THE OCCURRENCE AND EXPLOITATION OF GROUNDWATER IN WESTERN NIGERIA

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1.1 Most of the water which enters the surface of the earth as precipitation, for geological reasons and other factors, is unable to infiltrate very deeply into the ground, and soon reappears as run-off. But a smaller part percolates through and remains in storage for varying periods. All the water that exists below the surface of the solid earth is described as "subsurface water". Ground water is that part of the subsurface water which is in the zone of saturation. This definition of ground water by O. E. Meinzer (Water Supply Paper 489 pp.38 & 39) clearly embraces free ground water and pressure or confined water; as both are in the zone of saturation.

(*a*) **Free ground water:** This is water which occurs in the 'upper' zone of saturation, under a pressure not greater than the atmosphere. The aquifer containing the water is described as an un-confined aquifer. Most wells in Nigeria derive their water from unconfined aquifers. The upper zone of saturation is the water table and it is usually the level of water in a well penetrating the aquifer. The water table is not always horizontal; it undulates gently and may follow the general configuration of the ground profile.

(b) **Pressure or Confined Water:** This is under a pressure exceeding that of the atmosphere at its upper surface and occurs at the deeper zone of saturation and when penetrated by a well or bore, the water will rise to that of free water in the unconfined zone. If it rises to reach the surface, it is known as artesian, otherwise as "sub-artesian" water. Fluctuations in the levels of water in wells penetrating confined aquifers result primarily from changes in pressure rather than changes in storage volumes. Occasionally the piesometric surface falls below the bottom of the confining bed, and an unconfined aquifer results.

1.2. Small quantities of water can be encountered in what are commonly known as perched aquifers. They occur when water is trapped by impervious layers before it reaches the zone of saturation. Usually perched aquifers are found in alluvial flats, where lenses of clay or shale are present above the main water bearing aquifers. These layers obstruct the downward movement of water. They are also found in more solid formations where cracks and pore spaces are cut off from the main aquifer.

1.3. Springs are natural discharges from ground water reservoir and are classfied according to the character of the opening through which they emerge. Some examples are contact, fissure, fracture, depression and solution springs.
Springs may occur in practically any type of country but are usually situated at points of emergence of the water table by reason of the existence of an impervious layer which obstructs the downward movement of the water. They are good indications of the occurrence of ground water in any locality.

1.4. Ground water occurrence in an area is dependent on several factors chief of which are its geology, rainfall, topography and vegetation. Though much can be gained by a thorough examination of rock exposure as regards its water

bearing qualities; a wild statement based on superficial rock exposure alone is fraught with uncertainties. A geological section of the strata is the more reliable way of ascertaining the ground water occurrence of any region. In Nigeria, there is very little knowledge available on the thickness of the underlying formations, and their characteristics. There may be isolated cases in recent years of some data obtained during exploration for oil, and in the coal mining areas of the Eastern Region and tin mining areas of the Plateau. Most wells and bore holes were carried out by inexperienced hands; and very little data, if any, were collected as regards the geological section of the formation where the wells or bores are located. A beginning has been made in recording useful information on the type of rock formations encountered during boring in some parts of the country.

PRELIMINARY INVESTIGATION FOR GROUNDWATER SOURCES

2.1. The Western Nigeria five-year Development Programme has intensified our search for groundwater sources as the most economical source of water for rural areas. The main advantage from the point of view of cost is that there is no need for the construction of expensive dams and intakes, only disinfection with chlorine is necessary because of the purity of water obtained from the boreholes. On the other hand, water derived from surface sources is often badly poluted. Unfortunately groundwater occurrence is confined to only a part of the Country and therefore in general both surface and subsurface sources are used. Definite preference is, however given to groundwater sources where both surface and subsurface sources are available.

2.2. Whenever a town is scheduled for a water supply, its location will predetermine the type of supply to a certain extent. The routine therefore is to find out whether it is situated in any of the following geological regions — Fig. 1.

Post Aocene Coastal Plains (The Coastal Area)

2.3. This belt stretches from the Dahomey Boundary with varying widths until it is lost in the Niger Delta. The sandy terrain is of low elevation. Some seventy five miles east of Lagos, there is a characteristic change from sand to mud with a corresponding change to swamp.

2.4. Shallow wells to a depth of 20 — 30 feet will produce potable water. Some attempts to obtain water from greater depths often as deep as 900 ft. have been abandoned because of salt water intrusion.

Pleistocene:-

2.5. This is composed of mainly alluvium, gravels, sands and clays. The sandy bed is several hundreds of feet thick and it is extremely porous. In the wetter parts of this area, shallow tube wells have proved successful. About 400 such wells have been constructed and equipped with manually operated pumps. These wells are inexpensive and are quite easily installed screens are fixed round the well point to prevent sand intrusion. The water obtained from these wells is of good quality as it has been effectively filtered through sandy layers. In the drier parts of the Delta, boreholes of medium depths (250 — 400'), and in some cases with a sub-artesian rise of 200' have yielded as much as 10,000 g.p.h. The water from these boreholes is acidic with pH often as low as 4.5.

The Aocene Tertiary: (The Dissected Margin)

2.6. This is composed of the land mass hedged between the Niger Delta (stret-

ching westwards) and the Precambrian Basement Complex of the Western Plains forming the Northern Boundary. Boreholes with yields varying from 800 g.p.h. to 500 g.p.h. have been obtained. The yield decreases with the approach to the crystalline boundary of the Precambrian series.

Precambrian Basement (The Western Plains)

2.7. These are composed of ancient matamorphic crystalline rocks and are interspersed by streaks of quartzite and Schist. Most rocks of Precambrian origin are impermeable, but the shear zones cleavage and fissures usually attributed to them provide ample space for groundwater storage. Very little drilling has been carried out in this basement complex as in the absence of any geophysical and hydrological surveys it is not easy to predict the occurrence of waterbearing faults or fissures.

2.8. It would be seen from the foregoing that the location of a town to be supplied with water from subsurface sources is very important. If the town is located in the Precambrian Basement complex boreholes are often ruled out. If situated in coastal areas, the Niger Delta or in the Eocene Tertiary belt then further considerations would have to be given to the supply from a borehole, a dug well or well point depending on the quantity of water required. The same is true to a lesser extent for the coastal plains and Eocene Tertiary area.

2.9. These geological areas are ill-defined because :-

(*a*) the areal extent of the bed-rock formation is not yet fully known.

(b) the lithographic characteristics of the water-bearing formations in many cases are still to be studied.

and (*c*) there are wide variations in the superficial rock formations within the same group. Inspite of these anomalies, the occurrence of groundwater follows the broad patterns exhibited by the superficial geology as indicated.

2.10. Having decided, from geological considerations, that the town is situated in a favourable groundwater location the next step is to study the available well or borehole data in the locality. This is not always found easy because of the deplorable scantiness of existing data. It is however often possible to get local information about dug wells from the inhabitants though depths of wells and time of construction are often exaggerated. If the stories narrated by the people correlate with geological characteristics of the area, then a decision is taken to either make an exploratory drilling or carry on with drilling of a borehole.

