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Developing groundwater for rural water supply in Nigeria: a report of the May 2005 training course and summary of groundwater issues in the eight focus states

Groundwater Programme

Commissioned Report CR/05/219N

BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

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Developing groundwater for rural water supply in Nigeria: a report of the May 2005 training course and summary of groundwater issues in the eight focus states

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Measuring recovery after a bailer test (photo © NERC)

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Morgan Burke of the International Association of Ireland helped to facilitate the training course in Jos. Thanks also to Dr Offodile and Sunday Mangai for sharing their experience at the training course.

The project was funded by DFID, through the OASIS Resource Centre.

Summary

The British Geological Survey was commissioned to strengthen the capacity of the rural water supply and sanitation agencies in eight states in Nigeria to undertake groundwater resource evaluation and development. These states (Jigawa, Benue, Enugu, Eketi, Zamfara, Kwara, Borno and Ebonyi)are the focus of a current FGN/UNICEF WES Project, supported by DFID. The opportunity was also taken to assess the hydrogeological issues facing the eight states and to suggest ways to help meet this need.

The training course

To meet these terms of reference a two-week training course was held in Jos, Plateau State during May 2005. The course focussed on the most pressing problems faced by groundwater professionals in Nigeria (as agreed at a 2-day workshop in Abuja), whilst at the same time providing a broader introduction to groundwater theory and techniques.

- The course was based on the recent book, funded by DFID, "Developing groundwater: a guide for rural water supply" which was handed out to all participants.
- Given the short time available, it was impossible to cover all relevant aspects of hydrogeology in detail. Instead, course participants were presented with basic material on important topics, and given the means to access further information and resources.
- Thirty-two participants attended the course, which was facilitated by Alan MacDonald and Jude Cobbing from the British Geological Survey, with help from Morgan Burke from the International Association of Hydrogeologists, Ireland.
- The training course covered the following topics: groundwater environments, siting wells and boreholes, supervising drilling, assessing the yield of a source and water quality. A variety of teaching methods were used including lectures, group discussions, practical sessions and field visits.
- During the course, links were encouraged between the professionals from the different states.

Hydrogeological Constraints in groundwater development

Part of the aim of the workshop and training course was to identify constraints on developing rural water supplies in Nigeria – and in particular the eight focus states. The primary aim was to identify the physical constraints, due to the hydrogeological conditions and the methods of developing groundwater. A broader institutional analysis was outside the scope of the study. Nigeria is a large country with diverse conditions, therefore, some issues are unique to individual states, while others are more generic. Information was gathered from a variety of sources: (1) presentations (at Abuja workshop) made by the General Managers of the rural water supply and sanitation agencies for the eight focus states; (2) questionnaires and group discussions at the training course; (3) evaluation of the training course at Jos; and (4) an overview of the groundwater conditions across Nigeria. The time available for this review was limited, therefore, this analysis should be treated as preliminary. The following were highlighted:

- the diverse hydrogeological conditions, requiring different methods to develop groundwater;
- areas where the groundwater resources are poorly understood and difficult to develop using conventional techniques;

- specific issues, such as declining water-levels and poor quality water in certain areas;
- poor capacity for carrying out essential tasks, such as geophysics, yield tests and chemical analysis of the groundwater;
- limited access to spare parts for equipment;
- a perception that budget holders do not appreciate the costs involved in developing a safe sustainable water supply.

Recommendations

To extend coverage of sustainable rural water supplies throughout Nigeria it is essential to increase the technical capacity of the rural water supply sector. Below are several broad recommendations.

Increased networking within Nigeria: between different states and also more broadly within the groundwater community. The training course was an excellent opportunity for staff from different states to make links. Continued communication should be actively encouraged through regular workshops, and email contact. National organisations such as the Nigerian Association of Hydrogeologists can also be an excellent forum for exchanging ideas.

Strengthening of teaching institutions: the NWRI in Kaduna has responsibility for training water professionals. Although, they have considerable skills in certain areas, their capacity in rural water supply issues is poorly developed, and they are not in a position to provide appropriate training to the staff in the state rural water supply and sanitation agencies. To function better, the institute's capacity in the groundwater aspects of rural water supply must be strengthened and the culture altered to give rural water supply issues a higher priority. A programme to help train the trainers should be considered.

Benchmarking: There is general confusion about the standard of work required for developing rural water supplies. There would be considerable benefit on agreeing certain standards within the eight focus states. This would need to be sufficiently flexible to allow the professionals in each state to use techniques most suited to their groundwater environment, but clear in the scope of work that is expected (e.g. sources sited using appropriate methods, yield accurately assessed using a pumping test, water quality tested within project areas etc.).

Targeted groundwater studies: There are some complex groundwater issues in the focus states that will need to be addressed if rural water supply coverage is to be extended.

- Reviewing and making accessible existing research in Nigeria.
- Producing usable groundwater development maps for the States.
- Further studies:
    - prevalence of poor quality water – particularly arsenic and fluoride, and the impact of sanitation
    - overexploitation of groundwater, falling water tables and declining yields: more needs to be done to understand recharge to the groundwater resources.
    - finding better methods to exploit groundwater in areas where success rates are low – areas of poorly weathered basement, or low permeability sediments.

1 Introduction

Access to safe drinking water is a key ingredient for better health and reducing poverty. However, more than half of the rural people in Nigeria do not have access to a safe and reliable water supply. Faced with this reality, the international community have set Millennium Development Goals (MDGs) to help focus on activities that will address poverty and pursue sustainable development: one of these targets is, by 2015, to reduce by half the number of people without access to safe reliable water supplies. Across much of rural Nigeria, the only realistic water supply option is groundwater – alternative water resources are unreliable and expensive to develop and maintain. Therefore, understanding and developing groundwater resources is of critical importance if real progress is to be made towards the Millennium Development Goals (MDGs).

Against this background the British Geological Survey was commissioned by DFID and UNICEF through the OASIS Resource Centre to strengthen the capacity of key rural water supply professionals, to undertake groundwater resource evaluation and development in eight focus states (Jigawa, Benue, Enugu, Eketi, Zamfara, Kwara, Borno and Ebonyi) and to briefly assess the hydrogeological issues faced in the eight states. These states are the current focus of a Federal Government of Nigeria (FGN) / United Nations Children's Fund (UNICEF) / Water and Environmental Sanitation (WES) project supported by the UK Department for International Development (DFID). The location of the eight states is shown in Figure 1. The agreed outcomes for the work were specifically:

- Improved groundwater evaluation and development techniques used by state hydrogeologists.
- Increased communication of groundwater staff between the 8 focus states.
- Scoping study of the hydrogeological issues facing the eight states.

