SEDIMENTARY AQUIFERS OF BAUCHI STATE

By

AKAHA CELESTINE TSE

Geology Programme

Abubakar Tafawa Balewa College Ahmadu Bello University, Bauchi

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APPROVED:

SUPERVISOR:

Signature---------------

Name: DR E.F.C. DIKE Date: 22/7/87

PROGRAMME:

CO-ORDINATOR:

Signature---------------

Name:-----------------Date:---------

Dean of School:

Signature---------------

Name:----------------Date:----------

DEDICATION

TO MY PARENTS

MRS. KWAGHEMBE TSE

AND

LATE MR. THADDEUS TSE

FOR THEIR PARENTAL CARE

A C K N O W L E D G E M E N T

I wish to express deep appreciation to my Project Supervisor, Dr. E.F.C. Dike who in between his time, gave useful suggestions and criticisms at various stages of this work. Not only did he correct the scripts, but also stimulated my interest in hydrogeology.

My gratitude also go to my brothers and sisters, and to members of the AZO and Jor families, especially Ambrose, Elizabeth, Hebert and Jude, for their wonderful support, understanding and encouragement throughout the duration of my studies. I extend my thanks to all staff of the Geology Programme ATBC/ABU Bauchi, for the training I received from them.

To numerous friends and class mates whom space does not permit me to list all their names, I say thank you for the company and help rendered throughout the course of my studies. Also my appreciation goes to my room mates for the past six years, Iorfa and Azembe for the spirit of togetherness.

Lastly, I wish to thank the Water Surveys Group, Bauchi, and the Bauchi State Urban Utilities Board, from whom much of the data used for this project work was obtained through my project supervisor, borehole records and Consultant reports for the BSADP borehole projects were also made available to me for this project.

A B S T R A C T

Considerable ground water reserves occur in Bauchi State in both the basement and sedimentary rocks. From the surface geology, Sedimentary rocks occupy 56% of the surface area of Bauchi State and their aquifers supply about 62% of the total water needs of the state. However, water occurs locally at various depths in these rocks due to variations in lithology, Physiography and structure. Results of the present work show that geophysical surveys using Em and VES methods achieve a satisfactory success rate in locating water in the basement and sedimentary aquifers respectively. From the BSADP Borehole Programme, both high (over 400l/m) and low yielding boreholes have been encountered, as the various rock units of the Sedimentary formations have variable aquifer characteristics and yields. At present, the Bima Formation is the most exploited of all the aquifers. The Kerri-Kerri and Chad formations also have high yielding boreholes and are therefore important aquifers too.

Some central areas like Dukku and Tula have acute water problems because of the very deep levels of occurence of the water table. Water supply to such areas is by the integrated borehole schemes using booster stations.

Various completion techniques are used but the most efficient and durable wells will appear to be totally gravel packed ones. The Kerri-Kerri, because of its high yielding boreholes and large surface area, will prove to be a major water supply formation if adequately exploited.

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INTRODUCTION

1.1 Statement of Research and Scope of Work

The Government of Bauchi State since its inception in 1976, in performing one of its Social Welfare responsibilities, commissioned the State's Water Board to explore and exploit the water resources of the State for both urban and rural Communities. On the basis of work done in this respect by Professional consulting firms specialising in water resources (e.g Water Surveys, Edok-Eter Mandilas, Consulint, Conred, Mitsui), data on the current knowledge of the occurence, distribution and characteristics of groundwater aquifers in the State have accumulated up to 1986.

These studies show that the State has considerable groundwater reserves, with the Sedimentary formations having a greater proportion of the reserves. However, there are local variations in the depth to the water bearing horizons and yields are also not uniform for all the geologic formations. Inspite of all these works, there is no comprehensive hydrogeological data base on which water resource appraisal of the State can be based. The hydrogeological data is scattered, as many organisations are involved in the execution of water works for the State Government.

This research project is, therefore, an attempt to compile a fair but critical and representative summary of groundwater investigation and exploitation in areas of the State whose water supply is from sedimentary aquifers. Also, an attempt will be made to present a summary of groundwater conditions in the various hydrogeological units in relation to the data which has become increasingly available in terms of the aquifer characteristics (e.g. depth to water table, yield, etc) based on borehole studies. Thus critical observations on the properties of these aquifers will be made.

Much of the data is drawn from published and unpublished studies, especially those of Water Surveys Ltd; Edok-Eter Mandilas Ltd, Conred, Consulint Ltd, Bauchi State Water Board and the Geological Survey of Nigeria (1977-1986)

In addition to academic value, the result of the findings will help organisations interested in the area, in future planning, execution and development of water projects. This work may also serve as a guide to further studies on the subject.

1.2 Location of Study area

Bauchi State lies between Latitude 9°30' and 12°30' N, and Longitude 8°42' and 11°50'E. It is bounded by Kano State in the north west, Borno State to the north east, Gongola State in the east and by Plateau State in the south. Its total land area is 66,510.045 Km^2 and this constitutes approximately 7.2% of the total land area of Nigeria.

The area of Study lies in the eastern and northern parts of the State, all of which are underlain by sedimentary Formations (see Fig 1).

1.3. Geography

1.3.1. Topography and drainage

The area provides a diversity of topographical forms. The sedimentary rocks form good hills e.g in Bima Sandstones, fold structures and defined with strong structural and elliptical hill patterns particularly in Lamurde anticlines.

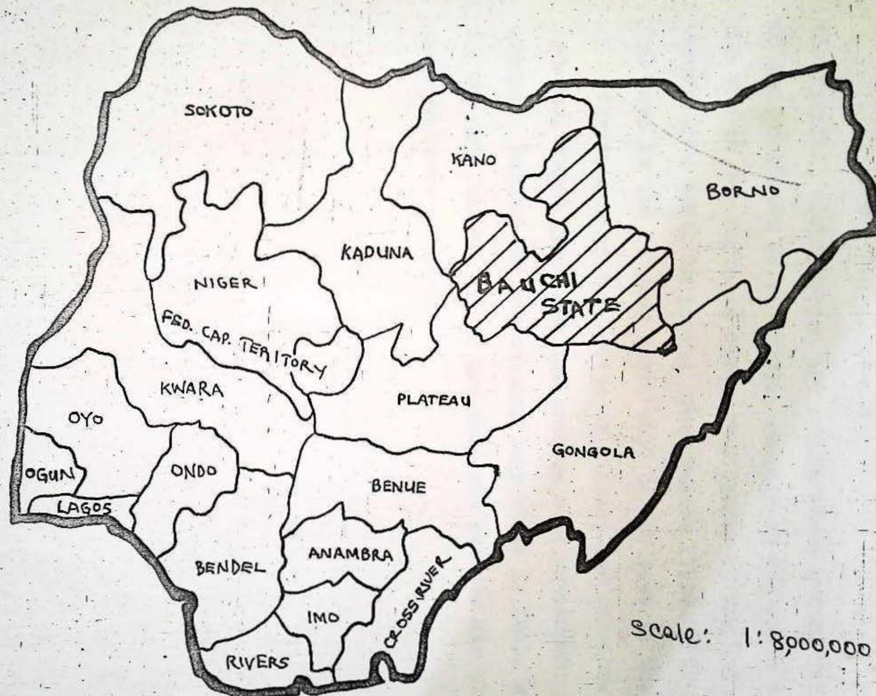
Cuestas are the commonest landforms in areas underlain by Bima Sandstone. Numerous volcanic plugs and cones occur in the South and east e.g Tangale Peak (1293m) which rises above the Bima sandstone south of Kaltungo. Generally however, the topography is gentle. Drainage is by a system of rivers. The Gongola, Jama'are and Dingaiya are the three major river systems. Others include Pai and Iggi rivers where flow is seasonal. There are several other minor seasonal streams that traverse the area of study. The three major river systems have their headwaters rising on Basement crystalline rocks: the Gongola and Jama'are rising on the Jos Plateau while that of Dingaiya lies within the Bauchi Plain.

1.3.2 Climate and Vegetation

Oscillatory movement of the intertropic front exerts principal control on the climate of Bauchi State. Topographic features provide secondary variations. The area lies within the Savannah. Two seasons are distinct: wet and dry seasons. The wet seasons starts in May and ends in September. The remaining months (October - April) constitute the dry seasonx marked by little or no rainfall.

Harmattan is between mid-October to January/Feburary; and the period is characterised by low temperatures (between 18-21°C). There is a lot of dust particles during this period, which is being transported by winds from the Sahara desert.

Cyclic variations in climate involving desertification are marked by shorter annual rainfall periods and a decrease in the amount of rainfall.



Map of Nigeria showing the
FIG.1— Location ~~map~~ of Bauchi State.

The rainfall distribution and amount shows a high rate in the southwest of the State, average in the south east and low in the northern lobe. The length of the wet season varies from North to South. Mean values (1956-1977) are 190 days in the extreme south west to 100 days in the north.

Vegetation is a function of climate and consists of sShrubs, thorn trees and low grasses with occasional bare ground. During the wet season, vegetation is full, but in the dry season, leaves are shed and grasses die giving a good exposure of rocks.

1.4 Previous Work

Attempts to improve the water supply of Bauchi span over the years. Falconer and Longbottom (1911) undertook reconaissance traverses of the area during the early mineral survey of Northern Nigeria. The Geological Survey of Nigeria started hydrogeological investigations in Nigeria in 1928 and undertook the actual exploitation of groundwater in rural communities by means of hand-dug, concrete-lined wells. Many reconaissance surveys for the purpose of selecting suitable sites for water wells have been made and results of these works are recorded in published and unpublished reports of the Geological Survey.

Raeburn and Jones (1934) published an account of the geology and water supply of the Chad Basin. This provides a general description of the hydrogeology of that part of Chad drainage basin which also lie within Bauchi State. Accounts of the geology and water supply of Gombe (Thompson 1958) has been published. In 1963, Carter et al; published maps and the geology of parts of North East Nigeria, which also includes the old Bauchi Province.

The creation of more States in 1976 led to the establishment of a Water Board in each State charged with exploring and exploiting water resources. Since then, the Bauchi State Water Board has worked succintly towards this objective. Professional consulting firms specialising in water resources have been contracted to define the water resources of the State in all its ramifications.

Thus Water Surveys (Nig) Ltd; Edok-Eter Mandilas (Nig) Ltd, Conred (Nig) Ltd and Consulint Co. Ltd have published works on the ater resources of the State up to 1986.

All these form the basis for groundwater studies in Bauchi State, and therefore this work.

1.5 Methodology of Present Work

Two basic approaches were employed for this work: data aquisition and data synthesis.

Data acquisition involved the collection of water borehole information as regards the study area. This was done from the offices of Water Surveys Group and Bauchi State Urban Utilities Board (Water Section).

Data synthesis involved a detailed and critical desk study of the data acquired. Discussions with staff and students were also important during this stage.

CHAPTER TWO

AQUIFER PROPERTIES AND CHARACTERISTICS

2.1 Brief Geology of Bauchi State

Bauchi State is divided into two major geological regions: areas underlain by Crystalline Basement rocks and those underlain by sedimentary formations (fig 1).

Crystalline rocks underlie the western part of the State while sedimentary formations (Cretaceous to Recent) cover the rest of the State, and are associated with occassional volcanics. Migmatites and gneisses of the Crystalline Basement are intrudded by Older Granite rocks (foliated orphyritic granites and bauchites) and younger Granite Suite rocks (mainly medium grained granites granites porphyry and acid volcanics). The east and north east of the State belong to the Benue and Gongola Cretaceous rift system and consist of folded marine and continental sequences (Carter et al; 1963). A central belt of unfolded Tertiary continental Sediments overlap both Crystalline Basement and Cretaceous rocks. In the North, the Quarternary locustrine sediments of the Chad Formation overlap Crystalline and Tertiary rocks.

