Partners for Water and Sanitation

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Partners for Water and Sanitation

Hydrogeological survey report analysis and recommendations

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Executive Summary

Partners for Water and Sanitation is providing technical support to WaterAid Nigeria and Enugu small towns water supply and sanitation unit in the Enugu State European Commission Water Facility (ECWF). The ECWF support project is helping to improve access to water and sanitation in six small towns of three local government areas (LGAs) of Enugu state (Igbo-Etiti, Nkanu East, and Udenu). As an initial step, WaterAid commissioned De-Hilcon International Ltd. to undertake a hydrogeological survey of the area. This document presents the Partners for Water and Sanitation's review of the survey work and report.

The hydrogeological survey presents information on the geology of each area; a description of water features (streams, springs, wells/boreholes); information on aquifer properties and potential sustainable yields; and the results of water quality analyses of samples collected in the small towns. The report is divided into two: the first section examining the situation in the two Nkanu East towns; the second section looking at the towns in Udenu and Igbo Etiti, which are both located in areas with similar hydrogeology.

In Nkanu East, the underlying geology is predominantly shale (Awgu and Eze Aku). These are considered poor aquifers with current exploitation limited to shallow hand dug wells in the weathered zones/laterites (and possibly minor sandstones/limestones units). More significant groundwater supplies may be obtained where dolerite intrusions occur in the shale, although the number and location of these is unknown based on the available information. It is unclear without detailed geological mapping and knowledge whether the Awgu and Agbani Sandstones are present in these areas and hence also represent potential drilling targets alongside the dolerite intrusions. Surface water is present in the area in the form of (often ephemeral) ponds and streams, some of which may be spring fed.

In Udenu and Igbo Etiti the underlying geology is predominantly sandstone (Ajali Sandstone and Nsukka, Upper Coal Measures). The Ajali Sandstone is considered a good aquifer and there is existing groundwater exploitation (although not necessarily in the study towns). The sandstones are thick and high values of hydraulic conductivity and specific yield are reported. These aquifer characteristics imply that it should be possible to abstract good yields without excessive drawdown of water levels. There are relatively few surface water features because of the permeable surface geology; spring-fed streams are often ephemeral.

A number of issues have been identified with the hydrogeological survey both in terms of the information considered and the way it is presented. The main limitations are:

- the narrow extent of literature review and use of existing mapping and data
- lack of clear mapping and identification of locations of samples, water features, data points etc.
- limited information on aquifer properties in some areas and no consideration of groundwater level data and known seasonal or long term trends

- the need to put estimates of available recharge and sustainable yield within the context of a conceptual understanding of the aquifer system including: extent and geometry of the aquifer; recharge and discharge zones (connections with the surface water system); existing demands on the groundwater (current abstractors and the need to maintain surface flows); likely demands of potential new groundwater sources.

The hydrogeological survey concludes that there is scope for groundwater abstraction in both areas and that drilling of deep boreholes (anywhere between 60 and 244 metres) should go ahead, prefaced by surface geophysical surveys. However, these conclusions are unfounded, particularly when taken in context of the lack of a conceptual model to inform the decision making process. There is no justification at this stage to drill boreholes to the depths identified in the report.

We make the following recommendations for further work:

- Improve the literature review process and link to references within the baseline report

- Fully understand the geological and hydrogeological setting of the study area

- Improve the topographical, geological, hydrogeological maps for the area from community participation and existing institutional data

- Undertake thorough hydrological/hydrogeological analysis

- Carry out surface geophysical surveys where appropriate

- Proceed with a targeted drilling programme

- Develop a conceptual model of the aquifer system, to be updated as new information is gathered

- Establish links with institutions and local government to ensure the best use is made of existing local knowledge

This approach will allow rational decisions on investment in water supply projects in Enugu to be based on robust scientific observations and information.

It is likely to be difficult to find significant groundwater sources in the Nkanu East areas. Exploration should focus on identifying the locations of dolerite intrusions within the Awgu Shales (using EM34/aeromagnetic interpretation); exploratory drilling and yield testing should then be undertaken.

From the available information, it is likely to be relatively straightforward to provide high yielding groundwater sources in Udenu and Igbo Etiti (compared to Nkanu East). The key will be in ensuring that abstractions do not impact downstream users of groundwater (both direct groundwater abstractors and those relying on spring or baseflow fed surface water). Careful construction will be needed to avoid contamination of water supply infrastructure due to hydraulic connections with surface waters and sanitation structures. Understanding the borehole depth for the required yield is also important as this will have a significant implication on project costs.

1 Introduction

1.1 Background and terms of reference

Partners for Water and Sanitation is providing technical support to WaterAid Nigeria and Enugu small towns water supply and sanitation unit in the Enugu State European Commission Water Facility (ECWF). The ECWF support project is helping to improve access to water and sanitation in 6 small towns of 3 local government areas (LGAs) of Enugu state (Igbo-Etiti, Nkanu East, and Udenu).

Enugu state, Nigeria, is known for its very complex geological terrain. Sourcing water is a huge challenge. The ECWF support project is designed to achieve sustainable access to water and sanitation for over 200,000 inhabitants of the selected communities of Enugu state, and WaterAid Nigeria is the main implementing partner for the project.

Due to limited resources and time, the ECWF project team is determined to ensure effective investment of funds and timely delivery of infrastructure; Partners for Water and Sanitation is providing UK expertise to help this project team. A team of partners will be providing support on a project fast-tracking and management plan later in the year but, prior to this, hydrogeological input is required to help with interpretation of hydrogeological survey work which has recently been completed. This document presents the partners' review of the hydrogeological survey.