WESTERN NIGERIA BOREHOLE SUPPLY PRACTICE

3.1. Villages and towns with populations varying from 200 to over 30,000 are being supplied from well points and boreholes respectively. The decision to supply a town with ground water is usually based on a favourable geological and hydrological location. The quantity of water required is also a governing factor. Before the commencement of drilling operations, the Engineer in Charge of investigation would study very carefully all existing logs from boreholes and wells in the vicinity. His investigation will include the following :-

(*a*) (*i*) An examination of the combined pumpage of water from other boreholes and wells in the neighbourhood.

(*ii*) Whether there is an adequate replenishment of the water with-

drawn from the formation.

(*iii*) The collection of water from existing boreholes for analyses of their chemical and bacteriological properties. This is very important from the point of view of corrosion and encrustation. The physical properties such as odour and colour are also noted.

(*b*) A thorough consideration of the best borehole to develop the maximum yield with the least drawdown. In many instances an accurate assessment of conditions leading to this ideal is often impossible because ground conditions may vary structurally within a short instance. Because of these possible geological changes, it is unsatisfactory to rely entirely on logs from neighbouring wells to the extent of forecasting the type of water bearing formation likely to be encountered. Reference to logs from nearby boreholes are useful just as a guide; and cannot be regarded as conclusive.

(*c*) An examination of the quality and cost of materials to be used for a particular well. The ability of a material to resist corrosion and encrustation is usually examined in conjunction with its strength to withstand formation pressures. This is most important in the selection of metals for casings, and screens used in our water which has a pH varying from only 4.4 to 7 in many boreholes so far drilled in the Region. Serious consideration has been given to the use of acid resisting metals for these casings and screens despite higher capital expenditure. There were a few bitter experiences in the country such as at Agbor and Warri where expensive boreholes have had to be abandoned because they collapsed as a result of corroded casings and screens.

BOREHOLE DRILLING IN WESTERN NIGERIA

3.2 The entire programme for borehole drilling has been assigned to a firm of contractors because of shortage of technical staff. Planning and Supervisory duties are carried out by the Ministry's staff.

3.3. I have emphasised the handicap due to scantiness of hydrogeological data; and since the gigantic five-year Development Programme cannot be held up because of this, the practice now is to confine drilling to areas with favourable geological formations. Time factor has made any exploratory test drilling virtually impossible. The location of a borehole even in a geologically favourable area is chancy-and there is no sufficient guarantee that water of adequate quantity shall be struck. It is not uncommon to drill far deeper than expected where the exhibited geological patterns indicated otherwise. In many instances predictions about depths of boreholes, the quantity and quality of water obtainable have been found to be almost exact, but there are a few instances where as much as 50—100 ft. difference of estimated depth have occurred. Also estimated possible yields have been inaccurate in a few cases.

3.4. These unexpected results have been due mainly to unforeseen local variations in the strataand the transmissibility of the aquifers encountered. A thorough exploratory investigation including the use of geophysical survey equipment could have helped in forecasting more reliable results. Some expensive holes have been abandoned because of failure to strike water at desirable depths. Since no guarantee of yield is included in the contract, the employer has to pay for the cost of any futile drilling.

3.5. When considering groundwater supply on a widespread scale, some mention ought to be made about the methods employed in drilling. Broadly, two main methods are used.

3.6. Percussion drilling is used more often in Western Nigeria because of the ease with which it can be adapted to a wide range of soil and geological conditions existing in the Country. When speed is the criterion, a rotary rig is preferred. From the point of view of the contractor, speed is very important especially when rotary drilling is almost ten times as fast as percussion drilling where other factors are similar.

3.7. I have observed that aquifers are much easier to detect with a percussion rig than with a rotary rig since the amount of water used in percussion drilling is much less than that required for rotary drilling.

3.8. These rigs are often used in very difficult country, and because of this, percussion rigs which are lighter and much easier to handle have a striking advantage over rotary rigs which require quite a lot of preparation before the commencement of drilling. Added to this is the capital cost of the rotary rig which is about four-times that of a percussion rig.

3.9. Occasionally and for some reasons, instructions are passed to drilling contractors to stop work in a particular hole. If a rotary rig is employed, any stoppage for a length of time could result in losing the hole, a continuous drilling is therefore preferred with a percussion rig, stoppage for the same period is not likely to result in any serious mishap.

3.10. Where large thicknesses of very weak strata such as sand occur, it is much easier to use a rotary drill. This condition occurs in the Delta provinces.

3.11. I would like to quote Mr. W. R. W. Ferguson an authority on Rural Water Supplies in Northern Nigeria and Ghana on the performances of both types of drilling rigs in different geological strata.

Formation	*Percussion*	*Rotary*
Dunesand	Difficult	Fast
Sand and Gravels	"	"
Boulders in Alluvial plains	"	"
Clay and Silts	Reasonable	"
Shales	Fast	"
Poorly Cemented Sandstones	Fair	Slow
Limestones	Fast	Fast
Chalk with flint boulders	Fast	Slow
Fissured formations	Fair	Slow and very difficult.
Granites	Slow	Slow and expensive.

It is considered that when drilling between 250—450', a percussion rig would be more suitable. For weak grounds and deeper holes, a rotary rig ought to be used. Generally a percussion rig is preferred where details of strata are unknown.

LOGS FROM BOREHOLES

4.1 One of the conditions of contract stipulates that samples of soil and rock

taken when drilling through various strata should be identified by the contractor. The same samples should also be sent to the Geological Survey Department for identification and analysis. This ensures that all samples are cross checked.

4.2. The contractor forwards its report on soil and rock samples to the Chief Water Engineer in the Ministry of Works and Transport. The same is done by the Geological Survey Department. All samples are permanently kept in the Geological Survey Department where an archive is provided for this purpose. All records of boreholes and wells drilled in the region and in Nigeria as a whole can be readily obtained from the Geological Survey Department. Apart from the immediate usefulness of the records obtained when drilling a particular hole, the hydrogeological Survey of the Country would have some data to draw upon when such an enterprise is embarked upon in the future.

The Contractor is also required to furnish the Water Supplies Division with a copy of the illustrative diagrams of the geological formation penetrated, the static water level and the proposed positioning of the submersible pump. Fig. 2 is a typical Geological index for borehole sections, and Fig. 3 is a typical section obtained from a borehole drilled at Ikeja area Lagos.

4.3. Once the contractor reports the completion of a borehole, an Engineer from the Water Supplies Division is asked to measure the depth of the borehole in order to evaluate payment to the Contractor. He is also expected to measure the verticality of the hole which should not be more than 4 ins. 100 Ft.

4.4. The measurement of the depth was usually carried out by using a heavy weight or float attached to the end of a steel tape. An error of two to six inches often resulted when this method of measurement was employed as its accuracy depended on the kind of metal used for the tape and on whether the weighted end would float or not. The accuracy of measurement is important not only for evaluating payment to the Drilling Contractors but also for fixing pumping levels for various capacities. It is also essential for determining power costs and the proper setting of pump bowls.