The Bima Sandstone is the oldest sedimentary formation and comprises 91-3,000m thickness of shallow water, cross bedded sandstone and occasional mudstone. It covers 2500km^2 of terrain. This sandstone is a continental, alluvial, fluviatile and dettaic sequence, lying on an irregular floor of the Crystalline Basement. It is succeeded by the passage beds of the Yolde Formation, a shoreline - near shore sequence comprising sandstones, siltstones and mudstones.

Next is the marine Cretaceous shales of the Gongola, Fika and Pindiga formations. There are clay shales, up to 1000m thick. Most of the shales are Turonian to early Maestrichtian in age representing the Central marine phase of the Benue Trough. Occassionally, there are intraformational lenses of porous sandstones but generally the shales are non-porous with tight joints. The lower part of this sequence of Turonian age is a Limestone - shale facies and at Ashaka to the north east has t thick limestone bed quarried for cement.

Estuarine clay-shales, siltstones and sandstones of the Gombe andstone overlie the shales, apparently unconformably. This unit represents a continental marginal phase of the Benue Trough in the late Cretaceous.

Following prolonged erosion, the Tertiary continental basin of the Kerri-Kerri sediments accumulated on the eroded surface of the Gombe Formation. The sediments are grits, sandstones, siltstones and kaolinitic clay.

Sitting on a floor of downwarped Kerri Kerri and Crystalline rocks is the Quaternary Chad Formation of lacustrine and fluvial beds. The formation consists of quartz sands, clays, silty clay, and rarely, gravel. alluvium bearing rivers develop north eastwards towards the Lake Chad, and southwards and eastwards towards river Benue.

The last desert incursion of 20,000 years ago left fossil dunes in the northern part of the State. These are composed of sand and silt, covering the Chad outcrop in some places. Tectonic activity, vigorous up to the Santonian, with volcanic activity, was minimal by the time the Tertiary beds were laid down, and subsequent movement was limited to warping.

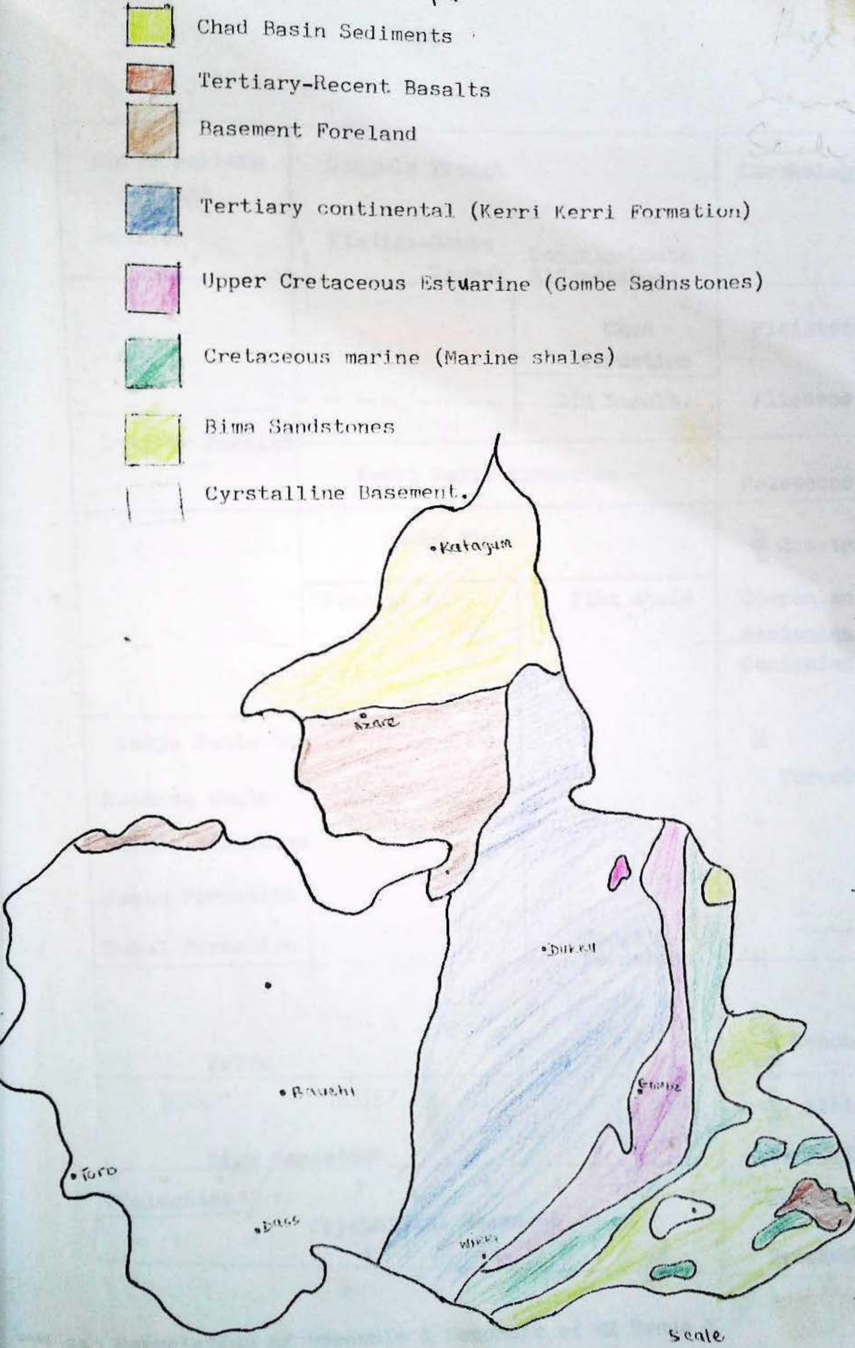


Fig 2: Geological units of Bauchi State.
Source: Geological survey of Nigeria, 1974.

North eastern Trough	Gongola Trough		Chronology
Dadiya	Pindiga-Gombe Zambuk	Gongila-Gombe Ridge-Ashaka	
		Chad Formation	Pleistocene
Longuda Basalts		Bid Basalt	Pliocene
	Kerri Kerri Formation		Paleocene
	Gombe St.		U L Maestritchtian
	Pindiga Fm	Fika shale	Companian Santonian Coniacian
Lamja Sandstone Numanha shale Sekule limestone Jessu Formation Dukul Formation		Gongila Formation	U M Turonian L
Yolde			U M L Cenomanian
Bima Sandstone			U M L Albian U. Aptian
Volcanics	Crystalline Basement		Jurassic Precambrian

Table 2a: Correlation of Mesozoic & Cenozoic of NE Benue & Gongola Trough (after Popoff et al (1986).

2.2 Definition and Distribution of Sedimentary aquifers of Bauchi State

The definition and distribution of sedimentary aquifers of Bauchi State follows the geology of the State. North and east of the State is underlain by sedimentary rocks (Cretaceous to Recent) and these, together with the fadama (alluvium and flood plains) of the river systems in the areas define the aquifers. For practical purposes seven hydrogeologic units have been identified in the sedimentary areas and these correspond to the following groundwater units: (Wadrop 1975)

1. Older Cretaceous sandstones and mudstones
2. Marine shales
3. Gombe sandstone
4. Kerri-Kerri formation
5. Chad Formation
6. Alluvium aquifers
7. Fossil dunes.

A description of these aquifers follow in the next section.

The distribution of the aquifers in the state is linked to Local Government Areas underlain by Sedimentary rocks. From the South to the north, these are Tangale Waje, Alkaleri, Akko, Gombe, Dukku, eastern part of Darazo, Misau, Shira, Jama'are, Katagum and Gamawa Local Government areas.

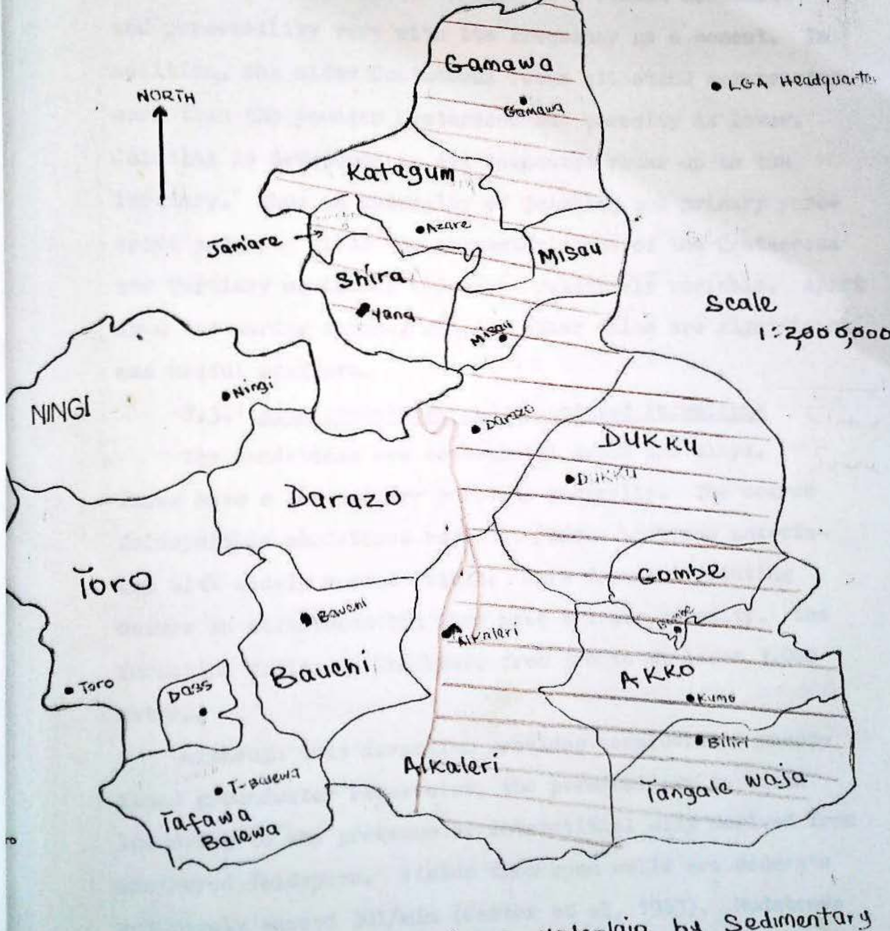


Fig 3: Local Government Areas underlain by Sedimentary Formations. (ruled)

Source: Water Surveys (1986)

2.3 Description of the aquifers

Each geologic unit of Bauchi State is, infact, a groundwater aquifer. The mineralogy of the sedimentary aquifers indicate that they were derived from crystalline rocks so that transported kaolin is a common component and permeability vary with its frequency as a cement. In addition, the older Cretaceous rocks withstand compression more than the younger Cretaceous and porosity is lower. Jointing is developed in all compacted rocks up to the Tertiary. Thus an interplay of jointing and primary pore-space porosity gives the characteristics of the Cretaceous and Tertiary aquifers, which are relatively variable. Apart from the marine shales, all the other units are significant and useful aquifers.

2.3.1 Bima Sandstones and associated Formations

The sandstones are continental sands and clays. These have a low primary porosity generally. The coarse feldspalthic sandstones have a porous horizons associated with widely spaced joints. More frequent jointing occurs in siltstones but they have a lower porosity. The formation varies in thickness from 91m to at least 3,000 metres.

