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LOW PERMEABILITY ROCKS IN SUB-SAHARAN AFRICA
Groundwater development in the Tabora Region, Tanzania

Groundwater Systems and Water Quality Programme
Commissioned Report CR/02/191N

BRITISH GEOLOGICAL SURVEY

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LOW PERMEABILITY ROCKS IN SUB-SAHARAN AFRICA
Groundwater development in the Tabora Region, Tanzania

J Davies and B É Ó Dochartaigh

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Villagers carrying out a bail test in Kabale village, Nzega, Tanzania

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FOREWORD

Access to adequate water supplies is a basic need of all rural communities in Sub-Saharan Africa. Many such communities rely upon the small quantities of groundwater held within thin weathered zones and fractures in low permeability ancient Precambrian and younger rocks that underlie much of the region. The identification and assessment of these water resources especially during periods of prolonged drought, is a major challenge. Data collected during borehole drilling, the monitoring of water levels and water abstraction are vital for the planned sustainable development of such resources. This case study demonstrates how NGOs and government departments can best develop these limited resources with only limited additional inputs to those normally used.

This report is one of a series of outputs from the UK Department for International Development (DFID) Knowledge and Reasearch (KaR) project R7353 – Groundwater from low permeability rocks in sub Saharan Africa. In addition to the report authors, the BGS project team includes Alan MacDonald and Jude Cobbing. The project aims to "Improve assessment of groundwater resources in low permeability rocks in sub-Saharan Africa enabling reliable supply of wholesome water to poor communities for improved health". To achieve this the project has produced:

- A manual describing the standard hydrogeological survey methods.
- A technical report describing applicability of survey methods to the hydrogeology of Sub-Saharan Africa.
- Short technical reports describing the groundwater resource assessment of four areas representing typical low permeability aquifers found in sub-Saharan Africa: two detailed studies in Tanzania and Ghana; and two at reconnaissance level in Zambia and Ethiopia
- Laminated groundwater development maps of the Tabora/Nzega area of Tanzania and the Afram Plains area of Ghana.
- Workshops to disseminate the results of the project in Tanzania, Ghana, Uganda and the UK.

The results of the project, described in a series of 15 reports, manuals and papers, have formed the basis of a 10 day training programme for borehole technicians undertaken with World Bank funding in Malawi. These project products have been widely disseminated through workshops held with WaterAid in Ghana and Tanzania; WEDC workshops for Nigerian UNICEF water project managers held in UK; and a World Bank funded training programme in Malawi.

ACKNOWLEDGEMENTS

A large number of individuals in the UK and Tanzania have contributed invaluable assistance to the project. In addition to support for project implementation, the provision of existing data and the collection of field data, many individuals in Tanzania have freely given their advice, and provided the local knowledge so important to carrying out the project tasks. These include individuals from the WaterAid Tabora office; TAHEA and the Anglican Church water supply programmes in Tabora; the Ministry of Water, Dodoma (Hydrogeology section); the Drilling and Dam Construction Agency, Dar es Salaam; the Geological Survey, Dodoma; and the WaterAid Dodoma and Dar es Salaam offices. We would particularly like to thank Eng Herbert Kashililiah, Program Manager, WaterAid Tabora, Tanzania for his unstinting hospitality and organisational skills which ensured that our work in Tanzania ran smoothly and pleasurably. In the UK key assistance was provided by Dennis Kentish, WaterAid, London. Our colleagues at BGS provided many useful comments during the compilation of this report and the associated database.

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EXECUTIVE SUMMARY

The provision of adequate water supplies to meet the needs of rural communities is an important element of the aim to alleviate poverty and ill-health in Sub-Saharan Africa. The development of the small quantities of groundwater found at shallow depth in thin weathered zones and fractures in ancient Precambrian rocks are important for the well-being of many rural communities in the region. A major challenge to the water sector is the identification and assessment of these resources especially during prolonged droughts. The collection of point source data during borehole drilling and time variant data by the monitoring of water levels and abstraction rates are vital for the sustainable development of such resources. This case study, with an associated manual of simple methods, seeks to demonstrate how development of limited groundwater found within Precambrian age metamorphic and granitic basement rocks of the Dodoman and Nyanzian groups can be undertaken. This study was undertaken in Tabora, Tanzania in association with WaterAid and partner NGOs as part of the UK Department for International Development (DFID) Knowledge and Research (KaR) project R7353 – Groundwater from low permeability rocks in sub Saharan Africa..

During August and September 2000, a BGS team worked in the field with project staff from WaterAid, their partner NGOs in the Tabora/Nzega Region (in particular TAHEA and the Anglican Church), the Ministry of Water and the Drilling and Dam Construction Agency (DDCA). During the work, BGS demonstrated a series of methods for groundwater resource assessment to enhance a typical borehole siting and drilling programme. These techniques included accurate location of village and borehole sites; observation of relationships between rock outcrops and topographic features; selection of drilling sites using geological, geomorphologic and geophysical criteria; collection and analysis of data during drilling; use of simple test pumping methods; and collection and analysis of water samples. The location of and available data from about 60 water supply boreholes in the Tabora Region were collated into a database to enable better interpretation of the development potential of the hydrogeological units present. The database is to be found on the enclosed CD-ROM which can be accessed directly as a series of specific folders and data files or via a series of hyper-text links between the electronic version of this report and the database folders.

The geological characteristics of the low permeability and low yielding rocks that underlie the Tabora/Nzega Region are complex. The series of Dodoman gneisses and granites and Nyanzian greenstones and schists that underlie the area are some of the oldest rocks found in sub-Saharan Africa. They have been affected by faulting associated with the southern extension of the East African rift system that has produced a series of half graben valleys infilled with Tertiary to recent deposits that are still seismically active. These valley infills comprise thick sequences of lacustrine sediments, evaporites and volcanic rocks that overlie down-faulted weathered country rocks and palaeosols horizons. Groundwater potential depends on geology, structure (fracture patterns), geomorphology, and past climates. Within the Dodoman gneissic rocks, groundwater occurs in shallow weathered zones and in deeper fracture zones. The shallow weathered zone aquifers contain young, recently recharged water, which flows rapidly down-slope to discharge along valley side dambo-like spring zones. Shallow wells in these deposits can contain groundwaters contaminated with high levels of nitrate. Older, more mineralised waters are found in the deeper fracture zones. In the Nyanzian rocks, water bearing fracture zones, buried beneath younger Mesozoic and Quaternary sediments, cannot be determined using geophysical survey methods. Many of these groundwaters, especially within the lacustrine sediments, were found to contain high levels of fluoride, known to cause health problems.

The installation of boreholes for water supply should be undertaken as part of a comprehensive groundwater development programme comprising (i) identification of the groundwater potential of an area; (ii) selection of suitable sites for borehole (or hand dug well) installation; and (iii) appropriate design and construction of boreholes or wells. Most of the techniques for assessment

of groundwater potential of an area can be carried out relatively easily, cheaply and quickly, and much useful information can be gathered during drilling programmes. Use of these procedures in the Tabora/Nzega area has been summarised as a poster and on a laminated map with illustrated cross-section and tabulated methods sheet designed for field use, as enclosed within this report. The combined use of data from maps, reports, field surveys, remotely sensed data and geophysical surveys, offers a powerful way of assessing groundwater potential, and siting water supply boreholes. Data collected during borehole drilling and testing will refine this assessment. All boreholes, wet or dry, are important sources of information. The locations of and data from all boreholes should be recorded. The monitoring of borehole abstraction rates, water levels, and water quality provides information for assessing the long-term sustainability of an aquifer, and early warning of water supply problems, such as over-abstraction or the effects of drought. In Tabora/Nzega, the monitoring of water levels in operating boreholes is not possible, there being no access for water level dippers. Borehole completion designs should be amended to allow such access

1 Introduction

1.1 GROUNDWATER DEVELOPMENT IN LOW PERMEABILITY ROCKS - THE BGS PROJECT

In sub-Saharan Africa, effective groundwater development often provides the best solution to rural community water supply problems (MacDonald and Davies 2000). Untreated groundwater is usually of good quality and safer for domestic use than traditional surface water sources. Groundwater use can help reduce health problems associated with unprotected surface water sources, such as malaria, cholera and guinea worm. Alternative water supplies, such as piped water from rivers or dams, or rainwater collection systems, can be considerably more expensive and difficult to manage, especially in areas prone to seasonal drought. Where sufficient groundwater resources are available, traditional hand dug wells can be used to exploit shallower groundwater and boreholes to exploit deeper groundwater. Both these abstraction systems are reliable and easy to maintain at community level if appropriate training and mechanical support are provided AND if sufficient renewable groundwater resources are present. However, in areas underlain by low permeability rocks, groundwater resources are limited, and without careful siting and management, wells and boreholes may fail, as experienced in the Tabora Region.

Ancient Precambrian basement rocks underlie most of sub-Saharan Africa. Younger sedimentary rocks occur within rift structures, inland alluvial basins and narrow coastal marine basins. Apart from a few limestones and deltaic alluvial sediments, most of these rocks have low permeability, although most are covered by tropical soils and weathered materials which often have higher permeability. Many studies have been made of groundwater occurrence in Precambrian basement rocks (e.g. see Wright and Burgess (eds) 1992). More recently, groundwater occurrence in low permeability sedimentary rocks in West Africa has been investigated (Davies and MacDonald 1999). That study addressed the application of geophysical borehole siting techniques and development of simple more applicable methods for the testing of wells and boreholes.

The current project has applied these techniques to different low permeability rocks in the Tabora Region, Tanzania and the Afram Plains, Ghana, during short-term field visits. BGS hydrogeologists have demonstrated the application of these techniques to improve the understanding of groundwater potential in a wider range of difficult, low permeability geological settings that commonly occur in sub-Saharan Africa. An associated manual, designed for field use, provides detailed practical instruction in the hydrogeological survey techniques applied during the project, which are described only briefly in this report (MacDonald, Davies and Ó Dochartaigh 2002).

This report summarises work carried out as part of a groundwater resource assessment in parts of the Tabora Region of Tanzania over a six week period in August and September 2000. It provides practical examples of appropriate groundwater resource assessment, using techniques developed in Nigeria and other places. The report also presents data collected in the field during the project and collated from other sources, including previous drilling programmes. The work in Tanzania was facilitated by WaterAid in conjunction with the ongoing WaterAid rural water supply programme in the Tabora Region. Field investigations were carried out by two hydrogeologists from BGS with assistance from staff from WaterAid; their NGO partner organisations, in particular TAHEA and the Anglican Church; the Ministry of Water and the Drilling and Dam Construction Agency (DDCA). Members of the village water committees, the community mobilisers who work with WaterAid to facilitate community involvement, and the general community also participated fully in all aspects of the fieldwork programme. During the final week of the BGS visit three seminars were held, in Tabora, Dodoma and Dar es Salaam, with representatives from both public and private organisations involved in water supply. The seminars provided an opportunity to present initial results from the field surveys, describe the field techniques used to a larger number of people than those who were able to take part in field surveys, and to discuss some of the most pressing problems faced by those involved with rural water supply in Tanzania. An itinerary for the BGS visit to Tanzania is presented on the accompanying CD-ROM.

This report, with an accompanying groundwater resource map and database stored on a CD-ROM, is a practical example of an appropriate assessment and development programme for rural groundwater supply, presenting new hydrogeological data collected in the field and existing data collated from other sources. The report is also available in digital format on the accompanying CD-ROM, as are the raw data, held in updateable spreadsheets. Hypertext links have been inserted in the digital version of this report and their presence is indicated in this printed version (in blue, underlined font) to link text directly to data files held on the CD-ROM. The data files include diagrams, text and tables in Microsoft Word, charts and spreadsheets in Microsoft Excel, and photographs in JPEG formats based on the Windows 2000 operating system. Users of this report are encouraged to download these files and use them for report preparation, data entry and GIS inputs. A digital version of the associated manual with more details of the hydrogeological survey techniques (MacDonald et al, 2002) is also presented on the accompanying CD-ROM.

1.2 BACKGROUND

The Tabora Region is located in mid-western Tanzania on the central plateau, between latitude 4° - 7° south and longitude 31° - 34° east (Figure 1). The region covers an area of 76,150 km^2, representing 9 percent of mainland Tanzania, and lies at an altitude of between 1000 and 1800 metres above mean sea level. The area is bounded to the north by the Manonga Valley, to the east by Wembere River, to the south by the Ugalla River and to the west by the Malagarasi swamps. Tabora is located on an east-west trending regional watershed.

The population of the Tabora Region in 1996 was estimated at 1,226,000, of which 78 percent live in rural areas. The rapid population increase since 1980 has occurred mainly due to the influx of farmers, attracted by fertile soils and improving infrastructure, and mine workers, attracted by diamond and gold mining developments. The region is divided into the five administrative districts of Igunga, Nzega, Tabora, Urambo and Sikonge, which are subdivided into 18 divisions, comprising 133 wards and a total of 455 villages. Access to the area is by rail, air and road. The roads are in a poor state and are often impassable during the wet season.

The natural vegetation cover of the region is predominantly miombo woodland, with acacia/cambretum woodland in the drier northeast and east. However, the region is now dominated today by bushed grassland, presumed to be largely a result of the degradation of natural forests through cultivation and overgrazing. The broad, flat valleys are generally covered by mbuga (black cracking clay) soils, and in places support dense vegetation, although much of the native valley vegetation has been cleared for rice cultivation during the rainy season.

