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Determination Of Aquifer Hydraulic Properties And Water Well Performance Using Pumping Test Techniques At NLNG Headquarters Office Port Harcourt

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Abstract:** An attempt has been made in this study to evaluate the Groundwater resource and aquifer potential of a well at the Headquarters office of the Nigeria Liquidied Natural Gas, in Port Harcourt, Nigeria. Groundwater is usually chosen as the most suitable source of drinking water, the supplies of which are brought to the surface by rehabilitating existing boreholes or drilling new ones. Pumping tests and drawdown test are the practical way of obtaining an information of the borehole's efficiency and its optimal production yield. During drawdown and pumping tests the value of the pumping rates is kept constant through all the steps of the tests. Basically, the goal of a pumping test in any aquifer test is to estimate hydraulic properties of an aquifer system. For the pumped aquifer, one seeks to determine transmissivity, hydraulic conductivity, well specific yield and storativity (storage coefficient), among others. A pumping test consists of pumping groundwater from a well, usually at a constant rate, and measuring the change in water level (drawdown) in the pumping well and any nearby wells (observation wells) or surface water bodies during and after pumping. Two types of pumping tests were performed in this study, well constant rate pumping test and step down pumping test. Constant rate pumping test was performed by pumping groundwater from the newly constructed well at constant rate of 16 m^3/hr for 72 hours. Pumping rates for three step down tests were carried out for one hour at a pumping rate of 23.44, 16.07 and 12.09 m^3 per hour respectively. During this period, the abstraction flow rate and groundwater level in the investigatory well and all the monitoring wells were recorded at the same frequency. Data collected from the test was analyzed and the results indicate that the well has the capacity to produce at the designed flow rate of 15 cubic meters per hour without running dry or affecting the production capacities of the other pre-existing observatory wells. Sspecific capacity of the well was obtained to be 0.91m^2/hr while the transmissivity was 162.7 m^2/hr.

***Keywords:** pumping test, aquifer, hydraulic conductivity, transmissivity, groundwater*

I. INTRODUCTION

As a step to determining the Ground water resources and aquifer potentials of the study area, pumping test was carried out in an investigatory well in the NLNG Head office complex, situate in Port Harcourt Nigeria. Groundwater is defined as the water that comes from rain or some other precipitation products which flows into the subsurface and fills up cracks and other porous soul and rock materials (Groundwater Dictionary, 2011). It is an essential resource of great social, environmental and economic importance. It accounts for early over 97% of the world's freshwater and serves as the basic source for all streams, springs, and rivers.

Groundwater is frequently chosen as the most suitable source of drinking water, supplies of which are brought to the surface by rehabilitating existing boreholes or drilling new ones. Ground water occurs almost everywhere beneath the land surface and is an integral part of a complex hydrologic cycle that involves continuous movement of water on Earth. The relatively abundant occurrence of potable ground water is a major reason for its use as a source of water supply worldwide. The upper surface of the saturated zone is called the water table. Contrary to popular belief, groundwater does not form underground rivers. It fills the pores and fractures in underground materials such as sand, gravel, and other rock, much the same way that water fills a sponge. The unconfined and confined saturated formations in the subsurface can only be extracted by well bore.

The hydraulic analysis of wells to evaluate the ground water potentials using pumping test data, falls in the specialized field of groundwater hydrogeology, while the analysis of the hydraulics of wells for the evaluation of ground water potentials by pumping tests falls in the category of groundwater hydrology. This concept was developed after the well acclaimed law of flow introduced by Henri Darcy. According to this law, the discharge through porous media is proportional to the product of the hydraulic gradient; the cross-sectional area normal to the flow and the coefficient of permeability of the mater (Gulraiz and Hasan, 2016).

Hydrogeologists determine the hydraulic characteristics of water-bearing formations, by conducting pumping tests (Houben, 2015). Pumping Test is conducted to examine the aquifer response, under controlled conditions, for the abstraction of water. The basic principle of a pumping test is that if we pump water from a well and measure the pumping rate and the drawdown in the well then, we can substitute these measurements into an appropriate formula and can calculate the hydraulic characteristics of the aquifer. It is also called as aquifer tests for aquifer parameter evaluation. Pumping tests are a practical way of obtaining an idea of the borehole's efficiency and its optimal production yield. Pumping test consists of pumping groundwater from a well, usually at a constant rate, and measuring water levels in the pumped well and any nearby wells (observation wells) or surface water bodies during and after pumping. A pumping test is a practical, reliable method of estimating well performance, well yield, the zone of influence of the well and aquifer characteristics (i.e., the aquifer's ability to store and transmit water, aquifer extent, presence of boundary conditions and possible hydraulic connection to surface water).