Although this formation provides considerable unconfined groundwater reservoirs, the permeability is often low owing to the presence of interstitial clay derived from weathered feldspars. Yields from open wells are moderate and rarely exceed 30l/min (Carter et al, 1963). Mudstones are characterised by close joints with no primary permeability but within sandstones and siltstones show hydraulic continuity.

The consequence is that all the pre-marine Cretaceous units form one groundwater unit for practical purposes. However, varying degrees of water table elevations are created because of lateral discontinuities (i.e. lateral interruptions of hithological continuities by interbedded shales and clays). The Bima forms 7% of the area of Bauchi State.

2.3.2. Marine Formations

These include the Dukui, Jessu, Sekule, Numanha, Gongila and Pindiga formations and the Fika shales which consist chiefly of shales and mudstones with thin linestones. The marine shales contain local sandy horizons (Thompson, 1956)

The Dukui formation consists of a sequence of shales and thin linestones. The Jessu formation is an alternating sequence of shales and sandy mudstones with subordinate sandstones. The Sekule is a sequence of shales and linestones in which the shales are thicker than the limestones. Numanha and Lamja formations are shales and sandstone beds respectively.

Most of the strata are virtually impermeable owing to the shales and wells produce very small yields unless a thick weathered horizon is penetrated or where there is a local occurence of sandstones. In many districts, the groundwater in these formations is unsuitable for human consumption due to high salt contents e.g at Gombe, a borehole in the Pindiga formation was not brought into production because of high sulphate content (Barber et al, 1965). However, wherever recharge is possible, water is of acceptable quality.

The marine shales constitute 7% of the state land area. They confine the Bima sandstone aquifers away from their outcrops.

2.3.3. Gombe Sandstones

These are younger Cretaceous (Maestrichtian) estuarine and deltaic sandstones, sultstones, shales and iron stones. The beds appear to grade upward from marine shales through impermeable clays, then siltstones with pockets of coal, to coarser sandstones at the top. Before the advent of sedimentation in the Tertiary, they were strongly weathered and eroded. The irregular surface was lateritised as well as all the more permeable bands in the upper part of the sequence.

The brown silts are the most important aquifers. They have closely spaced vertical and horizontal open joints lined with ferruginous cement and have high transmissivity. Pressure water conditions are found locally e.g. at Gombe Town, borehole number GNS 1892 met pressure water in the Gombe sandstone with a small draw down and high yield. The sandstones form 4% of the area of the State.

2.3.4 Kerri Kerri Formation

This is a continental sequence of Paleocene age deposited under mainly fluvial and lacustrine conditions, and underlies much of the central part of Bauchi State. The formation is predominantly arenaceous, consisting of loosely cemented sands and grits, clayey sandstones, massive clays and silts. Bands of ironstone and conglomerate occur locally. Much of the Kerri Kerri sediments were deposited on the floor of the hills and ranges of the older Gombe Formation.

The beds of this Formation have thick layers of impermeable kaolinites traversed by major widely spaced joints.

In unjointed areas, occassional clay content gives rise to perched aquifers, while the directional jointing causes rapid movement of groundwater to the southwest of the State to feed springs, seepages and water table lakes e.g. Wikki spring in the Yankari Games Reserve. The saturated portions of the Kerri Kerri formation contains a large quantity of water though much of this is not readily exploitable owing to the low permeability of the sediments because of interstitial clay and silt in the sandstones. Also in some localities, the saturated rocks may occassionally occur at considerable depths e.g. in Dukku.

Groundwater in this aquifer normally occur under water table conditions. The maximum proven thickness of the Kerri Kerri x is 215 metres. It has a wider geographic importance than all the other sedimentary aquifers but current information shows it has the most untapped aquifer resources (Dike, 1987). It constitutes 29% of the total area of Bauchi State.

2.3.5 Chad Formation

The Chad Formation is a fresh-water sedimentary sequence of pleistocene (?Pliocene) age (Raeburn and Jones 1934). It consists of a sequence of clays, sandy clays and silt in which beds and lenses of sand and gravel occur at various level. The formation was deposited on a surface formed by Kerri-Kerri formation and Cretaceous sediments, and the Basement Complex.

Groundwater occurs here under water table conditions, in perched aquifers, as confined and semi-confined water. The lacustrine to fluvial sediments of this formation are underlain either by the Kerri Kerri, or by thickly weathered crystalline rocks, both of which constitute moderate aquifers.

North eastwards of the State a much better assemblage of mainly lacustrine beds with a few useful aquifers is obtained. Recharge is through modern and fossil alluvium of old and modern drainage rising on crystalline rocks trending north-eastward, into the Chad Basin sediments. The alluvium of the modern Jama'are feed a groundwater ridge in the formation.

The Chad formation covers 11% of Bauchi State land area (Wadrop Report, 1985).

2.3.6 Alluvium Deposits

These are coarse to medium grained sediments with occassional occurence of clay. The alluvium is a common aquifer below the larger river beds on crystalline terrain, and in the biggest rivers, it is permanently saturated with sub-surface flow. In small rivers, saturated alluvium occur in permanent pockets.

Recharge is by seasonal rainfall and stream flow. Release of rain water trapped in silt terrace alluvium supplements the recharge. Coarse sand alluvium is also a useful source of water. It occurs where rivers, traverse sedimentary terrain and wherever an upstream source of sand exists.

2.3.7 Fossil Dune Sands

These occur in the extreme north of the State. Although they are limited, they are useful sources of groundwater. The sparse vegetation coupled with porous surfaces and low rates of run-off and transpiration, results in the dunes being rapidly filled with water during the rains. Lateral drain out is also rapid though less permeable sands give sub-perennial seepages into interdune swamps.

Table 2: Stratigraphic sequence in relation to significant aquifers (underlined) and their more important characteristics.

UNIT	LITHOLOGY	DEPTH OF WATER(M)	PERMEA-BILITY	STORAGE
Alluvium	Silts, clays, Sands, gravels	Shallow	Variable	Good
Dunes	Sands	0-25	High	Good
Chad (Lacustrine)	Sands, Silts clays	10-35	Moderate	Good
Kerri-Kerri (Continental)	Sandstone, Siltstone, Clays,	10-200	Moderate	Good
Gombe Sandstone (Younger Cretaceous)	Sandstones, Siltstones Clays, shales	10-40m	Moderate	Good
Marine shales (Pindiga Formation	shales	-	-	-
Bima(Associated formation (Older Cretaceous)	Sandstones, Mudstones	10-120	Variable	Patchy
Plateau Lava	Basalts	Shallow	High	V.Low
Crystalline	Weathered Zones, Joints	3-18 25-30	Variable	Low

Source

1. Water surveys (Nig) Ltd. (1986)

2.4 Comparison of the aquifer characteristics.

2.4.1 Results

A total of 53 borehole records spread fairly over the area of study were collected.
Table 3 Shows records of the boreholes in terms of lithology, geologic formations penetrated, total depth and other hydraulic properties. Detailed lithologies of some of them are presented in Appendix 1. For the purpose of computing the critical yields of some of the wells, pumping test results have been obtained and are presented in Appendix II while the plotted characteristic curves are given in Appendix III. Appendix IV shows typical completion techniques in selected boreholes which reflects the general trend.

Boreholes constructed by the Geological Survey of Nigeria are included in Table 3 to show depth conditions. Yields from them are not discussed together with the others because information on their completion techniques are inadequate and therefore unreliable.

2.4.2. Discussion of Results

In terms of the total land area underlain by the sedimentary formation, the relative abundance is as follows: Kerri 53%, Chad 20%, Bima 13%, and Marine and Gombe formations 7% each. Although all these combined have considerable ground water resources, it can be shown that the occurence of the groundwater is dependent on the lithology physiography, and structure of the underlying rocks.

Table 3: Records of Borehole Characteristics (Contractors Reports, Bauchi Water Board)

BOREHOLE LOCATION & NUMBER	SUMMARY OF LITHOLOGY	FORMATION PENETRATED	TOTAL DEPTH (M)	TESTED YIELD (YS)	STATIC WATER LEVEL (M)	DRAW DOWN (M)	TRANS-MISSIVITY (M^2SEC)
Billiri Laushi No.3	Colluvium and medium to coarse sandstones with clay	Bima	108	6.50	32.25	5.60	
Gombe No.57		Bima	316	6.11	49.30	44.95	
58		Bima	204	4.68	3.66	71.34	
59		Bima	332	3.13	12.50	37.30	
60		Bima	305	7.00	17.80	36.10	
61		Bima		8.75			
63	Alternate layers of sand, sandstones and clays	Bima	28	6.00	27.20	25.33	
64	Sandstone with sands and claystones	Bima	311	4.40	17.40	36.04	
Alkaleri No. 1	Coarse sand, gravel with clay impregnatons and weathered granite	KeriKerri+ Basement	81	4.36	27.94	9.00	
2	Medium-coarse sand peables with clay and high weathered granite	KeriKeri+ Basement	126	5.07	15.88	12.82	79x10
Azare No. 6	Sands and slightly weahtered granite	Kerikeri + Basement	80	0.62	29.20	25	67x10
No. 11	Sands and slightly-highly wheathered granites	[redacted]riKeri+ Basement	[redacted]	[redacted]	14.98	35	66x10
Lanzai No. 3	Sands and gravels with some clay	Kerikeri	243	13.86	63.55		2.08
Sade No. 3	Sands and gravels	KeriKeri	189	5.43	40.64	0.96	
Darazo No. 5	Sands and peables with clay	Keri Keri	262	3.36	42	11	2.5x
Misau No. 3	Medium-coarse sand, some peables and very little clay	Kerikeri	72	11.35	9,83	1.12	9.58
Hardawa No.3	Medium-coarse sands, flesh granite	Kerikeri + Basement					
Chinade No.2	Sandstones and weathered granites of the basement	Keri-Keri Basement	66	1.56	7.53	22	1.75
Dukku No.1	Sands and sandstones with clay intercalations	Gombe	240	1.07	143.10	1.67	-3x
No.5	Sands and santstones with clay intercalations	Gombe	289	1.51	40.70	2.47	5.5x
Gombe No. 9		Gombe	112	0.88	49.67	10.67	

Table 3: Record of Borehole Characteristics

Borehole Location & Number	SUMMARY OF LITHOLOGY	Formation Penetrated	Total Depth(l/s)	Yield (l/s)	Static Water Level(m)	Drawdown (m)
Sawa DR 84 SW 45		Kerri Kerri	55	0.33	16.00	11111
Zindiri DR 107 NW 25		Kerri Kerri	58	0.33	20.35	20.33
GSS Gamawa Dr. 62 SW 13		Chad	72	1.08	15. 3	9.5
GSS Katagum Dr. 61NE21		Chad/Alluvium	v90	7.00	17.29	11.03
Dirishe DR108 SW-15		Kerri Kerri	75	1.75	56.81	0.86
Jiro DR108 NW-32		Kerri Kerri	36	4.67	17.91	0.28
Papa DR108 SE-16		Kerri Kerri	60	3.50	33.7	0.4
Sabon Sara DR83-NE24		Chad	40;5	0.60	5.63	10.68
Bodinga DR 83 SE-33		Chad	53	0.43	15.92	3.18
Masama DR 83 SE-32		Chad	42	0.70	25.39	3.32
Duku GSN 947		Kerri Kerri	104	0.53	96.92	0
Duku GSN 1350		Kerri Kerri 1	189	126	164	Not determ
Azare GSN 1894		Kerri Kerri	91	1.26	21.3	11
Azare GSN 2171		Basement	114	1.26	16	41.15
Azare GSN 2187		Basement	126	1.26	16	Not Deter
Jalam GSN 967		Kerri Kerri	94	2.52	57.91	"
Jigawa GSN 972		Kerri Kerri	64	2.52	52.42	"
Danbam GSN 964		Kerri Kerri	41	1.51	17.67	"
Gombe GSN 1751		Pindiga/Yolde	104	4.29	14.63	11.86