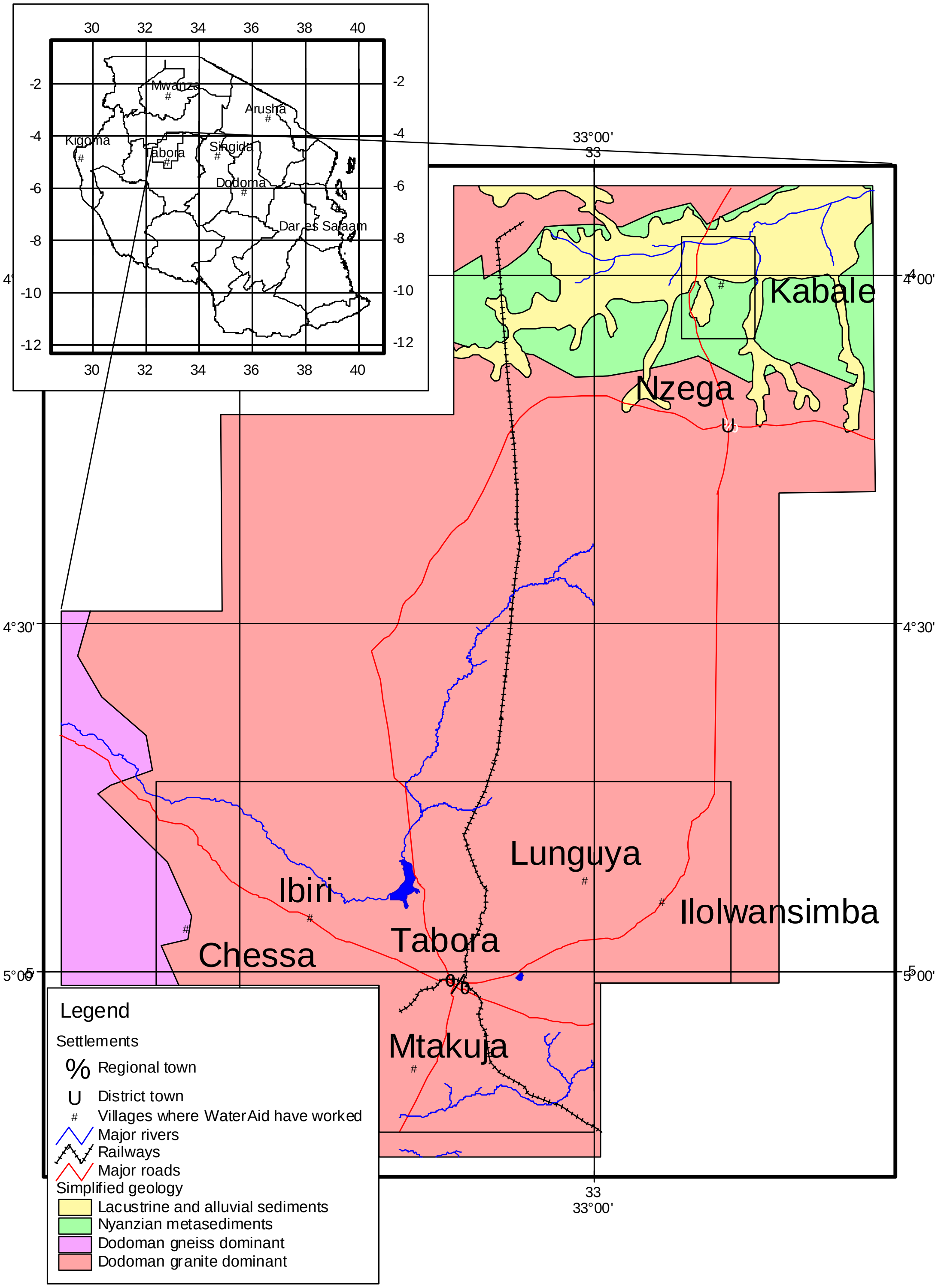


Figure 1 **Tanzania and the study areas in the Tabora Region, showing basic geology and the location of villages where field investigations were carried out**

Most of the Tabora/Nzega Region is underlain by Precambrian igneous and metamorphic rocks of the Dodoman and Nyanzian systems. In the northeast of the region, Mesozoic sedimentary rocks, interbedded with volcanic rocks, overlie the older basement landscape. Quaternary deposits include river alluvial deposits in major valleys, such as the Manonga valley, widespread ferricrete and laterite soils, and thick, clayey mbuga soils in dambo like valleys.

1.3 THE WATER SUPPLY PROBLEM IN THE TABORA REGION

The Tabora Region has pronounced wet and dry seasons. Traditional water sources comprise rivers, ponds, hand-dug wells and pits (mainly unlined), and valley-side springs. These sources are vulnerable to contamination by effluent carried by surface runoff or leaking from pit latrines. Standing water can form breeding grounds for mosquitoes. Water-related health problems that occur include malaria, cholera and diarrhoeal diseases, which often peak at the onset of the rainy season. During the dry season ephemeral rivers dry up and water levels in wells, ponds and pits fall, often drying completely, so that women and children have to walk to more distant sources. These become over-exploited, and as the dry season progresses longer periods must be spent queuing for ever-decreasing supplies. The valley-side springs, many of which are perennial, are invaluable to local communities for domestic water supply and small-scale irrigation.

The earliest known rainfall record for the Tabora Region dates from 1925; more recent records date from 1964 (Mitchell 1984). The records show that most rainfall occurs between November and April, with virtually no rainfall between June and September. There is abundant oral and observational evidence for a prolonged dry period between 1997 and 2000, with little rain during the nominal wet seasons of 1998-99 and 1999-2000. Tabora town suffered a severe water shortage during 2000, with water rationing initiated mid-way through the dry season. During this time, the two reservoirs that provide almost all of the town’s water came close to drying up completely (Figure 2). Agriculture as well as water supply was affected, with a decline in traditional wet season paddy rice cultivation and an increase in the cultivation of cassava, conventionally grown as a drought crop. A general shortage of grazing led to large-scale temporary migration among the pastoralists and their cattle herds who make up the bulk of Tabora’s rural population. Migration from the Tabora Region is believed to have caused significant environmental degradation, particularly in reserve areas of protected forests, and to have reached as far as the Zambian border to the southwest.

Figure 2 One of the two reservoirs serving Tabora town, photographed in September 2000, showing extremely low reservoir water levels

The overall shortage of surface water supplies and the growing regional population place a premium on locating sustainable groundwater resources. However, groundwater development is constrained by uncertainty about groundwater availability in different geological units. Groundwater is not universally available: limited quantities occur in the near surface weathered zone, along fractures within the Precambrian crystalline basement rocks, in Pleistocene alluvial sands and gravels, and Mesozoic sediments. Using properly sited and constructed boreholes and hand-dug wells, these resources can be usefully developed, and the expensive drilling and construction of dry boreholes can be minimised.

The earliest known study of water resources in the Tabora Region was carried out by the Geological Survey Department in the 1920s (Wade 1927). This study describes the widespread use of hand-dug wells and valley-side springs in the area, and efforts to improve these sources by constructing collecting trenches, sumps and sub-surface dams. None of these improved structures is known to still exist. The first detailed investigation of groundwater resources in the region was carried out during the 1970s and reported in the Tabora Water Master Plan (Brokonsult AB 1980). WaterAid and other NGOs, the Ministry of Water, and private concerns are currently developing groundwater resources. The WaterAid programme, with partner NGOs TAHEA and the Anglican Church, is currently the largest rural groundwater development project in the region. Since 1990 some 67 boreholes in 10 villages have been drilled and fitted with hand pumps. Unfortunately, a large number of the boreholes drilled have been unsuccessful: either dry, or producing too little water to support a hand pump. The sites of dry boreholes are not normally recorded, but each costs approximately UK£1500 to drill. The construction of a successful borehole with casing and screen costs a further £1500. A number of boreholes, originally thought to be successful and so constructed and fitted with hand pumps (about £1000 per hand pump unit), have subsequently exhibited declining yields and/or deteriorating water quality. This means that the additional costs of installing screen, casing and a hand pump in a borehole (approximately UK£2500) is lost when the borehole fails after only one or two years of use. Some of the problems of falling yields and deteriorating water quality may be seasonal – e.g. groundwater levels fall naturally during the dry season. However, to date there has been little or no testing of newly drilled boreholes, and no long-term monitoring of operational boreholes. There is therefore still little understanding of the yield potential of individual boreholes and the nature of the groundwater resource on a larger scale. Many of the problems faced in siting and maintaining successful boreholes in the Tabora Region can be addressed by simple hydrogeological and data management techniques, most of which can be easily incorporated into current water supply projects.

1.4 SUMMARY

The Tabora Region is a remote part of central Tanzania with a largely rural population of approximately 1,226,000. Rural communities experience severe water shortages during the 4 to 5 month dry season. The hydrogeology of the area is complex, with widespread occurrence of low permeability rocks. Although groundwater can be found in quantities that warrant the installation of boreholes with hand pumps for village supply, the groundwater resource and its long-term sustainability is difficult to assess given the present level of knowledge and understanding. Where initially successful boreholes show diminishing yields during prolonged droughts, communities that have become reliant upon groundwater as their main source of water during the dry season experience renewed difficulties.

2 BGS Investigations

This section summarises the application of a range of appropriate hydrogeological survey techniques during this project to investigate the groundwater potential of parts of the Tabora Region, and should be read in conjunction with the associated manual (Macdonald et al, 2002). The procedures followed as part of this investigation underpin a basic groundwater resource assessment. Used together, they will make it possible to collect better quality data, to use these data more effectively, to improve the understanding of the groundwater resource and so to improve the success of groundwater supply projects. A hydrogeological assessment of the study areas, drawing on field data and illustrating the level of interpretation possible using these techniques, is presented in Section 3.

Field investigations were carried out in 4 of the 10 villages in which WaterAid have worked in the Tabora Region. The bulk of investigations were done in Kabale village, Nzega District, in the northern part of the Tabora Region. Additional work was carried out in Mtakuja, Ibiri and Lunguya villages, all within 20 kilometres of Tabora town. In Kabale, field investigations focused on 7 new borehole sites. In the villages near Tabora, 6 proposed borehole sites, selected to replace unsuccessful boreholes, were investigated using EM34 surveys and 6 completed boreholes were test pumped. Groundwater samples for hydrochemical analysis were collected from boreholes and traditional wells in all 4 villages. Available data for all of the 10 villages in which WaterAid have worked were also collated and are presented here and on the accompanying CD-ROM. The available data for each of the villages are summarised in Table 5.

2.1 PRELIMINARY WORK

2.1.1 Relevant organisations

Initially, all the organisations associated with water supply development, hydrogeology or geology in the Tabora Region were identified. More details of contacts at these organisations are presented on the accompanying CD-ROM.

- WaterAid
- TAHEA
- Anglican Church
- Ministry of Water
- Drilling and Dam Construction Agency
- Tabora Regional Government (including Land Use, Planning and Irrigation Departments)
- Nzega District Council
- Geological Survey of Tanzania
- Department for International Development East Africa
- Institute of Land Resource Assessment, University of Dar es Salaam
- Water Resources Institute
- LifeWater International

2.1.2 Current Practice

The hydrogeological aspects of current practice for borehole site selection, drilling, testing and management in WaterAid's rural water supply projects in the Tabora Region is described briefly here.

In each community where WaterAid plans to construct boreholes for water supply, 3 provisional borehole-drilling sites are selected by a WaterAid team in consultation with the community. A geophysical survey team then carries out electrical resistivity surveys at each of these sites to investigate the thickness and nature of the weathered zone. The results of these surveys are interpreted and used to decide which site is the most favourable for a water supply borehole, and the depth to which the borehole should be drilled. A borehole is then drilled to the recommended depth. If the borehole appears to yield plenty of water, based on the amount of water blown to the surface during drilling, the borehole may be finished at a shallower depth. If it appears to yield very little water, it may be continued to a deeper depth, but boreholes are not generally drilled deeper than the top of the unweathered bedrock (50-100 m). If, after drilling to this depth, the borehole is dry or the apparent yield is so small that it is believed to be too small to support a hand pump, the borehole is abandoned. If the apparent yield is believed to be large enough to support a hand pump, the borehole is constructed with screen, casing and a filter pack, a hand pump, and a sanitary concrete seal to protect the borehole from pollution at the wellhead. Basic field water quality testing may be done to check water pH, conductivity and occasionally fluoride (using unreliable indicator papers); however, this is not routine. The location of the borehole is recorded by its name and village, and is not generally recorded accurately on a map. The location of abandoned dry or very low-yielding boreholes is not generally recorded.

2.1.3 Literature Review

A desk study of maps, reports and remotely sensed data obtained in Tanzania and the UK was undertaken. The database produced provided a first indication of the geological and hydrogeological character of the study areas. The maps and related data sources, including topographic, geological and aeromagnetic anomaly maps, aerial photographs and satellite images, are listed in Appendix 1. 1:50,000 scale topographic maps of parts of the Tabora Region were obtained from the Land Survey Department. Vegetation maps at a scale of 1:250 000 for most of the Tabora Region were obtained from the Institute of Land Resource Assessment. Various geological maps, including dye line copies of field maps of parts of the Tabora Region at 1:100 000 and 1:125 000 scale, as well as aeromagnetic maps at 1:100 000 scale, were obtained from the Geological Survey of Tanzania.

Available literature sources, from the UK and Tanzania are listed in an annotated bibliography. These sources describe aspects of:

- the geology and hydrogeology of Tanzania
- the geology and hydrogeology of low permeability rocks and tropical soils
- the use of remotely sensed data and geophysical survey methods for groundwater exploration
- background material on rainfall, rivers and other geographic aspects of the Tabora Region.

A particularly useful source is the Tabora Region Water Master Plan, which describes studies done in the 1970s that provide a comprehensive, if dated, overview of the groundwater resources of the region (Brokonsult AB 1980). The Water Master Plan reports can be consulted at the office of the Regional Water Engineer in Tabora and the DDCA office in Dar es Salaam.

A cloud free digital Landsat TM satellite image (for details see Appendix 1) was obtained for project use.

2.1.4 Creating a base map

A digital base map was created in ArcView®, a desktop geographical information system (GIS). Topographic maps at 1:50,000 scale covering the study areas in the Tabora Region were scanned and registered to the same projection as the satellite image by BGS remote-sensing experts. Selected parts of the available geological maps were digitised. Various layers of data were prepared, including roads, paths, rivers, lakes and reservoirs, locations of major settlements, geological boundaries and photo-lineations. The exact locations of minor settlements and existing boreholes in the study areas were determined using a global positioning system (GPS) and plotted on the base map.

The base map was used to provide an initial assessment of the suitability of potential borehole sites, based on geology, topography, lineations visible on the satellite image (which may relate to potentially water-bearing geological structures, such as fractures) and surface hydrology.

2.1.5 Reconnaissance survey

A groundwater reconnaissance survey of parts of the Tabora Region was undertaken during September 1999 (Davies and Ó Dochartaigh 1999). Resistivity surveying, drilling methods, borehole construction techniques and hand pump operation were observed in three villages close to Tabora town. Observations of geological exposures in the area, and the overall relationship between geological units, were also made.

2.2 GEOLOGICAL SURVEYS

Simple geological surveys were carried out at village sites prior to geophysical and drilling work. These surveys need basic equipment, including a GPS to accurately locate rock exposures, a geological hammer for collecting fresh samples, and a hand lens to inspect samples. A camera is also useful to record rock exposures. Knowledge of the basic local geology is an essential foundation to understanding the groundwater potential of the area. A typical survey includes:

- Inspection of rock samples from traditional hand dug wells
- Inspection of near-by river and stream exposures, if present
- Inspection of traditional water sources and discussions with local community members about these and other potential water development sites.

2.3 GEOPHYSICAL SURVEYS

In sub-Saharan Africa, two geophysical survey methods are commonly used to identify groundwater-bearing targets for siting boreholes. These are frequency domain electromagnetic induction (EM34) (Figure 3); and vertical electrical resistivity sounding (VES) (Figure 4). Detailed descriptions of these methods are given in the associated manual.

Figure 3 EM34 equipment in operation

Figure 4 ABEM Terrameter electrical resistivity equipment in operation

The results of all geophysical surveys must be carefully interpreted based on the local geology. Although the application of both these survey methods for siting boreholes in crystalline basement areas in sub-Saharan Africa is relatively well studied, methods for the interpretation of surveys on other rock formations are not well understood. Interpreting the results of geophysical surveys on sedimentary or metamorphic rocks, using techniques developed for crystalline basement rocks, can cause very inaccurate results.

Electrical resistivity traversing and vertical electrical sounding (VES) surveys have been carried out at most potential borehole sites in the villages in which WaterAid has worked in the Tabora Region. A Ministry of Water geophysical team, using an ABEM terrameter, carries out these surveys. The survey results help indicate the thickness and nature of the weathered zone, and so inform the depth of drilling. Detailed data from 22 VES surveys in 3 villages, Lunguya, Mtakuja and Msangi, and summary data from 7 surveys in Ilolwansimba village, have been collated and are presented in digital files on the associated CD-ROM. A summary of the available data is given in a table in Appendix 2, and hyperlinks from this table link directly from the digital version of this report to more detailed data stored on the accompanying CD-ROM.