Aquifer test and aquifer performance test (APT) are alternate designations for a pumping test. In petroleum engineering, a pumping test is referred to as a drawdown test. Hydrogeological studies include determination of aquifer parameters by conducting pumping tests on dug / bore / tube wells and analysis of pumping test data. Basically, pumping tests are conducted for a wide variety of reasons, including the following:

- ✓ To determine the reliable long-term yield (or 'safe' yield) of a borehole.
- ✓ To assess the hydraulic performance of a borehole, usually in terms of its yield-drawdown characteristics
- ✓ To derive the hydraulic properties of the aquifer.
- ✓ Pumping tests are the classic (and perhaps the only) way to derive in situ aquifer hydraulic properties, such as transmissivity and the storage coefficient, or to reveal the presence of any hydraulic boundaries.
- ✓ To test the operation of the pumping and monitoring equipment,
- ✓ To determine the effects of abstraction on neighboring abstractions (sometimes referred to as derogation).
- ✓ To determine the environmental impact of the abstraction, and
- ✓ To provide information on water quality.

A. THE STUDY AREA

The study area is the Nigeria Liquified Natural Gas (NLNG) Head office complex, situate in Port Harcourt, Rivers State Nigeria. The area lies in the very prolific Niger Delta basin (Figure 1)

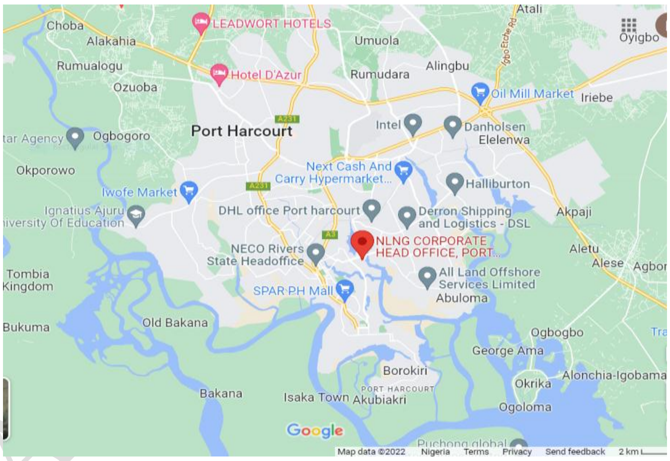

Figure 1: Satellite map of the study area (Google map)

B. GEOMORPHOLOGY, GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The formation of the Niger Delta Basin is linked to the development of the Benue Trough as a failed arm of a rift triple junction associated with the separation of African and South Ameriacan plates and the subsequent opening of the South Atlantic. Oomkens, E. (1974). Basically, the area consists of medium coarse to coarse unconsolidated sands with groundwater at the water table atmospheric pressure. The top sediments are aerated unconsolidated and highly variable thickness throughout the area. Onuoha and Mbazi (1988), Amechi and Horsfall (2015) The subsurface geology of the Niger Delta consists of three lithostratigraphic units (Benin, Agbada and Akata Formations) which are in turn overlain by quaternary sediments. The Benin formation is about 2100m thick and is made up of over 90% massive, porous and coarse sands. [Allen 1965]. This formation is the most prolific aquifer in the region. The high permeability of Benin formation, the overlying lateritic red sand and weathered top of the formation provide the hydrologic condition favoring aquifer formation in the area. (Short and Stauble 1967). Groundwater potentials are very high due to the high permeability, high recharge potential and considerable aquifer thickness. The water in most of the area has high iron content and water table varying between 1.0m to 15.0m inland.

The aquifer here is usually unconfirmed and is encountered at varying depths. Fig. 1. Shows the satellite map of the study location. The Niger Delta spreads across a number of ecological zones, comprising sandy coastal ridge barriers, brackish/saline mangrove, freshwater and swamp forest

J. O. Etu-Efeotor *at al.* (1990). Recharge to aquifers is by direct infiltration of rainfall, which ranges annually from 2540 mm on mainland to about 5010 mm towards the coast J.O.Etu-Efeotor, at al (1983). The wettest months are May to October while the driest month months are December to March, although some pockets of rain is likely to fall in the driest months A.E Ofoma, et al (2006). Groundwater in the area occurs in shallow aquifers belonging to the coastal plain sand, comprising of sand, gravel and clay intercalations. Borehole yields is very good, with production rates of about 20,010 l/h and borehole success rate is usually high J.O.Etu-Efeotor, at al (1983).