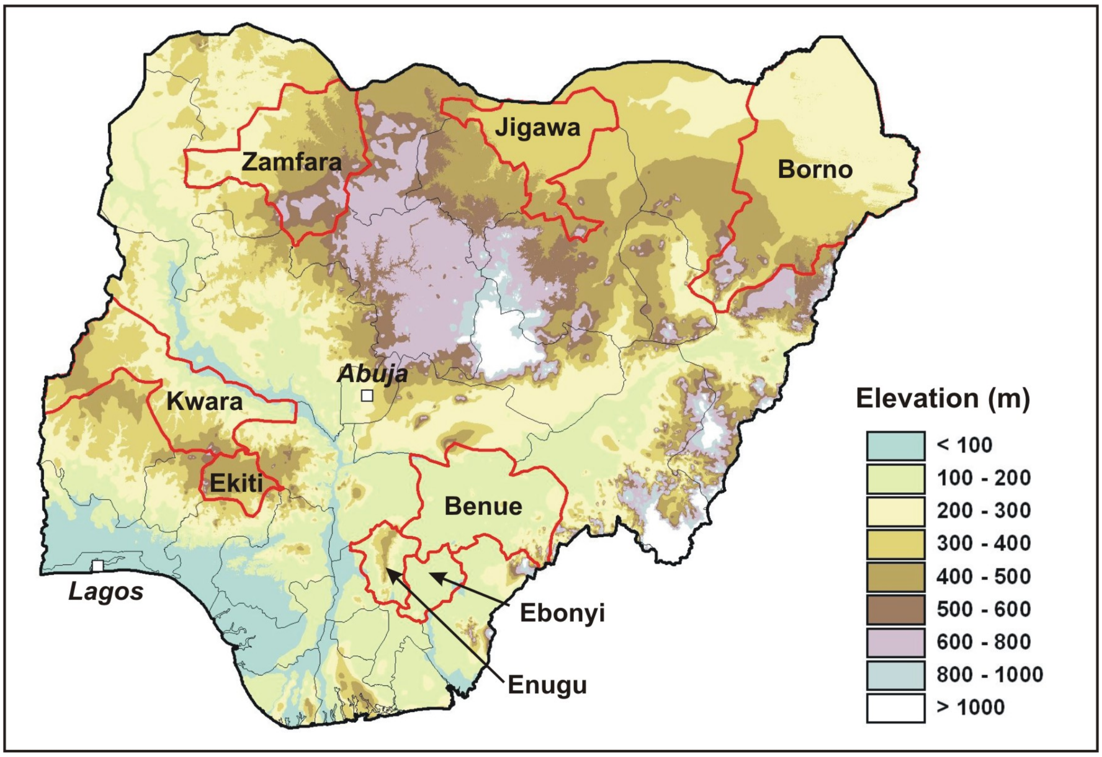

Figure 1 The location of the eight focus states.

The logframe and terms of reference for the project are given in Appendix 1.

The following work was undertaken between April and June 2005, by BGS in order to achieve these outcomes:

1. A training course was prepared, based on previous BGS course in Malawi (Davies et al.2002) and the book *Developing Groundwater: a guide for rural water supply* (MacDonald et al. 2005).
2. A 2-day workshop was held in Abuja on 3-4 May 2005 involving representatives from the eight focus states, UNICEF, the Federal Ministry of Water Resources (FMWR) and the National Water Resources Institute (NWRI), to help identify the main issues of concern and, therefore, better target the training course.
3. A 2-week field training course on developing rural groundwater supplies in a Nigerian context was run from 9 – 19 May 2005. The training course was based in Jos and had a large component of fieldwork. The course was originally designed for participants from the 8 focus states and UNICEF, FMWR, NWRI. However, representatives came from 15 states, rather than the 8 originally anticipated, the additional states were Abia, Niger, Cross River, Gombe, Kebbi, Ogun and the hosts, Plateau State.
4. A scoping study was undertaken of the hydrogeological issues faced by the eight focus states.

This report summarises the aims, methods and outcomes of the training course, and also forms a scoping study of the hydrogeology of the eight focus states, and the issues facing the rural water supply professionals in these states.

2 Introduction to the hydrogeology of Nigeria

The eight focus states are spread throughout Nigeria (Figure 1): Kwara and Ekiti states are in the west of Nigeria; Benue, Enugu and Ebonyi states in the east; and Zamfara, Borno and Jigawa states in the North. The setting of the different states is diverse and topography, rainfall and geology vary markedly. Consequently, the groundwater potential varies, as do the methods required to locate and develop sustainable groundwater supplies.

Figure 2 shows the average annual rainfall across Nigeria for the period 1951 - 1995. The northern states have low rainfall: Jigawa has the lowest rainfall of the eight states with mean annual rainfall less than 750 mm, and a short rainy season of only 4 or 5 months. Rainfall increases to the south where Ebonyi state has more than 2000 mm per year and a rainy season that can last for more than 6 months. Rainfall varies from year to year, however, and in general, the variation in the north of the country is greater than in the south.

A simplified hydrogeological map of Nigeria is shown in Figure 3. This has been derived from information from the Geological Map of Africa (UNESCO 1987). The four main environments are described below (see MacDonald et al. (2005) for a more detailed description of these environments and the terminology).

Crystalline basement comprises ancient igneous and metamorphic rocks, generally over 550 million years old. Much of the Nigerian crystalline basement rocks are granite and gneisses, with some metamorphosed sediments in the east of the country. Groundwater is found within the weathered zone or in deeper fractures. All of the focus states, except Enugu and Ebonyi,