During the BGS investigation, EM34 traverses were carried out using Geonics equipment at all borehole sites in Kabale village and 6 sites at the Tabora villages. Most surveys were done using a 20 metres coil separation. At some sites further surveys at 10 metres and 40 metres coil separations were undertaken. Measurements were taken at station intervals of 20 metres, except for surveys at 10 metres coil separation for which the station interval was reduced to 10 metres. Readings were made in both vertical and horizontal orientations. Electromagnetic (EM) surveying can be used to identify potentially water-bearing vertical or near-vertical anomalies, such as fracture zones. With knowledge of the sub-surface geology, EM survey results can also be used to indicate the depth and nature of the weathered zone.

A total of 56 EM34 traverses were carried out and are summarised in Table 1. The detailed geophysical survey data collected are presented in digital files on the accompanying CD-ROM.

Survey ID	Sub village	Village	Coil separ-ation (m)	Length of survey (m)
K1	Kasela	Kabale	20	500
K2	Kasela	Kabale	20	500
K3	Kasela	Kabale	20	500
K4	Kasela	Kabale	20	500
K5	Mwagundu	Kabale	20	500
K6	Mwagund	Kabale	20	500
K7	Mwagundu	Kabale	20	500
K8	Mwagundu	Kabale	20	500
K9	Itonjamandi	Kabale	20	500
K10	Itonjamandi	Kabale	20	500
K11	Itonjamandi	Kabale	20	500
K12	Itonjamandi	Kabale	20	500
K13	Kabale	Kabale	20	500
K14	Kabale	Kabale	20	500
K15	Kabale	Kabale	20	600
K16	Kabale	Kabale	20	500
K17	Lubaga	Kabale	20	400
K18	Lubaga	Kabale	20	500
K19	Lubaga	Kabale	20	500
K20	Lubaga	Kabale	20	500
K21	Busigili	Kabale	20	500
K22	Busigili	Kabale	20	500
K23	Busigili	Kabale	20	500
K24	Busigili	Kabale	20	500
K25	Kasela2	Kabale	20	500
K26	Kasela2	Kabale	20	500
K27	Kasela2	Kabale	20	500
K28	Kasela2	Kabale	20	500
K29	Itonjamandi	Kabale	40	200
K30	Itonjamandi	Kabale	40	200
K31	Itonjamandi	Kabale	40	200
K32	Kabale	Kabale	40	400
K33	Kasela	Kabale	40	200
K34	Busigili	Kabale	40	200
K35	Busigili	Kabale	10	200
K36	Lubaga	Kabale	40	200
K37	Lubaga	Kabale	10	200
K38	Kabale	Kabale	10	200
K39	Itonjamandi	Kabale	10	200
K40	Kasela	Kabale	40	200
K41	Kasela	Kabale	10	200
K42	Kasela2	Kabale	40	500
K43	Kasela2	Kabale	40	500
K44	Kasela2	Kabale	40	500
K45	Kasela2	Kabale	40	500
K46	Mwagundu	Kabale	40	200
K47	Mwagundu	Kabale	10	200
M48	Kazana	Mtakuja	20	500
M49	Kazana	Mtakuja	20	600
M50	Kikundi A	Mtakuja	20	500
M51	Kikundi A	Mtakuja	20	500
L52	Kalembela	Lunguya	20	500
L53	Kalembela	Lunguya	20	500
I54	Manyilili	Ibiri	20	1320
I55	Makunguwe	Ibiri	20	920
M56	Tiara B	Mtakuja	20	1200

Table 1 Summary of EM34 surveys carried out in the Tabora Region during BGS investigations

2.4 BOREHOLE DRILLING PROGRAMME

Methods used to drill, construct and develop boreholes in low permeability rocks, and techniques for data acquisition during drilling, are described in the associated manual. Details of the drilling specifications used during the BGS field visit are given in Appendix 3.

During the BGS field visit, 7 boreholes were drilled in Kabale village at sites located by WaterAid. The locations and indicated depths of 6 of these had been determined by the results of VES surveys carried out by the Ministry of Water geophysical team. The final borehole site was located using the results of EM34 surveys. Borehole locations are shown in Figure 5. Summary information on the boreholes is given in Table 2.

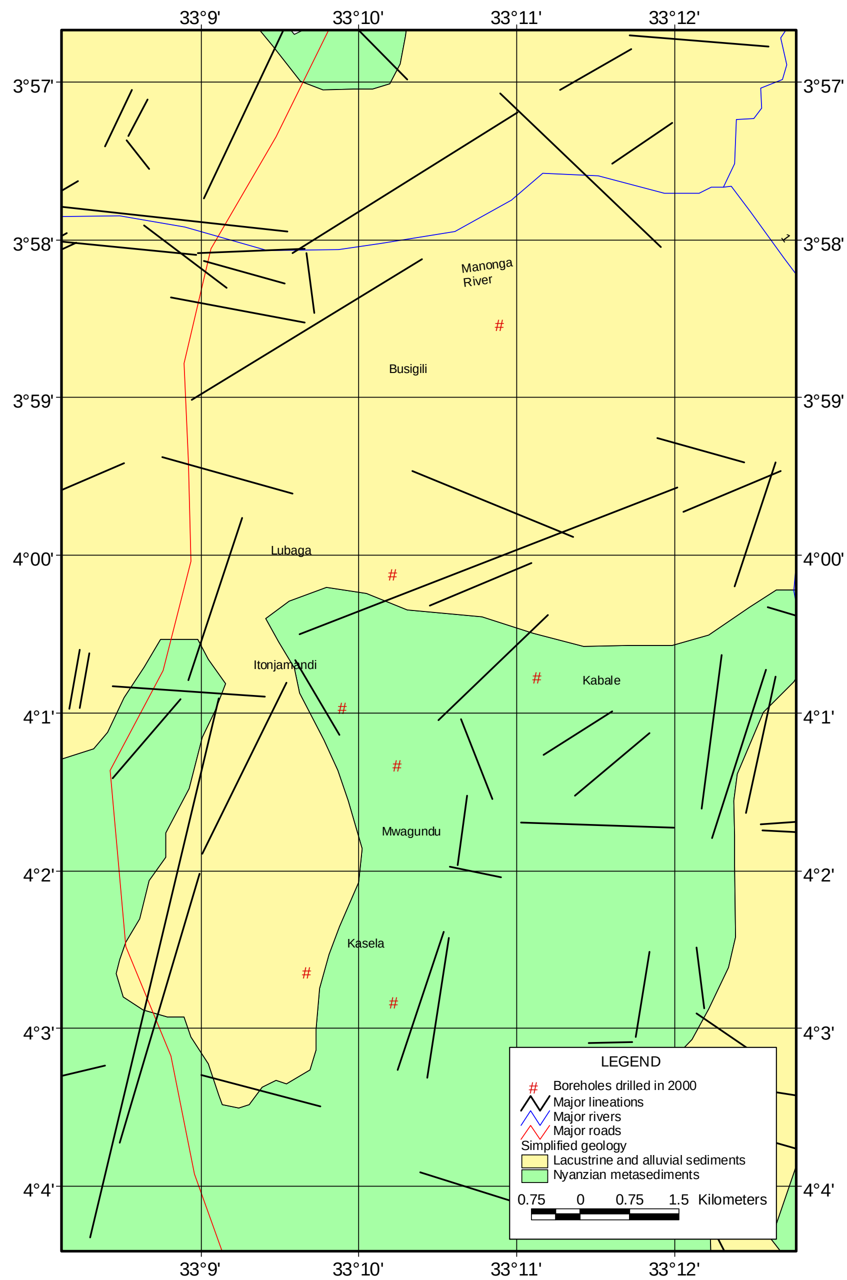


Figure 5 Location of boreholes drilled in Kabale village, Nzega, during the BGS field visit

During drilling, detailed geological and hydrogeological data were collected and used to assess the hydrogeological potential of the main geological formations encountered. These data are presented in digital files on the accompanying CD-ROM. The hyperlinks indicated in Table 2 link from the digital version of this report directly to the detailed data. The hyperlink from the borehole number links to a simplified geological log and casing details, and a graph of drilling penetration rate. The hyperlink from the subvillage name links to a detailed geological log with associated photolog.

Borehole Number (log)	Sub village (photolog)	Latitude	Longitude	Aquifer formation	Date drilling completed	Drilled depth (m)
1	Kasela 1	-4.058567	33.173517	Weathered phyllite	12/08/00	67.5
2	Mwagundu	-4.026167	33.173917	Weathered and fractured amphibolite	14/08/00	75
3	Itonjamandi	-4.018200	33.166517	Tertiary and Precambrian volcanic ash	16/08/00	68
4	Kabale	-4.014133	33.193150	Weathered phyllite	19/08/00	68.5
5	Lubaga	-3.999900	33.173400	Tertiary lacustrine sediments	21/08/00	32.5
6	Kasela 2	-4.054567	33.161600	Tertiary lacustrine sediments and Precambrian metasiltstone	22/08/00	61.5
7	Busigili	-3.965767	33.188033	Tertiary lacustrine sediments	31/08/00	61

Table 2 Summary information for boreholes in Kabale village, Nzega District

Data collected by WaterAid during previous drilling programmes in the Tabora Region were also collated and are presented in digital files on the accompanying CD-ROM. Varying levels of data are available from boreholes in 10 villages (see Table 5). A summary of geological and hydrogeological information from these boreholes is given in a table in Appendix 4, and hyperlinks from this table link directly from the digital version of this report to more detailed data stored on the accompanying CD-ROM.

2.4.1 Drilling and rock chip sampling

Drilling was carried out by the Drilling and Dam Construction Agency using a Schramm T64 rig mounted upon a 6x4 Volvo truck (Figure 6). Details of the drilling system used are given in Appendix 3. During the drilling of each borehole the following data were collected and analysed:

Penetration logs – the times taken to drill 1 m intervals were recorded.

Drilling yield – The rates of flow of water blown to the surface during down-the-hole hammer drilling were measured to determine the first water strike level, subsequent water strike levels and borehole yield at the end of each drilling rod length.

Rock chip samples – rock chips were collected at 0.5 m intervals during drilling and geologically logged to provide an accurate indication of rock type variation with depth. Washed rock chip samples were logged by noting colour (using Munsell Colour Charts), grain size (using standard charts and hand lens), relative hardness, and the presence of limestone (using nitric acid). Successive chip samples, placed in sequence within a sectioned pipe as a pseudo-core section to show changes in colour with depth, were photographed to provide a permanent record. These pseudo-cores, or photo-logs, are presented in digital files on the accompanying CD-ROM. The hyperlinks from the subvillage name in Table 2 link from the digital version of this report to the associated photolog.

Figure 6 A DDCA T64 Schramm drilling rig at Busigili, in the Manonga Valley at Kabale, Nzega

2.4.2 Borehole design, construction and development.

WaterAid's requirements for village water supply boreholes are that each borehole should supply 200 to 250 people with 20 litres of water per head per day. At average pumping rates this requires a yield of 0.2 to 0.3 litres/second. If, once drilled, a borehole shows sufficient yield, it is constructed with screen, casing and gravel pack, developed, and fitted with a hand pump.

Currently the decision as to whether a borehole yield is sufficient is made by a subjective assessment of the volume of water flow during drilling and airlifting. If no water flows during drilling, the borehole is immediately abandoned. Although in some cases this is appropriate, in many situations an assessment of borehole potential solely from behaviour during drilling can be misleading and can lead to unsuitable decisions. During the field study, a number of boreholes that were assessed as suitable during drilling and constructed were later observed to be dry or very low yielding. Conversely, at least one borehole, which appeared dry on drilling, was test pumped after the borehole was allowed to recover over night, and proved to be capable of supporting a hand pump. The simple test pumping techniques demonstrated during the field study (see Section 2.6) allow a better assessment of borehole potential yield to be made.

If a borehole is considered suitable for a hand pump, the productive parts of the borehole are screened and gravel packed and the rest of the borehole is lined with plain casing. A pack of 2-4 mm of clean coarse sand acts as a formation stabiliser in loose weathered materials, and in conjunction with the screen as a filtration device to prevent fine sand or loose weathered material from entering the borehole where it can damage the pump or infill the hole. In aquifer formations, such as hard fractured granite, a gravel pack and screen may not be necessary.

Following borehole and gravel pack construction, the borehole is cleaned. An airline is inserted to the base of the borehole and compressed air is used to lift water to the surface and remove sediment from the screen and fine material from the gravel pack and surrounding aquifer formation. The borehole is airlifted for one hour or until the water produced is considered clean. The air development procedure involves moving the airline up and down the borehole so that all levels of the screen are equally developed.

Observations during the field study showed that water pumped from a number of recently constructed boreholes (such as many in Ibiri) quickly became sandy, indicating that either the gravel pack was not properly cleaned during air lifting, or that the pack is too coarse to act as an effective filter. In very fine-grained formations, such as highly weathered granite, it may be necessary to use a finer-grained gravel or sand pack, and to ensure that the airlifting procedure is rigorously followed. A longer period of airlifting may be necessary to ensure clean water is produced.

2.5 TEST PUMPING

Test pumping a borehole provides an indication of the performance characteristics of the borehole and the hydraulic properties of the aquifer. Basic data collected during test pumping, such as borehole yield, water level drawdown and water level recovery, are used to estimate the specific capacity of the borehole (specific capacity is the borehole yield divided by the drawdown in rest water level, measured in metres3/metre/day), aquifer transmissivity, storage coefficient and water inflow rates.

In low yielding aquifers, such as those in the Tabora Region, the BGS team demonstrated the use of two easy to use test pumping systems, one using simple bailers, and one using small electrical submersible pumps known as Whale pumps. The results of these simple pump tests allow boreholes that cannot support a hand pump to be identified and abandoned before money is spent on constructing them with screen, casing and gravel pack, while boreholes which can support a hand pump can be identified and constructed, and not abandoned unnecessarily.

2.5.1 Bail tests

This simple to use bail test technique uses locally made bailers form from 1 metre lengths of 75 mm diameter galvanised iron pipe sealed off at one end (Figure 7). Normally 2 bailers are used together to withdraw a certain volume of water from the borehole within a measured time period. The water level in the borehole is measured until it returns to normal, and the time taken for recovery is recorded. Analysis of the results provides a first approximation of the aquifer properties in the vicinity of a borehole, and simple criteria indicate whether the borehole is likely to support a hand pump. Bail tests can be carried out immediately after drilling, before screen and casing are constructed, or later, before hand pump installation. Details of the bail test system and analysis methods are given in the associated manual (MacDonald, Davies and Ó Dochartaigh 2002).

Figure 7 Test pumping a low yielding borehole using a two bail system

A total of 17 bail tests were carried out in the Tabora Region during BGS fieldwork: 10 in Kabale village, 6 in Ibiri and 1 in Lunguya. Tests in Kabale were carried out both pre- and post-borehole development on 6 of the 7 newly drilled boreholes. Tests in Ibiri and Lunguya were carried out on boreholes completed earlier in 2000. The bail test results were analysed using a simple interpretation technique, the Theis recovery method, and the computer code BGSPT. A summary of the results from bail test analysis is given in Table 3.

