki	West and north west of AA	3
		Total	**150**

Deep boreholes were developed in Akaki, Fenta and Legedadi areas in addition to the already existing boreholes at different pockets in the city of Addis Ababa.

The city administration used to provide water from dispersed location within the city from deep water wells and springs by connecting to the pipeline network before the identification of well fields in the outer periphery in additional to the surface water sources. The amount was injected to the system from these sources was 60,000 m^3/day.

One of the groundwater development well fields identified was Legedadi deep wells phase I project. This project well drilling commenced was in 2015. These well fields were located in Legedadi, Legetafo and Ayat areas in Berek woreda of Oromia regional state at the distance of 30 kms from the city center of Addis Ababa town. The amount of water extracted from these well fields is 40,781 m^3/day. The project is supplying water to five condominium sites of Bole and Yeka sub cities in Addis Ababa town (WWDSE, 2015).

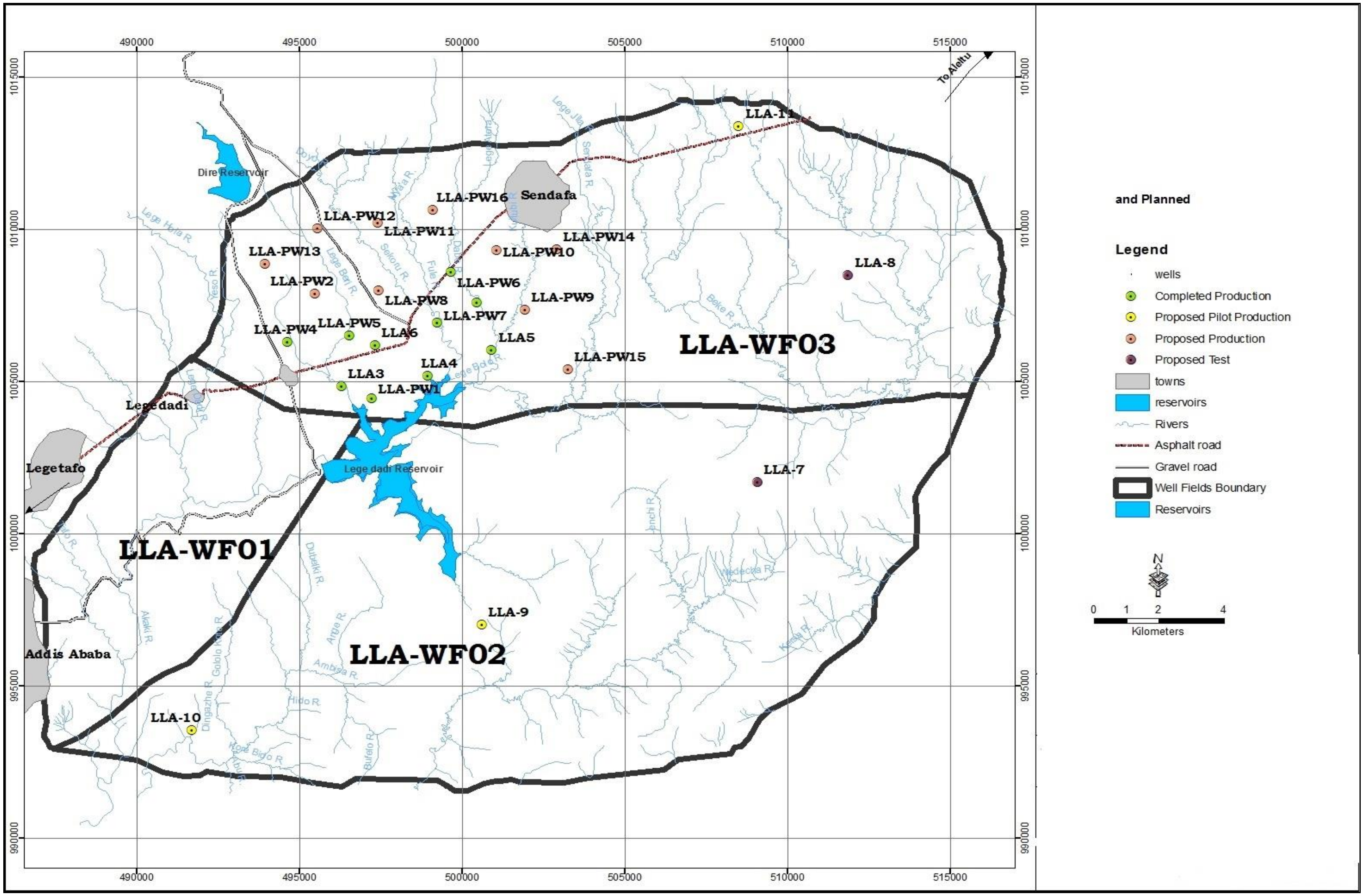


Figure 1: Location Map of Groundwater Wells in Legedadi-Legetafo-Ayat well field adapted from (WWDSE, 2015)

According to Mott MacDonald report (2011), Akaki phase I project was developed in Akaki and Fanta well fields. The purpose of the development of this well fields were to serve the southern parts of the city administration which includes Akaki and Saris areas as well as an extended areas from west to East part of the city from up to Legedadi area.

1.2 Description of the Study Area

1.2.1 Location

Akaki Phase II Project site is the area considered in this study. The study area is located southwest of Addis Ababa and in Akaki river basin which is part of the upper Awash River Basin. It is approximate coordinates are 38^0 44' 00" - 38^0 49' 18.79" E and 8^0 47' 25.50"- 8^0 53' 6.23" N and its elevation ranges between 2110 and 2050 m.a.s.l. The prospective site is bordered by Addis Ababa City on the north, by Furi Mountain on the southwest and by Guji Mountain on the southeast. It forms flat plain surrounded with scoria and vesicular basalt hills. The total area of the prospective site is more than 100 km2 (WWDSE, October 2010).

1.2.2 Water Supply

Addis Ababa Water and Sewerage Authority is a Government Organization responsible for providing safe water supply and sewerage services for the city of Addis Ababa. The Authority is providing water for the city from surface water sources (3 dams Legedadi, Dire and Gefersa reservoirs), and groundwater developed in the city and city periphery with additional supplies from groundwater pumped from Akaki well field to the south of Addis Ababa, and other wells and springs within the city. However, the available water supply systems suffice only to meet 50% to 65% of the present demand during the publication of the report in 2010 (WWDSE, October 2010). After nine years the figure mentioned above is estimated to be lower due to the intensive growth of the city population compare to the service provision.

The areas with greatest water shortage are in the north, west, and south-east of the city, and also areas of new development. Akaki area groundwater prospective site (SWAWF) is one of the five prospective groundwater sites identified around Addis Ababa city.

The Akaki Groundwater supply projects were developed in three phases I, II and III. The capacity of each phase is indicated in the table 2. Part of the existing water supply to Addis Ababa is from well fields near Akaki, which supply the city using the existing "Emergency Project" pumping stations and transmission system, completed in 2000.

Table 2: The capacity of the different phases of Water supply System

No	Water supply System	Capacity (m^3/day)
1	Phase I	42,000(currently)
2	Phase II	83,000
3	Phase IIIA	70,000
4	Phase IIIB	70,000

The Akaki Phase I design was to produce 52,000m^3/day and what achieved afterwards due to declination of the discharge is not greater than 42,000 m^3/day. The water produced from the Akaki Phase II well field from is connected to DCI riser main of DN ranging 200 to 900 to deliver water to the central reservoir located south of Gelan condominium. The amount of water injected to this water supply system of the city is 83,000 m^3/day that is a higher amount than phase I of the project. Out of the total amount 73,000 m^3/day is conveyed to GW-2 reservoir located in Saris area with 4 pumps of discharge capacity 141 l/s within DN800 having total length of 11.5 kms. Further out this amount 40,000 m^3/day is pumped to GW-3 with DN600 DCI pipe of 4.1 kms length to reservoir located Gotera using 4 pumps of discharge capacity 116 l/s. The remaining water in GW-2 Reservoir 33,000 m^3/day is pumped to the system to feed the household.

Out of the total groundwater extracted from phase II well fields the remaining 10,000 m^3/day is pumped for two kilometers length DN400 DCI pipe to augment the reduction of the phase I well field through the existing system to GW-1 reservoir located near Jati Kidane Mihret Church in Akaki area with two pumps of each discharge capacity 127 l/s.

The ever growing water demand of the city initiated for further development of groundwater at the vicinity of Akaki in phase and this was continued to Phase III in A and B categories. This project is done with foreign loan particularly category B and sometimes referred as Soft loan project. These groundwater wells are planned to supply western and central part of the city mainly Hana Mariam, Lebu and Alem Bank areas. The total water production is 70,000m^3/day (Mott MacDonald, 2011).

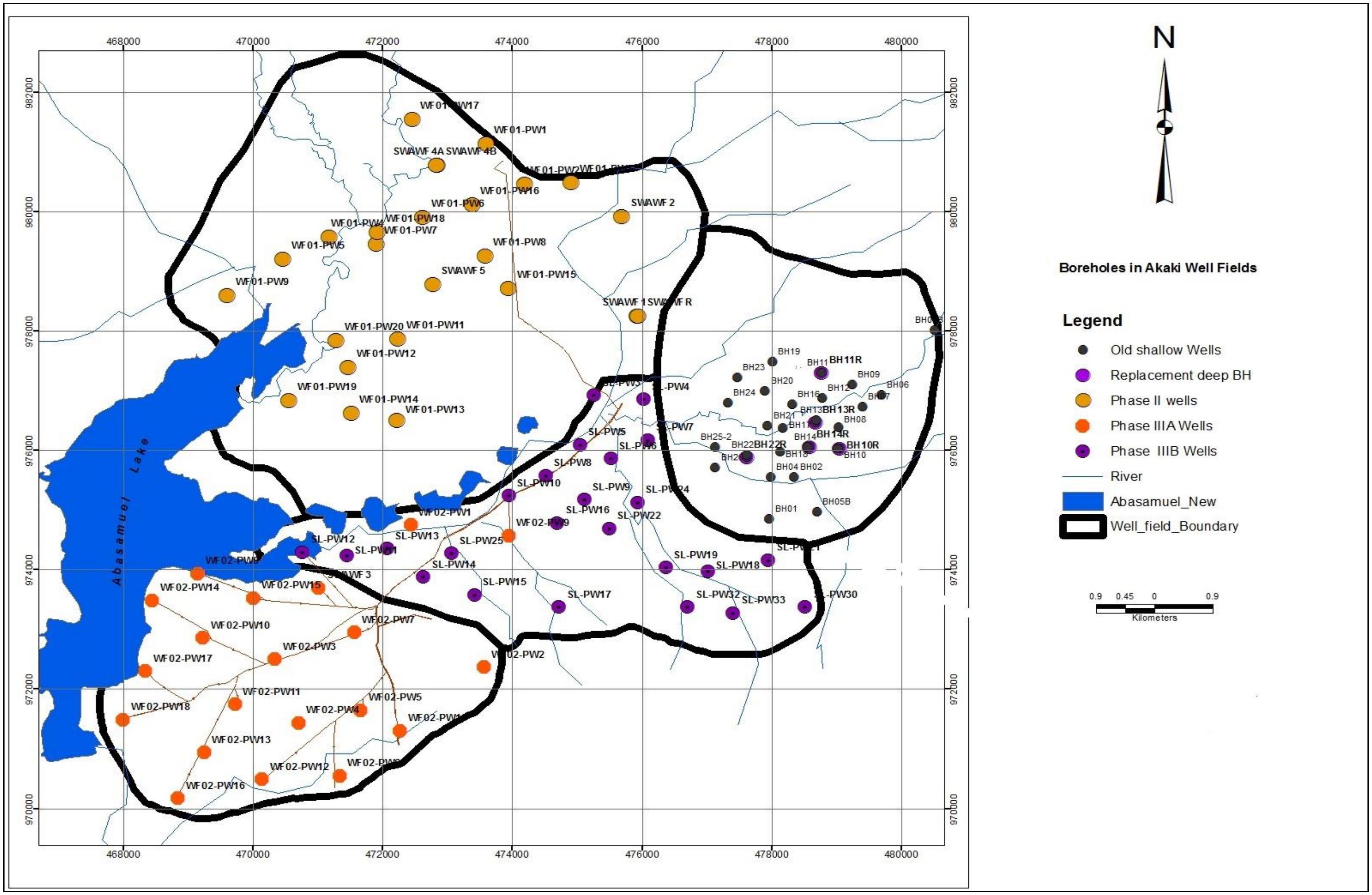


Figure 2: Location Map of Akaki Groundwater Well Fields Adapted from (WWDSE, 2014)

1.2.3 Geology and Hydrogeology

Addis Ababa is the capital city of Ethiopia found in Akaki river catchment surrounded by mountains. The city is located south of Entoto Mountains, boarding with the Mount Furi in the south west and mount Yerer in the South East. It encompasses 520 square kilometers area.

According to Engeda (2001), the geological study of Addis Ababa city and its surrounding indicates as the city is established over trachytes, rhyolites, basalts and pyrocalistic formation in the north and the north east, and basaltic formations in the central and southern parts of the city. The eastern Bole area and central area of Ledeta of the city has a formation of ignimbrites. The southern and south east west part of the city is trachy basalt trachyte, ignimbrite and tuff formations.

The Akaki area formation is lacustraine deposits. Alluvial and residual soils with a deposit layer varying from 5 to 50 meters. The hydrogeology studies of the Akaki well filed are mainly young volcanic rocks of lava flow and tectonic fractures. The main aquifers in Akaki phase II project site are Scoria, Scracoceous and fractured basalts. The fractured basalt is less potential aquifer compared to the others. The annual recharge of Akaki area is ranging from 51-100 mm per the catchment area. The static water level of the well filed is in the range of 20-30 meters from the bed of Akaki River.

In Akaki Phase-II project a total of 25 boreholes were drilled during the project period. The depth of the wells ranges from 250 to 552 meters depth from the ground surface. The yield of these wells during the initial pump test was in the range of 30-100 l/s.

1.3 Statement of Problem

Akaki phase II groundwater development project is the deficit augmentation phase where water wells are drilled in Akaki area specifically in the outskirt of the city at Gelan area of Oromia Regional State administration.

The city water supply is more and more depends on the groundwater development in addition to the existing surface sources. Optimal beneficial use can be obtained where the surface and ground water interact (combined use of groundwater and surface water sources) which involves the coordinated and planned operation of both surface water and groundwater resources to meet water requirements in a manner whereby water is conserved.

As the same time Addis Ababa city has shown tremendous growth in the last two decades horizontally and vertically. The existing surface water sources are not coping with the ever growing water consumption. As the town residents, industries and commercial centers water consumptions increase the groundwater resource become under pressure.

The nature of the groundwater abstraction has also increased all over the world including in Ethiopia. Groundwater is stored within aquifers recharged from precipitation, leakage of rivers, lakes and canals. The climate change has an effect on the intensity, duration and quantity of the precipitation of the local area that affects the groundwater recharge.

The development of groundwater has to take into consideration the sustainability and resilience to climate change. The main challenges are to optimally explore the groundwater sources leads to trend of overuse. The exponential growth of population and the change in the living standards, good personal hygiene, backyard gardening, growth of commercial and industries sectors has doubled the per capita water demand resulting in 50% additional water pumping from the well fields. The groundwater abstraction has been estimated to grow by tenfold of the initial in the past 10 years due to the absence of regulation and systematic monitoring (ECDSWC, 2017).

The consideration of cost and the use of single well test instead of multiple well tests during the development of a city water supply have minimized the determination of the true aquifer nature and characteristic of the well field. In addition, the consideration the maximum discharge without accounting the well efficiency in the range within 65% to 85% has resulted in the excessive abstraction of water beyond the well capacity. The groundwater level have been decreasing in unsustainable manner, hence, requires the need for groundwater management to be strengthened. Furthermore understanding the nature and character of the aquifer condition and monitoring the groundwater level and water quality is the key to sustainably use the resource (Mark Smith et al., 2016). In the WWDSE the Akaki Phase II Well field final report has under estimated the transmissivity values in some cases and overestimate in others which resulted inadequate use of the wells and excessive use in some wells. This requires assessing, differentiating and interpreting the particularities of each well in terms of aquifer characteristics.

According to Robert et al. (2013) the existence of groundwater governance, regulatory policy and management are the vital for the sustainable use of groundwater. In most countries groundwater management policy is nested within the broader national water management without given major attention. The distinctive nature of the groundwater requires its own policy in terms of assessment, planning, controlling and using different instruments of groundwater resources management.

The failure of integration of different concerned sector governance ministries to monitor and manage groundwater resource is becoming the challenge. For instance, according to the Ministry Environmental, forest and climate change the cooperation in groundwater monitoring with the ministry of Water and Energy is very limited and attention is given only to surface water sources. Furthermore according to the interview with AAWSA senior staff lack of attention and allocation of appropriate budget to have properly trained human resources, equipment and tools to regularly monitor, collect data, process and disseminate the analysis for action has contributed for unsustainable management of this resource.

This study will assess the existence of policy framework for groundwater management practices in general and particularly the role of the monitoring the well field performance of Akaki Phase II project to limit the excessive abstraction of water that inhibits the change of the aquifer characteristic. It also answers the question of the availability of resources to regularly monitor the groundwater in the project area. The study will recommend the solutions to improve the practices and suggests groundwater management issues to optimally use the project area groundwater resource.

1.4 Research Objective

1.4.1 General Objective

The research objective is to assess the groundwater management practices and the effect of abstraction of water without proper groundwater monitoring system on the sustainable use of the Akaki Phase II well field.

1.4.2 Specific Objective

1. To assess the groundwater management and monitoring practices by AAWSA and the stakeholders
2. To assess the effect of the abstraction of water from the well on the efficiency of the well
3. To assess the existing trained human resources, equipment and instruments used to monitor in Akaki phase II well field.
4. To assess the groundwater governance, policy and management including the roles of stakeholders
5. To determine and compare with the design report aquifer characteristic using pumping test data

1.5 Significance of the Study

The significance of this study is twofold in terms of creating a policy dialogue among stakeholders to improve the groundwater governance and management practices

The study will also create understanding and importance of groundwater monitoring to determine the safe and sustainable extraction of water without disturbing the groundwater balance.

The study will create awareness to initiate policy dialogue among different concerned line ministries to discuss on the need of separate groundwater governance and management policy.

It also identifies the gap of the existing Groundwater monitoring practices to strengthen formation of staff, equipping the current technology and establishing networking at the international, national regional states level.

The study findings serves as research based evidences for well characteristic change from the initial design and helps the management to take appropriate decisions that reduces speculations.

The analyses of the study will help to check the hydraulic parameters from the initial data collected and recommend operation considerations for the sustainable use of the well field.

1.6 Structure of the Thesis

This thesis is composed of six chapters. Chapter one is introduction and tries to define water and its use, hydrological cycle, the progressive development of the city water supply system, groundwater sources specifically about the Akaki well fields, the description of the study area, statement of problem, research objective and significant of the research.

Chapter two is all about literature review. In this chapter the thesis paper tries to cover a lot of key points like definition of groundwater, types aquifer, aquifer parameters, types of pump test, aquifer analysis and hydraulic parameters, Historical development of groundwater monitoring, what is the objective of monitoring and what are the main focuses of Groundwater. It attempts to give us some knowledge regarding groundwater level monitoring and different kind of water level measuring devices. It also helps us to understand the General framework for Addis Ababa region and the definition of well rehabilitation.

Chapter three gives an overview on the study area and the methodology to be followed in the study of the thesis. The methodology achieved by reviewing secondary data is collected from different organizations and adjustment done before used for analyses. This includes correction for drawdown for well loss using well efficiency and correction for partial penetration using Kozeny correction factor, Conducting field data collection, questionnaire, interviewing and focus group discussion. This chapter ended by analyzing the secondary data gathered by using Excel and the aquifer parameters were determined using Cooper- Jacob method and Recovery method.

Chapter four states the result of the study, assessing the outcomes from the qualitative and quantitative data by using tables and charts. Furthermore a lot of ideas were discussed depending on the results found. The quantitative data is compared with the initial WWDSE well completion report.

Chapter five presents the general conclusions, summary of the major results of the findings and recommendations was given.

2. Literature Review

2.1 Groundwater

Groundwater is the most abundant source of available freshwater in the world excluding glaciers and polar caps. It is also the critical underlying resource for human survival and economic development in extensive drought-prone areas. Sometimes it is called 'the hidden asset'. Knowing its existence and its importance is not well recognized and as a consequence the measures which are required to protect and manage it in an environmental sustainable way are either not taken or are taken too late. Traditionally it was thought that the soils and rocks overlying groundwater bodies would provide sufficient protection to groundwater. However groundwater monitoring, scientific research and investigation have shown that quantity and quality are in full and continuous interaction so that, the proper management of groundwater, both from technical and economical point of view requires a full understanding of both process. This kind of understanding requires proper information. (Johannes Grath et al., 2009)

In Ethiopia groundwater so far is mainly utilized for drinking water supply. It takes care at present of 70% of rural water supply and plays a major role in several of the largest cities namely Addis Ababa, Dire Dawa, Mekelle, Bushoftu, Harar and a number of medium-sized towns. Groundwater use in irrigation, particularly large and medium scale commercial uses, is still very modest but several ambitious plans for groundwater based irrigation are on the future projects. In a number of areas with shallow groundwater farmer-driven groundwater development is taking off in many parts of the country. In these days groundwater contribution is recognized. With a series of regional groundwater assessments the scope for sustainable groundwater use is larger than assumed previously and the knowledge is evolving. Compared to other parts of the country, the groundwater potential in Addis Ababa region is relatively well investigated. (*Ethiopia: Strategic Framework for Managed Groundwater Development 2013)*

2.2. Types of Aquifer

Groundwater groupings have been developed at several scales. Most often groundwater systems have been categorized by describing overall properties of geologic materials or lumping earth materials in units with similar hydro geological properties. Depending upon the availability of groundwater, there are three main types of aquifer: confined, unconfined, and leaky *(Kruseman, 2000).*

2.2.1 Confined Aquifer

A confined aquifer is bounded above and below by an aquiclude. In a confined aquifer, the pressure of the water is usually higher than that of the atmosphere, so that if a well taps the aquifer, the water in it stands above the top of the aquifer, or even above the ground surface. We then speak of a free-flowing or artesian well (Kruseman, 2000).

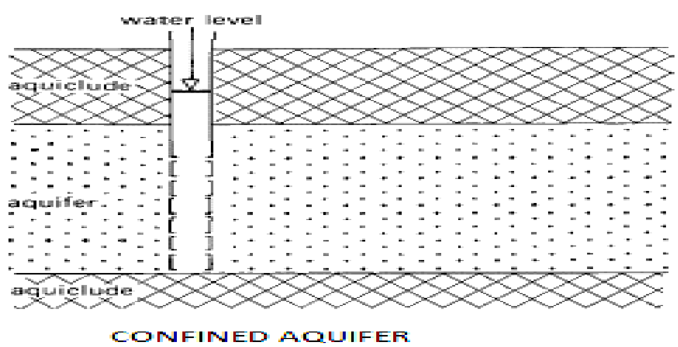


Figure 3:- confined aquifer

2.2.2 Unconfined Aquifer

An unconfined aquifer also known as a water table aquifer, is bounded below by an aquiclude, but is not restricted by any confining layer above it. Its upper boundary is the water table, which is free to rise and fall. Water in a well penetrating an unconfined aquifer is at atmospheric pressure and does not rise above the water table *(Kruseman, 2000).*

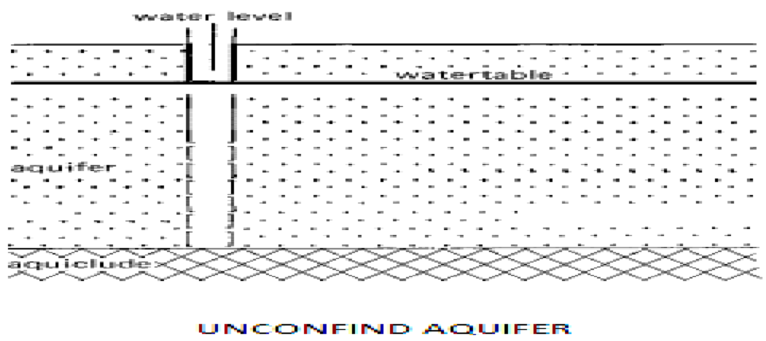


Figure 4:-: Unconfined aquifer

2.2.3 Leaky Aquifer

A leaky aquifer also known as a semi-confined aquifer, is an aquifer that's upper and lower boundaries are aquitards, or one boundary is an aquitard and the other is an aquiclude. Water is free to move through the aquitards, either upward or downward. If a leaky aquifer is in hydrological equilibrium, the water level in a well tapping it may coincide with the water table. The water level may also stand above or below the water table, depending on the recharge and discharge condition *(Kruseman, 2000).*

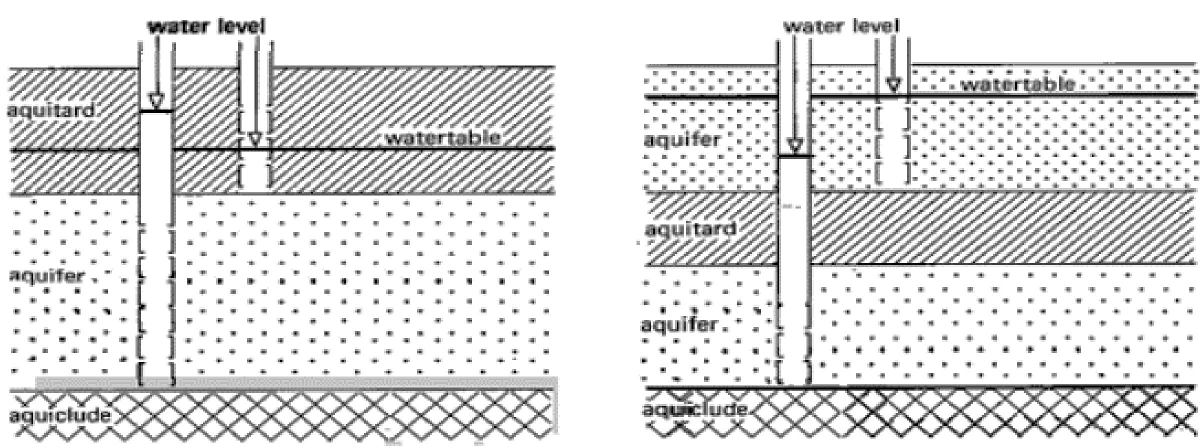


Figure 5:-Leaky aquifer

2.3. Aquifer Parameters

As groundwater becomes more important as a source of pure water, improved hydro geological knowledge, new groundwater exploration technologies and data processing methods must be efficient to facilitate investigations and evaluation of groundwater resources. The properties of the aquifer that influence well performance are depth, areal extent, number of water bearing formations exposed to the well, and the hydraulic properties of the aquifer. The properties of an aquifer may be expressed in terms of hydraulic conductivity, transmissivity, and storativity and aquifer depth. Interpolating aquifer properties between boreholes is often difficult with little or no data in which to base these extrapolations. Therefore, in areas with few pumping test information, the spatial distribution of aquifer properties cannot be confidently calculated.

2.3.1 Transmissivity

Transmissivity is an essential hydraulic property of aquifers and water bearing materials. In common with permeability, transmissivity provides a representation about the water bearing features of hydro-geological bodies. Transmissivity values enable us to assess possibilities of groundwater abstraction, in the first approximation. Therefore, knowledge of transmissivity distribution helps us to draw important conclusion from hydro-geological studies.

By definition, Transmissivity (T) is a measure of the amount of water that can be transmitted horizontally through a unit width by the fully saturated thickness of an aquifer under a hydraulic gradient equal to 1. Transmissivity is equal to the hydraulic conductivity multiplied by the saturated thickness of the aquifer and is given by:

$$T = Kb \qquad (2.1)$$

Where; K = hydraulic conductivity [LT-1]

b = saturated thickness of the aquifer [L]

Transmissivity is well defined for the analysis of well hydraulics in a confined aquifer in which the flow field is essentially horizontal and two-dimensional, in which b is the (average) thickness of the aquifer between upper and lower confining layers. It is, however, not well defined in unconfined aquifer but is still commonly used. In this case, the saturated thickness is the height of the water table above the top of the underlying aquitard (impervious layer) that bounds the aquifer.

2.3.2. Storativity

The storativity of an aquifer of thickness b is the volume of water released from the storage per unit surface area of the aquifer per unit decline in hydraulic head or potentiometric surface.

The storativity, S, of a confined aquifer is defined as:

$$S = Ss*b \qquad (2.2)$$

Where Ss is the specific storage term, and represents the volume of water that an aquifer releases from storage per unit surface area of aquifer per unit decline in the component of hydraulic head normal to that surface .

Storativity values are dimensionless and range in value from 0.005 to 0.00005, such that large head changes over extensive areas are required to produce significant yields from confined aquifers and for water table aquifers 0.05 to 0.30.

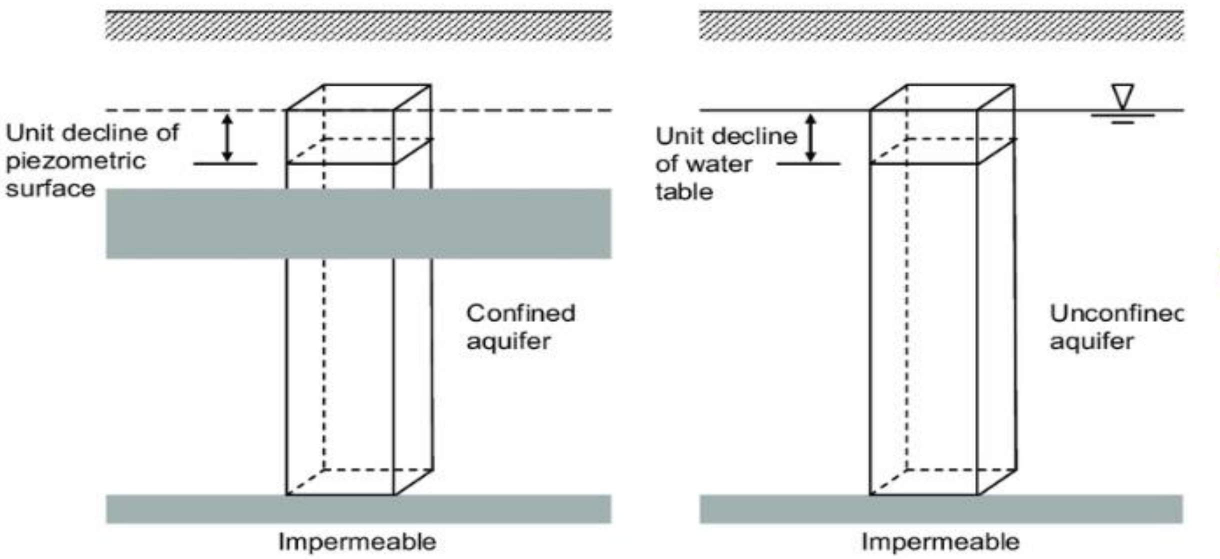


Figure 6: -Definition of storage coefficient in confined and unconfined aquifers.

Theoretical, Storage coefficient (storativity) can be used to calculate the volume of water contained within an aquifer or that will be released when it is pumped. However, not all of the groundwater stored in an aquifer can be accessed. Most is needed to provide the gradient for groundwater to flow or to maintain spring flow, and keep the seawater interface in a safe position. Some water will also be so tightly held by natural capillary, friction or suction forces, that no pump will be able to extract all of it.

2.4 Types of Pump Test

Pumping tests are a commonly used method to determine the transmissivity (and, if the thickness of the aquifer is known, the hydraulic conductivity) and the storage coefficient of an aquifer. The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring drawdown as function of time. These measurements are then incorporated into an appropriate well flow equation to calculate the hydraulic parameters of the aquifer. In well filed pumping test principles can be applied on Single Well or Multi-Well systems.

A single well pumping test involves pumping at a constant or variable rate and measuring changes in water levels during pumping and recovery. Such tests are used to determine T and K when water level recovery is too rapid for slug tests and no observation wells or piezometers are available.

Some of the disadvantages of single well tests are:

- Well construction (e.g. partial penetration) can lead to an underestimation of aquifer transmissivity.
- Storativity cannot be reliably determined; and
- Single well test analyses typically make no allowance for leakage, or other recharge/no-flow boundaries (SMITH, 2008).

A multiple well test is implemented by pumping a well continuously and measuring water level changes in both the pumped and observation wells during pumping or subsequent recovery. Properly designed and conducted multiple well tests can be used to define the overall hydro geologic regime of the area being investigated, including T, S and/or specific yield of a zone. They also can help design municipal well fields, predict rates of groundwater flow, determine interconnectivity between saturated zones, and design a remediation system. Two basic types are constant discharge and variable discharge. The former is performed by pumping at a constant rate for the duration of the test, while the latter is distinguished by changes in rate. Measurements obtained from the pumping well generally are less desirable for calculating hydraulic properties because of the irregularities induced from the operation of the pump and well bore storage. Obtaining data from observation well(s) allows for characterization of the pumped zone over a larger area *(strickland, 2006).*

2.4.1 Duration of a Pumping Test

The question of how long a pumping test should last is difficult to answer as the period of pumping depends on the type of aquifer and the degree of accuracy desired in establishing its physical properties. Economizing on the pumping period is not recommended as the costs of running the pump a few extra hours are low compared with the total costs of the test.

Moreover, better and more reliable data are obtained if pumping continues until the cone of depression has stabilized and does not seem to be expanding further as pumping continues. At the beginning of the test, the cone develops quickly as the pumped water is initially derived from the aquifer storage immediately around the well. But, as pumping continues, the cone expands and deepens more slowly as, with each additional meter of horizontal expansion, a larger volume of stored water becomes available. This may often lead inexperienced observers to conclude that the cone has stabilized, or in other words that steady state has been reached. In reality, the depression cone will continue to expand until the recharge of the aquifer, if any, equals the discharge. Kruseman (2000) suggest that, under average conditions, steady-state flow is generally reached in leaky aquifers after 15 to 20 hours of pumping, and in a confined aquifer, after 24 hours. In an unconfined aquifer, the cone of depression expands more slowly, so a longer period of pumping is required, say, three days.

If a steady state has been reached, simple equations can be used to analyze the data and reliable results will be obtained. Besides, the longer period of pumping required to reach steady state may reveal the presence of boundary conditions previously unknown, or in cases of fractured formations, will reveal the specific flows that develop during the test. Preliminary plotting of drawdown data during the test will often show what is happening and may indicate how much longer the test should continue

2.4.2 Preliminary Pump Test

Before implementing a constant-rate or step-drawdown pumping test, the well should be developed adequately to reduce the influence of well construction on aquifer response. Preliminary pumping test are the usually the first tests that are performed during well pumping tests. They are implanted so that the well can settle. These provisional pumping tests are commonly conducted for 2 hours prior to step drawdown test;

- to check the possible discharge of the well,
- to check the maximum anticipated drawdown,
- To decide the pump position for the step drawdown test.

2.4.3 Step-Drawdown Pumping Test

A step drawdown test provides a measure of well performance that can be used to estimate well's efficiency and determine an optimal pumping rate for the well, as well as provide an estimate of maximum yield under various water level conditions.

Water levels in a pumping well decrease with pumping duration as well as increased pumping rate. This water level decrease, or drawdown, is made up of two components: aquifer loss and well loss.

a. Aquifer loss is head loss caused as water flows towards a well screen. Here the flow is assumed to be laminar, and the loss is proportional to the resistance provided by the material forming the aquifer.
b. Well loss is often associated with non-linear head loss where water flow is turbulent. Turbulent flow occurs when water passes rapidly through the well screen, and can occur in parts of the aquifer immediately adjacent to the screen. Additional turbulent losses can occur in the pump and rising column. The higher the flow the more turbulence and so the percentages of non-linear well losses increase with pumping rate.

In a step drawdown test, water is initially pumped at a known, low rate and water levels and time recorded until drawdown begins to stabilize. The pumping rate is then increased and water levels are again recorded until the drawdown again begins to stabilize. A step test should have at least three steps that cover a wide range of flows, preferably matching or exceeding the proposed design flow.

Step drawdown test data can be analyses with the Eden-Hazel (1973) method, which is based on the Jacob straight line method to give an estimate of transmissivity *(Smith, 2008).*

2.4.4. Constant-Rate Pumping Test

The constant-rate test is the most familiar type of pumping test performed, and its concept is very simple: the borehole is pumped at a constant rate for an extended period (from several hours to several days or even weeks) while the water levels and pumping rates are monitored. During constant-rate pumping tests, groundwater is extracted from the aquifer and regulated to maintain a constant, uniform rate. The pressure response within the pumped well is monitored during the active withdrawal (drawdown) phase. Ideally, a constant-rate test should be long enough for the water level to reach or at least approach equilibrium. How long it takes to do this depends on the hydraulic properties of the aquifer. Usually, the drawdown against time is recorded a period of 72 hour by keeping the discharge at a uniform rate.

Maintaining a steady pumping rate during a constant rate test is sometimes a problem, especially if the chosen pumping rate results in a large drawdown. This is because for centrifugal pumps (the most commonly used type of pump) there is a relationship between pumping rate and pumping head. Incidentally, the pump must be set at a depth that is several meters below the deepest water level expected during the test. During a constant-rate test, it is worth roughly plotting the data in the field as the test proceeds, in case these deviations are observed. Decisions can then be made about extending or shortening the planned test length, or trying a different pumping rate.

2.4.5 Recovery Test

When the pump is stopped at the end of a pumping test, the water level in the well and in the observation wells start rising, this is referred to as the recovery of groundwater level. The fall in water level (drawdown) below the original static water level (before pumping) and during the recovery period are known as residual drawdown. Figure 7 shows a schematic diagram of change in water level with time during and after pumping. Recovery tests are valuable for several reasons:

- They provide a useful check on the aquifer characteristics derived from pumping tests, for very little extra effort – just extending the monitoring period after the pump has been switched off.
- The start of the test is relatively 'clean.' In practice, the start of a constant-rate test, for example, rarely achieves a clean jump from no pumping to the chosen pumping rate. Switching a pump off is usually much easier than starting a pump and the jump from a constant pumping rate to no pumping can be achieved fairly cleanly.
- Similarly, recovery smoothed out small changes in the pumping rate that occurred during the pumping phase, and there is no problem with well losses from turbulent flow. This results in more reliable estimates of aquifer properties when the recovery data are analyzed.

The transmissibility of the aquifer can be calculated by analyzing the residual drawdown, which will provide an independent check on pumping test results. The rate of recharge to the well during the recovery period is assumed to be constant, whereas it becomes difficult to control the pumping rate in the field. Moreover, in case of recovery test, measurements of recovery can also be made in the well in the absence of an observation well. The residual drawdown s can be calculated as follows (*Theis, 1935):*

$$s' = Q4\pi T\left(W(u) - W(u')\right) \tag{2.3}$$

Where, $u = \frac{r^2 S}{4Tt}$ and $u' = \frac{r^2 S\prime}{4Tt\prime}$

Equation (2.3) can be approximated as

$$s' = \frac{2.30Q}{4\pi T} \log \frac{t}{t\prime} \tag{2.4}$$

Where s’= residual drawdown in m

r = distance in m from well to piezometer

T = transmissivity of aquifer in m^2/d

S = storativity during pumping, dimensionless

S' = storativity during recovery, dimensionless

t = time in days since the start of pumping

t' = time in days since the cessation of pumping

Q= rate of discharge in m^3/d

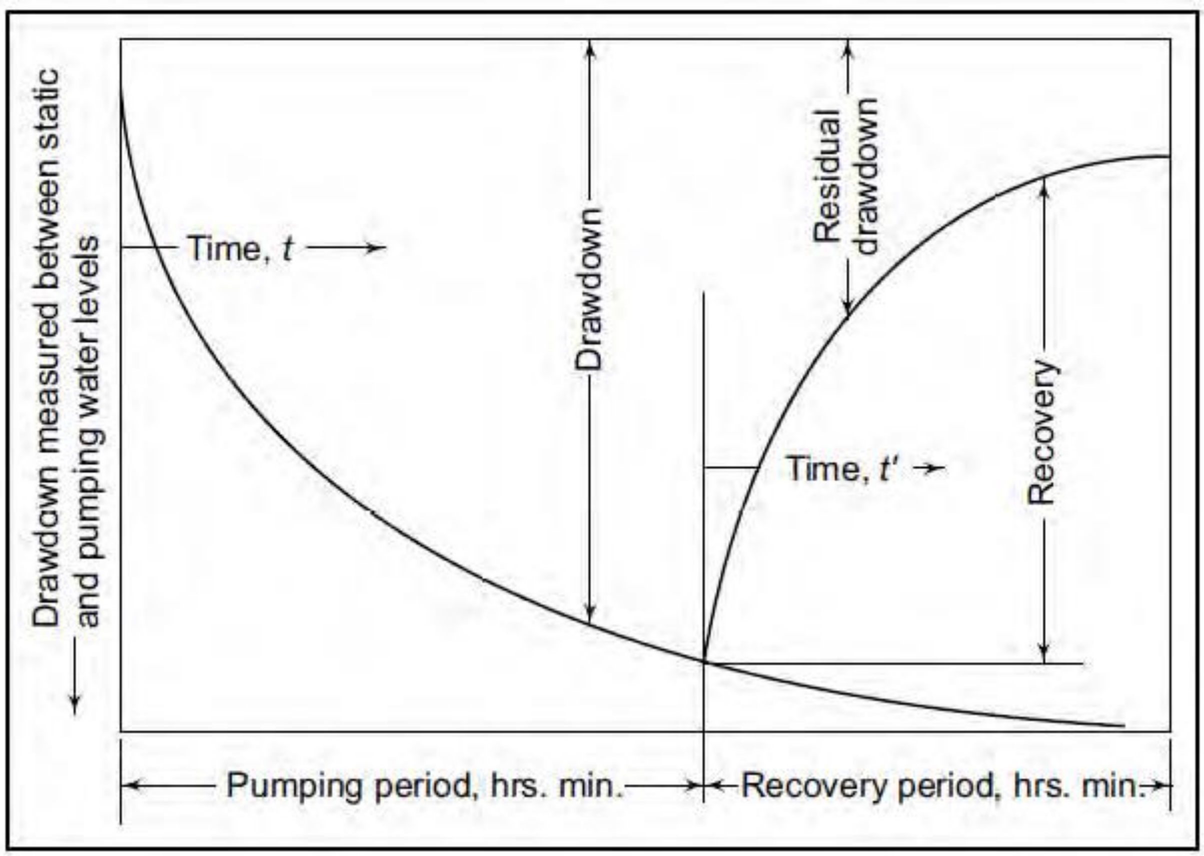


Figure 7:- The drawdown and recovery curves near observation well near a pumping well

The residual drawdown s' versus t/t' are plotted on a semi – logarithmic paper. The slope of the straight line so plotted equals 2.30Q/4πT, so that for $\Delta S'$, the residual drawdown per log cycle of t/t', the transmissibility becomes.

$$T = \frac{2.30Q}{4\pi\Delta S'} \quad (2.5)$$

The recovery test method cannot be used to determine the comparable value of S (A.M.MICHAEL, 2008).

2.4.6 Correction of Pump Test Data

Pumping tests are used to determine in-situ properties of water-bearing formations and define the overall hydro-geological regime. Such tests can determine transmissivity (T), hydraulic conductivity (K), storativity (S), connection between saturated zones, identification of boundary conditions, and the cone of influence of a pumping well in a groundwater extraction system .The water-level data collected before, during, and after the test must converted to drawdowns by subtracting the static water from the measured water level and should be expressed in appropriate units.

Before being used in the analysis, the observed water levels may have to be corrected for external influences (i.e. those not related to the pumping). To find out whether this is necessary, one has to analyze the local trend in the hydraulic head or water table. The most suitable data for this purpose are the water level measurements taken in. If, after the recovery period, the same constant water level is observed as during the pre-testing period, it can safely be assumed that no external events influenced the hydraulic head during the test. If, however, the water level is subject to unidirectional or rhythmic changes, it will have to be corrected. Unidirectional variation is when the aquifer is be influenced by natural recharge or discharge, which will result in a rise or a fall in the hydraulic head.

By interpolation from the hydrographs of the well and the piezometers, this natural rise or fall can be determined for the pumping and recovery periods. This information is then used to correct the observed water levels. Rhythmic fluctuations of the hydraulic head may be atmospheric pressure. Hydrographs of the well and the piezometers, covering sufficiently long pre-test and post-recovery periods, will yield the information required to correct the water levels observed during the test.