4.5. Early in 1962 an electrical gadget was ordered for the measurement of depth of boreholes to the top water level. It is also used for measuring the depth of the aquifer. In this method flashlight batteries are made to generate electric current. A shielded electrode is suspended by a pair of insulated wires. When the electrode touches the water surface, the indicator of a voltmeter flicks, thus registering a closed circuit. It is advisable to leave the cable and electrode hanging in the well between readings in order to avoid introducing errors which may be caused by bending the wire in an attempt to pull it out — and let it down again. This device has been found to be quite accurate, quick and easy to manipulate (Fig.4).

4.6. Readings obtained are usually certified by both the Engineer and the Contractor before the Engineer leaves the site.

4.7. The information required of the contractor includes the following :-

(1) The location of the borehole.
(2) The Boring No.
(3) Ground Level O.D.
(4) Type of boring

(5) Inclination and bearing of hole
(6) Type of lining tube
(7) Date started and completed
(8) The description of each rock type and depth below the surface
(9) Thickness of each soil and rock type.
(10) O.D. of Lower Contact.
(11) Levels and limits of zone in rock which show definite characteristics such as well — marked joints or shear planes.
(12) Level at which water is struck
(13) Level at which water rises in borings and rate of rise.
(14) Level at which circulating water is lost as this shows presence of open fissures or porous strata.

4.8. Negligence on the part of the contractors to record any or all of these essential information during drilling has caused them some time and financial losses, A typical example was with the borehole drilled at Ilaro. This happened when the driller rushed to the office to complain that he had used more than five times the required quantity of gravel without any appreciable rise in level of the gravel pack. A closer study revealed that a fault had been struck just below the final level of the gravel pack. The drillers noticed this during drilling but failed to record the level of the open fissure.

4.9. It was finally agreed that the gravel packing be continued until the level rose. The gravel pack was left for a period of a month to see whether there would be any further loss or settlement. Fortunately there was no further settlement after a month.

PHYSICAL AND CHEMICAL ANALYSES OF WATER SAMPLES FROM BOREHOLES

5.1. A very important aspect of the responsibility of the Ministry is to see that all water, raw or otherwise ultimately meant for human consumption is thoroughly tested both qualitatively and quantitatively. These tests are carried out by the Government analyst at Ibadan or Lagos where there are well-equipped laboratories for the purpose. In order to obtain very useful information, analysis of the water is usually conducted from the stand-point of its corrosiveness or incrustation with reference to the type of casing and screens to be installed. Since ordinary mineral analysis does not furnish all the information required, the dissolved gases, the degree of acidity or alkalinity are given special consideration.

Method of collecting samples from boreholes:

5.2. In order to avoid stagnant ground water, samples are usually collected from boreholes after pumping for some time. Samples are usually collected in two clean jars of a quart capacity each. The jars are thoroughly rinsed with the water obtained from the source before the sample is taken. The jars are then securely covered and identified by the location of the borehole, the date of sampling, name of driller, depth of borehole, static water level and the drawdown. A record is made on the site of any peculiar odour or colour.

5.3. The reports of the analyses are sent to the Ministry of Works and Transport for interpretation. It is here that a decision is taken as to whether the water should be treated on a large scale to remove odours, tastes, hardness, and dissolved

gases. It is more especially important to base the selection of metals used for casings, screens, pump parts on the findings of the chemist.

5.4. It is advisable to take samples at regular intervals in order to obtain a representative quality of the water at various cross — sections.

5.5. Three chemical analyses of water from three different boreholes are recorded below :-

(*a*) *Iboro I*

Date 16/8/60

CHEMICAL ANALYSIS.

Lab. No.	WCAO. 4
Sample	Borehole Water
Description	Clear, colourless, with very fine brown deposit.
Colour (Hazen Units)	5
	Parts per Million.
Chlorides as Cl.	33
Chlorides as NaCI	54. 5
Total Alkalinity and $CaCO_3$	20
Total hardness as $CaCO_3$	139
including Ca as $CaCO_3$	84
Sulphates as $Na_2 SO_4$	Trace
Silica as SiO_2	14
Iron in solution	0. 04
Nitrogen	
Ammoniacal	0.013
Albuminoid	0. 01
Nitrite	0. 03
Nitrate	20
Oxygen absorbed in 3 hours at 37°C from permanganate	0. 33
Total solids dried at 180°C for 1 hour	3001
pH. Value	5. 5

Acidity (mls 0.5% $Na_2 CO_3$ /per 100 miles sample).

(b) *Ibeshe Borehole I.*

Lab. No.	—	15/10/60
Sample	—	WCAP 6.
Description	—	Borehole Water
Colour (Hazen Units)		Opalescent, yellowish 70.
		Parts per Million.
Chlorides as Cl.		42
Chlorides as NaCl.		69
Total Alkalinity as $CaCO_3$		290
Total Hardness as $CaCO_3$		290
Including Ca. as $CaCO_3$		105
Sulphates as $Na_2 SO_4$		Trace
Silica as SiO_2		18
Iron in Solution		0. 1
Nitrogen		
Ammoniacal		0. 16

Albuminoid	0.007
Nitrite	0.001
Nitrate	0. 5
Oxygen absorbed in 3 hours at 37°C from permanganate	0. 75
Total Solids dried at	180°C — 680
Dissolved Solids	180
Total Solids after gentle ignition	480
pH. Value	7. 0
Acidity (miles 0.5% $Na_2 CO_3$ per 100 miles samples) —	2. 1

(c) *Asbestos Cement Factory* 14/4/61

Lab. No.	WCC 1
Sample	Borehole
Description	Slightly opalescent with few deposits.
	Parts per Million.
Chlorides as Cl	8
Chlorides as NaCl.	13
Total Alkalinity as $CaCO_3$	5
Total Hardness as $CaCO_3$	5
including Cas as $CaCO_3$	2. 5
Sulphates as $Na_2 SO_4$	Absent
Silica as SiO_2	5
Iron in Solution	0. 04
Nitrogen	
Ammoniacal	0.002
Albuminoid	0.002
Nitrite	0.001
Nitrate	0. 5
Oxygen absorbed in 3 hours at 37°C from permanganate	0. 5
Total Solids dried at 180°C for 1 hour.	40
pH. Value	4. 4
Acidity miles 0.5% $Na_2 CO_3$ per 100 miles sample —	5.

5.6. The chemical and physical analyses of the water obtained from Iboro I. and the borehole drilled at the Asbestos Cement Factory indicate that the water is highly corrosive. The presence of chlorides in higher quantity would still have added to the corrosiveness of the water.

5.7. The water from Iboro Borehole is purely for domestic usage and the total hardness obtained does not justify expenses on installation for softening processes. The total hardness of the sample from the Asbestos Cement Factory is insignificant and the water is quite suitable.

5.8. The sample obtained from Ibeshe Borehole I. has the highest pH. value of all samples so far obtained from boreholes already drilled in the region. On the other hand the proportion of total dissolved solids is one of the highest so far recorded anywhere from boreholes in the region.

An important deduction from the results is the salinity of the three samples.

(*i*) Iboro Borehole I

NaCl. — 54.5 ppm.

(*ii*) Ibeshe Borehole I
NaCl. — 69 ppm.

(*iii*) Borehole for the Asbestos Cement Factory.
NaCl. — 13 ppm.