As set out in the terms of reference, the objective is to provide a thorough interpretation of the hydrogeological survey report, its adequacy, and the feasible next steps on sourcing for water in the three local government areas. It has been agreed the review will include:

a. A summary of the overall contents, layout and structure of the report and high level recommendations for areas of work that appear to have been omitted, overlooked or require further work.
b. Technical appraisal of the various sections of the report that highlights the strengths or what has been covered so far and recommendations for further work – a "gap analysis" as what is essential to be covered at this stage of the project.

The Partners who have contributed to this review are:

Lesley McWilliam – Atkins Ltd.
Phil Merrin – United Utilities

This report presents combined comments from both Partners.

1.2 Information provided

The hydrogeological survey report on which this review focuses is:

A FINAL REPORT ON HYDROGEOLOGICAL SURVEY IN UDENU, IGBO ETITI AND NKANU EAST LOCAL GOVERNMENT OF ENUGU STATE
Author: DE-HILCON INTERNATIONAL LTD, April 2009

As additional background information, a set of maps has been made available to the Partners showing the geology, hydrogeological potential and existing government maintained groundwater sources for Enugu State. These maps were produced for a 2006-07 DFID supported study by Cranfield University in association with Enugu State Ministry of Public Utilities (Cranfield University 2006).

1.3 Scope of the hydrogeological survey

WaterAid provided a scope for commissioning the hydrogeological survey. This provided background on why the survey is needed and how it fits into the overall ambitions to provide safe water in this area. The specific aims for the survey (referred to as the data collection and collation exercise) were set out as follows:

> Reliability and validity of groundwater analysis strongly depend on the availability of large volumes of high-quality data. Putting all data into a coherent and logical structure supported by a computing environment helps ensure validity and availability and provides a powerful tool for hydro-geological studies.
>
> The Geological Investigations of the small towns in WANG's focal LGAs will provide an understanding of the three dimensional geologic framework of the area. This knowledge is necessary to understand the ecosystems, watersheds, aquifer recharge and protection, and effective environmental remediation. The interim research will provide the bases for a state wide geologic mapping, reinterpretation of existing geomorphic features, aquifer-system framework delineation, hydrogeology, mineralogy and sedimentology. Other benefit of the research includes maintenance of the state wide sinkhole and Coastal database.

These requirements are translated into more specific tasks in the introductory section of the De-Hilcon report (page 3) as follows:

1) Develop an understanding of the hydrogeology (groundwater recharge, hydraulic characteristics, discharge dynamics and surface water distribution).
2) Provide a preliminary estimation of sustainable yield.
3) Identify information gaps and recommend future actions required to enable the sustainable provision and management of the water resources in the study area. This report provides an assessment of the Imilike- Enu, Iheakpu-obollo Afor, Idoha, Ozalla-Uwenu, Nomeh and Okeani–Aniyi surface and groundwater resources.

1.4 Structure of this review document

This review is set out in the following way:

- Section 2 provides a summary of the hydrogeological survey and comments on the overall quality of the work, in terms of the approach to the survey, activities undertaken and reporting.
- In Section 3 a more detailed technical review is provided, examining each section of the hydrogeological survey report.
- Section 4 gives a brief summary of the hydrogeology of interest areas, based on the information presented.
- Section 5 provides details of recommendations that are felt should be given attention in order to progress the baseline report.

2 Overview of hydrogeological survey

2.1 Summary of contents

The survey examines the groundwater (and surface water) resources of six small towns in Enugu state. The areas covered are:

Local Government Area (LGA)	Small town
Udenu	Iheakpu-obollo
	Imilike- Enu
Igbo Etiti	Idoha
	Ozalla-Uwenu
Nkanu East	Nomeh
	Okeani–Aniyi

The report is divided into two: the first section examining the situation in the two Nkanu East towns; the second section looking at the towns in Udenu and Igbo Etiti, which are both located in areas with similar hydrogeology.

In each of these two sections, the broad approach to the survey is as follows:

- Description of location
- Geology – formations present and hydrogeological potential (from literature)
- Water features – description of streams, springs, wells / boreholes
- Hydrogeological map – hand-drawn sketch map showing geology and water features
- Water quality analysis – samples from rivers, springs, boreholes

The survey for Udenu and Igbo Etiti also considers:

- Recharge estimates and implications for a water balance for the area
- Aquifer properties – as estimated in previous reports and pumping tests
- Conceptual understanding and assessment of sustainable yield.

The survey has been primarily a desk based study, collating existing data from the literature, probably supplemented by field walk-over surveys to help with preparation of the sketch maps. The only new data collected for the survey appears to be the water quality analysis for 10 sites in the Nkanu East area and four sites in Udenu/Igbo Etiti.

The difference in approach for the two areas probably reflects the fact that Udenu/Igbo Etiti is on a sandstone aquifer which is already exploited and therefore some borehole and aquifer test information exists. The study area in Nkanu East on the other hand, is located on an aquifer with limited potential where there is little existing groundwater development and therefore more limited scope for data collation.

The basic conclusions are that there is scope for groundwater abstraction in both areas and that drilling of deep boreholes (anywhere between 60 and 244 metres) should go ahead, prefaced by surface geophysical surveys. The only potential issue with quality identified was bacterial contamination at the Nkanu East sites, with implications for water treatment needs. However, these conclusions should be considered in light of our review comments below and recommendations in Section 5.

2.2 Coverage of the survey and key omissions

The overall approach to the work is reasonable i.e. compilation of existing data, supplemented by analysis of water quality at key locations, and drawn together into an overall understanding of aquifer behaviour. It is sensible to split the study between the Udenu/Igbo Etiti and Nkanu East sites as these represent geologically distinct domains. However, there are omissions in the content of the hydrogeological survey: essentially each of the tasks listed in Section 2.1 could have been taken further. In some instances this information may already have been considered by the local experts but has not been communicated in the reporting. The most obvious omissions from the survey are:

Wider literature survey – there have been previous studies of the hydrogeology of Enugu state and these should be made reference to. Where specific local information is not available, review of studies in neighbouring areas with similar geology can also be useful. Some relevant work is referred to in Section 3 (and included in our reference list).