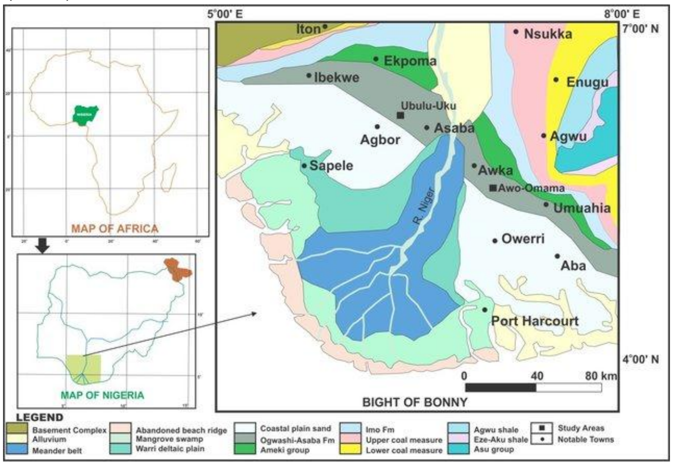

Figure 2: Geologic map of the Niger Delta Region showing the study area

II. BACKGROUND THEORY

An understanding of the basic terminologies used in this study is vital and necessary. Hence the following.

An *aquifer* is the water bearing formation on which the screen is placed. The aquifer type for well confined aquifer as layers of impermeable clay border the aquifer at 250 and 312 meters.

Static water level is the level of water in the well when no water is being taken out, either by pumping or free flow. Generally expressed as the distance from the ground surface to the water level in the well.

Pumping level is the level at which water stands in a well when pumping is in progress. It is also known as the dynamic water level.

Drawdown this means the extent of lowering of the water level when pumping is in progress. It is the difference in feet (or m) between the static water level (SWL) and the pumping level.

Well yield is a measure how much water withdrawn from the well over a period of time and measured in m^3/hr or m^3/day. Simply put, the volume of water per unit of time discharged from a well, either by pumping or free flow.

Residual drawdown. When pumping is stopped, water level rises and approach the observed SWL before pumping started. During such a recovery period, the distance that the water level is found to be below the initial SWL is called residual drawdown.

Specific capacity is the quantity of water a well can produce per unit of draw down. It is a measure of well efficiency and in comparing the efficiency of a well over time. Specific capacity is calculated by dividing pumping rate (yield) over drawdown ($Q/\Delta h$)

Transmissibility is the measure of the ability of an aquifer to transmit and to store water.

Hydraulic conductivity (K) Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement. In theoretical terms, hydraulic conductivity is a measure of how easily water can pass through soil or rock: high values indicate permeable material through which water can pass easily; low values indicate that the material is less permeable.

III. MATERIALS AND FIELD PROCEDURE

The field equipments and procedures engaged during the study is presented in the following sections.

A. FIELD EQUIPMENT AND MATERIALS

The following field equipments were employed in course of the study;

- ✓ Extension cords to tap water from source,
- ✓ Submersible pump; grundfos sp 17-7
- ✓ Flow meter
- ✓ Dip meter (electronic-water level sounder)
- ✓ Stop watch
- ✓ Thermometer
- ✓ P^H meter
- ✓ Conductivity meter
- ✓ Discharge pipe, reducers, and connectors.

B. PUMPING TEST PROCEDURE

Pumping test was carried out following conventional procedures (Kruseman and de Ridder(2000); *Bruin and Hudson (1955) and* The well was pumped at a controlled rate and water-level responses particularly drawdowns were measured at given time intervals. Data from pumping tests were used to evaluate well performance and estimate the hydraulic properties of aquifers in which screens are placed. Two parameters were computed for this borehole: specific capacity of the well and aquifer transmissibility. Data collected from the pumping test was analysed and the results indicated that the well has the capacity to produce at the designed flow rate of 15 cubic meters per hour without running dry or affecting the production capacities of the other two wells drilled in the the NLNG Head office complex Port Harcourt, Rivers state Nigeria.