Jama'are No.1	Mainly sand and clay	Chad	41	7	4.78	24.40	
No.2	Brown, Fine-coasrse snads with fieldspars. Quartzitic	Chad	39	8	4.75	4.02	
Gamawa No.1	Sand, gravel, sandstones	Chad	284	4.04	19.90	0.80	$3.3x10^{-3}$
Udubo No.1	Sand, gravel and sandstones	Chad	162	[illegible],41	24.40	1.50	$3,4x10^{-4}$
Gombe No.1		Tolde	54.8	4.9	2.44	19.9	
No.3		Pindiga	86.0	6.5	31.39	11.89	
55		Gombe & Pindiga	714	0.67	43	-	
21		Tolde	80	5.05	10.19	15.06	
70		Bima & Basement	193	26.1	13.9	3.4	
Zambuk 152NE-11	Sands, silts and clay	Bima	51	0.67	13.55	9.28	
Wade 153NW-2	Sand and clay	Bima	24	0.33	5.42	10.78	
Shiga 153NW-4	Sand and clay	Bima	28	0.37	7.36	8.06	
Gamawa [illegible]62 SW,		Chad	93	8.00	19.75	14.54	

Generally, boreholes penetrating the Bima formation are deeper than those penetrating the other formations, although there are local variations in depths where holes may penetrate formation other than the Bima and may be deeper. Whereas the deepest well is BH 58 Gombe which penetrates the Bima, the shallowest in the same formation is at 28m (BH 153NW-4 Shiga). Depths of wells in Gombe formation are generally high, in the range of 200m. The deepest well here is 298m while the shallowest is 112m deep. In Kerri Kerri formation, the deepest hole is 262m (BH 5 Darazo) while in Jiro, a borehole penetrating the same formation is only 36m deep. The extreme depths in chad formation are 248m and 40m respectively, where as the Pindiga and Yolde formation have average borehole depths of 80m. In the latter, depth to the water table depends on the level of occurence of sands, as the shales do not form an aquifer.

In places where boreholes draw water in an aquifer of Kerri Kerri formation and Basement rocks (I.e. Basement foreland areas), the general trend is for the depths to be shallower than when only the Kerri Kerri were penetrated elsewhere. There variations in depth of the wells are due to local conditions that affect the water levels e.g. subsurface geology, stratigraphy, recharge facilities like proximity to main rivers or ancient river courses and physiographic factors like hills and valleys.

The average depths of boreholes and thus depths to the water table in the sedimentary areas with respect to table 3 can be summarised as follows:

Formation	Average Depth (M)
Chad	130.92
Kerri Kerri	91-110.14
Gombe	216.67
Marine shales	81
Bima	310

[illegible] Water level depth (from water Board Records)

These depths closely agree with results of boreholes drilled by the Bauchi State Agricultural Development Project (BSADP) all over the place.

The tested yield values are variable for the aquifers. It is highest (26.1 litres/sec) for BH 70 Gombe which penetrates the Bima into the Basement. A very high yield (13.861/s) is also recorded in BH 3 Lanzai which draws its water from an aquifer of Kerri-Kerri formation. Although there are many high yielding boreholes from the BSADP borehole programme of 1205 wells made up of 1165 handpump and 40 mechanised wells (Wadrop report 1985), where yields as high as 6.67 l/s are obtained, yields from other [illegible] Programme boreholes do not give such high values. Wells drilled under the BSADP Drought Relief Programme (1986) are of this category. If the yields from these wells shown in table 3 are not considered because of the circumstances and condition under which they were drilled and completed, the lowest yield values of 0.41/s, 0.621/s, and 0.881/s are for BH 3 Hardawa, BH 6 Azare and BH 9 Gombe which penetrate the Kerri-Kerri/Basement, Kerri-Kerri/Basement, and Gombe formations respectively. Average yields computed from boreholes under study give the following results:

Formation	Average Yield (l/s)
Chad	3.80
Kerri Kerri	4.95
Kerri Kerri + Basement	2.64
Combe	1.15
Bima	4.72

Table 5: Average Formation water yields (from Water Board Records)

Although the volume of water yielded into a well is primarily a function of the groundwater reserves in an aquifer, the yield is greatly enhanced by development and completion methods adopted e.g the casing programme and the placement of screen at water bearing horizons. In the BSADP Programme of 1205 wells, a combination of these factors result in high yielding boreholes many of which produce over 6.67 litres per second.

Draw down values are better in the Kerri Kerri Formation, with the Bima having comparatively the highest values. Transmissivities are of the order of 10^{-2} to $10^{-4} m^2/sec$ in Kerri-Kerri and Chad formations whilst the Basement Foreland aquifers have the lowest values (10^{-5} to 10^{-6} m^2/sec).

There is definitely a correlation between the aquifer yields and the total land area occupied in terms of the total supplies. Correlation also exist between the yields and the nature of the sediments.

The Kerri Kerri, consituting 53% of the sedimentary formations coupled with its fairly high average yields is therefore expected to contribute considerably to the total water supply if it is exploited as much as the Bima. . The arenaceous and highly jointed sediments of the Bima formation are favourable factors for water supply in the aquifer. Poor yields usually result from locally kaolinite cemented sediments of the Kerri Kerri.

One fact that emerges from this work is that despite yield values in favour of Bima formation by earlier workers, the Kerri-Kerri has proved to have relatively higher yields.

This earlier importance accorded the Bima as a better aquifer is quite erroneous because such studies of aquifer properties have been restricted (especially to Gombe) in contrast to a wider geographic study this work reaches (in terms of BSADP borehole yields examined in places like Darazo, Lanzai, Alkaleri, Gamawa etc.). However, the Bima, which is very rich in medium to coarse arenaceous material, and contains a number of faults and fractures (Akko and Iyiorhibe 1984), is significantly very high yielding. Existing data and previous research results are heavily biased in favour of Bima formation because it is the most developed and exploited of the sedimentary aquifers.

Average yield values also show that the Chad Formation and ancient sand dunes have considerable groundwater resources as to form important aquifers. This may be related to alluvium of the Jama'are River which feeds a groundwater ridge in the formation. The Gombe sandstones and marine shale formations have poor yields. The case in the former may be explained by its limited outcrop coupled with the low permeability of its strata (silt and silty sands in sandstone layers, siltstones and mudstones: Conred1978). The marine shales are not of aquifer type but where there is alocal occurence of sandstone horizon, yields are high (as in BH 1 and BH 3 Gombe).

The areas where KerriKerri overlie the Basement (Basement Foreland areas) are poor aquifers with limited water resources (average of 2.361/s) and can only be selectively exploited in fractured and deeply weathered zones.

The dry nature of some boreholes in the Kerri Kerri formation are local physiographic conditions of dry sand units in such places. This is confirmed by geophysical investigation which show high resistivity values indicative of dry sands (Ako 1983).

2.5 Conclusion

From the results available and the discussion, broad conclusions have emerged:

(a) Generally, water table conditions vary with locally available conditions. All the formations are characterised by extremes in the depth of occurence of grounwater.

(b) Yields, to some extent, depend on borehole construction, development and completion techniques.

(c) The Bima is the most extensively developed aquifer of all the formations in terms of the number of boreholes sited.

(d) Although the Bima, at present, supplies about 50% of the total water need of the State, and is therefore ranked as the best aquifer, the Kerri Kerri with its high average yields, coupled with the superior land area, may be a major supplier of water if properly exploited as the Bima.

(e) The marine shales are not aquifers, but local sandstone horizons in them may give high yields in boreholes drilled in such areas.

CHAPTER THREE

EXPLORATION AND EXPLOITATION TECHNIQUES

3.1 Use of geophysical methods in Exploration

Surface investigation for groundwater employ a variety of methods which provide information concerning its occunence under certain conditions. These methods are in some cases only partially successful in that results usually leave the hydrogeologic conditions incomplete.

Geologic methods, involving interpretation of geologic data and field reconaissance, represent important step in any groundwater investigation. This enables large areas to be rapidly and economically appraised on a preliminary basis as to their groundwater development potentials. Although geologic investigations begin with data collection and analysis, and hydrogeologic interpretation of existing topographic maps, aerial photographs, geological maps and logs, and other relevant records, this is complimented by geologic field reconaissance and by analysis of available hydrologic data on stream flow and springs, well yields, groundwater recharge, discharge and levels, and water quality.

Also using the technology of remote sensing, aerial photographs of the earth taken at various electromagnetic wavelengths provide useful information regarding groundwater conditions. Thus photogeology can differentiate between rock and soil types and indicate their permeability and areal distribution, and hence, areas of groundwater recharge and discharge.

Aerial photographs also reveal fracture patterns in rocks, which can be related to porosity, permeability and ultimately well yields. In areas with very deep water tables, hydrobotanical studies of vegetation is useful for e.g. phreatophytes can be used to define depths to the water table. These are plants found in both deserts and moist environments and have deeply penetrating roots that reach the water table. Because they have low tolerance for salts and use a lot of water, they serve as useful guide for portable water in semi-arid environments.

Geophysical survey, using several methods (refraction sismic, electrical resistivity and conductivity, Em methods) is useful in defining acuifers in basement and sedimentary areas. In Bauchi State, some of these methods have been used in exploration of sub-surface water in the sedimentary areas by the Water Surveys Group.

3.1.1 Site Selection

Geological interpretation is the basis for selection of sites for borehole drilling in the sedimentary areas although this may be combined with resistivity techniques. In the Crystalline Basement and Basement foreland areas, aerial photographic study and geophysical surveys are important and widely used for site selection (Wadrop 1981).

3.1.2 Geophysical Exploration Methods

Geophysical methods detect anomalies of physical properties within the earth's crust. Density, magnetism, elasticity and electrical resistivity are properties most commonly measured. Pronounced differences in these properties can be interpreted in terms of geologic structure, rock type and porosity, water content and water quality.

The electrical resistivity method is based on resistivity response by rock materials to a passed electric current and this response depends on the material, density, porosity, pore size and shape. The two electric parameters usually considered are the total longitudnal conductance and the apparent resistivity, these parameters are supplied by electrical sounding surveys. This method does not directly supply any data on the size of the main aquifer, but it ensures that there is a correlation between the thickness of the sandy clayey weathered horizon, and the total availability of water from the aquifer.

The seismic refraction method involves the creation of small shocks at the earth's surface, and measuring the time required for the resulting sound to travel known distances. These seismic waves follow the same laws of light: they may be reflected or refracted at any interface where a velocity change occurs. At shallow depths, reflected rays are not resolved because they carry much less energy than refracted rays. Hence for depths of up to 300m, refraction methods are exclusively used.

The gravity method measures differences in the density of the earth's surface that may indicate lithologic structure. Although this method is of very little significance in exploration for water, it can be useful under special geologic conditions such as a large burried valley where the gross configuration of an aquifer can be detected from gravity variations (Spangler et al 1968). The magnetic method measures contrast in magnetic properties, but these are rarely associated with water. This method therefore has relatively little relevance.