2.4.6.1 Well Efficiency and Correction for Well Loss

Well efficiency is the ratio between the theoretical drawdown and the actual drawdown measured in the well. It is expressed in percent:

$$\text{Well Efficiency} = \frac{\text{Theoretical Drawdown (s0)}}{\text{Measured Drawdown (sw)}} * 100\% \quad (2.6)$$

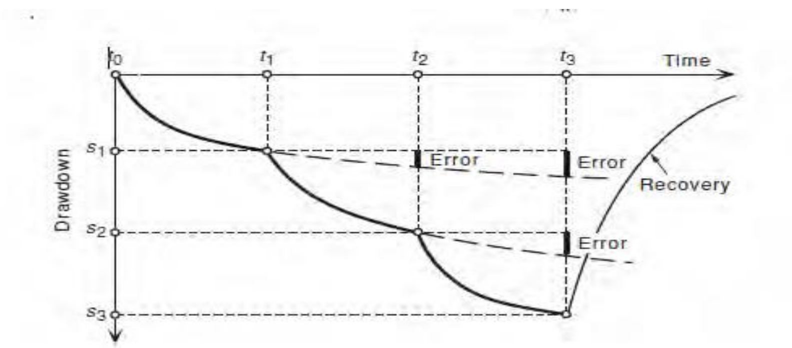


Figure 8:- Components of drawdown recorded at the end of each step showing errors made if drawdown s1, s2, and s3 where used directly to draw graph Q versus S/Q

$$\eta = \frac{St}{Sa}$$

Where: $Sa = St + S$ (2.7)

$$\eta = \frac{St}{St + Sw}$$

$$\eta(St + Sw) = St$$

$$Sw = \left(\frac{1-\eta}{\eta}\right) St \qquad St = \left(\frac{\eta}{1-\eta}\right) St$$

$$Sa = \left(\frac{\eta}{1-\eta} + 1\right) Sw$$

$$Sa = \left(\frac{1}{1-\eta}\right) Sw$$ Thus

$$Sw = (1-\eta) Sa \qquad (2.8)$$

Before the observed drawdown can be used for any analysis the drawdown must be corrected. By using the well efficiency correction to the drawdown can be done to the observed drawdown by subtracting the well loss drawdown (Sw) from the observed well filed drawdown data.

Consequently, well efficiency decreases with an increasing pumping rate. Determining well efficiency and well loss is highly recommended because it provides valuable information about the well performance and can be used to make an informed decision regarding the well pumping rate, maintenance, and rehabilitation. A well efficiency of 70 percent or more is usually considered acceptable. If a newly developed well has less than 65 percent efficiency, it should not be approved without a thorough analysis of the possible underlying reasons. This may include well redevelopment followed by new performance testing *(kersic, 2009).*

The relationship between drawdown and discharge can be expressed as the specific capacity of a well $\frac{Q}{Sw}$which describes the productivity of both the aquifer and the well. The specific capacity is not a constant but decreases as pumping continues also decreases with increasing Q The well efficiency, Ew, is defined as the ratio of the aquifer head loss to the total head losses; it reads when expressed as a percentage.

$$\mathrm{Ew} = \left\{\frac{B_1 Q}{BQ+CQ^P}\right\} \quad (2.9)$$

The well efficiency according to Equation above can be assessed when both the results of a step-drawdown and those of an aquifer test are available. The former are needed for the values of B, C, and P and the latter for the value of B1. In practice, only the results of a step-drawdown test are usually available. The substitution of the B, C, and P values into Equation above would overestimate the well efficiency, because B >B1. For these cases, Driscoll (1986) introduced another parameter, Lp, being the ratio of the laminar head loss to the total head losses; it reads when expressed as a percentage *(W.Delleur, 2007)*

$$\mathrm{Lp} = \left\{\frac{B_1 Q}{BQ+CQ^P}\right\} \quad (2.10)$$

2.4.6.2 . Correction for Unconfined aquifer

The water table in an unconfined aquifer is equal to the elevation head (potential). Since transmissivity in unconfined aquifers is not constant and it will decrease with increasing drawdown, there is no closed solution for this aquifer type. That is why the measured drawdown is corrected, and the pumping test is interpreted as being in a confined aquifer.

For most analysis solutions, the aquifer is assumed to be of constant thickness. This assumption can be accepted if the saturated thickness does not decrease more than 25 percent. If the decrease is greater than 25 percent, then the drawdown data should be corrected prior to analysis (Dawson and Istok, 1991).In an unconfined aquifer, this condition is not met if the drawdown is large compared to the aquifers original saturated thickness. Where this occurs, the Jacob (1944) correction may be applied:

$$S_{cor} = s\left(1 - \frac{s}{2D}\right) \qquad (2.11)$$

Where;

- Scor is the corrected drawdown,
- s is observed drawdown and
- D is the original saturated aquifer thickness.

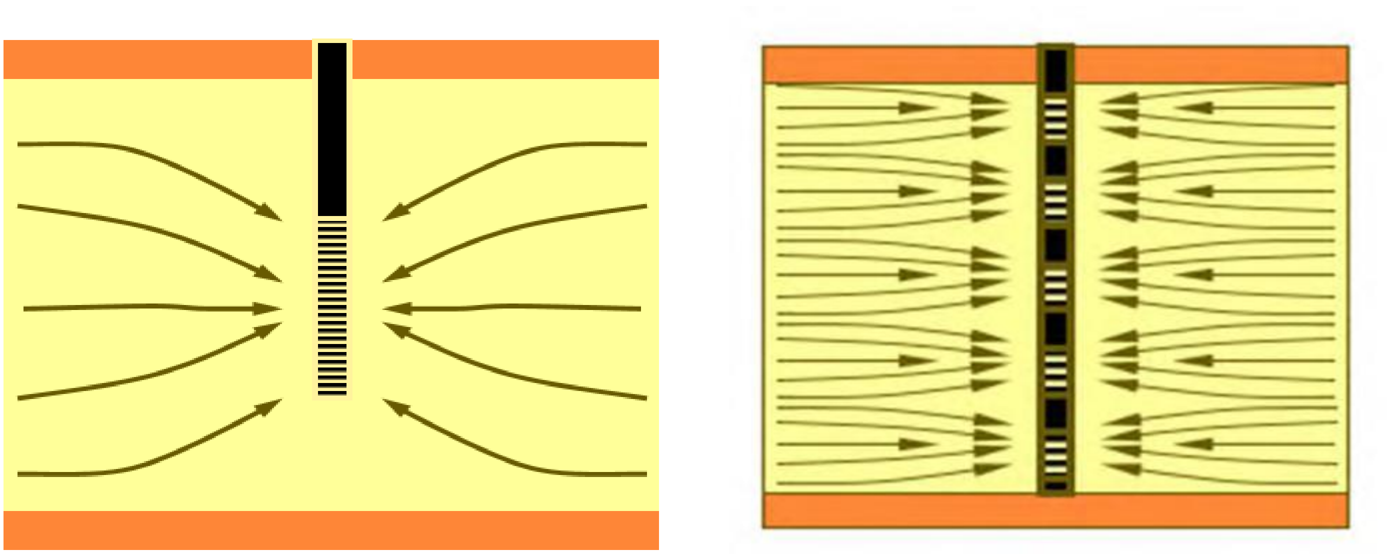
However, this correction is based on the Dupuit-Forchheimer assumption (groundwater flows horizontally and hydraulic gradient is equal to the slope of the water table). Neuman (1975) showed that this assumption is not valid for an unconfined aquifer until the later portion of the test when the drawdown matches the Theis type curve. Therefore, the correction is not recommended with early and intermediate data *(Dawson and Istok, 1991).*

2.4.6.3 Correction for Partial Penetration

It is quite common in developing aquifer drilling, entire aquifer thickness cannot be drilled, and as the thickness is not known .But most analysis for aquifer properties considers/assumes the well to penetrate the aquifer fully and this assumption does not satisfies pumping tests. Therefore, it is necessary to consider the effects of partial penetration.

There are two cases where partial penetration may occur. The first case is when the aquifer is not fully penetrated and the second case arises from the casing arrangement of the well. These two cases are show blow in figure 9.

Partial penetration of the well into the aquifer causes vertical component flow to happen in the vicinity of the well and which in turn causes a head loss in the pumping well. When the well only partially penetrates the aquifer, the average flow path length is increased so that a greater resistance to flow is encountered.



(a) (b)

Figure 9:- Partial Penetration (a) when the aquifer is not fully drilled (b) due to Blind and Screen section of the well.

Kozeny (1933) contributes the following approximate reduction factor to correct specific capacity (Q/s) for the effects of partial penetrations.

$$F = \frac{L}{B}\left[1 + 7COS\left(\frac{\Pi L}{2B}\right)\sqrt{\frac{r}{2L}}\right] \qquad (2.12)$$

Where

- b = is the total aquifer thickness (m)
- r = is the well radius (m); and
- L = is screen length (m).

The equation is valid for $L/b < 0.5$ and $L/r > 30$. Accordingly the required correction for the possible effect of partial penetration is conduct by considering the geometric mean of the each correction factors for the combination of blind and screen in casing arrangements of the wells, so that it can be used for the adjustment of the observed drawdown data for the analysis of such conditions.

2.5. Aquifer Analyses and approximation of hydraulic parameter

It is somewhat easy to calculate hydraulic characteristics if the aquifer system (i.e. aquifer plus well) are precisely known. This is generally not the case, so interpreting a pumping test is primarily a matter of identifying an unknown system. System identification includes the construction of diagnostic plots and specialized plots. Diagnostic plots are log-log plots of the drawdown versus time since pumping started. Specialized plots are semi-log plots of drawdown versus time, or drawdown versus distance to the well; they are specific for a given flow regime. Both plots must be constructed, because the diagnostic value lies in the typical combination of the log-log and semi-log plots.

The capacities of an aquifer to transmit water under a hydraulic gradient and to yield water from storage is when the water table or artesian pressure declines are generally expressed, in terms of a coefficient of transmissivity and coefficient of storage respectively. Determination of these two constants is almost always involved in quantitative studies of groundwater problems. In fact, no matter what methods are adopted, the aquifer's parameters should be unique. In this thesis, we adopt traditional methods Cooper-Jacob straight line method and residual/recovery drawdown vs. time method to determine these two parameters.

2.5.1 Cooper and Jacob Method

It was observed by Cooper and Jacob (1946) that for small values of r and large values of t, u is so small, that the series of W (u) in Eq. $S = \frac{Q}{4\pi t}$W (u) becomes negligible after the first two terms. Therefore, for small values of u (u < 0.01) the drawdown can be approximated by using the following relationship

$$S = \frac{Q}{4\pi T}\left(-0.5772 - \log e \frac{r2S}{4Tt}\right) \qquad (2.13)$$

Converting to decimal logarithms, the Cooper and Jacob equation is as follows:

$$S = \frac{2.303Q}{4\pi T}\log\left(\frac{2.25Tt}{r^2}\right) \qquad (2.14)$$

To apply the Cooper and Jacob equation 2.14, this is an equation for a line, plot s as a function of log (t) on semi-logarithmic axes and draw a straight line through the data.

To determine the transmissivity (T) and storativity (S) uses following equation:

$$T = \frac{2.303Q}{4\pi\Delta s} \qquad (2.15)$$

By extrapolating the straight line of the semi-log plot to intersect the zero drawdown axis to, the time for s=0 can be noted as S can be computed as

$$S = \frac{2.25Tt_o}{r^2} \quad (2.16)$$

Where: - Δs is the drawdown difference per log cycle of t.

The use of this straight line method comes with restrictions thus assumptions are made to the derivation of this equation. As the equation is based on the Theis equations the assumption made by Theis also apply for Cooper and Jacob solution. The assumptions given by Cooper and Jacob are:

- aquifer has infinite areal extent
- aquifer is homogeneous, isotropic and of uniform thickness
- control well is fully penetrating
- flow to control well is horizontal
- aquifer is confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the control well can be neglected

2.5.2 R- Squared (R^2)

Uses of the Cooper-Jacob method is the simples from of determination of transmissivity and storativity of a given aquifer by using a semi-logarithmic graph of drawdown verses logarithms of time data and fitting a best straight line through the scattered point in the graph. Drawing of this straight line by hand on as semi-log graph with no leanings toward a single data point on the graph is tedious job.

Different software's have been developed that can draw this straight line using regression analysis with a blink of an eye and can give as the degree of accuracy. This software use a statistical variable known as R-squared to determine the best fit line on a graph is representing the data points on a graph.

R-squared is a statistical relationship between two series of events. It is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determinations for multiple regressions. The definition of R-squared is fairly straight-forward; it is the percentage of the response variable variation that is explained by a linear model. Or:

$$R^2 = \frac{Explained\ Variation}{Total\ Variation} \qquad (2.17)$$

R-squared is always between 0 and 1. Zero indicates that the model explains none of the variability of the response data around its mean. And 1 indicates that the model explains all the variability of the response data around its mean. Therefore, the uses of R-squared value in Cooper-Jacob semi-log graph gives as the degree of accuracy of the straight line and has been used in this thesis not only for Cooper Jacobs's analysis but also in different topics that involves best fit lines.

2.5.3 The Recovery Method for Determining the Coefficient of Transmissibility

When the pump is shut down after a pumping test, the water levels in the well and the piezometers will start to rise. This rise in water levels is known as residual drawdown (s'). It is expressed as the difference between the original water level before the start of pumping and the water level measured at a time t' after the cessation of pumping.

The recovery method developed by Theis (1935) has proved useful for determining the coefficient of transmissibility of an aquifer if the coefficient of storage remains virtually constant throughout both the period of pumping and the subsequent period of recovery. However, if the coefficient of storage does not remain constant, the water-level drawdown data, when plotted on a graph, do not fall along a straight line that passes through the origin. Instead, most of the data fall along a smooth curve that does not pass through the origin, and the coefficient of transmissibility can be determined from the slope of this curve regardless of any variation in the coefficient of storage. The Theis recovery method is widely used for the analysis of recovery tests. Strictly speaking, this method is only valid for confined aquifers which are fully penetrated by a well that is pumped at a constant rate. Nevertheless, if additional limiting conditions are satisfied, the Theis method can also be used for leaky aquifers and unconfined aquifers and aquifers that are only partially penetrated by a well.

$$s' = \frac{Q}{4\pi T} \log \frac{t}{t'} \qquad (2.18)$$

The graph of equation 2.18, where s' is plotted against log (t/t') is a straight line. If the value of Q is known, T can be determined from the slope of the line. The slope of the line equals 2.3Q/4πT so that Δs′, the change in residual drawdown over one log cycle of t/t′, enables a value of transmissivity to be found from:

$$T = \frac{2.3Q}{4\pi \Delta s'} \qquad (2.19)$$

Where Δs′ is the residual drawdown difference per log cycle of t/t'.
Here we keep in mind that the assumption made by Theis is also applied in the recovery method. The general procedure in the determination of transmissivity recovery method is brief below.

1. For each observed value of **s'**, calculate the corresponding value of t/t
2. For one of the piezometers, plot **s'** versus t/t' on semi-log paper (t/t' on the logarithmic scale)
3. Fit a straight line through the plotted points;
4. Determine the slope of the straight line, i.e. the residual drawdown difference $\Delta s'$ per log cycle of t/t'
5. Substitute the known values of Q and $\Delta s'$ into Equation 2.25 and calculate T.

It is always good practice to measure the residual drawdowns during the recovery period. Recovery-test measurements allow the transmissivity of the aquifer to be calculated, thereby providing an independent check on the results of the pumping test, although costing very little in comparison with the pumping test. Unlike the Theis and Cooper–Jacob methods, it is not likely for a value of storativity (S), to be determined by this recovery test method

2.6 Historical Development of Groundwater Monitoring

According to international groundwater resource assessment center (2004) the first network for monitoring groundwater levels was set up in England/Wales around 1845. Other European countries followed in the twentieth century. Systematic monitoring in Europe started in the period 1950-1980. By now there are more than a 30 years recorded data available. In year 1920 France set up the first groundwater quality network in Europe.However, systematic groundwater quality monitoring in most countries started not earlier than 1980. First groundwater monitoring in the USA dates from the beginning of the twentieth century, IGRAC (2004) cited in a report "Water Fact Sheet, History of Water Resources Activities of the USGS"(USGS, 1985).

In many developing countries the start of international projects on groundwater assessment or on urban water supply from groundwater marks the first steps in monitoring.

Unfortunately many of these projects have led to only short-term records that stopped not long after the end of the project. Development and status of groundwater monitoring networks depend on many factors. On the one hand monitoring networks are adjusted to the development of groundwater resources exploitation and the increasing impacts on the environment. Monitoring networks may evolve from very incoherent collections of wells in the reconnaissance stage of groundwater resources assessment to multifunctional networks for complex situations of groundwater exploitation. There are great influences on the actual state of the networks such as. climate, topography and hydrogeology as well as population density, economy, etc.

Groundwater monitoring generally starts with local problems, for instance, when groundwater levels drop because of groundwater withdrawal or when the quality of pumped water is deteriorating. In such cases monitoring will be conducted on a local scale, whenever possible by making use of available wells.

In this stage investments made for observation of water levels or sampling and analysis of groundwater quality are often kept to a minimum. Such local networks may never develop into more permanent ones if the reason for their existence vanishes after some time, this shows it is just project oriented monitoring system.This is the fate of many local monitoring networks, created for the purpose of temporary studies. Also many networks installed for national or international groundwater resources development projects have ended up like that. These situations can be found in practically any country of the world where groundwater is important for development. Conditions change, for instance, where and when water supply requires data on a more permanent operational basis, or where conflicting interests are constantly demanding attention. (Jousma and Roelofse, 2004)

Table 3 :- Groundwater monitoring stage - variation among countries (IGRAC, 2004)

Category	Countries (examples)
As far as known, no significant and systematic groundwater monitoring going on Only scattered and temporal groundwater monitoring activities, mostly problem driven.	Africa: Burkina Faso, Eritrea, Kenya, Mozambique, Sudan, Zimbabwe;
	Asia: Myanmar;
	C- & S-America: Bolivia, Paraguay, and Uruguay;
Local groundwater monitoring networks running for several years already, with regular frequency (e.g. networks around well fields)	Africa: Benin, Central African Republic ,Ethiopia, Namibia, South-Africa, Djibouti;
	Asia:, Indonesia; Palestine, Syria, Yemen; N-America: Canada;
National or regional reference groundwater monitoring networks operational in combination with local groundwater monitoring networks	Africa: Botswana, Egypt, Mauritius, Seychelles, Tunisia;
	Asia: China, India, Japan, Korea, Malaysia;
	Australia; New Zealand;
	Europe: Austria, Belgium, Bulgaria, Denmark, Finland, Germany, Hungary, Italy, Moldova, Netherlands, Poland, Romania, Slovenia, Switzerland;
	N-America: USA, Mexico;
	C- & S-America: Barbados, Brazil, Chile;

Based on the available data three stages of groundwater monitoring have been considered:

1. No significant and systematic groundwater monitoring going on or only project-wise or problem driven. This is a situation often found in countries, where groundwater development is in an early stage.
   Data on groundwater levels or groundwater quality are monitored within the framework of local and temporal projects.
2. Local groundwater monitoring networks monitored with regular frequency for several years. This situation exists in countries, where systematic groundwater development and monitoring have become important. However,

the situation may also be found in countries where no need for large regional or national groundwater monitoring networks exists.

3. National or large regional reference groundwater monitoring networks in combination with local networks. Many countries are planning their groundwater development with the help of a national monitoring network or large regional groundwater monitoring networks.

The networks are used to investigate the properties of regional groundwater systems and their potential and suitability for water supply. Provision of licenses for withdrawal may be made dependent from these estimates (for instance in India and Moldova). A combination of a national or large regional and local networks offers the advantages of flexibility. Many countries use such combinations for their groundwater management.

2.7 Monitoring Oobjectives

A clear specification of monitoring objectives and required information is critical information for design of a monitoring network that is meant to provide the necessary data for water management. From experience it turns out that a significant share of the costs of monitoring may be saved if the objectives are well defined and specified. Monitoring objectives can be defined from different perspectives. At least two "levels" of objectives can be distinguished:

- The management level of objectives. Management objectives are for instance: a developing groundwater resources for drinking water supply, optimization of crop production, protection of nature conservation areas, restoration of wetlands, dealing with claims concerning damage, etc.
- The technical level of objectives. Technical objectives are for example: to determine the directions of groundwater flow, to establish the areas of infiltration and seepage, to quantify the relation between groundwater and surface water, to feed the groundwater models, etc.

- Groundwater level monitoring for water supply and groundwater management With respect to the main focus of groundwater level monitoring in different countries, roughly four categories can be distinguished, see table

Table 4:- Groundwater level monitoring focus - variation among countries (IGRAC)

Stage	Main focus	Objectives	Regions and Countries (examples)
1	Assessment	Reconnaissance of groundwater systems (including spatial patterns and temporal trends) and assessment of the potential for water supply.	Africa: Botswana, Djibouti, Ethiopia, Seychelles, South Africa, Tunisia
			Asia: China, India, Japan, Korea, Myanmar, Palestine, Yemen
			Europe: Belgium, Bulgaria, Denmark, Hungary, Italy, Poland, Moldova, Netherlands, Romania, Slovenia
			N-America: Canada (Quebec), USA, Oceania:
			Australia, New Zealand
			S-America: Argentina, Barbados, Brazil, Chile, Uruguay
2	Optimized	Development Groundwater levels monitored for optimization of groundwater withdrawal	Africa: Benin, Central African Republic;
			Asia: China, Japan, S-Korea, Malaysia, New Zealand, Palestine;
			Europe: Belgium (F+W), Denmark, Finland, Moldova, Slovenia;
			N-America: Canada (Quebec);
			C- & S-America: Argentina, Barbados;
3	Integrated	Management Integrated water management and control of groundwater resources (pro-active).	Asia: India
			Australia; N-America: USA;
			Europe: Netherlands, Germany, Hungary

Regarding the purpose of groundwater monitoring, different stages have been distinguished. The focus of groundwater monitoring may be mainly on

(1) Groundwater assessment,

(2) Optimized development of groundwater resources, or

(3) Integrated water management.

Another objective of groundwater monitoring to establish monitoring system is based on the response to information needs

There are four basic objectives for establishing a monitoring system:

1. Resource monitoring to increase the understanding of the groundwater system in a basin (recharge, discharge, interaction with surface water, changes in quality and quantity over time)
2. Compliance monitoring to get information on the effectiveness of management measures. This has two main dimensions:
   - Measuring groundwater use and aquifer response to collect the necessary information for management measure related to quantity (such as restrictions to number of wells, well yields and well spacing or regulation to prevent groundwater levels of wells and well fields to drop below a certain level)
   - Measuring groundwater quality parameters of abstracted groundwater to check compliance with prescribed maximum levels.
3. Protection monitoring for potential impacts on specific groundwater infrastructure or groundwater bodies: typical examples are the protection of:
   - Well fields or springs for public water supply against depletion and quality hazards
   - Urban infrastructure against land subsidence
   - Archaeological sites against rising water tables
   - Strategic water reserves against depletion or quality hazards
   - Groundwater dependent ecosystems against undesirable changes in water quantity and/or quality
4. Pollution containment monitoring to provide early warning information on impacts of potential pollution hazards from:
   - Intensive agricultural land use
   - Industrial sites of specific industries
   - Solid waste land fills
   - Land reclamation areas

A monitoring plan should include:

- Details of the method to be used to measure abstracted water volumes.
- If using a metering device, how often measurements will be taken.
- Whether water levels will be monitored in a production borehole or an observation borehole.
- If an observation borehole is to be used for monitoring, its location in relation to the production borehole.
- Details of the method to be used for measuring resting water levels.
- The frequency that resting water levels will be monitored
- What measures will be adopted to ensure the proposed monitoring plan will be implemented.
- If there is a potential risk of saline intrusion identified, detail and frequency of conductivity monitoring.

Network types and configuration

The groundwater monitoring network can be classified by its function into three systems:

i) **Primary (reference monitoring)** –the main purpose is to evaluate the well fields and production and monitoring wells water levels and water quality trends due to continuous abstraction, land use changes and climatic variations. The monitoring considers both production and monitoring wells within the well fields.

ii) **Secondary (Protection monitoring)** - Protection against potential impacts of well fields. Monitoring wells will be considered around the well fields mainly along the groundwater flow direction upstream of the well fields to evaluate incoming treat to the well fields (reduction of recharge, incoming pollution, etc.).

iii) **Tertiary (Pollution Containment)** - Primary and secondary networks are often combined to a wide-spaced regional network with denser spaced parts in areas of particular interest. Early warning for production wells located nearby industrial complex, waste disposal, waste water treatment sites, etc.

The monitoring wells will be located between the pollution source and production wells if the groundwater flow from the pollution source to the production wells. The terminology of primary and secondary networks can be used to link these networks to respectively “overall objectives”, valid for large regions and “specific objectives”, used to focus on particular aspects and usually local conditions.(Jousma and Roelofse, 2004)

2.8 Groundwater Level Monitoring

By studying the trend of resting water levels over a long period of time, it is possible to establish whether an abstraction is operating sustainably or not. Groundwater levels are typically high in the winter and low in the summer. A trend over a number of years that demonstrates groundwater levels are declining indicates that there is unsustainable abstraction in that area. This information is useful for an operator as it helps them to better manage their water usage and alerts them to any water shortage problems that could severely threaten the operations at their site.

A groundwater level, whether it is the water table of an unconfined aquifer or the piezometric surface of a confined aquifer, indicates the elevation of atmospheric pressure of the aquifer. Any phenomenon that produces a change in pressure on groundwater will cause the ground- water level to vary. Differences between supply and withdrawal of groundwater cause levels to fluctuate. Stream flow variations are closely related to groundwater levels.

Other diverse influences on groundwater levels include meteorological and tidal phenomena, urbanization, earthquakes, and external loads. Finally, subsidence of the land surface can occur due to changes in underlying groundwater conditions.

The process of urbanization often causes changes in groundwater levels as a result of decreased recharge and increased withdrawal.

In rural areas, water supplies are usually obtained from shallow wells, while most of the domestic wastewater is returned to the ground through cesspools or septic tanks. Thus, a quantitative balance in the hydrologic system remains.

As population increases, many individual wells are abandoned in favor of deeper public wells. Later, with the introduction of sewer systems, storm water and wastewater typically discharge to a nearby surface water body .Thus, three conditions disrupt the subsurface hydrologic balance and produce declines in groundwater levels. (Todd, 2005)

1. Reduced groundwater recharge due to paved surface areas and storm sewers
2. Increased groundwater discharge by pumping wells
3. Decreased groundwater recharge due to export of wastewater collected by sanitary sewers

2.8.1 Secular Variations

Secular variations of groundwater levels are those extending over periods of several years or more. Alternating series of wet and dry years, in which the rainfall is above or below the mean, will produce long-period fluctuations of levels. Rainfall is not an accurate indicator of groundwater level changes because of subsurface losses as well as travel time for vertical percolation. The travel time may vary from a few minutes for shallow water tables in permeable formations to several months or years for deep water tables underlying sediments with low vertical permeability.

Furthermore, in arid and semiarid regions, recharge from rainfall may be essentially zero. Shallow water tables show definite responses to rainfall, Recharge is the governing factor (assuming annual withdrawals are constant); it depends on rainfall intensity and distribution and amount of surface runoff.

2.8.2 Seasonal Variations

Many groundwater levels show a seasonal pattern of fluctuation. This results from influences such as rainfall and irrigation pumping that follow well-defined seasonal cycles. Highest levels occur in late spring and are lowest in winter. In irrigated areas where frozen ground is not a factor, lowest levels normally occur during fall at the end of the irrigation season.

The amplitude depends on recharge, pumpage, and the type of aquifer; confined aquifers normally display a greater range in levels than do unconfined aquifers.

2.8.3 Short-Term Variations

Groundwater levels often display characteristic short-term fluctuations governed by the primary use of groundwater in a locality. Clearly defined diurnal variations may be associated with municipal water-supply wells. Similarly, weekly patterns occur with pumping for industrial and municipal purposes.

Water level Measuring Devices

1. A measuring tape: - The basic water-level measuring device is a steel tape typically coated with ordinary carpenter’s chalk. This is the simplest water-level measuring device considered accurate at moderate depths;
2. A tape with electric sensor: - Electric sensors are suspended on the end of a marked cable. When the sensor encounters conductive fluid, the circuit is completed and an audible or visual signal is displayed at the surface;
3. Float type devices :-rest on the water surface and may provide a continuous record of water levels on drum pen recorders or data loggers. Float sizes range from 1.6 inches to 6.0 inches in diameter, but are only recommended for wells greater than 4 inches in diameter, due to loss of sensitivity in smaller diameter bore holes;
4. Pressure transducers:-are suspended in the well on a cable and measure height of water above the transducer center. Transducers are available in diameters as small as 0.75 inches;

5. Acoustic well probes use the reflective properties of sound waves to calculate the distance from the probe at the wellhead to the water surface. Acoustic probes are designed for well diameters as small as 4 inches and are limited to water depths greater than 25 feet (Ritchey J. D., 1986);

6. Air lines are installed at a known depth beneath the water and by measuring the pressure of air necessary to discharge water from the tube, the height of the water column above the discharge point can be determined. The choice between manual observation and use of automatic recording depends on:
   - Information needs (e.g. the need for frequent data or high level of accuracy);
   - Institutional and financial conditions (designation of tasks and budgets, availability of trained staff, availability of cheap labor, etc.);
   - Logistic and other conditions (distance to the wells, availability of transport, accessibility of the spot, permits, etc.).

2.9 Practical Framework for Addis Ababa Region

The strategic framework for managed groundwater development in Ethiopia is prepared by a core team under the guidance of the MoWR from January up to June 2010 and resulted in a report Ethiopia: Strategic Framework for Management Groundwater Development. Below are the practical frameworks for Addis Ababa region.

2.9.1 Policy Adjustments

An encouraging development is the cooperation between Addis Ababa and Oromia Regional State with respect to land use planning and regional development. Cooperation between Oromia Regional State and the Addis Ababa City Administration needs to be further elaborated, since the aquifer is shared between the two regions. The Oromia Special Zone consists of six woredas surrounding Addis Ababa.

Land use plans have been prepared and been approved for the Oromia Special Zone. In the land use plan prime land is allocated for agriculture and floriculture, whereas land that is less suitable is allocated to housing. The development of new heavy industry is planned in the South East of the Special Zone, away from the shallow aquifer recharge area. Environmental protection zones are planned around the urban centers, stretching for 3-5 kilometers.
Along perennial and intermittent streams and around reservoirs buffer strips of 50 to 100 meters have been designated. The land use planning could be further expanded to include managed recharge – retaining run-off in recharge zones, dovetailing road design and urban design with recharge. The plan needs to be extended to include the Addis Ababa City Administration and due attention need to be given to its implementation.

Otherwise, the integrated land use plan within Oromia Special Zone alone couldn't be enough to protect the hydro-geological system, as the source of major pollutants is the city. (Ethiopia: Strategic Framework for Managed Groundwater Development, 2013)

2.9.2 Policy for Private sector roles

Where groundwater has taken off it has been through private sector investment and services. This requires both a facilitating environment and a regulatory regime. There needs to a clear vision on how to engage the private sector in groundwater development and management in the Addis Ababa region, including: - Clarity on regulatory procedures - Opportunities to develop private sector role and capacity in drilling, well operation, monitoring compliance and communication.

2.9.3 Support for Regulation

The reverse side to enlarged private sector involvement is better regulation. Currently regulation is weak and has no priority, as is clear to the meager manpower dedicated to it, the logistical means and the political support for enforcement. If a groundwater use is to intensify and extent to agro economic use, regulatory activities need to be better resourced both in Addis Ababa and in Oromia.

This should start by enforcing the regulations that are there by making the minimum required resources to do so available

2.9.4 Well Development Guidelines

It is proposed to develop national well drilling guidelines and the Ministry of Water Resources has made a start on this issues. The urgency of these guidelines is particularly high in the Addis Ababa region where intense exploratory drilling is taking place. In the drilling of the test wells a large variation in quality and techniques is observed. The well drilling guidelines would help to set quality and abstraction standards in well development and to protect the well drilling sector against unfounded complaints. The well drilling guidelines should make use of standardized well designs – in the case of Addis Ababa in particular issues associated with increasing diameter of the wells should be handled carefully, as the wells that are currently drilled are bigger in dimension which adds to the vulnerability of deeper aquifers unless proper protection measures are in place. (Ethiopia: Strategic Framework for Managed Groundwater Development, 2013)

2.9.5 Strengthen Regulatory body

Groundwater regulation should be strengthened. Licensing is now done by Addis Ababa EPA and Oromia Water Resources Bureau, but the effort is piecemeal and incomplete. On top of this the former licensing institution has mandate conflict. There is a large backlog particularly in the Addis Ababa city limits with many wells unregistered. Any effort in groundwater regulation should start with reconstructing an up-to-date database of production wells – privately and publicly owned. There have been cases of the EPA being overruled moreover by the major stakeholders – when it objected on the development of some new AAWSA wells. Rather than overruling it is better than adding an objection clause to the current regulation. All in all regulatory enhancement should be practical with licensing and after licensing requirements being at par with the capacities of the regulatory bodies and the well owners. *(Ethiopia: Strategic Framework for Managed Groundwater Development, 2013)*

There are a large number of organizations whose activities have a bearing on the sustainable use of groundwater – from regulation, abstraction, and recharge and quality point of view. It is encouraging that groundwater has already moved into the realm of land use planning – opening the scope to manage groundwater beyond the water domain, yet there is no organization that masterminds the management or development of groundwater.

Although there are few institutions like the MoME who are directly accountable, the development and management mandates of the water resources in Ethiopia is practically spread over many institutions. At federal level the main stakeholders are the Ministry of Water and Energy, the Federal Environmental Protection Agency, the Ministry of Mines - in particular the Ethiopian Geological Survey, the Ministry of Agriculture (as it concerns land use), the Ministry of Urban Planning and Ministry of Health and in the private sector the large groundwater user industries. Drillers' Association and Ethiopian Association of Hydro geologists are also key actors. At regional level the major stakeholders are the Oromia Water, Mineral and Energy Bureau, the Addis Ababa Water Supply and Sanitation Authority, the Addis Ababa Environmental Protection Agency, the Oromia Land Use and Environmental Protection Bureau, and Housing Bureaus and Regional Urban Bureaus. Several of the organizations mentioned above undertake activities that have a bearing on sustainable groundwater management – but so far have no explicit program in the field.*(Ethiopia: Strategic Framework for Managed Groundwater Development,2013)*

2.9.6 Linking Knowledge and Research parties

The complaint from practitioners and policy makers' vis-à-vis the knowledge institutes is that

(a) Groundwater development and management gets very scant attention and

(b) The attention is often far from practical.

There is a need to re-engage – by having trainee, guest lecturers, and discussion on the curriculum and engaging university staff and students in studies.

This is possible with the universities and vocational training centers in the region. A mechanism that can be utilized in this respect is the University Water Sector Partnership, the Ethiopian Institute of Water Resources and many other water and environment programs in different universities that aim to bridge such gaps and coordinate activities in this respect.

2.9.7 Private Sector Roles

Private sector roles in groundwater development need to expanded and intensified – among other the Drillers Association and large groundwater user industries. Incentive structures should be created for private well developer to expand their business – both through contract arrangements and through financial incentives. At present focus has been on strengthening public sector for instance through procurement of drilling rigs – but more incentives should be created by strengthening private sector capacity. This can be done by a number of activities:

- License consultancy companies for drilling in shallow to very deep aquifers
- Carry out regular audits of work done by drillers and consultants, and
- Link extension of permits to performance

2.9.8 Supply Management

Several supply side measures also contribute to the sustainable management of the groundwater. Conjunctive use is an important one. In case of the Addis Ababa area the operation of surface water reservoirs and groundwater abstractions should be synchronized.

The surface water storage is the management of a groundwater basin implies a program of development and utilization of subsurface water for social or economic nature to obtain the maximum quantity of water to meet predetermined quality requirements at least cost.

A conjunctive use management study requires data on surface water resources, groundwater resources, and geologic conditions; data on water distribution systems, water use, and wastewater disposal are also necessary more vulnerable to dry spells.

By maintaining a balance in water supply from both surface water and groundwater, the provision of water to Addis Ababa and other fast growing cities in the region is secured during cycles of dry years too. - There is also a need to consider the sharing of water from both (newly developed) surface water and groundwater sources between the Addis Ababa and the Oromia Regional State.

In the catchment of Addis Ababa there is scope for enhanced recharge – particularly when linking recharge to improved watershed management programs, road planning and land use planning. Also the urban surface entire in the region increases the removal of storm water – and subsequent retention and reuse becomes more important. Storm water can be collected and spread over recharge zones – provided water quality allows. The spread over of Akaki and other polluted rivers for irrigation agriculture is a typical example for negative consequences.

Managing waste and storm water

Water use in the Addis Ababa area depends on both surface and groundwater and it is important that water from both sources is managed in a conjunctive manner. This concerns the water supply to Addis Ababa where groundwater can act as a safety valve in drought years compensating for low surface water supplies.

2.10 Well Rehabilitation

Well rehabilitation comprises all measures that are undertaken to restore the functionality of a well, and generally consists of various treatments or redevelopment methods. The treatment method selected must be tailored to the problem. Groundwater enters the well with a minimal amount of head (energy) loss due to the efficient combination of well construction techniques and proper selection and placement of a well screen and filter pack. Drawdown is proportional to the well’s flow rate and increases linearly as the well’s flow increases. Unfortunately, an ideal well is not common in the real world. The occurrence of an actual water well problem is generally due to a complex set of criteria specific to a region and site. These include the type, thickness, and transmissibility of the aquifer; well type, methods, and materials used in the original well construction; well yield vs. screened area and pumping rate.

Each of these parameters must be given proper consideration during determination of a well rehabilitation evaluation and procedure.

It is also wise to collect all available historical pumping and water level data—past maintenance and rehabilitation data and logs associated with the subject well and other local wells—and investigate information relative to the aquifer to help determine or verify any trends, issues, or potential long-term problems. These are the first acid tests you should perform before undertaking any specific well rehabilitation procedures. *(Georg H. & Christop T., 2007)*

4. Research Methodology

The general methodology involves the points shown in Figure 10. The research methodology adopted in this study includes review of the existing secondary data and review documents, field level assessment and observation, questionnaire based data collection and group discussions. Furthermore relevant data (mainly pumping test data) are collected. The pump test will be analyzed by making use of standard methods. (Cooper-Jacob methods and Theis recovery method).As these methods need some data correction related to partial penetration and un-confined-ness (if they exist). The outcome of these test analysis (hydraulic parameters of the aquifer) are finally compared with the measured (the values in the well completion report) for critical evaluation of the parameters. These critical evaluations will let us understand why the wells show a decrease of discharge in the day to day operation.

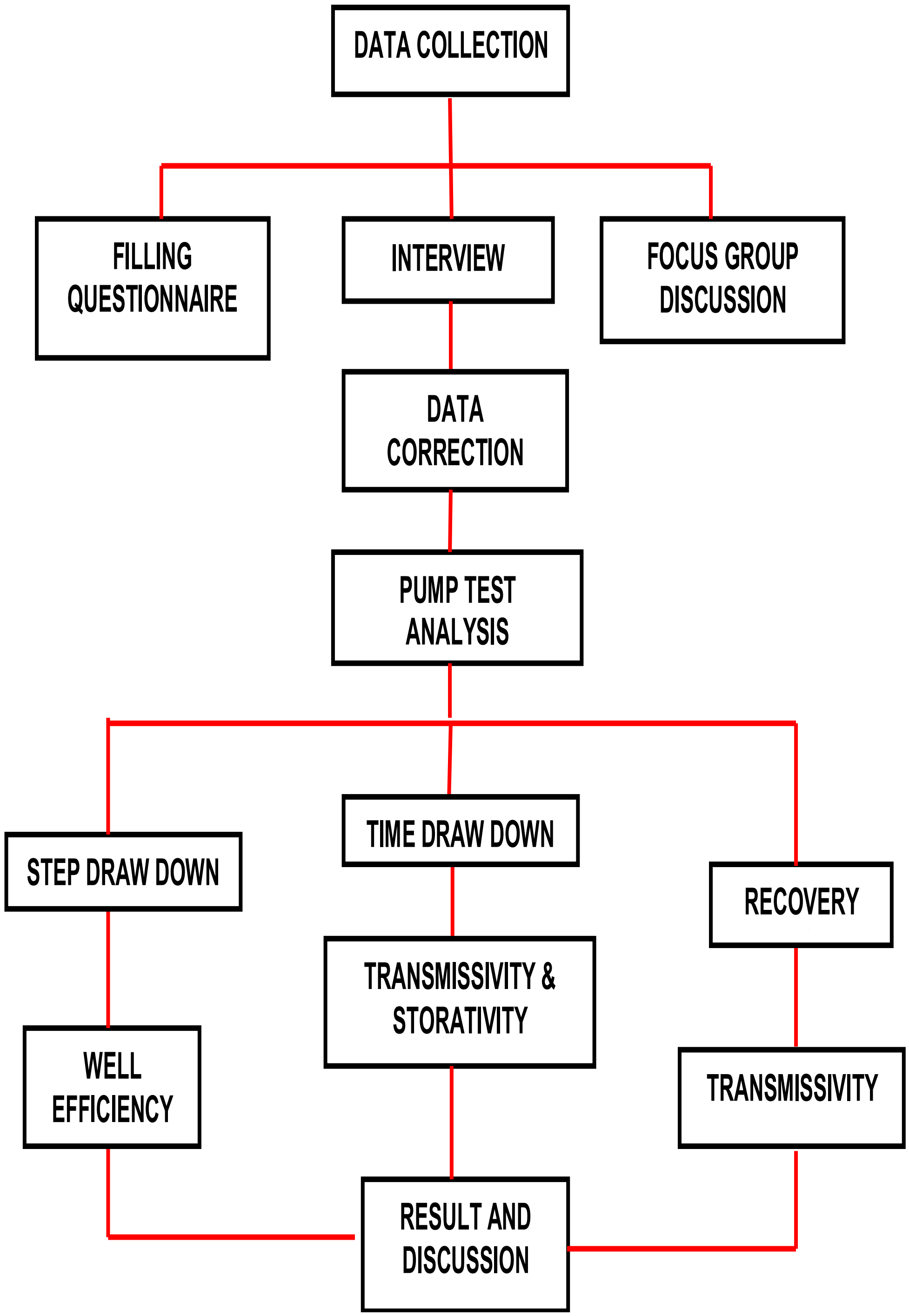


Figure 10: Flow of Research Methodology

3.1 Description of Study area

The research area is located in Southern suburb of Addis Ababa locally called Akaki area. The well field took the name from Akaki River that drain from Addis Abba to this well field, It is situated to the southeast of Akaki town about 22 km south of the center of Addis Ababa. The well field covers an area of about 16 km square and comprises 25 production wells and four monitoring wells.

The aquifers in the well field area are mainly from young volcanic rocks largely made of scoria, and fractured vesicular basalts with little to no weathering. The aquifer is largely due to processes related to lava flow and tectonic fractures. The aquifer to the north of the well field mainly covering the city of Addis Ababa and in the mountains north of the city are largely due to weathered and fractured volcanic rock with minor sediments deposited between different series of lava flows.

The main groundwater movement is from north to south in the central and northern part of the Akaki River catchment and towards the southeast direction in the lower part of the Catchment.

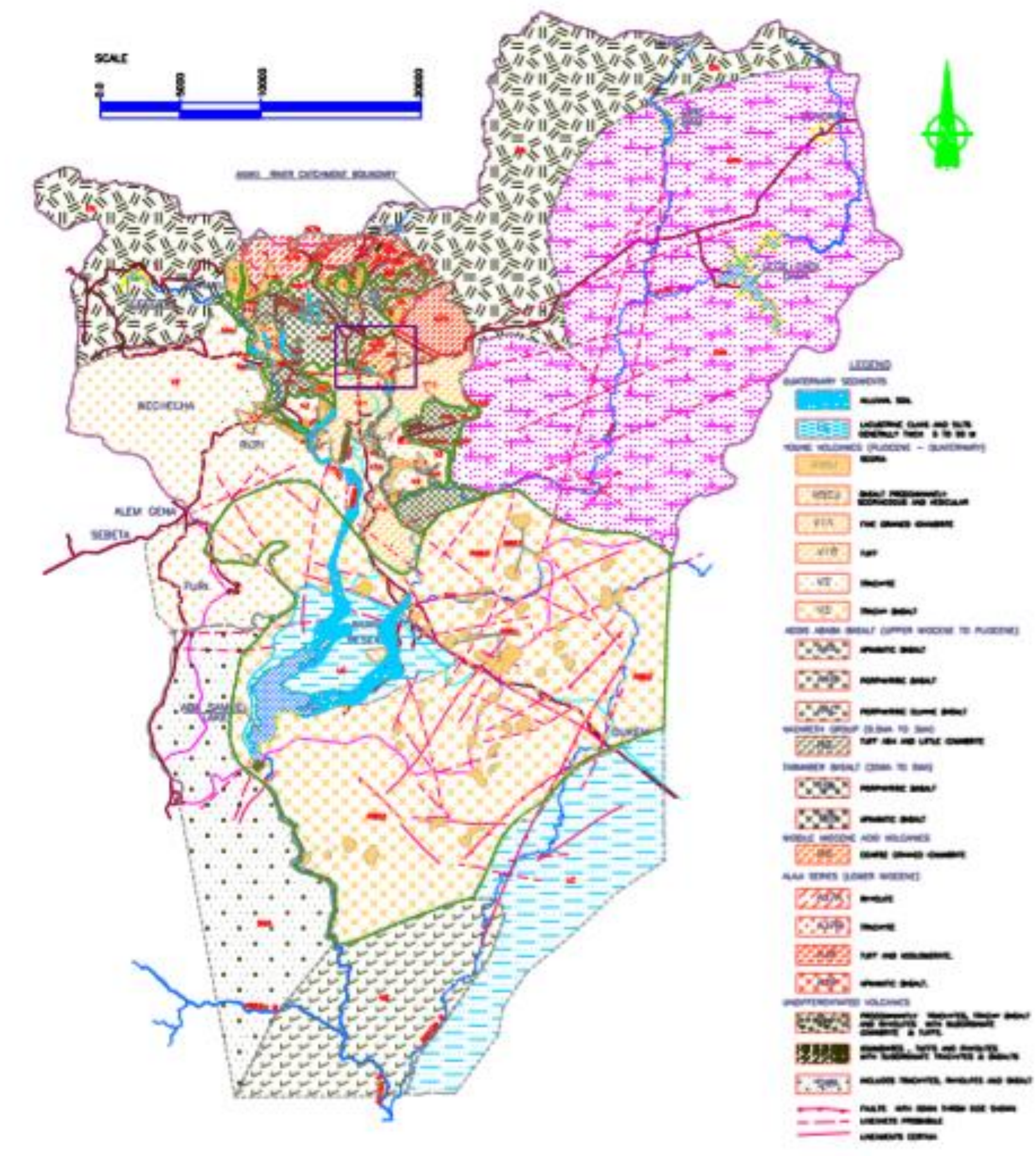


Figure 11:- Geological Map of Akaki River Catchment (Adapted from BCEOM/Sureca 2000)

3.2 Data Ccollection

3.2.1 Review of Secondary data and Documentation

Secondary data related to Akaki Phase II starting from the inception phase, development, operation and monitoring has been requested from AAWSA, ECDSWC-WEDSS, MoWE and MoEFCC. Except MoEFCC the other organizations has provided secondary data and review documentations.