Two types of pumping tests were performed, well constant rate pumping test and step down pumping test. Constant rate pumping test was performed by pumping groundwater from the newly constructed well at constant rate

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for 72 hours at a rate of 16 m^3/hr. Pumping rates for three step down tests were carried out for one hour at a pumping rate of 23.44, 16.07 and 12.09 m^3 per hour respectively. Measurement of water levels (drawdown) in the pumped (investigatory) well was executed while in two other wells in the vicinity of the investigatory well no measurements were carried out on them. The two other wells were pre-existing wells (wells 1 and 2) at the NLNG Head Office Port Harcourt. Both wells which served as observational wells were observed to be still flowing as artesian wells during the operation of the pumping tests. It is therefore believed that the investigatory well had no impact on the performance of the two previously drilled wells.

a. WATER LEVEL MEASUREMENT

Water levels in the well were measured by means of electronic deep meter. Initial water level or static water level was measured and recorded immediately before pumping began. The static water level in this instance was recorded at 0.00 m as the well flow was artesian. Measurements of drawdown in the pumping well were done with deep meter and a stop watch. Water level was measured roughly logarithmically, for example, every 30 seconds from 0 – 10 minutes, every minute from 10 – 30 minutes, every 5 minutes from 30 – 120 minutes, every 10 minutes from 120 minutes to the end of the test.

b. CONSTANT RATE PUMPING TEST

This test was performed to monitor flow rate above the required flow rate for a long period of constant pumping. Well response rate especially drawdown was measured at specified time intervals during this period of pumping.

A 72-hour pump test was conducted for well-3 which was performed from October 1 to October 3, 2019. Grundfos SP 25 – 80 watts pump which delivers an average Pumping rate of 25 m^3 per hour which is higher than the recommended 15 m^3 per hour water requirement from the borehole was employed for the pumping test. The flow meter was used to calculate the volume of water discharged from the well.

c. STEP-DOWN PUMPING TEST

The step-drawdown was conducted on the 4^{th} of October 2019, following after Fetter (2001), Kawecki, (1995) and Kærgaard (1982)). This test was designed to investigate the performance of the pumping well under controlled discharge conditions for a shorter period of time. The step down test is used primarily to determine the extent of well development. If the well is poorly developed, the test will determine the extent of the problem.

Three tests were carried out, discharge rate starting from 23.44 m^3/hour and increased to 16.07 m^3/hour, 12.09 m^3/hour and 18m^3/hour (Cooper and Jacob, 1947). The flow rates were obtained by adjusting a valve attached to the flow line, each step was made to be of equal durations, lasting for one hour. Figure 3 shows the scheme adopted for the pumping rates in step-drawdown test for well-3, consisting of the three steps:

Figure 3: Pumping test in progress at the study area

IV. RESULTS AND DISCUSSIONS

A. THE RESULTS OBTAINED IN THE STUDY ARE HERE DISCUSSED

B. ESTIMATION OF SPECIFIC CAPACITY

Specific capacity is the measure of the well efficiency which is the quantity of water a well can produce per unit of drawdown. Following after Bierschenk (1963), the investigatory well's specific capacity was obtained thus,

$$Sc = Q/\ ho\text{-}h, \quad (1)$$

Where,

Sc is the specific capacity (m^2/day),

Q is the pumping rate (in m^3/ day) which was maintained at 18.7m^3/hr,

h_o-h is the well drawdown during pumping, which was, 20.7- 0 = 20.7m,

It therefore follows from Equation (1) that,

$$Sc = (Q/ho\text{-}h) = 18.7/20.7\ m^2/hr = 0.91 m^2/hr$$

This results shows that the well will operate at 0.91% efficiency at approximately 18m^3/hr

C. ESTIMATION OF TRANSMISSIVITY (T)

Transmissibility (T) of an aquifer is the rate at which water is transmitted through an aquifer under a unit width and a unit hydraulic gradient. The initial Specific Capacity value is often used to estimate the transmissibility (T) of the aquifer. It equals the aquifer's hydraulic conductivity (K) times the aquifer thickness (b). i.e.

$$T = k\,b$$

Or

$$T = \frac{Q}{2\pi(S_1 - S_2)} \ln\left(\frac{r_2}{r_1}\right)$$

Normally, the higher the transmissibility, the greater the capability of the aquifer to move water into the well and also lower the drawdown in the well.

Using the approach of Theis (1930), the aquifer's transmissivity was evaluated at the pumping well, thus;

$$T = \frac{Q}{4\pi s} W(u)$$

And the storativity was obtained from,

$$S = \frac{4Tut}{r^2}$$

where T is transmissivity (m^2/day); Q is pumping rate (m^3/day); s is drawdown (m); W(u) is Theis well function (dimensionless); u is time parameter (dimensionless); t is elapsed time (minutes); r is radius (m); S is storativity (dimensionless)

Following after Driscoll (1986), Equation (3), we estimated the transmissibility of the investigatory well, thus,

For a confined aquifer:

$$T = 185.8 * Q/s. \quad (4)$$

Where,

R is transmissibility and Q/s is the Specific Capacity (in m^2/hr),

Hence,

$T = 0.91 \times 185.8 = 167.2\ m^2/hr$

This obtained value of transmissibility is within the range of values (from 92 - 450 m^2/hr) obtained in the Niger Delta by previous.

a. PUMP TEST DELIVERABLES

The well Well specific capacity 0.91m^2 per hour.