5.9. Even though the borehole for the Asbestos Cement Factory is nearer the coast than the other two boreholes, its salinity is considerably less. This was hardly expected.

5.10. It is hardly surprising to discover that both boreholes at Iboro and Ibehse contain a certain amount of $CaCO_3$ in view of the established fact that there are large deposits of lime in the district where the boreholes are located. Eweko Cement Factory has been constructed in the area.

5.11. The results of the chemical analyses of samples A and C and the majority of boreholes in the region have brought home to us the unpleasant fact that we have to spend more in order to combat the corrosiveness of our water. The use of steel casing is now fully discouraged inspite of its low cost when compared with other anti-corrosive casings. Consideration is being given to the use of :-

(*i*) Glass — Fibre liner pipes with plastic screen
(*ii*) Liner pipes and Screen both of Noral A 56S.
(An aluminium — Magnesium — manganese alloy).
(*iii*) Asbestos Cement liner pipes with Everdur Screen.

An attempt to use flexo-plastic pipes for casings failed because :-

(*a*) the pipes were of poor standard and were not manufactured in accordance with the specification required.
(*b*) Method of jointing was unsatisfactory. The Asbestos Cement pipes used for lining a borehole at Badagry crashed mainly because the contractors were inexperienced in the use of these pipes.

5.12. Cathodic protection had been considered and it was felt that this should be an added safeguard to the use of the most resistant materials.

5.13. Another possible, but expensive solution is to install a double lining of mild steel with annular space filled with a neat cement grout.

5.14. Pumps cased in zinc free bronze and an insulating washer in Neoprene or Tufnol used between the pump and the steel rising main would no doubt lengthen the lives of the pumps. Neurosta screens already acclaimed for its anti-corrosive properties is now being installed.

MEASUREMENT OF YIELD

5.15. Yield tests are scrupulously carried out in order to ensure that only boreholes of proved yields are developed. Apart from the determination of the specific capacity i.e. the yield of a well per foot of drawdown, we are interested in (*a*) the maximum theoretical yield i.e. the yield at maximum drawdown. and (b) the maxium practical yield i.e. the yield at the practical limit of drawdown.

5.16. The practical drawdown is the distance between the T.W.L. in the bore-

hole to the top of the well screen. Pumping below the top of the screen dewaters that much distance of the screen which therefore contributes practically nothing to the yield. At the same time, the formation immediately surrounding the screen is also dewatered and nearly all the flow would pass through a reduced thickness of sand.

5.17. Yield tests, to serve any useful purpose, are conducted after several days of pumping. It has been found that pumping tests carried out within a short time of completion of drilling have in some instances, differed by as much as 30% when the test is again carried out after several days of pumping. We have tried in the past to measure yield by the volumetric method. Late a rectangular or triangular weir was used. Recently, however, the orifice meter method has been standardised upon. The volumetric and weir methods are rather cumbersome. On the other hand Circular orifice weir is compact, easy to install and reasonably accurate.

5.18. The method of measurement is illustrated in Fig. 5. In order to achieve a high standard of accuracy, the following precautions are taken during measurements :-

(*a*) The discharge pipe is supported in a horizontal position.
(b) The discharge is free and without any obstructions.
(*c*) The edges of the orifice opening are sharp and clean; and chamfered to 45° with the upstream sharp edge.
(*d*) The head measuring device must not protrude beyond the inside surface of the pipe and must be free from air bubbles.
(*e*) The piezometric connection must be perpendicular to the discharge pipe when readings are taken.
(*g*) Calibration charts are checked prior to commencement of tests.

5.19. After pumping has started, the drawdown is measured by the electrical sounder which has been previously described. Experience has shown that it is practically impossible to obtain the same drawdown measurement as the water level is constantly moving, but generally downwards. When about three readings within the hour show no appreciable change, it is assumed that equilibrium conditions have been reached.

5.20. After pumping, recovery of levels is usually taken at intervals; and a recovery diagram plotted.

5.21. Water discharged during yield tests is channelled to a distance where recirculation is virtually impossible. At Sabongida and Igbogilla where the boreholes are artesian; temporary connections were made to a few stand-pipes to supply the inhabitants before the construction of the reticulations for the towns.

THE DESIGN OF RURAL WATER SUPPLIES SCHEMES

6.1. Two important conditions must be satisfied prior to the design of any scheme based on a borehole supply :-

(*a*) A guaranteed yield from the borehole
and (b) The depth of the static Water Level from the ground surface must be such as to permit economic pumping.

These two conditions have been fulfilled in many boreholes so far drilled in the region. Notable exceptions were Ijebu-Ode and Meko Boreholes where yields

were poor. At Atan granite was struck at a depth of 45 ft; and the hole had to be abandoned. It was therefore necessary to resort to alternative sources of supply inspite of the expenditure of over £5,000 on drilling the three boreholes.

6.2. On the other hand, the depth of static water level invariably affects the pumping costs. Two deep boreholes drilled at Ogbona (710 ft.) and Fugar (525 ft.) have T.W.L.S of 520 ft and 432 ft respectively. Apart from pumping costs, the cost of drilling is considerably greater — and attempts may be made for alternative surface sources of supply.

6.3. Once a decision has been made to develop a borehole, basic calculations are made on the assumption that the life of the supply would be about twenty years. Two boreholes are usually provided for each scheme. In large undertakings three or four boreholes may be used. This arrangement allows for about 50 — 100% stand-by.

6.4. The schemes are designed for an ultimate consumption of 10 gallons per head per day based on "20 - year projected" population figures. In brief the Engineering design can conveniently be divided into three phases :-

(a) The design of the screens, casings, and the pumps.
(b) The Treatment
(*c*) The Reticulation.

The Hydraulics of Wells

6.5. The fundamental relationship between yield and drawdown can be obtained from the formula

$$Q = K' \frac{H^2 - h^2}{\log \frac{R}{\frac{}{2}}} \quad \text{and}$$

$$Q = 2\,K't\,\frac{H - h}{\log \frac{R}{\frac{}{r}}}$$ for unconfined and confined aquifers respectively where.

Q = The discharge in gallons per day
K' = A constant varying with the fineness and porosity of the formation.
H = The static head or distance from the static water level to an impervious stratum.
h = The distance from the pumping level outside of well casing to the bottom of the well.
H—h — The drawdown or amount of lowering due to pumping.
R = The radius of the circle of influence in feet.
r = The radius of the well in feet.
and t = The thickness of water bearing stratum.

A further consideration of the basic formula on the assumption that H and h are nearly equal, would mean that

$$Q = \frac{K'\,(H+h)\,(H-h)}{\log \frac{R}{\frac{}{r}}}$$

can be expressed more simply as equal to

$$\frac{2K' H(H - h)}{\log \frac{R}{r}}$$

This indicates that Q is proportional to the depth of water H, the drawdown H —h and to log $\frac{R}{r}$. It is sufficient for practical purposes for the "direct proportions" relationship between yield and drawdown to be used in computations provided that the drawdown is small compared with the total static depth.

6.6. Where drawdown is a considerable portion of the total static depth the relationship is that of a curve rather than that of direct proportion. The curve interpreting these relationships for both artesian and non-artesian wells are shown at Fig.6. That for Artesian is practically a straight line and that for a non-artesian well is a curve.