Two examples of the application of bail tests during the BGS field study are given below.

Case Study 1 – Kabale borehole was apparently dry borehole on drilling, but accumulated water slowly when it was left to stand overnight. Because the borehole intercepted no significant productive fractures, flow to the borehole occurs by slow seepage from the weathered phyllite. The rest water level after one night was deep, at about 26 metres below ground level (mbgl). However, pre-construction bail testing suggested that the borehole yield was close to that needed to supply a hand pump, and so the borehole was constructed and developed. A post-construction/development bail test showed that borehole yield had significantly improved during development (cleaning of the borehole screen and filter pack by airlifting), and that the borehole was likely to comfortably sustain a hand pump.

Case Study 2 – Bail tests were carried out on 6 boreholes in Ibiri before they were fitted with handpumps. Of these, 3 failed the criteria of the simple bail test interpretation technique, either because borehole water levels dropped too far during bailing, or because they took too long to recover. These boreholes are unlikely to be able to supply the minimum yield of 0.2 litres/second needed to sustain a handpump. Had the boreholes been bail tested immediately after drilling, their potential could have been assessed more accurately and they could have been abandoned without being constructed with screen, casing and gravel pack. This would have saved the cost of the materials and a new and hopefully more successful borehole could have been drilled.

2.5.2 Whale pump tests

The simple to use and portable Whale pump test pumping system uses a 0.1 litre/second capacity pump that is powered by a 12 V car battery. The pump yield is similar to that of a hand pump, and it has a hydraulic lift of 18 metres. The system, its use and methods of data analysis are described in the associated manual.

The hydraulic lift of the Whale pump makes it practical for testing most boreholes in the Tabora District, where rest water levels even in the dry season are generally above 15 mbgl. In Kabale village rest water levels in several the boreholes are below 18 mbgl and therefore could not be tested using this system. In those boreholes that could be tested, gas coming out of solution in the groundwater caused cavitation and pump failure after several minutes of pumping. Only 2 Whale pump tests of longer than 10 minutes were run during BGS fieldwork, and these were of 55 minutes duration. A summary of the results from these Whale pump tests is given in Table 4. Details of the bail test data and results are presented on the accompanying CD-ROM.

Borehole	Village	Rest water level (mbgl)	Time pumped (minutes)	Effective pump rate (m^3/d)	Maximum Drawdown (m)	t_{50} (minutes)	t_{75} (minutes)	Pass/Fail/ Maybe	T (m^2/d) from Theis	T (m^2/d) from BGSPT	Comments
Kasela 1	Kabale	29.38	53	5.434	4.11	>162	>162	Fail	0.12	0.27	predevelopment
Kasela 2	Kabale	12.64	27	10.67	0.48	3.5	13	Pass	7.65	8.49	predevelopment
Kabale	Kabale	26.39	57	5.053	2.3	20	40	Fail	0.53	2.97	predevelopment
Lubaga	Kabale	13.87	34	8.471	0.75	13	59	Fail/Maybe	2.9	1.85	middevelopment
Kabale	Kabale	25.98	57	5.18	1.16	12	31	Maybe/Pass	0.92	2.78	postdevelopment
Kasela 1	Kabale	25.88	46	6.306	4.54	100	165	Fail	0.08	0.33	postdevelopment
Mwagundu	Kabale	15.25	26	11.26	0.83	2	5	Pass	2.94	13.55	postdevelopment
Lubaga	Kabale	13.98	20	14.17	0.80	8	30	Pass	3.87	2.32	postdevelopment
Itonjamandi	Kabale	10.22	20	14.28	0.78	3.5	9	Pass	4.43	8.61	postdevelopment
Kasela 2	Kabale	12.65	18	16.3	0.78	2	7	Pass	7.2	9.90	postdevelopment
Kategili A2	Ibiri	3.46	11	21.61	7.24	210	>400	Fail	7.83	0.02	postdevelopment
Kategili B1	Ibiri	4.67	13	22.73	2.86	5.5	13	Pass	3.47	3.41	postdevelopment
Mpungu B	Ibiri	4.38	13	22.73	4.35	>40	>75	Fail	1.28	0.15	postdevelopment
Makunguwe B	Ibiri	2.54	12	23.51	3.09	5	8	Pass	8.6	4.83	postdevelopment
Mpungu A1	Ibiri	3.75	14	20.03	8.13	65	>130	Fail	2.04	0.07	postdevelopment
Mpungu A2	Ibiri	2.40	13	21.74	5.49	18	29	Fail/Maybe	4.97	1.04	postdevelopment
Marudio A	Lunguya	12.165	20	14.22	3.275	29	80	Fail	4.73	0.20	postdevelopment

Table 3 Summary of bail test data from Tabora Region

Borehole	Village	Rest water level (mbgl)	Time pumped (days)	Q (m3/d)	s max (m)	T (m2/d) from Theis recovery data	T (m2/d) from BGSPT recovery data
Mwagundu	Kabale	15.2	0.038194	2.6	0.42	4.4	7.33
Makunguwe	Ibiri	2.575	0.038194	11.78	3.385	5.39	2.1969

Table 4 Summary of Whale pump test data from Tabora Region

2.6 WATER QUALITY INVESTIGATIONS

Understanding the chemical nature of groundwater is vital to ensure that water provided to communities is safe. For example, in the northern part of Tabora Region it is known that high fluoride levels often exist in groundwater. High fluoride concentrations in drinking water can be harmful to health, causing fluorosis of the teeth and bones. Hydrochemical testing is particularly important in areas such as this where a potential problem is suspected. Hydrochemical variations can also be used to indicate the nature of groundwater flow in an aquifer.

2.6.1 Sample collection

Groundwater samples were collected in each of the 4 villages where field investigations were carried out, and were analysed for major and minor ions. A total of 28 water samples were taken: 21 from WaterAid boreholes and 7 from hand dug wells. Samples from boreholes were mainly taken during bail tests after 5 to 10 bails (25 to 50 litres) had been removed. A small number of samples were taken from a single bail. Samples from boreholes already equipped with a hand pump were collected from the pump head. Samples from hand dug wells and pits were taken from a single bucket. Field determinations of pH, specific electrical conductance (SEC) and temperature were also made for each sample. Two 30 ml filtered samples were collected from each source, one acidified with concentrated nitric acid and one unacidified. The GPS was used to accurately locate the location of each sample point.

2.6.2 Laboratory determinations

Groundwater samples were submitted for chemical analysis at BGS Wallingford. A comprehensive suite of inorganic major, minor and trace element concentrations were determined. The results of the hydrochemical analysis of the Tabora samples are presented in Appendix 5.

2.7 MONITORING HYDROLOGICAL AND HYDROGEOLOGICAL DATA

Monitoring of groundwater levels and rainfall provides essential data for assessing the sustainability of groundwater systems and for long term planning. Rainfall data, such as monthly rainfall totals, are needed to accurately define seasonal rainfall patterns. Seasonal variations in groundwater levels are also important for understanding the groundwater resource, and can be correlated with rainfall patterns. Long term trends in groundwater levels can provide an early warning if the resource is being over-exploited. Currently, NGOs involved in rural water supply are encouraged to monitor health and poverty indicators, but little emphasis is placed on monitoring the state of the groundwater resource.

There is currently no routine monitoring of groundwater levels in the Tabora Region, and little or no knowledge of seasonal and long-term groundwater level fluctuations. The hand pumps installed in water supply boreholes do not allow access for water level monitoring. The Tabora Regional Government monitors rainfall.

2.8 DATA MANAGEMENT

Data management is an important part of groundwater development work. Effectively collecting, analysing and using hydrogeological data can increase understanding of how groundwater exists in an area, which can improve the success and cost-effectiveness of groundwater development projects. It is important that good quality data are not only collected routinely during ongoing activities, such as village surveys and drilling, but that they are collated and stored in an easily understood and available manner. This normally means that copies of all data should be held in one place from which they are available for use. One of the most important parts of groundwater data management is the accurate recording of spatial data, such as village and borehole locations. Accurately locating sites such as boreholes can be done using a relatively inexpensive handheld global positioning system (GPS). The coordinates of each site, and any associated information (such as borehole name, depth and geology, date of drilling, and so on) can then be recorded on paper and the locations marked on paper topographic maps, or they can be entered them into a digital spreadsheet or database (such as Microsoft Excel or Access) and the locations plotted in a geographical information system (GIS).

The data collected during BGS field investigations in the Tabora Region were stored digitally using a word processor, a spreadsheet programme and the GIS software ArcView™. ArcView™, as with all GIS, is ideal for displaying and analysing spatial data. Spatially referenced data (data with coordinate locations, such as borehole sites or villages) are recorded in tables (the 'spatial database') and displayed graphically as maps by ArcView™. Two particular advantages of GIS are that it can easily and effectively produce maps which can be tailored to project needs, and it can quickly and effectively analyse collected data for spatial patterns. Examples of simple groundwater potential maps produced using ArcView™ for the study areas in Nzega and Tabora are presented in Appendix 6, and in digital format on the accompanying CD-ROM. Similar maps for areas in Ghana, Nigeria, Ethiopia and Zambia, using different levels of data, are presented in digital format on the accompanying CD-ROM.

The data which were entered into an ArcView™ database during the BGS field studies include all borehole sites visited during the BGS investigations, and all other WaterAid boreholes for which GPS locations had been recorded; all sites where samples for hydrochemical analysis were collected; the locations of a number of traditional hand dug wells, and the lines of all EM34 surveys carried out during the study.

2.9 THE DATA

An understanding of hydrogeological conditions in any area can only be obtained through analysis of relevant data. The data collected during the BGS field investigations in Tabora were brought together with other data from the various sources described in Section 2.1, and from previous WaterAid groundwater development work in the region. The available data for 10 villages in which WaterAid has worked in the region are summarised in Table 5 and the data are presented on the accompanying CD-ROM. Hyperlinks link directly from the digital version of this report to some of the data on the CD-ROM.

2.10 SUMMARY

In summary, this section has described the various techniques that were used during hydrogeological investigations in the Tabora Region. Together, these techniques allow basic groundwater data for a small area to be collected, leading to a better understanding of the groundwater resources in the area. The techniques are:

- Reviewing existing data and literature, including maps, photographs and satellite images, on the geology and hydrogeology of the area
- Creating a base map using the available data, and using this for an initial assessment of the suitability of potential borehole sites. In this study a digital base map was created using a GIS, ArcView™.

- Accurately locating all relevant sites, including villages, boreholes, hand dug wells and geophysical surveys. This can be done using a hand held GPS.
- Carrying out geophysical surveys (electrical resistivity and EM34) at each potential borehole site to assess the thickness and nature of the weathered zone and indicate the presence of potentially water-bearing structures
- Collecting rock chip samples every 0.5 metre during borehole drilling and measuring penetration rates for every 1.0 metre drilled
- Logging rock chip samples in the field to identify water-bearing horizons, and assembling and photographing 'pseudo-core' sections to create a permanent record
- Testing boreholes using a simple bail test, and/or a Whale pump test, to give a first indication of borehole potential
- Obtaining groundwater samples for hydrochemical analysis from boreholes and hand dug wells, and relating the results to geology and hydrogeology
- Recording the collected data so that it can be easily retrieved and analysed, such as in digital spreadsheets, digital form and plotting spatial data on the base map.

Village	Baseline community/ water supply survey	Number of recorded boreholes [1]	Borehole locations recorded	Associated geophysical surveys		Bore-hole depths	Construction details	Pump depths	Borehole geological logs	Borehole rest water levels	Pump test/ quantitative borehole yield	Qualitative borehole yield assessed	Water quality analysis
				VES[2]	EM34								
Chessa		8	Yes						Some basic			Yes	
Ibiri		10	Yes						Basic			Yes	Some (Appendix 5)
Ilolwansimba		8	yes	Summary data for 7 surveys		Yes	Yes	Yes	Yes (on CD)		Some	Yes	Some (Appendix 5)
Itundu	Yes												
Kabale	Yes	7	Yes (Table 2)		Yes (on CD)	Yes (Table 2)	Yes		Detailed (on CD)	Yes (Table 3)	Yes (Table 3)		Yes (Appendix 5)
Lunguya		4		Detailed data for 3 surveys (on CD)					Basic (on CD)				Some (Appendix 5)
Msangi		6		Detailed data for 8 surveys (on CD)		Yes	Yes				Yes		
Msimba		5				Yes	Yes						
Mtakuja		13		Detailed data for 10 surveys (on CD)		Yes	Yes		Basic (on CD)			Yes	Some (Appendix 5)
Nsololo		5				Yes	Yes		Basic (on CD)				

[1] Boreholes which were dry on drilling are not always recorded [2] Exact locations of VES surveys are not normally recorded

Table 5 Summary of groundwater data availability for the study areas in the Tabora Region

3 Hydrogeology of the Tabora Region

3.1 INTRODUCTION

This section describes the hydrogeology of parts of the Tabora Tabora Region based on available literature and map resources, previous work carried out by WaterAid and the field investigations carried out as part of the current study (described in Section 2). A very brief summary of the regional climate, hydrology, vegetation cover and geology is provided, followed by an outline of the geology and hydrogeology of each of the main geological units in the study areas. To help interpret this information, a short summary of the groundwater potential of each unit is given, based on the available data.

3.2 CLIMATE AND HYDROLOGY

Climate, in particular the amount and distribution of rainfall, is the dominant influence on water resources in the Tabora Region. Temperatures are warm, with a mean annual temperature around 23°C, and do not vary much throughout the year (Table 6). Rainfall is seasonal, falling almost entirely between November and May. The dry season lasts from June to October, during which occasional showers may occur (Table 7). In the west of the region average annual rainfall is over 1,000 mm, decreasing to 700 mm or less in the east. Table 7 presents mean monthly rainfall for 1964/65 to 1975/76 and, for comparison, monthly rainfall for 1925, which was a wet year compared to the later 20th century means.

Month	Mean Maximum Monthly Temperature (°C)	Mean Minimum Monthly Temperature (°C)	Monthly Mean Temperature (°C)
October	32	19	26
November	31	19	25
December	28	18	23
January	28	17	23
February	28	17	23
March	28	17	23
April	28	17	23
May	28	16	22
June	28	15	22
July	28	14	21
August	29	16	23
September	31	17	24

Table 6 Mean monthly temperatures at Tabora (°C) for 1964/65 to 1975/76 (from Mitchell, 1984).

Month	Mean Monthly Rainfall at Tabora (mm), 1964/65-1975/76	Mean Minimum Monthly Rainfall at Tabora (mm), 1964/65-1975/76	Monthly Rainfall at Tabora Station (mm), 1925	Monthly Rainfall at Nzega (mm), 1925
October	16	4	51	32
November	102	68	584	362
December	164	110	203	83
January	96	60	127	114
February	114	66	127	51
March	146	96	178	203
April	101	67	0	38
May	26	6	25	45
June	0	0	0	6
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0

Table 7 Monthly mean and minimum rainfalls at Tabora (mm) for 1964/65 to 1975/76 (from Mitchell 1984), and monthly rainfall at Tabora and Nzega for 1925 (Wade 1927).