Local geological mapping and cross sections – show each of the study areas mapped against the geological units discussed in the text (rather than simple lithological descriptions such as 'fine grained sands'), with annotated cross sections to illustrate aquifer thickness, depth of abstractions, confined / unconfined conditions and connectivity between units.

Consideration of existing use and likely demand – all assessments of potential for further abstraction need to take into account the current users of the groundwater, how much they take and over what period. Surface water users also need to be considered where the groundwater provides baseflow or spring flow to streams and ponds. The demand for water for the potential new sources also needs to be calculated although it is acknowledged that an assessment of supply/demand does not form a specific part of the baseline survey but it is an important requirement. Recharge assessments / catchment water balances and estimates of sustainable yield can then be set in this context: it is essential that new abstractions are not at the expense of current users downstream or within the same aquifer system.

Groundwater level information – although discussed generically in the Udenu/Igbo Etiti part of the report, no data on groundwater levels are presented in the survey. This may be because there are no data readily available, in which case a groundwater level survey should be considered. Groundwater levels can provide an indication of groundwater flow directions (and catchment divisions), thickness of the unsaturated zone (and therefore connection with surface water and likely recharge paths), seasonal variations in storage, long term trends (e.g. drawdown of the water table due to over-abstraction) and interaction between neighbouring boreholes and between aquifer units.

Seasonality of hydrological information – all of the considerations of rainfall / recharge estimates, availability of surface water etc. need to allow for the seasonal variation in these features. Estimates based on annual average values are likely to be misleading. Monthly rainfall and evaporation data were mentioned in the report but not presented.

Aquifer properties and potential yields in Nkanu East – no information from existing boreholes is presented for this area. This may be because there is little groundwater abstraction (other than from shallow hand-dug wells) but if this is the reason it should be clearly stated. For consistency, the two sections of the report should be structured to cover the same topics – even if there are not sufficient data to complete each part of the analysis for both areas.

Whether or not these items should have been covered by De Hilcon in the hydrogeological survey depends on exactly how their contract and brief were set up; it may in any case have been appropriate to phase the work, with a brief initial review (represented by the De Hilcon report) followed up by a more in-depth hydrogeological baseline study.

2.3 Clarity and structure of reporting

There are some shortcomings in the way the information is presented in the report. Whilst the basic structure, separated into two main sections, is clear, there is not a systematic structure within each section. For example information on hydraulic conductivity is separately presented in “groundwater hydrology” and “aquifer hydraulic properties” and further new information in the conclusions. The main specific issues in interpreting the report are:

- Site locations / mapping
- Source of samples for water quality analysis
- References for data presented
- Presentation of conceptual hydrogeology as a context for recharge and yield calculations

These problems are considered in turn below.

There are also numerous typographic errors, incorrect scientific units, missing figures and contradictory statements; the table of contents does not reflect the structure of the report. Whilst it may still be possible to understand what is meant in the report, these problems undermine confidence in the work and mean that the reader must apply a degree of interpretation. More precise reporting, which is thoroughly checked, would reduce scope for future mis-application of results.

2.3.1 Site locations / mapping

In order to fully understand the physical environment of the LGAs, it is necessary to include all available background information, locations and maps at the start of the report so that the reader can familiarise themselves with the area and the principal issues that are under discussion within the remainder of the document.

Clear, accurate maps are essential, both to site the study area within the wider regional geological / hydrogeological setting, and to show the location of features in the study area which are being referred to in the text. This would include all water-dependent features (springs, streams, boreholes), surface geology and settlements and roads.

No state / regional scale maps are provided in the report and the town locations are not given accurately enough to pinpoint the study locations on the Cranfield University maps. Local hydrogeological maps are provided but these are extremely unclear, in part due to scanning, but also because the symbology is not consistent (including shading for geology type), the geology is not referenced in the same terms as described in the text, and locations discussed in the text are not all included. The approach with the maps is good (hand drawn sketches are appropriate and flexible to use in this context) but more care should be taken to ensure the detail is accurate.

2.3.2 Source of samples for water quality analysis

This issue is related to the mapping discussed above: the location from which each of the water samples were collected needs to be shown on map. In addition, the type of water feature should be described in as much detail as possible (borehole, spring, stream etc.; associated geological formation; depth), along with comments on how the sample was collected (e.g. was the borehole pumped through or was standing water taken).

Without this information it is impossible to understand the implications of the water quality analyses.

In the first section of the report, the samples in Okeani–Aniyi are listed from pond and river sources only (i.e. surface waters) and yet the discussion of results frequently refers to groundwater. This needs clarification. The second set of sample locations (in Udenu/Igbo Etiti) is more clearly identified but further information on geology, borehole location and timing of the sample is required.

2.3.3 References for data

For all data presented in the report, the source of the information should be referenced, as a full document reference or by inclusion of the source data in an appendix. Any specific values given, such as aquifer hydraulic conductivity or borehole yield, should be accompanied by the location and geological formation to which they apply and the method of calculation and any assumptions implicit in the data. Some assessment of the reliability of the information should also be given. Again, inclusion of borehole/test locations on maps is essential.

2.3.4 Presentation of conceptual hydrogeology

Before estimates of water availability and borehole yields can be made, the geological and hydrogeological information needs to be drawn together into a coherent picture of the groundwater (and surface water) system. The calculation of sustainable abstraction for example relied on an estimated volume of aquifer recharge – over what area is this calculated? What are the existing demands on the water in that area (water supplies, contribution to springs and rivers)? How does the availability (and demand) vary with season? As well as this water balance approach, consideration needs to be given to feasible borehole yields, dependent on local aquifer transmissivity and storage properties, and expected water level drawdown.