Electromagnetic (EM) methods use equipment designed to measure longitudnal conductivity in terrains. Here, a simuosidally varying magnetic field electromagnetically induces current in the ground in such a manner that their amplitude is linearly proportional to the terrain conductivity. Through the use of this technique, ground[illegible] contact is avoided and it is possible to map terrain conductivity virtually as fast as the Operator can walk. Two types of Geonics equipment are used for this purpose: the EM 31 and EM 34-3. By their use, electromagnetic waves are introduced into the ground and they reflect conductivity proportional to the linearments. The equipment employs two coils at a known distance. Both vertical and horizontal measurements are taken. The EM 31 has an effective penetration depth of 6m and is used as a reconaissance tool. For definite and accurate information, the EM 34-3 which has penetration depths of 7.5-60m is used (Geonics Ltd. 1980)

3.2. Geophysical Methods: Application in the Sedimentary Areas of Bauchi State.

Surface investigation of groundwater resources in the sedimentary areas of the State is carried out using geophysical methods. However, the choice of methods is reflected in its cost effectiveness, its ease of use and interpretation, the nature of the terrain and in some cases, the desire for accelerated investigation by the contractors as dictated by the clients.

In Bauchi State, the Gravity and magnetic methods have never been used, probably due to their limitations. By means of the seismic method, it is possible to ascertain the depth to the unaltered compact impermeable bedrock and to identify depressions which constitute preferential flow paths of groundwater. By use of this method, especially in the basement foreland areas where a sedimentary cover overlies, the Basement rocks in the State, it is possible to an idea as to the water resources of the aquifer by determining its thickness. In the past, seismic refraction method was used in the State but because it uses highly skilled labour for operation and interpretation, it was applied, to only a relatively limited extent during the early stages of groundwater investigation. Today, it has been abandoned in favour, of the electrical methods.

The Geonics equipment employing the electromagnetic induction techniques is adopted for geophysical survey in search of groundwater. Two Geonics instruments, EM31 and EM 34-3 have been found, to be suitable for locating water. The EM 31, because of its ease of operation, is used as a reconnaisance tool. Results of drilling indicate that sites registering an EM 34-3 value above 18 millions at a 20m coil separation on both horizontal and vertical dipole modes have a satisfactory probability of success. EM 34-3 surveys have been used in site selections where surficial sediments are non existent or thin, as in the Basement foreland area Research indicates that in using the Geonics equipments, two sites be normally marked, the second serving as an alternative in case the first is unsuccessful.

At Azare floor mill, Geonics EM 31 and EM 34-3 gave readings of 25mmhos/m (horizontal) and 36 mmhos/m (vertical) using a coil separation of 20m; and 27mmhos/m (horizontal) and 25mmhos/m(vertical dipole) using a coil separation of 40m. This successfuly located a borehole and subsequent drilling yielded good results.

In locations where a substantial thickness of sediments overlie the crystalline rocks, the EM 34-3 proved to be inadequate. The contact resistivity equipment ABEM terrameter SAS 300 achieved better results. This involved either depth sounding or vertical electrical sounding (VES) (Water surveys Group 1983). Ako and Osunde (1982) carried out a geophysical survey of the Kerri Kerri formation in Darazo using the electrical resistivity method. A total of 29 Schlumberger VES sounding stations were occupied using the ABEM SAS-300 Terrameter and the SAS-2000 Booster. A qualitative and quantitative interpretation of the VES data they obtained correlated the increase in value of transverse unit resistance (T^1) and total longitudnal conductance (s) with increase in thickness of the sedimentary sequence.

Areas with the highest T^1 values during subsequent drilling corresponded to zones with highest borehole yields.

It should be noted that in many cases, neither of the geo-physical techniques were helpful in assessing the potential for completing a successful borehole either because the depth to the crystalline rocks was too great or conductivity contrast between the sediments and decomposed bedrock was insufficient.

3.3. Exploitation Programme: Borehole Construction

Companies involved in borehole drilling in Bauchi State include Edok-Eter Màndilas, Conred, Mitsui and Preussag. The Water Board also drills some wells. Mitsui and Edok-Eter Mandilas had similar construction techniques.

3.3.1 Construction Methods

Commonly, drilling rigs used were top drive mud and air rotary machines.

The drilling process for boreholes, whether hand pump operated or mechanised, involved an initially large diameter hole, which decreased with increasing depth as the bit is changed until the final depth was achieved. In each case, a surface casing was installed to a depth of about 6m from the ground surface.

In a programme involving 1165 boreholes in the state, over 75% were drilled with air. A degradable mud, or on occassions, bentonite drilling mud was used by Mitsui where drilling mud was required.

3.3.2 Borehole design

In constructing village boreholes, two main designs have been used as a standard (see plate 1).

The first design consists of a 100mm slotted PVC casing fitted with 100mm slotted PVC screen, slot width varies from 1.5-0.5mm. These were used in boreholes drilled to less than 60m depth (Wadrop Report 1983).

The second design consists of a 100mm diameter steel casing with 100mm diameter wire wound stainless steel screen. This design is for deeper

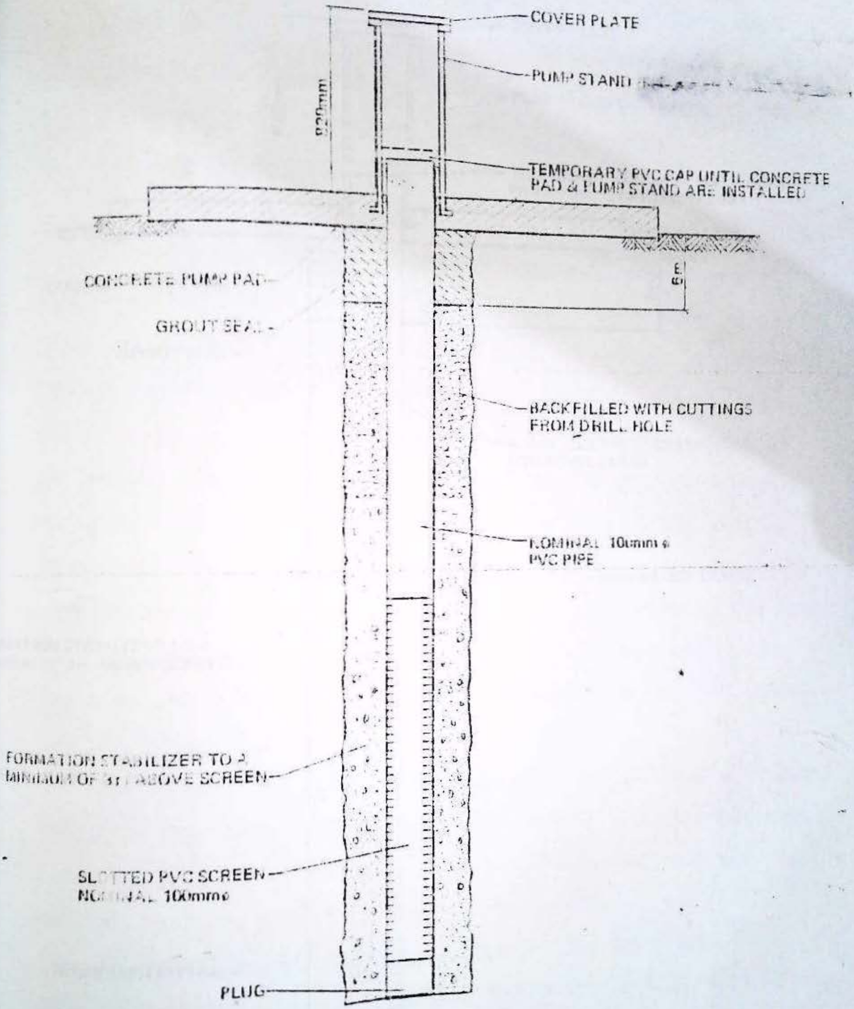


Plate 1 : Borehole Design No 1

source: B. S. A. D. P.
DROUGHT RELIEF PROGRAMME

BOREHOLE DESIGN NO.1

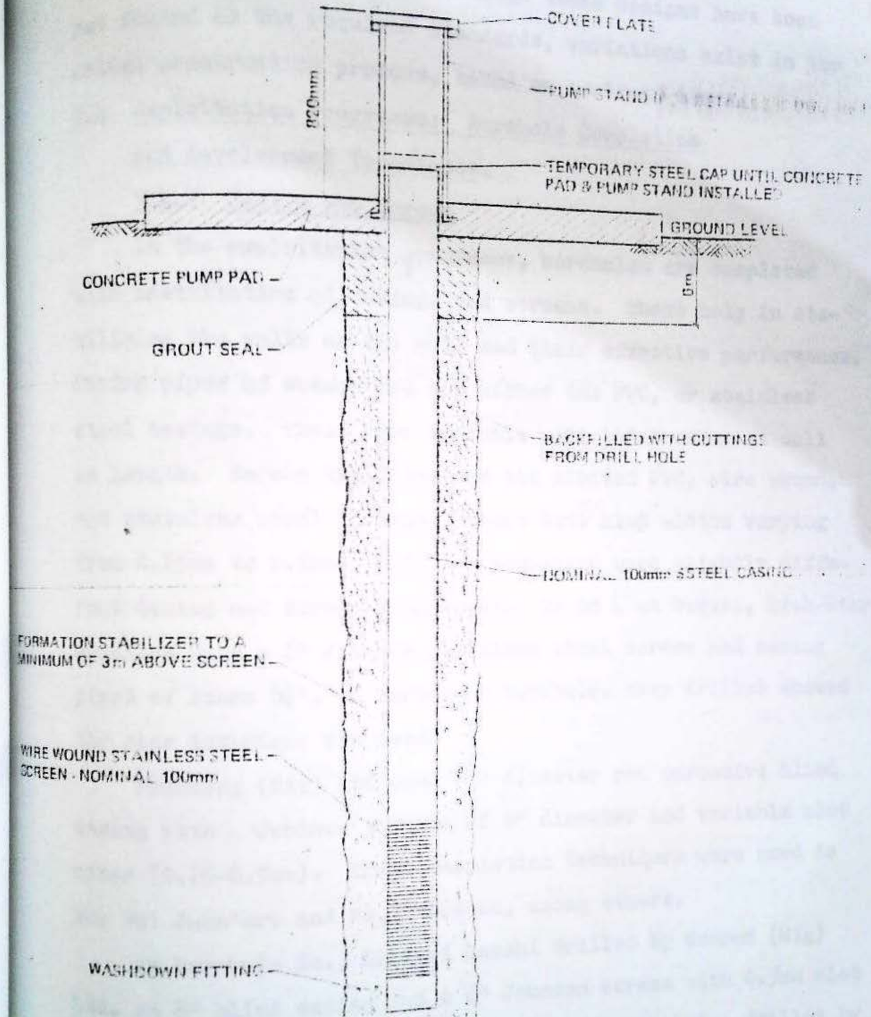


Plate 1 Borehole Design No. 2

Source: B.A.T. DROUGHT RELIEF PROGRAMME

BOREHOLE DESIGN NO. 2

and mechanised boreholes. Although these designs have been put foward as the required standards, variations exist in the actual construction process, based on contract terms.

3.4 Exploitation Programme: Borehole Completion and development Techniques.

3.4.1 Casing and Screen

In the exploitation programme, boreholes are completed with installation of casings and screens. These help in stabilising the walls of the well and their effective performance. Casing pipes of common use are either the PVC, or stainless steel casings. These have variable wall thicknesses as well as length. Screen types include the slotted PVC, wire wound, and stainless steel screens. There have slots widths varying from 0.25mm to 0.5mm. Drilling companies used slightly different casing and screen programmes. In BH 4 at Darazo, Edok-Eter Mandilas used a 6" Johnson stainless steel screen and casing pipes of sizes 8⅝". A survey of boreholes they drilled showed the same technique was used.