The Tabora Region is drained to the west and southwest by the Igombe and the Ugalla River systems, which both flow ultimately to Lake Tanganyika. The region is drained to the northeast by the Wembere River system, which flows to the inland Lake Eyasi. Tabora town is located on the regional watershed. The main river valleys are wide and flat. During the rainy season they are generally wet and may experience flooding. The larger rivers are perennial, although they may experience very low flows during the later parts of the dry season. There are no known gauging stations on any of the rivers in Tabora Region. A new national study of river basin management has been initiated by the Ministry of Water with support from the World Bank and should be a source of future data.

3.3 REGIONAL GEOLOGY

Precambrian crystalline basement rocks underlie most of Tanzania. Around a core of ancient granitic rocks forming the Tanzanian craton are wrapped younger Precambrian metamorphic belts. Less common are younger (Mesozoic and Quaternary) sedimentary rocks, which occur to the west and east of this Precambrian mass, deposited in the down-faulted sections of rift valleys, where they are interbedded with volcanic rocks. Patterns of weathering and sediment deposition during the Quaternary were also dominated by climate. Soil-water interaction controlled the weathering of granitic rocks on valley sides, producing clays that were removed and re-deposited on valley bottoms to create dambos. The geology of the Tabora Region has been discussed by a number of authors (e.g. Barth 1990; Bell and Dobson 1981; Bond 1967; Dong, Peacor and Murphy 1998; Dixey 1942; Ebinger et al 1997; Flint 1959a, b; Gilkes and Suddhiprakarn 1979; Harpum 1970; Maboko 1995; Maboko and Nakamura 1995a, 1995b; Quennell, McKinlay and Aitken 1956; Nilsen et al 1999 and Tardy et al 1973).

The geology of the Tabora Region is summarised in Table 8. Each of the major geological units is considered separately in the following sections: Dodoman Series granitic and gneissic basement, Nyanzian Series metamorphic basement, Mesozoic sedimentary rocks and Quaternary sediments, and soils. A description of each rock type is given, based on local and regional geological maps and descriptions and on an analysis of rock samples obtained during drilling. The results of geophysical investigations on each rock type are interpreted in terms of the geology and hydrogeology. An overview of the hydrogeology of each rock type is then presented, based on current understanding, with reference to groundwater quality where data are available. Finally, a summary of the general groundwater development potential for each rock type is given.

System	Lithology
Soils	Clayey mbuga soils; weathered red soils; lateritic soils and ferricrete.
Quaternary sediments	River alluvial sands and gravels with clays.
Mesozoic sedimentary rocks	Interbedded lacustrine marls and evaporites; alluvial fan deposits (sands, silts and gravels, often including evaporitic clasts); ancient ferricretes and wind-blown sands; volcanic ashes.
Nyanzian Series	Metamorphic rocks, including banded ironstones; metamorphosed volcanics, including tuffs and ashes; schists and amphibolites.
Dodoman Series	High-grade metamorphic rocks, including granites; gneisses; quartzite; schists and amphibolites; migmatites.

Table 8 The main rock types present in the Tabora Region

3.4 REGIONAL HYDROGEOLOGY AND GROUNDWATER DEVELOPMENT

3.4.1 Dodoman Series

3.4.1.1 LOCAL GEOLOGY

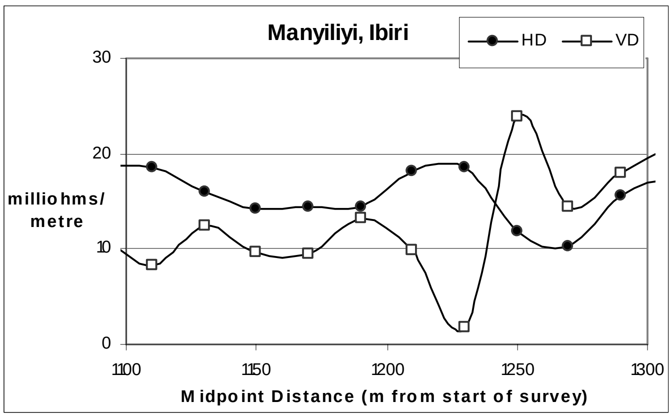
Rocks of the Dodoman Series crop out over most of Tabora Region, apart from the most northerly part close to Lake Victoria. Originally a mixture of volcanic and sedimentary rocks, they have been strongly metamorphosed and deformed. They are some of the oldest known rocks in Africa. They form extensive, dissected plateaus lying between 1000 and 1200 m asl above sea level, with scattered isolated hills that can reach 1400 metres above sea level. The hill tops are often capped by giant boulders and tors derived from spheroidal weathering. In the southwest and northeast of the Tabora Region these hills form northwest to southeast trending ranges. Between the hills are broad, flat valleys, which are believed to be often bounded by faults.

The main rock types of the Dodoman Series are granites and gneisses, usually medium to coarse grained and pink to grey in colour. The gneisses are hard and resistant to weathering, and so often form hills. Metasedimentary rocks are occasionally seen, particularly coarse grained, dark or silvery grey coloured schists, and quartzites.

Geological logs from boreholes drilled in Dodoman rocks in the Tabora Region show that the shallow weathered zone can be up to 45 metres thick, but is usually between 15 and 25 metres thick. A typical weathered sequence in Dodoman rocks comprises a band (perhaps 2 metres thick) of silty sand and laterite at the surface, underlain by a band of clay, of similar thickness or slightly thinner. Beneath this are silts, sands and gravels with occasional thin (a few centimetres) bands of clay. Towards the base of the weathered zone the material often becomes poorly sorted, with larger pebbles and boulders. Fractures are often present in bedrock at the base of the weathered zone, particularly along valley-bounding faults. The unweathered state of the granites, gneisses and schists is not seen at the ground surface.

3.4.1.2 GEOPHYSICAL INVESTIGATIONS

The main application of EM34 on basement rocks such as the Dodoman is to identify major faults or fracture zones at the base of the weathered zone, which are potentially water bearing features. A total of 11 EM34 surveys, covering 6.5 kilometres, were carried out over rocks of the Dodoman Series, all at 20 metre intercoil spacing, and all intersecting an existing dry borehole. The depth range of these surveys was approximately 10 to 20 metres, so where the weathered zone is thinner than this, the EM34 surveys can be used to identify fractures beneath the weathered zone. A typical EM34 response over a fault in Dodoman rocks is shown in Figure 8.



From left to right, this graph is interpreted as follows:
From 1100m to 1200m, the EM34 response indicates rocks with higher conductivity overlying rocks with lower conductivity – typical for weathered granite overlying unweathered granite.
Between 1200m and 1250m the rapid variations in vertical dipole (VD) response indicate the presence of a fault beneath the shallow weathered zones.

Figure 8 Typical EM34 response over a fault in Dodoman crystalline basement rocks

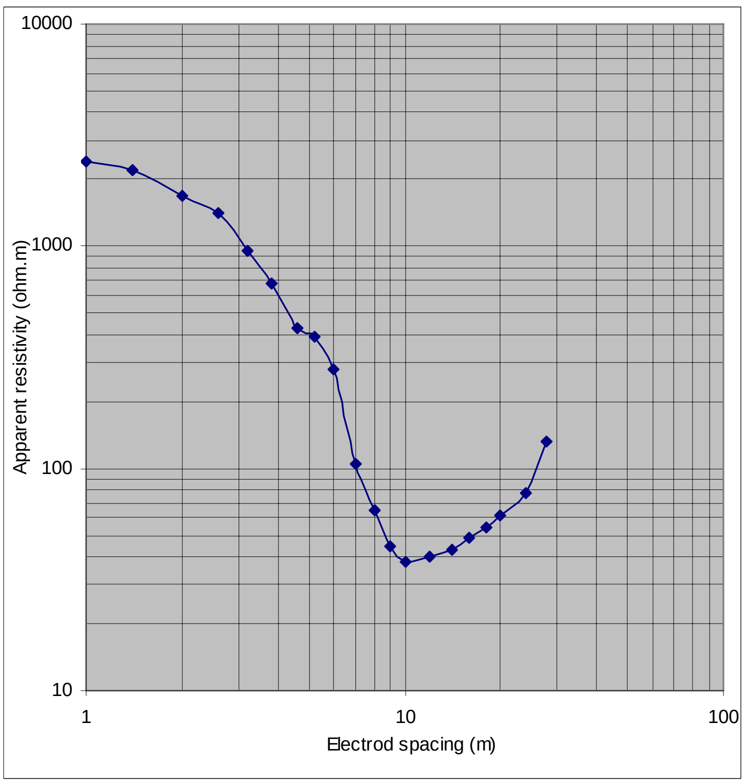
Hydro-geology unit	Description of rocks	Field techniques
Unit 1a Upper slope soils	Nodular, hard, red-brown ferricrete with white clay at base. 2 – 10 m thick.	Ferricrete often visible at surface: its thickness may be seen in existing wells. **EM34** – high conductivities when saturated, low conductivities when dry.
Unit 1b Lower slope soils	Light brown sands with interbedded clay and clay at base. 2 – 10 m thick.	Sands often visible at surface. Their thickness may be seen in existing wells, or investigated using a hand auger. **EM34** – generally very low conductivities.
Unit 1c Valley bottom soils	Dark grey, cracking mbuga clays with thin sands and calcrete nodules; gravels at base. 2 – 10 m thick.	Gravel thickness may be seen in existing wells, or investigated using a hand auger. Difficult to identify gravels with **EM34** as high conductivities from brackish clays tend to mask responses from deeper units.
Unit 2 Weathered Dodoman igneous and metamorphic rocks	Weathered brown, grey and red-brown rocks, medium to coarse grained and varying from quite hard to very soft. 2 – 20 m thick.	**EM34** – low to moderate conductivities. **Resistivity** – 10-20 ohm m.
Unit 3 Unweathered Dodoman igneous and metamorphic rocks	Hard white, black, pink, dark green or black rocks. Fine to coarse grained. Fractures most common near top. Over 50 m thick.	**EM34 –** to identify fractures (look for noise and anomalies). Only useful if weathered zone < 30-40 m thick. Very low conductivities over solid granite. **Resistivity** >1000 ohm m

Figure 9 The lithological units present in the Tabora area (as in Figure 10) and typical EM responses expected from each

The typical EM responses produced by the various lithologies present are shown in Table 9. The EM34 results could not generally be used to identify specific lithologies or the thickness of the weathered zone, since different rock types gave similar EM34 responses. The only survey to indicate changing lithology with depth was at Kalembela A, Lunguya, where weathered feldspar, quartz and amphibolite overlay pegmatite. The EM34 has distinguished the high conductivity of the weathered minerals from the very low conductivity of pegmatite (Table 10).

Site	**HD:VD**	**Interpretation of conductivity change with depth**	**Lithology taken from borehole log**
Kalembela A, Lunguya	HD much greater than VD	Much lower conductivity at depth	Weathered feldspar, quartz and amphibolite over pegmatite

Table 10 EM34 response and lithology between 10 and 20 metres depth at Kalembela A, Lunguya



Layer	Thickness	Resistvity
1	1.15	2700
2	1.15	900
3	9.15	90
4	0.25	38
5	13.8	24
6		360

Figure 10 Typical VES survey results on weathered Dodoman granite (at Mtakuja Centre) showing interpreted layer thicknesses

VES surveys carried out on Dodoman rocks give more information on the thickness of soils and weathered zones (see Appendix 2). A typical VES survey results over weathered Dodoman granite is shown in Figure 9, with interpreted layer thicknesses. The high resistivity surface material represents dry soil. The relatively high resistivity layer beneath it may be dry silt or silty sand. The low resistivity material beneath this is generally interpreted as a weathered aquifer containing groundwater. However, the presence of clay minerals can also give low resistivity measurements, and can mean low permeability weathered material with little groundwater. Saline water can also produce very low resistivity readings, and later analysis of groundwater from the borehole drilled at this site showed it to have a specific electrical conductance (SEC) of 2250 µS/cm@25ºC, too saline to drink. This high reading may explain some of the low resistivity readings at this site.

3.4.1.3 HYDROGEOLOGY

Groundwater in Dodoman rocks is found in three main aquifer zones, controlled largely by topography and weathering: a near surface weathered zone, a deeper weathered zone, and a fracture zone in bedrock beneath the weathered zone. Figure 10 shows a conceptual model of groundwater storage and flow in these zones in a typical hill-to-valley profile in Dodoman granite-gneiss terrain. These are:

The **near surface aquifer** (unit 1a and 1b in Figure 10) consists of highly weathered sands, often in conjunction with ferricretes, underlain by clay that has been leached out of the sands. The zone is usually a few metres thick. Ferricrete zones are often developed near the top of hills, with the sandier deposits further down slope, grading into clayey mbuga soils in valley bottoms. This aquifer is unconfined and receives abundant recharge in the wet season. Water tends to flow rapidly downslope and discharges quickly in valley bottoms as springs or as baseflow to rivers. Springs can occur along the base of valley slopes at the junction between the sands and the valley floor clay-rich mbuga soils. Shallow groundwater is usually present in this zone only during the wet season and for one to two months afterwards, after which all remaining water has discharged to the ground surface in the valleys. Virtually all hand dug wells and pits in the Tabora Region are dug into this shallow aquifer, normally to depths of 5 to 10 metres, and by late in the dry season all are dry or have only a few centimetres of water in the base (Figure 11).

Because pit latrines are also dug into this highly permeable zone, shallow groundwater is at risk of contamination. Latrines should not be sited close to and upgradient of any water point (borehole, hand dug well, spring or river).

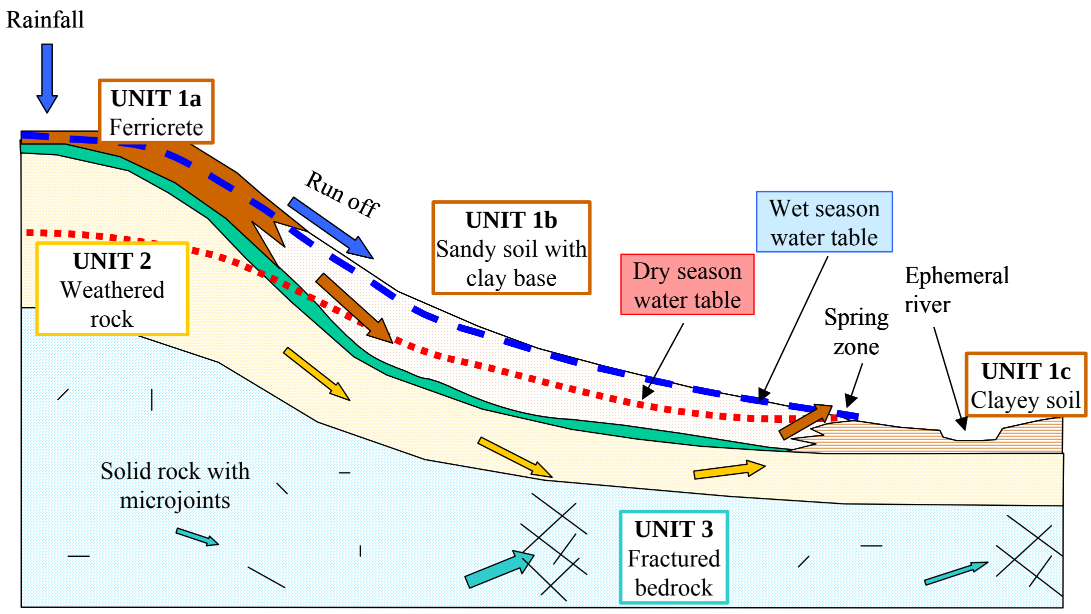


Figure 11 Conceptual model for groundwater existence in a typical profile in the Dodoman Series

The deeper weathered aquifer consists of fractured and less-weathered bedrock beneath the near surface clay layer. The thickness of this zone varies, but it does not normally extend deeper than 40 metres, and is often thickest along valley sides and thinnest in the middle of valleys. It receives less recharge than the near surface aquifer, but groundwater tends to flow more slowly, and may be present all year round. Transmissivity tends to be higher near the top and to fall with depth – this is often reflected by the declining yields of shallow boreholes as water levels fall during the dry season.