6.7. The relationship of yield to drawdown in a borehole plays an important part in the selection of screen to be used for the borehole. It also gives an indication as to where best to fix the pump.

6.8. As an example, from the curve for a non-artesian borehole a drawdown of about 60% would mean about 85% relative yield and about 40% of the depth would still be available for the screen. If the maximum depth of water were 50 Ft; a screen length of 20 ft. may be chosen. The relative yield is however determined such that over-pumping is avoided at all costs.

6.9. After obtaining the length of the screen; a reasonable entrance velocity of water to the screen is between 0.10 to 0.25 ft/Sec. Higher velocities are avoided as much as possible. If entrance velocity obtained is too high, the easiest way of reducing the entrance velocity for a given slot opening is to increase the screen length or its diameter.

6.10. In designing the most suitable screen for a borehole due cognisance is taken of the availability of suitable materials for gravel packing. The gravel should consist of well — rounded pebbles with minimum size less than the aperture of the screen.

The borehole is constructed such that the gravel can be replaced from the surface when required.

6.11. Optimum entrance velocity should be chosen such that sand-carrying would be reduced to the minimum. Since the portion of the screen above the pumping level would serve no useful purpose, the position of the screen is chosen also in consideration of the actual position of the pump when installed. The useful life of the screen is endangered if any portion of it is inserted above the pumping level as it will be exposed to air which contributes to the rate of corrosion and incrustation. Care is usually taken to avoid the use of too long a screen for economic reason in addition to the other reasons given above, It is also false economy to use screens which are too short.

Pumps:

6.12. The choice of pumps is governed by the three main operating conditions :-

(*a*) Quantity of water to be delivered by the pump.

(b) The total lift.
(c) The speed.

Sumo-submersible pumps were used in many boreholes; but K.S.B. pumps have recently been decided upon because our experience with sumo pumps has not been satisfactory especially with regard to maintenance and the purchase of spare parts.

The pump is run continuously for not less than one hour and not more than six hours. Speed is measured with a tachometer. The discharge and head measurements are usually carried out as previously described.

6.13. Variable speed drive is preferred for the pumps in order that maximum efficiency can be maintained especially in view of the variable conditions that are likely to be met during operation; an example of which is the seasonal fluctuation in water levels.

6.14. No treatment is incorporated in the supplies because of the high purity of the water obtained from the boreholes.

6.15. Reticulation consists of the rising main which delivers water to a reservoir capable of half a day's supply. Water is distributed by gravity to different parts of the town. Asbestos cement pipes are normally used with diameter ranging from a minimum of 3" diameter to a maximum of 8" diameter. Standpipes are located such that :-

(a) Nobody is obliged to walk for more than 200 yds. to the nearest standpipe.
(b) Not more than 400 people would be served by one standpipe.

SUMMARY — ANALYSIS OF DRILLING RESULTS ETC

7.1. Groundwater cannot be economically exploited unless there is an adequate knowledge of the quantity available and where it can be found. This knowledge can be acquired either by :-

(a) Embarking on a country-wide investigation for groundwater.
or (b) By a gradual collection of hydrogeological data during the process of exploitation. Alternative (a) though preferable is very expensive. On the other hand alternative (b) is a slow process which will take years to achieve.

7.2. The Federal Geological Survey has produced a report on groundwater occurrence in Western Nigeria based on the interpretation of available logs from existing wells and boreholes.

7.3. The distribution of groundwater broadly follows the geological pattern exhibited in various parts of the country. Results obtained from boreholes recently drilled have been very convincing in this respect. The geological map Fig. 1 shows some of the boreholes drilled within the past two years. Nearly all boreholes drilled in the Bende Ameki Group have been successful. This bed stretches from the Coast near Lagos to some point inland and runs parallel to the Coast through Abeokuta, north of Ijebu-Ode and from here slowly converges to a narrow strip towards the River Niger. The rock varies in composition; and it is often a mixture of sand, gravel and clay. The success of any bore depends on which of the three predominates. The following is a list of some of the boreholes drilled in this formation :-

Name of Borehole	*Depth of Borehole*	*Static Water Level*	*Yield G.P.H.*
Aiyetoro	179 ft.	69'— 0"	4,200
Iboro	110 "	34'— 0"	8,000
Ishaga	252 "	66'— 0"	6,900
Ilaro	436 "	68'— 0"	5,900
Ado-Odo	316'—8"	60'— 8"	10,000
Maryland	315'	81'— 0"	10,000
Mushin	380'—7"	55'— 0"	7,300
Ibegun	95'—0"	9'—10"	10,950
Ijebu-Ode	203'	154'— 0"	2,400
Imushin	253'	173'	7,800
Igbogilla	235'—0"	34'— 0"	5,000

7.4. Boreholes situated on the boundary of this geological formation and the Basement Complex which consist mainly of granites have poor yields even when successful. They are :-

Name of Borehole	*Depth of Borehole*	*Static Water Level*	*Yield G.P.H.*
Meko	193'	141'— 0"	360
Atan	35'—0"	Abandoned	
Ijebu-Ode I.	203'—0"	154'— 0"	2,370
Ijebu-Ode II	6'—0"	Abandoned	
Ijebu-Ode III	180'—0"	"	

The poor yield was expected, and the other boreholes, Ijebu-Ode II and III. proved conclusively that a more thorough investigation is required for boreholes drilled near the boundary with the Basement Complex.

7.5. Success has attended drilling in the Post Eocene (teritiary) Coastal plains sands and lignite series. The sand bed here is several hundreds of feet thick and is extremely porous. The lignite series appears in shallow lenticular beds of shales and clays and often gives rise to springs when it crops out of the surface.

7.6. The statistics of the few boreholes recently drilled in this geological area are :-

Name of Borehole	*Depth of Borehole*	*Static W.L.*	*Yield G.P.H.*
Benin	206'	0'—6"	15,000
Asaba I	150'	74'—0"	21,000
Asaba II	149'	80'—0"	21,300
Ogwashi-Uku	299'	Abandoned	

This belt is a prolific source of water. Ogwashi-Uku produced a freak result — and the explanation is that the borehole was drilled where there is a local geological variation from that of the surounding area.

7.7. Very little success was achieved in the upper and lower Coal Measures which form the southern boundary with the Pre-Cambrian Basement Complex.

Name of Borehole	*Depth of Borehole*	*Static W.L.*	*Yield G.P.H.*
Ifon	265'—0"	206'	2,800
Sabongida	404'—0"	Artesian	2,900
Agenebode	424'—0"	353'	—

The borehole at Sabongida was artesian. The yield of these boreholes are poor according to expectation.

7.8. As indicated earlier the bulk of the Country north of the Bende-Ameki and the upper and lower Coal Measures is the Precambrian Basement Complex. This is predominantly composed of ancient metamorphic and igneous rocks which are interspersed by streaks of quartzite, schist and granite.

7.9. Two boreholes drilled at Ogbona and Fugar struck water at 710 ft. and 525 ft. respectively. The static depths of water at Ogbona and Fugar of 614'—6" and 432 ft. respectively did not permit testing with the pump available. A new Test pump capable of delivering water from the two boreholes was ordered; and the tests are now being carried out.