3 Technical appraisal

In this section a summary is given of the main sections of the De-Hilcon report, describing in detail the important information and data that have been included in the text, together with areas that need to be developed further as part of this baseline study.

3.1 Nkanu East LGA: Nomeh and Okeani–Aniyi towns

3.1.1 Site location and description

As noted above, it is essential that accurate maps showing locations of the study areas within the wider state context and showing detail of the local area are provided. Whilst the De-Hilcon report provides a useful summary of the location of the study areas within Nkanu East using the latitude and longitude co-ordinate references (these need to be checked and verified, they are not entirely consistent with the references quoted on the sketch maps), it is difficult for the reader to appreciate the locations of the small towns and their spatial relationship to each other and within Enugu state given the lack of provision of an accurate map to show such level of detail. Such maps could include topography, surface water features, major roads, towns, villages and the locations of pertinent water features that have been identified on the sketch maps provided at the back of the report such as boreholes and wells.

Relating the locations of the small towns and the geography of the area to the geological framework discussed on pages 4-5 of the report is a fundamental link that needs to be made in order to understand the water supply issues under discussion. Valuable information is included within the report text (e.g. discussions relating to water features in the vicinity of Nomeh and Okeani–Aniyi towns on page 5) but without a map to relate these observations to, the details in effect become meaningless within the context of this report. Accurate positioning of features using GPS units is a very useful way of organising many geographical data together.

3.1.2 Geology / hydrology

The basic description of the geological setting in the Benue Trough sequence and the hydrology of the area (p.4-6) need to be improved by including a more comprehensive commentary. Of particular importance, and a requirement of this baseline survey, is for the project team to understand the detail of the stratigraphy within the Benue Trough sequence and the hydrogeological significance and resource potential of each geological unit for the small towns under consideration. A pictorial representation of the geology and hydrogeology of Enugu state and the small towns would be beneficial to include at this stage of the project. Such maps are known to exist (e.g. compiled by Cranfield University in association with Enugu State Ministry of Public Utilities, 2006) and these have already been provided to the Partners for Water and Sanitation project team. Including such maps in the report would be useful. Further guidance and interpretation of the geology and hydrogeology could be met from in country support (e.g. University of Nigeria, Enugu State Government). Other more detailed maps may be available once contact with suggested Nigerian institutions is made.

Reference is made within the report to the various geological units that are known to exist in the Nomeh and Okeani–Aniyi areas. These are primarily the Awgu and Nkporo Shales, Awgu Sandstone (including the Agbani Sandstone which is understood to behave as an unconfined aquifer within the Awgu Shale). Dolerite intrusions in the Agbani Sandstone are known to exist (Davies and MacDonald, 1999). These structures can provide substantial borehole yields once their locations are identified. This can be achieved through a combination of geophysical reconnaissance (EM34) with interpretation of aeromagnetic data. Groundwater storage in these environments is within fracture systems. A much fuller description of these geological units would be beneficial and reference to previous work (such as the British Geological Survey study) should be made where the possible resource potential of each unit is described. The Awgu Shale is known not to provide useable quantities of groundwater due to its soft, shaley, carbonaceous, low porosity nature, apart from the Agbani Sandstone and some thin limestone horizons where present which do have a limited potential for groundwater development. The occurrence of the limestone and sandstone horizons should be investigated further as part of this project in conjunction with locating the dolerite intrusions.

Understanding the setting of the Nomeh and Okeani-Aniyi study areas within this sequence of aquifer and non-aquifer units is essential in understanding the potential for groundwater resources. Nomeh is in the south of Nkanu East and the Cranfield University maps indicate the underlying geology is Awgu Shale and Eze Aku Shale, an area not generally favourable for groundwater development (beyond small scale supplies) and with no existing government maintained groundwater sources. The sketch maps suggest Okeani-Aniyi is a short distance further north, but on similar outcrop geology dominated by shales. The Cranfield mapping shows the Awgu Sandstone and Agbani Sandstone units at outcrop only in a very limited area of Nkanu East. Potential aquifer units in the study areas may therefore be limited to the more minor limestone and sandstone sequences within the Awgu Shale, locally weathered shales, the overlying laterite sequence and most importantly, the locations of the igneous intrusions which may be the only realistic option for the development of small town water supplies.

Water quality is known to be poor from within the Awgu Shales, highly mineralized in places (gypsum) and sometimes containing saline groundwaters. It is also known that shallow hand dug wells through the laterite sequence and into the weathered part of the Awgu Shale quickly dry out following the rainy season but no reference is made to this characteristic. Evidence gathered in the Oju/Obi LGA study by BGS corroborates this.

The absence of existing boreholes in the two study towns (if the situation shown on the sketch maps is correct) is consistent with the situation of low groundwater potential indicated on the Cranfield University maps, associated with the low permeability shale deposits.

3.1.3 Water quality

A large part of the report, pages 6-13, discusses water chemistry for Nomeh and Okeani-Aniyi and the results of quality samples that have been collected for analysis to inform the project team. The context and requirements for collecting these samples is not clear and limited details are given about where the samples were collected from. A list of site names for the samples is given on page 9 which corresponds to the river and pond names in Okeani-Aniyi (page 5) i.e. all ten samples are of surface water in the Okeani-Aniyi area. However, this is contradicted by much of the commentary on results which refers to groundwater and spring samples as well as surface water. The sample locations should be clearly shown on a map and a description given of each source type (pond, stream, springs, shallow wells, boreholes) and how the water was sampled. Reference should be made to whether the surface waters (e.g. ponds) are believed to be in connection with the groundwater. The sample depth and expected geological provenance should be given for groundwater samples. Without placing the results in the context of the environment from which they were collected and some link made between the results and the hydrogeology, interpretation of the data is almost impossible and it is not clear at this stage how meaningful these results actually are.