AAWSA is the city responsible government organization for the development and operation of the city water supply and sewerage including Akaki Phase II Project. It is directly accountable to the city administration. It owns the project, employs contractors and consultants to realize it as per the development plan of the city. It is also the primary authority that keeps the documentation of all works related to its given mandate. Akaki Phase II project well field development and completion reports and other relevant data of the wells were collected for this study.

The other government organization that produces and keeps document of the studies of Akaki phase II project is Ethiopian Construction, Design and Supervision Works Corporation – Water and Energy Design and Supervision Sector (ECDSWC-WEDSS).

This organization was responsible for the consultancy and supervision during the study of the well field, pilot well development, pump testing and supervision during productive well construction. Detail data of the study, test well and productive was baseline data and other supervision reports were collected.

Federal Ministry of Water and Energy is the federal responsible body for the sector development, Policy and regulation formation, controlling and licensing of the sector actors. The sector actors and stakeholders shall also comply with the policies and regulation of the Ministry. The responsible department in the ministry has provided policy and guideline documents of the water sector and similar data with that of AAWSA.

Federal Ministry of Environment, Forest and Climate Change are also one of the ministries responsible for the groundwater management and monitoring according to the ministry of water policy document. However, the ministry has no any data and documentation related to the groundwater.

This research analyses the primary data collected while the pump test was conducted in the Akaki deep well in December, 2014. Hence the primary pump test data like the step drawdown test, constant pumping test, recovery test were considered in the analysis and comparison with the final report of WWDSE.

This comprises the gathering of validated and organized data (secondary data) of Borehole information such as:- constant rate test, step drawdown test, recovery test, final drawdown, pumping duration, static water level, dynamic water level, well depth and design discharge.

The final report of WWDSE states as 26 well drilled. Out which 11 of them neither connected with the water supply system nor have no raw pumping test data. Six wells have no pump test data and the remaining five are not connected to the system due to various reasons.

Out of the 15 wells analyses done seven wells (WF01-PW04, WF01-PW05, WF01-PW09, WF01-PW16, WF01-PW17, WF01-PW19 and WF01-PW20) have the raw Step Drawdown Test data. Efficiency is calculated for these wells.

3.2.2 Field Data Collection

In order to understand the existing status of the Akaki Phase II well field an assessment of 21 water wells out of 26 (81%) was conducted by this research. The visit incorporated the well data collection and updating of the parameters in the data collection sheet, measurement of the current water discharge, recording of the current operational status, physical observation of the well and its infrastructure and taking pictures, inventory of the monitoring equipment installed, and check its functionality and conduct discussion with operators, supervisor technicians and guards conduct as well conduct an inventory the human resources engaged in the operation.

3.2.3 Questionnaire

The primary data is collected using a questionnaire prepared Annex 6. The objective of this data collection is to assess the existence of groundwater monitoring policy and practices and its level of standard in comparison to the international. It is also to assess the level of effect of the groundwater monitoring practice to sustain the system positively if practiced or negatively if not practiced.

It is also to study what key parameters are considered during monitoring the groundwater. It is also to evaluate the allocation Human, Financial and material resources for the groundwater monitoring functions of sector responsible body.

3.2.4 Interview and Focus Group Discussion

Focus group discussion was conducted with two groups of employees of AAWSA. The first focus group consists of three Civil Engineers and a hydro-geologist and the second group consists of 13 participants of the well operators (10), supervisors (3) of five wells namely WF01- PW11, 12, 13, 14 and SWAWF05. The Operators are as the same time working as a guard of the well since leaving in the compound of the site.

The discussion with the first focus group was conducted at office level. It focused on the practice of groundwater monitoring, analysis of data collected and decision making.

The second focus group discussion was conducted at field level focusing on the observation of the operators and supervisors on variability of the water production of wells through, frequency of rehabilitation and replacement of pumps, duration of operation and the water extraction in comparison with the baseline information recommend during well completion.

3.3 Data Analysis

The entire analysis made was for the determination of the physical characteristics of the aquifers, such as the aquifer's design discharge, transmissivity and storage coefficient (storativity) are computed. The determination the aquifers parameters for each well is concluded via curve–fitting by EXCEL 2010 tool. The obtained hydraulic parameters were compared with the parameters obtained in their original (applied) reports.

There are different methods used for the determination of the aquifer physical characteristics. Two common methods that are used in this thesis are: -

- Cooper and Jacob Drawdown versus Time Graph and
- Residual Drawdown versus Time Graph

For comparison purpose for the uncorrected pumping test data Transmissivity and Storativity was also determined with the two methods by using the Excel 2010 version.

Before being used in the analysis, the observed water levels may have to be corrected for external influences (i.e. those not related to the pumping

Presentation of Data Time drawdown, and distance information should be presented in the form of graphical plots. These graphical plots are necessary for any further analysis because calculation of hydraulic properties and characterization of the hydro-geologic regime is most easily interpreted through analysis of the shapes of data arrays on the plots.

Many analytical solutions are available for interpreting aquifer pumping test data. The assumptions incorporated within each solution must be evaluated with respect to consistency with site conditions including: the type of pumping and observation wells (fully- or partially-penetrating); the pumping rate (constant versus variable); and aquifer conditions (confined or unconfined).

The physical characteristics of the aquifers, the necessary parameters such as the aquifer's transmissivity and storage coefficient are computed. Such duty of an approximating the aquifers parameters for each well is concluded via curve–fitting by basic EXCEL tool.

Cooper and Jacob methods: - Cooper and Jacob (1946) attempted to simplify Theis's equation, such that a solution using a single sheet of semi-log graph paper was possible. Is based on the Theis formula from u = r2S/4KDt, it will be seen that u decreases as the time of pumping t increases and the distance from the well r decreases. Accordingly, for drawdown observations made in the near vicinity of the well after a sufficiently long pumping time, the terms beyond in u in the series become so small that they can be neglected, so for small values of u ($u < 0.01$).

It was noted by Cooper and Jacob that for small values of r and large values of t, u is small the straight- line approximation for this method should be restricted to small values of u ($u<0.01$) to avoid large errors. The major advantage of this method is its simplicity. It only requires semi-log graph paper or a standard software spreadsheet package. It suffers from the some limitations and assumptions. The Cooper–Jacob approximation is only valid for a situation where u is small (say, $u < 0.05$); that is, where r is small and/or t is large. In practice, however, this condition is often satisfied (and at small values of t, the time–drawdown response is often swamped by well-bore storage effects in any case).

Theis recovery method: -When the pump is shut down after a pumping test, the water levels in the well and the piezometers will start to rise. This rise in water levels is known as residual drawdown's'. It is expressed as the difference between the original water level before the start of pumping and the water level measured at a time t' after the cessation of pumping.

It is always good practice to measure the residual drawdown's during the recovery period. Recovery-test measurements allow the transmissivity of the aquifer to be calculated, thereby providing an independent check on the results of the pumping test, although costing very little in comparison with the pumping test.

Residual drawdown data are more reliable than pumping test data because recovery occurs at a constant rate, whereas a constant discharge during pumping is often difficult to achieve in the field.

3.3.1 Correction of Pump Test Data

Prior to using the drawdown data collected from a pumping test, it may be necessary to correct for either external sources or effects induced by the test. The pumping (aquifer) test is the standard technique for estimating various hydraulic properties of aquifer systems, viz., transmissivity (T) and storage coefficient (S), for which the graphical method is widely used. And also data from recovery phase are available to interpret the well parameters.

In this thesis, before the interpretation of each pumping well was done for the determination of the aquifer parameters, adjustment to the data was conducted in two ways:-

- Correction on drawdown using efficiency of the well,
  - Conducted for wells WF01-PW04, WF01-PW05, WF01-PW09, WF01-PW16, WF01-PW17, WF01-PW19 and WF01-PW20 using the step drawdown data collected from WWDSE.
  - From the step drawdown test for each well the efficiency of the wells was calculated and from the well efficiency the drawdown caused by well loss
- Correction on drawdown for partial penetration,
  - Conducted for well WF01-PW04, WF01-PW05, WF01-PW06, WF01-PW07, WF01-PW08, WF01-PW09, WF01-PW11, WF01-PW12, WF01-PW14, WF01-PW15, WF01-PW16, WF01-PW17, WF01-PW18(10), WF01-PW19 and WF01-PW20 using the casing arrangement data collected form WWDSE.
  - By using the casing arrangement for each individual well the effect of partial penetration on the drawdown is determined by using a factor developed by Kozeny's correction factor. The Kozeny's correction factor is obtained by calculating the geometric mean of each screen and blind length combination.

By multiplying the correction factor to the observed drawdown the actual drawdown is obtained as if the well was a fully penetrating well.

After the correction for the drawdown was done for each well by using appropriate method from the above stated methods correction was also applied for unconfined aquifers.

3.3.2 Result Interpretation

The final step is to interpret the results obtained which involves comparing the hydro-geologic parameters and well efficiency and well yields with the designed (as existing in the well completion reports) for possible failure in the design and study and/or post construction failure. The interpretation suggested possible learning outcomes for future understanding of failures.

Out of the twenty-six well-developed in Akaki phase II for 15 well the standard method of aquifer analysis by the two methods was performed in order to obtain the hydraulic parameter of the aquifer and also to compare the result with the completion report.

4. Study Results and Discussion

The result and discussion part mostly contains the comparison between the corrected drawdown and uncorrected drawdown, comparison between results obtained by the two methods (Cooper-Jacob and a recovery method). It also discusses the values obtained from the WWDSE and comparing them with the result determined in this paper. In addition these chapters elaborate the qualitative data obtained from questionnaire, interview and focus group discussion.

4.1. Basic Description of each of the Wells

As per the contact agreement with AAWSSA, Six drilling campiness were given the task of drilling and contraction of wells located at the Akaki areas.

- These were CGC Overseas Construction. Ltd which was given the task of drilling and constructing six wells (SWAWF2, SWAWF4B, WF01-PW6, WF01-PW8 WF01-PW14),and WF01-PW16),
- Al-Nile Business Group Plc. was give four well for drilling and construction (SWAWF5,WF01-PW1,WF01-PW2 And WF01-PW11)
- China Geo-Engineering Corporation Ethiopian Branch was given one well for drilling and construction (WF01-PW3)
- Layne International LLC Branch was given three wells for drilling and construction (WF01-PW4,WF01-PW5 and WF01-PW9)
- Shandong Geo-Mineral Engineering was given two wells for drilling and construction (WF01-PW15 and WF01-PW17)
- Tana Water well drilling plc. was given three wells for drilling and construction (WF01-PW10(18),WF01-PW19 and WF01-PW20)

The location of these nineteen wells in Akaki well fields are sparsely distributed throughout the Akaki area, in Addis Ababa City Administration and in Oromia Region. The basic well characteristics of each of the nineteen wells are shown in table 5.

After drilling of each well was concluded, the wells were slotted with water level observation pipes as all of the nineteen wells are considered as a single well test. And also permanent casings and couplings for open wells were installed in all the wells after completion of drilling and logging. Some of the wells were left open and uncased on the lower part when the physical property of the rocks of the well walls are found to be sound and free from collapsing (WWDSE, 2015).

Table 5: - Basic well characteristics of Akaki Phase II deep wells

Prospective site/well field	Well Index	Well type	Coordinate UTM Zone 37 Adindan		Elev, m	Contractor	Depth, m	Static water level, m	Dynamic water level, m	Q, test, (l/S)
			UTM east	UTM north						
Akaki	SWAWF-2'	Test well	475841	980128	2064	CGCOC	448	9.45	98.8	54.5
Akaki	SWAWF-4B	Test well	472919	980832	2064	CGCOC	480	7.18	16.9	90
Akaki	SWAWF5	Test well	472848	979715	2058	ANBG	486	9.7	14.2	90
Akaki	WF01-PW2	Pilot Production	474290	980673	2072	ANBG	250	21.2	106.1	62.5
Akaki	WF01-PW3	Pilot Production	475010	980705	2081	CGCEB	481.6	21.8	90.5	28
Akaki	WF01-PW04'	Production well	471277	979792	2053	Layne	500	37.38	132.8	122
Akaki	WF01-PW05	Production well	470530	979406	2051	Layne	510	14.53	125.01	140
Akaki	WF01-PW6	Production well	472630	979912	2096	CGCOC	532	8.4	92.9	78.78
Akaki	WF01-PW8	Pilot Production	473683	979475	2059	CGCOC	483.7	17.5	99.9	50
Akaki	WF01-PW9	Production well	469673	978794	2053	Layne	514	19.22	149.74	70
Akaki	WF01-PW11	Pilot Production	472268	978066	2059	ANBG	500	27.5	81.5	62.15
Akaki	WF01-PW12	Pilot Production	471401	977301	2055	ANBG	480	34.1	39.7	100
Akaki	WF01-PW14	Production well	476877	976374	2056	CGCOC	552	39.8	42	76.32
Akaki	WF01-PW15	Production well	474037	978932	2066	SGEC	492.1	30.3	117.9	40
Akaki	WF01-PW16	Production well	473447	980394	2068	CGCOC	549.73	11.4	143	31.28
Akaki	WF01-PW17	Production well	472554	981756	2066	SGEC	477.38	Artesian	85.7	48.75
Akaki	WF01-PW10(18)	Production well	472012	979857	2059	Tana	272	9.32	13.01	140
Akaki	WF01-PW19	Production well	470650	977039	2045	Tana	510	54.43	109.18	67
Akaki	WF01-PW20	Production well	471470	978047	2056	Tana	504	26.7	127.02	40

4.2 Well Eefficiency

A step drawdown tests usually leads to a measure of well performance that can be used to estimate well's efficiency and for guidance in deciding on optimum pumping rate for a later constant-rate pumping test. Determining well efficiency and well loss is highly suggested because it provides valuable information about the well performance and can be used to make an informed decision regarding the well pumping rate, maintenance and rehabilitation. Since raw step drawdown data was available for seven well in the Akaki Phase II Deep Well project, the well efficiency of these wells have been determined and comparison was done with the result collected from WWDSE. These values are tabulated on Table 6.

Table 6:- Well efficiency of seven well of Akaki Phase II wells

Well Index	Well Efficiency	
	From WWDSE	Calculated
WF01-PW04	30.18%	29.97 %
WF01-PW05	86.20%	45.92 %
WF01-PW9	79.28%	39.63 %
WF01-PW16	58.56%	19.22 %
WF01-PW17	58.56%	37.15 %
WF01-PW19	87.63%	52.97 %
WF01-PW20	65.64%	33.50 %

Well efficiency range in the hydro geologist's society is defined to be within the range of 65% to 85%. As it can be seen in table 6 in the calculated column in this study all are below the given range.

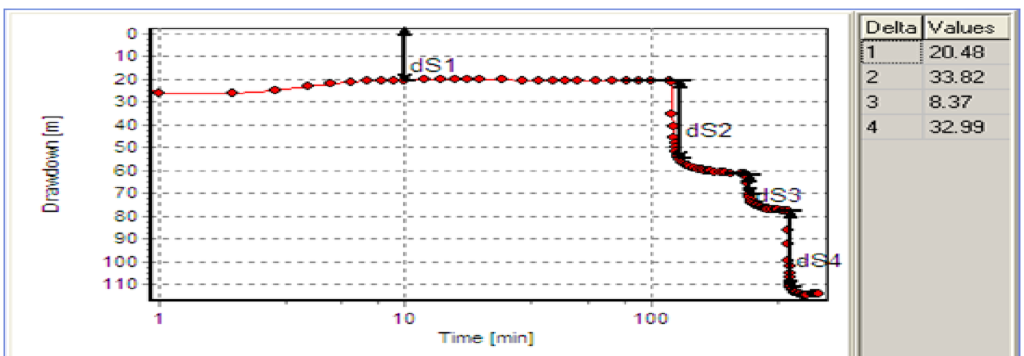
Step drawdown test was performed on WF01-PW4 using discharges of 110 lit/s, 120lit/s, 130lit/s and 142lit/s. The liner well loss coefficient (B) and the non- liner well loss coefficient (C) was determined from this step drawdown test and were found to be 4.61E-02 and 1.00E-05 respectively. Using these values the efficiency was determined for each of the corresponding discharges.

A constant pumping rate of 122 lit/s for WF01-PW4 was used as pumping rate, which resulted in a well efficacy of 29.97%. This low well efficiency could have been avoided with low discharging rate as it can be observed in Table 7.

Table 7:-.Relation between discharge and well efficiency for well WF01-PW4

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
42.015	42.015	9504	0.004421	4.61E-02	1.00E-05	32.67
51.868	93.883	10368	0.009055	4.61E-02	1.00E-05	30.79
63.454	157.337	11232	0.014008	4.61E-02	1.00E-05	29.11
76.418	233.755	12268.8	0.019053	4.61E-02	1.00E-05	27.32

In case of well WF01-PW16 the calculated and the one reported in the WWDSE document have big difference in well efficiency. Figure 12 below show the step drawdown test with its step drawdown given in WWDSE document. Based on this delta values from the figure reported in WWDSE, the efficiency was calculated and the result of well efficiency was close to 58.56% Table 8 shows values for B, C and the efficiency from the WWDSE report calculated based on figure 12 by WWDSE and Table 9 shows values of B, C and the efficiency calculated by this research based on figure 13.



	B	C	Q	CQ	B+CQ	E=B/B+CQ	%
step-1	0.013	5.27E-06	864	0.004553	0.017553	0.74060233	74.06023
step-2	0.013	5.27E-06	1728	0.009107	0.022107	0.58806074	58.80607
step-3	0.013	5.27E-06	2132	0.011237	0.024237	0.53635906	53.63591
step-4	0.013	5.27E-06	2703	0.014243	0.027243	0.47719276	47.71928

Where **B**-Well loss **Q**-Discharge (l/s)
C-Aquifer loss **E**-Efficiency (%)

Figure 12:- .Step drawdown Test and Delta values for well WF01-PW16 given in WWDSE report.

Table 8:- Values of B, C and well efficiency from WWDSE for WF01-PW16 based on figure 12.

	B	C	Q	CQ	B+CQ	E=B/(B+CQ)	%
step-1	0.013	0.00000527	864	0.004553	0.017553	0.74060233	74.060
step-2	0.013	0.00000527	1,728	0.009107	0.022107	0.58806074	58.806
step-3	0.013	0.00000527	2,132	0.011236	0.024236	0.53640011	53.640
step-4	0.013	0.00000527	2,703	0.014245	0.027245	0.47715510	47.716

Table 9:- .Values of B, C and well efficiency calculated for WF01-PW16 based on figure 13.

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
21.45	21.45	864	0.024826	1.62E-02	4.20E-05	30.85
62.04	83.49	1728	0.048316	1.62E-02	4.20E-05	18.24
77.79	161.28	2132	0.075647	1.62E-02	4.20E-05	15.31
114.2	275.48	2703	0.101916	1.62E-02	4.20E-05	12.48

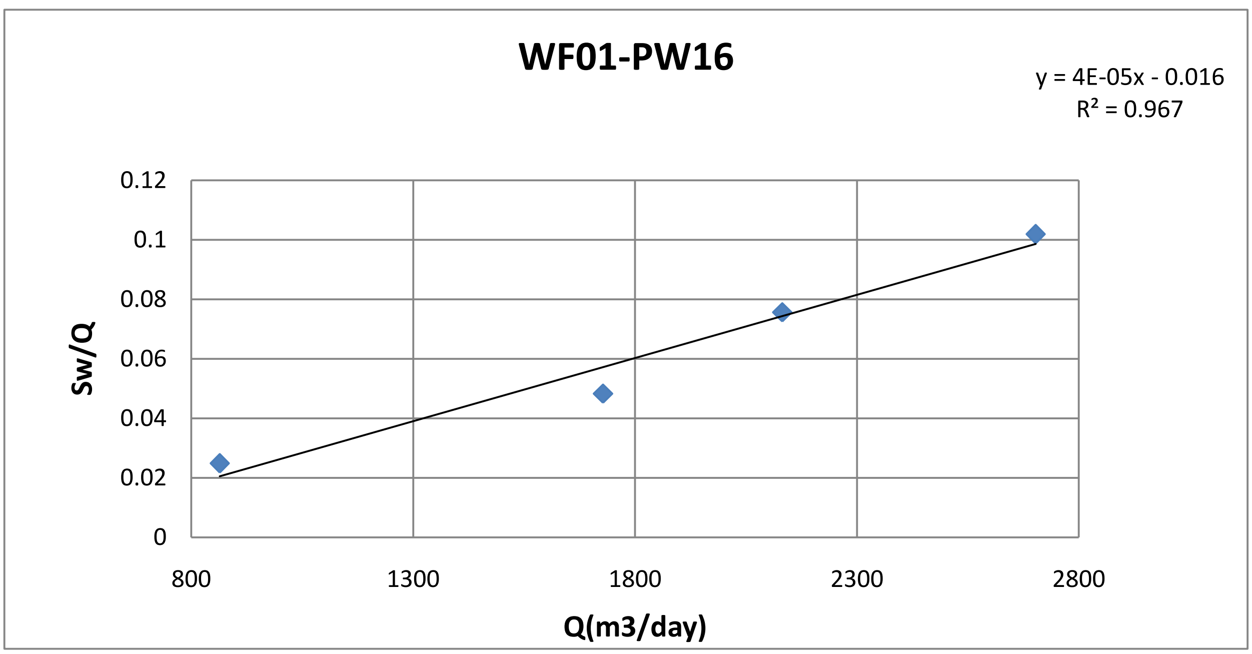


Figure 13:- .Sw/Q vs. Q plot

The actual values of the well efficiency determined by step drawdown test for discharge values of 10lit/s 20lit/s 24.68 lit/s and 31.28 lit/s for WF01-PW16 for a constant pumping rate of 31.28 lit/s is 19.22%, which is well below the accepted well efficiency range. Values of the well efficiency of WF01-PW16 with the corresponding discharge values are tabulated in table 10 below.

Table 10:-Discharge and well efficiency of well WF01-PW16.

Q (Lit/sec)	Efficiency (%)
10.00	30.85%
20.00	18.24%
24.68	15.31%
31.28	12.48%

The drawdown in a pumped well consists of two components: the aquifer losses and the well losses. By using the well efficiency the drawdown was corrected for both WF01-PW4 and WF01-PW16 which result a much reduced value drawdown in both of the wells.

The well efficiency analysis of the remaining five wells is included in the appendix 1 with the raw step drawdown test. Also the raw step drawdown data for all seven wells is included.

4.3 Partial Penetration

Out of twenty-six wells developed in Akaki phase II project fifteen of the well have done Kozeny correction factor to correct the measured drawdown for the head loss caused by partial penetration. Including the step drawdown test data available wells in the WWDSE report these wells are.WF01-PW4, WF01-PW5, WF01-PW9, WF01-PW16, WF01-PW17, WF01-PW19 and WF01-PW20. In order to compute the hydraulic parameter the partial penetration correction is performed. By arranging the blind and screen for each of the fifteen well. The observed drawdown is adjusted by using the geometric mean as a Kozeny correction factor. List of the correction factor are shown in Table 11.

The casing arrangement collected from WWDSE and the analyses calculated for the correction are attached in the appendix -B for the fifteen well of Akaki phase II.

Table 11:- .Kozeny correction for fifteen of Akaki Phase II wells

Well ID	Kozeny Correction factor
WF01-PW4	0.597
WF01-PW5	0.589
WF01-PW6	0.459
WF01-PW7	0.511
WF01-PW8	0.744
WF01-PW9	0.678
WF01-PW11	0.548
WF01-PW12	0.468
WF01-PW14	0.562
WF01-PW15	0.532
WF01-PW16	0.481
WF01-PW17	0.459
WF01-PW18	0.567
WF01-PW19	0.564
WF01-PW20	0.537

4.4. Drawdown –Time Plots for Uncorrected and Corrected Drawdown

Based on the well efficiency, partial penetration and correction for unconfined aquifer the observed drawdown for the entire fifteen well have been adjusted. For wells WF01-PW04, WF01-PW05, WF01-PW09, WF01-PW16, WF01-PW17, WF01-PW19 and WF01-PW20 combination of correction for well loss, partial penetration and unconfined aquifer was used. The plot of drawdown vs. time for well WF01-PW04 is shown in figure14 with the corrected and uncorrected drawdown. The plots for the reaming six wells are given in the appendix part.

For wells WF01-PW06WF01-PW07, WF01-PW11, WF01-PW12, WF01-PW14, WF01-PW15 and WF01-PW18 correction is done for both partial penetration and unconfined aquifer. By using this, the drawdown vs. time plot for both the uncorrected and corrected drawdown was done for these seven wells and figure 15 shows plot for observed and corrected drawdown for WF01-PW06.The plots for the reaming six wells is given in the appendix part.

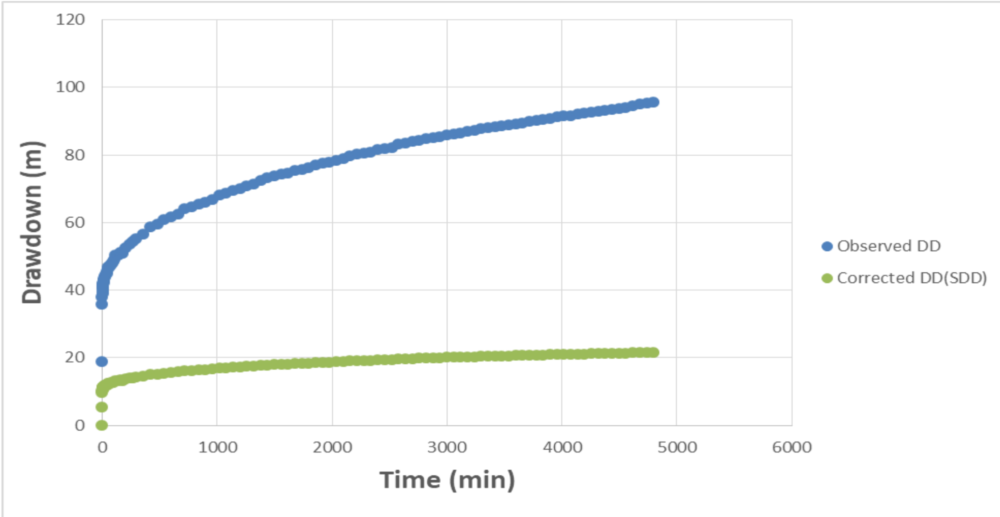


Figure 14:- Plot for observed and corrected drawdown for WF1-PW04.

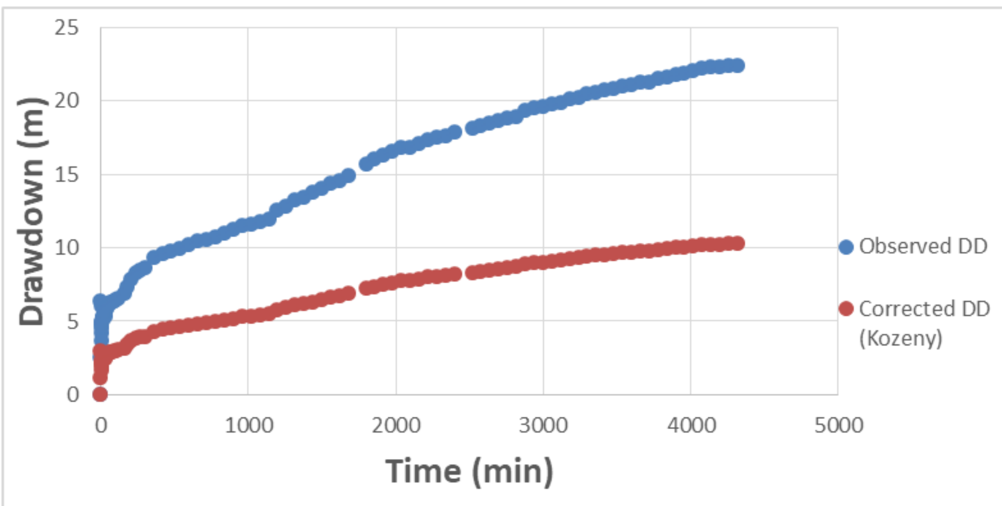


Figure 15:- Plot for observed and corrected drawdown for WF1-PW06.

4.5. Transmissivity and Storativity Values for Akaki Phase II Deep Wells.

Determining the transmissivity and discussing on their interpretive techniques, transmissivity values of each fourteen well have be calculated by using the Cooper-Jacob and the recovery method with the both the corrected drawdown and uncorrected drawdown using Excel 2010 version. These results are also compared with the values collected from WWDSE.

Determination of storativity is another goal of this paper. Consequently, the storativity values of each of the fourteen wells have be calculated by using the Cooper-Jacob method. In the case of single well pumping tests the storativities are generally overestimated. It is usually a difficult task and to state that the result calculated can express the true nature aquifer characteristic is pessimistic. Keeping in mind the previously stated statement the storativity of fourteen wells has been calculated for Akaki phase II Deep well and is discussed below.

4.5.1. Transmissivity and Storativity Values Using Cooper-Jacob Method.

As the Copper Jacob method is a simplification of the Theis solution, the pumping well should fully penetrate a confined, homogeneous and isotropic aquifer. The semi-log plot of the drawdown vs. time the best fit line is done using Trend line tool which in turn give us the equation of the line and the R-square value to show how the line represents the points in the drawdown vs. time plots. The plots for the entire fourteen well are show in figure 37 to figure 50 in the appendix part. Figure 37 to figure 43 shows the semi-log plots of the observed drawdown and corrected drawdowns where the correction is for well loss drawdown. And figure 44 to figure 50 shows the semi-log plots of the observed drawdown and the corrected drawdown where the correction is done for the effects of partial penetration. The result of the transmissivity and storativity values for seven wells, using the Cooper-Jacob method, is tabulated in table 12 below for both the uncorrected and corrected drawdown. Here well efficiency is used to determine the drawdown loss in the well. Whereas, table 13 shows the transmissivity and storativity values for the fourteen wells with correction done to the drawdown using Kozeny correction factor. In both table the drawdown correction also includes correction for unconfined aquifer.

Table 12:-.Transmissivity and storativity values for seven wells using Cooper-Jacob method using step drawdown

Well Index	Pumping rate (m^3/day)	Radius of well (m)	SDD	Best Line for observed DD			Best Line for Corrected DD			Estimated to in days		Transmissivity m^2/day		Storativity	
				Slop	Intercept	R-square	Slop	Intercept	R-square	for observed DD	for corrected DD	for observed DD	for corrected DD	for observed DD	for corrected DD
WF01-PW4	10540.8	0.1778	0.300	8.301	16.7	0.906	1.65	6.301	0.932	1.34E-01	2.20E-02	101.72	522.37	0.6725	0.5668
WF01-PW5	12096	0.1778	0.459	10.920	13.780	0.936	3.073	10.01	0.959	2.83E-01	3.85E-02	87.66	308.04	1.2267	0.5860
WF01-PW9	6048	0.1778	0.396	9.751	68.910	0.964	1.749	25.08	0.975	8.53E-04	5.92E-07	50.18	277.24	0.0021	0.0000
WF01-PW16	2702.6	0.1778	0.192	5.483	84.620	0.885	-0.45	8.366	0.840	1.98E-07	7.62E-08	39.64	130.41	3.88685E-07	4.912E-07
WF01-PW17	4212	0.1778	0.372	4.445	49.532	0.9529	1.5204	19.322	0.988	1.45E-05	3.03E-06	77.23	220.66	5.52839E-05	3.3E-05
WF01-PW19	5788.8	0.1778	0.530	2.081	37.710	0.990	0.209	14.11	0.959	3.00E-28	4.79E-30	213.14	2,211.32	2.19595E-30	5.23E-28
WF01-PW20	3456	0.1778	0.335	1.465	88.380	0.888	0.232	22.6	0.889	6.31E-27	4.94E-43	183.68	856.34	5.72864E-26	2.091E-41

Table 13:-.Transmissivity and storativity values for fourteen wells using Cooper-Jacob method using Kozeny correction factor.

Well Index	Pumping rate (m^3/day)	Radius of well (m)	Kozeny correction factor	Best Line for observed DD			Best Line for Corrected DD			Estimated to in min		Transmissivity m^2/day		Storativity	
				Slop	Intercept	R-square	Slop	Intercept	R-square	for observed DD	for corrected DD	for observed DD	for corrected DD	for observed DD	for corrected DD
WF01-PW4	10540.8	0.178	0.597	8.30	16.70	0.91	3.34	12.17	0.93	1.34E-01	2.62E-02	101.72	257.70	0.6725	0.3335
WF01-PW5	12096	0.178	0.589	10.92	13.78	0.94	3.94	12.84	0.96	2.83E-01	3.85E-02	87.66	246.44	1.2267	0.4689
WF01-PW6	6806.6	0.178	0.459	2.74	-3.92	0.84	1.04	-1.02	0.86	4.18E+00	2.66E+00	192.01	499.22	3.97E+01	6.56E+01
WF01-PW7	626.4	0.178	0.511	9.55	25.55	0.90	4.65	14.67	0.88	6.89E-02	4.26E-02	5.29	10.63	2.59E+01	32.26
WF01-PW9	6048	0.178	0.678	9.75	68.91	0.96	3.06	42.50	0.97	8.53E-04	9.42E-07	50.18	155.10	2.12E-03	4.97E-07
WF01-PW11	5369.8	0.152	0.548	4.59	12.72	0.98	1.35	8.90	1.00	6.27E-02	1.34E-03	93.77	317.61	0.3953	0.0287
WF01-PW12	8640	0.152	0.468	0.41	1.92	0.93	0.19	0.84	0.94	9.49E-03	1.21E-02	1,600.23	3,684.25	1.02E+00	3.00E+00
WF01-PW14	6594	0.178	0.562	0.20	0.36	0.95	0.10	0.15	0.96	1.73E-01	2.07E-01	2,518.91	5,256.85	2.15E+01	5.39E+01
WF01-PW15	3456	0.178	0.532	2.28	69.29	0.56	0.82	39.59	0.92	6.00E-14	1.21E-21	126.74	337.07	3.76E-13	2.02E-20
WF01-PW16	2702.6	0.178	0.481	5.48	84.62	0.89	2.53	41.46	0.89	1.98E-07	7.64E-08	39.64	83.99	3.89E-07	3.17E-07
WF01-PW17	4212	0.178	0.459	4.45	49.53	0.95	1.88	23.87	0.99	1.45E-05	3.03E-06	77.23	179.61	5.53E-05	2.69E-05
WF01-PW18(10)	12096	0.152	0.564	0.34	0.06	0.73	0.18	0.05	0.73	8.50E-01	7.70E-01	2,861.83	5,280.76	1.64E+02	2.74E+02
WF01-PW19	5788.8	0.178	0.564	2.08	37.71	0.99	0.22	15.03	0.96	3.00E-28	5.36E-30	213.14	2,081.24	3.16E-27	5.51E-28
WF01-PW20	3456	0.178	0.537	1.47	88.38	0.89	0.37	36.37	0.89	6.31E-27	3.46E-43	183.68	528.08	5.73E-26	9.04E-42

- DD-Drawdown
- SDD-Step Drawdown

4.5.2. Transmissivity Values Using Recovery Method

One of the practical ways to estimate the aquifer parameter is to measure the water level rise by time in the production or observation wells after the pumping test stoppage. This is referred to as the recovery test which starts just after the pump shut. The recovery method serves as a check and alternative to the pumping test.

The transmissivity values for all of the twelve wells have been determined using their recovery drawdown data. For WF01-PW05 this method was not applied because the raw recovery drawdown data have some missing data. By using the time when pumping was stop (t'), the semi-log plot of the residual drawdown vs. (t/t') was plot for three of the well. These are WF01-PW11, WF01-PW12 and WF01-PW14. The remaining wells are plotted using residual drawdown vs. log10 (t/t'). Here also the use of best fit line was applied for the points in the plots. Table 14 and Table 15 show the result for the transmissivity of both the corrected and the uncorrected drawdown for the wells. Figure 50 through figure 61 in the appendix shows the residual drawdown vs.log10 (t/t') for twelve of the wells. From figure 51 to figure 56 are plots were the residual drawdown plots contain the correction to for well loss using well efficiency as well as kozeny factor and correction for unconfined aquifer, where are figure from 57 to 62 contains the drawdown plots were where the effects of partial penetration is considered in addition to unconfined aquifer correction.

Storativity value by this method cannot be determined as in all case of the wells, single well test is conduct. The other reason being due to wellbore storage effects, unknown effective radius, and difficulty in finding the time of zero recovery as needed for the application of Cooper and Jacob method. On the other hand, Jacob observed that the storage coefficient estimation is generally greater during the pumping period than the recovery period.

Table 14:- Transmissivity and values for twelve wells are using the Recovery method with Kozeny correction factor.

Well Index	Pumping rate (m^3/day)	Radius of well (m)	Kozeny correction	Best fit line for observed DD			Best fit line for corrected DD			Transmissivity (m^2/day)	
				Slop	Intercept	R-square	Slop	Intercept	R-square	For observed DD	For corrected DD
WF01-PW4	10540.8	0.178	0.597	25.24	-	0.81	13.12	-	0.742	76.48	147.12
WF01-PW6	6806.6	0.178	0.589	6.929	-	0.875	2.896	-	0.902	179.89	430.40
WF01-PW8	4320.0	0.152	0.744	14.04	-	0.942	8.713	-	0.74	56.34	90.79
WF01-PW9	6048.0	0.178	0.678	24.69	-	0.871	15.16	-	0.85	44.86	73.06
WF01-PW11	5369.8	0.152	0.548	3.914	6.62	0.962	1.591	3.85	0.94	144.61	269.40
WF01-PW12	8640.0	0.152	0.468	0.157	1.45	0.891	0.072	0.67	0.89	4,394.90	6,592.36
WF01-PW14	6594.0	0.178	0.562	0.157	0.64	0.822	0.084	0.37	0.819	3,450.03	5,750.04
WF01-PW15	3456.0	0.178	0.532	13.37	-	0.821	5.903	-	0.693	47.33	107.21
WF01-PW16	2702.6	0.178	0.481	23.54	-	0.75	7.852	-	0.933	21.02	63.03
WF01-PW17	4212.0	0.178	0.459	12.70	-	0.90	4.447	-	0.975	60.73	173.44
WF01-PW19	5788.8	0.178	0.564	8.108	-	0.969	4.011	-	0.93	130.74	264.29
WF01-PW20	3456.0	0.178	0.537	10.12	-	0.894	4.93	-	0.935	62.54	128.37

Table 15:- Transmissivity and values for six wells are using the Recovery method with SDD.

Well Index	Pumping rate (m^3/day)	Radius of well (m)	SDD	Best fit line for observed DD			Best fit line for corrected DD			Transmissivity (m^2/day)	
				Slop	Intercept	R-square	Slop	Intercept	R-square	For observed DD	For corrected DD
WF01-PW4	10540.8	0.178	0.2997	25.24	-	0.81	6.59	-	0.74	76.48	292.90
WF01-PW9	6048.0	0.178	0.678	24.69	-	0.871	8.85	-	0.85	44.86	125.13
WF01-PW16	2702.6	0.178	0.192	23.54	-	0.75	3.14	-	0.93	21.02	157.76
WF01-PW17	4212.0	0.178	0.372	12.70	-	0.90	3.60	-	0.98	60.73	214.31
WF01-PW19	5788.8	0.178	0.530	8.108	-	0.969	3.818	-	0.938	130.74	277.65
WF01-PW20	3456.0	0.178	0.335	10.12	-	0.894	3.075	-	0.935	62.54	205.81

Summary of hydraulic parameters by using Excel-spread sheet is calculated both for the uncorrected and corrected drawdown data estimation of Transmissivity are performed and the geometric mean result obtained by the two methods is compare with the result of WWDSE. Even though for a particular aquifer should have only one transmissivity and storativity values for the same well. The fifteen well calculated transmissivity values are as shown in table 16 .The results clearly show that there is clear variation from the one in the designed documents of WWDSE.

The overestimated transmissivity are seen in WF01-PW06, WF01-PW07, WF01-PW08, WF01-PW12 and WF01-PW18 (10). The underestimated transmissivity are seen in WF01-PW04, WF01-PW05, WF01-PW09, WF01-PW11, WF01-PW14, WF01-PW15, WF01-PW16, WF01-PW17, and WF01-PW19and WF01-PW20. Over estimation of transmissivity imply that the well is expected to be pumped beyond its yielding capacity. Conversely the under estimated transmissivity will make the yield to be lower than the capacity of the aquifer.

As it is highlighted in table 17 storativity values for WF01-PW06, WF01-PW07, WF01-PW12, WF01-PW14 and WF01-PW18 (10) have storativity values greater than one, which is not acceptable in hydro-geological society. These values may have risen due to that fact observed drawdown data when the constant pumping test is being conducted have not been recorded correctly. In some cases the storativity values are close to zero they may not even be considered as reliable values.

According to this study out of the two methods (Cooper Jacob and Theis Recovery) applied in the analysis that of Cooper Jacob gives higher transimissivity value. The interpretation of single well test with Cooper Jacob method is more accurate than other methods. Furthermore, this method is not affected significantly by vertical anisotropy and partial penetration (Keith J. et al. 2006)

Table 16:- Transmissivity of the fifteen wells for Akaki Phase II Deep Wells by using step drawdown and kozeny factor as a correction factor on the drawdown.

Transmissivity (m^2/day)										
Well Index	SDD		Kozeny Factor		Method used		Excel 2010		Geometric Mean	
	From WWDSE	Calculated	From WWDSE	Calculated		From WWDSE	No Drawdown Correction	With Drawdown Correction	GeoMean with No correction	GeoMean With correction
WF01-PW4	30.18%	29.97%	-	0.597	Cooper-Jacob	96.7	101.72	366.90	88.20	275.98
					Recovery		76.48	207.59		
WF01-PW5	86.20%	45.92%	-	0.589	Cooper-Jacob	66.2	87.66	275.52	87.66	275.52
					Recovery		-	-		
WF01-PW6	-	-	-	0.459	Cooper-Jacob	1590	192.01	499.22	185.85	463.53
					Recovery		179.89	430.40		
WF01-PW7	-	-	-	0.511	Cooper-Jacob	26.5	5.29	10.63	5.29	10.63
					Recovery		-	-		
WF01-PW8	-	-	-	0.744	Cooper-Jacob	106	-	-	56.34	90.79
					Recovery		56.34	90.79		
WF01-PW9	79.28%	39.63%	-	0.678	Cooper-Jacob	81.5	50.18	207.36	47.44	140.81
					Recovery		44.86	95.61		
WF01-PW11	-	-	-	0.548	Cooper-Jacob	105	93.77	317.61	116.45	292.52
					Recovery		144.61	269.40		
WF01-PW12	-	-	-	0.468	Cooper-Jacob	5810	1,600.23	3,684.25	2,651.95	4,928.28
					Recovery		4,394.90	6,592.36		

Transmissivity (m^2/day)										
Well Index	**SDD**		**Kozeny Factor**		**Method used**		**Excel 2010**		**Geometric Mean**	
	From WWDSE	**Calculated**	**From WWDSE**	**Calculated**		**From WWDSE**	**No Drawdown Correction**	**With Drawdown Correction**	**GeoMean with No correction**	**GeoMean With correction**
WF01-PW14	-	-	-	0.562	Cooper-Jacob	2220	2,518.91	5,256.85	2,947.93	5,497.92
					Recovery		3,450.03	5,750.04		
WF01-PW15	-	-	-	0.532	Cooper-Jacob	177	126.74	337.07	77.45	190.10
					Recovery		47.33	107.21		
WF01-PW16	58.56%	19.22%	-	0.481	Cooper-Jacob	65.4	39.64	104.66	28.87	102.16
					Recovery		21.02	99.72		
WF01-PW17	58.56%	37.15%	-	0.459	Cooper-Jacob	107	77.23	199.08	68.49	195.91
					Recovery		60.73	192.80		
WF01-PW18 (10)	-	-	-	0.564	Cooper-Jacob	16200	2,861.83	5,280.76	2,861.83	5,280.76
					Recovery		-	-		
WF01-PW19	87.63%	52.97%	-	0.564	Cooper-Jacob	251	213.14	2,145.30	166.93	762.32
					Recovery		130.74	270.88		
WF01-PW20	65.64%	33.50%	-	0.537	Cooper-Jacob	263	183.68	672.47	107.18	330.61
					Recovery		62.54	162.54		

Table 17:- Storativity of the fifteen wells in Akaki Phase II Deep Wells by using Step drawdown and Kozeny factor as a correction factor on the drawdown.