Preussag (Nig) Ltd used 6⅝" diameter non corossive blind casing with Johnson screens of 6" diameter and variable slot sizes (0.25-0.5mm). These completion techniques were used in BHs No1 Jama'are and No.3 Hardawa, among others.

In borehole No.3 Billiri Laushi drilled by Conred (Nig) Ltd, an 8" blind casing and a 6" Johnson screen with 0.5mm slot size were used. This is a common trend in boreholes drilled by Conred.

The Geological Survey also used casings and screens of variable diameters.

Appendix IV shows a more complete information on completion techniques used in some boreholes in the sedimentary areas. Their target formations are contained in Table 3.

From these results, it can be said that the completion techniques are similar all over the area, although depths of placement of the screens and casings vary with borehole depths and horizons of water occurence.

The mechanised boreholes are normally constructed using a 150mm steel casing and 100mm wire wound screen. In a few cases, a 100mm slotted PVC screen was installed with a packer connection to the 150mm steel casing. Where a low yield was expected, 100mm PVC casing and slotted screens were used.

3.4.2 BACKFILL and gravel packs

Generally, the back filling of the annular space between the screen and the formation is done with drill chips from the drill hole. Sand packing is done with clean sands and Mitsui Co. Ltd used sands from the beds of the major rivers and sieved them for this purpose. The residual sand was used as fine aggregates for the concrete pads.

In areas with fine sand formation, a control measure employing a fine sand pack was used e.g. in Dukku area, well graded sand from Japan was used in such boreholes. In Gombe area, 55 boreholes drilled needed a fine sand pack. This was obtained by sieving locally available alluvial deposits.

The basic installation approach in the standard borehole design is to place the stabilisers at 3m above the top of the screen section. Then the annular space is sand packed or back-filled with drill cuttings to within 6m of the ground level. The upper six metres of the annular space is filled with a slurry cement to form a sanitary seal, and the surface

3.4.3 Borehole Development

In the BSADP Programme of 1205 wells, air surging and water jetting were the commonest methods used, although in a few cases, surging with a bailer was necessary to remove the fine fraction from the water bearing formation (see 3.4.1).

On each of the village boreholes, a concrete pad is constructed to support the hand pump, provide a platform for the borehole user, and to provide sanitary protection. These pads are constructed such that the borehole casing extends a short distance above the pad surface over which a pump stand is erected. Around the pad, a backfill consisting of coarse gravel is placed. This serves to promote run-off away from the pad (Plate 1).

3.4.4 Pumping Tests

On each borehole completed, a pumping test (or yield test) is conducted:

(a) To ensure that water is clearly rid of drilling fluid;

(b) to verify that there is an adequate yield to sustain a hand pump water supply;

(c) to achieve additional development of the borehole screen and water bearing formation; and

(d) to obtain information on the drawdown characteristics of the borehole so that the appropriate depth for the hand pump intake may be chosen.

Especially for the purposes (b) and (d), a two way pumping test was adopted (Conred, Edok-Eter Mandilas, Preussag). The first involved a multistage (from 3-5 stages) test from the static water level.

From this stage, the yield, duration of test and drawdown for each well were recorded. Following this, a second test called the single stage test was performed, noting the duration and yield. There after, recovery measurements took place for a period of time and residual drawdown recorded (Table 6: Appendix II).

Evaluation of the pumping test results is normally by application of the JACOB non-equilibrium methods from the recovery measurement of the single stage test. By a combination of this method and the curves drawn, the transmissivity and critical yield of each borehole is obtained.

After these tests, the borehole is disinfected (using concentrated chlorine solution) and a temporary cap is installed for sanitary purposes.

Table 6: TYPICAL PUMPING TEST RESULTS FOR A SELECTED BOREHOLE

Borehole No.3 SHIRA: 4STAGE PUMPING TEST

STAGE	DURATION	YIELD(YB)	DRAWDOWN(M)
1	2 hrs	1.06	0.97
2	2 hours	1.64	3.39
3	2 hours	1.96	5.27
4.	1 hour	2.51	8.73

RECOVERY MEASUREMENTS

Date	Hour	Time Since pumping Stopped(s)	Dynamic Water level (m)	Residual Drawdown (m)	$\frac{t+t}{t}$
10/2/78	18.41	1	13.83	4.73	
		2	10.10	1.00	
		3	9.23	0.13	
		4	9.22	0.12	
		5.	9.21	0.11	
		6	9.21	0.11	
		7	9.20	0.10	
		10	9.19	0.09	
		15	9.19	0.09	
	19.00	20	9.19	0.09	
		25	9.18	0.08	
		30	9.18	0.08	
		40	9.17	0.07	
		50	9.17	0.07	
		60	9.17	0.07	
	19.55	75	9.16	0.06	

Source: Water Board Records

3.5 Observation wells and recharge

These are wells used to monitor recharge into a well under static conditions e.g. in seasons of heavy draft and heavy recharge. They show changes in groundwater levels in production wells located within a distance of each ~~other~~ other. Observation wells can thus be used to compute some hydraulic properties like transmissivity, permeability and storage coefficient of a well during pumping tests.

In Gombe, two production boreholes (BH 60 and BH 61) have observation wells located at 48.8 and 48.9m from them respectively. These were used to compute the hydraulic properties of aquifers in Gombe subctachment area (Ako and Iyioriobhe 1986).

Groundwater recharge in Bauchi State is mainly by rainfall. In some arees, it is influenced by proximity to rivers. Boreholes with good recharge have small drawdowns with high recovery rates e.g. in BH 3 Sade, located in Kerri Kerri Formation, the total depth of the hole is 189m with a static water level of 40.64metres. The tested yield was 5.431/s involving a multi-stage pumping test of three steps. On each step, there was a low drawdown (average of 0.96m). The drawdown measurements lasted for five minutes but the water level recovered completely right away from the first minute.

In Borehole No.2 at Jama'are, recovery rate of the 39m deep hole (with a drawdown of 4.02m and a static water level of 4.75m) and a yield of 81/s was 102% in six hours.

These are two cases of extreme recovery rates that probably depended on the recharge. Recharge/discharge xx also may be influenced by the interborder under-ground water exchange between sedimentary parts of Bauchi State sharing boundaries with the other states e.g.Kano, Borno and Gongola (Dike 1987).

3.6 Cost and Lifespan of Boreholes

These depend on a number of factors. Cost depends on the consultancy services in site selection, the drilling, development and completion techniques, the type of pump installed and spare parts. The lifespan of a well is a function of its completion techniques and maintainance. Information available from agencies involved in borehole construction in the state show that average cost for a borehole is about ₦40,000 (upto 1986). However, those with less elaborate completion techniques, cost less. Boreholes constructed under the 1986 BSADP Drought Relief Programme are of this category. They were required over an emergency period and the programme was large, covering 1342 villages and 1449 boreholes. The average cost of such village boreholes is approximately ₦17,000 each.

The life span of a borehole varies and depends on the original completion and development methods and subsequent maintainance. Wells drilled by the Geological Survey of Nigeria between 1948 and 1961 in the Old Bauchi province are still in good working condition e.g. BH No. GSN1138 DUKKU in Kerri-Kerri formation (Borehole design: casing, to 91m of 33cm diameter, 91-139m of 27cm diameter, 139-199 of 17cm diameter; screen, 183-193 m of 10.46 diameter) was drilled in 1952.

However, a longer lasting borehole would be one which is completely gravel packed, and, over the years, given a good and regular maintainance (Dike 1987).

3.7 General Problems in exploration and exploitation OF WATER

These problems are variable. There are instances where inaccessibility hampers exploration efforts.

The possibility of rapid lithologic variations in areas where different rock types of non-water bearing horizons overlie one another gives rise to dry holes. This is common in the marine shales of Pindiga and Yolde formations which show lithologic discontinuities. In some other cases, the boreholes may give very low yields.

In other areas, the water table is at considerable depths. Thus holes are exceptionally deeper than normal. This leads to higher cost of drilling and development of the wells. The Kerri-Kerri formation is characterised by such high depths, especially on the high ridges where water depths are well over 100 metres. In such cases the depth of the holes are too great for installation of hand pumps.

In Gombe sandstones, some boreholes drilled had problems of fine sands being pumped into the water bearing zones, that made completion of the holes difficult. Even after extensive development, the water continued to contain very fine sand when the normal completion techniques were applied. In order to reduce or eliminate this problem, modification on the construction and development techniques were employed. A 165.6 mm hole was drilled. The location of the water bearing strata was delineated by electric log. The hole was then reamed to 265.6mm of the required depth. A 100mm slotted PVC screen was installed and a fine sand pack set. The problem of fine sand puming was therefore overcome by use of thicker and finer sand pump coupled with prolonged development.

Other problems include well failure due to drying up of boreholes. In a borehole drilled in Billiri Laushi by Conred to a depth of 58m (in the Bima formation), the well dried up in a few seconds after clear water circulation and a surging with air development was carried out.

Boreholes GSN 1350 No.1 and 3 in Dukku have been abandoned due to small water rise and low yield respectively.

CHAPTER FOUR

ROLE OF SEDIMENTARY AQUIFERS IN THE WATER RESOURCE DEVELOPMENT OF BAUCHI STATE.

4.1 Introduction

A great proportion of the total xland area of Bauchi State (about 56%) is underlain by sedimentary formations which have considerable water reserves for both domestic and industrial use. At present, great efforts are being made by the State Government to exploit these reserves and supply portable water to both urban and rural communities. For this purpose water supply schemes have been established with zonal offices at Gombe, Azare and Bauchi which had supplies of approximately 11.4 million 7.8million and 12.1million litres/day respectively as at 1981 (Bauchi State Water Board Report 1981).

However in some areas like Dukku and its surrounding (Kerri Kerri formation) and Tula and environs (Bima formation), depths to the water table are beyond reach of economic exploitation and maintainance. Therefore some other water supply schemes are adopted. In Tula, there is an intake arrangement where a stream head from a hill produces water at 3.47l/s and this is trapped in an embankment, then pumped to the town.

From results of groundwater investigations, sedimentary aquifers have a lot of prospects in the future water resource development of the state as the urban and rural water supply schemes indicate.

4.2 Integrated Rural Borehole Scheme: A Case Study

This is a scheme whereby water is extracted from xxxxxxy boreholes and sent to booster stations from where it is piped to areas of need. This is the case with Dukku and its surrounding where natural water occurence is not easy to be reached by drill (see 4.1). In a programme to salvage the situation, seven boreholes were sunk on the bank of the Gongola River at Gombe-Abba, about 24km west of Dukku. The aquifer taps water from the Kerri Kerri formation. The characteristics of the boreholes are summarised in Table 7.

From these boreholes, water is pumped to tanks in a booster station situated between Dukku and Gombe Abba. From this station the water is conveyed by pipes to Dukku and its surroundings:

Borehole Location & No.	Depth (M)	Yield(l/s)	SWL(M)	Drawdown(m)
Gombe-Abba No.1	60	15	2.9	0.8
2	60	10.03	2.9	20
3	60	4.38	3.0	7.6
4	60	11.25	2.8	5
5	60	18.75	2.8	6

Table 7: Borehole Characteristics: Dukku water Scheme

Investigation show that at present, only one of the boreholes is used to serve Dukku and even this is underutilised. The Bauchi State Utilities Board plans to extend the Scheme to other places.