7.10. It is apt to mention that several springs emanate in the Precambrian Basement Complex.

7.11. At Ilugun, in this geological formation, a tube well near a stream struck water at 50' but the yield is insignificant. I would wish to emphasise that the results quoted give only a general picture of groundwater occurrence in various parts of the region. An extensive hydrogeological investigation and research would be required in order to forecast groundwater occurrence much more accurately. This will involve more investigation in the field backed up with laboratory analyses of all soil and rock samples and the trained eye of a geologist.

7.12. Field investigation may mean the use of up-to-date methods and equipment for mapping groundwater contours. The use of the Electrical Resistivity and the siesmic methods would supplement the available information whenever necessary.

7.13. It is superfluous for the Region to embark on a countrywide investigation using both the siesmic and Electrical Resistivity methods now in view of the expenses involved; more especially since areas where groundwater can be obtained have been roughly delineated.

7.14. The laboratory is very important for all subsoil investigations more so when a search for water is involved. Therefore all soil and rock samples are tested for their porosity, permeability and specific yield. Such tests are carried out in the Soils Mechanics Laboratory attached to the Ministry of Works and Transport; and the results transmitted to the Water Supplies Division.

Construction

7.15. Each borehole supply is designed as a scheme; suitable materials are used to meet specific conditions. The type of screen used is dependent on the hydraulics of the aquifer and other factors obtained in the boreholes. Hagusta

Screens and slotted screens have been used. Experience has shown that where conditions are similar a borehole with a slotted screen produces a greater yield than Hagusta Screens. Slotted screens are however, much more easily silted up.

7.16. Where two or more boreholes are required for a scheme, they are spaced at a distance of not less than 300 yards apart in order to avoid interference during pumping.

7.17. Strict sanitary precautions are taken in order to insulate contaminated water from getting into a borehole. The upper 10 ft. of the gravel surface is filled with cement grout. The pump house is protected against flooding, and are properly drained.

7.18. Until lately, groundwater exploitation in the Region has been very insignificant, mainly because of the abundance of surface water. The present trend towards more exploitation of groundwater is rooted in economics. Inexpensive headworks for a borehole supply and purer water which hardly requires any treatment have been jointly responsible for the attention now being paid to the exploitation of our groundwater resources.

CONCLUSION

8.1. The study of ground water problems of Nigeria has focussed attention on the paucity of hydrological data. In order to overcome this, the collection of hydrological data should be vested in a Central Authority under the aegis of the Federal Government. This centralisation has been practised successfully in many highly developed countries. The United Nations Organisation is empowered to help developing countries both technically and financially in the collection of data; and an approach to the United Nations Organisations in this respect would be worthwhile. Planning should include the vigorous training of personnel. The practical development of the Nation's ground water resources is impossible without an adequate number of trained engineers and technicians. There is fortunately a scheme by all the Governments of the Federation in this direction.

8.2. Comparative designs for irrigation and waterworks should be carried out after a thorough hydrological investigation of the possible sources. The choice of a particular source should be dictated by its economic advantage and long-term benefits provided the water is satisfactory in all other respects. The conjunctive use of surface and subsurface sources have relevant advantages and may be satisfactory in special circumstances. The indiscriminate development of ground water sources in preference to surface water is not advocated. There is however an overall financial advantage in giving priority to a groundwater source when sufficient and suitable quantity can be obtained. The choice of waterworks equipment should be based on the physical and chemical properties of the water and other climatic conditions prevailing at the source of supply.

8.3. All wells and boreholes should be properly logged and their yield, chemical and physical properties recorded daily. Their locations should be indicated on a map prepared specially for that purpose.

8.4. A comprehensive statute governing the boring of wells, ground water usage and safeguards against pollution and sea water intrusion should be drawn up.

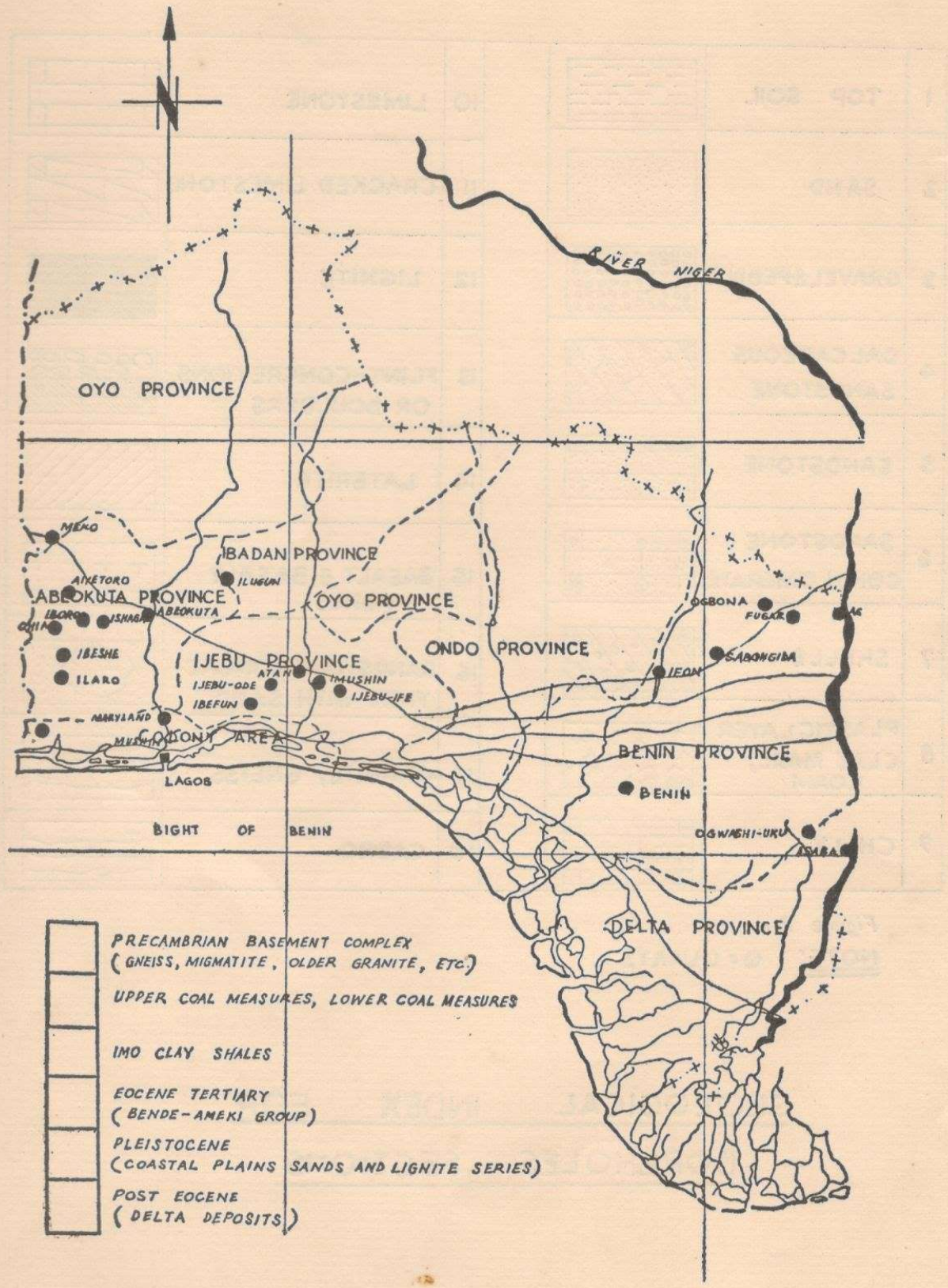
8.5. The unique diversity of ground water conditions in Nigeria makes research an absolute necessity. Properly controlled research will be of immense value to stock farming and irrigation.