With regards to the data quality, reference is made to checking the ionic balance but this is not done. In fact, there is a significant imbalance for all samples (in some cases >60%) which is cause for concern. The generally low ionic content means larger % errors may be expected but nonetheless the reasons for the poor ionic balance should be identified. The balance is positive suggesting that an anion, significant in this particular location, may have been omitted from the calculation. However, it is more likely to be an error in the analysis or reporting. Analysis of blanks and standard solutions should always be included as a quality check in this type of work and multiple samples should be collected from the same location. It is assumed that the zero sulphate concentration reported for the river samples (8-10) are an error.

Within this section, reference to WHO guidelines for drinking water quality is made. Placing the inorganic sample results within this context is a useful conclusion as it indicates the suitability of the samples collected for community drinking water supplies. However, the guidelines referred to are the first edition – the current (third) edition should be considered instead. In fact, of the chemical parameters analysed there is only a health-related guidance value for nitrate (50 mg/l). For other components, high concentrations may present acceptability problems (taste, colour etc.) but the samples generally have very low concentrations of all components. The very low hardness (and generally low ionic content) could cause problems with corrosion as there is little buffering potential in the water. The pH of the samples (6.2 to 6.8 correcting for typos) is at the low end of that usually desirable to avoid problems in treatment and distribution processes. The relatively high iron results may suggest a contribution from lateritic soils.

The report discusses the Sodium Adsorption Ratio (SAR) and % sodium (usually considered in conjunction with electrical conductivity) which are indicators of the suitability of the water for irrigation. The indices are both low for all samples and basis for the conclusion that spring water quality is good but streams and ponds are not (page 12) is not clear at all.

The most obvious cause for concern is the bacteriological contamination: all samples were noted to have high coliform counts (compared to a WHO standard of zero per 100ml). However, it is not made clear what incubation temperature was used i.e. whether the values are for total coliforms or thermo-tolerant coliforms. Thermo-tolerant coliforms are a good indicator of faecal contamination (human or animal waste) whereas “total coliform bacteria are not acceptable indicators of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in almost all untreated supplies” (WHO, 2008).

The bacteriological contamination needs to be considered in terms of the particular sampling location: is there a local contamination issue or does it reflect the quality of whole water body? If these are surface water samples, contamination is not surprising. The situation needs to be corroborated with evidence collected at community level as part of wider survey work and understanding the connectivity between the surface water and groundwater systems is essential. The bacteriological issues may be overcome by simple treatment. The WHO guidance recognises that "in the great majority of rural water supplies, especially in developing countries, faecal contamination is widespread. Especially under these conditions, medium-term targets for the progressive improvement of water supplies should be set." In terms of prevention of faecal contamination, any new sources that are developed should be managed in the context of water safety plans.

For the reasons described above, without firmer knowledge of the source of the water that has been analysed, it remains challenging for any meaningful conclusions to be made with respect to the water chemistry. The suite of parameters chosen for analysis mainly covers the major ions. It does not include many of the chemical parameters for which high levels would cause health concern, such as arsenic and fluoride, and therefore does not give conclusive data on the suitability of water for drinking. The parameters chosen are more appropriate for identifying the general character of the water, and therefore its hydrogeological provenance, with the similarities/differences between samples from different sites indicating the hydraulic continuity / flow paths between different sources of water. It appears that all ten samples are similar in this respect, there are not notable differences between different ponds or between the rivers and the ponds.

Collection and analysis of water quality samples is expensive and time consuming and so the sample locations and parameter suites for any further sampling should be considered very carefully. Ideally, in order to make the best use of these data already collected, more information would be provided on how and where the sampling was carried out.

3.2 Udenu and Igbo Etiti LGAs: Imilike- Enu, Iheakpu-obollo Afor, Idoha and Ozalla-Uwenu towns

3.2.1 Location and geology

The comments in Section 3.1.1 above relate equally to Udenu and Igbo Etiti: the location of the study towns must be shown on a map in relation to general location within the state and the outcrop geology (as described in pages 14-15). Again, latitude and longitude are given but the location and areal extent described in the text is not completely consistent with that shown on the sketch maps.

That said, discussion surrounding the geology of small towns of Imilike-Enu, Iheakpu-Obollo, Idoha and Ozalla-Uwenu (pages 14-15) is more comprehensive than for the Nomeh and Okeani–Aniyi section. The geology in this region comprises Ajali Sandstone (poorly sorted, coarse, cross bedded sands), overlain in some areas by the Nsukka formation (Upper Coal Measures) (clay, sandstones, shales). Laterite deposits also overlie the sandstone. Both the Ajali and Nsukka formations can be considered as aquifers.

The geometry and relationship between the units is not clearly described in the hydrogeological survey report: for example, on page 15 the Nsukka formation is (correctly) described as overlying the Ajali Sandstone, whereas on page 18 it is described as being a confined unit below the Ajali; the thickness of the Ajali Sandstone is given in different parts of the report as 406m and 20-60m (values around 100m appear to have been used in some calculations). A simple, clear description of the geology, both regionally and local to each of the study towns is needed (backed up by sketch cross sections).

The Cranfield University maps show only the Ajali Sandstones at outcrop, perhaps indicating that the Nsukka has limited areal coverage at outcrop, important only locally on high ground. The Ajali Sandstone is considered to have very good potential for groundwater development and the map of existing government maintained facilities shows a clear band of boreholes sited on the Ajali Sandstone outcrop.