Figure 12 Hand dug pit near the end of the dry season, showing low water level

Beneath the weathered zone there are linear zones of **fractured bedrock**, which often occur beneath valleys, since valleys tend to develop along fracture zones. Fracture zones have limited width and depth, but can have high permeability, and can store significant quantities of groundwater. However, they may receive only limited amounts of recharge, because valleys are generally covered by clay-rich soils, which inhibit recharge. This means that initially high borehole yields may fall over time as groundwater storage is used up and not replaced.

3.4.1.4 HYDROCHEMISTRY

Groundwater in weathered Dodoman rocks is generally of Na-Cl or $Na\text{-}HCO_3$ type. Conductivities in about half the sampled boreholes in Dodoman rocks were low, below 200 µS/cm, but in about a third of boreholes were over 1200 µS/cm. One borehole sampled showed a conductivity of over 5000 µS/cm and chloride levels of over 1700 mg/l. This salinity was reportedly only experienced in the dry season, and is believed to be related to the abstraction of spring water for irrigation nearby, which may be 'scavenging' all the available shallow, newly recharged water. The borehole, which also taps deeper sources, is then likely to be left with only deeper, older groundwater from a fracture zone, which has been excessively mineralised by ion exchange during long contact with the surrounding rock. During the wet season, new recharge provides fresh water to flush the aquifer, and salinity will decrease.

Fluoride levels were low (below 1 mg/l) in most sampled boreholes, but a third showed fluoride levels above the WHO limit of 1.5 mg/l. Most of the sampled boreholes also showed high levels of iron and aluminium, exceeding the WHO guideline values.

Most of the sampled boreholes showed low levels of nitrate and often of chloride, indicating minimal levels of faecal and other organic pollution.

White, turbid water was seen in some boreholes in Ilolwansimba village, caused by weathering of clay minerals (Figure 12).

Figure 13 White turbid water resulting from weathering of clay minerals in the weathered aquifer

3.4.1.5 GENERAL HYDROGEOLOGICAL DEVELOPMENT POTENTIAL

The groundwater potential of Dodoman crystalline basement rocks varies depends on the nature and degree of weathering, and on the presence of fracture zones that can transmit groundwater. The most appropriate technology to exploit groundwater in Dodoman rocks depends on which of the three hydrogeological zones is being targeted.

The shallow sandy weathered zones on upper hillslopes only store groundwater during the wet season and for a short period afterwards. During this time this aquifer can be tapped by shallow hand dug wells. The typical thickness of this aquifer is small enough to make a hand dug well practical, and because wells have a much larger seepage area than boreholes, a well is more effective at intersecting groundwater flow down the hill slopes.

The lower slopes of valleys, where the weathered zone is thickest, are likely to contain groundwater for most, if not all, of the year. Shallow boreholes to the base of the weathered zone are suitable for exploiting this aquifer. They should be carefully constructed with screen, casing and a suitable filter pack to prevent fine-grained weathered material from entering the borehole.

Groundwater in deeper fracture zones can only be exploited by boreholes. The boreholes need to be carefully located to intersect the fracture zones. EM34 surveys can often locate the presence of potential fracture zones beneath the weathered zone. Only the uppermost part of the bedrock is likely to contain suitable fractures, so that boreholes in this zone in the Tabora District should be a maximum of 70 metres deep.

Natural groundwater quality in Dodoman rocks is generally moderate. However, the levels of aluminium, iron and fluoride are high enough to cause health concerns. Occasional high conductivity and chloride concentrations appear to be linked to local hydrogeological conditions and to be seasonal. However, they may also be indicative of long-term trends, which would be of greater concern as it may indicate over-abstraction.

3.4.2 Nyanzian Series

3.4.2.1 LOCAL GEOLOGY

Precambrian Nyanzian Series rocks occur around and to the northwest of Nzega and Shinyanga and in the Serengeti and Musoma areas. They form irregular outcrops up to 65 by 30 kilometres across, surrounded by granitic intrusions of the Dodoman Series. Across much of the Manonga valley, north of Nzega, they are overlain by lacustrine deposits from the ancient lakes Eyasi and Victoria and by Quaternary alluvial deposits (Figure 13).

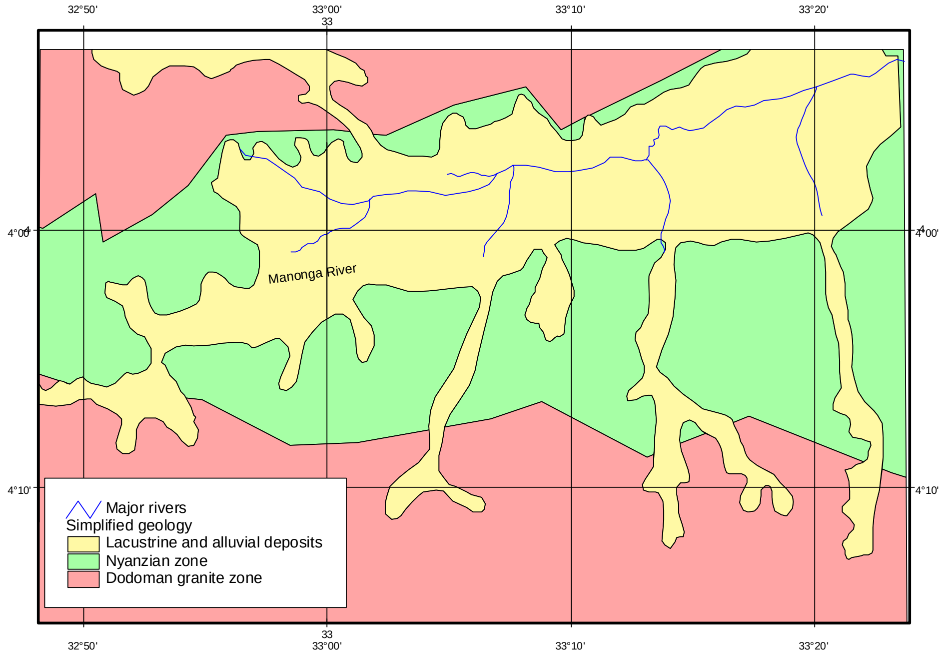


Figure 14 Basic geology of the Kabale study area, Nzega District

The main rock types of the Nyanzian Series are banded ironstones (dark coloured quartzite with band of iron-rich minerals that weather to bright red), schists and metasiltstones (whitish grey when weathered), and metamorphosed ash deposits (largely dark grey or black).

The typical Nyanzian landscape forms gently rolling lines of hills and ridges, and is usually covered by short grass or brush vegetation. The less resistant Nyanzian formations have been largely eroded and covered by lacustrine and alluvial sediments, which now cover much of the lower lying areas. Metamorphosed volcanic rocks form low, often flat-topped hills, while banded ironstone is more resistant to weathering and forms sharp-crested ridges.

Five of the 7 boreholes drilled in Kabale village penetrated Nyanzian rocks, and showed four distinct Nyanzian lithologies: phyllitic schist, often characteristically silvery-grey in colour; amphibolitic schist; metasiltstone; and fine-grained ash deposits of a light grey colour. No boreholes were drilled into the banded ironstones. In all of the boreholes, Nyanzian rocks were overlain by at least 10 metres and sometimes over 60 metres of Mesozoic sedimentary rocks (see Section 3.4.3). At most of the boreholes the top of the Nyanzian lies between 30 and 50 metres depth. The uppermost part of the Nyanzian Series was weathered in all the boreholes. The base of the weathered zone can be difficult to identify, but it varies from a few metres to at least 30 metres thick. Fracture zones in the deeper, less weathered part of the sequence were identified at a number of horizons during drilling, often coinciding with water strikes.

3.4.2.2 GEOPHYSICAL INVESTIGATIONS

A total of 35 EM34 surveys, covering 14.5 kilometres, were carried out over Nyanzian rocks in Kabale, at 5 sites where drilling proved Nyanzian rocks at depths of less than 60 metres. Because the deepest effective penetration of EM34 is approximately 40 metres, in most cases the maximum EM response was from the overlying lacustrine and alluvial deposits. The usefulness of the EM34 surveys was maximised by running surveys at 3 different intercoil spacings at each site, allowing interpretation of lithological changes with depth. However, it is difficult to infer a typical EM response for any of the observed Nyanzian lithologies. It was also impossible to identify the presence of fracture zones in solid bedrock at the base of the weathered zone, since at an average of over 40 metres this is too deep for EM34 to penetrate.

VES surveys were carried out at a small number of sites over Nyanzian rocks in Kabale villages but the results were not able to be collated here.

3.4.2.3 HYDROGEOLOGY

The occurrence of groundwater in Nyanzian rocks in the Nzega area is controlled by topography and location on the hill-valley profile, rock lithology and tectonic structure (Figure 14). As with the Dodoman rocks there is a near surface weathered zone, a deeper weathered zone and a fracture zone beneath the weathered zone. The Nyanzian at Nzega was found to include layers of schist, phyllite, amphibolite, volcanic ash, metasiltstone and banded ironstone. Each of these lithologies has very different weathering characteristics, and this appears to be a major control on groundwater potential. The degree of fracturing is also a control on borehole yield. It is difficult to make conclusions from the eight boreholes drilled into Nyanzian rocks during this study, but the following observations are made.

- Nyanzian phyllitic schists formed a poor aquifer, even where there is a thick weathered zone, probably because weathered phyllite is rich in clay, and therefore has low transmissivity. The 2 lowest yielding boreholes drilled at Kabale (Kasela 1 and Kabale) both penetrate phyllitic schist.
- The borehole at Mwagundu, penetrating amphobolititic schist, has a moderately good yield. Weathered amphibolitic schist contains less clay and is likely to have higher transmissivity than weathered phyllite.
- The metasiltstone appears to weather to gravel size material, and not to produce much clay, resulting in a relatively high transmissivity weathered zone. The highest yielding borehole at Kabale (Kasela 2) penetrates weathered metasiltstone.
- None of the boreholes penetrated solely ash deposits, so their hydrogeological characteristics cannot be distinguished from the other lithologies. However, ash deposits are likely to behave in a similar way to fine sands, allowing slow groundwater flow.

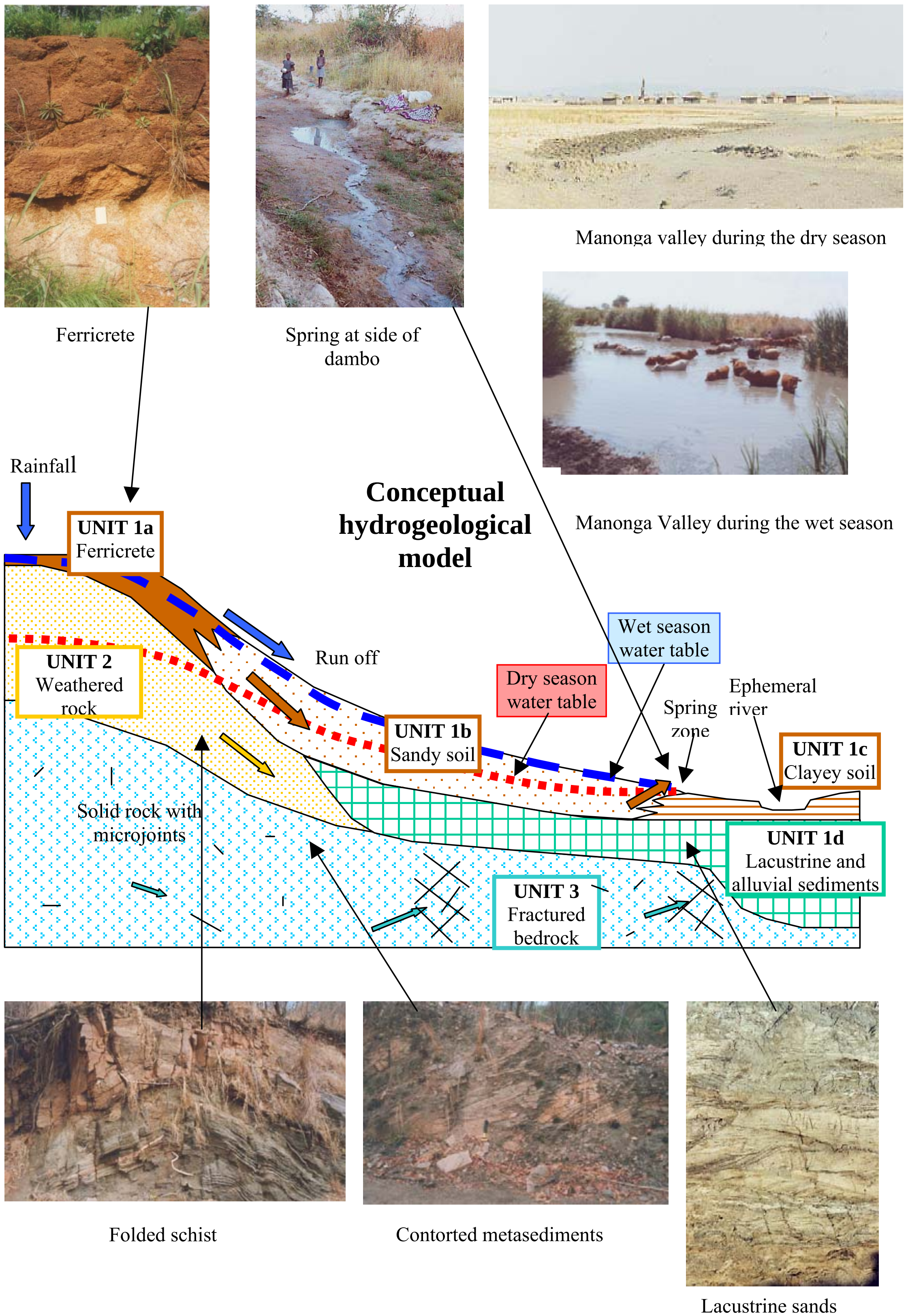


Figure 15 Conceptual model of groundwater occurrence with typical land forms and lithologies in the Nyanzian (weathered and fractured bedrock) and the Mesozoic (lacustrine and alluvial deposits) of the Nzega area, Tanzania

3.4.2.4 HYDROCHEMISTRY

The quality of groundwater from the Nyanzian and Mesozoic rocks in the Kabale boreholes cannot be distinguished, since most of the boreholes penetrate both aquifer types, so that water abstracted from the boreholes is likely to be a mix of both water types. In general, the waters are $NaCa(HCO_3)$ type, with relatively high conductivities, from 600 to 1100 μS/cm. Barium concentrations exceed in WHO guideline of 0.7 mg/l in all 5 boreholes. Fluoride concentrations in the 5 boreholes that penetrate Nyanzian rocks range from 0.8 to 2.5 mg/l, with 3 exceedences of the WHO recommended guideline of 1.5 mg/l. A sample collected from a hand dug well that penetrated Nyanzian phyllite at the base of Mesozoic (possibly Quaternary) gravels had a fluoride concentration of 15 mg/l, high enough to cause skeletal fluorosis. Perhaps by chance, this water also had extremely high conductivity, at over 2800 μS/cm, which caused such a poor taste that the well was no longer used for drinking water. Nitrate and chloride levels are low to moderate.