8.6. Nigeria in the year 2,000 A.D. would have a population of some 60 million. Vast agricultural lands would be under cultivation by up-to-date methods. Most of our requirements would be manufactured locally. Better public health and higher standard of living will be the rule rather than the exception. The role of ground water in the future development of the country is inestimable; and a down-to-earth policy to gear the development of the resources is justifiable regardless of the capital expenditure. It is a wise investment for the future.

8.7. A Water Policy for the Nation should be drawn up to include the Exploitation, Utilisation and future development of the Nation's ground water Resources.

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RIVER NIGER
OYO PROVINCE
IBADAN PROVINCE
ABEOKUTA PROVINCE
OYO PROVINCE
ONDO PROVINCE
IJEBU PROVINCE
COLONY AREA
BENIN PROVINCE
DELTA PROVINCE
MEKO
AIYETORO
ILUGUN
ABEOKUTA
IBORO
ISHAGA
OHIA
IBESHE
ILARO
IJEBU-ODE
ATAN
IMUSHIN
IJEBU-IFE
IBEFUN
MARYLAND
MUSHIN
LAGOS
BIGHT OF BENIN
OGBONA
FUGAR
SABONGIDA
IEDO
BENIN
OGWASHI-UKU
ASABA
PRECAMBRIAN BASEMENT COMPLEX
(GNEISS, MIGMATITE, OLDER GRANITE, ETC.)
UPPER COAL MEASURES, LOWER COAL MEASURES
IMO CLAY SHALES
EOCENE TERTIARY
(BENDE-AMEKI GROUP)
PLEISTOCENE
(COASTAL PLAINS SANDS AND LIGNITE SERIES)
POST EOCENE
(DELTA DEPOSITS)

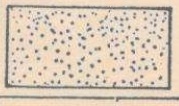
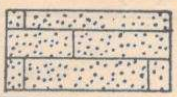
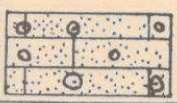
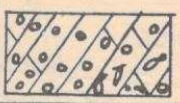
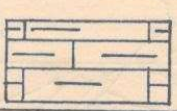
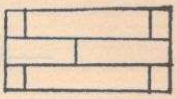
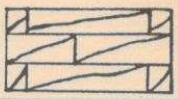
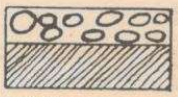
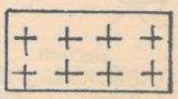
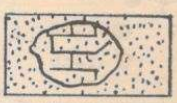
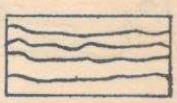
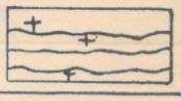
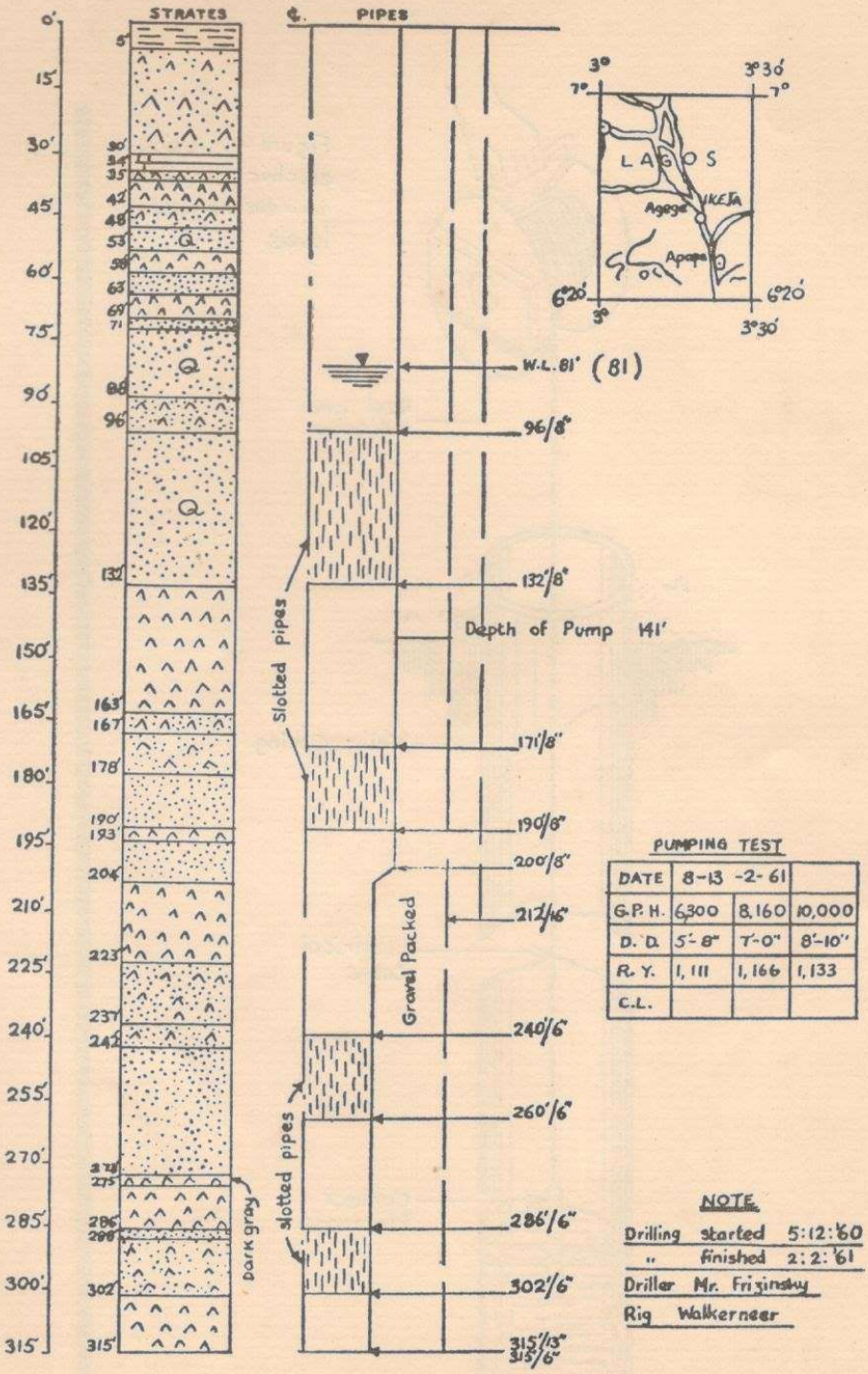
1	TOP SOIL	
2	SAND	
3	GRAVEL & PEBBLE	
4	CALCAREOUS SANDSTONE	
5	SANDSTONE	
6	SANDSTONE CONGLOMERATE	
7	SHELLS	
8	PLASTIC LAYER CLAY, MARL, LOAM	
9	CHALK	
10	LIMESTONE	
11	CRACKED LIMESTONE	
12	LIGNITE	
13	FLINT-CONCRETIONS OR BOULDERS	
14	LATERITE	
15	BASALT & BASALT ASHES	
16	SANDSTONE CONCRETION WITH SAND	
17	GRANITE, GNEISS	
18	GABRO	

Figure 2.