3.2.2 Hydrology and groundwater levels

This section highlights the importance of spring flow during the wet season, and notes that these cease to flow during the dry season, suggesting ephemeral characteristics, maybe from lateritic deposits or the weathered part of the bedrock. Some commentary on the river system is also made but no reference to the maps given.

This section requires more detailed description of the climate and rainfall patterns as this is important to determine the possible water supply options for the LGAs. Figure 2 (mean monthly rainfall and evaporation) is missing from the report.

Table 1 makes reference to borehole logs and presents aquifer parameters for each location. However, no indication is made of where these data are taken from, where the boreholes are located and what analysis was carried out in order to derive the results listed. The hydraulic conductivities listed are very high for sandstone but could be reasonable for a very coarse, friable formation. An understanding of the assumptions on aquifer geometry is needed to interpret the specific discharge and transmissivity calculations. Do the total discharge values represent operational output at these sites or discharges during testing?

The report suggests that there is some vertical hydraulic connection between the members of the Nsukka Group and the Ajali Sandstone but this needs to be expanded with evidence as part of the link between the geology and hydrogeological potential.

The section relating to groundwater levels requires strengthening. An explanation of the basic principles of recharge is given, but the text is very confusing. Some discussion about likely recharge pathways in relationship to the geology is required, again to link the geology to an indication of the potential storage within the aquiferous strata present. No groundwater level data are provided in this section although in the conclusion section the water table is described as 10-64 m (below ground level?). If formal monitoring data are not available, anecdotal information may be useful, for example frequency of drying of existing wells, known seasonal patterns and long term trends, typical depth to the water table compared to surrounding surface water features. Figure 3 (water levels / hydrograph separation) – it is not clear what these data are supposed to represent.

3.2.3 Aquifer Hydraulic Properties

Information is provided from testing at two nearby boreholes, although again locations of the boreholes are not given or shown on a map. No details are given as to which geological formations these pumping tests were carried out in and therefore the significance of the results. It is impossible to distinguish whether these results are representative of aquifer conditions across the study area. Reference is made to the “RCC report 1993” but this is not included in the appendices to the report. Important literature that has already been written needs to be collected as part of this baseline study.

It would have been preferable to include the other aquifer property data mentioned in the report (page 18, page 28) in this section, and all with consistent units, so that the values can be compared. The values for hydraulic conductivity from this “RCC report” are much lower (and more realistic) than the others.

Some comment on aquifer storage properties should be included in this section.

3.2.4 Water Quality

Water samples from four locations have been analysed, both surface water and groundwater:

- Iyi-Awo stream in Imilike, Udenu LGA
- Mmiri oma spring in Idoha, Igbo Etiti LGA
- Iyi udo spring in Idoha, Igbo Etiti LGA
- Ozalla II borehole in Ozalla Uwenu, Igbo Etiti LGA

Again more information on the sampling should be given, including borehole depth, geological formation and means of sampling the springs (do they capture flow immediately it rises to the surface, or in a downstream channel?). Dates for the sampling should be reported.

The results do not allow conclusions to be made on groundwater chemistry evolution and the relationships between surface water features and the underlying groundwater because the settings for sample locations (including geology) are not sufficiently described.

In this case a different suite of chemical parameters has been analysed, with more focus on those with human health implications, rather than the major ions. Again, the WHO standards applied should be updated: those given for arsenic and fluoride are correct but the current standard for copper is 2 mg/l and for cyanide is 0.07 mg/l (WHO 2008). For other parameters, preferred limits relate only to customer acceptability (colour, turbidity, chloride, hardness). Although all measured parameters fall within guidelines, there are a few points of note:

- Arsenic in the spring and stream waters is at the WHO limit. The detection limit for the analysis method should be stated – it may be that 0.01 mg/l is the lowest reportable value?
- Similarly, for cyanide the detection limit should be reviewed (although reported values are well below the guideline).
- Hardness is very low for all samples which can lead to corrosion problems.
- pH is an important parameter for the operation of treatment and distribution systems. The reported values in mg/l make no sense. pH 6 for the borehole water is fairly low.

No results of bacteriological analysis are given (despite a discussion of bacterial contamination on pages 25 and 29).

3.2.5 Aquifer understanding

This section provides some basic statements on groundwater recharge, borehole yields and water quality but it cannot be used to inform the project requirements. Evidence for direct recharge is based on what information? A summary of yield variation is provided but an explanation of what may control the distribution of fractures is not given. The source of the data on borehole yields is not referenced. There is a clearly defined need for a conceptual model to be developed here accounting for all data that has been collected and in the context of the geology and hydrogeology of Enugu State and Udenu and Igbo Etiti LGAs. (Similarly, a conceptual model for the Nkanu East study areas should be developed.)

3.2.6 Assessment of sustainable yield

This section provides a very simple water balance but does not put this into the context of the water supply requirements or existing water use. What would be more useful is to examine the storage potential of the formations, looking at some generic figures for porosity and permeability alongside the limited pumping test analyses to calculate aquifer properties (transmissivity). Furthermore, there is a requirement to put the hydrogeological results within the context of what is required at a community/STU level by WaterAid (e.g. 250 people require 25 L/d each). This link is a significant part of understanding whether the borehole yields examined are suitable, will determine whether groundwater is a viable option for these communities and how many boreholes may be required to satisfy demand. Quantification of yield on a local scale yield rather than a full aquifer resource volume is also more meaningful and would be more beneficial to the project goals. (Again, these considerations should be applied to the Nkanu East study areas as well as the Udenu/Igbo Etiti areas.)

Note that there are errors in the simple calculation presented: it is suggested that the sustainable yield is 70% (or 60%) of estimated recharge but the values quoted are 40% of recharge.

The report acknowledges that within some of the area, it is difficult to maintain surface water storage due to the permeable nature of the underlying sandstone units.