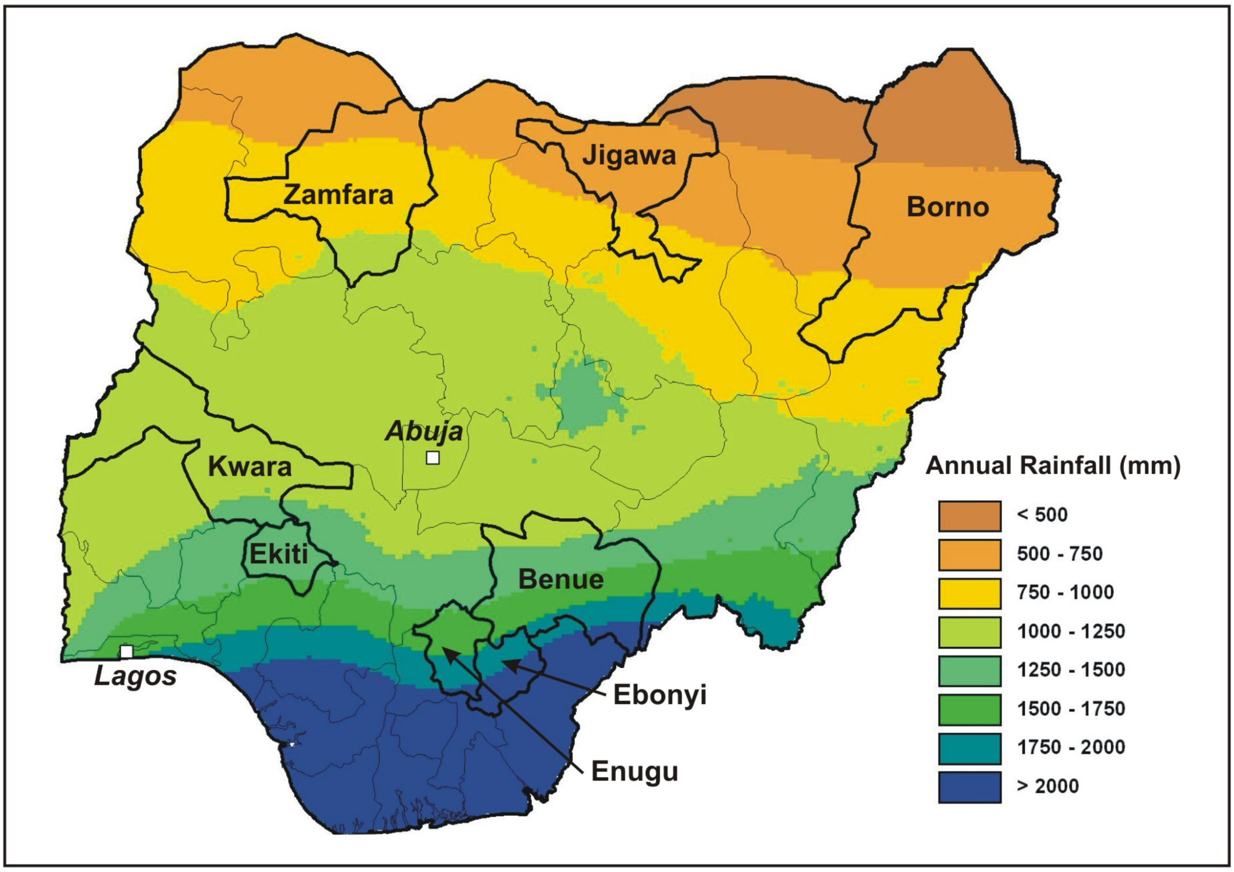

Figure 2 Mean annual rainfall for Nigeria for 1951 – 1995 (data from New and Hulme 1997).

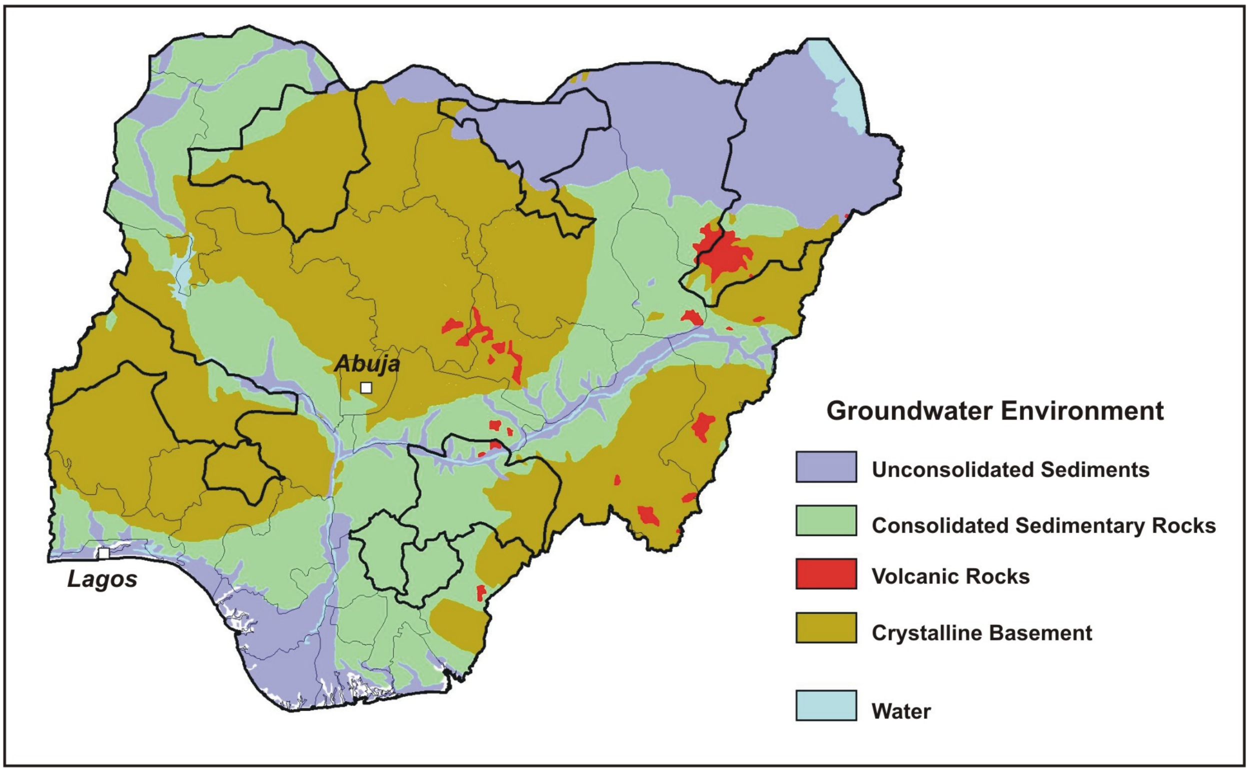

Figure 3 A simplified hydrogeological map of Nigeria.

are underlain in part by crystalline basement.

Unconsolidated sediments comprise sands, gravels, silts and clays. The sediments are generally young and have not undergone any processes to lithify them into rock. In Nigeria, there are considerable sands and gravels associated with the main rivers, delta and coastal plain. All the focus states have some water supplies developed from unconsolidated sediments. In the north, the Chad basin and Kerri-Kerri formation form large unconsolidated aquifers in the north. Unconsolidated aquifers can often contain significant groundwater. However, they can be prone to over-exploitation, so if recharge is limited (such as in the Chad basin, or the Kerri-Kerri formation) water levels can fall rapidly.

Consolidated sediments form highly complex aquifers. They comprise sandstone limestone siltstone and mudstone. The most prolific aquifers are found within sandstone and limestones. Mudstones are the least productive rock and unfortunately make up a large proportion of consolidated sedimentary rocks. The location of the consolidated sedimentary rocks in Nigeria is shown in Figure 3. Most of the states have some consolidated sedimentary rocks within them, with Ebonyi, Enugu and Benue being almost totally underlain by them.

Volcanic rocks are not widespread in Nigeria. The only focus state that they are present in is Borno. The groundwater potential of volcanic rocks is highly variable, reflecting the complex nature of the rocks. Often the best targets for groundwater are the fractured and rubbly zones between individual lava flows, or the contact between the volcanic material and older rocks.