NOTE: Q = QUARTZ

GEOLOGICAL INDEX FOR BOREHOLES SECTIONS



PUMPING TEST

DATE	8-13-2-61		
G.P.H.	6300	8,160	10,000
D.D.	5'-8"	7'-0"	8'-10"
R.Y.	1, 111	1, 166	1, 133
C.L.			

NOTE.

Drilling started 5:12:'60
" finished 2:2:'61
Driller Mr. Frizinsky
Rig Walkerneer

Figure 3.
SCALE:- 1" = 30'-0"

BOREHOLE MARYLAND IKEJA

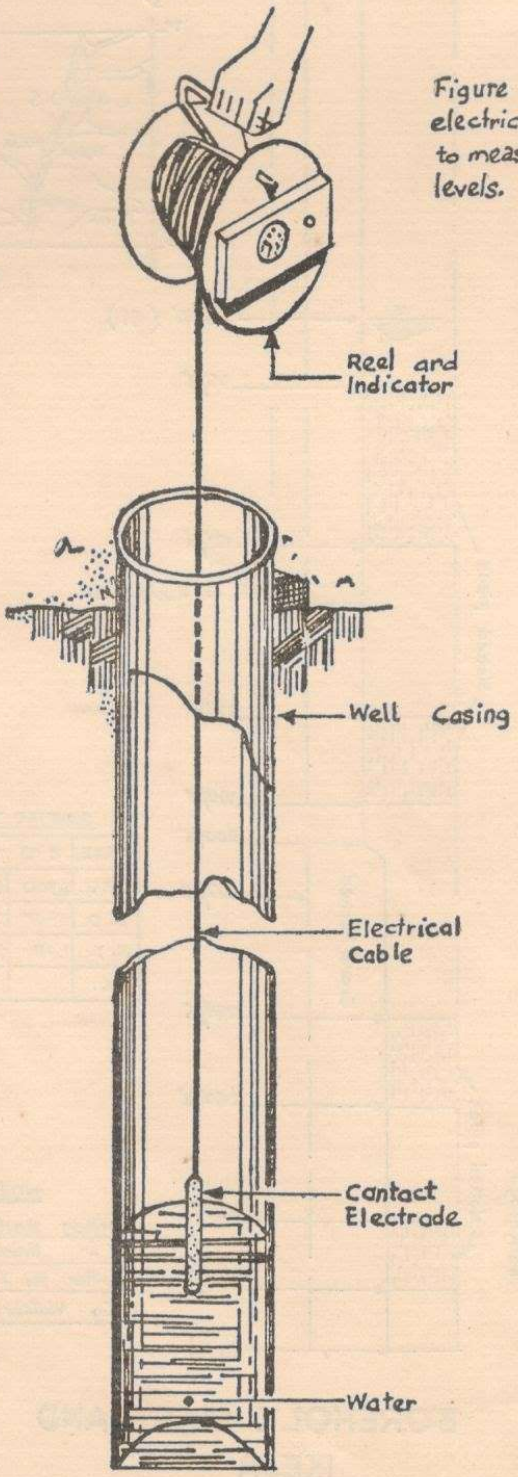


Figure 4. Using electric sounder to measure water levels.

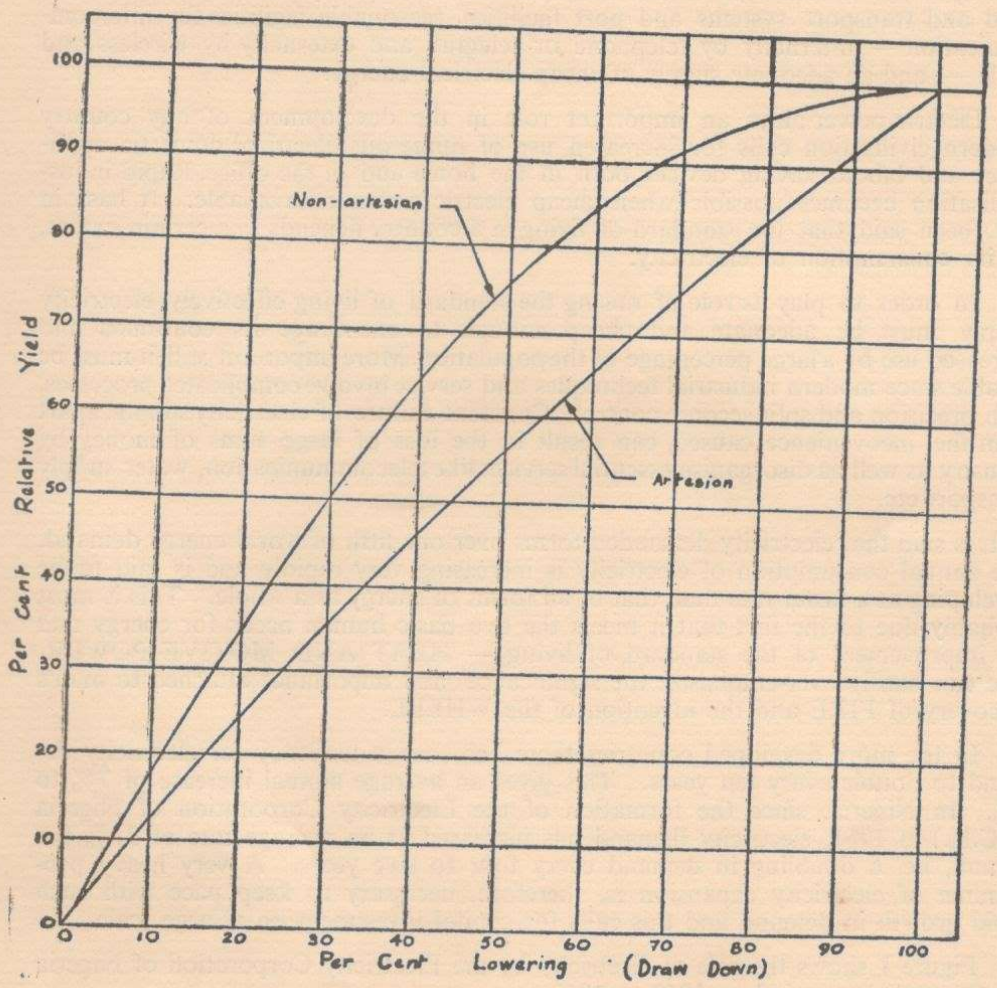


Figure 6

RELATION OF DRAWDOWN TO YIELD IN WATER-TABLE & ARTESIAN WELLS