4.3 Dams

Locally, some areas suffer severe water shortages. Such marginal areas lie around the north central part of the State e.g. Dukku, Hardawa, Jama'are, Chinade and Kilbori. A long term solution to such water problems is obviously the construction of dams, as borehole yields are low and inadequate. But because the topography in the sedimentary areas is far more gentle than in the Crystalline Basement areas, dam sites are less frequently found, and for rural supplies, communities are usually small, and the cost of building dams are prohibitive.

For the forseeable future, boreholes will continue to be the solution to rural water needs.

Mini-dams are constructed locally with earth embankments by communities. These trap water during the rainy seasons and provide a useful source of water in the long dry periods, although the water quality is usually unfit for human consumption.

4.4 Integrated Borehole Scheme: Alternate Use

Considering the fact that Bauchi State has a predominantly agricultural population, the rural borehole schemes can be planned to serve purposes other than providing drinkable water. One of such purposes could be farming, in which case the wells could be used in the dry season for farming. The net effect would be to use the borehole scheme as a means of irrigation to improve cropping seasons and probably achieve two crops a year.

4.5 Future of Sedimentary aquifers in Bauchi State

The various urban and rural water supply schemes have a total water yield of about 31.3million litres per day out of which the sedimentary areas supply 19.2 million litres per day representing 61.29% (see 4.1) This confirms that sedimentary formations constitute the most important aquifers. Therefore for a very long time, they will continue to be the main source of water supply to 56% of the area of the state. By the use of the Integrated Borehole Scheme as that of Dukku, the sedimentary aquifers will continue to be the saving grace for areas with acute water problems.

CHAPTER FIVE

Conclusions and Recommendations

The result of the present work has led to many broad conclusions namely:

1. The sedimentary formations underlie about 56% of the State's land area.

2. They have considerable underground water reserves and supply, and as at 1981, supply about 62% of the total water needs of the state.

3. The depth to the water table in the aquifers of this formation is influenced by topographic features, as well as the thicknesses of formations,

4. Bima and Kerri Kerri Formations, and to some extent, the Chad Formation, are the most significant aquifers.

5. The Bima is at present the most developed and exploited of all the aquifers of the State.

6. The marine shales do not constitute an aquifer, but where there is a local occurence of permeable sand horizon, water is readily available.

7. The occurence of water in some localities (e.g. Dukku, Tula) is at too great a depth to be exploited by boreholes successfully.

8. Only a sustained programme of borehole scheme can take care of the water requirements of both the Urban and rural communities.

From the above and other conclusions in 2.5, it is hereby recommended that:

(a) More effort should be made to explore and exploit water in formations other than the Bima. The Kerri-Kerri, with its superior land space coupled with a comparable high yield, ...uch more attention than it has so far received. Otherwise the aquifers in the Bima Formation may be impaired by over-exploitation.

(b) Academic studies on the water conditions over the area should not be localised but spread fairly to achieve representative and more accurate results.

(c) The Integrated Rural Borehole Scheme initiated at Dukku be extended to other areas with comparable water problems as a long-term solution where costs permit.

(d) Where feasible, borehole schemes be designed to serve as a means of irrigation which could increase the cropping seasons to two periods during the year.

(e) A hydrogeological data bank be established for the State which could be used to formulate policies on development projects involving water resources.

(f) A regulatory body be set up to control the development of water resources of the State so that aquifers are not damaged due to uncontrolled over-production.

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Appendix J

Log of some boreholes used in aquifer tests

Source: Water Board Records

Appendix I: Log of some of the Boreholes used in aquifer Tests.

Boreholes No. 1 Alkaleri

Depth	Thickness	Lithology
6 feet	6	Lateritic soil with gravel
13	7	Gravel with little clay
19	6	Red silty medium-Coarse sand with gravel
22	3	Coarse sand with gravel
33	11	Medium - Coarse soil
39	6	Coarse sand clay content increase at depth
45	6	Sandy clay
48	3	Coarse sand with gravel
59	3	White clay
54	3	Gravel with clay
58	4	Clay with sand
64	6	Gravel with clay
67	3	Clay with sand
72	5	Clay with sand and gravel
75	3	Highly weathered granite
77	2	Moderately weathered granite
79	2	Slighly weathered granite
81	2	Fresh granite

Borehole No. 3 Hardawa

Depth(m)	Thcikness(m)	Lithology
3	3	Reddish brown soil
6	3	Gravel, Yellow, mainly quartz
8	2	Quartz conglomerates, Yellow, well rounded
12	4	Sand with some conglomerates slightly coarse gravelly
15	3	Medium-gravelly sands with well rounded conglomerates
27	12	Sand, Yellow, coarse gravelly, angular grain
30	3	Weathered granite
80		[illegible] granite

Borehole No.3 Billiri Laushi.

Depth	Thickness	Lithology
2	2	Soil gravelly to fine, brownish
6	4	Sand very coarse, reddish, Subangular, well sorted pink and brownish orthoclase richs subordinate quartz, traces of muscovile
17	11	Sand gravelly to coarse, brown reddish, sub-angular, formed by signments of weathered granite and fregments of sils-tone , greenish and brownish, well handed.
32	15	Sand coarse and very coarse, clayeye, brown reddish, subangular with fragments of weathered granite and brown-reddish muds-tone.
39	5	Clay, reddish and greenish
72	33	Sandstone coarse to medium, yellowish, sub-angular, well sorted fairly cemented, white and hyaline quartz rich, sub-ordinate orthoclase.
108	36	Sandstone coarse to medium, whitish to yellowish and light reddish, sub rounded fairly sorted, poorly cemented. Pooantz rich, sub-ordinate orthoclase.

Borehole No.3 Misau

Depth	Thickness	Lithology
7 m	7	Brown clay with little sand
234	227	Medium-Coarse sand, fine peables with littleclay
237	3	Fresh granite

Borehole No. 2 Jama'are

Depth(m)	Thickness(m)	Lithology
3	3	Sand, muddy, fine grained, whitish brown
6	3	sand, fine grained, whitish brown
13	7	sand, fine-medium grained, feldspathic,brownish
18	5	sand, medium coarse grained, quartz feldspathic brown.
22	4	Sand, coarse grained, feldspatic quartzitic, brown.
23	1	sand, fine grained, brownish
30	7	Sand, coarse grained, feldspatoquartzitic,brown
36	6	clay, slightly sandy, grey
39	3	clay, grey in colour.

Borehole No. 3 Sade

Depth(m)	Thickness(m)	Lithology
5.	5	Fine to medium sand with brown clay
12	7	Medium to coarse sand with brown clay
14	2	Coarse sand to very fire gravel with clay
31	17	Medium to coarse sand with brown clay
32	1	fine grav-l with white clay
44	12	Coarse sand to very fine grain white clay
50	6	Coarse sand
56	6	Medum to coarse sand with small amount of clay
99	43	Fine, medium-coarse sand with little clay
108	9	coarse sand to very fine gravel
138	30	Coarse sand to very gravel with clay
140	2	purple clay and little fine sand
[illegible]		Coarse sand to fine gravel with little clay.

Zanzai

Depth(m)	Thickness(m)	Lithology
1	1	Brown top soil
7	6	Silt clay with small amount of fine sand
12	5	Whitish clay
31	19	Grey clay with small amount of peables & sands
36	5	Brownish clay with sand and fine peables
53	17	Brownish clay with sand
65	12	Medium-very coarse sand with clay and find peables
70	5	Medium to carse sand with clay
89	19	Clay with sand
93	4	Medium-coarse sand with small amounts of clay
98	5	whitish plastic clay with small amounts of sand
106	8	Medium to coarse sand with small amount of clay
108	2	whitish clay and sand
114	6	Medium-very coarse sand with small amount of clay
116	2	clay with some sand
119	3	coarse sand with clay and fine peables
123	4	white clay with sand
138	15	Medium-coarse sand with clay and peables
140	2	clay with sand
153	13	clay with small amounts of sand

1	8	Medium-coarse sand and small amount of clay
9	28	clay with sand
1	22	Medium to coarse sand with clay and peable
4	3	Grey clay with small amounts of sand
19	5	Medium-coarse sand with gravel
24	5	Medium-coarse sand with clay and peables
36	12	Grey clay with small amounts of sand
38	2	Medium-coarse sand with small amounts of clay and fine peables.

Borehole No. 64 Gombe

Depth(m)	Thickness(m)	Lithology
2	2	Soil sandy coarse, earthy
13	11	Sand, coarse to fine unsorted, quartz grains
26	13	Fine to coarse sandstone, cemented, subrounded quartz
38	12	Sand, coarse-fine, unsorted, subrounded quartz grains
102	64	Sandstone, coarse fine siltstone & claystone, cemented
133.	31	Sandstone, coarse fine and silstone, medium cemented
167	34	Clay with sand and siltstone, greenish to violet
266	49	Sandstone with siltstone and few clay, unsorted
273	13	Sandstone with claystone, poody cemented unsorted.
277	4	Sand, coarse; medium sorted, subangular quartz grains

311	33	Sand coarse with claystone and siltstone whitish to light brown, whitish quartz, subangular.

Borehole No.1 Jama'are

Depth(m)	Thickness(m)	Lithology
3	3	Mud reddish brown overburden
9	6	clay, reddish brown
24	15	sand, mediumcoarse grained yellowish grey
27	3	Sand, clayeye, medium-coarse, reddish brown
33	6	Sand coarse, gravelly, reddish brown
36	3	clay, dark grey
41	5	sand, fine-coarse grained, gravelly xxx whitish

Borehole No. 153NW-2 Wade

Depth(m)	Thickness(m)	Lithology
4	4	Light brown clayey medium quartz sand
5	1	fine clayey quartz sand
14	9	Light brown coarse to fine sand
16	2	silty clay
23	7	coarse sand
24	1	sandy clay

Appendix II

Typical pumping test results

Spurce: Bauchi State Water Board Records

APPENDIX II: TYPICAL PUMPING TEST RESULTS

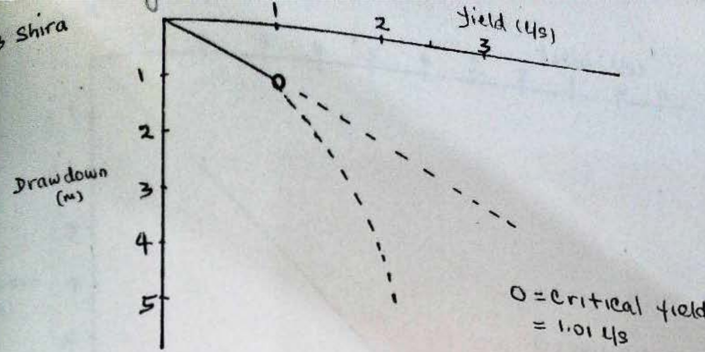
Borehole Location & Number	Stage	Duration(hrs)	Yield(l/s)	Drawdown(m)	Duration(hr
Shira No. 3	1	2	1.06	0.97	
	2	2	1.64	3.39	
	3	2	1.96	5.27	
	4	1	2.51	8.73	
Misau No.3	1	2	4.84	5.04	
	2	2	7.03	7.02	
	3	2	8.72	8.71	
	4	3	11.35	14.87	
Lanzai No.3	1	2	10.72	2.55	
	2	2	11.98	2.70	
	3	2	1.39	2.97	
Chinade No.2	1	1	1.23	16.25	3
	2	1	1.61	24.37	
	3	1	1.85	31.19	
Alkaleri No.1	1	1	1.89	0.82	6
	2	1¼	3.12	1.32	
	3	2	4.36	2.06	