3.4.2.5 GENERAL HYDROGEOLOGICAL DEVELOPMENT POTENTIAL

The evidence suggests that shallow boreholes drilled into the weathered zone in Nyanzian rocks (up to 50 metres deep) are more likely to be successful if they target metasiltstone or ash deposits, and if they are located where the weathered zone is thickest. Thick weathered zones tend to have high storage and are likely to contain groundwater for most, if not all, of the year.

Higher yields are likely from deeper boreholes targeting fracture zones beneath the weathered zone, but where the weathered zone is thicker than 40 metres, it is impossible to identify these using EM34. As with Dodoman rocks, only the uppermost part of the bedrock is likely to contain suitable fractures, so that boreholes should be a maximum of 80 metres deep.

The natural quality of groundwater from Nyanzian rocks is moderate to good, but the high concentrations of fluoride and barium are of concern since they may form a health risk.

3.4.3 Mesozoic and Quaternary Deposits

3.4.3.1 LOCAL GEOLOGY

Mesozoic and Quaternary age deposits crop out in many areas across the northeast of the Tabora Region (see Figure 13). Mesozoic lacustrine (lake) deposits, comprising pale-coloured marls, were laid down in the deeper parts of ancient lakes, such as the proto-Lakes Victoria and Eyasi, which formed in faulted half graben rift valleys. Evaporites, largely white to light grey and brown gypcrete, calcrete and silcrete, formed in shallower waters around the edges of these lakes. They are usually interbedded with alluvial fan deposits laid down on the lake shores, which comprise sands, silts and gravels, often with evaporitic clasts. Ancient ferricretes and red, oxidised, wind-blown sand deposits, similar to modern soil deposits at the surface, are found at a number of levels in the sequence. The succession of these deposits was probably controlled by the water levels in ancient lakes, which in turn were controlled by ancient climates. The thickness of these deposits therefore varies across the study area. Volcanic ashes such as thin black layers of obsidian, are also found interbedded in the evaporite sequence, deposited during volcanic eruptions.

The main Quaternary deposit is alluvium, laid down by rivers along the major valleys, such as the Manonga and Wembere valleys. These sands, silts and gravels, often cross-bedded, blanket the broad river valleys (as seen in the Busigili borehole in the Manonga valley).

3.4.3.2 GEOPHYSICAL INVESTIGATIONS

EM34 surveys carried out over Mesozoic sediments appear to show that the evaporites and alluvial fan deposits are characterised by moderate conductivities, between 20 to 40 milliohms. There was generally little difference between vertical and horizontal dipole readings, implying that there is no consistent change in conductivity with depth.

Sandy river alluvium, where the clay content is low, is characterised by low conductivity, which may allow it to be distinguished from deeper weathered zones, where clay contents and conductivities are higher. However, if clay-rich and/or brackish soils, which have extremely high conductivities, overlie alluvium, the response of deeper formations can be masked. This was the case at Busigili (see Section 3.4.4, below).

VES surveys were carried out over a small number of sites on Mesozoic and Quaternary sediments in Kabale village, but the results were not able to be collated here.

3.4.3.3 HYDROGEOLOGY

Groundwater appears to be found preferentially in coarser, gravelly horizons within Mesozoic sediments, that occur as alluvial fan-glomerate deposits along the faulted edges of the half graben structures rather than the lacustrine evaporites. These sediments are likely to have high storage, and will transmit groundwater at moderate rates. The Lubaga borehole, which was constructed solely in interbedded Mesozoic alluvial fan and lacustrine sediments, was one of the highest yielding new boreholes in Kabale: it was bail tested at an equivalent yield of almost 15 m^3/day for a drawdown of less than 1 metre.

River alluvium on flood plains appears to contain significant volumes of groundwater for most of the year. Boreholes drilled into the alluvium by the mining company Resolute have reportedly provided high yields.

3.4.3.4 HYDROCHEMISTRY

Most of the boreholes that penetrate Mesozoic and Quaternary sediments in Kabale also penetrate Nyanzian rocks, so the groundwater quality of each rock type cannot be distinguished. Three water samples were collected from boreholes or hand dug wells which only penetrate Mesozoic or Quaternary sediments, and these show waters of $NaCa(HCO_3)$ type, with moderate conductivities, from 400 to 900 µS/cm. Water collected from a hand dug well in Quaternary alluvium at Busigili was the only sample from the Nzega area to show manganese levels above the WHO recommended limit. The water samples show moderate to high barium levels (from 0.5 to 4.27 mg/l) and generally low to moderate fluoride levels (from 0.7 to 1.9 mg/l). The hand dug well containing water with 15 mg/l fluoride (see Section 3.4.2.4), which penetrated Nyanzian rocks at its base, also penetrated Mesozoic (possibly Quaternary) gravels, and it is not possible to determine which of the aquifer units is the source of the extremely high fluoride levels.

Samples from the boreholes penetrating only Mesozoic or Quaternary sediments have moderate organic nitrogen and generally low chloride levels, suggesting low levels of organic pollution.

3.4.3.5 GENERAL HYDROGEOLOGICAL DEVELOPMENT POTENTIAL

The evidence from the Kabale drilling programme suggests that the Mesozoic lacustrine and alluvial fan sequence forms a moderate to good aquifer. Because there appears to be preferential groundwater flow in the more gravelly alluvial fan layers, which tend to be deposited on the sloping shores of the ancient lakes, the highest groundwater potential in these sediments may be found closer to modern-day Nyanzian outcrops.

Groundwater in flood plain river alluvium is traditionally exploited by shallow hand dug wells or pits, although these can collapse easily because of the unconsolidated nature of the sands and because of the presence of swelling clay layers. Constructing boreholes in these deposits is not easy because of swelling clays; once drilled, it is difficult to screen out the very fine grained sands and prevent them entering and blocking the boreholes. The most appropriate method of groundwater development in these deposits may be improved hand dug wells, dug a suitable distance below the normal dry season water level to ensure sufficient storage, and constructed carefully and shored up to avoid collapse. Groundwater quality within the alluvium is affected by the presence of overlying brackish or saline clays. The shallow sands are also vulnerable to pollution from the surface.

3.4.4 Soils

3.4.4.1 LOCAL GEOLOGY

Lateritic soils and ferricretes are common in the Tabora Region, developing preferentially where there is abundant and rapid groundwater throughflow, such as on hill slopes. They consist of a red, iron rich soil, up to several metres thick, from which clays have been washed out (leached) by flowing water. The clays accumulate at the base of the soil zone in a distinct layer. Iron oxides in the soil accumulate as purple-red, iron-rich nodules, which over time coalesce to form hard ferricrete bands (Davies and MacDonald 1999). The thickness and nature of the lateritic zone is controlled by the physical and chemical nature of the underlying geology.

Dark grey, very fine-grained, clay-rich mbuga soils develop on river valley flood plains, partly due to the leaching of clays from valley-side soils. These dry out and crack in the dry season, and hydrate and swell in the rainy season. High evapotranspiration often results in brackish or even saline soils.

3.4.4.2 GEOPHYSICAL INVESTIGATIONS

Although soil characteristics are not the focus of specific investigations, the nature of soils has a large effect on geophysical properties measured at the surface. The conductivity of the soil often dominates the response of resistivity and EM34 surveys, particularly when depth of penetration is shallow (such as with EM34 surveys at 10 metre intercoil separation). This was seen most clearly in the EM34 surveys at Busigili, where the presence of thick, clay-rich mbuga soils which are likely to be brackish or saline caused extremely high conductivity readings (EM34 surveys K21-K22, K23-K24 and K34-K35).

3.4.4.3 HYDROGEOLOGY

The near-surface ferricrete crusts in lateritic soils are generally highly permeable, and will allow rapid and substantial groundwater flow during the wet season. The clay layer at the base of the ferricrete has low permeability, allowing only very slow groundwater flow, so that it acts to impede the downward percolation of groundwater.

The mbuga soils on flood plains are relatively impermeable, containing only small amounts of very slow flowing water. They therefore impede recharge to underlying aquifers.

3.4.4.4 HYDROCHEMISTRY

Groundwater samples were taken from 4 hand-dug wells in ferricretes during this study. Although this is not a large enough sample to draw firm conclusions on groundwater types, a number of observations can be made. Conductivities in 2 of the samples are low (less than 200 μS/cm), with low chloride and nitrate levels. A third shows high conductivity with high chloride and organic nitrogen, strongly indicative of local faecal or other organic contamination. The fourth showed high conductivity, moderately high chloride but low nitrate, which may also be indicative of pollution. The waters were elevated in iron, aluminium and barium, exceeding WHO the recommended limits in most cases. Fluoride concentrations in 2 of the samples (3.9 and 6.0 mg/l) significantly exceeded the recommended limit of 1.5 mg/l.

Mbuga soils contain very little groundwater and are not used for water supplies. However, their often brackish or saline nature may affect the quality of any recharge to underlying aquifers, causing elevated conductivity levels.

3.4.4.5 GENERAL HYDROGEOLOGICAL DEVELOPMENT POTENTIAL

The groundwater resources of shallow soils are strongly seasonal. The permeable zones, in particular the ferricrete crusts, can contain much water during the wet season, but this flows quickly through the zone and discharges in valleys, so that water levels fall rapidly soon after the onset of the dry season. Shallow hand-dug wells can tap this aquifer zone during the wet season, but alternative sources must be found during the dry season.

Groundwater in shallow, highly permeable zones is highly vulnerable to contamination from the surface, particularly from faecal effluent from pit latrines, as latrines tend to be dug into the same shallow layers. Latrines should be carefully sited so they are not up gradient of any shallow water source.

3.5 OVERVIEW OF GROUNDWATER CHEMISTRY

Groundwater chemistry is controlled by rock mineralogy; recharge sources, evapotranspiration and contamination from the surface. Based on the limited number of water samples analysed after the BGS field study, a general overview of groundwater chemistry in the different aquifer types is given here. The current WHO guideline maximum values for selected inorganic chemicals in groundwater and comments on their occurrence in the Tabora Region are shown in Table 10. Figure 15 presents Piper trilinear plots to illustrate overall hydrochemistry.

Groundwater in weathered Dodoman rocks is generally of Na-Cl or Na-HCO_3 type. Conductivity varies considerably, from under 200 to over 1200 μS/cm in most cases. The higher conductivity waters are more likely to be from deeper, older groundwater sources, such as fracture zones, while groundwater in the shallower weathered zone is likely to be younger and less mineralised, with lower conductivity. Most of the sampled boreholes showed low levels of nitrate and chloride, indicating that there is little anthropogenic contaminants. In most samples, iron and aluminium concentrations were higher than the WHO recommended limits. Fluoride and barium concentrations were also higher than the recommended limits in a number of samples.

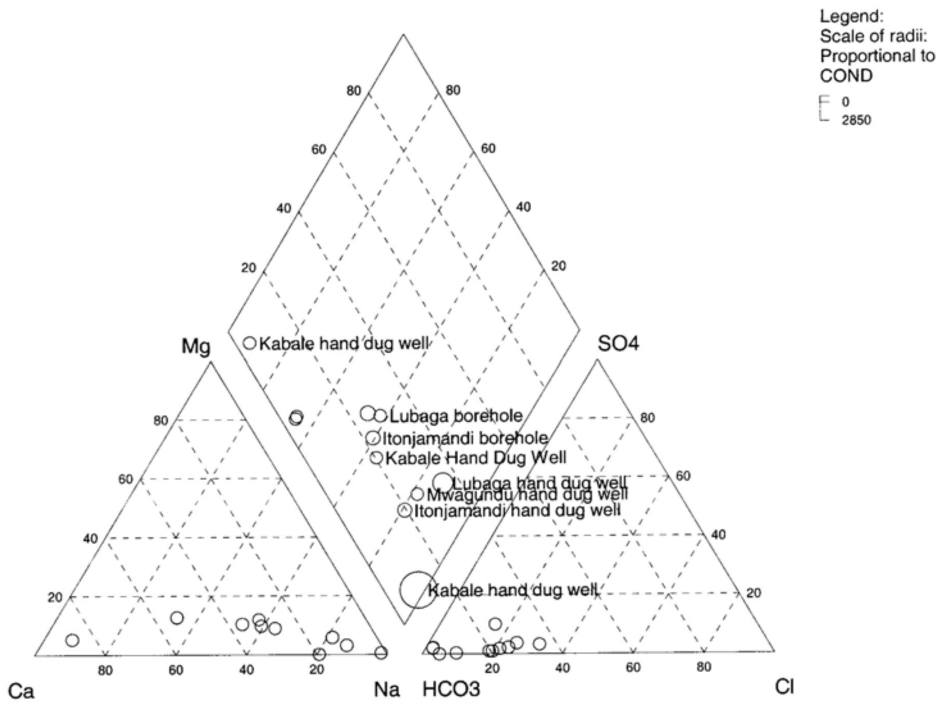
Parameter	Chemical symbol	WHO guideline maximum value (mg ℓ^{-1})	Comments on occurrence in the Tabora Region
3.5.1.1.1	*Chemicals of health significance*		
Arsenic	As	0.01	Below detection level
Barium	Ba	0.7	12 exceedences. Greater problem in metamorphic rocks and Mesozoic sediments, but also occurs in granitic rocks.
Beryllium	Be	NAD	Below detection level
Boron	B	0.5	One 0.4 mg/l, rest below detection level
Cadmium	Cd	0.003	Two exceedences
Chromium	Cr	0.05	One exceedence
Copper	Cu	2	Most below detection level, rest low
Fluoride	F	1.5	12 exceedences. Greater problem in metamorphic rocks and Mesozoic sediments, but also occurs in granitic rocks.
Lead	Pb	0.01	3 exceedences, rest below detection limit
Manganese	Mn	0.5	1 exceedence in Quaternary alluvium; 1 in weathered granite and laterite
Molybdenum	Mo	0.07	Most below detection level, rest low
Nickel	Ni	0.02	One exceedence, most below detection level
Nitrate	NO_3	50	Not measured
Selenium	Se	0.01	All below detection limit of 0.03
3.5.1.1.2	*Substances that may give rise to complaints by consumers*		
Aluminium	Al	0.2	16 exceedances in granitic rocks and shallow wells in ferricrete.
Ammonia	NH_3	1.5	Not measured
Iron	Fe	0.3	10 exceedances in granitic rocks and shallow wells in ferricrete.
Potassium	K	10	1 exceedence, most below 5
Sodium +	Na	200	6 exceedences in granitic rocks and shallow wells in ferricrete.
Zinc	Zn	3	All low

NAD – No Available Data

Table 9 WHO guideline maximum values for inorganic chemicals in groundwater and comments on their occurrence in the Tabora Region

In most cases, the chemistry of groundwater from Nyanzian aquifers cannot be distinguished from that from Mesozoic or Quaternary alluvial aquifers, since boreholes penetrate both or all these aquifer units. Three water samples were collected from boreholes or wells that only penetrate Mesozoic or Quaternary alluvial sediments, and these showed generally similar chemistry to the mixed samples. In general, sampled waters from boreholes penetrating these aquifer types are $NaCa(HCO_3)$ type, with moderate to relatively high conductivities, from 400 to 1100 μS/cm. Nitrate and chloride levels are low to moderate, suggesting low levels of anthropogenic contamination. In most samples from boreholes penetrating both Nyanzian and Mesozoic aquifers, fluoride and barium concentrations exceed the WHO recommended guidelines. In the 3 samples from boreholes and wells penetrating only Mesozoic and Quaternary aquifers, fluoride levels are low to moderate, and barium levels are moderate to high.