Storativity								
Well Index	**SDD**		**Kozeny Factor**		**Method used**	**From WWDSE**	**With No Drawdown Correction (Geomean)**	**With Drawdown Correction (Geomean)**
	From WWDSE	**Calculated**	**From WWDSE**	**Calculated**				
WF01-PW4	30.18%	29.97%		**0.597**	Cooper-Jacob	1.28	6.72E-01	4.35E-01
WF01-PW5	86.20%	45.92%	-	0.589	Cooper-Jacob	1.27	1.23E+00	5.24E-01
WF01-PW6	-	-	-	0.459	Cooper-Jacob	0.9	3.97E+01	6.56E+01
WF01-PW7	-	-	-	0.511	Cooper-Jacob	0.07	2.59E+01	3.23E+01
WF01-PW8	-	-	-	0.744	Cooper-Jacob	0.6	0.00E+00	0.00E+00
WF01-PW9	79.28%	39.63%	-	0.678	Cooper-Jacob	0.5	2.12E-03	2.01E-06
WF01-PW11	-	-	-	0.548	Cooper-Jacob	1.2	3.95E-01	2.87E-02
WF01-PW12	-	-	-	0.468	Cooper-Jacob	17.9	1.02E+00	3.00E+00
WF01-PW14	-	-	-	0.562	Cooper-Jacob	33.17	2.15E+01	5.39E+01
WF01-PW15	-	-	-	0.532	Cooper-Jacob	0.46	3.76E-13	2.02E-20
WF01-PW16	58.56%	19.22%	-	0.481	Cooper-Jacob	0.24	3.89E-07	3.95E-07
WF01-PW17	58.56%	37.15%	-	0.459	Cooper-Jacob	0.57	5.53E-05	2.98E-05
WF01-PW18 (10)	-	-	-	0.564	Cooper-Jacob	38.04	1.64E+02	2.74E+02
WF01-PW19	87.63%	52.97%	-	0.564	Cooper-Jacob	1.22	3.16E-27	5.37E-28
WF01-PW20	65.64%	33.50%	-	0.537	Cooper-Jacob	0.398	2.17E-24	1.37E-41

- The storativity values for Akaki Phase II deep well for some well are in the accepted ranges where as the result for the other wells (WF01-PW05, PW06, PW07, PW12, PW14 and PW18 (10) are not in the acceptable range due to the disadvantage of using the (productive well) single well pumping test.

4.6 Assessment Result of Qualitative Data

Groundwater Monitoring questionnaires were prepared as indicated in Appendix-6. The following four objectives were to be achieved with the questionnaires.

1. To analyze and identify the effect of monitoring and regulation of groundwater extraction and analysis of its consistence.
2. To assess the existing trained human resources, well field monitoring practice and analyze the effect in the performance of water production of the wells
3. To assess the equipment installed and availability of measuring instrument in the well site
4. To assess the practice of well performance, access to data collected , data handling and use the interpretation for decision making

The questionnaire were filled and responded by 18 persons 7 from AAWSA, 8 from ECDSWC-WEDSS and 3 from MoWE.

Getting the right response from the right person who has the knowledge of groundwater management was difficult and time consuming. It required repetitive appointment and communication with the respondents person get the paper timely filled. The detail questionnaire is available in Appendix-6.

The assessment results are presented in a narrative and table forms as indicated below.

Table 18:- Questionnaire Result Objective 1

Objective	Main Focus	Persons responded	Response			
			Yes (%)	No (%)		
1	Implementation of GW Monitoring at national level	18	7 (39%)	11 (61%)		
	Existence policy / guideline to refer on groundwater monitoring	18	3 (17%)	15 (83%)		
	Existence of responsible government. body for GWM	18	3 (17%)	15 (83%)		
	Study Area Akaki Phase II Project					
	GWM practice	15	3 (20%)	12 (80%)		
	All wells GWM being conducted	7	6 (86%)	1 (14%)		
	Is all GWM Parameters recorded during monitoring	7		7 (100%)		
	Date analysis being done	7	7 (100%)			
			Assessment	Optimized development	Sustainability of use	Integrated water management
	Focus of the groundwater Monitoring (GWM)	18			7 (39%)	11 (61%)
			Temporary	Permanent		
	The institutional essence of GWM	18	7 (39%)	11(61%)		
			Large Scale network	Specific purpose	Both	
	The type of GWM Network	18	3 (17%)	14 (77%)	1 (6%)	

Objective	Main Focus	Persons responded	Response			
			On project wise	Regular frequency for several years	Regional Reference monitoring Practice	
	Existing Stage of GWM	18	18 (100%)			
			Sufficient	Insufficient	None	
	Budget allocation for GWM	18		7 (39%)	11 (61%)	
			Monthly	Weekly	Daily	As required
	Frequency of GWM in Phase II	7				7 (100%)
			WT Decline	Yield reduction	Pollution	
	Akaki phase II problem encountered	7	1 (14%)	6 (86%)		
			Paper Format	Electronic Gadget	Automated	
	Data Collection tools	7	7 (100%)			
			Future Planning	Maintenance	Sustain the system	
	Purpose of Analyzed outcome	7	1 (14%)	1(14%)	5(72%)	
			Low Yield	Well Construction defect	Aging	Burning of Pump
	Causes of well Malfunctioning	7(more than one answer)	4(44.4%)	1(11.1%)	2(22.2%)	2(22.2%)
			power	Breakdown		
	Cause of interruption	7	6 (86%)	1 (14%)		

Table 19:-: Questionnaire Result Objective 2

Objective	Main Focus	Persons responded	Response	
			Yes (%)	No (%)
2	Conducting special training to staff on GWM	18	3 (17 %)	15 (83%)
	Presence of written training manual on GWM	18	1 (6%)	17(94%)
	Regularity of the refresher training on GWM	18		18 (100%)
	Staffing and organizational arrangement	The number of staff assigned for GWM are 7 , the level of education at department level and supervisory are BSc in hydraulics degree graduates while the others have completed elementary school		

Table 20:- Questionnaire Result Objective 3

Objective	Main Focus	Persons responded	Response	
			Yes (%)	No (%)
3	The presence of GWM equipment maintenance facility	7	3 (43 %)	4 (57%)
	Presence of sufficient spare parts for maintenance	7	1 (14%)	6(86%)
	Presence of sufficient equipment for measurement (Automatic recorder, deep meter, discharge meter, etc.)	7	3 (43%)	4 (57%)
	Functionality of the above equipment	7	2 (29%)	5(71%)
	Collected Data Quality id ensure through regular supervision and consistency check	7	7 (100%)	

Table 21:-: Questionnaire Result Objective 4

Objective	Main Focus	Persons responded	Response	
			Yes (%)	No (%)
4	Printed paper format as a tool for data collection	7	1 (100%)	
	Commonly used parameters measured during monitoring are discharge, water level	7	1 (14%)	6(86%)
	Presence of sufficient equipment for measurement (Automatic recorder, deep meter, discharge meter, etc.)	7	3 (43%)	4(57%)
	The time consistency of data collection is always morning beginning of work	7	1 (14%)	6(86%)
	The data recording at the head quarter is regular	7	5 (71%)	2(29%)
	Collected Data is accessible for other actors for use	7	6 (86%)	1(14%)
	Staff assign for database management	7	7 (100%)	
	Collected Data is Regularly analyzed	7	1 (14 %)	6(86%)
	Dissemination of the analysis for other stakeholders for maintenance, controlling of the abstraction, other national purposes	7	6 (86%)	1(14%)
	The quality of existing GWM practice	18		18(100%)

4.7 Performance and Functionality of wells

In Akaki Phase II well field in total 26 wells was drilled. Out these 21 wells are connected to the town water supply system while the other 5 are abandoned due to low yield and being shallow in depth. The wells are constructed in years 2008 to 2013.

AAWSA through its Water Supply and Sanitation Development and Rehabilitation Project Office entered the following contract agreements with seven drilling contractors for drilling, construction and pumping test works to facilitate and assist the study to obtain valuable subsurface information and to meet the objective of the project. The detail is shown in the Appendix 7.

The field observation and data collection of this study considered only those connected to the system. In this well field all 20 sites were visited. Out of these wells 19 are operational while 1 was not operational during the field visit. These functional wells are located between elevations ranging 2045 to 2096 meters above sea level.

Table 22:- Operational wells in New city (Phase II) Akaki wells

ID	Borehole Name	Location	Construction Year	X (m)	Y (m)	Elevation (m)	Daily Average Operation Hours	Optimum Yield l/s)
1	SWAWF-2'	Addis Ababa	2008	475841	980128	2064	21.87	33
2	WF01-PW2	Addis Ababa	2009	474290	980673	2072	22.66	29
3	WF01-PW3	Akaki	2009	475010	980705	2081	22.18	10
4	SWAWF-4B	Akaki	2009	472919	980832	2064	22.57	35
5	WF01-PW4'	Oromia	2013	471277	979792	2053	23.56	64
6	SWAWF-5	Oromia	2009	472848	979715	2058	22.06	76.76
7	WF01-PW5'	Oromia	2013	470530	979406	2051	22.71	-
8	WF01-PW6	Oromia	2010	472630	979912	2096	21.14	54
9	WF01-PW8	Oromia	2009	473683	979475	2059	22.81	13
10	WF01-PW9	Oromia	2013	469673	978794	2053	22.77	50
11	WF01-PW10(18)	Oromia	2011	472012	979857	2059	22.25	100.11
12	WF01-PW11	Oromia	2009	472268	978066	2059	20.45	45.33
13	WF01-PW12	Oromia	2010	471401	977301	2055	22.71	66.48
14	WF01-PW13	Oromia	2010	472114	976834	2058	20.86	19
15	WF01-PW14	Oromia	2010	476877	976374	2056	22.69	120
16	WF01-PW15	Oromia	2010	474037	978932	2066	21.92	26
17	WF01-PW16	Oromia	2010	473447	980394	2068	22.65	17
18	WF01-PW17	Oromia	2010	472554	981756	2066	17.81	44.08
19	WF01-PW19	Oromia	2012	470650	977039	2045	22.67	54.84
20	WF01-PW20	Oromia	2012	471470	978047	2056	22.34	33

The amount discharge from well to well is different with a minimum of 10 l/s to a maximum of 120 l/s. as indicated in the chart below. In terms of production of water the current optimum yield from these wells is 890.6 l/s. The minimum hours of pumping per day are 20 while the maximum nonstop for 24 hours in a day. While the initial recommended yield range 12-140 l/sec and planned in a range of 10-24 hours per day of operation. More than 50% are pumped on average almost 24 hours per day.

Figure 16: Well Efficiency

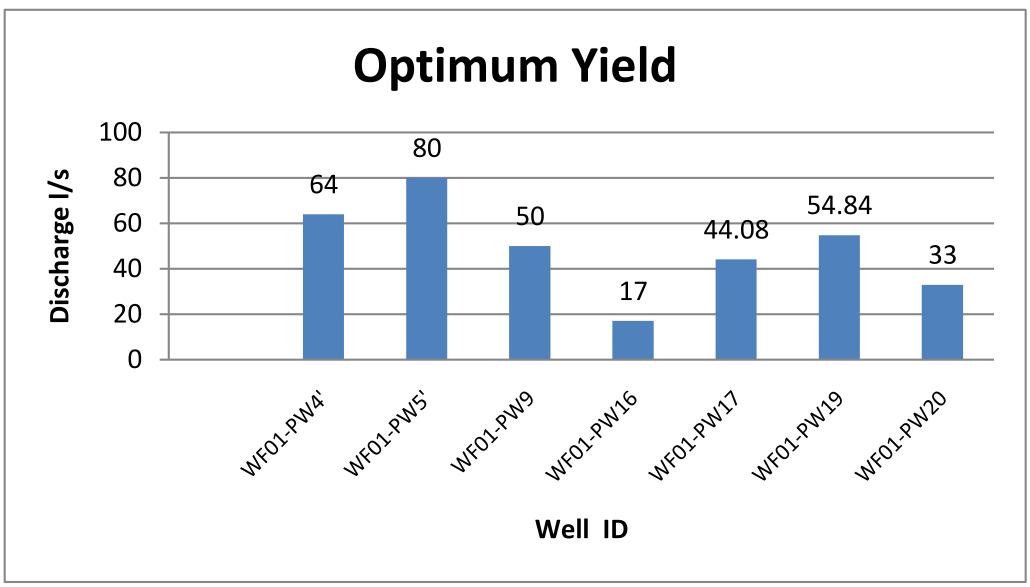


Figure 17:- Optimum Discharge of the Wells during the study

A constant withdrawal of water from these wells caused the highest draw down of water table in the well field. Some wells shows significant water level drop. For instance borehole WF01-PW6 showed water level drop of about 28 meters. Initially, the pump position was 120 m and the discharge was on average 47.5 l/s being operational for 24 hrs. The dynamic water level declined from 92.2 m to pump inlet screen level and was dry running. As there was no level control functional the decline of dynamic water table was noticed as the yield of the well decreased and water pumped intermittently.

As the pump was not able to draw water from the well the position of the pump was lowered to 135 m below ground. Similar problem was noticed in WF01-PW10 (18) pump position was lowered changed from 55 m to 107 m below ground.

The study finding also confirms the actual situation where WF01-PW6 and WF01-PW10 (18) were having over estimated transimissivity. WF01-PW6 is considered to be of higher transmissivity value of 1590 while this study calculates to be 463.53 m^2/day. Similarly WF01-PW10 (18) is estimated of Transmissivity value of 16200 while the study finding calculates to be 5280.76 m^2/day. Water was drawn from at higher discharge than the actual capacity of the aquifer that resulted in the fast depletion of the water table.

Borehole WF01-PW14 pump position during the commencement of operation was 100 m below ground. The pump of this well was burnt due to declining dynamic water table. While conducting the data collection WF01-PW14 pump replacement and rehabilitation was completed by lowering the pump position 118 m. Its optimum yield also recovered to the recommended discharge 120 l/sec.

Figure 18:- : Borehole WF01-PW14 under maintenance

In this project site 6 pumps has been observed, collected from PW4, PW5, PW6, PW14, PW18 and PW20, which was burned due to water level fluctuation. As the finding of this research indicates, for instance PW6 and PW18 were over pumped and the water table was below the suction level possibly the pumps were running dry. As the result pumps were burnt.

4.8 Groundwater Monitoring Practice

Ethiopian water sector strategy document states groundwater to be developed and optimally utilized for different purposes. The document further mentions as abstraction of the water to be balanced with the sustainable yield of the aquifer. In order to regulate the excess withdrawal of water from deep wells, it proposes the establishment a regulatory norms and development of regular monitoring system of the changing variables and undertaking continuous complete inventory of these sources being constructed.

The study conducted in 2013 with a title Practical framework for Strategic framework for managed groundwater development in the greater Addis Ababa area states as groundwater monitoring is nonexistent as some of the monitoring wells are not functioning.

The study result conducted in the chapter above also confirms 61% of the respondents understand as the national level groundwater monitoring is not existent except the effort being done in haphazard way with few well fields in Addis Ababa water supply project by AAWSA. In particular there are no efforts of integration of the networking with other well fields' data collection. Some of the respondents 83% believe that there is national policy to be referred as guideline and no one has a chance to refer it and notice if groundwater management as stated in article 2.2.4 and 2.2.6 of the national water policy the water resources information management is required and the groundwater exploitation shall be limited to the sustainable yield determined by the competent authorities and establish regulatory norms. Except this statement being mentioned in the policy the establishment of the competent authority and the norms are not done practical.

Even the Akaki Phase II well field the groundwater monitoring practice not regular, inconsistent, focused only on limited visible parameters like discharge and time of operation.

As indicated in the survey result 80% of the respondents believe that the groundwater monitoring is not sufficient and inconsistent in the data collection verification and use.

The groundwater monitoring parameters measured (well depth, ground water level, areal extent, number of water bearing formations, hydraulic conductivity, transmissivity, storativity and aquifer depth) are very few and which does not help to take evidence based decision as 100% respondent in AAWSA. The existing attempt of monitoring by AAWSA is integrated water management not for the sustainable use rather to meet the demand side of the water supply by continuous pumping without considering its effect. The current institutional essence is to do groundwater monitoring for specific purpose while 77% of the respondents assumes as groundwater networking establishment enhances the effective and sustainable use of the groundwater resources.

4.9 Capacity of Institutions for Groundwater Monitoring

The national water policy document in its institutional and legal framework part states as water resources management institute is to be established for the sustainable development, management of the water sector and control of violation legal provisions of water resources use that leads to prosecution, however, this has never been made practical. The policy enabling environment section considers the capacity building of the staff in attaining the appropriate skills and encourages professionalism.

According to the data result 83% of the respondents believe that AAWSA is the owner of the projects and as the same time responsible for monitoring the groundwater in their well fields. However, the staff number assigned for groundwater monitoring is limited and has no special training. For instance, the head office staffs working in the groundwater monitoring has no diversified professional background. At the field level the well operators are both guards and with low level of education. More than 83% of the questionnaire respondent mention as no special training is conducted and written training manual is not available.

In Akaki phase II well field all wells were initially equipped with electromechanical equipment that was able automatically records the static and dynamic water tables, discharge and relevant parameters. It used to be regulated and being operated from the central station. 57% of the respondent says as there is not sufficient equipment (like measuring electrical deep meter and level control, automatic well data recorder, etc.) for conducting groundwater monitoring in AAWSA. Even if, these instruments and tools are available it is not functional. During the study this central system was not operational. There is no continuous supply of spares parts and a skilled person to maintain the system.

4.10 Legal, Rregulatory and Institutional Setting for GW Monitoring

Ethiopia has a water resource management policy, water sector development program, water sector implementation strategy documents. The Federal Government Ministry of Water and Energy is the primary responsible body for the policy formulation, preparation of the five year sector development plan. It is also regulators the water resources management and defines the priority use of water. It is also licenses sector developing contractors and consultants.

Water Resources Management Policy of Ethiopia was implemented since 1999 as a guiding essential national policy document to steer the development and management of the country's water resources. The National Water Sector Strategy document was developed and issued in 2001 as a roadmap to translate the policy into action. The third document available is the Water Sector Development Program (WSDP) of 15 years in 5 years phases starting from 2002 and continued to date in the phase of Growth and Transformation plan of the country.

According to the water sector development program document, groundwater potential of the country is approximately 40 billion m^3 (B.Berhanuet.al.2014)

As the climate change is a challenge and the influence affecting the surface water sources, groundwater has now become a strategic resource for economic growth, poverty reduction, environmental sustainability, and for climate change adaptation by rural and urban livelihoods (Seifu, 2010).

The policy document in its goal envisages promoting the national efforts of efficient, equitable and optimal utilization of all available water resources taking also into consideration the groundwater resources.

In those documents mentioned above the groundwater management and monitoring was not given major emphasis despite this water resource is the true potential of the country in addressing the water needs in the future.

Conclusion and Recommendation

5.1 Conclusion

In this study qualitative and quantitative data collection and analysis was done. The research objective is to assess the groundwater management practices and the effect of abstraction of water without proper groundwater monitoring system on the sustainable use of the Akaki Phase II well field.

According to the analysis of the pump test through different methods, the transmissivity values obtained in this research has great variation from the study Report of WWDSE. Among the 15 wells analyzed 10 have underestimated transmissivity whereas the 5 wells are expected to have overestimated transmissivity. The wells where the transmissivity underestimated found to have pumped lower yield than their discharging capacity. On the other side the overestimated transmissivity predict good aquifer with better yield than the capacity of the aquifer which was underutilized. The assumption taking before the analysis of the research that states high abstraction of water from all wells was not found to be right except those mentioned above. There is no much pumping to indicate depletion of the water in well field. However, decline discharge noted which could be from the clogging of the screen, absence regular well rehabilitation and decrease of the well efficiency. The 5 wells expected to have overestimated transmissivity. The water production of these wells is beyond the capacity of the aquifer which resulted in excessive abstraction of water and fast decline of the dynamic water table that damaged the submersible pump due dry running (eg. WF01-PW6 and PW18). The effects of partial penetration has caused a large head loss in the four well namely WF01-PW06, WF01-PW12, WF01-PW16 and WF01-PW17

Another major focus that should be considered during construction of wells is that of its casing arrangement and installation. The arrangement of blind and screen materials in any give well brands the aquifer as a partial penetrated aquifer making the approach of flow path to curve at the intake, this in turn causes the head loss in the well to be greater.

In Akaki Phase II deep wells the effects of partial penetration has caused a large head loss in the four well namely WF01-PW06, WF01-PW12, WF01-PW16 and WF01-PW17. As a result, the observed drawdown in these four wells drops significantly when the effect of partial penetration is considered. This head loss could have been avoided by designing the best combination of blind and screen length in these wells.

In the determination of the optimal yield of the well efficiency has to be considered in the range of 65-85%. In the development of Akaki Phase II deep well step draw down test that helps to determine the efficiency of the well is conducted for 7 wells out of 15 well tested which is less than 50%.This shows as attention is given for the maximum yield pumped without considering efficiency.

The 7 wells step draw down test conducted had efficiency in a range of 19.22-52.97% which is not within the recommended range of 65-85%. These wells (WF01-PW04, WF01-PW05, WF01-PW16, WF01-PW9, WF01-PW17, WF01-PW19 and WF01-PW20) designed and recommended discharge is not attained and in the future it might fail to provide the initial designed yield in design period. The observed drawdown is expected to be worked out while the well efficiency is very low or the effects of partial penetration is high thus the actual aquifer parameters will result in unrealistic values. However, when major stress is given to the well drawdown loss by considering either the well efficiency or partial penetration the observed drawdown will have a lesser drawdown than originally thought. This corrected drawdown in turn can be used for describing the true nature of the aquifer.

The case of single well pumping tests the storativity are generally overestimated, due to well losses inside the production well, this leads to cause high drawdown on the plot of the straight line of time versus drawdown. The storativity values for Akaki Phase II deep well for some well are in the accepted ranges where as the result for the other wells (WF01-PW05, WF01-PW06, WF01-PW07, WF01-PW12, WF01-PW14 and WF01-PW18 (10)) are not acceptable. Thus it can be concluded that storativity values determination through a single well test is not possible.

In general, the groundwater sources of the Akaki Phase II has wrong assumptions in the design phase since it neither consider the factors above nor use data correction techniques in the analysis of the pumping test.

This study has identified AAWSA has some gap on the operation and groundwater management practice due to the gap observed in having the true nature of the aquifer. Even after observing change in the wells performance it has taken no systematic monitoring to re-evaluate the well field aquifer characteristic either through the test wells and/or through the production wells.

Furthermore, this study can conclude practice of systematic monitoring of water levels in production wells and piezometer wells is totally absent in AAWSA well fields especially in Akaki Phase II prospective area.

The capacity of AAWSA in conducting ground water monitoring is not adequately budgeted and lacks sufficiently trained personnel and logistics. The main reasons are having lack of institutional priority, limited resource allocation and malfunctioning of the monitoring equipment. The water well monitoring parameters are limited and incomplete to have full understanding of the well. There should be a clear monitoring program is designed, enough resources shall be allocated. The monitoring shall not be limited in the individual wells but consider the total well field being integrated with other well fields to make wider in area coverage.

Among the 20 wells visited and analyzed almost 19 functional wells showed a reduction of yield compared to the data gathered in the design, construction and commencement of the operation phase of the wells. The absence of systematized Groundwater monitoring and data management strategy (data collection and reporting, data quality evaluation, validation, processing and presentation) has contributed for not timely acting and sustainable use of the well field.

Despite the existence of Water Resource Management policy in Ethiopia, ground water monitoring is not given major emphasis and the focal institution mentioned the policy to be established is not designated.

The country water sector policy is not fully implemented taking into consideration the groundwater future potential to be the major source water for different functions. No major emphasis is given in practice. The legal, regulatory institutional and technical frameworks are not elaborated for the sustainable and protection of the groundwater resources. The national regional groundwater monitoring programs not launched or delegated.

The role and participation of the community and the private sector is not detailed. The institutions that are given the mandate of groundwater monitoring are not effectively coordinated. The capacity of AAWSA in conducting groundwater monitoring is not adequately resourced and lacks sufficiently trained personnel, logistics and funding. The data collection, validation, analysis and presentation and exchange structure is weak to benefit the decision makers. The ground water monitoring is practiced only to study, map the potential and develop ground water source for water supply.

5.2 Recommendations

For the project like AKAKI Phase II, which is supply water to a metropolitan city, determination of the true aquifer parameters is very important.

GW Monitoring shall be given emphasis to be institutionalized and for the purpose of evaluation of the well field for the optimal withdrawal of water, integrated water management and control by the sector ministry.

The pump testing to be conducted to determine transmissivity and storativity has to be done in a professional way considering all the types and nature of the aquifer. Using the raw observed drawdown data without considering well efficiency or effects of partial penetration for the determination of transmissivity and storativity is still being applied in the hydro-geological society's all over Ethiopia. As this was of interpretative techniques have lead wells most wells to dry up swiftly due to the fact they are being over pumped and also due to this interpretative techniques in some cases the full potential of the well are not being used.

The well design and installation of the screen and blind casing need to have best combination to reduce head loss and increase efficiency of the well. Determination of well efficiency should be given foremost importance when development of a well in any given well fields. As this indicates if the well should be abandoned if it has a very low efficiency or it will specify if the well discharge should be decreased in order to prolong the wells life expectancy.

Major projects like Akaki Phase II estimation of the aquifer parameters shall be tested with having observation well (Multiple well test) despite the higher cost required. A single well test has a very serious drawback in aquifer property determination due to challenges and drawback in standard analysis and result interpretation.

The groundwater monitoring effort in Akaki phase II well field shall be strengthened. Long term monitoring program shall be developed. The necessary budget shall be allocated for development of human resources, training staff, provision of appropriate monitoring equipment and conducting regular and consistent monitoring.

The provision of electromechanical equipment and spare parts shall be conducted for timely rehabilitation and maintenance of the well. Periodic well maintenance and rehabilitation should be practiced on wells with high discharge.

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Appendix 1- Raw Step Drawdown Test.

I. Step Drawdown Test for WF01-PW04

Table 23:- Step drawdown test for WF01-PW04

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T1=T+240	water level, m	Drawdown	T1=T+360	water level, m	Drawdown
1	52.65	18.10	121	80.80	88.26	241	92.91	152.24	361	103.41	226.20
2	61.90	27.35	122	81.53	88.99	242	93.00	153.33	362	104.03	226.82
3	64.00	29.45	123	81.84	89.30	243	93.29	152.63	363	105.56	228.34
4	65.13	30.58	124	81.94	89.41	244	93.52	152.86	364	105.77	228.56
5	66.77	32.22	125	82.57	90.04	245	93.46	152.79	365	105.89	228.67
6	67.54	32.99	126	82.10	89.56	246	93.64	152.98	366	105.99	228.78
7	67.87	33.32	127	82.18	89.65	247	93.77	153.10	367	106.12	228.91
8	68.26	33.71	128	82.27	89.73	248	93.83	153.17	368	106.17	228.96
9	68.50	33.95	129	82.35	89.81	249	93.99	153.32	369	106.16	228.94
10	68.91	34.36	130	82.45	89.91	250	94.01	153.34	370	106.19	228.98
12	69.26	34.71	132	82.45	89.91	252	94.09	153.43	372	106.36	229.15
14	69.59	35.04	134	82.70	90.16	254	94.20	153.54	374	106.43	229.21
16	69.89	35.34	136	82.76	90.22	256	94.42	153.76	376	106.56	229.35
18	69.77	35.22	138	82.88	90.35	258	94.50	153.84	378	106.54	229.33
20	70.17	35.62	140	82.96	90.43	260	94.62	153.96	380	106.77	229.56
25	70.66	36.11	145	83.21	90.68	265	94.87	154.20	385	108.00	230.79
30	71.08	36.53	150	83.55	91.01	270	94.01	153.35	390	107.19	229.98
35	71.44	36.89	155	83.66	91.13	275	95.23	154.56	395	107.36	230.15
40	71.80	37.25	160	83.94	91.40	280	95.39	154.73	400	107.57	230.36
45	72.11	37.56	165	83.12	90.59	285	95.65	154.98	405	107.74	230.52
50	72.37	37.82	170	83.30	90.77	290	95.86	155.20	410	107.83	230.62
55	72.60	38.05	175	84.47	91.94	295	95.85	155.18	415	108.13	230.92
60	72.84	38.29	180	84.65	92.12	300	96.11	155.45	420	108.19	230.97
70	73.32	38.77	190	84.01	91.47	310	96.52	155.85	430	108.55	231.34
80	73.69	39.14	200	85.20	92.67	320	96.92	156.25	440	108.87	231.66
90	74.05	39.50	210	85.55	93.02	330	97.13	156.47	450	109.52	232.31
100	74.42	39.87	220	85.91	93.37	340	97.26	156.59	460	110.33	233.12
110	74.62	40.07	230	86.11	93.57	350	97.75	157.08	470	110.57	233.36
120	76.57	**42.02**	240	86.42	**93.88**	360	98.00	**157.34**	480	110.97	**233.76**

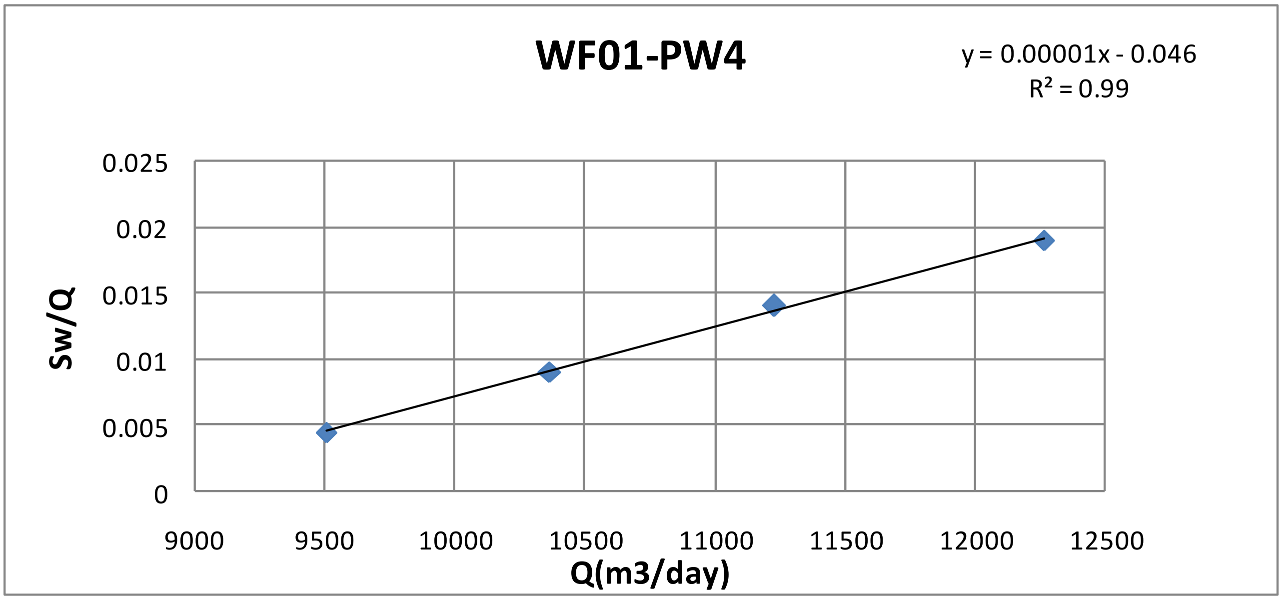


Figure 19:- .Sw/Q vs. Q plot for WF01-PW04

Table 24:-.Values for B, C and well efficiency for WF01-PW04

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
42.015	42.015	9504	0.004421	4.61E-02	1.00E-05	32.67
51.868	93.883	10368	0.009055	4.61E-02	1.00E-05	30.79
63.454	157.337	11232	0.014008	4.61E-02	1.00E-05	29.11
76.418	233.755	12268.8	0.019053	4.61E-02	1.00E-05	27.32

II. Step Drawdown Test for WF01-PW05

Table 25:- Step drawdown Test for WF01-PW05

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T1=T+240	water level, m	Drawdown	T1=T+360	water level, m	Drawdown
0	10.65	0	120	37.3	53.3	240	58	121.35	360	71.16	195.02
1	22.15	11.5	121	52.48	68.48	241	62.65	126	361	77.13	200.99
2	34.25	23.6	122	52.27	68.27	242	64.55	127.9	362	77.89	201.75
3	37.06	26.41	123	52.4	68.4	243	64.77	128.12	363	78.27	202.13
4	37.08	26.43	124	52.58	68.58	244	64.85	128.2	364	78.99	202.85
5	37.3	26.65	125	52.68	68.68	245	64.93	128.28	365	78.56	202.42
6	37.3	26.65	126	52.76	68.76	246	65	128.35	366	78.72	202.58
7	37.3	26.65	127	52.79	68.79	247	65.22	128.57	367	78.74	202.6
8	37.3	26.65	128	52.83	68.83	248	65.35	128.7	368	78.72	202.58
9	37.3	26.65	129	53.08	69.08	249	65.45	128.8	369	78.74	202.6
10	37.3	26.65	130	53.04	69.04	250	65.68	129.03	370	78.42	202.28
12	37.3	26.65	132	53.2	69.2	252	65.75	129.1	372	79.05	202.91
14	37.3	26.65	134	53.33	69.33	254	65.94	129.29	374	79.03	202.89
16	37.3	26.65	136	53.45	69.45	256	65.96	129.31	376	79.16	203.02
18	37.3	26.65	138	53.54	69.54	258	66.13	129.48	378	79.26	203.12
20	37.3	26.65	140	53.65	69.65	260	66.26	129.61	380	79.4	203.26
25	37.3	26.65	145	53.9	69.9	265	66.47	129.82	385	79.94	203.8
30	37.3	26.65	150	54.25	70.25	270	66.75	130.1	390	80	203.86
35	37.3	26.65	155	54.6	70.6	275	67	130.35	395	80.38	204.24
40	37.3	26.65	160	54.84	70.84	280	67.42	130.77	400	80.42	204.28
45	37.3	26.65	165	55.07	71.07	285	67.65	131	405	78.69	202.55
50	37.3	26.65	170	55.24	71.24	290	67.97	131.32	410	81.3	205.16
55	37.3	26.65	175	55.4	71.4	295	68.05	131.4	415	79.98	203.84
60	37.3	26.65	180	55.68	71.68	300	68.35	131.7	420	79.79	203.65
70	37.3	26.65	190	56.22	72.22	310	68.75	132.1	430	79.7	203.56
80	37.3	26.65	200	56.56	72.56	320	69.35	132.7	440	82.39	206.25
90	37.3	26.65	210	56.98	72.98	330	69.69	133.04	450	83.18	207.04
100	37.3	26.65	220	57.29	73.29	340	70.06	133.41	460	83.36	207.22
110	37.3	26.65	230	57.72	73.72	350	70.09	133.44	470	83.74	207.6
120	37.3	26.65	240	58	74	360	71.16	134.51	480	84.34	208.2

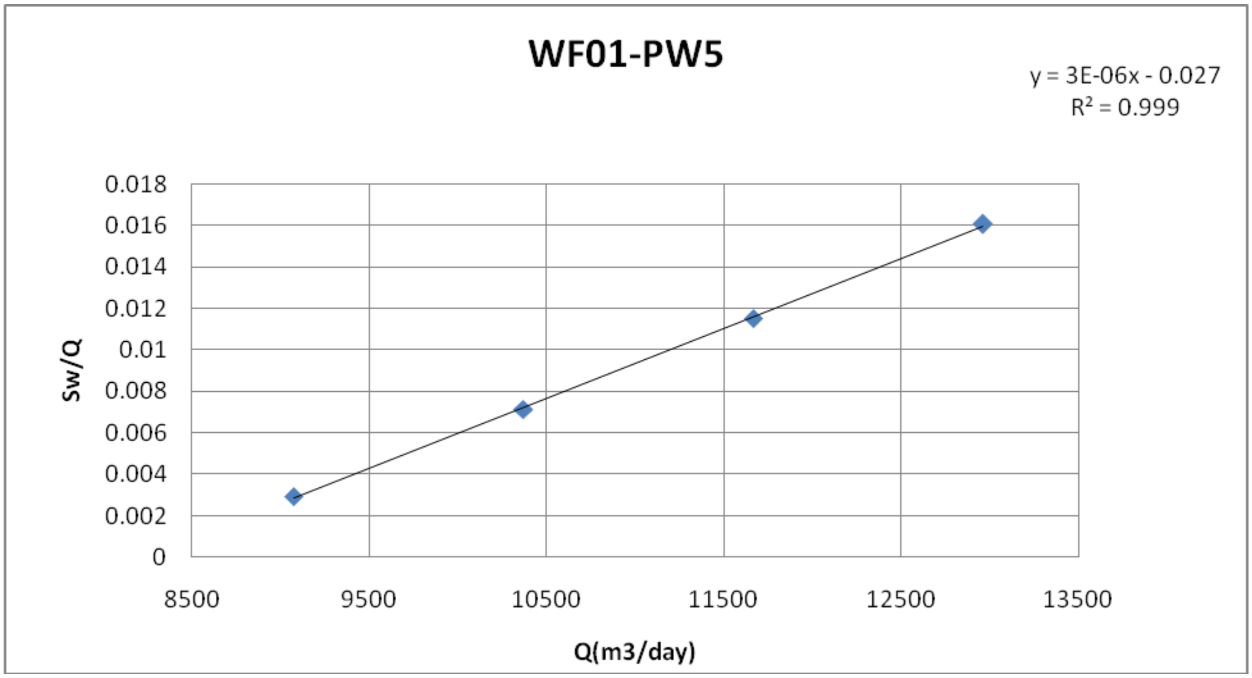


Figure 20:-.Sw/Q vs. Q plot for WF01-PW04

Table 26:-.Values for b, c and well efficiency for WF01-PW05

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
26.65	26.65	9072	0.002938	2.78E-02	3.00E-06	50.52
47.35	74	10368	0.007137	2.78E-02	3.00E-06	47.19
60.51	134.51	11664	0.011532	2.78E-02	3.00E-06	44.27
73.69	208.2	12960	0.016065	2.78E-02	3.00E-06	41.68

III. Step Drawdown Test for WF01-PW09

Table 27:- Step drawdown Test for WF01-PW09

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T1=T+240	water level, m	Drawdown	T1=T+360	water level, m	Drawdown
0	22.64	0	120	72.04	98.8	240	90.8	185.72	360	111.3	294.88
1	63.04	40.4	121	85.27	112.03	241	99.5	194.42	361	124.9	308.48
2	66.3	43.66	122	85.36	112.12	242	100.8	195.72	362	127.4	310.98
3	69.3	46.66	123	85.94	112.7	243	101.85	196.77	363	128.4	311.98
4	69.6	46.96	124	86.41	113.17	244	103.82	198.74	364	129.2	312.78
5	68.7	46.06	125	86.43	113.19	245	105.4	200.32	365	129.7	313.28
6	68.9	46.26	126	86.45	113.21	246	105.7	200.62	366	129.8	313.38
7	69.3	46.66	127	86.46	113.22	247	106.29	201.21	367	130	313.58
8	68.9	46.26	128	86.47	113.23	248	106.41	201.33	368	130.2	313.78
9	69.06	46.42	129	86.48	113.24	249	106.63	201.55	369	130.4	313.98
10	69.14	46.5	130	86.49	113.25	250	107.09	202.01	370	130.7	314.28
12	69.34	46.7	132	86.5	113.26	252	108.36	203.28	372	130.86	314.44
14	69.39	46.75	134	86.8	113.56	254	108.41	203.33	374	130.94	314.52
16	69.58	46.94	136	86.93	113.69	256	108.6	203.52	376	131.09	314.67
18	69.58	46.94	138	87	113.76	258	108.7	203.62	378	132.4	315.98
20	69.68	47.04	140	87.8	114.56	260	108.7	203.62	380	132.8	316.38
25	69.71	47.07	145	87.9	114.66	265	108.99	203.91	385	133	316.58
30	69.8	47.16	150	88.1	114.86	270	109.04	203.96	390	133.51	317.09
35	70	47.36	155	88.23	114.99	275	109.09	204.01	395	133.55	317.13
40	70.11	47.47	160	88.26	115.02	280	109.16	204.08	400	133.62	317.2
45	70.12	47.48	165	88.3	115.06	285	109.38	204.3	405	133.96	317.54
50	70.15	47.51	170	88.4	115.16	290	109.46	204.38	410	135.03	318.61
60	70.26	47.62	180	88.96	115.72	300	109.48	204.4	420	135.64	319.22
70	70.27	47.63	190	89.19	115.95	310	109.71	204.63	430	136.59	320.17
80	70.5	47.86	200	89.47	116.23	320	110.64	205.56	440	136.67	320.25
90	71.16	48.52	210	89.5	116.26	330	110.82	205.74	450	136.8	320.38
100	71.32	48.68	220	90.04	116.8	340	110.85	205.77	460	136.94	320.52
110	71.6	48.96	230	90.55	117.31	350	110.9	205.82	470	137.19	320.77
120	72.04	49.4	240	90.8	117.56	360	111.3	206.22	480	137.58	321.16

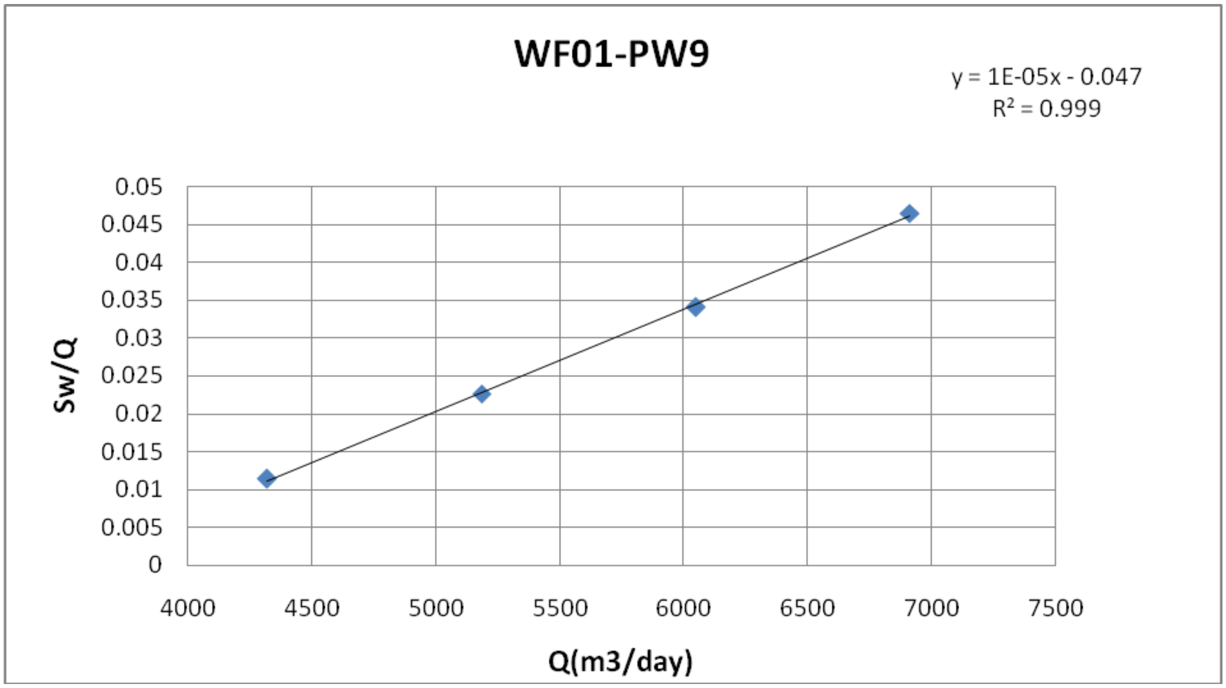


Figure 21:-.Sw/Q vs. Q plot for WF01-PW09

Table 28:-Values for B, C and well efficiency for WF01-PW09

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
49.4	49.4	4320	0.011435	4.71E-02	1.30E-05	45.59
68.16	117.56	5184	0.022677	4.71E-02	1.30E-05	41.12
88.66	206.22	6048	0.034097	4.71E-02	1.30E-05	37.44
114.94	321.16	6912	0.046464	4.71E-02	1.30E-05	34.37