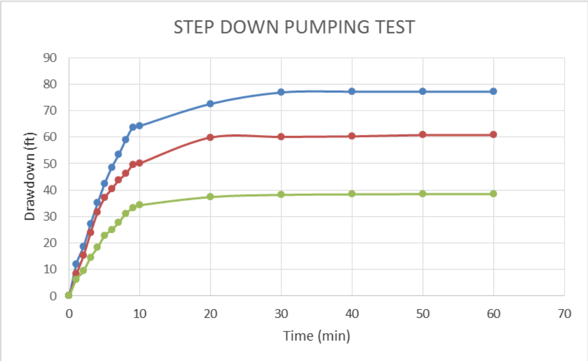
The Dynamic water level was 20.1 meters.

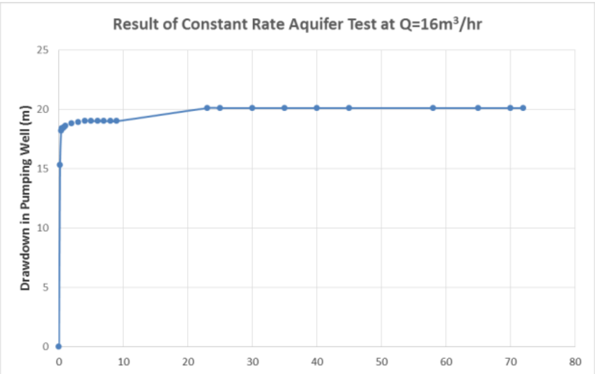
The Draw down was 20.1 meters

The Well yield was 16m^3 per hour using specified pump

The Recovery time was 2 min 31 sec

The Transmissibility of well aquifer was 167.2 m^2 per hour





V. CONCLUSION AND RECOMMENDATIONS

From the investigation carried out in this study, we make the following conclusions and recommendations.

A. FINDINGS

Pumping test has been carried out in this study. A pumping consists of pumping groundwater from a well, usually at a constant rate, and measuring the change in water level (drawdown) in the pumping well and any nearby wells (observation wells) or surface water bodies during and after pumping. Two types of pumping tests were performed in this study, well constant rate pumping test and step down pumping test. Constant rate pumping test was performed by pumping groundwater from the newly constructed well at constant rate of 16 m^3 / hr for 72 hours. Pumping rates for three step down tests were carried out for one hour at a pumping rate of 23.44, 16.07 and 12.09 m^3 per hour respectively.. During this period, the abstraction flow rate and groundwater level in the investigatory well and all the monitoring wells were recorded at the same frequency.At the end of the pump test operation, it was observed that the Pumping of well-3 had no impact on the performance of the two previously drilled wells at the study area (Head Office complex of the NLNG).

The maximum safe yield, defined as, the capacity of an aquifer to supply water without causing a continuous lowering of the water table or piezometric surface, is not affected by the abstraction of water from the well. Since no drawdown was noticed in the observation well during pumping test, it implies that pumping this investigatory well at about 18 cubic meter per hour will not affect the well field or other boreholes around the study area. This is to say that the rate at which the ground water is replenished by rainfall and other sources is higher than water extraction from well three.

The transmissibility of well three was noticed to be quite high, this of course implies that the aquifer is capable of transmitting 185.8 cubic meter of water per meter per day. This very high volume of water can be transmitted into the well through the aquifer. The problem of over pumping is therefore very unlikely for this well at the 18 cubic meters per day or less.

The well can be pumped for a very long time without affecting the aquifer and surrounding wells.

As an artesian well, the draw down on this borehole was initially rapid but stabilised after few minutes.

Since the piezometric head for pumping with 15 cubic meter per hour pump did not provide significant drawdown, the possibility of saline water intrusion is very minimal.

The recommended depth of pump is 50 meters.

B. RECOMMENDATION

It is recommended that Specific Capacity testing should be performed at least annually and water levels (static and pumping) should be collected to provide early detection of potential well problems. Rehabilitation work should be scheduled when a well's Specific Capacity drops by 15% or more.

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