The groundwater potential of the individual states is discussed in more detailed in Chapter 4.

3 The training course

3.1 BACKGROUND

The 2-week training course was based on a previous BGS training course in Malawi (Davies et al. 2002) and the book *Developing Groundwater* (MacDonald et al. 2005). The content of the course was modified to take account of the particular needs of the focus states as identified in a 2-day workshop in Abuja.

The course concentrated on practical skills for overcoming common problems in the different groundwater environments in Nigeria, although broader objectives were also realised (see below). The course tried to be responsive, in that it would respond to the stated needs of the participants. For example, the course devoted a larger than planned proportion of time to operating and maintaining geophysical equipment, and to interpreting the results of geophysical surveys. Almost all of the participants expressed a desire to cover geophysics in some detail. Several evenings were spent, after "formal" course hours, in going over geophysical data and interpretations. However, the course still maintained a broad balance of material in order to expose participants to other techniques and perspectives.

3.2 BROAD OBJECTIVES OF THE COURSE

The course aimed, through the discussion and teaching of practical methods for groundwater development in Nigeria, to realise the following broad objectives:

1. Course participants should be aware of the different sources of information on geology and groundwater in Nigeria, and know how to access information.
2. Course participants should appreciate that there may be different solutions for groundwater problems in different places in Nigeria, since the subsurface environment is complex and is heavily dependent on geology.
3. Course participants should be aware of the value of hydrogeological data.
4. Course participants should be able to draw on a larger range hydrogeological techniques when considering a problem.
5. Course participants should understand the importance of resource sustainability.
6. Course participants should be familiar with the role and needs of the community in ensuring long-term project success.
7. Course participants should meet hydrogeology professionals from other states, share techniques and experiences, and be able to contact each other after the course.

Good progress was made towards these broader objectives through the discussion and teaching of specific geological and hydrogeological topics, which included:

- Basic groundwater theory and measurement.
- The different sources of groundwater information.
- Geological environments and weathering patterns and profiles, and their importance to groundwater occurrence.
- Field geophysical techniques and geophysical interpretation.
- Drilling methods and drilling supervision
- Different borehole designs and construction methods.

- Groundwater quality, sanitary surveys, and appropriate borehole design.
- Borehole development, pumping tests and bailer tests
- Accessing hydrogeological information, and continued professional development.
- The importance of "non-technical" factors such as dialogue with stakeholders, funding, cooperation between contractors and relations with the community.

The course timetable and a more detailed description of the course is given in Table 1.

3.3 THE COURSE PARTICIPANTS

The course was held from Monday 9 May to Thursday 19 May 2005 at the Crest Hotel, Old Airport Road, Jos, Plateau State. Twenty-eight participants started the course, and this number rose to thirty-two by the end of the course. Two participants were from the Federal Ministry of Water Resources in Abuja, and another two were from the National Water Resources Institute in Kaduna. All of the rest were hydrogeologists, geophysicists or groundwater technicians from State RWSSA agencies, involved day to day with groundwater exploitation in rural areas. A list of participants is given in Appendix 3.

There was a wide variation in participants levels of training and experience. Most of the participants did not have a formal qualification in geology or hydrogeology. The majority had several years or more experience in exploiting groundwater for rural water supply, although two or three had just started their jobs and had little knowledge or experience. Those with considerable experience tended to specialise in one aspect of groundwater work, mainly geophysics, but were lacking in experience in other important areas. All of the course participants had a good command of English. The course facilitators used the variation in skills and experience to promote discussion within the group, and to increase awareness of the different branches of hydrogeology.

Two course facilitators from the BGS, Alan MacDonald and Jude Cobbing, conducted the course. They were assisted by Morgan Burke of TES Consulting Engineers, Dublin, Ireland, who arrived on Friday 13 May under the auspices of the Burdon Commission of the

Figure 4 The course participants.

International Association of Hydrogeologists (IAH). Jeff Davies of the BGS, although not present in Jos, provided considerable technical assistance and organisational advice. Sunday Dada of UNICEF was present throughout the course and took care of all logistical and administrative matters. Mr. I M Ziyok, general manager of Plateau State RWSSA, also provided crucial assistance with arranging the practical fieldwork.

3.4 METHODS AND RESOURCES

The course balanced lectures on groundwater topics, discussions and group work sessions with practical field demonstrations of equipment and techniques. A total of four of the ten days of the course were spent on practical demonstrations in the field, at various sites in Plateau State. Most of the rest of the time was spent either in the classroom or just outside it. (A summary of the day-to-day activities of the course is given in Table 1).

The **lectures** made use of frequent questions and opportunities for discussion, both in order to involve all participants and to enable the facilitators to evaluate the teaching as it progressed. Several discussions frequently took place during the course of each lecture. Most of the lectures were given by the course facilitators, although several participants also gave lectures on their areas of expertise.

Figure 5 A lecture on permeability and porosity.

The **group work** sessions normally involved dividing the class up into four groups of about seven people each; the groups were changed round every day. Each group would work on the problem or material and report back to the class via a representative and a flipchart. All the participants engaged well with the group work.

Figure 6 Group work on permeability and porosity.

Field sessions involved all participants travelling (by minibus) to locations within 2 hours (usually less than 1 hour) of Jos. These sessions included a field visit to examine geological outcrops and weathering patterns, training in the use of geophysical equipment, a visit to a drilling site, and conducting pumping tests on newly drilled boreholes. Participants were provided with basic field equipment (a hand lens, field sheets and grain size chart), and a short discussion was held on field techniques and field safety before the work began.

Reference Material: Each participant received a copy of *Developing Groundwater: a guide for rural water supply* (MacDonald et al. 2005). A copy of the book *Ground Water Study and Development in Nigeria* (Offodile, 2002) was also given to each participant. This text presents groundwater material and case studies from around Nigeria.

Those participants who were interested were provided with **software** (freeware) for interpreting geophysical data, as well as digital photographs taken during the course and reports and maps from earlier BGS work in Nigeria, all on CD. Informal training sessions on using this software were held in the evenings.

Figure 7 Field visits on the training course. Clockwise from bottom left: measuring the recovery from a bailer test; EM34 fieldwork, examining fracturing in a quarry, resisitivity sounding; and drilling supervision.

3.5 MEANS OF EVALUATION

To be effective, a training course must be evaluated while ongoing. Evaluation techniques used during this course are described below.

- Each day started with a short summary of the previous day's activities from the participants, which gave the facilitators an opportunity to judge how well the material had been understood, and whether the main messages had been successful.
- A roundup meeting between the facilitators each day to discuss the level of interest, standard of questions and level of participation in class activities. The following days activities were then adjusted accordingly.
- Standard of answers to specific questions asked by facilitators or field demonstrators.
- Levels of skill, awareness and knowledge displayed in the field by the participants.
- Discussion during and after the course with UNICEF and NWRI staff.
- Informal discussion with participants during and at the end of the course.