IV. Step Drawdown Test for WF01-PW16

Table 29:- Step drawdown Test for WF01-PW16

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T1=T+240	water level, m	Drawdown	T1=T+360	water level, m	Drawdown
0	10.73	0	120	32.18	42.9	240	72.77	145.53	360	88.52	239.07
1	40	29.27	121	45.68	56.4	241	80.62	153.38	361	96.79	247.34
2	37	26.27	122	51.28	62	242	83.57	156.33	362	103.08	253.63
3	35.89	25.16	123	56.31	67.03	243	84.07	156.83	363	110.13	260.68
4	33.65	22.92	124	58.91	69.63	244	82.82	155.58	364	112.76	263.31
5	32.83	22.1	125	60.64	71.36	245	76.45	149.21	365	115.69	266.24
6	32.01	21.28	126	62.28	73	246	76.39	149.15	366	117.71	268.26
7	31.61	20.88	127	63.7	74.42	247	76.34	149.1	367	119.3	269.85
8	31.31	20.58	128	64.62	75.34	248	79.61	152.37	368	120.4	270.95
9	31.21	20.48	129	65.44	76.16	249	81.01	153.77	369	121.17	271.72
10	31.09	20.36	130	66.09	76.81	250	82.3	155.06	370	121.68	272.23
12	30.85	20.12	132	67.07	77.79	252	83.85	156.61	372	122.51	273.06
14	30.68	19.95	134	67.7	78.42	254	84.71	157.47	374	123.01	273.56
16	30.76	20.03	136	68.21	78.93	256	85.31	158.07	376	123.41	273.96
18	30.76	20.03	138	68.61	79.33	258	85.65	158.41	378	123.79	274.34
20	30.81	20.08	140	68.9	79.62	260	85.96	158.72	380	123.88	274.43
25	30.99	20.26	145	69.53	80.25	265	86.33	159.09	385	124.28	274.83
30	31.12	20.39	150	69.98	80.7	270	86.69	159.45	390	124.6	275.15
35	31.22	20.49	155	70.28	81	275	86.84	159.6	395	124.81	275.36
40	31.36	20.63	160	70.6	81.32	280	87.07	159.83	400	125.05	275.6
45	31.48	20.75	165	70.9	81.62	285	87.27	160.03	405	125.19	275.74
50	31.49	20.76	170	71.05	81.77	290	87.5	160.26	410	125.31	275.86
55	31.49	20.76	175	71.3	82.02	295	87.61	160.37	415	125.47	276.02
60	31.52	20.79	180	71.46	82.18	300	87.75	160.51	420	125.58	276.13
70	31.48	20.75	190	71.78	82.5	310	87.92	160.68	430	125.43	275.98
80	31.53	20.8	200	71.92	82.64	320	88.07	160.83	440	124.72	275.27
90	31.6	20.87	210	72.22	82.94	330	88.25	161.01	450	124.68	275.23
100	31.66	20.93	220	72.4	83.12	340	88.41	161.17	460	124.78	275.33
120	32.18	21.45	240	72.77	83.49	360	88.52	161.28	480	124.93	275.48

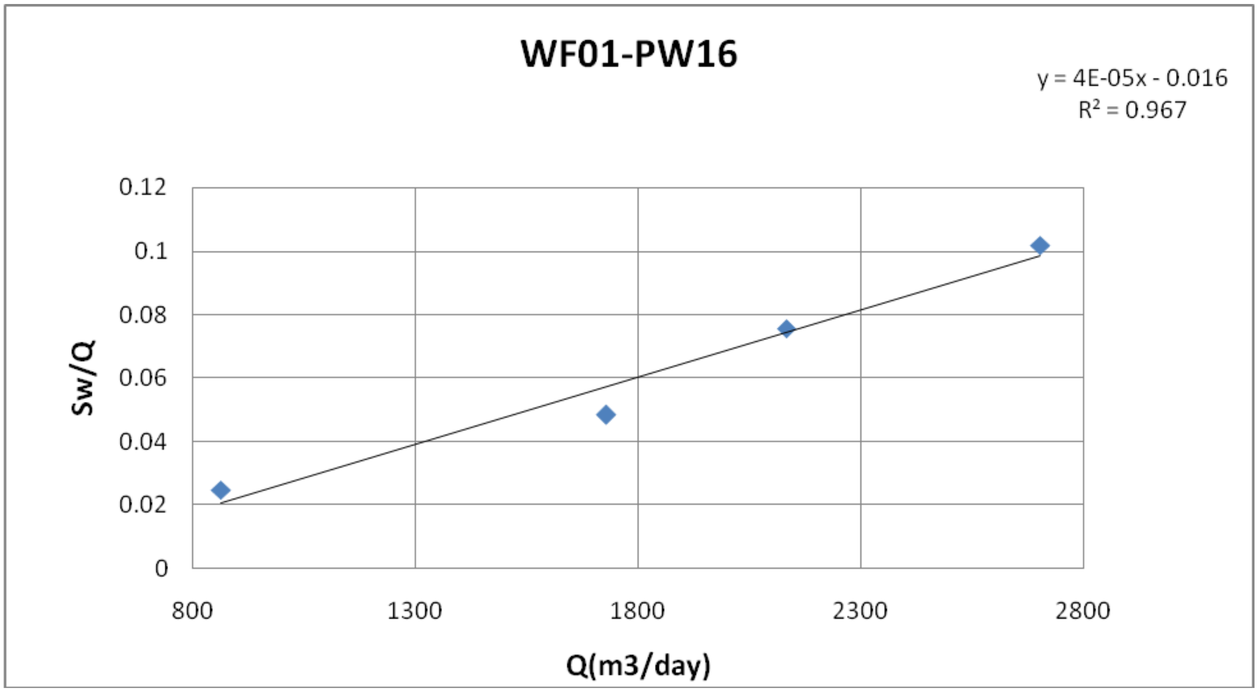


Figure 22:-.Sw/Q vs. Q plot for WF01-PW16

Table 30:-.Values for B, C and well efficiency for WF01-PW16

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
21.45	21.45	864	0.024826	1.62E-02	4.20E-05	30.85
62.04	83.49	1728	0.048316	1.62E-02	4.20E-05	18.24
77.79	161.28	2132	0.075647	1.62E-02	4.20E-05	15.31
114.2	275.48	2703	0.101916	1.62E-02	4.20E-05	12.48

V. Step Drawdown Test for WF01-PW17

Table 31:- Step drawdown Test for WF01-PW17

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T1=T+240	water level, m	Drawdown
0	0	0	120	19.4	38.8	240	50.73	120.86
1	28.05	28.05	121	30.41	49.81	241	57	127.13
2	36.45	36.45	122	33.25	52.65	242	60.7	130.83
3	35.8	35.8	123	34.63	54.03	243	64.18	134.31
4	32.13	32.13	124	38.41	57.81	244	64.55	134.68
5	24.15	24.15	125	40.74	60.14	245	65.42	135.55
6	20.6	20.6	126	41.79	61.19	246	65.9	136.03
7	19	19	127	42.55	61.95	247	66.25	136.38
8	18.2	18.2	128	43.14	62.54	248	66.37	136.5
9	17.9	17.9	129	43.56	62.96	249	66.56	136.69
10	17.7	17.7	130	43.9	63.3	250	66.73	136.86
12	17.6	17.6	132	44.45	63.85	252	67.02	137.15
14	17.6	17.6	134	44.85	64.25	254	67.24	137.37
16	17.69	17.69	136	45.24	64.64	256	67.5	137.63
18	17.77	17.77	138	45.55	64.95	258	67.65	137.78
20	17.65	17.65	140	45.83	65.23	260	67.83	137.96
25	17.9	17.9	145	46.43	65.83	265	68.25	138.38
30	18.15	18.15	150	46.82	66.22	270	68.48	138.61
35	18.38	18.38	155	47.26	66.66	275	68.76	138.89
40	18.5	18.5	160	47.56	66.96	280	69.04	139.17
45	18.66	18.66	165	47.98	67.38	285	69.2	139.33
50	18.8	18.8	170	48.29	67.69	290	69.56	139.69
60	19.1	19.1	180	48.75	68.15	300	70.29	140.42
70	19	19	190	49.1	68.5	310	70.8	140.93
80	19.12	19.12	200	49.44	68.84	320	71.16	141.29
90	19.23	19.23	210	49.86	69.26	330	71.44	141.57
100	19.15	19.15	220	50.35	69.75	340	71.76	141.89
120	19.4	19.4	240	50.73	70.13	360	72.27	142.4

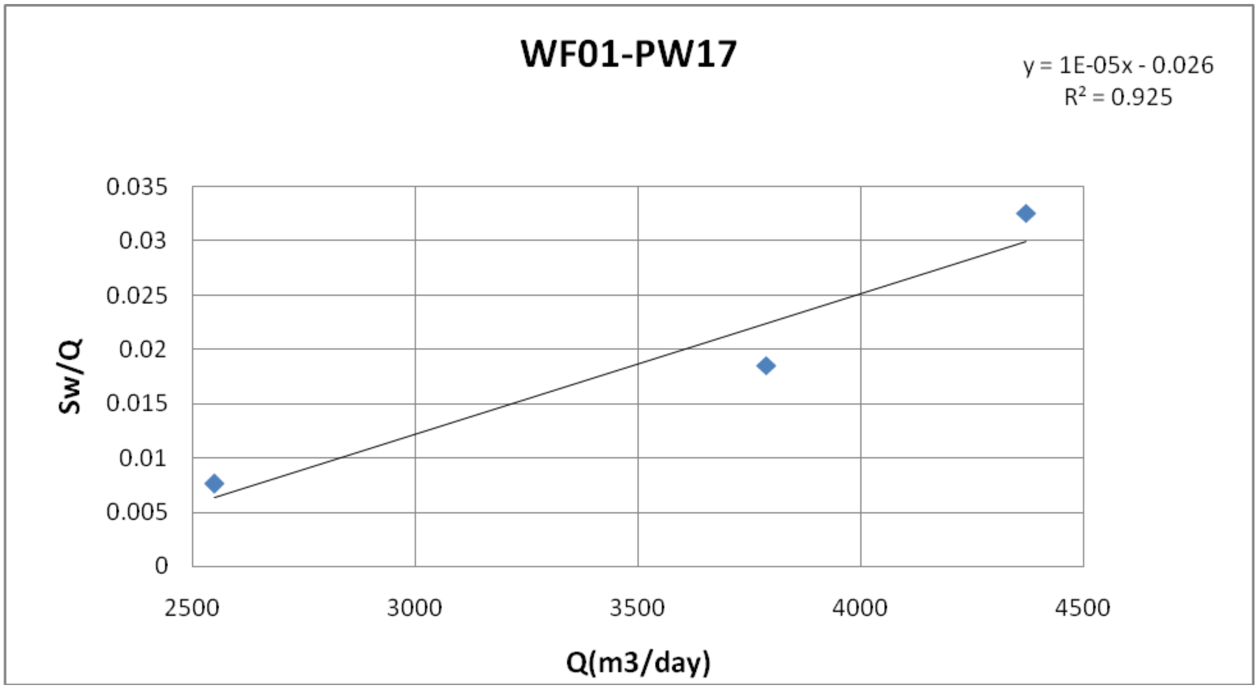


Figure 23:-.Sw/Q vs. Q plot for WF01-PW17

Table 32:-Values for B, C and well efficiency for WF01-PW17

∆ (m)	Sum of ∆	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
19.4	19.4	2548.8	0.007611	2.66E-02	1.30E-05	44.52
50.73	70.13	3786.912	0.018519	2.66E-02	1.30E-05	35.07
72.27	142.4	4371.84	0.032572	2.66E-02	1.30E-05	31.87

VI. Step Drawdown Test for WF01-PW19

Table 33:- Step drawdown Test for WF01-PW19

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T2=240+T	water level, m	Drawdown	T3=360+T	water level, m	Drawdown
0	53.89	0	120	74.62	20.73	240	82.87	28.98	360	94.15	40.26
1	69.3	15.41	121	77.2	23.31	241	90.4	36.51	361	100.7	46.81
2	70.5	16.61	122	78.28	24.39	242	91.2	37.31	362	101.3	47.41
3	70.8	16.91	123	79.7	25.81	243	91.59	37.7	363	101.55	47.66
4	71.06	17.17	124	79.88	25.99	244	91.78	37.89	364	101.65	47.76
5	71.08	17.19	125	80	26.11	245	91.97	38.08	365	101.78	47.89
6	71.2	17.31	126	80.1	26.21	246	91.97	38.08	366	101.84	47.95
7	71.26	17.37	127	80.3	26.41	247	92.1	38.21	367	101.91	48.02
8	71.38	17.49	128	80.67	26.78	248	92.14	38.25	368	102	48.11
9	71.45	17.56	129	80.77	26.88	249	92.19	38.3	369	102.04	48.15
10	71.55	17.66	130	80.84	26.95	250	92.21	38.32	370	102.13	48.24
12	71.7	17.81	132	80.96	27.07	252	92.3	38.41	372	102.15	48.26
14	71.82	17.93	134	81.06	27.17	254	92.41	38.52	374	102.2	48.31
16	71.99	18.1	136	81.1	27.21	256	92.48	38.59	376	102.25	48.36
18	72.11	18.22	138	81.18	27.29	258	92.53	38.64	378	102.34	48.45
20	72.2	18.31	140	81.24	27.35	260	92.6	38.71	380	102.4	48.51
25	72.36	18.47	145	81.37	27.48	265	92.72	38.83	385	102.52	48.63
30	72.6	18.71	150	81.49	27.6	270	93.08	39.19	390	102.6	48.71
35	72.8	18.91	155	81.63	27.74	275	93	39.11	395	102.69	48.8
40	72.92	19.03	160	81.7	27.81	280	93.09	39.2	400	102.76	48.87
45	73.1	19.21	165	81.8	27.91	285	93.16	39.27	405	102.92	49.03
50	73.17	19.28	170	81.91	28.02	290	93.24	39.35	410	103.03	49.14
55	73.28	19.39	175	82	28.11	295	93.38	39.49	415	103.1	49.21
60	73.42	19.53	180	82.1	28.21	300	93.47	39.58	420	103.16	49.27
70	73.68	19.79	190	82.2	28.31	310	93.54	39.65	430	103.27	49.38
80	73.92	20.03	200	82.4	28.51	320	93.75	39.86	440	103.4	49.51
90	74.1	20.21	210	82.52	28.63	330	93.87	39.98	450	103.45	49.56
100	74.31	20.42	220	82.67	28.78	340	93.94	40.05	460	103.54	49.65
120	74.62	20.73	240	82.87	28.98	360	94.15	40.26	480	103.7	49.81

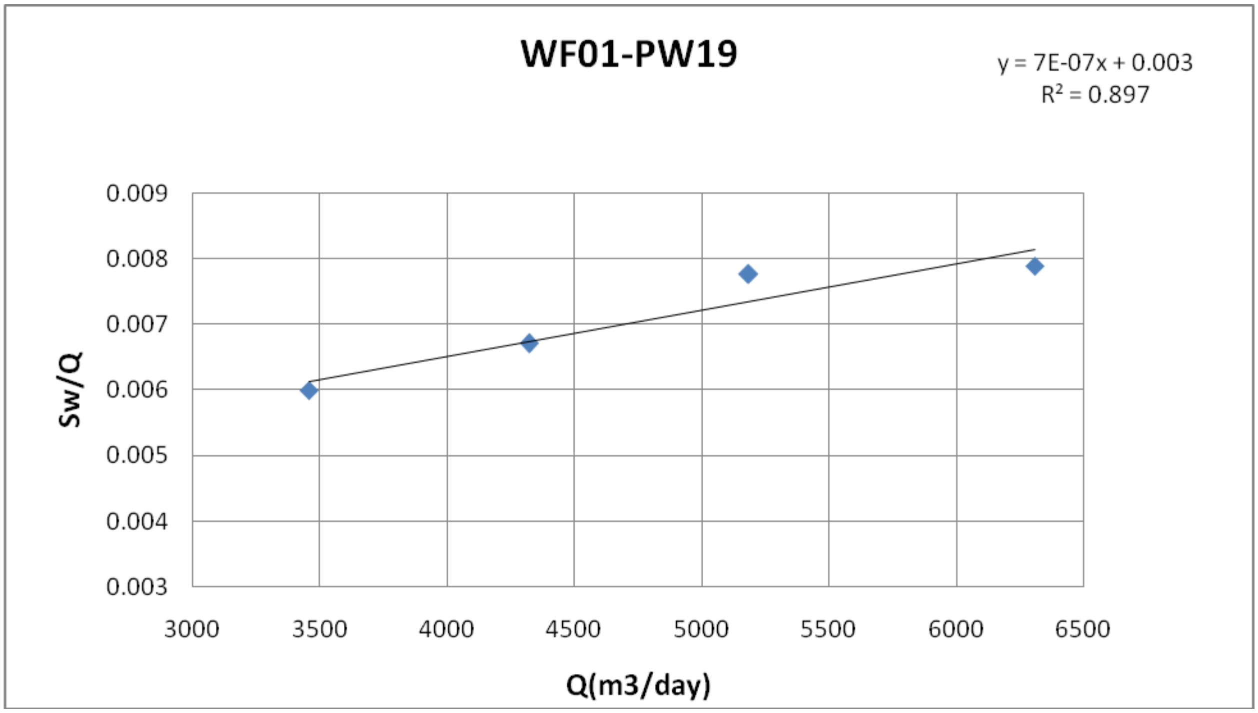


Figure 24:-.Sw/Q vs. Q plot for WF01-PW19

Table 34:- Values for B, C and well efficiency for WF01-PW19

Δ (m)	Sum of Δ	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
20.73	20.73	3456	0.005998	3.71E-03	7.00E-07	60.54
8.25	28.98	4320	0.006708	3.71E-03	7.00E-07	55.10
11.28	40.26	5184	0.007766	3.71E-03	7.00E-07	50.56
9.55	49.81	6307.2	0.007897	3.71E-03	7.00E-07	45.67

VII. Step Drawdown Test for WF01-PW20

Table 35:- Step drawdown Test for WF01-PW20

Time, min	water level, m	Drawdown	T1=T+120	water level, m	Drawdown	T2=240+T	water level, m	Drawdown	T3=360+T	water level, m	Drawdown
0	26.3	0	120	76.82	50.52	240	88.62	62.32	360	101.06	74.76
1	70.5	44.2	121	79.7	53.4	241	91.25	64.95	361	113.48	87.18
2	73.4	47.1	122	82.6	56.3	242	93.1	66.8	362	118.35	92.05
3	76.6	50.3	123	84.1	57.8	243	94.29	67.99	363	119.72	93.42
4	74	47.7	124	84.9	58.6	244	94.83	68.53	364	119.75	93.45
5	72.4	46.1	125	85.4	59.1	245	95.33	69.03	365	119.86	93.56
6	71.83	45.53	126	85.55	59.25	246	95.69	69.39	366	119.97	93.67
7	71.8	45.5	127	85.82	59.52	247	96.2	69.9	367	120.06	93.76
8	71.82	45.52	128	86.02	59.72	248	96.73	70.43	368	120.47	94.17
9	72.1	45.8	129	86.24	59.94	249	97.06	70.76	369	120.77	94.47
10	72.24	45.94	130	86.39	60.09	250	97.17	70.87	370	120.96	94.66
12	72.6	46.3	132	86.56	60.26	252	97.53	71.23	372	121.23	94.93
14	72.93	46.63	134	86.92	60.62	254	97.67	71.37	374	121.76	95.46
16	73.36	47.06	136	86.97	60.67	256	97.8	71.5	376	122.4	96.1
18	73.6	47.3	138	87	60.7	258	98	71.7	378	122.7	96.4
20	73.85	47.55	140	87.09	60.79	260	98.06	71.76	380	123.24	96.94
25	74.22	47.92	145	87.22	60.92	265	98.18	71.88	385	123.86	97.56
30	74.62	48.32	150	87.35	61.05	270	98.57	72.27	390	124.73	98.43
35	74.9	48.6	155	87.47	61.17	275	99.6	73.3	395	125.24	98.94
40	75.2	48.9	160	87.55	61.25	280	99.78	73.48	400	125.79	99.49
45	75.4	49.1	165	87.63	61.33	285	99.92	73.62	405	126.27	99.97
50	75.51	49.21	170	87.72	61.42	290	100	73.7	410	126.74	100.44
55	75.63	49.33	175	87.68	61.38	295	100.06	73.76	415	127.16	100.86
60	75.74	49.44	180	87.86	61.56	300	100.1	73.8	420	127.56	101.26
70	76	49.7	190	87.95	61.65	310	100.17	73.87	430	127.74	101.44
80	76.25	49.95	200	88.08	61.78	320	100.54	74.24	440	127.9	101.6
90	76.42	50.12	210	88.2	61.9	330	100.73	74.43	450	128.29	101.99
100	76.55	50.25	220	88.3	62	340	100.9	74.6	460	128.76	102.46
120	76.82	50.52	240	88.62	62.32	360	101.06	74.76	480	128.76	102.46

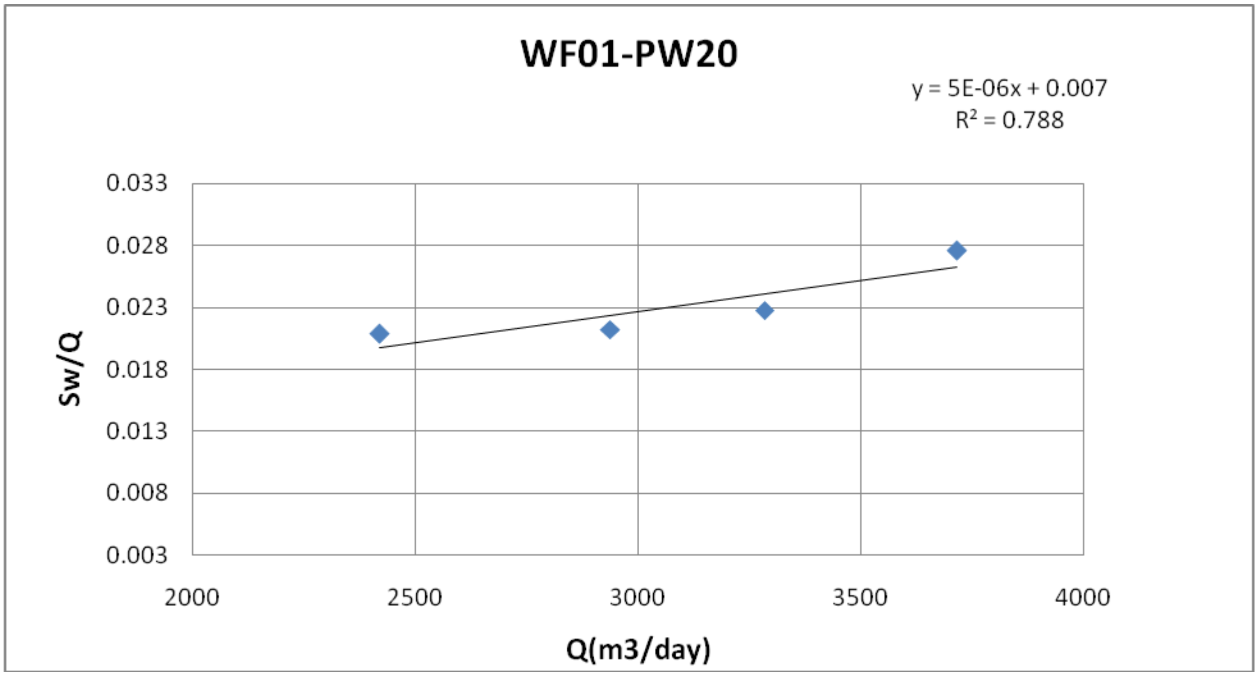


Figure 25:-Sw/Q vs. Q plot for WF01-PW20

Table 36:-. Values for B, C and well efficiency for WF01-PW20

Δ (m)	Sum of Δ	Q (m^3/day)	Sw/Q	B	C	Efficiency (%)
50.52	50.52	2419.2	0.020883	7.65E-03	5.00E-06	38.75
11.8	62.32	2937.6	0.021215	7.65E-03	5.00E-06	34.26
12.44	74.76	3283.2	0.02277	7.65E-03	5.00E-06	31.80
27.7	102.46	3715.2	0.027579	7.65E-03	5.00E-06	29.18

Appendix 2- Casing Arrangements

Effect of partial penetration determined by using Kozeny correction factor which is given by:-

$$F = \frac{L}{B}\left[1 + 7COS\left(\frac{\Pi L}{2B}\right)\sqrt{\frac{r}{2L}}\right]$$

Table 37:-.Kozeny correction factor for WF01-PW04

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778	r'=	0.1016								
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
1	131.7		132.7								14”
131.7	137.5	138.52		5.82	65.466817	0.04201559	6.984775927	0.123591723	1.863260494	0.078286	14”
137.5	143.34		5.82								14”
143.34	149.2	11.64		5.82	65.466817	0.5	4.951717884	0.123591723	1.611991347	0.80599567	14”
149.2	160.83		11.67								14”
160.83	178.3	29.11		17.44	196.17548	0.59910684	4.12513651	0.071396618	1.294520796	0.77555626	14”
178.3	190		11.7								14”
190	201.6	23.33		11.63	130.82115	0.49849979	4.963357816	0.08743011	1.433946918	0.71482223	14”
201.6	213.3		11.7								14”
213.3	236.6	35		23.3	262.09224	0.66571429	3.512275523	0.061769334	1.21695092	0.81014161	14”
236.6	243.9		7.3								14”
243.9	249.8		5.9								8”
249.8	261.4	24.8		11.6	228.34646	0.46774194	5.195842651	0.066176358	1.343841943	0.62857123	8”
261.4	273		11.6								8”
273	284.6	23.2		11.6	228.34646	0.5	4.951717884	0.066176358	1.327686655	0.66384333	8”
284.6	296.2		11.6								8”
296.2	302	17.4		5.8	114.17323	0.33333333	6.063106661	0.093587503	1.567431012	0.522477	8”
302	313.6		11.6								8”

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778	r'=	0.1016								
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
313.6	319.4	17.4		5.8	114.17323	0.33333333	6.063106661	0.093587503	1.567431012	0.522477	8”
319.4	336.9		17.5								8”
336.9	348.6	29.2		11.7	230.31496	0.40068493	5.66000344	0.065892946	1.372954301	0.5501221	8”
348.6	360.2		11.6								8”
360.2	377.7	29.1		17.5	344.48819	0.60137457	4.104975339	0.053878169	1.221168557	0.73437972	8”
377.7	389.2		11.5								8”
389.2	395.1	17.4		5.9	116.14173	0.33908046	6.03129434	0.092790999	1.559649827	0.52884678	8”
395.1	406.7		11.6								8”
406.7	424.4	29.3		17.7	348.4252	0.60409556	4.080715847	0.053572908	1.218615816	0.73616041	8”
424.4	430.2		5.8								8”
430.2	436	11.6		5.8	114.17323	0.5	4.951717884	0.093587503	1.463418912	0.73170946	8”
436	441.8		5.8								8”
441.8	459.3	23.3		17.5	344.48819	0.75107296	2.671750677	0.053878169	1.143949036	0.85918919	8”
459.3	470.9		11.6								8”
470.9	482.5	23.2		11.6	228.34646	0.5	4.951717884	0.066176358	1.327686655	0.66384333	8”
482.5	488.3		5.8								8”
488.3	494.2	11.6		5.8	114.17323	0.5	4.951717884	0.093587503	1.463418912	0.73170946	8”
494.2	500		5.8								8”
									Geo. Mean	0.5969	

- (from 243.9m-500m) radius of the casing used is r'=0.1016m

Table 38:- Kozeny correction factor for WF01-PW05

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778		r'=	0.1016							
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
1	130.7		131.7								14”
130.7	148.2	149.2		17.5	196.850	0.11729	6.881647297	0.071274119	1.490483346	0.1748221	14”
148.2	154.1		5.9								14”
154.1	165.7	17.5		11.6	130.484	0.6629	3.539401428	0.087543093	1.309850148	0.8682435	14”
165.7	177.5		11.8								14”
177.5	183.3	17.6		5.8	65.242	0.3295	6.083804147	0.123804629	1.753203116	0.5777601	14”
183.3	195.1		11.8								14”
195.1	212.5	29.2		17.4	195.726	0.5959	4.153642227	0.071478636	1.296896681	0.7728083	14”
212.5	224.3		11.8								14”
224.3	241.7	29.2		17.4	195.726	0.5959	4.153642227	0.071478636	1.296896681	0.7728083	14”
241.7	247.6		5.9								14”
247.6	266.8		19.2								8”
266.8	278.4	36.7		11.6	228.346	0.3161	6.155653686	0.066176358	1.407358741	0.4448327	8”
278.4	284.3		5.9								8”
284.3	301.7	23.3		17.4	342.520	0.7468	2.715286274	0.05403277	1.146714439	0.8563447	8”
301.7	319.4		17.7								8”
319.4	325.2	23.5		5.8	114.173	0.2468	6.481024616	0.093587503	1.60654291	0.3965085	8”
325.2	337		11.8								8”
337	342.8	17.6		5.8	114.173	0.3295	6.083804147	0.093587503	1.569368038	0.5171781	8”
342.8	354.5		11.7								8”
354.5	377.8	35		23.3	458.661	0.6657	3.512275523	0.046693228	1.163999481	0.7748911	8”
377.8	389.5		11.7								8”
389.5	395.3	17.5		5.8	114.173	0.3314	6.073541388	0.093587503	1.568407572	0.5198151	8”
395.3	407		11.7								8”
407	412.8	17.5		5.8	114.173	0.3314	6.073541388	0.093587503	1.568407572	0.5198151	8”

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778		r'=	0.1016							
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
412.8	424.6		11.8								8”
424.6	430.4	17.6		5.8	114.173	0.3295	6.083804147	0.093587503	1.569368038	0.5171781	8”
430.4	442.2		11.8								8”
442.2	453.8	23.4		11.6	228.346	0.4957	4.984802801	0.066176358	1.329876094	0.6592548	8”
453.8	459.7		5.9								8”
459.7	482.9	29.1		23.2	456.693	0.7973	2.196067787	0.046793751	1.10276225	0.8791782	8”
482.9	488.7		5.8								8”
488.7	500.4	17.5		11.7	230.315	0.6686	3.485078946	0.065892946	1.229642119	0.8221036	8”
500.4	506.3		5.9								8”
									Geo. Mean	0.5892	

- (from 247.6m-506.3m) radius of the casing used is r'=0.1016m

Table 39:- Kozeny correction factor for WF01-PW06

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	20		20								26
20	109		109.5								14
109	115	135.5		6	67.4915636	0.04428044	6.983091062	0.121723731	1.850007897	0.081919169	14
115	127		12								14
127	133	18		6	67.4915636	0.33333333	6.063106661	0.121723731	1.738023964	0.579341321	14
133	157		24								14
157	187	54		30	337.457818	0.55555556	4.501885134	0.054436507	1.245066903	0.691703835	14
187	199		12								14
199	211	24		12	134.983127	0.5	4.951717884	0.086071676	1.426202655	0.713101328	14

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
211	229		18								14
229	241	30		12	134.983127	0.4	5.664429267	0.086071676	1.487546918	0.595018767	14
241	259		18								14
259	277	36		18	202.474691	0.5	4.951717884	0.070277229	1.347993011	0.673996505	14
277	283		6								14
283	532										Uncased
									Geo. Mean	**0.4593002**	

Table 40:- Kozeny correction factor for WF01-PW07

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	20		20								26
20	116.7		117.4								14
116.7	141.3	162		24.6	276.715	0.1519	6.802007144	0.060115066	1.408903107	0.213945	14
141.3	159.5		18.2								14
159.5	171.8	30.5		12.3	138.358	0.4033	5.643184061	0.085015541	1.479758348	0.596755	14
171.8	183.6		11.8								14
183.6	202.05	30.25		18.45	207.537	0.6099	4.028561065	0.069414899	1.279642159	0.780476	14
202.05	219.75		17.75								14
219.75	238.2	36.2		18.45	207.537	0.5097	4.876045238	0.069414899	1.338470187	0.682176	14
238.25	250.3		12.05								14
									Geo. Mean	**0.510609**	

Table 41:-Kozeny correction factor for WF01-PW08

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1524										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	11		11								20
11	88	99.66		88.66	1163.517	0.8896	1.212452797	0.029316601	1.035544995	0.921246431	12
88	118		30								12
118	142	54		24	314.961	0.4444	5.363903247	0.056347138	1.302240598	0.578773599	12
142	160		12								12
160	172	24		12	157.480	0.5000	4.951717884	0.079686887	1.394586985	0.697293492	12
172	184		12								12
184	214	42		30	393.701	0.7143	3.040773011	0.050398413	1.153250133	0.823750095	12
214	244										12
244	250		6								12
250	483.7										Open
									Geo. Mean	0.7439	

Table 42:- Kozeny correction factor for WF01-PW09

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778	r'=	0.1016								
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
1	120.2		121.2								14”
120.2	137.6	138.6		17.4	195.726	0.1255411	6.864470772	0.071478636	1.490663008	0.1871395	14”
137.6	155.25		17.65								14”
155.25	178.5	40.9		23.25	261.530	0.5684597	4.392371624	0.061835717	1.271605449	0.7228564	14”
178.5	190.2		11.7								14”
190.2	207.63	29.13		17.43	196.063	0.5983522	4.131833854	0.071417096	1.295083575	0.7749161	14”
207.63	213.44		5.81								14”
213.44	230.85	23.22		17.41	195.838	0.7497847	2.684831687	0.071458105	1.191852985	0.8936331	14”
230.85	250.05		19.2								14”

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778	r'=	0.1016								
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult	F	Dia. of
250.05	261.64	30.79		11.59	228.150	0.3764209	5.812762056	0.087580851	1.50908665	0.5680518	8”
261.64	279.35		17.71								8”
279.35	290.96	29.32		11.61	228.543	0.3959754	5.690302291	0.087505383	1.497932082	0.5931443	8”
290.96	302.77		11.81								8”
302.77	320.18	29.22		17.41	342.717	0.5958248	4.154222806	0.071458105	1.296852889	0.7726971	8”
320.18	326.08		5.9								8”
326.08	331.9	11.72		5.82	114.567	0.496587	4.978158646	0.123591723	1.615259206	0.8021168	8”
331.9	337.8		5.9								8”
337.8	361.05	29.15		23.25	457.677	0.7975986	2.192438437	0.061835717	1.135571003	0.9057299	8”
361.05	372.86		11.81								8”
372.86	384.47	23.42		11.61	228.543	0.4957301	4.984774643	0.087505383	1.436194615	0.711965	8”
384.47	402.14		17.67								8”
402.14	413.75	29.28		11.61	228.543	0.3965164	5.68683783	0.087505383	1.497628923	0.5938344	8”
413.75	425.56		11.81								8”
425.56	442.98	29.23		17.42	342.913	0.5959631	4.152999612	0.071437592	1.296680291	0.7727735	8”
442.98	454.8		11.82								8”
454.8	466.46	23.48		11.66	229.528	0.4965928	4.978113723	0.087317563	1.434676758	0.7124502	8”
466.46	472.36		5.9								8”
472.36	478.17	11.71		5.81	114.370	0.4961571	4.981479023	0.123698039	1.616199186	0.8018888	8”
478.17	484.07		5.9								8”
484.07	501.5	23.33		17.43	343.110	0.7471067	2.711987613	0.071417096	1.19368228	0.8918081	8”
501.5	507.5		6								8”
									Geo. Mean	0.678135	

- (from 250.05m-507.5m) radius of the casing used is r'=0.1016m

Table 43:- Kozeny correction factor for WF01-PW11

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1524										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	30		30								24
0.5	100.76		101.26								12
100.76	118.62	149.12		17.86	234.3832	0.11977	6.876610435	0.065318584	1.449170453	0.1735662	12
118.62	124.56		5.94								12
124.56	142.42	23.8		17.86	234.3832	0.75042	2.678380349	0.065318584	1.174948011	0.8817047	12
142.42	154.23		11.81								12
154.23	172.07	29.65		17.84	234.12073	0.60169	4.102199489	0.065355187	1.268100014	0.7629985	12
172.07	195.87		23.8								12
195.87	207.76	35.69		11.89	156.03675	0.33315	6.064132359	0.080054649	1.485461988	0.4948765	12
207.76	213.74		5.98								12
213.74	225.65	17.89		11.91	156.29921	0.66574	3.51207815	0.079987405	1.280922016	0.8527547	12
225.65	250		24.35								12
250	250.5										14'' coupling
250.5	500										Uncased (open)
									Geo. M	0.54768	

Table 44:- Kozeny correction factor for WF01-PW12

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1524										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	40.5		40.5								24
40.5	114		114.5								12
114	138	179		24	314.96063	0.13408	6.845481852	0.056347138	1.385723313	0.1857953	12
138	162		24								12
162	174	36		12	157.48031	0.33333	6.063106661	0.079686887	1.483150097	0.4943834	12
174	192		18								12

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1524										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult	F	Dia. of
192	222	48		30	393.70079	0.62500	3.891887931	0.050398413	1.196144974	0.7475906	12
222	234		12								12
234	246	24		12	157.48031	0.50000	4.951717884	0.079686887	1.394586985	0.6972935	12
246	250		6								12
									Geo. Mean	0.467783	

Table 45:-Kozeny correction factor for WF01-PW14

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	10		10								26
0.5	125.68		125.68								14
125.68	137.41	147.41		11.73	131.94601	0.07957	6.945443746	0.087056635	1.604646958	0.1276881	14
137.41	143.57		6.16								14
143.57	155.29	17.88		11.72	131.83352	0.65548	3.609100577	0.087093767	1.314330164	0.8615184	14
155.29	167.44		12.15								14
167.44	197.28	41.99		29.84	335.65804	0.71065	3.076758464	0.054582255	1.167936414	0.8299886	14
197.28	209.56		12.28								14
209.56	221.86	24.58		12.3	138.35771	0.50041	4.948556578	0.085015541	1.420704217	0.7109301	14
221.86	228.05		6.19								14
228.05	240.33	18.47		12.28	138.13273	0.66486	3.520375188	0.085084744	1.299530222	0.8640082	14
240.33	251.18		11.85								14
251.18	552										Open(uncased)
									Geo. Mean	0.562039	

Table 46:- Kozeny correction factor for WF01-PW15

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	138.91		138.91								14
138.91	150.61	150.61		11.7	131.609	0.07768408	6.948001234	0.087168174	1.605644582	0.124733	14
150.61	156.47		5.86								14
156.47	191.6	40.99		35.13	395.163	0.8570	1.563424397	0.050305076	1.078648182	0.9244428	14
191.6	203.33		11.73								14
203.33	220.88	29.28		17.55	197.413	0.5994	4.122664134	0.071172516	1.29342038	0.7752571	14
220.88	226.75		5.87								14
226.75	244.4	23.52		17.65	198.538	0.7504	2.67832956	0.070970608	1.190082677	0.893068	14
244.4	250		5.6								14
									Geo. Mean	0.531555	

Table 47:-Kozeny correction factor for WF01-PW16

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2L/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	20		20								26
0.8	130		130.8								14
130	160.64	181.44		30.64	344.65692	0.1688713	6.755413026	0.05386498	1.363880185	0.23032015	14
160.64	166.77		6.13								14
166.77	197.27	36.63		30.5	343.08211	0.8326508	1.823462642	0.053988463	1.098445945	0.91462193	14
197.27	227.58		30.31								14
227.58	245.71	48.44		18.13	203.93701	0.3742775	5.825854294	0.070024816	1.407954377	0.52696558	14
245.71	250		6.24								14
250	549.73										14
250	549.73										Open(Uncased)
									Geo. Mean	0.4806017	

Table 48:- Kozeny correction factor for WF01-PW17

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2L/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	16		16								26
0.5	122.5		123								14
122.5	134.18	150.68		11.68	131.38358	0.0775153	6.948226714	0.087242773	1.606182563	0.124503666	14
134.18	140.08		5.9								14
140.08	151.78	17.6		11.7	131.60855	0.6647727	3.521222576	0.087168174	1.306938543	0.8688171	14
151.78	157.63		5.85								14

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2L/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
157.63	175.2	23.42		17.57	197.6378	0.7502135	2.680478727	0.071131997	1.190667804	0.893255052	14
175.2	181		5.8								14
181	477.38										Open
									Geo. Mean	0.458876	

Table 49:- Kozeny correction factor for WF01-PW18(10)

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1524										
Interval(m)		Length (m)	Length (m)		2L/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
0	24.3		24.3								23
1	57		58								12
57	87	112.3		30	393.70079	0.2671416	6.393298997	0.050398413	1.322212121	0.3532178	12
87	93		6								12
93	123	36		30	393.70079	0.8333333	1.816219873	0.050398413	1.091534599	0.9096122	12
									Geo. Mean	0.566826	

Table 50:- Kozeny correction factor for WF01-PW19

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778										
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
1	125.95		126.95								14"
125.95	150.15	151.11		24.16	271.7660292	0.159883529	6.780621933	0.060660001	1.411312535	0.22564563	14"
150.15	156.14		6.03								14"
156.14	174.25	24.14		18.11	203.712036	0.750207125	2.680543374	0.070063472	1.187808176	0.89110216	14"
174.25	180.3		6.05								14"
180.3	198.36	24.1		18.06	203.1496063	0.749377593	2.688962746	0.070160392	1.188658681	0.89075418	14"
198.36	204		6.04								14"
204	501										open
									Geo. Mean	0.5637	

Table 51:-Kozeny correction factor for WF01-PW20

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778		r'=	0.1016							
Interval(m)		Length (m)	Length (m)		2l/r	L/b	(7cos(3.14L/2b))	SQRT(r/2L)	(1+Mult Col.(H*I))	F	Dia. of Casing
From	To	b	Blind	Screen							
1	114.16		115.16								14"
114.16	126.19	127.19		12.03	135.3205849	0.094582907	6.922963867	0.085964287	1.595127655	0.150871811	14"
126.19	132.22		6.03								14"
132.22	156.3	30.11		24.08	270.8661417	0.799734308	6.931928436	0.060760682	1.421188699	1.13657336	14"
156.3	162.34		6.04								14"
162.34	186.43	30.13		24.09	270.9786277	0.799535347	2.172214715	0.060748069	1.13195785	0.905040312	14"
186.43	203.23		17.30								14"

A	B	C	D	E	F	G	H	I	J	K	L
r=	0.1778		**r'=**	0.1016							
Interval(m)		**Length (m)**	**Length (m)**		**2l/r**	**L/b**	**(7cos(3.14L/2b))**	**SQRT(r/2L)**	**(1+Mult Col.(H*I))**	**F**	**Dia. of Casing**
203.23	203.76		0.53								Telescopic
203.76	209.53		5.77								8"
209.53	215.27	29.34		5.74	112.992126	0.195637355	6.672392457	0.12445001	1.830379305	0.358090566	8"
215.27	221.06		5.79								8"
221.06	232.58	17.31		11.52	226.7716535	0.665511265	3.514205353	0.087846536	1.308710767	0.870961758	8"
232.58	255.55		22.97								8"
255.55	267.06	34.48		11.51	226.5748031	0.0508	6.060450007	0.087884689	1.532620762	0.077857135	8"
267.06	278.58		11.52								8"
278.58	290.11	23.05		11.53	226.9685039	0.0508	4.950032563	0.087808433	1.434654603	0.072880454	8"
290.11	307.39		17.28								8"
307.39	318.9	28.79		11.51	226.5748031	0.0508	5.665774624	0.087884689	1.497934839	0.07609509	8"
318.9	336.13		17.23								8"
336.13	347.66	28.76		11.53	226.9685039	0.0508	5.658586285	0.087808433	1.496871595	0.076041077	8"
347.66	359.18		11.52								8"
359.18	370.67	23.01		11.49	226.1811024	0.0508	4.956779181	0.087961143	1.436003964	0.072949001	8"
370.67	387.92		17.25								8"
387.92	399.42	28.75		11.50	226.3779528	0.0508	5.664429267	0.087922891	1.498032998	0.076100076	8"
399.42	416.66		17.24								8"
416.66	422.4	22.98		5.74	112.992126	0.0508	6.468604155	0.12445001	1.805017849	0.091694907	8"
422.4	433.89		11.49								8"
433.89	445.42	23.02		11.53	226.9685039	0.0508	4.944964358	0.087808433	1.434209571	0.072857846	8"
445.42	456.88		11.46								8"
456.88	468.4	22.98		11.52	226.7716535	0.0508	4.941566487	0.087846536	1.434099498	0.072852255	8"
468.4	479.93		11.53								8"
479.93	491.47	23.07		11.54	227.1653543	0.0508	4.950034024	0.087770379	1.434466365	0.072870891	8"
491.47	503.5		12.03								
									Geo. Mean	**0.537391963**	