3.2.7 Summary/conclusions/recommendations

The report provides a useful summary of the geological succession (Nsukka/Ajali) and quantifies the thickness of the units, but without a reference point to other literature. Useful aquifer properties of transmissivity and specific yield (indicating the storage potential of the sandstone) are also made, as is some further details on borehole yields. However, the sources of these data are unreferenced.

The report recognises the importance of geophysical methods for assessing groundwater resource potential and VES is recognized as a useful tool. However, evaluation of other methods such as EM34 in conjunction with aeromagnetic data interpretation, should be given to provide the best coverage and data acquisition at least cost. Before geophysical surveys are carried out, the specific aims should be defined and consideration given as to whether the differences (geological boundaries, saturated zones, fissure zones) are likely to be detectable. The surveys are most likely to be applicable in the shale aquifers of Nkanu East where minor water-bearing strata (sandstones, limestones), weathered zones and dolerite intrusions may be distinguished from the background low permeability strata.

Proposed borehole depths are given (220-244 metres) for Udenu and Igbo Etiti but these conclusions are unfounded, particularly when taken in context of the lack of a conceptual model to inform the decision making process. No details are given as to which geological formations such boreholes would target. Drilling boreholes to such depths will be extremely expensive and, based on the information known at this stage and without a full understanding of the hydrogeology, such borehole depths cannot be promoted at this stage of the project. Yields from such deep boreholes are likely to be low and the sustainability of any resource that is targeted is likely to be uncertain and probably poor.

Proposed borehole depths for Nkanu East (60-100m) are also considered to be unfounded. The only viable option for small towns is likely to be where dolerite intrusions are present within the Awgu Shale sequence and there is no justification at this stage to drill boreholes to the depths identified in the report.

When a full analysis of the geology and hydrogeology has been completed, drilling targets in the Nkanu East towns are likely to be the weathered sections of the sandstones in the Awgu Shales, fractured areas relating to dolerite intrusions (which can be deduced from EM34/aeromagnetic interpretation), thin limestones and maybe in combination with laterite groundwater storage. In Udenu/Igbo Etiti, the Ajali Sandstone could be targeted if the aquifer was in the correct location. Boreholes are likely to be much less deep than are proposed (maybe only 40m deep) and may be in conjunction with a shallow well system with high storage to capture water flow in the wet season or other alternative technologies (e.g. rainwater harvesting).

It is felt that a clear relationship between the geological environment and the supply/demand requirements for the small towns needs to be made. The likelihood of achieving borehole yields from the shale sequence to satisfy small town demands is low and such yields can only likely be met from where the dolerite intrusions can be confirmed with the associated high yielding fracture systems.

4 Hydrogeological summary

The following provides a summary of the hydrogeology of each of the two areas, distilled from the information provided in the hydrological survey reports and the Cranfield University maps. These descriptions should be considered initial views, to be verified and expanded as more information becomes available.

4.1 Nkanu East LGA: Nomeh and Okeani–Aniyi towns

- The underlying geology is predominantly shale (Awgu and Eze Aku). These are considered poor aquifers with current exploitation limited to shallow hand dug wells in the weathered zones/laterites and also from sandstones/limestones where present. Groundwater supplies can be located where dolerite intrusions occur although at this stage of the project, the number and location of these is unknown. It is unclear without detailed geological mapping and knowledge whether the Awgu and Agbani Sandstones are present in these areas and hence represent potential drilling targets alongside the dolerite intrusions.

- Bands of sands and silty shales marked along valleys (sketch maps), probably represent recent weathering deposits and may have no hydrogeological significance in the context of this study.

- Surface water is present in the form of (often ephemeral) ponds and streams – may be spring fed.

- Water chemistry of the ponds and streams in Okeani-Aniyi shows very low ion content. Water is relatively rich in magnesium and iron. High bacteria counts are recorded but these may be environmental rather than indicating faecal contamination.

- No information on aquifer parameters or existing borehole yields is available within this report. No attempt at recharge estimates has been made.

It is likely to be difficult to find significant groundwater sources in these areas. Exploration should focus on identifying the locations of dolerite intrusions within the Awgu Shales (using EM34/aeromagnetic interpretation). Mapping weathered zones and sandstone/limestone inclusions in the shale would be a useful exercise but may not provide the required yields for the small towns within this study. Exploratory drilling and yield testing should then be undertaken.

4.2 Udenu and Igbo Etiti LGAs: Imilike- Enu, Iheakpu-obollo Afor, Idoha and Ozalla-Uwenu towns

- The underlying geology is predominantly sandstone (Ajali Sandstone and Nsukka, Upper Coal Measures). The Ajali Sandstone is considered a good aquifer and there is existing groundwater exploitation (although not necessarily in the study towns);

- There are relatively few surface water features because of the permeable surface geology. Spring-fed streams are often ephemeral;

- Water quality at example springs and boreholes shows no initial cause for concern in terms of viability as drinking water. The water has a low ion content.

- The sandstones are thick (several hundred metres?) and high values of hydraulic conductivity are reported. Aquifer specific yield is estimated at 0.3. These aquifer characteristics imply that it should be possible to abstract good yields without excessive drawdown of water levels (and consequences for other users).

- Rainfall (and aquifer recharge) has strong seasonal variability and proposed groundwater development must allow for this factor.

From the available information, it is likely to be relatively straightforward to provide high yielding groundwater sources in these areas (compared to Nkanu East). The key will be in ensuring that abstractions do not impact downstream users of groundwater (both direct groundwater abstractors and those relying on spring or baseflow fed surface water) and to avoid contamination of water supply infrastructure due to hydraulic connections with surface waters and sanitation structures. Understanding the borehole depth for the required yield is also important as this will have a significant implication on project costs. The level of groundwater exploitation must also be sustainable in the long term with a firm understanding of the existing and future demand requirements.