Evaluation during the course greatly assisted in adapting the material in response to the needs of the participants as the course progressed. The process of evaluation also helped the facilitators to gain a realistic idea of the hydrogeological capacities and problems in each state (see later). Evaluation also helped to identify certain participants who were invited to give talks to the class on their particular areas of hydrogeological expertise.

3.6 SUMMARY

The course focussed on the most pressing problems faced by groundwater professionals in Nigeria, whilst at the same time providing a broader introduction to groundwater theory and techniques. Given the short time available, it would have been difficult or impossible to cover all relevant aspects of hydrogeology in sufficient detail. Instead, course participants were presented with basic material on important topics, and given the means to access further information and resources.

It was considered that one of the biggest advantages of the course was the building of links between the different professionals in the different states, and the improvement of ways of communication and problem solving. The course content was backed up by textual material that will serve as a reference and training resource.

Table 1 The contents on the groundwater training course.

Day 1	Opening ceremony Group Session: advantages and disadvantages of groundwater for rural water supply Introduction to the course Lecture 1: An overview of groundwater environments
Day 2	Lecture 2: Principles of hydrogeology Practical: porosity and permeability Group Session: calculation of radius of influence of a boreholes Lecture 3: an introduction to geology Field trip (1) Zara Maganada Quarry – fractured granite (2) Kuru – a section though weathered granite
Day 3	Field trip and practical exercise : Miango twin hills – resistivity sand EM surveys Lecture 4: Introduction to geophysical methods
Day 4	Field trip and practical exercise: Saya village – resistivity and EM surveys
Day 5	Lecture 5: Interpreting resistivity and EM data Group Session and exercise: interpreting data from Saya village and identifying a new borehole site.
Day 6	Lecture 6: Putting data together Group Discussions: Socio-economic factors in siting wells and boreholes. Field trip: Shere hills and Rayfield tin mine.
Day 7	Lecture 7: Water quality Lecture 8: Drilling methods Lecture 9: Different boreholes designs Group Session: what is the role of the hydrogeologists on a drilling site? Lecture 10: pumping test basics.
Day 8	Field trip: Gwash II – supervising drilling
Day 9	Field trip: Jwapkkan – pumping test using the bailer test Practical exercise: interpreting the data from the bailer test.
Day 10	Lecture 11: Summary and overview Group discussion: putting theory into practice. Invited speakers: the International Association of Hydrogeologists; the Nigerian Association of Hydrogeologists Invited lecture: Dr Offodile, Crystalline basement in Nigeria Closing ceremony Workshop dinner.

4 Major hydrogeological constraints on developing rural water supplies in the focus states

4.1 INTRODUCTION

Part of the aim of the workshops was to identify constraints on developing rural water supplies in Nigeria – an in particular the eight focus states. The primary aim was to identify the physical constraints, due to the hydrogeological conditions and the methods of developing groundwater. A broader institutional analysis was outside of the scope of the study. Nigeria is a large country with diverse conditions, therefore some issues are unique to individual states, while others are more generic. Information was gathered from a variety of sources:

- Presentations (at Abuja workshop) made by the General Managers of the rural water supply and sanitation agencies for the eight focus states. Also participatory discussions that followed.
- Questionnaires and group discussions from participants (state water engineers and geoscientists) at the training course in Jos.
- Evaluation of the training course at Jos.
- Preliminary review of the groundwater conditions across Nigeria.

4.2 AVAILABILITY OF GROUNDWATER

One of the main constraints on developing rural water supplies in Nigeria is the nature of the available groundwater resources. In some areas groundwater is ubiquitous and successful boreholes and wells can easily be developed. In other areas, sophisticated methods are required to locate targets for drilling. The availability of groundwater depends critically on the hydrogeology.

Figure 8 shows the general geology of Nigeria, with the location of the 8 focus states superimposed. The geology map has been simplified from the national map developed by the Geological Survey of Nigeria (1984), by using the UNESCO geology map of Africa (1987). Table 2 summarise the geology and hydrogeology of the 8 states. In addition to the specific issues for each state, there are several general issues that are important across the 8 focus states:

1. Natural water quality including arsenic and fluoride. Water quality is beginning to be addressed in the eight focus states. The FGN/UNICEF WES project has been establishing a system for drinking water quality control, monitoring and surveillance. However, reliably and systematically collecting, analysing and interpreting data nationally is a considerable challenge.
2. The sustainability of water supplies. In some areas groundwater-levels are falling – possible as a result of overexploitation and climate change. With the increased development of groundwater, particularly with submersible pumps, the sustainability of both the resource and supply must be addressed.
3. Contamination of water supplies. The increase in on-site sanitation in communities can threaten the quality of new water supplies. More needs to be done to understand environments and circumstances which can lead to contamination of new sources.