➢ (from 203.76m-503.5m) radius of the casing used is r'=0.1016m

Appendix-3 Drawdown –Time Plots for Uncorrected and Corrected Drawdown

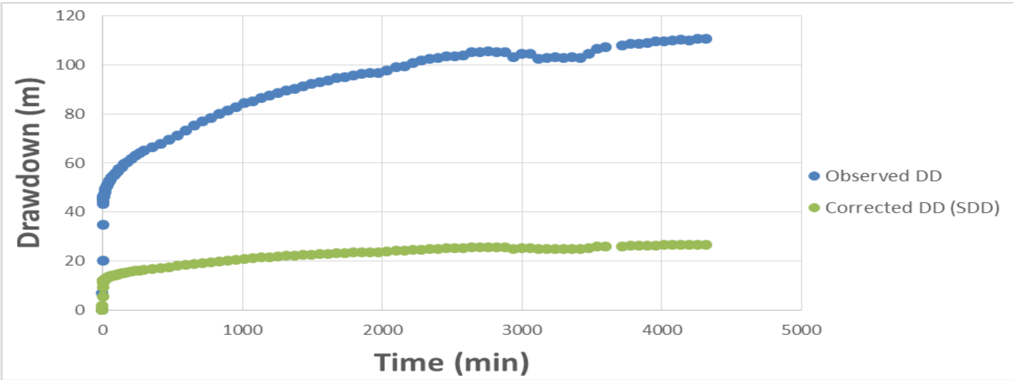


Figure 26:-.Plot for observed and corrected drawdown for WF01-PW05

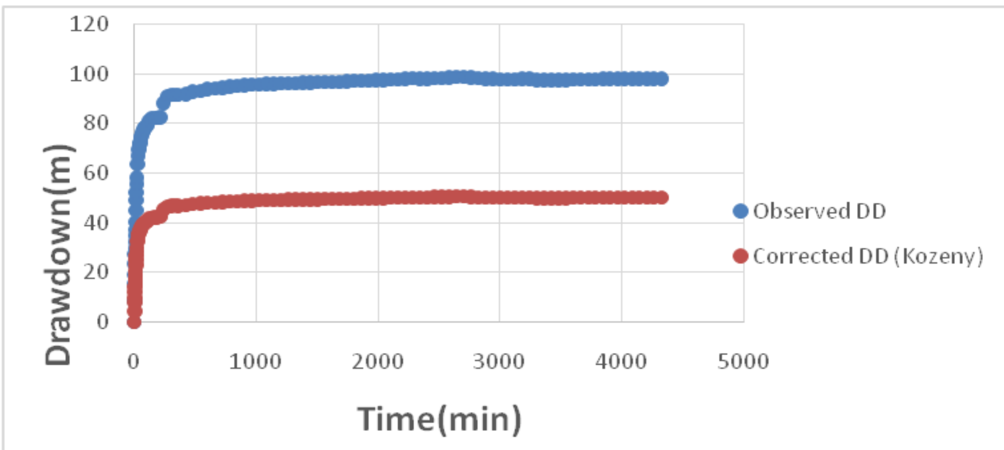


Figure 27:-Plot for observed and corrected drawdown for WF01-PW07

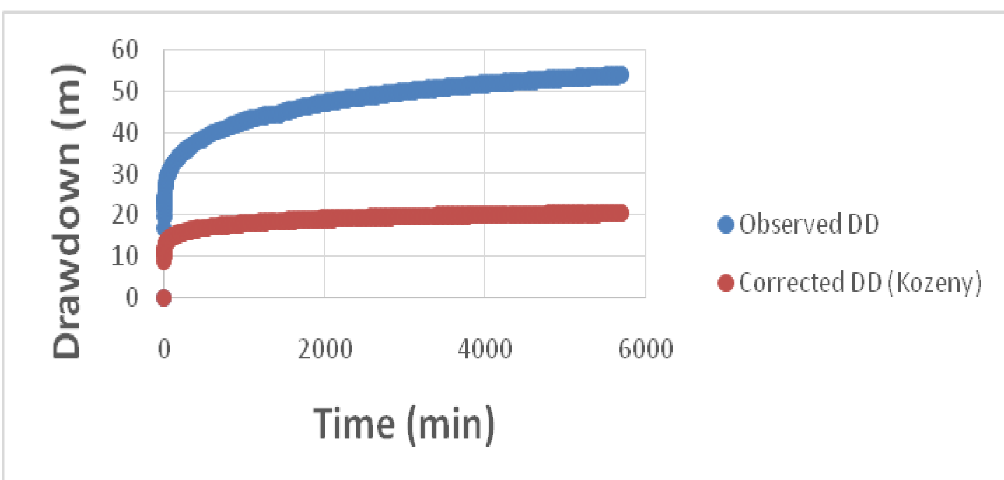


Figure 28:-.Plot for observed and corrected drawdown for WF01-PW11

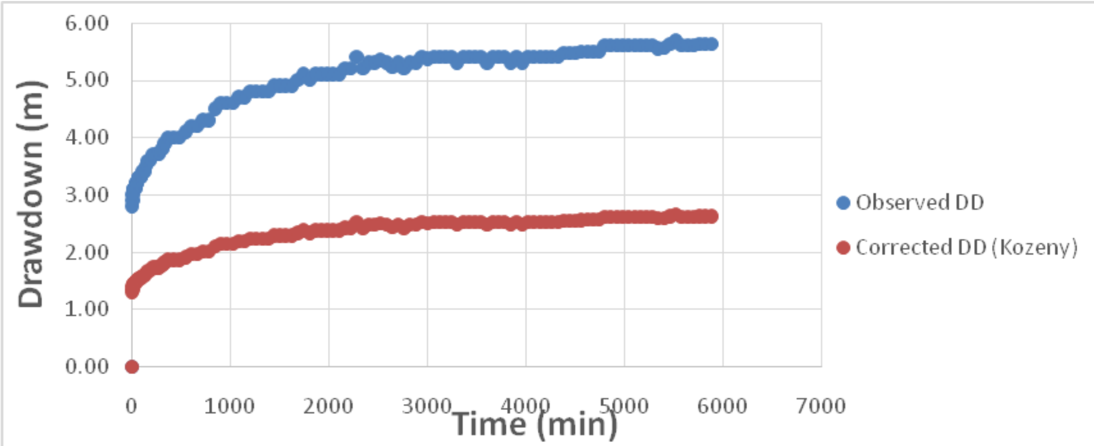


Figure 29:-Plot for observed and corrected drawdown for WF01-PW12

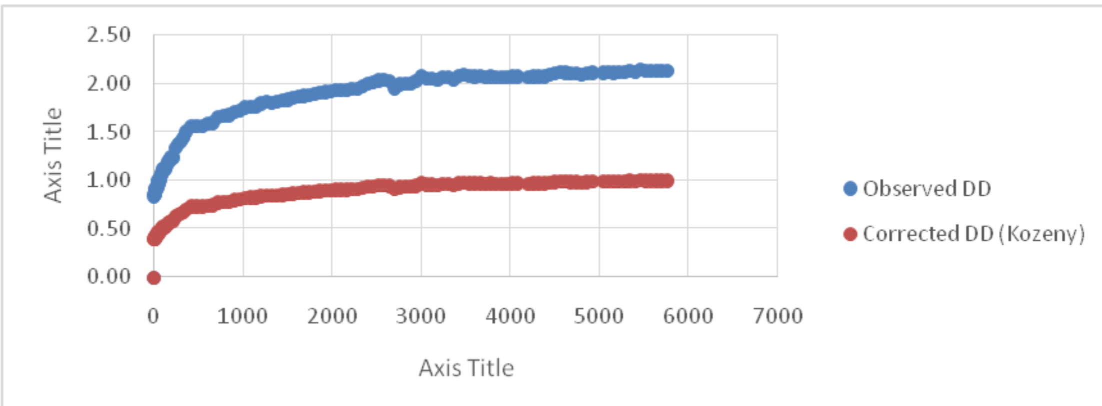


Figure 30:-.Plot for observed and corrected drawdown for WF01-PW14

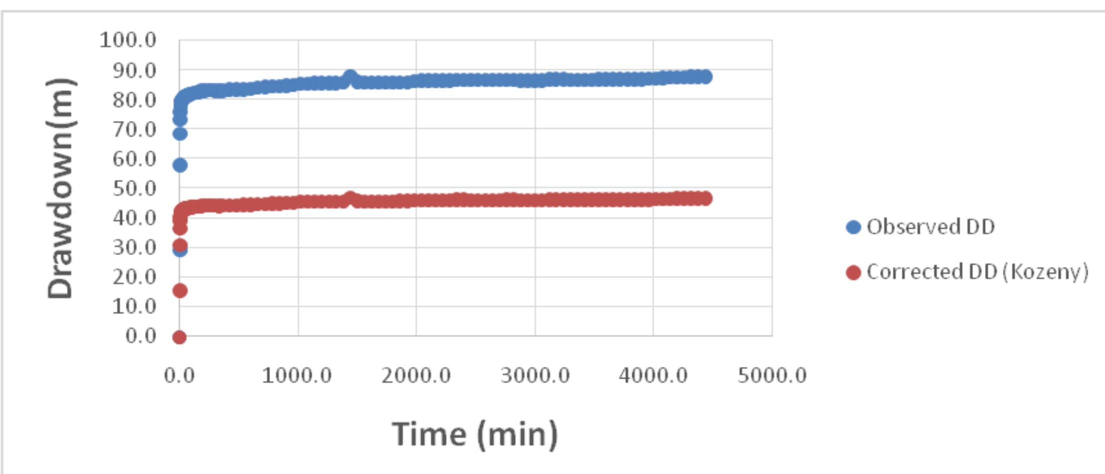


Figure 31:- Plot for observed and corrected drawdown for WF01-PW15

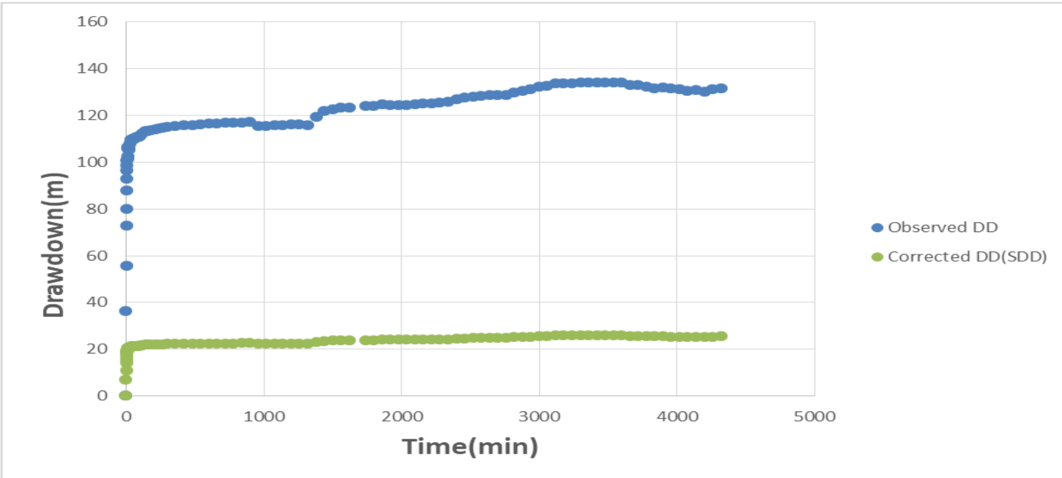


Figure 32:-.Plot for observed and corrected drawdown for WF01-PW16

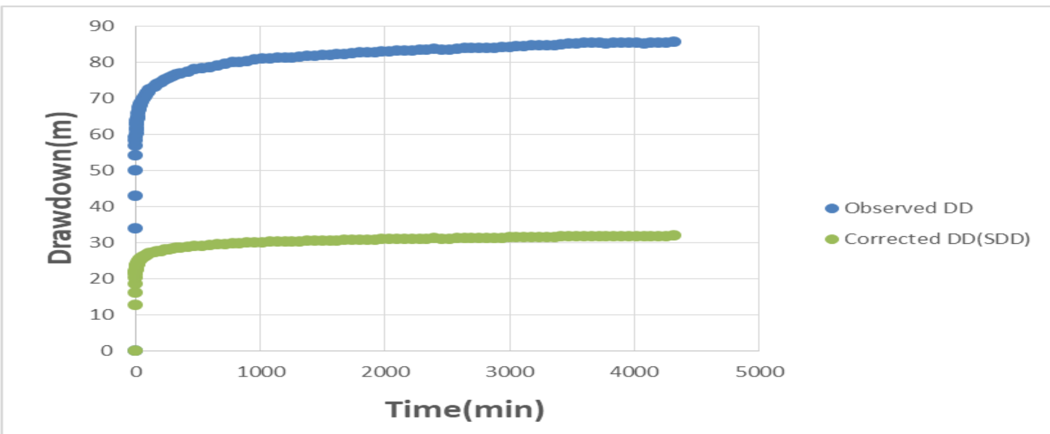


Figure 33:-Plot for observed and corrected drawdown for WF01-PW17

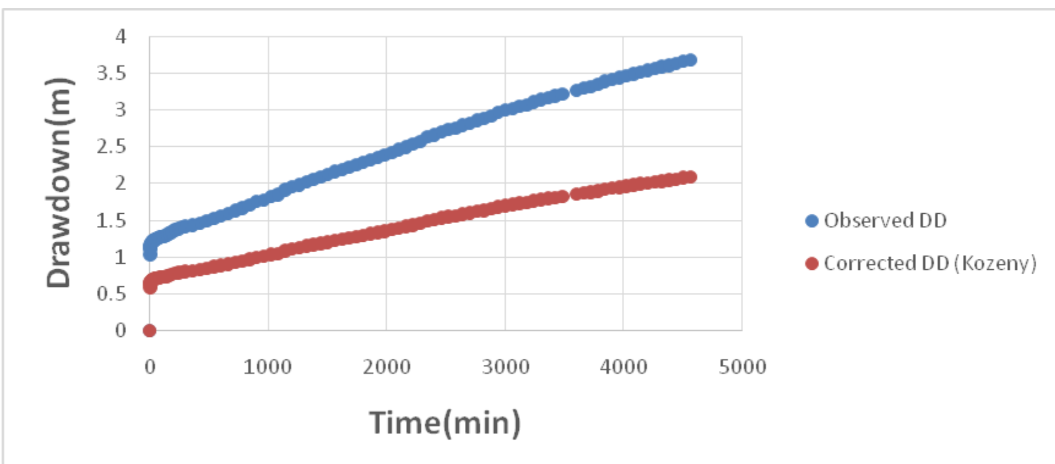


Figure 34:-.Plot for observed and corrected drawdown for WF01-18(10)

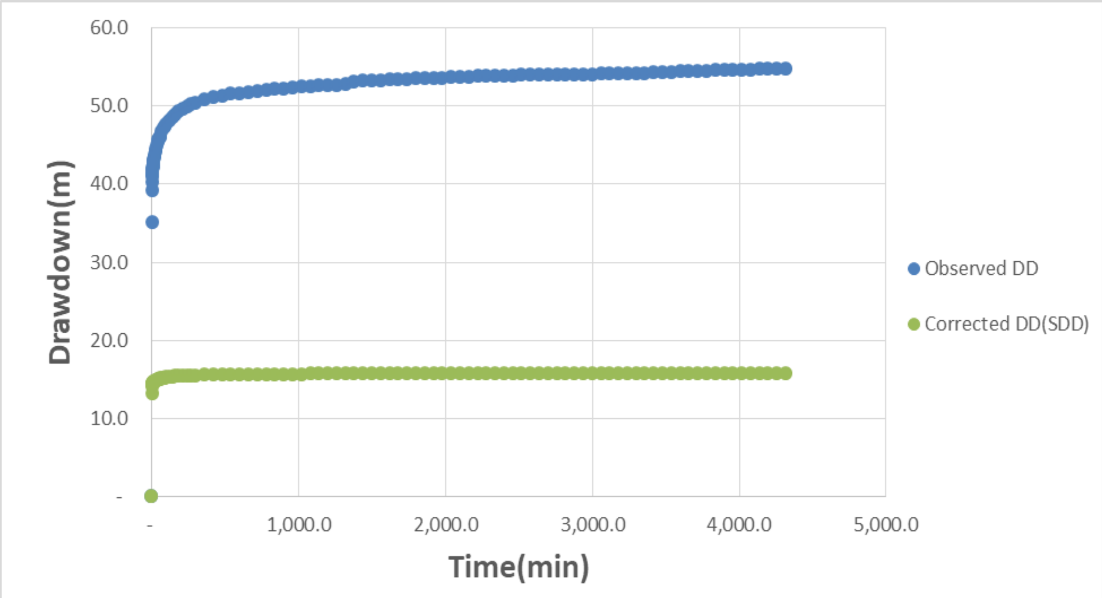


Figure 35:-. Plot for observed and corrected drawdown for WF01-PW19

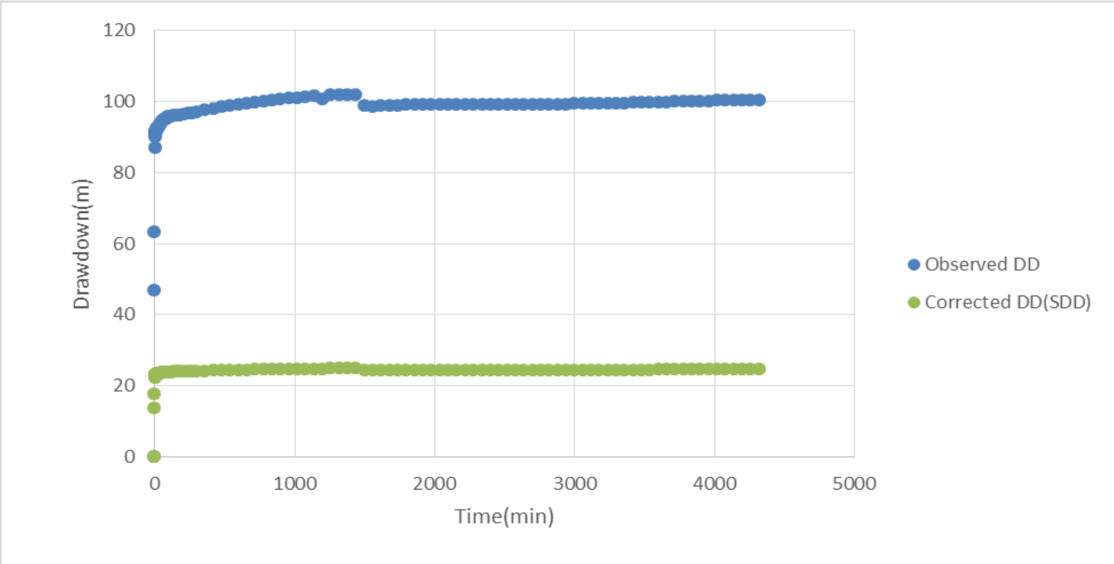
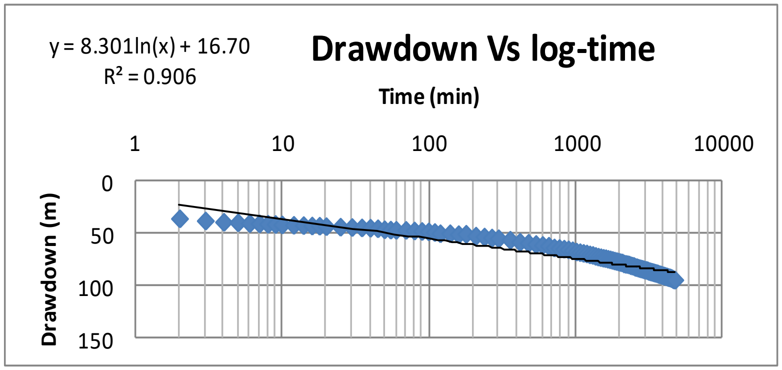


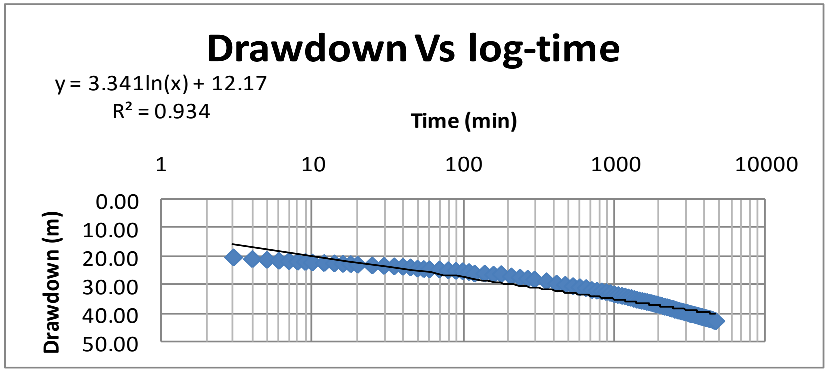
Figure 36:-Plot for observed and corrected drawdown for WF01-PW20

Appendix-4 Best Fit line for Cooper-Jacob method

a) observed Drawdown



b) Corrected Drawdown (Kozeny Factor)



c)Corrected Drawdown (SDD)

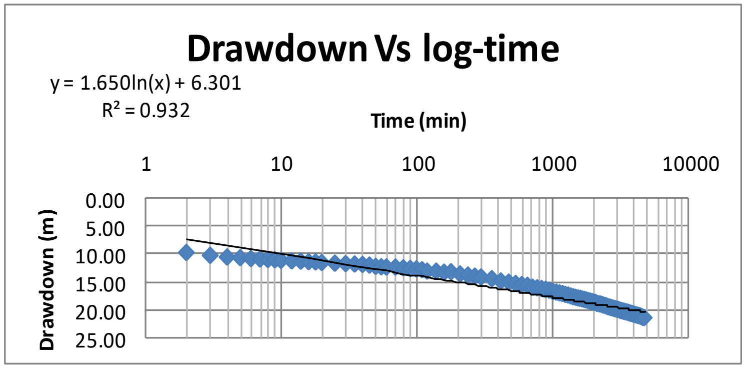
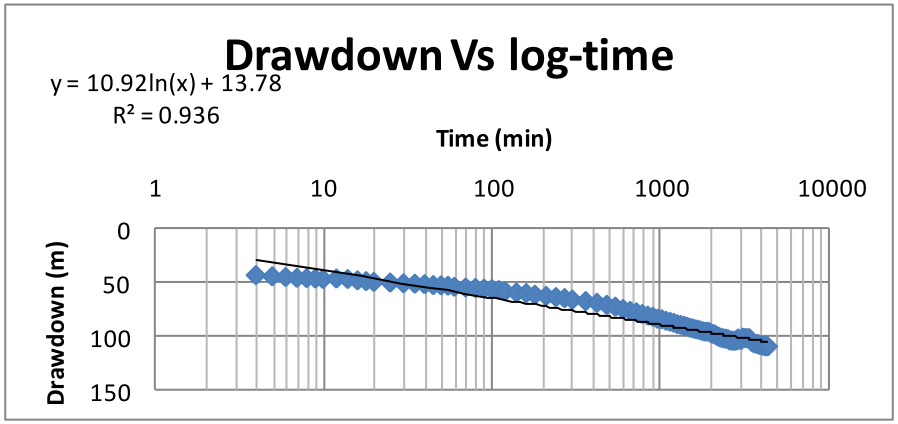
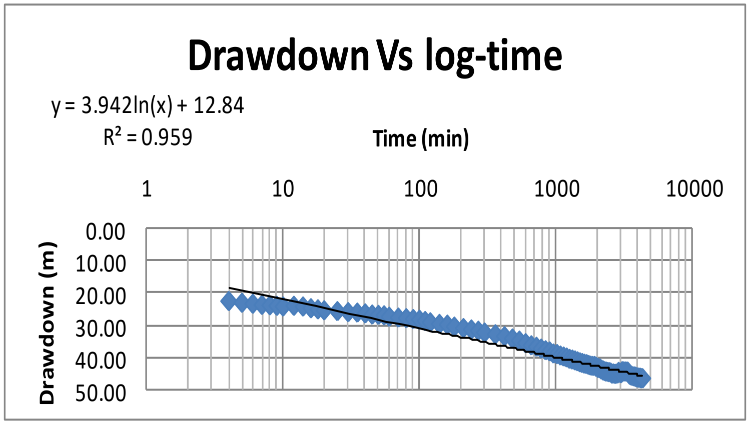


Figure 37:- Best fit line for (a,b,c) for WF01-PW04

d) Observed Drawdown



e) Corrected Drawdown (Kozeny Factor)



f)Corrected Drawdown (SDD)

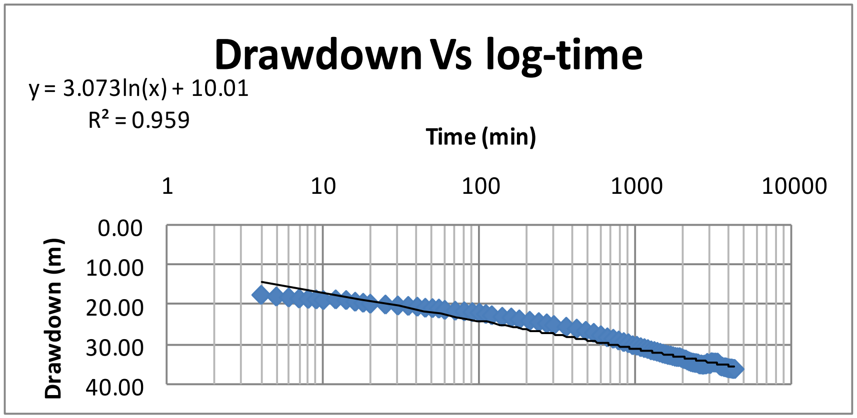
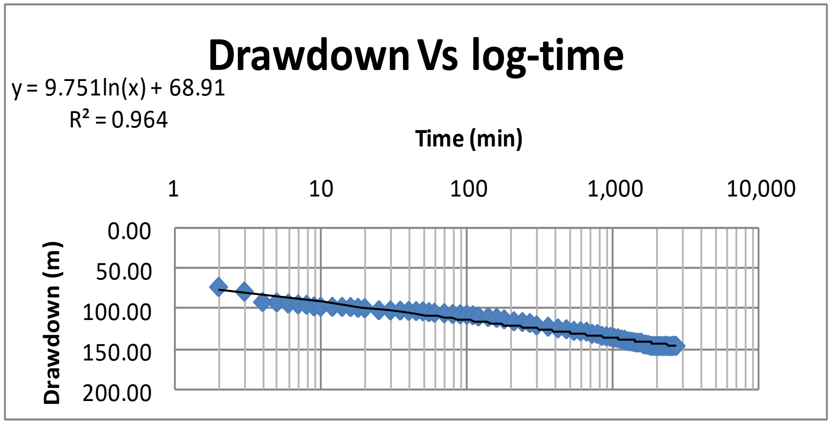
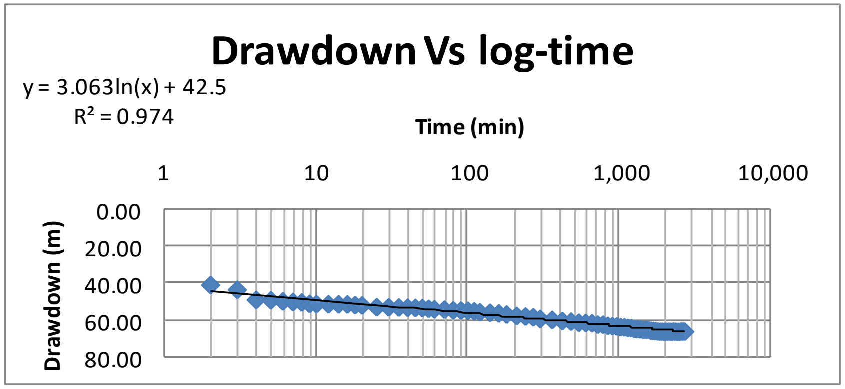


Figure 38:-. Best fit line for (d,e,f) for WF01-PW05

g) Observed Drawdown



h) Corrected Drawdown (Kozeny Factor)



i)Corrected Drawdown (SDD)

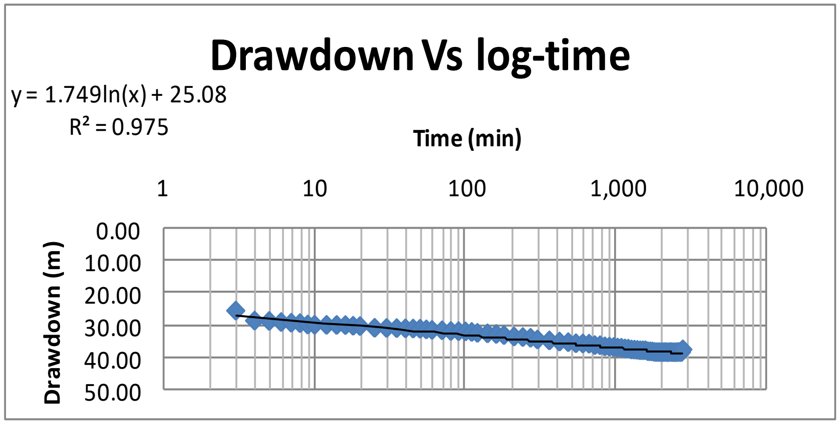
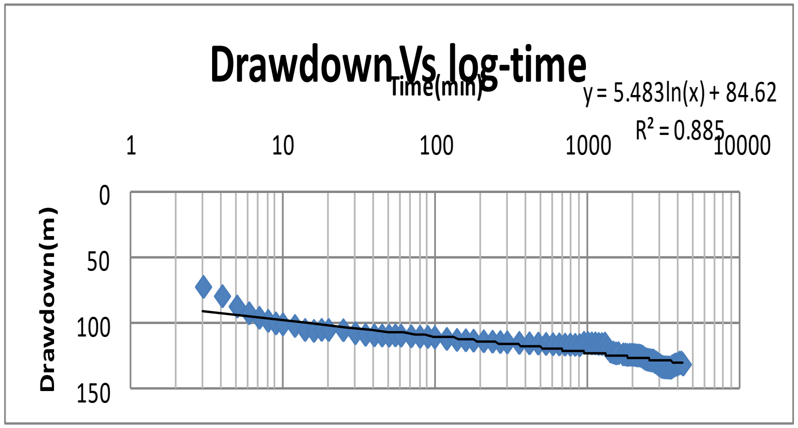
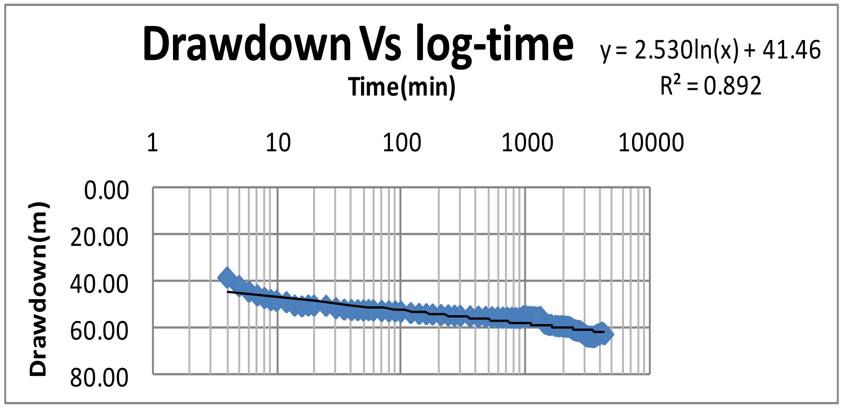


Figure 39:-. Best fit line for (g,h,i) for WF01-PW09

j) Observed Drawdown



k) Corrected Drawdown (Kozeny Factor)



l) Corrected Drawdown (SDD)

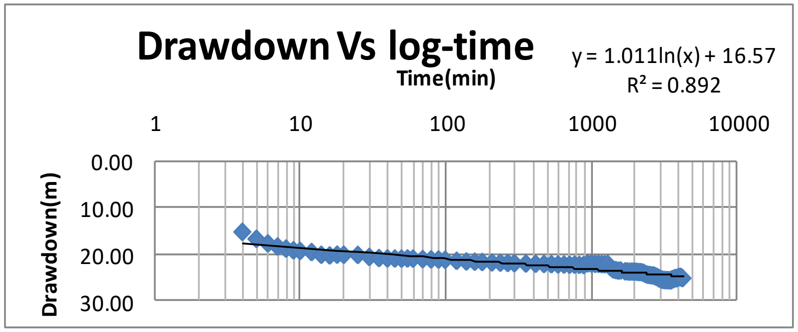
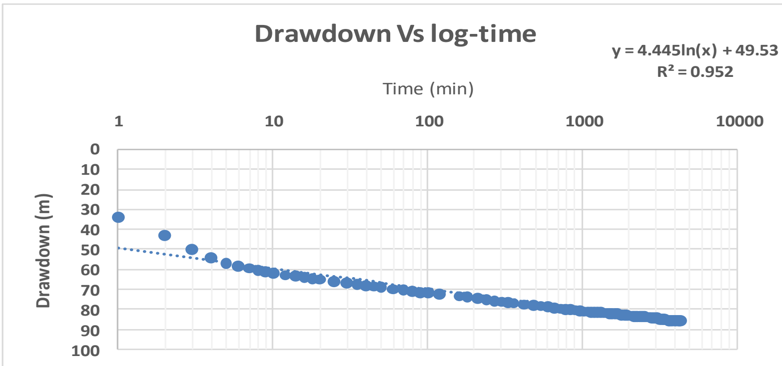
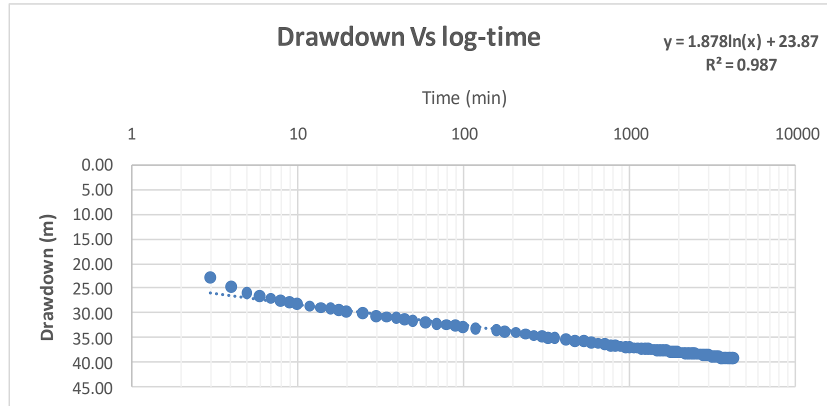


Figure 40:-. Best fit line for (j,k,l) for WF01-PW16

m) Observed Drawdown



n) Corrected Drawdown (Kozeny Factor)



o) Corrected Drawdown (SDD)

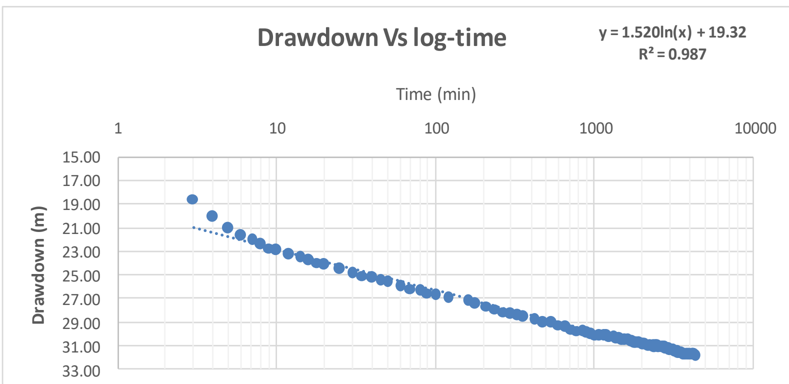
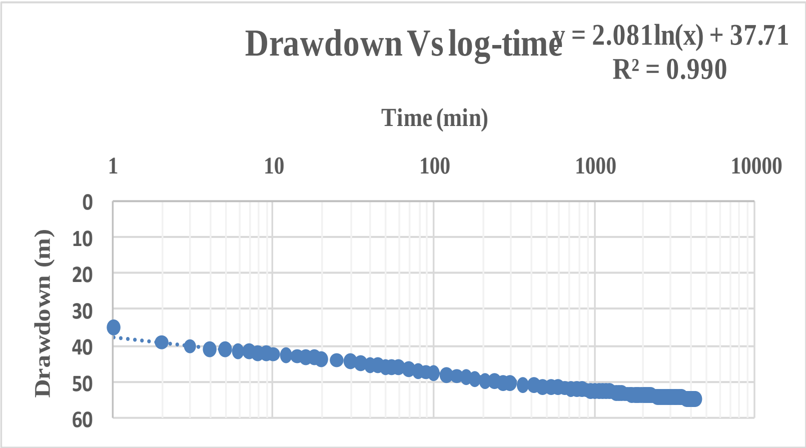
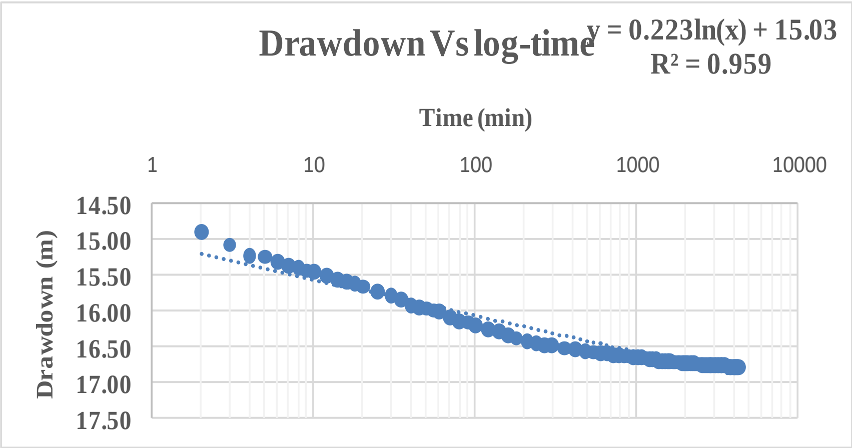


Figure 41:- Best fit line for (m, n,o) for WF01-PW17

p) Observed Drawdown



q) Corrected Drawdown (Kozeny Factor)



r) Corrected Drawdown (SDD)

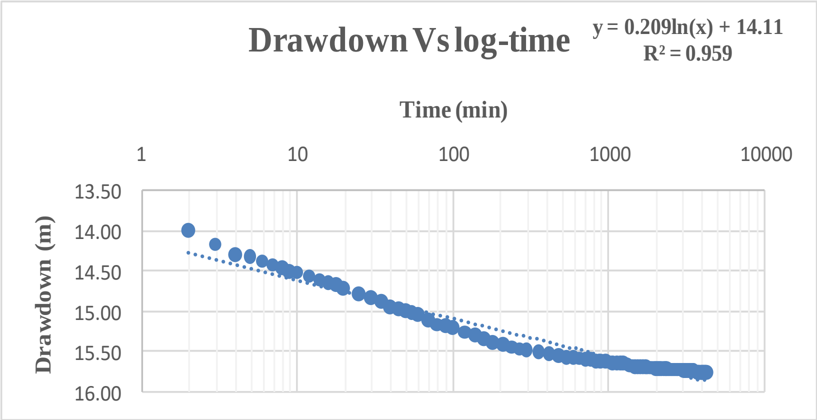
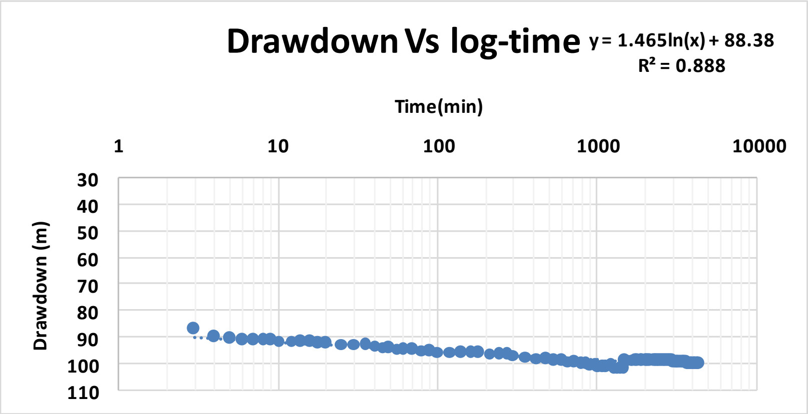
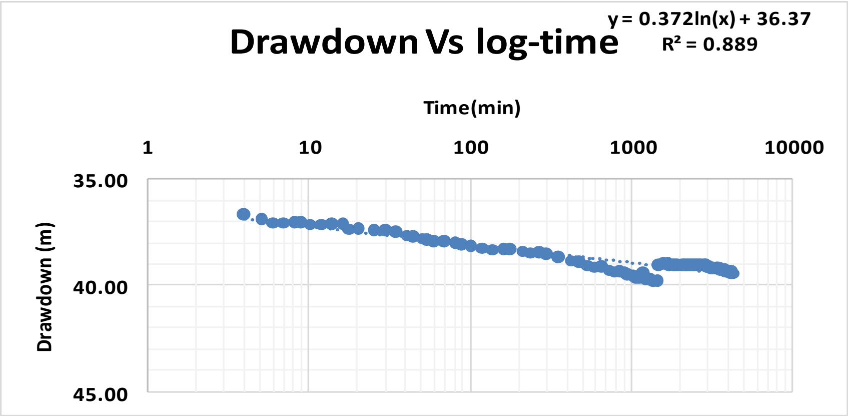


Figure 42:-. Best fit line for (p,q,r) for WF01-PW19

s) Observed Drawdown



t) Corrected Drawdown (Kozeny Factor)



u) Corrected Drawdown (SDD)

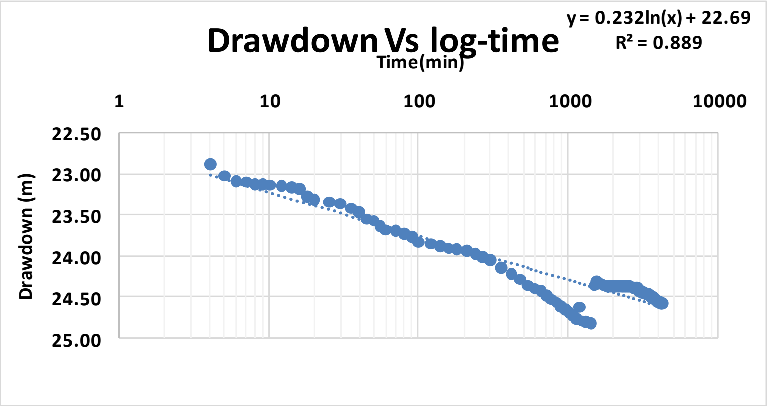
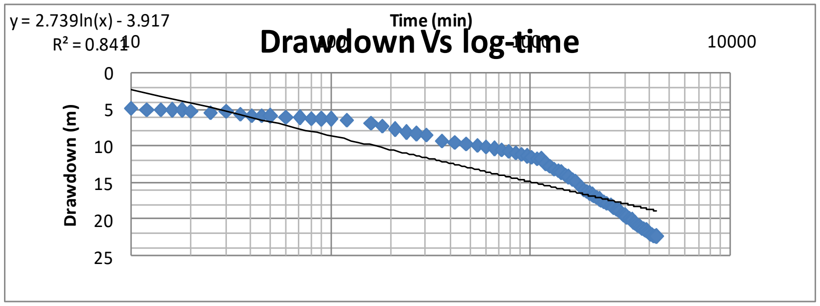


Figure 43:- Best fit line for (s,t,u) for WF01-PW20

v) Observed Drawdown



w) Corrected Drawdown (Kozeny Factor)

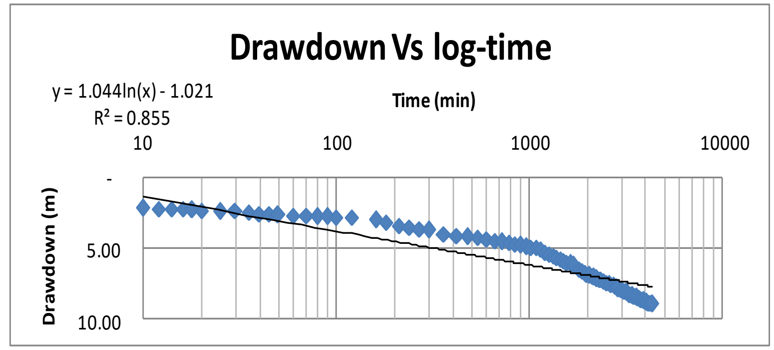
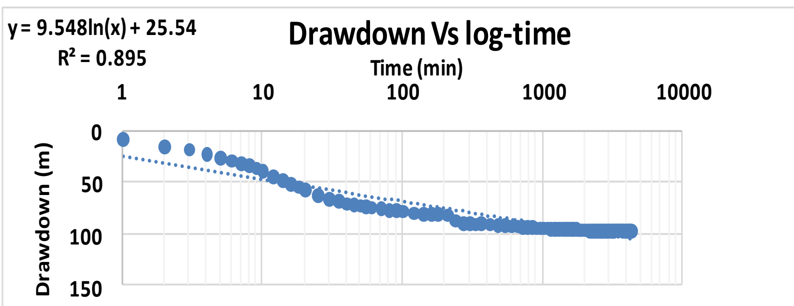


Figure 44:- Best fit line for (v,w) for WF01-PW06

x) Observed Drawdown



y) Corrected Drawdown (Kozeny Factor)

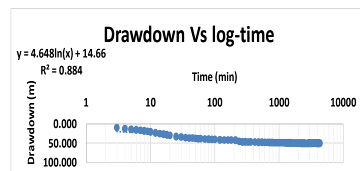
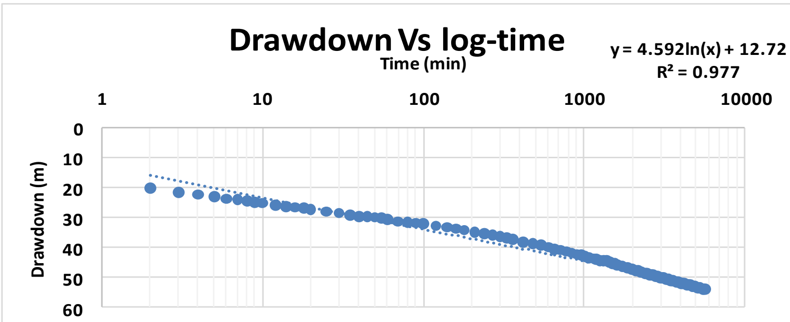


Figure 45:-. Best fit line for (x,y) for WF01-PW07

z) Observed Drawdown



a') Corrected Drawdown (Kozeny Factor)

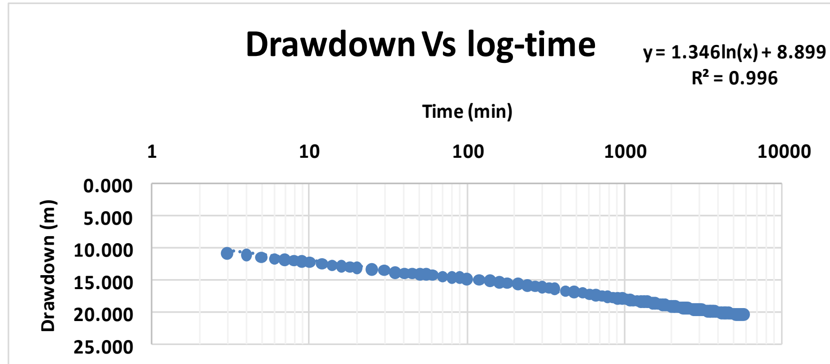
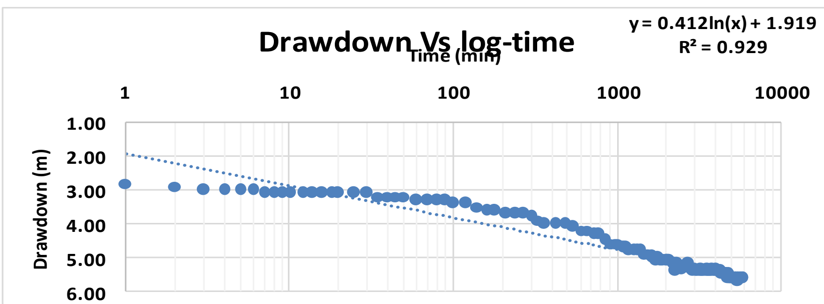