Borehole Location & Number	Stage	Duration(hrs)	Yield(l/s)	Drawdown(m)	Dration(hrs
Azare No. 11	1	2	1.00	1.17	6½
	2	2	1.45	2.82	
	3	2	1.98	26.34	
Sade No.3	1	1	2.18	0.50	
	2	1	2.90	0.66	
	3	1	3.75	0.96	
Gamawa No.1	1	2	2.04	0.40	6
	2	2	3.13	0.63	
	3	2	4.05	0.89	
Udubo No.1	1	2	3.63	2.20	
	2.	2	4.54	2.55	
	3	2	6.31	3.20	

Appendix III

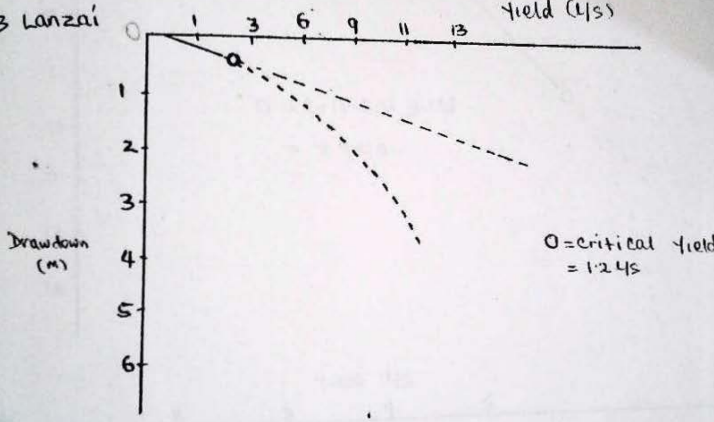
Characteristic curves of Some Boreholes showing Critical Yields.

BH 3 Shira

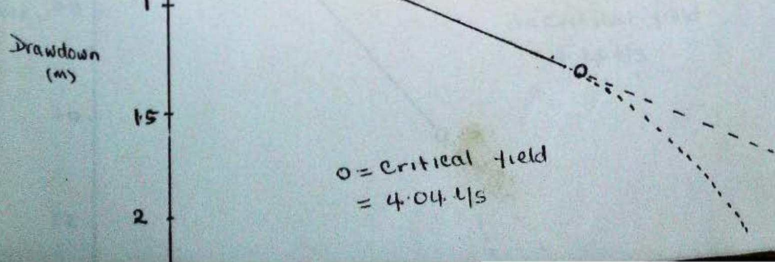


p2

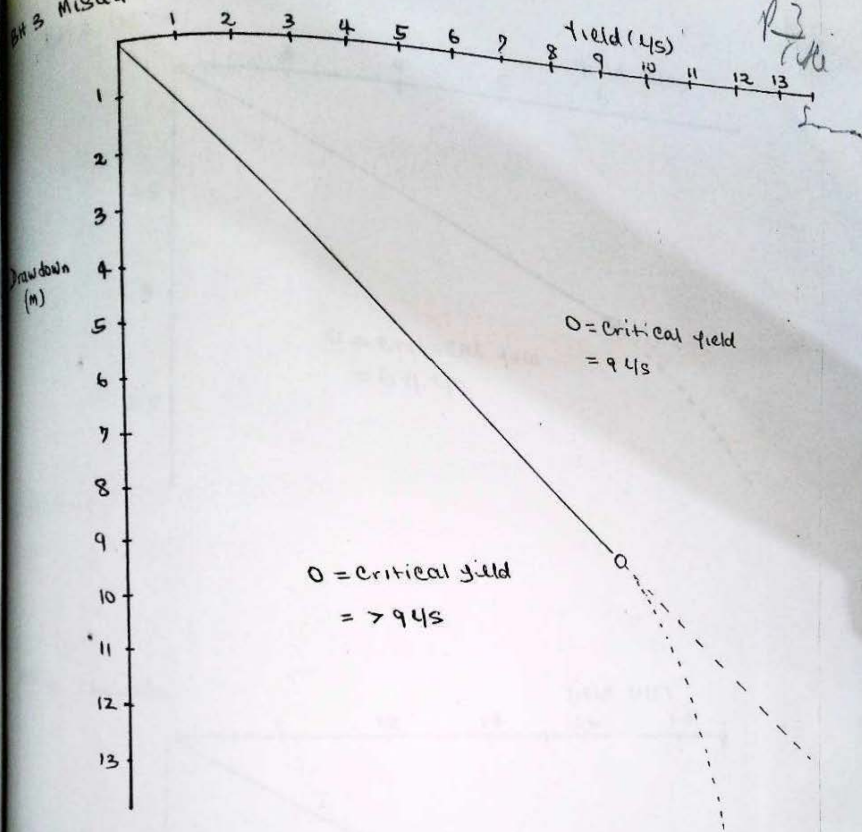
BH 3 Lanzai



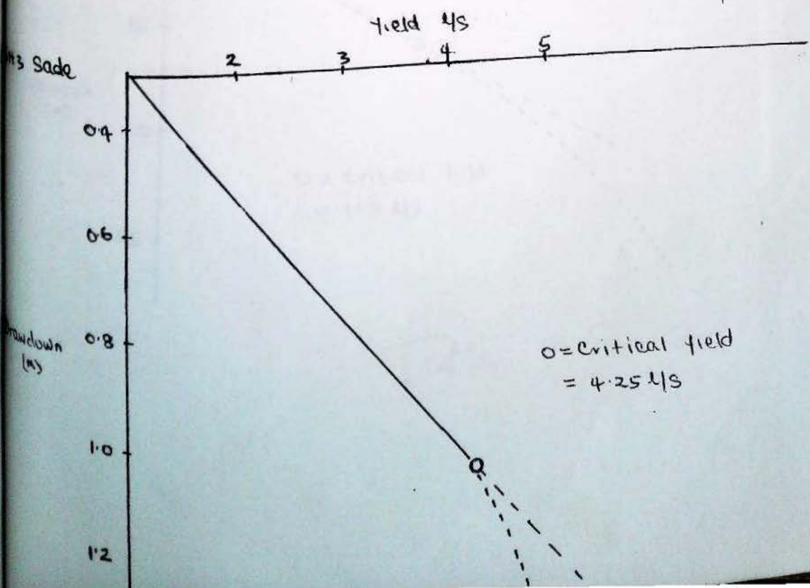
BH 1 Alkaleri



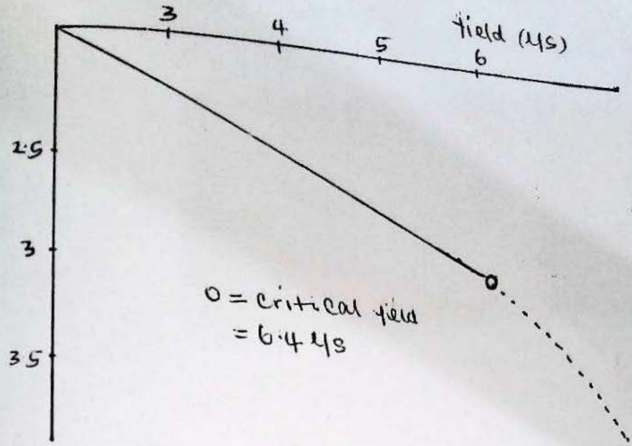
BH 3 Misau



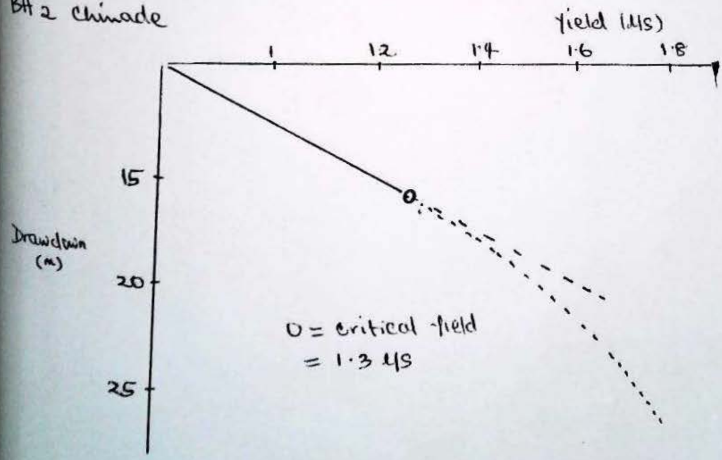
BH3 Sade



BH 1 Udubo



BH 2 Chinade



Title & Summary

Appendix IV

Typical borehole completion techniques

Source of data?

APPENDIX IV: TYPICAL BOREHOLE COMPLETION TECHNIQUES

BH No. & Location	Depth(m)	Casing From To (m)	Diameter (ins)	Screen From to (m)	Diameter (ins)	Gravel Pack(m)	Cementa (m)
11a Azre	54	0.6-27	$6\frac{5}{8}$"	27-35	6"	6.1-54	g.s to
		35 -52	"	51-52			
		52-54	"	51-52			
6 Azare	80	0.6-66	$6\frac{5}{8}$"	66-69	6"	6.1-64	g.s to
		79-80	"				
1 Shira	50	0.6-26	$6\frac{5}{8}$"	26-44	6"	6.1-50	g.s. to
		44 -50					
3 Shira	35	0.9-19	$6\frac{5}{8}$"	19-29	6"	6.1-35	g.s. to
		29-35	"				
2 Chinade	66	0.6-39	$6\frac{5}{8}$"	39-45	[illegible]	6.1-66	g.s. to
		45-51	"	51-63			
		53-66	$4\frac{1}{2}$"				
3 Lanzai	243	0.6 -104				6.1-244	g.s. to
1 Jama'are	41	0.5-12	$6\frac{5}{8}$"	12-24	6"	6.4-41	g.s. to
		24-27		27-33			
		33-36		36-40			
		40-40.5					

BH NO. & Location	Depth(m)	From To (m)	Diameter (ins)	Screen From To (m)	Diameter (ins)	Gravel Pack(m)	Cementation (m)
3 Billiri Laushi	108	0.90-796	6"	79.67 101.11	6"		g.s. to 10
		101.11-10[illegible].11					
DR 84SW45 Isawa	55			31.47			
DR 108SW15 Dirishe	75			7.5-745			
3 Hardawa	80	0.3-17.73	$6\frac{5}{8}$"	17.73035.74	6"		
		35-74.47.76					
		59.79-77.89					
1 Alkaleri	81	1-45	$6\frac{5}{8}$"	45-49	6"		
		49-59	"	59-63	"		
		63-72	"	72-78	"		
		78-81	"		"		
GSN 947 Dukku	104	Nil	-	-	-		
GSN Dambam 964	41	1-40	13cm				
3 Sade	189	0.50088	$8\frac{5}{8}$"	88-98	6"		
		******	"	120-126	"		
		126-141	$6\frac{5}{8}$"	141-145	"		
		145-160	"	160-164	"		
		164-171	"	171-181	"		
		171-189	"				

No. & Location.	Depth(m)	Casing From to (m)	Diameter (ins)	Screen From To (m)	Diameter (Ins)	Gravel Pack(m)	C
5 Darazo	0.6-68	$6\frac{5}{8}$"	68-73				
	73-134	"	134-138		6"		
	138-213	"	213-240		"		
	240-251	"	251-261		"		
	261-262	"			"		