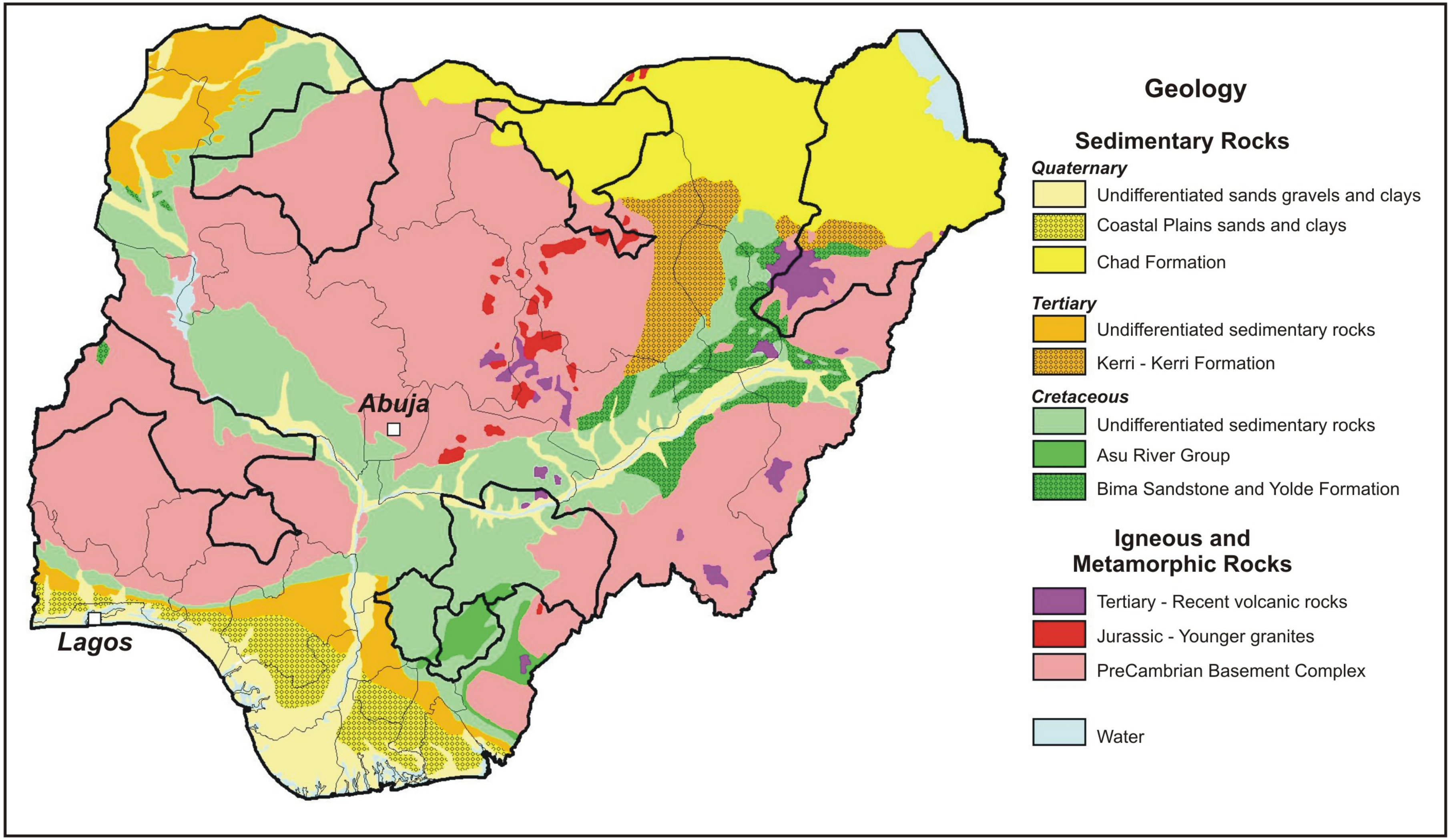

Figure 8 Geological map of Nigeria. Based on data from UNESCO 1987 and Geological Survey of Nigeria 1984.

Table 2 A summary of the geology and groundwater potential of the eight focus States.

	Geology	hydrogeology	Finding groundwater	Issues
Benue	Crystalline basement – mainly older granites Cretaceous sediments – complex interlayers of sandstones mudstones and limestones; including the harder mudstones of the Asu River Group.	Where weathered, the crystalline basement can be a good aquifer The Asu River Group is widely fractured and is a good aquifer for rural water supply. Within the sediments, the potential for groundwater varies widely – from easy to find groundwater in some of the sandstones, to very difficult in the soft mudstones. Dolerite intrusions within the sediments can be highly fractured and are potentially good targets for exploration	Geophysical methods are vital over much of the state – e.g. EM and resistivity to find deep weathered areas in the crystalline basement. The Asu River Group may be sufficiently fractured to not require detailed geophysics to site boreholes. EM and resistivity to unravel the difficult geology on the sediments. Magnetics and EM surveying to identify dolerite intrusions.	Soft mudstones or where sandstones are unconsolidated: Ogbadabo, Otukpo, Gwer, Gwer West and Obi.
Borno	Sandstone in the north (the Chad formation), unconsolidated gravel (Kerri, Kerri formation) and sandstone (Bima Sandstone) in the centre of the State. The south of the State is underlain by crystalline basement and volcanic rocks.	Groundwater is easy to find within the Chad formation, although water-levels are declining Groundwater is found in the Kerri-Kerri formation close to an are of recharge. The aquifer can be dry elsewhere. Groundwater is found in the volcanic rocks and basement, where they are weathered and fractured.	Within the sandstone and Kerri-Kerri formation, geophysics is probably of little use. More important is a knowledge of water-levels and recharge. Groundwater can be difficult to locate in the basement areas in the south. Geophysical methods, such as EM and resistivity are required.	Falling groundwater-levels in the sandstones, and particularly the Chad Basin. Locating good sites for boreholes and wells in the southern part of the State.
Ebonyi	Cretaceous Sedimentary rocks. Mostly the harder mudstones of the Asu River Group. Some areas of Eze-Aku Shale and soft Nkporo Shale.	The Asu River Group is widely fractured, and can generally support low yielding boreholes. It can be more difficult to find groundwater within the Eze-Aku Shales. The Nkporo shale is soft and sticky and contains little groundwater, unless intruded by dolerite contains little usable groundwater.	The Asu River group is widely fractured and geophysical methods are generally not required to site wells and boreholes. Maybe magnetcs and EM34 to identify targets within the Nkporo Shale and Eze-Aku Shale	Although it is easy to drill successful boreholes in the Asu River Group, there is little known about how sustainable these sources are. Some parts of the Asu river Group are difficult to develop, such as in Izzi and Ikwo LGAs The Nkporo Shale is a very difficult rock unit to find groundwater in (particularly Ivo and Afikpo South LGAs)). The rock type needs to be investigated to find out if usable groundwater can be found within it.

	Geology	hydrogeology	Finding groundwater	Issues
Eketi	Crystalline Basement Rocks including granites and metamorphosed sediments	Groundwater is found where the basement rocks are weathered.	Resistivity and EM34 can be useful at identifying where the weathering is thickest.	It is difficult to develop groundwater supplies in the basement rocks in Eton LGA – possibly because the rocks are too highly weathered.
Enugu	Cretaceous Sediments: interbedded sandstones and shales.	Groundwater is found within the sandstones, limestones and harder mudstones. The softer and more massive mudstones are difficult to develop for groundwater supplies.	Resistivity surveys and EM34 can be useful for distinguishing between sandstone and shale	A difficult state to find groundwater in. The softer Nkporo shales are difficult to develop. Investigations are required in various LGAs (Enugu North South and East, Isi Uzo) to find the best methods to develop groundwater.
Jigawa	Sandstone to the North (Chad Formation) and crystalline basement rocks in the south of the State.	The sandstones of the Chad formation are good aquifers and can sustain more than adequate yields for rural water supply. Water-levels have declined in the aquifer, however, and are commonly greater than 50 m deep. The crystalline basement rocks contain groundwater where weathered and fractured.	No geophysical surveys are required in the sedimentary areas. Resistivity surveys and EM34 can be used in basement areas to help \identify areas of thicker weathering or fractures.	The main issues in the state are the deep water-levels in the Chad formation, and low success rate in the weathered basement.
Kwara	Most of the State is underlain by basement rocks – mostly granites and gneisses, but with some meta-sediments. There are some Cretaceous sedimentary rocks close to the River Niger – mostly sandstones (Nupe Sandstone)	The basement rocks are weathered and generally contain sufficient groundwater for rural water. The sedimentary rocks are mainly sandstone, and are good aquifers.	Resistivity and EM surveys have been demonstrated to increase the success to identify areas of thicker weathering in the basement rocks. Geophysical techniques may not be necessary in the sandstone.	Over much of Kwara state, rural water supplies can be developed using existing techniques.
Zamfara	Crystalline Basement covers much of the state. This comprises granites and meta-sediments Cretaceous sedimentary formations.	The crystalline basement rocks in Zamfara State are sporadically weathered. The metasediments have different properties to the granites and need to be treated separately. The sedimentary rocks comprise of sandstones with some mudstones. The sandstones make good aquifers for rural water supply	Resistivity and EM surveys are important to help identify areas of weathering within the basement. The hydrogeology of the sedimentary rocks need to be understood to help site successful water points.	Some of the basement areas are poorly weathered, and groundwater can be difficult to find.