Figure 46:- Best fit line for (z,a') for WF01-PW11

b') Observed Drawdown



c') Corrected Drawdown (Kozeny Factor)

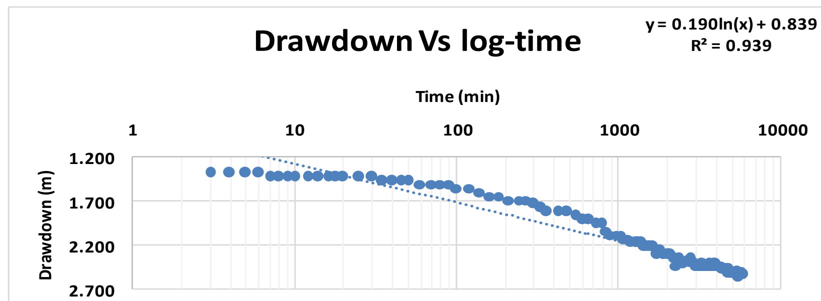
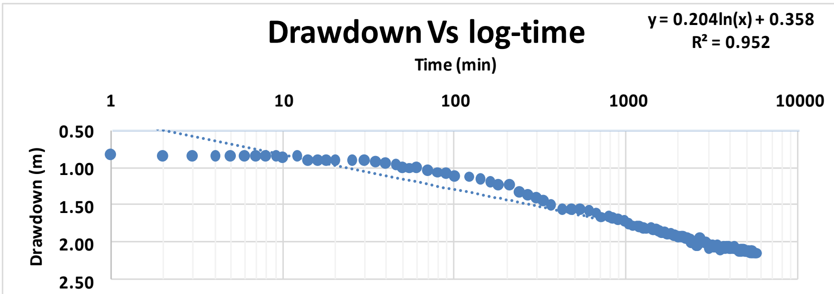


Figure 47:- Best fit line for (b',c') for WF01-PW12

d') Observed Drawdown



e') Corrected Drawdown (Kozeny Factor)

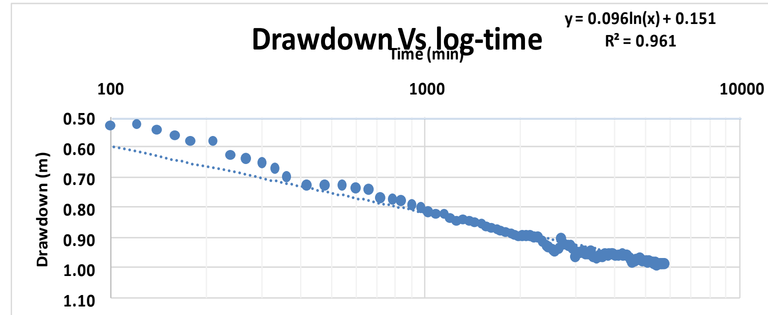
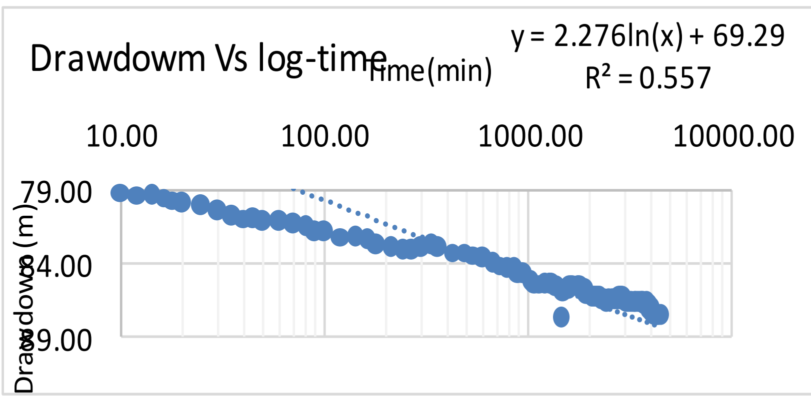


Figure 48:- Best fit line for (d',e') for WF01-PW14

f') Observed Drawdown



g') Corrected Drawdown (Kozeny Factor)

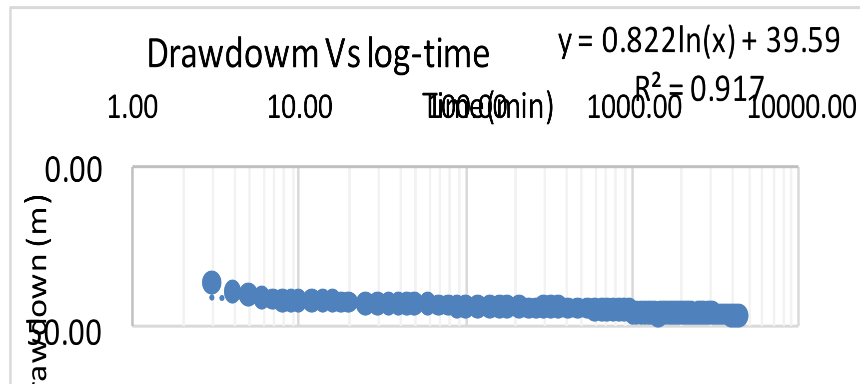
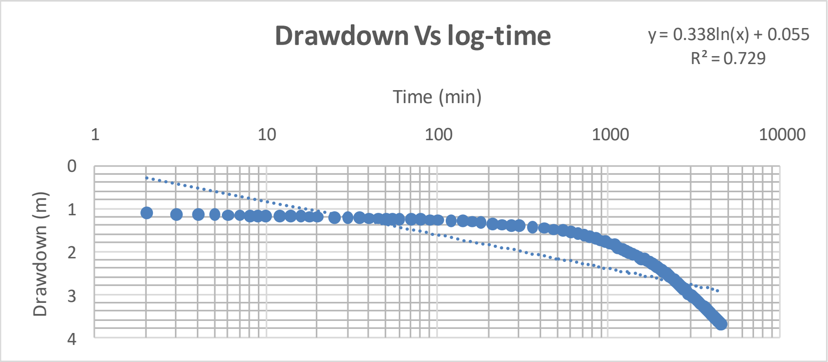


Figure 49:- Best fit line for (f',g') for WF01-PW15

h') Observed Drawdown



i') Corrected Drawdown (Kozeny Factor)

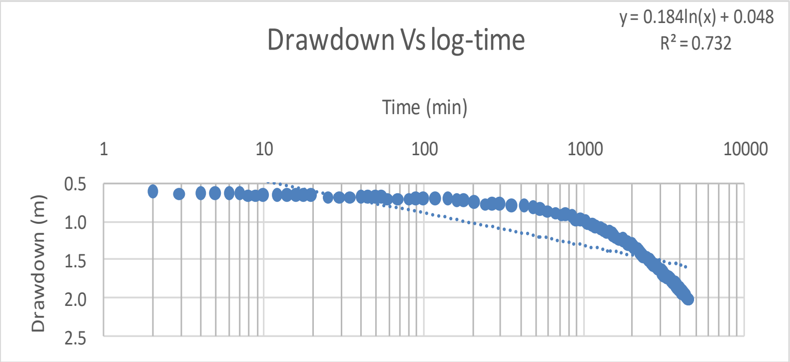
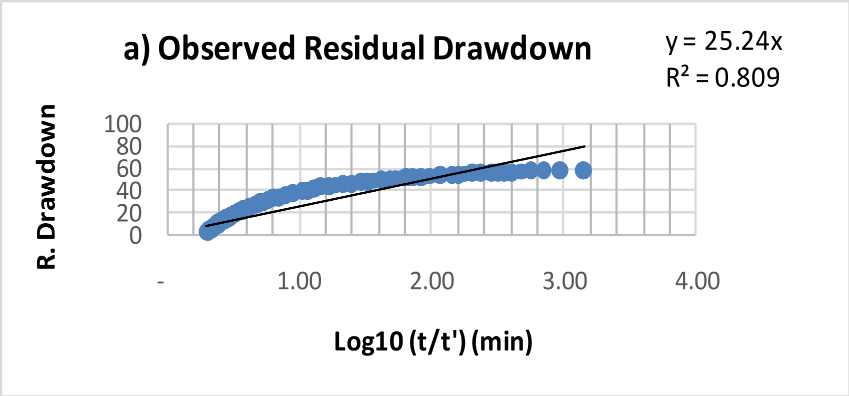
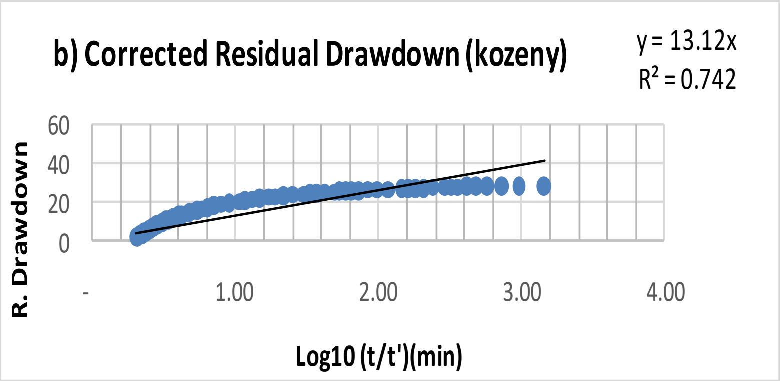


Figure 50:-. Best fit line for (h',i') for WF01-PW18(10)

Appendix-5 Best Fit line for Residual Drawdown





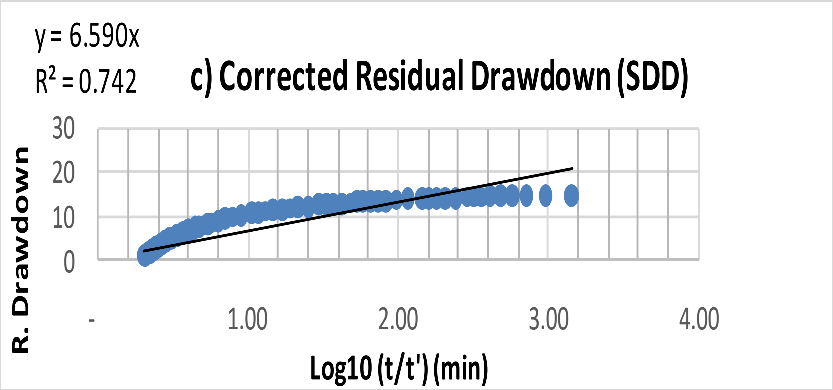


Figure 51:- Residual Drawdown plot for WF01-PW04

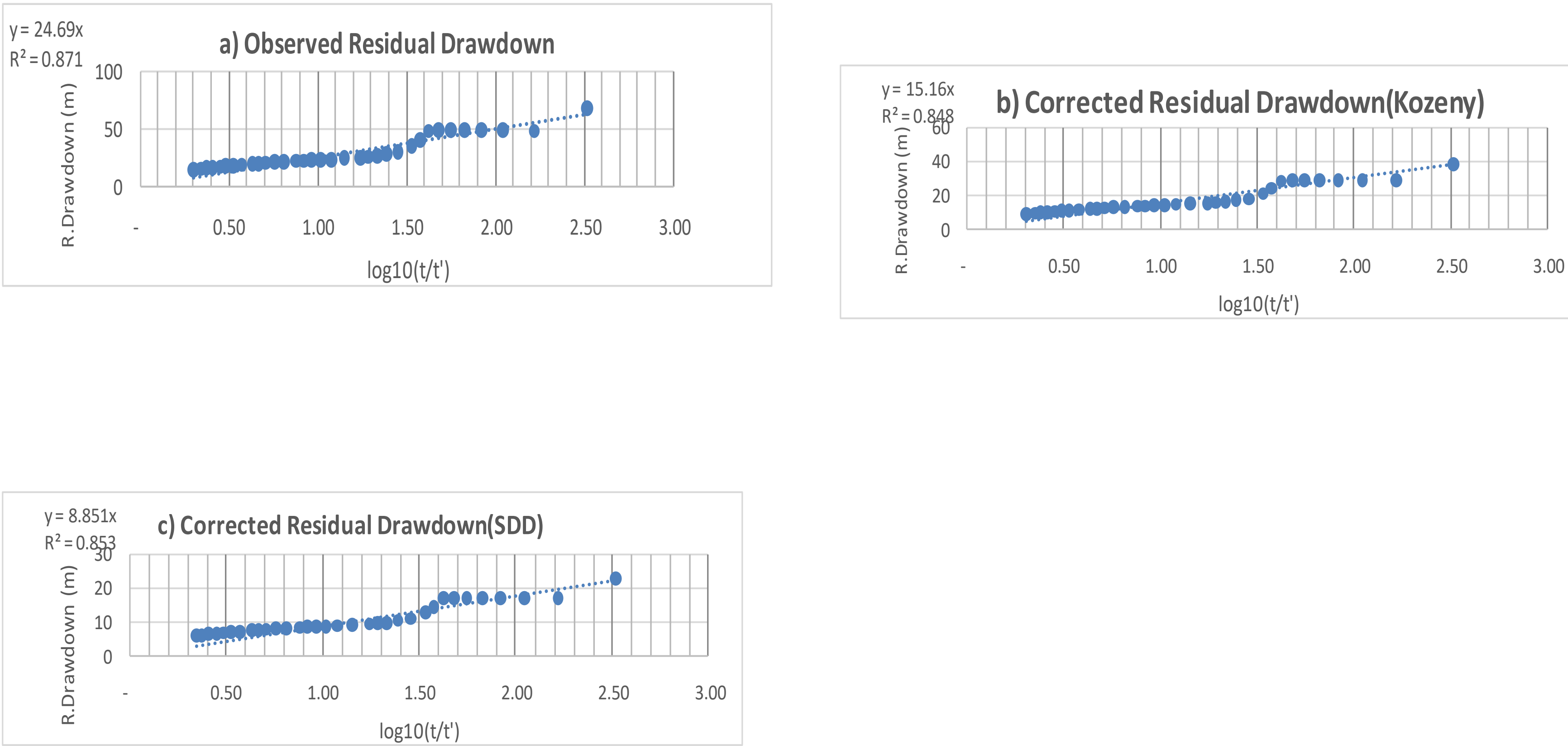


Figure 52:- Residual Drawdown plot for WF01-PW09

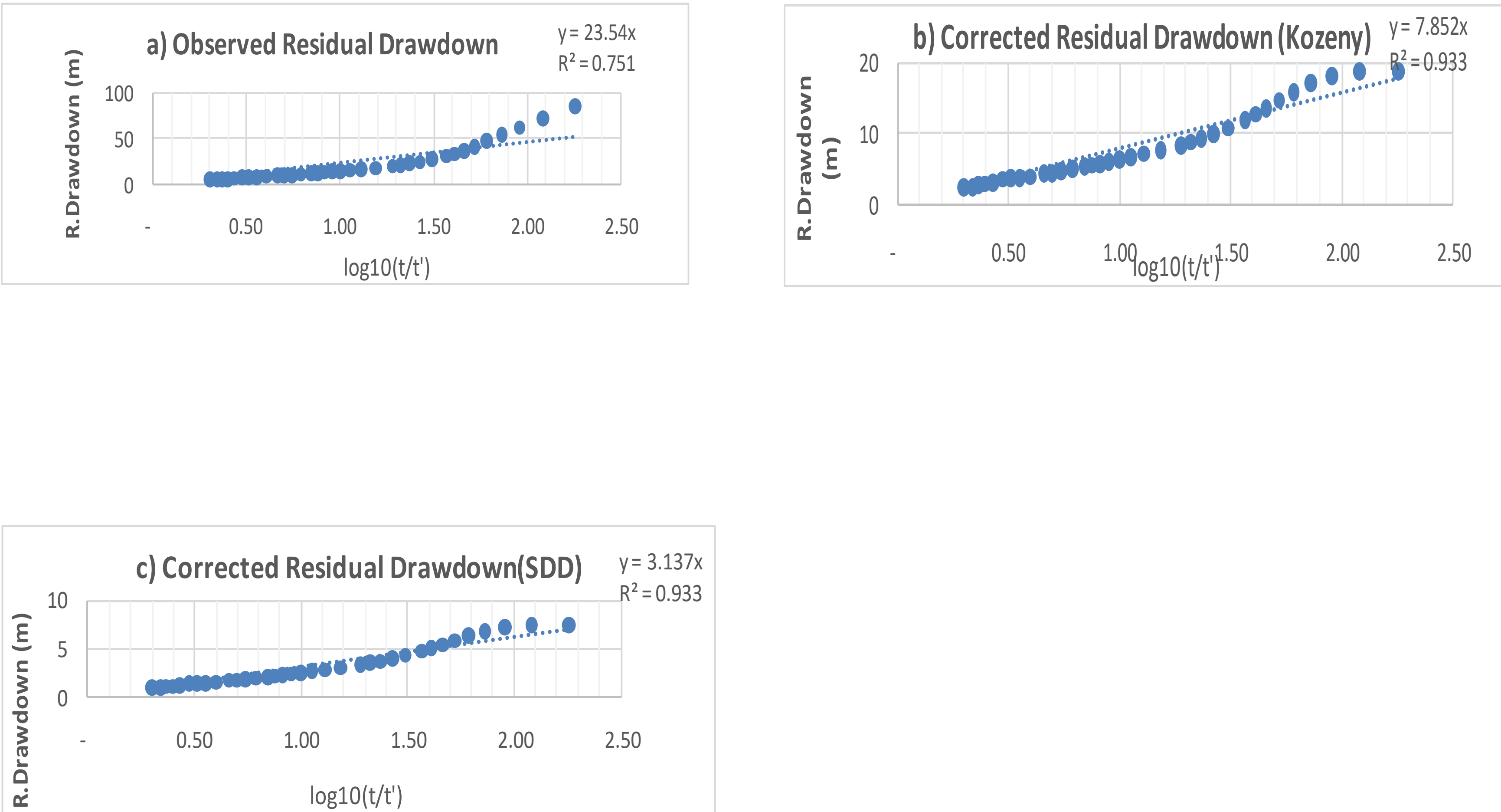
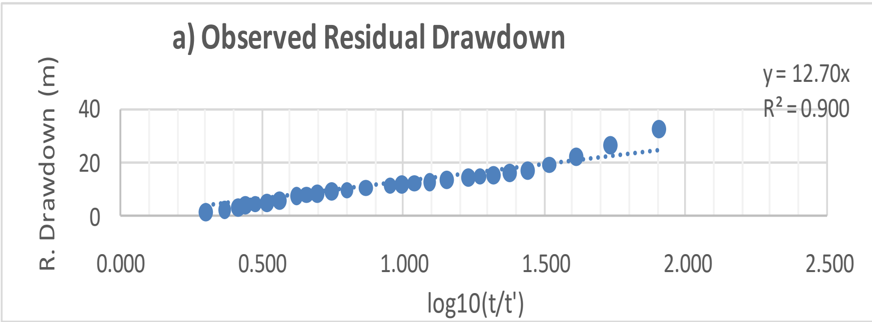
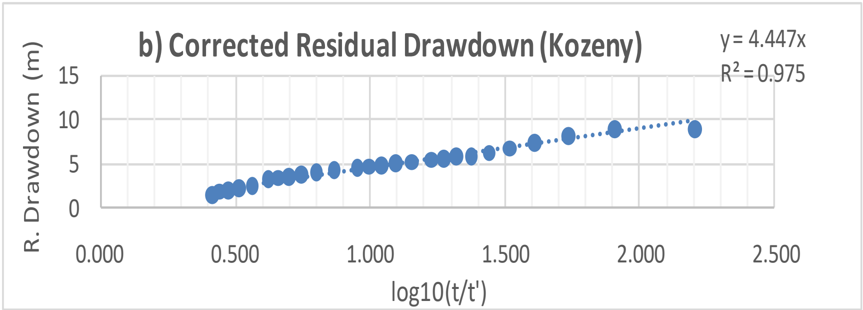


Figure 53:-Residual Drawdown plot for WF01-PW16





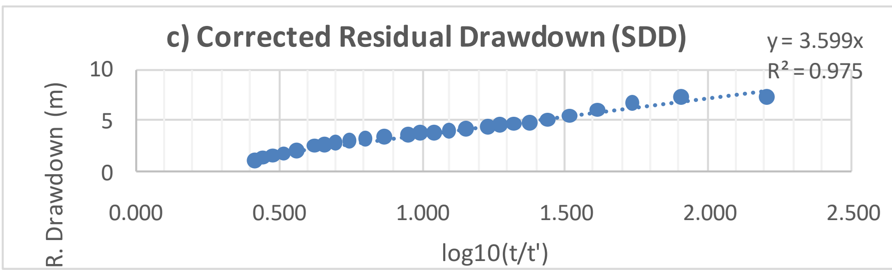


Figure 54:-. Residual Drawdown plot for WF01-PW17

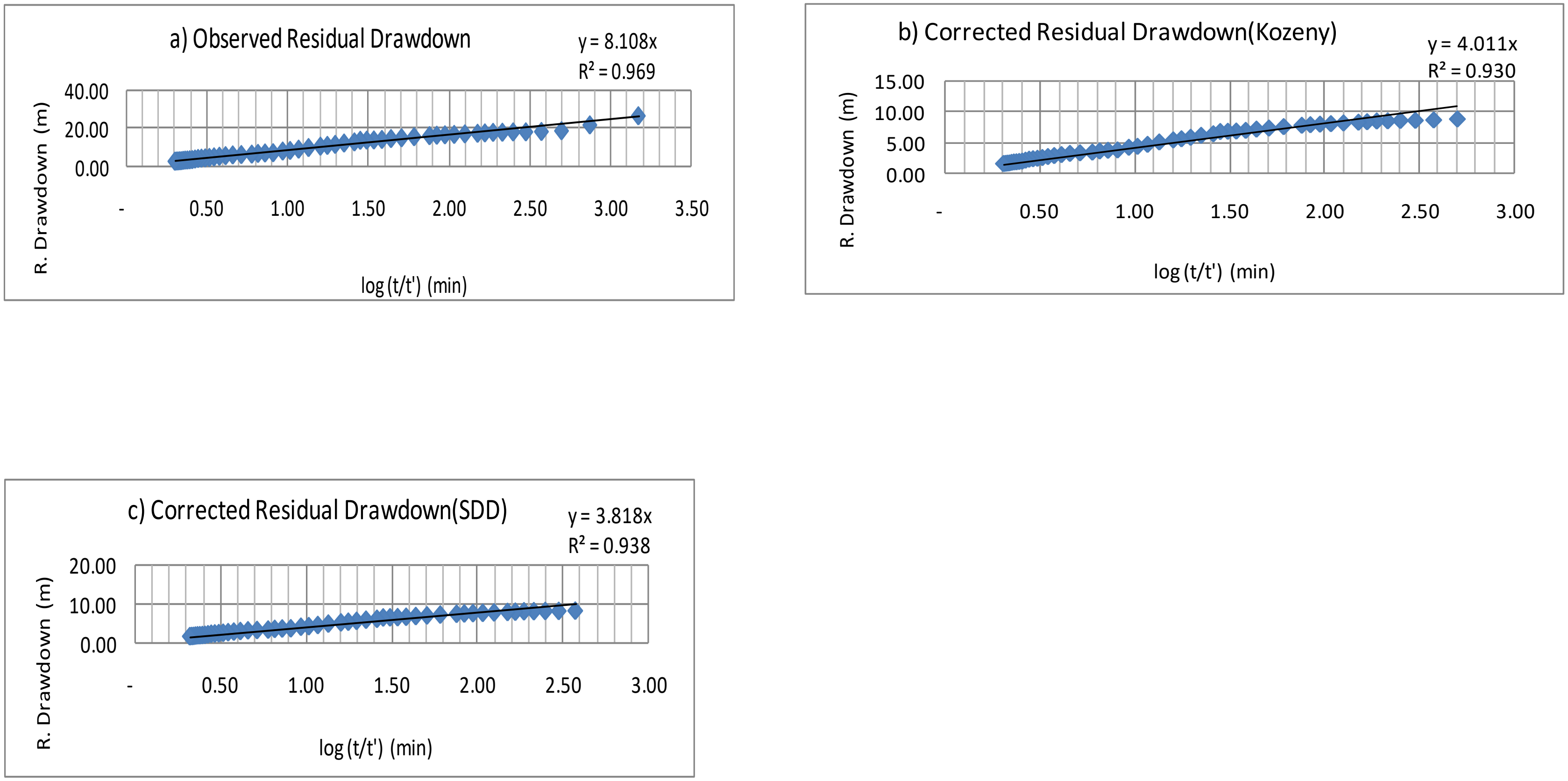


Figure 55:- Residual Drawdown plot for WF01-PW19

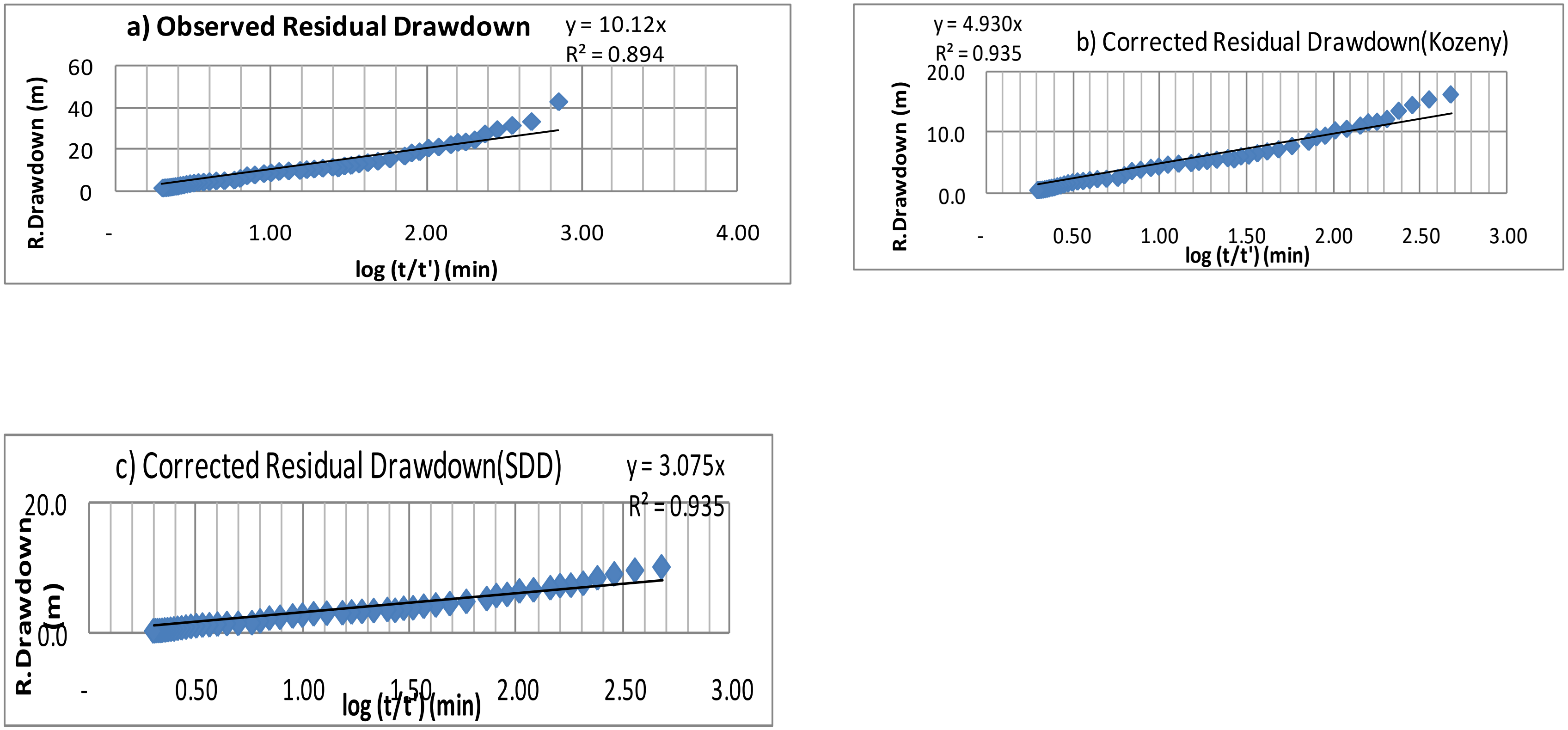


Figure 56:-. Residual Drawdown plot for WF01-PW20

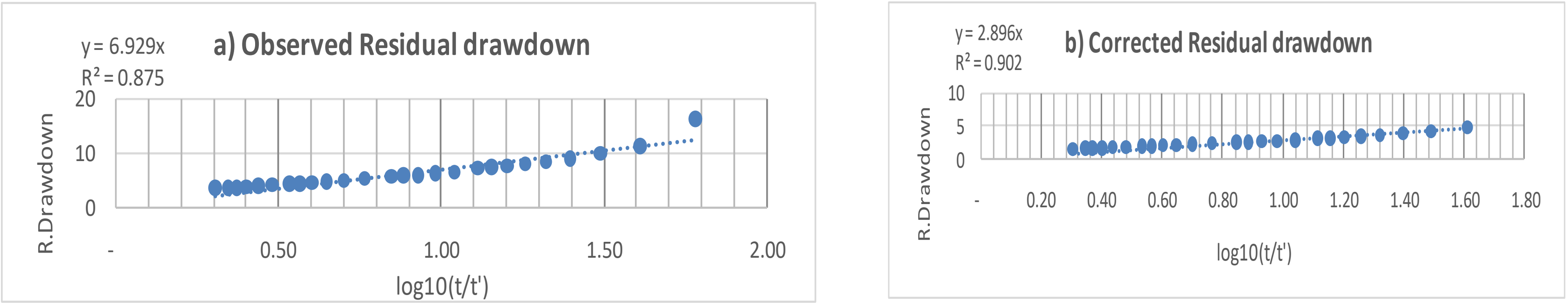


Figure 57:- Residual Drawdown plot for WF01-PW06

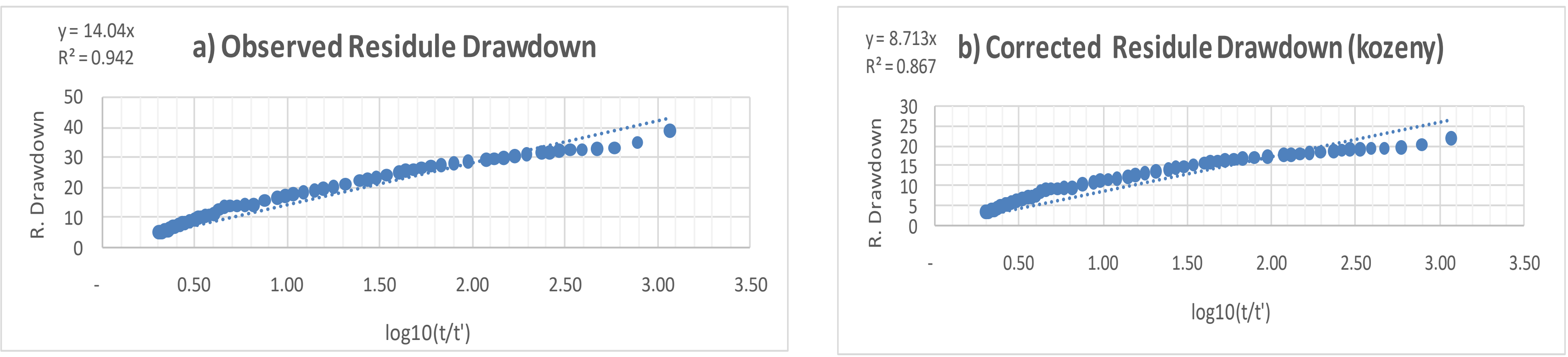


Figure 58:- Residual Drawdown plot for WF01-PW08

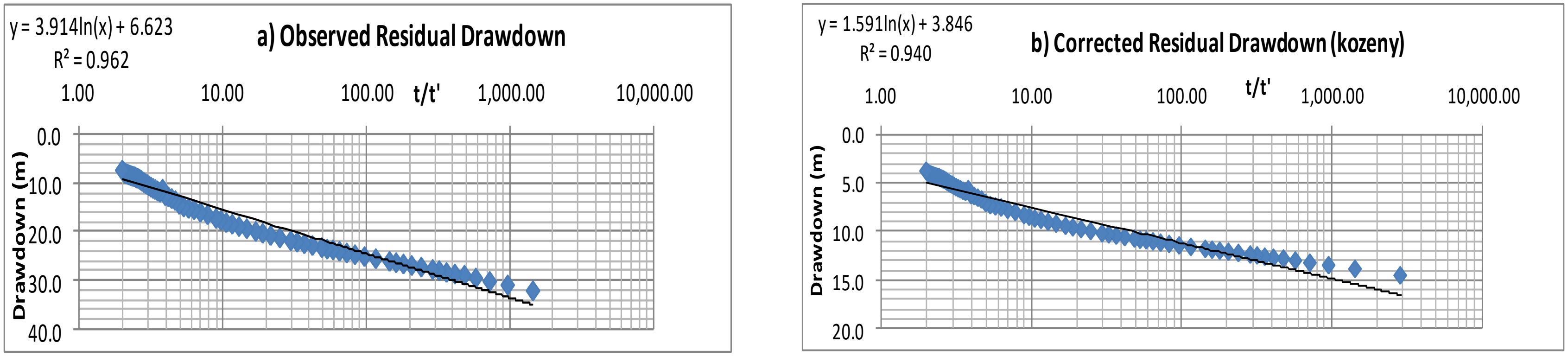


Figure 59:- Residual Drawdown plot for WF01-PW11

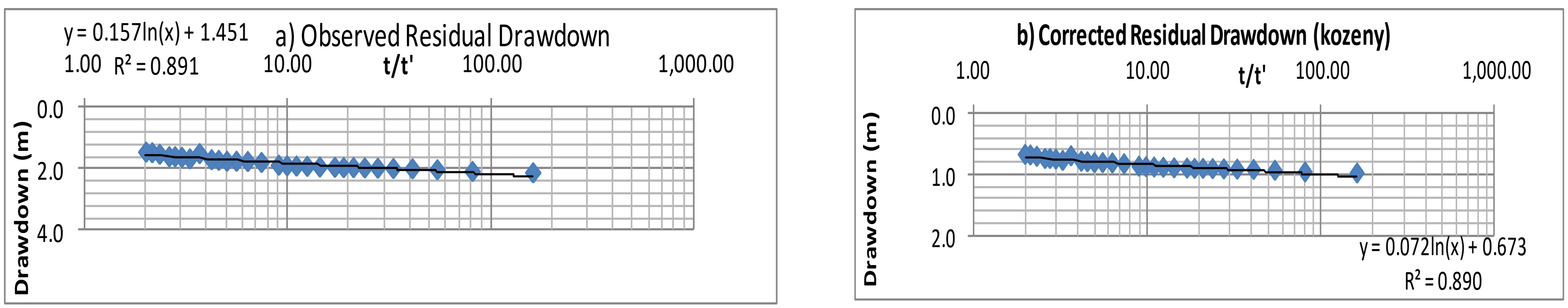


Figure 60:- Residual Drawdown plot for WF01-PW12

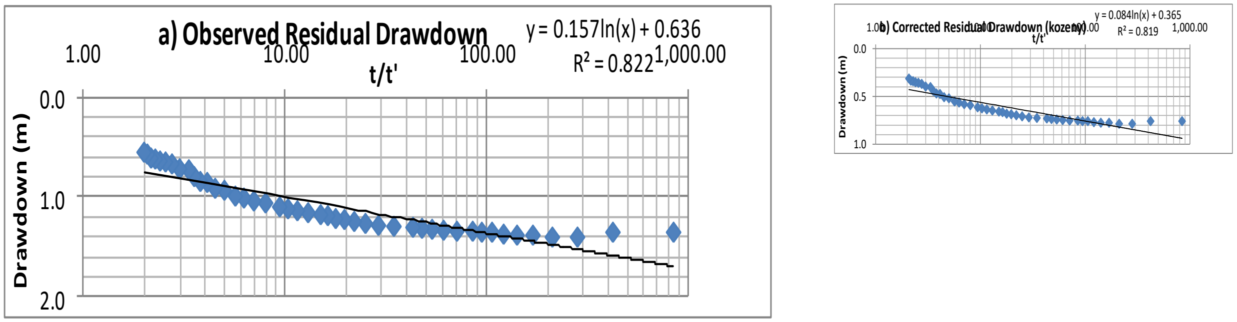


Figure 61:- Residual Drawdown plot for WF01-PW14

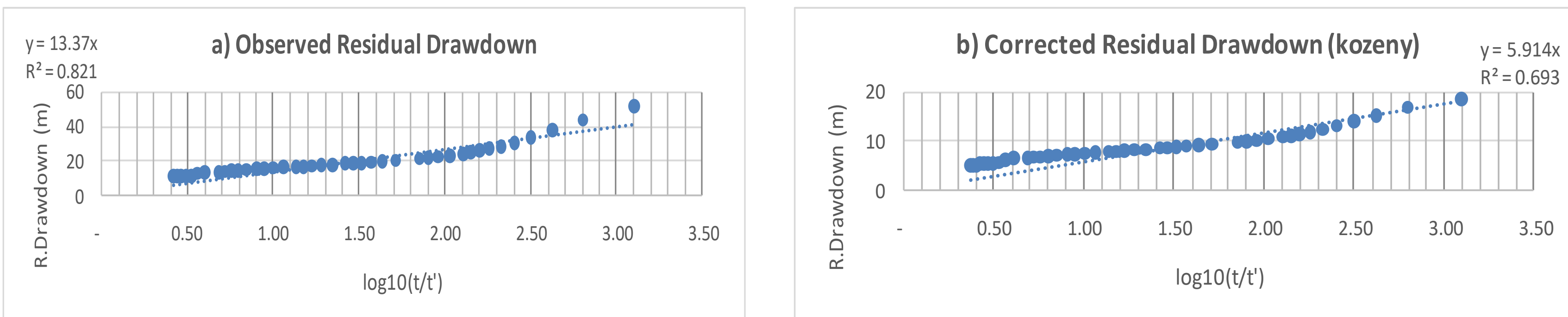


Figure 62:-Residual Drawdown plot for WF01-PW15

Purpose: objective 1

- to assess understand and compare the local and international GWM systems
- to assess the existence of regulatory policy groundwater extraction
- to Analyze the effect of excessive extraction of the groundwater

Appendix-6 Questionnaire Sample

Date__________________

A. Function ________________

B. Work place_________________

Objective 1:- To analyze and identify the effect of monitoring and regulation of groundwater extraction and analysis of its consistency

1. General

1.1 Is GW monitoring being conducted at national level ?

Yes ☐ No ☐

1.2 If yes, What is the objective of GW Monitoring

Management level[1] ☐ Technical level[2] ☐

1.3 If no, why?

Lack of logistics ☐

Lack of concern from top managers ☐

The value of monitoring is not known in the organization ☐

1.4 Is there any GW monitoring guideline/policy at national level ?

Yes ☐ No ☐

If Yes, Is it National guideline from MoWE ☐

International Guideline ☐

1.5 What is the focus of the GW monitoring (Choose relevant ones from the lists)?

Assessment ☐ Optimized Development ☐

Keep sustainability of the water supply ☐

Integrated water Management ☐

[1]developing groundwater resources for drinking water supply, optimization of crop production, protection of nature conservation areas, restoration of wetlands, dealing with claims concerning damage, etc

[2]to determine the directions of groundwater flow, to establish the areas of infiltration and seepage, to quantify the relation between groundwater and surface water, to feed the groundwater models, etc.

Purpose: Objective 1

- to assess if the GWM practice exists and its purpose
- to evaluate if all well field is covered by GWM
- to identify parameters Monitored
- to understand the GWM practices at field level
- to check if the data is systematically stored and analyzed
- to understand if the result of the analysis is used for performance evaluation and sustainable use of the well field
- to assess the findings of the GWM system

1.5.1 Is the GW monitoring?

Permanent ☐ Temporary ☐

1.6 Type of GW monitoring network and configuration

Primary[3] ☐ Secondary[4] ☐

Combination of primary and secondary ☐

1.7 Variation stage of GW monitoring?

Significant and systematic[5] ☐

Local running for years with regular frequency[6], ☐

National with local GW network[7] ☐

1.8 Is there a separate organizational structure in charge of GWM in the organization?

Yes ☐ No ☐

1.9 Is enough budgets allocated for the GWM?

Sufficient ☐ Insufficient ☐ None ☐

Amount per year (If known) __________

2. Specific to Research area

2.1 Do you conduct Groundwater Monitoring at Akaki Phase II well field?

yes ☐ No ☐

2.2 What is the frequency of monitoring?

Every 3 months ☐ Monthly ☐ Weekly ☐

Daily ☐ As required ☐

---

[3] Large-scale monitoring networks, usually covering aquifers of large regional size. They serve to provide data about groundwater system behavior and overall impacts on the groundwater situation caused by groundwater exploitation and other interventions

[4] serve specific purposes, such as monitoring water table decline around pumping well fields, monitoring effects of irrigation schemes, monitoring the groundwater levels in nature conservation areas, etc.

[5] No significant and systematic groundwater monitoring going on or only project-wise or problem driven

[6] Local groundwater monitoring networks monitored with regular frequency for several years. This situation exists in countries, where systematic groundwater development and monitoring have become important

[7] National or large regional reference groundwater monitoring networks in combination with local networks. Many countries are planning their groundwater development with the help of a national monitoring network or large regional groundwater monitoring networks

2.3 Which groundwater problem are encountered on Akaki Phase II well field?

Groundwater table decline ☐ Pollution ☐

Yield reduction ☐

others____
____
____

2.4 How many wells exist in Akaki Phase II Well fields? _________

2.5 Out of these wells how many of them are covered through GW monitoring system?_________

2.6 If not all, why the remaining is not covered in the GWM?
____
____
____

2.7 Which are the wells not included in the GWM
____
____
____

Is All GWM are the parameters (Piezometer records, Pumping rates, yield, aquifer characteristic, Planned water use, water quality, well rehabilitation) recorded?

Yes ☐ No ☐

2.8 How the information is collected, stored and used?

Paper format ☐ Electronic gadget ☐ Automated ☐

Others____

2.9 Using the information collected, is Analysis being conducted?

Yes ☐ No ☐

2.10 If yes, how frequently the analysis is done? ______________

2.11 Is the result of the analysis used for

Future planning ☐

Maintenance ☐ Sustains the system ☐

2.12 What are the findings?

____

____

____

2.13 Are there wells abandoned or malfunctioning wells with in Akaki well field?

Yes ☐ No ☐

If yes, how many? _________

List?____

2.15 Causes for being abandoned or malfunction

Low yield, ☐

Well construction defect, ☐

Aging ☐

Burning of Submersible pump ☐

Others____

2.16 Has ever been interruption of pumping?

Due to power ☐ Breakdown ☐

If yes, for how long it lasts?

Hours ☐ Days ☐ Weeks ☐

2.17 How many of the wells have standby generators?

____

____

____

____

Purpose: objective 2

- to assess the quantity of skilled human resources in GWM
- to understand the role and responsibilities each position (department, supervisor, guard, etc.) in GWM
- to understand the level of basic training, regularity of refresher training
- to assess the frequency of the data collection (per day, week)

Objective 2:- To assess the existing trained human resources, well field monitoring practice and analyze the effect in the performance of the well field

1. What are the organizational structure/ arrangement for GWM in the organization?

____

____

____

2. How many staff is involved? _______
3. What is the role of each level of the structure in GWM?

Department head office_______________

Field staff Supervisor____________

Site Guards______________

4. The level of education

Department head office (BSc/ Diploma/Certificate/ High School)

Field staff Supervisor (BSc/ Diploma/Certificate/ High School)

Site Guards (Elementary School/ illiterate)

5. Is there a special training for GWM staff ?

   Yes ☐ No ☐

6. If yes, is there a written training manual ?

   Yes ☐ No ☐

7. Is there regular refresher training ?

   Yes ☐ No ☐

   If yes, Frequency of the training per year_______

8. Frequency of the data collection by each field staff?

   Field staff Supervisor____________

   Site Guards______________

Purpose: objective 3

- to assess the type of instrument equipment installed to monitor the water wells performance
- to understand the quantity and level of functionality of the measuring instruments
- to understand the level of maintenance of the measuring instruments
- to understand the mechanism how to ensure the accuracy of the measurement
- understand the sufficiency of the instrument for the well monitoring

Objective 3:- To assess the equipment installed and availability instruments in the well to monitor the well performance

1. Type of equipment available to monitor the well performance?

(Automatic recorder, deep meter, discharge meter, observation pipe, pumping , time recorder, etc…)

2. How many of these equipment available for use?
   Automatic recorder_____________
   Deep meter__________________
   Discharge meter_________________
   Observation pipe_____________
   Pumping time recorder______________
   Others____
3. How many of these are functional?
   Automatic recorder_____________
   Deep meter__________________
   Discharge meter_________________
   Observation pipe_____________
   Pumping time recorder______________
   Others_______
4. On average how frequent these measuring instruments malfunction
   Monthly ☐ Quarterly ☐ Yearly ☐
5. Is there a maintenance unit of these instruments?
   Yes ☐ No ☐
6. If yes, how many trained technicians are available?______
7. Are spare parts available in the department?
   Yes ☐ Sufficient/insufficient No ☐
8. Is there enough measuring tools , equipment available to monitor the well performance
   Yes ☐ Sufficient/insufficient No ☐

9. How due ensure the quality of data collected from the field?

Regular supervision ☐ Consistency check Data triangulation

others____

____

____

Purpose: objective 4

- to assess the system of GWM (Manual/ Automatic)
- to assess the tools and formats for measurement t of the parameters
- to understand the period of data collected
- to understand how and where the database is stored
- to understand if the database is regularly analyzed and interpreted
- to understand if the analyzed information is used to improve and sustain the water well performance

Objective 4:- To assess the practice of well performance data collection, availability, storage and use

1. How is the well field data collection done

Manual ☐ Semi-automatic ☐ Automatic ☐

2. Is there a printed format to be field?

Yes ☐ No ☐

3. What are the contents (parameters to be measured) of the format used to collect well?

____
____
____
____

4. Is there a specific period time of the day the data is to be collected?

Yes ☐ No ☐

If yes when?__________

5. After field collection is the information stored in a database regularly

Yes ☐ No ☐

If yes where? ______________________

6. Is the database accessible for external use?

Yes ☐ No ☐

7. Is there a person in charge for the purpose in item 6 above ?

Yes ☐ No ☐

8. Is the data base analyzed regularly?

Yes ☐ No ☐

9. Is the analysis shared with the other departments / Stakeholders for use?

Yes ☐ No ☐

If yes, for what purpose?