5 Project recommendations

The work completed by De-Hilcon International Ltd as part of the baseline hydrogeological survey for three LGAs in Enugu State provides a useful starting point for this WaterAid project. However, it is suggested that some strengthening of the content of this report is required so that:

a) decisions made throughout the project period are made based on robust scientific observations and data rather than qualitative discussion and assumptions,
b) the proposed investment in water supply and sanitation projects in Enugu can be prioritised based on least cost/most benefit criteria.

Supplementing the baseline report with further evidence is essential to the success of this project. Therefore, the following suggestions are made:

1) **Improve the literature review process and link to references within the baseline report.** Numerous scientific papers in the fields of geology and hydrogeology have been published discussing the stratigraphy of the Benue Trough and an assessment of this work is important. In particular, reference is made here to work carried out by the British Geological Survey on behalf of WaterAid/DfID in Oju/Obi LGAs (1997-2000) in which similar problems for community water supplies were encountered and from which analogies can be taken.

2) **Fully understand the geological and hydrogeological setting of Enugu state.** The geology of the LGAs is variable and complicated. Therefore, understanding in detail the geological succession present and the likely groundwater resource targets is essential. Further fieldwork to collect reconnaissance exploration data is likely to be required before embarking on an extensive water drilling contract. Links here to recommendations listed in 9) below are made in order to prevent duplication of activities in assimilating data that may have already been collected and analysed.

3) **Improve the topographical, geological, hydrogeological maps for the area from community participation.** This approach should be considered to strengthen the maps of the area and therefore to assist with resource development. Communities and institutions should be involved to provide details on village locations (using GPS technology for accuracy) water resources requirements, hydrological/hydrogeological features and infrastructure, using observations and detailed mapping of the local geology to support the observations. An understanding of the current configuration of groundwater supply sources across the small towns, borehole locations (both successful and unsuccessful), any information from communities on borehole yields, whether the wells fail to supply water for part of the year and when is all useful information.

4) **Improve the topographical, geological, hydrogeological maps for the area from existing institutional data.** Collection and analysis of further data sets (if available) should be made, e.g. remote sensing & aerial photography data, LANDSAT, aeromagnetic data (to locate dolerite intrusions within the Awgu Shales), structural lineaments to focus on hydrogeological targets and possible drilling sites. Understanding in more detail the nature of the tropical soils and their hydrogeological potential as well as those of the bedrock units is also considered important as these could provide important groundwater resource options in geologically difficult areas maybe in conjunction with rainwater harvesting or surface water abstraction. Defining the locations of the most likely groundwater resource targets, i.e. the Agbani Sandstone where present and the locations of the dolerite intrusions, should form part of the recommendations of 2) and 3) above, in particular where these can be located using geophysical techniques.

5) **Hydrological/hydrogeological analysis.** Understand in more detail the climatic variations across Enugu state including the rainfall profile and seasonality, pertinent water features and their relationship to geology, interpretation of existing hydrogeological data or collecting of new data if required, recharge pathways and resource assessment. The potential for water supply schemes (groundwater or surface water) requires a thorough understanding of all of these aspects in order to provide sustainable small town supplies. Where data does not exist, new information may be required, e.g. community rainfall monitoring locations, simple pumping tests from existing water supplies, assessment of yields from existing or new boreholes, carrying out and interpretation of geophysical data, groundwater level monitoring. Reference is made in the Recommendations section of the De-Hilcon report to this exercise but a complex mathematical model may not be required if more simple interpretation techniques are considered more appropriate. Strengthening of the water quality data already collected should be considered, possibly using field techniques rather than laboratory analyses.

6) **Geophysics.** Consider the need to carry out surface geophysical measurements e.g. EM34 to locate groundwater bearing structures such as the Agbani Sandstones which will have a low electrical conductivity when compared to the high conductivity contemporaneous Awgu Shales. Collation and Interpretation of the aeromagnetic data is also seen as a priority in order to identify areas for further geophysical investigation. The use of surface geophysical methods is widely proven in groundwater exploration projects in sub-Saharan Africa and a similar approach here in Enugu would be worthwhile to corroborate the other evidence gathered.

7) **Targeted drilling programme.** Once all the data has been collected and assessed, it may then be possible to target potential groundwater supply options. Such test boreholes which may be needed to understand the vertical variations in geology and hydrogeology of the different geological formations under investigation whilst at the same time providing possible water supply solutions. Particular reference is made here to the need to provide a high standard of borehole construction with sanitary protection in order to prevent contamination of the aquifer (e.g. from latrines). An understanding of the location of latrines on a community level is important to prevent bacteriological contamination of the aquifer.

8) **Conceptual Model.** Bringing all of the data together as part of a region wide conceptual model is essential. This should include all geological/hydrogeological observations detailed above and any interpretation/assumptions made. A good conceptual model will improve the success rate of any subsequent drilling projects and reduce project costs. Sharing this information within the communities will assist with enhancing the conceptual model and new data/information can be added to it over time.

9) **Links with institutions and local government.** Information about the geology and hydrogeology of Enugu state already exists and bringing in project partners is suggested, particularly when discussing the viability of water supply options. Examples of such institutions and names that may be available for support could be:

- University of Nigeria, Nsukka
    i. Dr Celestine O. Okogbue
- A Edet - Department of Geology, University of Calabar, Nigeria
- MN Tijania, Department of Geology, University of Ibadan, Nigeria
- SMA Adelana, Geology Department, University of Ilorin, Nigeria
- A Onugba, OO Yaya, Department of Hydrogeology, National Water Resources Institute, Kaduna, Nigeria
- J Davies (Wallingford) & AM MacDonald (Edinburgh), British Geological Survey

This list is not exhaustive. Other contact names within country can be supplied to the project team.

6 Selected references

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