4.3 CAPACITY AND LOGISTICAL ISSUES

In addition to the availability of groundwater within each state, there are many other constraints on developing sustainable rural water supplies. These can be logistical, institutional, financial practical. Several of the issues raised consistently by participants as are discussed below.

Lack of key equipment. Table 3 indicates the available equipment for the states. The only state with all the necessary equipment is Ebonyi. Many states are missing key pieces of equipment. As a result, the yield (a key component in assessing "success") of a borehole is not determined in most States (See Table 4). During the training course a simple test (the bailer test) was demonstrated which can give an indication of yield. However, even this simple test requires a water-level recorder (dipper). This piece of equipment is fundamental to any groundwater programme and costs about £300. Also, there is little capacity to routinely and reliably collect and analyse groundwater samples – particularly for potentially harmful constituents, such as arsenic and fluoride.

*Inappropriate equipmen*t. Some suffered from having equipment that was inappropriate for the job. This could be aging drilling rigs with expensive or difficult to find spare parts, or geophysical equipment that is inappropriate to the geology, or difficult to use and interpret. For example in Ekiti, a resistivity meter, SAS 4000 was bought for the project (see Figure 9). This is much more sophisticated than the usual resistivity meter SAS 300. However, the extra sophistication is of no value for the project and only adds a layer of complexity (and vulnerability). There are several other examples from other States.

Table 3 Available equipment within the eight focus states.

	Benue	Borno	Ebonyi	Ekiti	Enugu	Jigawa	Kwara	Zamfara
Geological Maps	Y	N	Y	N	Y	N	N	N
Drilling Rig	Y	N	Y	Y	Y	Y	Y	Y
Working appropriate geophysical equipment	poor repair	N	Y	Y	Y	N	unable to use	N
Working water-level dipper	N	N	Y	Y	Y	N	N	N
Pumping test equipment	N	N	Y	N	N	N	N	N
Chemistry capability	Some	N	Y	Some	Some	Some	Some	N

Table 4 Work carried out after drilling to determine success and quality of source.

	Benue	Borno	Ebonyi	Ekiti	Enugu	Jigawa	Kwara	Zamfara
Assess the yield/success of source with a pumping test	N	N	Y	N	N	N	N	N
Chemical analysis of groundwater	Some	N	Some	Some	Some	N	Some	N

Poor access to spare parts. Many participants discussed their frustration with sourcing spare parts for equipment, or getting equipment reliably serviced or repaired. Although geophysics equipment is generally robust, if it fails, it requires to be serviced or repaired by specialists – which probably means sending it out of the country. Also spare parts, such as rechargeable batteries etc. must be sourced through an agent. For drilling rigs, it is particularly important to get genuine spare parts. There were several examples of States buying spare parts for rigs that turned out to be unusable, because they were not genuine.

What underlies many of these issues is poor funding, and lack of support from State Government. Many participants spoke of their frustration with trying to communicate their priorities to those in charge of the budget. The technical aspects of developing a safe sustainable water supply are more than just drilling a borehole. An appropriate method for siting the source is needed as well as a confident measure of the yield and quality of the source after it has been drilled.

For example, although many knew the importance of carrying out a pumping test to confidently measure the yield of a new source, none of the focus states could persuade their budget holders to fund this (some other states were able to do this). During the training course, participants were trained in a test that will only take one hour to complete and requires no expensive equipment. However, for even this inexpensive test to be routinely done it requires a regulator to insist on minimum standards when developing rural water supplies.

5 Meeting the need

Chapter 4 has highlighted some of the major constraints posed by the hydrogeology on developing groundwater in the eight focus States:

1. Diverse hydrogeological conditions, requiring different methods to develop groundwater.
2. Some areas where the groundwater resources are poorly understood and hard to develop.
3. Specific issues, such as declining water-levels and poor quality water.
4. Poor capacity for carrying out essential tasks, such as geophysics, yield tests and chemical analysis of the groundwater.
5. Poor access to spare parts for equipment.
6. A perception that budget holders do not appreciate the costs involved in developing a safe sustainable water supply – it is more than drilling a borehole.

As described earlier, the time available for this review was limited; therefore, only general recommendations can be made.

5.1 INCREASED NETWORKING WITHIN NIGERIA

The training course in Jos was an excellent opportunity for the groundwater professionals in each state to meet with each other, and others (such as the NWRI) within Nigeria. There are clearly benefits from increased networking between the professionals in different states. During the training course it was obvious that there were certain people within the group that had considerable experience with some equipment, or in a particularly hydrogeological environment. The training course allowed that experience to be shared. This can hopefully continue, and should be actively encouraged.

The Nigeria Association of Hydrogeologists also provides opportunities for increased networking. This network, which is linked to the International Association of Hydrogeologists, has more than 2000 members in Nigeria. Within its membership, there is a considerable knowledge base, although rural water supply is often seen as a poor relation within hydrogeology. There could be considerable benefits by more actively engaging with this association, and the broader experience of hydrogeology in Nigeria.

5.2 STRENGTHENING OF TEACHING INSTITUTIONS

The National Water Resources Institute based in Kaduna is the agency in Nigeria which trains water professionals. Several of their staff attended the training course in Jos, and workshop in Abuja. They have been tasked by UNICEF to help provide support and training to the staff in the rural water supply and sanitation agencies across Nigeria.

This institute requires considerable support to be able to carry out this function adequately. Although, they have considerable skills in certain areas, there capacity in rural water supply issues is poorly developed, and they are not in a position to provide appropriate training to the staff in the state rural water supply and sanitation agencies. To function better, the institute's capacity in the groundwater aspects of rural water supply must be strengthened and the culture altered to give rural water supply issues a higher priority. A programme to help train the trainers should be considered.

5.3 BENCHMARKING

The success and sustainability of water points could be improved by increased clarity over the scope and quality of work that is necessary to develop a water point. For example, geophysical methods are used in some areas where at best they are not strictly necessary, and at worst could be *reducing* success rates. Also, there is no consistency over how the boreholes are judged successful. Since pumping tests or yield tests are rarely carried out, there is no reliable information on how much water a borehole can produce. The same uncertainty surrounds water quality, although some water quality analysis is undertaken, there is no consistency, and important elements, such as arsenic and fluoride are not analysed for.