To regulate the well performance ☐

For maintenance ☐

To efficiently use the yield of the well ☐

For regional GW monitoring ☐

Others____

Thank you for completing the questionnaire your input is highly appreciated.

- ✓ Do you think the current practice is sufficient in the groundwater monitoring system to sustainably manage the performance of the well field?

Yes ☐ No ☐

If both ,what is your recommendation for future improvement

____

____

____

____

____

____

____

Appendix-7 Borehole information (Phase II)

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Addis Ababa region
2	Borehole Name	SWAWE-2'	* There is no Generator on site
3	Borehole Location	Akaki- Kality	* The static and dynamic water level data taken from design , due to absence of deep meter
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	
5	Operational status	Operational	
6	Construction Year	2008	
7	X-Coordinate (m)	475841	
8	Y-Coordinate (m)	980128	
9	Ground Elevation from AAWSA list (m)	2064	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	448	
13	Casing Diameter (Inches)	20-10	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	54.5	
16	Static Water Level (m)	9.45	
17	Dynamic Water Level (m)	98.84	
18	Optimum Yield l/s)	33	
19	Pump Position (m)	110	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	CGCOC Eth. Ltd	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	

No	DESCRIPTION	DESCRIPTION	
1	Unique Identification ID		* Located in Addis Ababa, Akaki town Salo Gora 09, about 2.5km to the west of Gelan condominium houses
2	Borehole Name	SWAWF-4B	* Drilled as a replacement well for the SWAWF 4A
3	Borehole Location	Akaki- Kality	* There is a Generator on site but not active
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2009	
7	X-Coordinate (m)	472919	
8	Y-Coordinate (m)	980932	
9	Ground Elevation from AAWSA list (m)	2064	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	480	
13	Casing Diameter (Inches)	20-10	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	90	
16	Static Water Level (m)	7.18	
17	Dynamic Water Level (m)	16.9	
18	Optimum Yield l/s)	65	
19	Pump Position (m)	66	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	CGCOC Eth. Ltd	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia regional state, about 3km to the south of Gelan condominium houses
2	Borehole Name	SWAWF-5	* There is no Generator on site
3	Borehole Location	Akaki- Woreda	* On 18/05/2018 the borehole was given 2 hr. rest
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2009	
7	X-Coordinate (m)	472848	
8	Y-Coordinate (m)	9797015	
9	Ground Elevation from AAWSA list (m)	2058	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	486	
13	Casing Diameter (Inches)	24-10	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	90	
16	Static Water Level (m)	9.69	
17	Dynamic Water Level (m)	14.2	
18	Optimum Yield l/s)	76.76	
19	Pump Position (m)	76	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	Al-Nile business Group PLC	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Addis Ababa ,Salo Gora 09 kebele in front of a Gelan condominium houses
2	Borehole Name	WF01-PW2	* There is no Generator on site
3	Borehole Location	Akaki- Kality	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2009	
7	X-Coordinate (m)	474290	
8	Y-Coordinate (m)	980673	
9	Ground Elevation from AAWSA list (m)	2072	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	250	
13	Casing Diameter (Inches)	24-12	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	62.2	
16	Static Water Level (m)	21.23	
17	Dynamic Water Level (m)	106.07	
18	Optimum Yield l/s)	26.6	
19	Pump Position (m)	120	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	Al-Nile business Group PLC	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Addis Ababa ,Salo Gora 09 kebele in front of a Gelan condominium houses
2	Borehole Name	WF01-PW3	* There is no Generator on site
3	Borehole Location	Akaki- Kality	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2009	
7	X-Coordinate (m)	475010	
8	Y-Coordinate (m)	980705	
9	Ground Elevation from AAWSA list (m)	2081	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	22hr.	
12	Borehole Depth (m)	481.6	
13	Casing Diameter (Inches)	20-12	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	28	
16	Static Water Level (m)	21.83	
17	Dynamic Water Level (m)	90.48	
18	Optimum Yield l/s)	10	
19	Pump Position (m)	114	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	China Geo-Eng. Corporation Eth. Branch	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE		

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state
2	Borehole Name	WF01-PW4	* There is no Generator on site
3	Borehole Location	Akaki- Kality	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2013	
7	X-Coordinate (m)	471277	
8	Y-Coordinate (m)	979792	
9	Ground Elevation from AAWSA list (m)	2053	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	500	
13	Casing Diameter (Inches)	24-8	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	122	
16	Static Water Level (m)	37.38	
17	Dynamic Water Level (m)	132.8	
18	Optimum Yield l/s)	64	
19	Pump Position (m)	201	
20	Riser Pipe Diameter (mm)	200	
21	Borehole Contractor	Layne	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE		

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state
2	Borehole Name	WF01-PW5	* There is no Generator on site
3	Borehole Location	Akaki- Kality	* On progress to make the well field operational
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Not operational	* If it is becomes operational ,the operational hour will be 22hr
6	Construction Year	2013	
7	X-Coordinate (m)	470530	
8	Y-Coordinate (m)	979406	
9	Ground Elevation from AAWSA list (m)	2051	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day		
12	Borehole Depth (m)	510	
13	Casing Diameter (Inches)	14-8	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	140	
16	Static Water Level (m)	14.53	
17	Dynamic Water Level (m)	125.01	
18	Optimum Yield l/s)	80	
19	Pump Position (m)	172	
20	Riser Pipe Diameter (mm)	200	
21	Borehole Contractor	Layne	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE	East Shoa	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state,Hechu kebele, Tuluya village
2	Borehole Name	WF01-PW6	* There is no Generator on site
3	Borehole Location	Dukem woreda	* pump position 135m
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* This specific borehole started giving low discharge but now it shows improvement by increasing its recovery time. In other words it has stopped working foe 24 hr.
5	Operational status	Operational	* The static and dynamic water level data taken from design , due to absence of deep meter
6	Construction Year	2010	
7	X-Coordinate (m)	472630	
8	Y-Coordinate (m)	979912	
9	Ground Elevation from AAWSA list (m)	2096	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	532	
13	Casing Diameter (Inches)	26-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	80	
16	Static Water Level (m)	8.43	
17	Dynamic Water Level (m)	92.9	
18	Optimum Yield (l/s)	54	
19	Pump Position (m)	111	
20	Riser Pipe Diameter (mm)	200	
21	Borehole Contractor	CGCOC Eth. Ltd	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE	East Shoa	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in region 14,Akaki woreda , about 2.5km to the south of Gelan condominium houses
2	Borehole Name	WF01-PW8	* There is no Generator on site
3	Borehole Location	Akaki - Kality	* The flow meter don't work
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2009	
7	X-Coordinate (m)	473683	
8	Y-Coordinate (m)	979475	
9	Ground Elevation from AAWSA list (m)	2059	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	483.7	
13	Casing Diameter (Inches)	20-12	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	50	
16	Static Water Level (m)	17.5	
17	Dynamic Water Level (m)	99.86	
18	Optimum Yield (l/s)	13	
19	Pump Position (m)	120	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	CGCOC Eth. Ltd	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state
2	Borehole Name	WF01-PW9	* There is no Generator on site
3	Borehole Location	Akaki - Kality	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2013	
7	X-Coordinate (m)	470470	
8	Y-Coordinate (m)	979206	
9	Ground Elevation from AAWSA list (m)	2049	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	514	
13	Casing Diameter (Inches)	14-8	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	70	
16	Static Water Level (m)	19.22	
17	Dynamic Water Level (m)	149.74	
18	Optimum Yield(l/s)	50	
19	Pump Position (m)	176	
20	Riser Pipe Diameter (mm)	200	
21	Borehole Contractor	Layne	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state
2	Borehole Name	WF01-PW10(18)	* There is no Generator on site
3	Borehole Location	Akaki - Kality	* Pump position =107m
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2011	
7	X-Coordinate (m)	472012	
8	Y-Coordinate (m)	979857	
9	Ground Elevation from AAWSA list (m)	2059	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	22hr.	
12	Borehole Depth (m)	272	
13	Casing Diameter (Inches)	23-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	140	
16	Static Water Level (m)	9.32	
17	Dynamic Water Level (m)	13.01	
18	Optimum Yield (l/s)	100.10	
19	Pump Position (m)	55	
20	Riser Pipe Diameter (mm)	180	
21	Borehole Contractor	Tana	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	
24	ZONE		

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, Hechu kebele
2	Borehole Name	WF01-PW11	* There is no Generator on site
3	Borehole Location	Akaki	* The static and dynamic water level data taken from design , due to a
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	
5	Operational status	Operational	
6	Construction Year	2009	
7	X-Coordinate (m)	472268	
8	Y-Coordinate (m)	978066	
9	Ground Elevation from AAWSA list (m)	2059	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	500	
13	Casing Diameter (Inches)	24-12	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	62.15	
16	Static Water Level (m)	27.15	
17	Dynamic Water Level (m)	81.53	
18	Optimum Yield (l/s)	45.33	
19	Pump Position (m)	110	
20	Riser Pipe Diameter (mm)	180	
21	Borehole Contractor	Al-Nile business Group PLC	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, Hechu kebele, Koticha village
2	Borehole Name	WF01-PW12	* There is no Generator on site
3	Borehole Location	Akaki	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2010	
7	X-Coordinate (m)	471401	
8	Y-Coordinate (m)	977301	
9	Ground Elevation from AAWSA list (m)	2655	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	480	
13	Casing Diameter (Inches)	24-12	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	101	
16	Static Water Level (m)	34.1	
17	Dynamic Water Level (m)	39.73	
18	Optimum Yield (l/s)	66.48	
19	Pump Position (m)	60	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	Al-Nile business Group PLC	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, Hechu kebele
2	Borehole Name	WF01-PW13	* There is no Generator on site
3	Borehole Location	Akaki	* The flow meter don't work
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2010	
7	X-Coordinate (m)	472114	
8	Y-Coordinate (m)	976834	
9	Ground Elevation from AAWSA list (m)	2058	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	400	
13	Casing Diameter (Inches)	20-12	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	22	
16	Static Water Level (m)	40.4	
17	Dynamic Water Level (m)	105.9	
18	Optimum Yield (l/s)	19.00	
19	Pump Position (m)	117	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	China Geo-Eng. Corporation Eth. Branch	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, Hechu kebele
2	Borehole Name	WF01-PW14	* There is no Generator on site
3	Borehole Location	Akaki	* It was under rehabilitation and at 21/05/2018 it becomes operational
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2010	
7	X-Coordinate (m)	476877	
8	Y-Coordinate (m)	976374	
9	Ground Elevation from AAWSA list (m)	2056	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	552	
13	Casing Diameter (Inches)	26-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	76.32	
16	Static Water Level (m)	39.79	
17	Dynamic Water Level (m)	41.93	
18	Optimum Yield(l/s)	120.00	
19	Pump Position (m)	118	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	CGCOC Eth. Ltd	
22	Budget Source		
23	Well Report in AAWSA Records	Yes	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, about 2.5 km south-east condominium houses of Gelan site
2	Borehole Name	WF01-PW15	* There is no Generator on site
3	Borehole Location	Dukem woreda	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2010	
7	X-Coordinate (m)	474037	
8	Y-Coordinate (m)	978932	
9	Ground Elevation from AAWSA list (m)	2066	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	492.1	
13	Casing Diameter (Inches)	26-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	50	
16	Static Water Level (m)	30.25	
17	Dynamic Water Level (m)	117.9	
18	Optimum Yield (l/s)	26.00	
19	Pump Position (m)	140	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	Shandong Geo-mineral Eng. Company	
22	Budget Source		
24	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE	East Shoa	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, Salo Gora 09 kebele
2	Borehole Name	WF01-PW16	* There is no Generator on site
3	Borehole Location	Akaki - Kality	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2010	
7	X-Coordinate (m)	473447	
8	Y-Coordinate (m)	980394	
9	Ground Elevation from AAWSA list (m)	2068	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	16hr.	
12	Borehole Depth (m)	549.73	
13	Casing Diameter (Inches)	26-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	50	
16	Static Water Level (m)	11.38	
17	Dynamic Water Level (m)	143.03	
18	Optimum Yield(l/s)	17.00	
19	Pump Position (m)	180	
20	Riser Pipe Diameter (mm)		
21	Borehole Contractor	CGCOC Eth. Ltd	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE	East Shoa	

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state, Salo Gora kebele
2	Borehole Name	WF01-PW17	* There is no Generator on site
3	Borehole Location	Akaki	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2010	
7	X-Coordinate (m)	472554	
8	Y-Coordinate (m)	981756	
9	Ground Elevation from AAWSA list (m)	2066	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	20hr.	
12	Borehole Depth (m)	477.38	
13	Casing Diameter (Inches)	26-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	50	
16	Static Water Level (m)	Artesian well	
17	Dynamic Water Level (m)	85.7	
18	Optimum Yield (l/s)	44.83	
19	Pump Position (m)	108	
20	Riser Pipe Diameter (mm)	200	
21	Borehole Contractor	Shandong Geo-mineral Eng. Company	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE		

No	DESCRIPTION	DESCRIPTION	REMARKS
1	Unique Identification ID		* Located in Oromia Regional state
2	Borehole Name	WF01-PW19	* There is no Generator on site
3	Borehole Location		
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2012	
7	X-Coordinate (m)	470650	
8	Y-Coordinate (m)	977039	
9	Ground Elevation from AAWSA list (m)	2045	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	501	
13	Casing Diameter (Inches)	24-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	67	
16	Static Water Level (m)	54.43	
17	Dynamic Water Level (m)	109.18	
18	Optimum Yield (l/s)	54.84	
19	Pump Position (m)	153	
20	Riser Pipe Diameter (mm)	200	
21	Borehole Contractor	Tana	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE		

No	DESCRIPTION	DESCRIPTION	
1	Unique Identification ID		* Located in Oromia Regional state, Hechu kebele
2	Borehole Name	WF01-PW20	* There is no Generator on site
3	Borehole Location	Akaki - Kality	
4	Primary Network destination of Borehole outlet pipe	New CT Reservoir	* The static and dynamic water level data taken from design , due to absence of deep meter
5	Operational status	Operational	
6	Construction Year	2012	
7	X-Coordinate (m)	471470	
8	Y-Coordinate (m)	978047	
9	Ground Elevation from AAWSA list (m)	2056	
10	Ground Elevation from Digital Terrain Model (m)		
11	Borehole Operation Hours per day	24hr.	
12	Borehole Depth (m)	504	
13	Casing Diameter (Inches)	23-14	
14	Casing Material	Steel	
15	Pump Test Yield (l/s)	40	
16	Static Water Level (m)	26.7	
17	Dynamic Water Level (m)	127.02	
18	Optimum Yield (l/s)	33.00	
19	Pump Position (m)	190	
20	Riser Pipe Diameter (mm)	150	
21	Borehole Contractor	Tana	
22	Budget Source		
23	Well Report in AAWSA Records ("Y"=Yes, "N"=No)	Y	
24	ZONE		

Appendix -8 Boreholes Not Connected to Water Supply System due to Different Reasons (Phase II)

Table 52:- Boreholes not connected to water supply system due to different Reasons (Phase II)

No	Index	Coordinates		Well depth, m	SWL, m	Casing dia. Inch	Pumping test		Reason for no-connection
		X	Y				Q ,l/s	DWL, m	
1	APW-01	475936	978248	416.0	40.3	12"-326 & 6"	-	-	abandoned due to failure of the contractor
2	SWAWF1R	475945	978251	417.0	45.2	12"-250 & open	12.1	152.0	Low yield
3	SWAWF4A	472846	980785	121.5	8.5	12"-91.75 & 6"	30.0	61.7	shallow well
4	WF01-PW1	473597	981135	500.0	21.7	12"-251.74 & open	10.5	86.4	Low yield
5	WF01-PW7	471909	979461	451.0	8.8	14"-250 & open-451	7.3	106.5	Low yield

Appendix-9 Summary of Well Completion Report

Table 53:-Well Completion Report

No	Prospective site/well field	Well Index	Well type	Coordinate UTM Zone 37 Adindan		Elev. m	Contractor	Depth, m	Static water level, m	Dynamic water level, m	Draw down, m	Q, test, (l/S)	Transmissivity (m^2/day)	Specific well yield, l/s/m
				UTM east	UTM north									
1	Akaki	SWAWF1	Test well	475936	978248	2059	ANBG	416	40.3	-	-	-	4.76*10^1	
2	Akaki	SWAWFR	Test well	475945	978251	2060	ANBG	416	45.2	156.4	111.2	12.1	5.83*10^1	0.1
3	Akaki	SWAWF2	Test well	475697	979915	2055	CGCOC	448	9.5	98.8	89.4	54.5	1.97*10^3	0.6
4	Akaki	SWAWF3	Test well	471027	973709	2056	CGCEB	379	44	58.2	14.2	90	6.06*10^2	6.3
5	Akaki	SWAWF4A	Test well	472846	980785	2180	CGCOC	120	8.2	60.5	52.3	30	1.29*10^4	0.6
6	Akaki	SWAWF4B	Test well	472836	980785	2058	CGCOC	481	8	16.9	9	90	3.44*10^4	10.1
7	Akaki	SWAWF5	Test well	472779	978788	2054	ANBG	486	9.7	14.2	4.5	90	8.67*10^1	20.1
8	Akaki	WF01-PW1	Pilot Production	473597	981135	2079	ANBG	500	21.7	98.3	76.7	10.5	2.03*10^2	0.1
9	Akaki	WF01-PW2	Pilot Production	474204	980459	2069	ANBG	250	21.2	106.1	84.8	62.2	5.75*10^2	0.7
10	Akaki	WF01-PW3	Pilot Production	474918	980486	2073	CGCEB	480	21.8	90.5	68.7	28	4.76*10^1	0.4
11	Akaki	WF01-PW4	Production well	471185	979580	2061	Layne	500	37.38	132.8	95.42	122	9.67*10^1	1.28
12	Akaki	WF01-PW5	Production well	470434	979201	2058	Layne	506	14.53	125.01	110.48	140	6.62*10^1	1.27
13	Akaki	WF01-PW6	Production well	472630	979912	2058	CGCOC	533	8.4	92.9	84.6	80	1.59*10^3	0.9
14	Akaki	WF01-PW7	Production well	471909	979461	2055	SGEC	500.8	8.8	106.9	98.1	7.25	2.65*10^1	0.07
15	Akaki	WF01-PW8	Pilot Production	473583	979260	2063	CGCOC	483.7	17.5	99.9	82.4	50	1.06*10^2	0.6
16	Akaki	WF01-PW9	Production well	470470	979206	2049	Layne	514	19.22	149.74	130.52	70	8.15*10^1	0.5
17	Akaki	WF01-PW11	Pilot Production	472245	977865	2056	ANBG	500	27.5	81.5	54	62.2	1.05*10^2	1.2
18	Akaki	WF01-PW12	Pilot Production	471476	977396	2049	ANBG	480	34.1	39.7	5.6	101	5.81*10^3	17.9
19	Akaki	WF01-PW13	Test well	472233	976508	2057	CGCEB	400	40.4	105.9	65.5	22	1.66*10^2	0.34
20	Akaki	WF01-PW14	Production well	471521	976630	2050	CGCOC	552	39.7	42	2.3	76.3	2.22*10^3	33.17

No	Prospective site/well field	Well Index	Well type	Coordinate UTM Zone 37 Adindan		Elev. m	Contractor	Depth, m	Static water level, m	Dynamic water level, m	Draw down, m	Q, test, (l/S)	Transmissivity	Specific well yield, l/s/m
21	Akaki	WF01-PW15	Production well	473944	978722	2066	SGEC	492	30.3	117.9	87.7	50	1.77*10^2	0.46
22	Akaki	WF01-PW16	Production well	473386	980122	2062	CGCOC	549	11.4	143	131	50	6.54*10^1	0.24
23	Akaki	WF01-PW17	Production well	472460	981553	2064	SGEC	500	Artesian	85.7	85.7	50	1.07*10^2	0.57
24	Akaki	WF01-PW18	Production well	471918	979657	1969	Tana	272	9.32	13.01	3.68	140	1.62*10^4	38.04
25	Akaki	WF01-PW19	Production well	470557	976837	1972	Tana	501	54.43	109.18	-	67	2.51*10^2	1.22
26	Akaki	WF01-PW20	Production well	471298	977837	1978	Tana	504	26.70	127.02	-	40	2.63*10^2	0.398

Appendix-10 Production Well Status

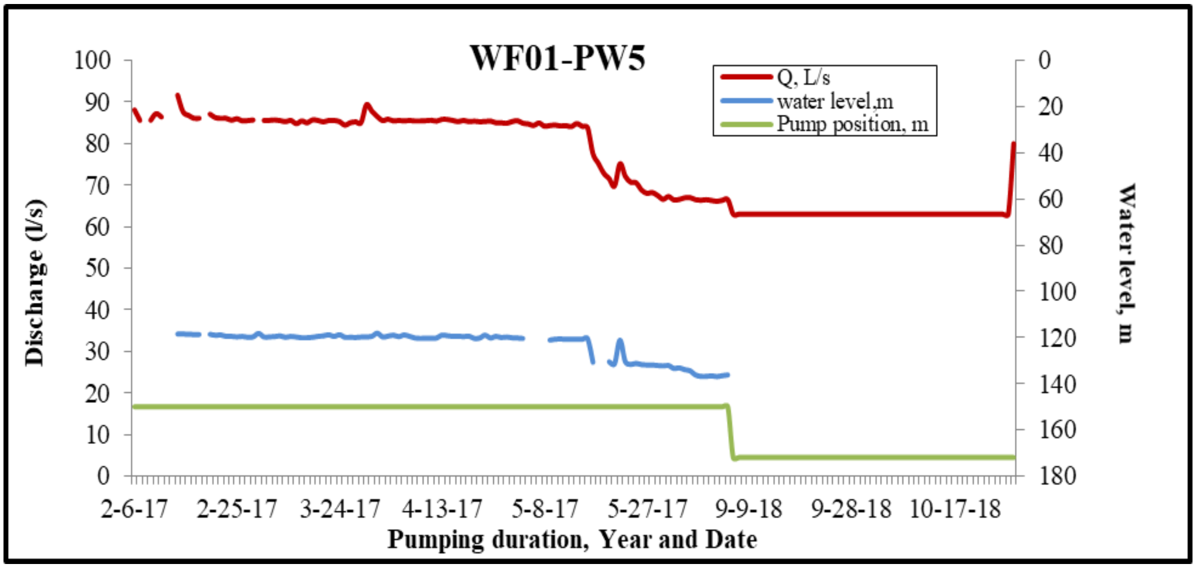


Figure 63:-Operation Borehole status WF01-PW5

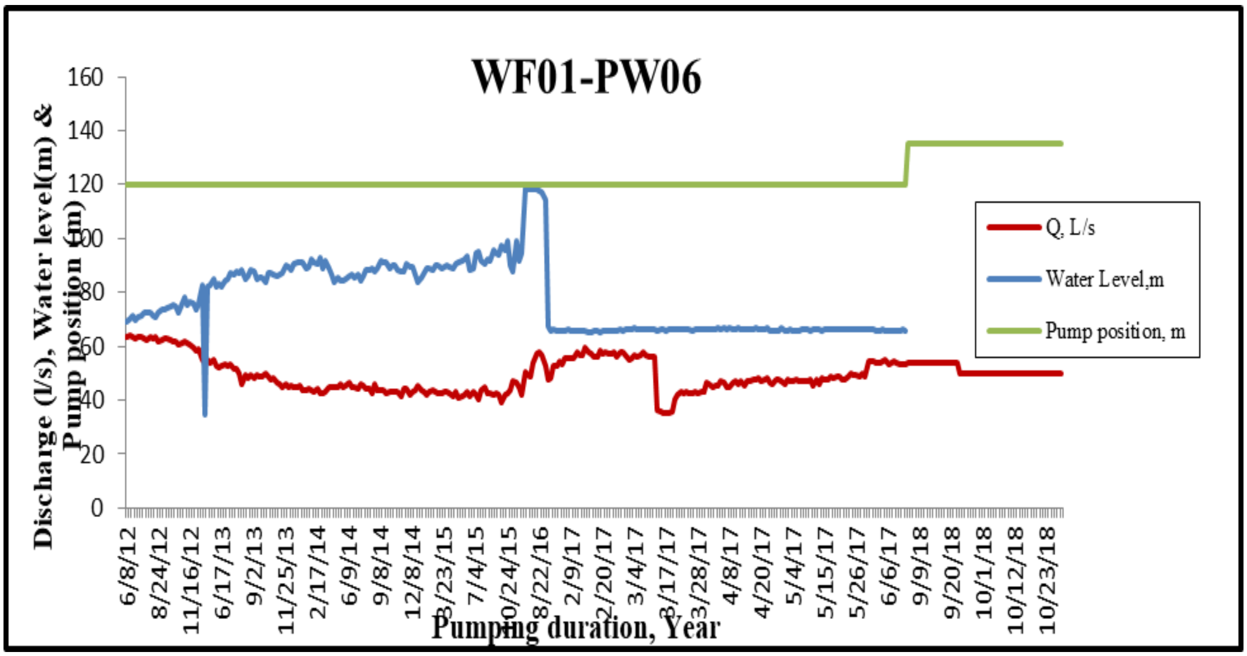


Figure 64:- Operation Borehole status WF01-PW06

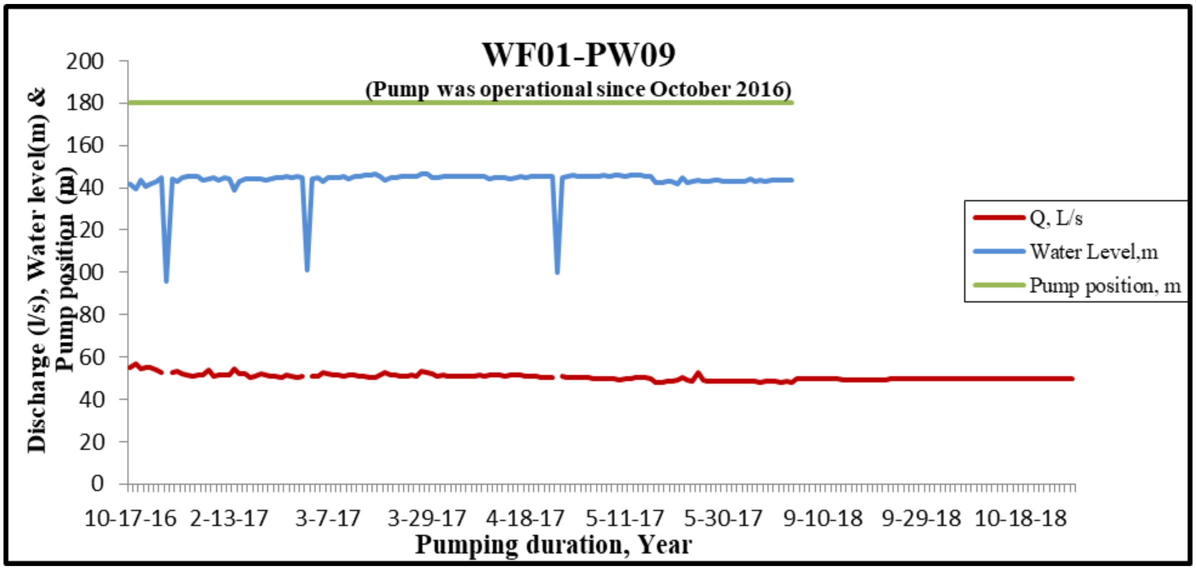


Figure 65:-Operation Borehole status WF01-PW09

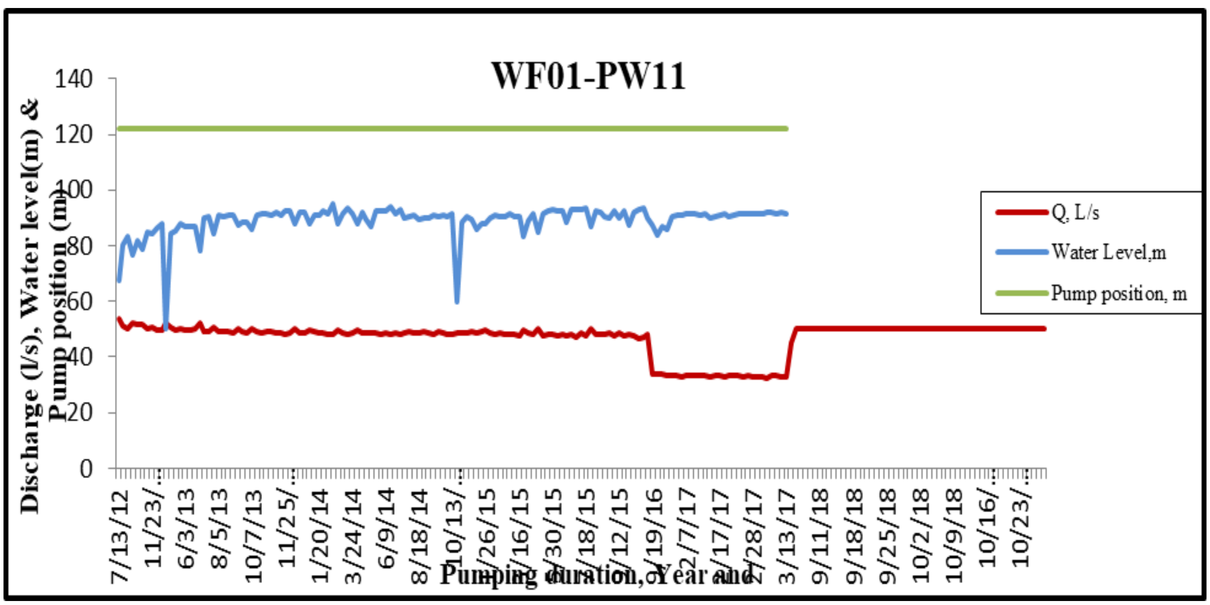


Figure 66:-Operation Borehole status WF01-PW11

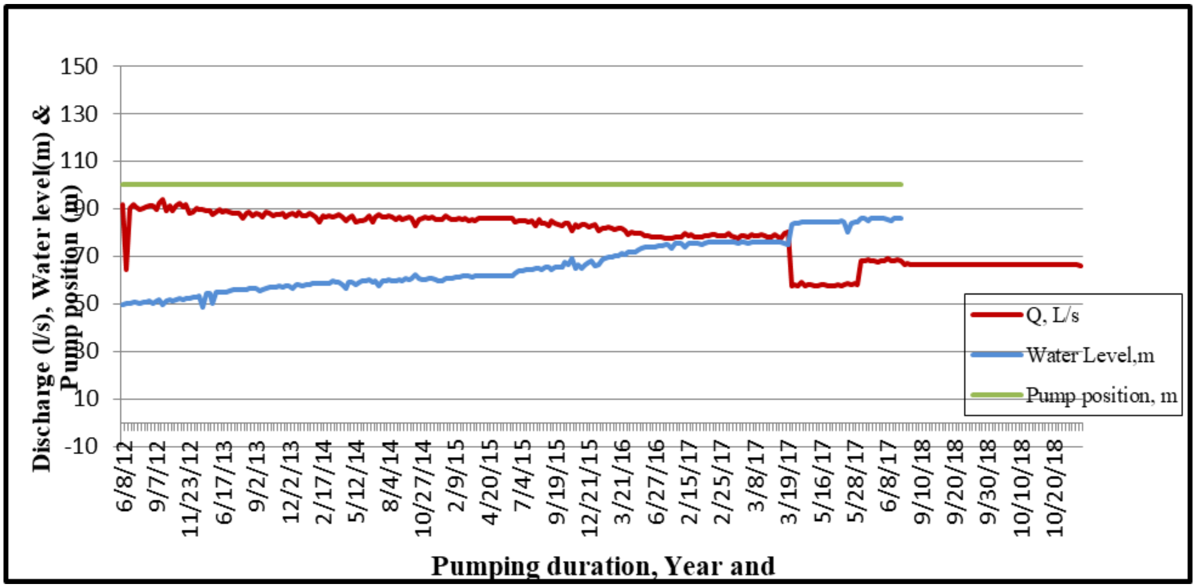


Figure 67:- Operation Borehole status WF01-PW12

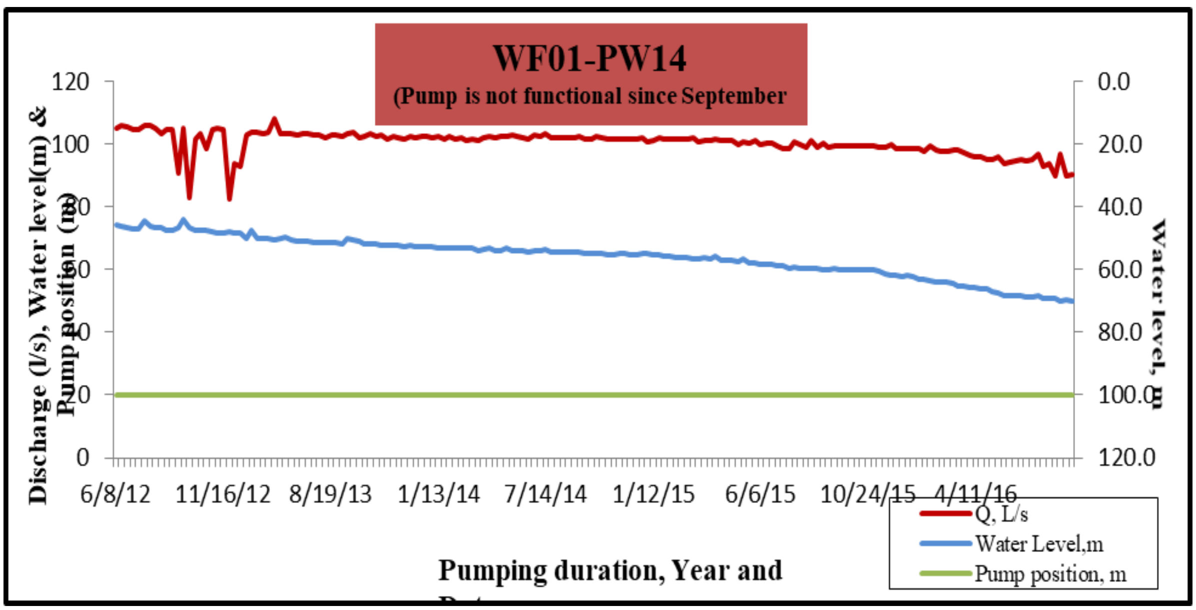


Figure 68:- Operation Borehole status WF01-PW14

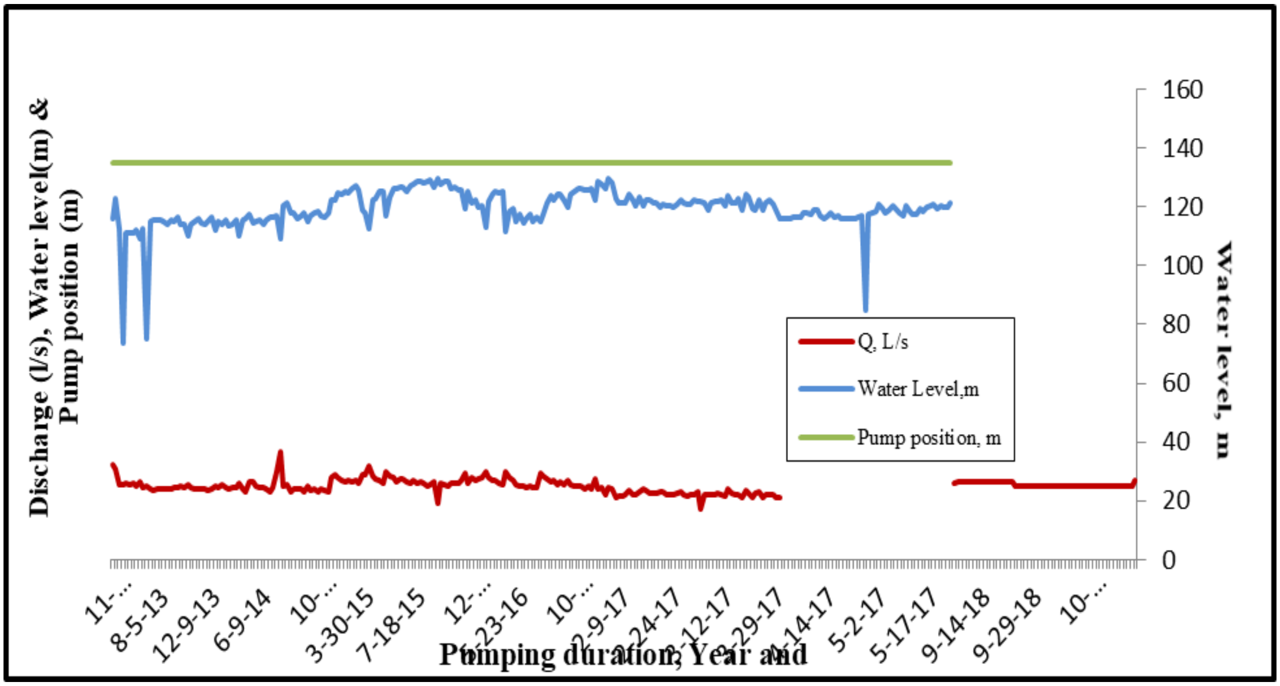


Figure 69:- Operation Borehole status WF01-PW15

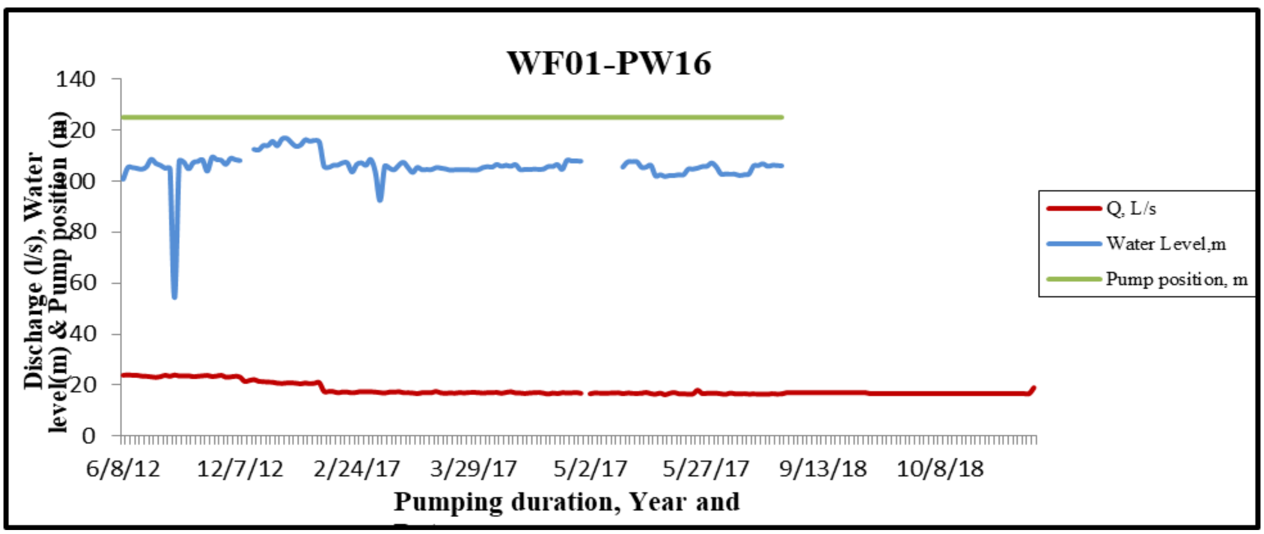


Figure 70:- Operation Borehole Operation Borehole status WF01-PW16

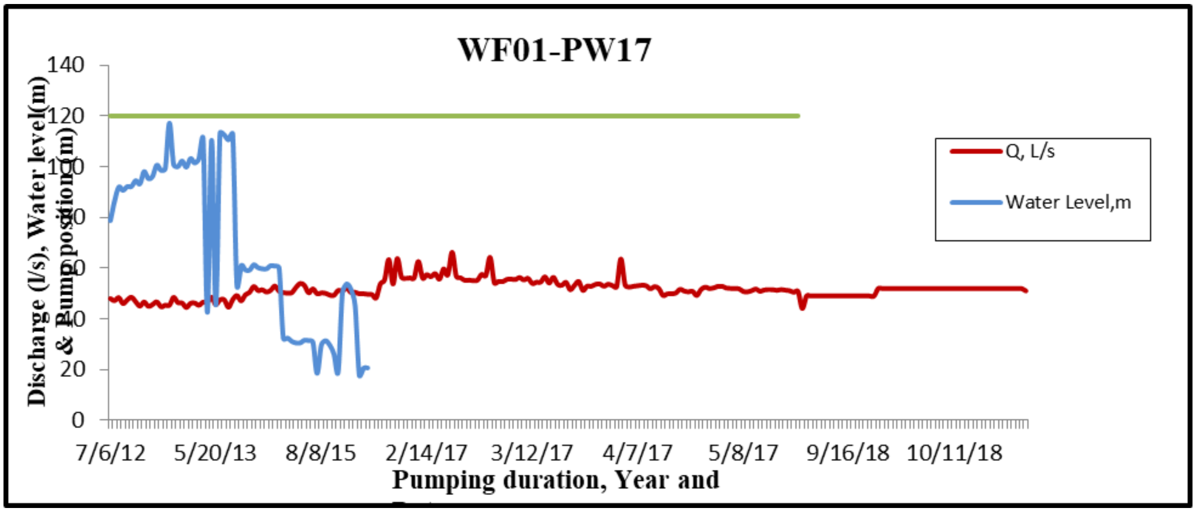


Figure 71:- Operation Borehole Operation Borehole status WF01-PW17

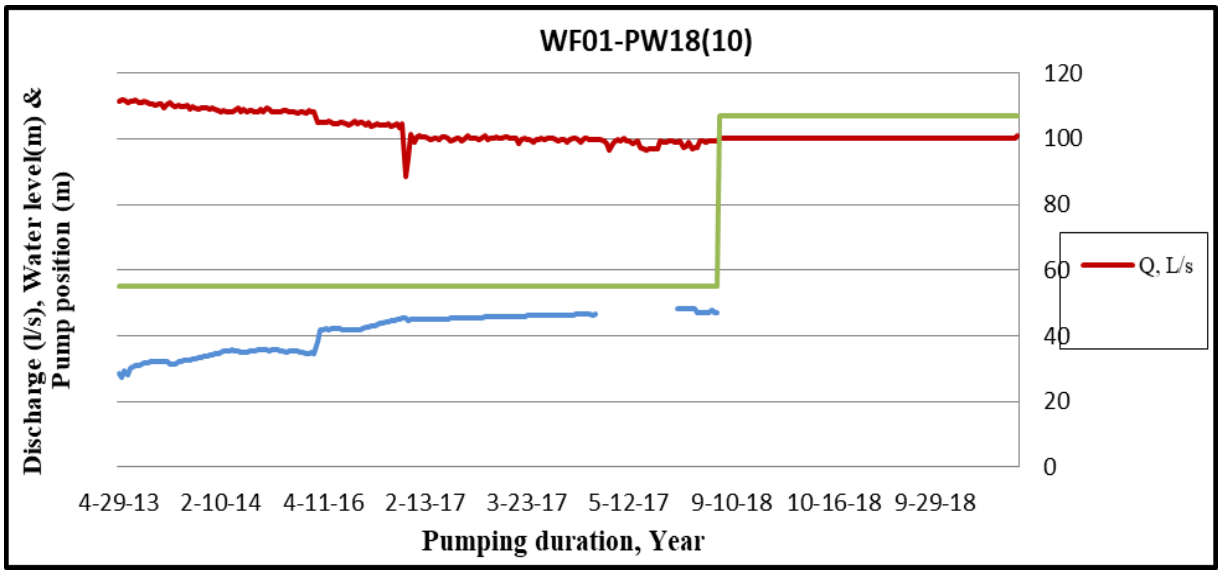


Figure 72:- Operation Borehole Operation Borehole status WF01-PW18 (10)