There would be considerable benefit on agreeing certain standards of work within the eight focus states. This would need to be sufficiently flexible to allow the professionals in each state to use techniques most suited to their groundwater environment, but clear in the scope of work that is expected (e.g. sources sited using appropriate methods, yield accurately assessed using a pumping test, water quality tested within a project areas etc.).

5.4 TARGETED RESEARCH

There are some complex groundwater issues in the focus states that will need to be addressed if rural water supply coverage is to be extended. For example, considerable research in crystalline basement areas of Zimbabwe, Malawi and Northern Nigeria in the 1980s has lead to the routine methods that are now used to develop groundwater in these areas (Wright & Burgess 1992). Recent research in Benue has lead to the development of groundwater in mudstone areas (Davies & MacDonald 1999, MacDonald et al. 2005).

Figure 9 Local government staff using a groundwater development map in Benue State.

Several activities must be considered:

1. Reviewing and making accessible existing research in Nigeria. There have been various studies into the groundwater occurrence and quality in Nigeria. However, these studies are generally not widely disseminated. Knowledge from academic studies and previous water supply project could be transferred for use by the current water supply professionals.

2. Producing groundwater development maps. An excellent way of making information on geology and hydrogeology more accessible is to produce groundwater development maps (see Figure 9).

3. Targeted new studies or research. There are certain issues that require further studies and sustained research to help inform the development of new community water supplies in Nigeria.

    - Prevalence of poor quality water – particularly arsenic and fluoride. Considerable effort must be made to sustain reliable and systematic national surveys of natural water quality, and also to predict the impact of on site sanitation to water supplies in different hydrogeological environments.

- Overexploitation of groundwater in parts of the country – falling water tables and declining quality. Linked to this is understanding the recharge to aquifers, and whether in some case the resources is non-renewable.
- Finding better methods to exploit groundwater in areas where success rates are low – areas of poorly weathered basement, or low permeability sediments.

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Appendix 1 Log Frame and terms of reference

The Federal Government of Nigeria (FGN) / United Nations Children's Fund (UNICEF) / Department for International Development (DFID) Water and Environmental Sanitation (WES) project aims to contribute to the development of improved capacity for WES at federal, state, LGA and community levels with increased participation from the private sector and civil society. This will include empowering communities to demand and achieve greater access to WES services and to use facilities safely and hygienically. Outputs of this project include improved systems and institutional capacity, improved coverage in sustainable water supply and sanitation and eradication of guinea worm. The project duration is from 2002 to 2007, starting with a two-year inception phase.

In 1996-2000 British Geological Survey hydrogeologists assessed the groundwater resources of the Oju/Obi LGAs of Benue State in association with Water Aid. This DFID funded work included the training of some UNICEF hydrogeologists. A preliminary manual describing field techniques for developing rural groundwater supplies forms an output of the DFID funded Low Permeability Aquifer in Sub-Saharan Africa KAR project. This manual has been expanded into a book entitled "Developing Groundwater: a guide for rural water supply" that incorporates wider BGS experience of groundwater development in Sub-Saharan Africa, Southern and South Eastern Asia and Central and Southern America. A training course for technical staff supervising the development of groundwater sources was developed by BGS for presentation in Malawi, funded by the World Bank. UNICEF Nigeria has requested BGS to present a similar course in Nigeria, using the "Developing Groundwater: guide" as the basic textbook. The course would aim to demonstrate practical techniques of groundwater resource assessment in the field within Benue State where most of the main aquifer formations occurring in Nigeria are to be found.

Purpose of Assignment:

The purpose of this technical assistance is to strengthen the capacity of the WES to undertake groundwater resource evaluation and development in eight focus states (Jigawa, Benue, Enugu, Eketi, Zamfara, Kwara, Borno and Ebonyi) and to briefly assess the hydrogeological issues faced in the eight states.

The workplan includes the following:

1. Prepare suitable training materials based on existing BGS resource material – to be undertaken in Abuja and Jos
2. Workshop/training course involving 20 FMWR, NWRI, UNICEF and eight focus state hydrogeologists to be undertaken at Makurdi including a 2-day participatory workshop to exchange experience and lessons learned from the eight focus states. The aim is to spend up to 2 hours discussing groundwater occurrence and development in each state, based upon a short case study presentation by each focus state hydrogeologist.
3. A flexible participatory training course based on the case study material from the workshop, using BGS resources material to cover resource evaluation, borehole siting and groundwater development. The course would be of 10 days duration with content based upon the chapters of the "Developing Groundwater: guidebook" with an additional session on collection, collation and use of groundwater data. The training will include practical sessions on borehole and well siting, drilling and construction at sites located around Makurdi making use of facilities at the local WES office.

4. Undertake a scoping study of the hydrogeological issues faced by the eight focus states. This will be based upon feedback from the participants and discussions held with UNICEF, FMWR, NWRI and DFID staff in Abuja. A draft report will be prepared during this period. A wrap-up session and debriefing will be held before departure. The report will be finalised in the UK.

Outcomes:

- Improved groundwater evaluation and development techniques used by state hydrogeologists.
- Increased communication of groundwater staff between the 8 focus states
- Scoping study of the hydrogeological issues facing the eight states.

Narrative summary	Verifiable indicators	Means of verification	Important assumptions
Goal Improve the quality of life of poor rural communities through provision of safe water from groundwater sources	More boreholes and wells providing lasting supplies of good quality water Reduction in distance walked to fetch water Reduction in water related illness	On going donor audits	Constructed water sources continue to supply good quality water
Purpose Improved well and borehole siting and installation Improved knowledge of groundwater occurrence and development in eight states of Nigeria gained.	Better success rates, fewer breakdowns Projects built up that are appropriate to the hydrogeological environments.	UNICEF programme reports Audit of UNICEF programme reports	Equipment and finance are made available Developable Groundwater is available in all states
KEY OUTPUTS 1. Improved groundwater evaluation and development techniques used by state hydrogeologists. 2. Increased communication and lesson learning between UNICEF groundwater staff 3. Scoping study of hydrogeological issues in eight states.	Use of appropriate techniques Better data collection from borehole construction programmes. Increased communication after training Availability of scoping report with recommendations for future development of groundwater resources in eight states	UNICEF staff owning and using groundwater development handbook. Project databases and reports UNICEF WES programme records. Scoping study report submitted to UNICEF	Suitable course candidates provided by FMWR, UNICEF and States
Activities 1. Travel to Nigeria 2. Produce training material 3. Facilitate workshop and training course 4. Produce scoping study – based on results of workshop and discussion groups	Submission of report on workshop, training course and scoping study of state needs.	Report submitted to UNICEF	

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