Groundwater in shallow ferricretes is usually young, recharged seasonally, and would be expected to have low conductivity. High iron concentrations are common, related to the iron-rich nature of the material. The high levels of aluminium and barium in these waters are also likely to be related to the chemical composition of the ferricrete. Fluoride levels in 2 of the shallow water samples significantly exceeded the WHO recommended limit. Shallow groundwater in the high permeability ferricrete is at high risk of contamination from human and animal activities at the surface, including pit latrines dug into the shallow aquifer unit. Water from one of the shallow wells sampled showed strong evidence of faecal contamination, and another shows some evidence.



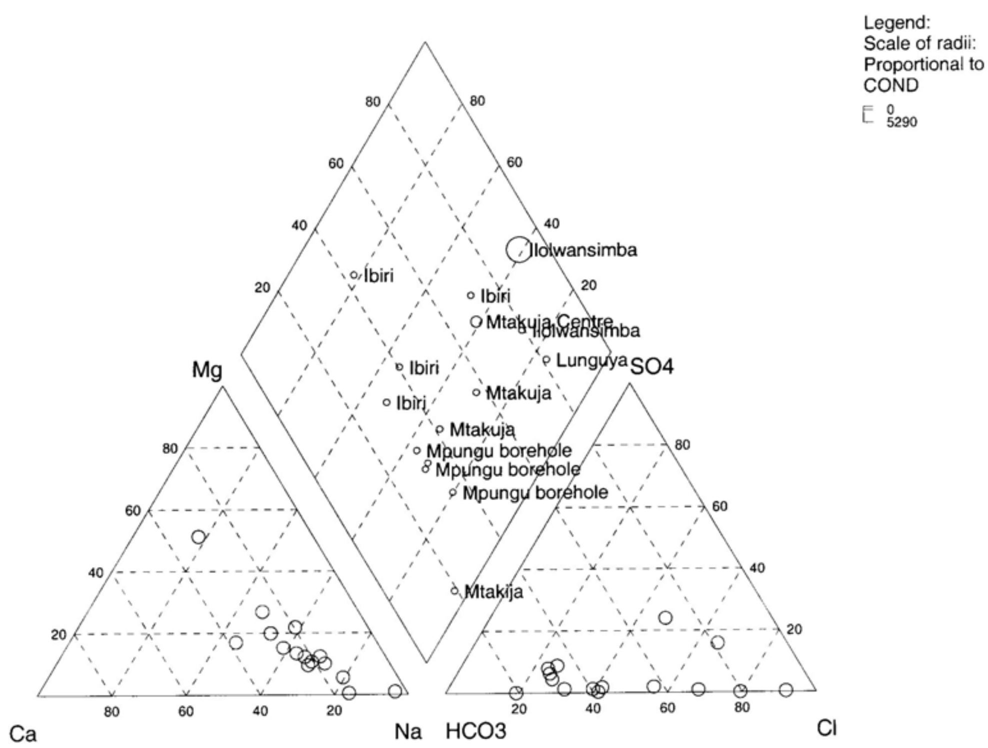


Figure 16 Piper trilinear plots of hydrochemistry – Kabale village, Nzega (top) and Tabora town area (bottom)

4 Dissemination

Within this project there are two important aspects of dissemination. One is the communication of the specific results of the field surveys to those involved in groundwater development in the Tabora Region, to improve understanding of groundwater potential in the study areas, and improve the success of groundwater development. The other is the communication of experience and techniques in groundwater investigation and development to those involved in groundwater development in wider areas, to improve the efficiency and increase the success of borehole siting and groundwater development.

There are a number of distinct targets for dissemination, for each of which a different focus and level of dissemination was appropriate:

- The staff of WaterAid and their partner NGOs; of the Ministry of Water; and of the Drilling and Dam Construction Agency, who are currently developing groundwater resources in the Tabora Region, and who played a vital role in field investigations during this project. Their participation provided an invaluable opportunity for the practical demonstration of appropriate techniques in groundwater development projects. Staff participated directly in operations such as EM34 surveying, sample collecting during drilling and test pumping and analysis, observing the practicalities of the techniques and the role they play in the overall groundwater investigation and development programme. Particular aspects discussed were the role that geology (rock type and structure) plays in determining groundwater potential; appropriate techniques for borehole siting and testing; and the benefits of collecting, managing and using appropriate hydrogeological data, including routine information from borehole drilling programmes, and long term environmental monitoring. Initial results and raw data from the field investigations were passed to WaterAid in digital form at the end of the field visit. Further results and interpretations, including a preliminary report (Davies and Ó Dochartaigh 2000), basic groundwater development maps for the Tabora and Nzega areas, and a poster summarising groundwater development in the region (all presented on the accompanying CD-ROM), were passed to all the organisations who took part in the field studies.
- Information on the aims of the project, and preliminary results, were presented in meetings to representatives involved with planning in the Tabora and Nzega District and Tabora Regional government. These were:
    a. Executive Director, Nzega District
    b. Planning Officer, Nzega District
    c. Regional Administrative Secretary, Tabora Region
    d. Senior Planning Officer, Tabora Region
    e. Land Use Officer, Tabora Region
    f. Regional Water Engineer, Tabora

A copy of the preliminary report (Davies and Ó Dochartaigh 2000) was later sent to each of these officials. The officials also provided much valuable information and assistance to the project, including up-to-date demographic and economic data for the region; access to aerial photographs; and facilitating contact with the Resolute gold mine near Kabale village, which was also drilling water supply boreholes for the mine at the time of the project.

Particular aspects discussed included the severe water shortages affecting the Tabora Region at the time of the study, including plans for future water supply development; and the use of GIS for data management and interpretation.

- A series of 3 half-day seminars held in the final week of the BGS visit to Tanzania provided the opportunity to describe the project and appropriate groundwater development techniques to a wider group of professionals involved in developing groundwater for water supply in Tanzania. Preliminary results of the field investigations were also presented at the seminars, to demonstrate the kind of information that can be collected over a relatively short period. The first seminar, in Tabora, was held with WaterAid and counterpart NGO staff and District and Regional government officials with a direct interest in the provision of rural groundwater supplies in the Tabora Region. The second seminar, in Dodoma, was presented largely to regional Ministry of Water officials. The third seminar, in Dar es Salaam, was presented to senior officials from the Ministry of Water, Drilling and Dam Construction Agency, and representatives of private drilling companies, NGOs, and university and other research institutions. Much of the discussion focussed on the most pressing problems facing those involved in groundwater resource development and water supply in Tanzania. The agenda presented at each seminar, a list of participants, and a summary of the main issues discussed at each of the seminars are presented in Appendix 7.

Feedback from the various dissemination activities, including informal discussions with field staff, and more formal consultation during the seminars, demonstrated the value of the current project at a number of levels:

- By working at community level with WaterAid and partner NGOs, the project has been better able to provide appropriate advice on local hydrogeological problems, such as low yielding boreholes or water quality issues.
- Project staff working in the field, from WaterAid and their partner NGOs, the Ministry of Water, and the DDCA, particularly appreciated the practical demonstration of more appropriate and simple methods of groundwater development. They are now more aware of available alternative techniques and of how best to apply these.
- At the main Ministry of Water offices, at regional and national level, officials are more aware of the quality of data that can be easily collected during routine water supply project work. They are more aware of the benefits for groundwater development of collecting, managing and utilising these data, to improve knowledge and understanding of the potential of groundwater resources across the country.

5 Conclusions, Discussion and Recommendations

5.1 ASPECTS RELATING DIRECTLY TO THE WATERAID PROGRAMME IN THE TABORA REGION

The data collected during the BGS hydrogeological surveys in the Nzega and Tabora areas, and the collation of available existing data, provide a framework for the development of groundwater resources in the region. The hydrogeological characteristics of the various low permeability rock types that underlie the Tabora Region are complex. Groundwater potential depends on many factors, including geology, structure (particularly fracture patterns), geomorphology, and past climates. The different geological units have different hydrogeological characteristics, but all are low yielding. Groundwater occurs in zones of weathering and in discrete fracture zones within bedrock. Shallower aquifer units, often on hillslopes, contain young, recently recharged water, which flows rapidly downslope to discharge in valleys. This rapid movement of water can also lead to rapid transport of contaminants in shallow zones, which is seen in the high levels of nitrate in some of the shallow wells tested. Older, more mineralised water is often present in fracture zones. In Nyanzian rocks, water bearing fracture zones are often buried too deep beneath Mesozoic and Quaternary sediments to be determined using geophysical survey methods. Water from most of the boreholes and hand dug wells tested had high levels of iron, aluminium, fluoride or barium, all of which are known to cause health problems if present in high enough concentrations.

During this project we have emphasised that installing boreholes for water supply should not be done in isolation, but should be part of a comprehensive groundwater development programme. Such a programme comprises (i) identification of the groundwater potential of an area; (ii) selection of suitable sites for borehole (or hand dug well) installation; and (iii) appropriate design and construction of boreholes or wells.

We have demonstrated that most of the necessary techniques for assessing the groundwater potential of an area can be carried out relatively easily, cheaply and quickly, and that much useful information can be gathered during ongoing drilling programmes. The combined use of data gathered from maps and other sources, field geological information, and remotely sensed data and geophysical surveys, offers a powerful approach to producing an initial assessment of groundwater potential, and siting successful water supply boreholes. Additional data collected during borehole drilling and subsequent testing will refine this assessment. **All** boreholes are important sources of information, wet or dry, and the locations of, and data from, all known boreholes should be recorded. Once a water supply borehole is in operation, the monitoring of borehole yields, water levels, and water quality, will provide vital information for assessing the long-term sustainability of the aquifer, and provide early warning of any water supply problems, such as over-abstraction or the effects of drought. It is currently not possible to monitor water levels in operating boreholes, because there is no access for water level dippers. Borehole completion designs should be amended to allow such access.

The hydrogeological descriptions presented in Section 3 of this report provide a fuller understanding of the nature of groundwater resources in the Tabora Region. However, they are preliminary, based on the current understanding of the hydrogeology of the area, and as with all scientific work, they should be updated as new information is collected. They should be used in conjunction with the groundwater potential maps produced during the project (Appendix 6), which provide a summary of the available information for field use.

Given the nature of current and emerging problems associated with water supply in the Tabora Region, the BGS work brought to light several issues concerning groundwater exploration and development which deserve further discussion:

The importance of accurate site recording and location:

In the past, water supply development programmes have often not located borehole and other important sites accurately, relying instead on sometimes-ambiguous place names. In addition, many dry boreholes drilled and then abandoned are not recorded at all. Ambiguously located or unrecorded sites are difficult to geo-reference, which hampers the production of accurate and extremely useful maps, such as water resource planning or groundwater development maps. Inexpensive GPS systems provide the most convenient and accurate means of locating boreholes, villages, rivers, roads and other data points. Alternatively, borehole sites should be located using 1:50 000 scale topographic maps or 1:40 000 scale aerial photography where these are available. Accurately located (spatially referenced) data points can be easily plotted on a map for location by future workers, or included in a geographical information system (GIS) for planning purposes. The WaterAid are using a GPS set provided by the project to accurately locate existing sites in project areas across the Tabora Region, which will enable better use of existing data.

Use of geophysical surveys for borehole siting.

Electrical resistivity surveys are commonly used to determine the apparent thickness of the weathered zone. Borehole sites are then located where this zone appears to be thickest. Unfortunately little attempt was made to accurately locate geophysical survey sites. Therefore correlating lithological data with geophysical survey data at specific sites was not always possible. BGS were able to demonstrate that geophysical surveys need to be undertaken in conjunction with the interpretation of aerial photography (used to locate linear target structures such as fault zones) with sites located on a 1:50 000 topographic map using a GPS if the optimum amount of information is to be obtained from the correlation of drilling data and geophysical survey results. BGS were also able to demonstrate the use of EM34 equipment for the rapid determination of lineament locations. Ideally target lineations should be located using EM34 traversing with electrical resistivity being used to investigate depths of weathering on the fault zone.

Data gathered during borehole drilling:

At little added expense, much useful geological and hydrogeological data can be gathered during the drilling of a borehole, including detailed geological descriptions, penetration rates, and flow rates. These data can be used to make a more objective preliminary assessment of the borehole potential, so that low yielding boreholes can be abandoned, and higher yielding boreholes identified and perhaps targeted for further development. Digital photographs of pseudocore sections can be used to record rock colour changes with depth that can be correlated with patterns of weathering, fracturing and water struck zones.

Test pumping:

Test pumping of boreholes in the Tabora Region is rarely done. The bail test developed by BGS and demonstrated during the field study in Tabora provides field personnel who are not trained in test pumping with a rapid, simple procedure to assess the general potential of a borehole, without undertaking a standard pump test. Simple rules of thumb are provided to help interpret these tests accurately. However, in some circumstances, particularly in fractured aquifers, interpretation can be more difficult, especially if the tests are carried out over short time periods (e.g. less than 5 hours). Fractured aquifer systems can initially give high yields, but if pumping continues they can be dewatered and may suddenly fail. If the borehole is believed to be abstracting from a fracture system (information collected during geophysical surveying and drilling can indicate this), a longer-term pump test should be carried out to allow a more accurate assessment of borehole potential.

Hydrochemical sampling:

Hydrochemical sampling, apart from establishing initial inorganic groundwater quality, can provide information about recharge and contamination. Water quality monitoring of new and operating water supply boreholes should be carried out in the Tabora Region. To provide initial indications of changes in water quality, the routine measurement of borehole water specific electrical conductance (SEC) would provide a useful guide. Field staff with limited training can quickly carry out this field measurement. The results obtained could be used to roughly define areas or depths of different water quality that could provide information on aquifer recharge, dewatering or anthropogenic contamination, especially within village environments.

Borehole monitoring:

Some boreholes in the Tabora Region have experienced declining yields and some have failed, after periods of abstraction lasting from a few months to a several years. The simple monitoring of borehole yields, which could be undertaken informally by the borehole users, would provide a warning of this problem. Informal monitoring could also be used to identify construction problems such as pump failures. Water level monitoring and water conductivity measurements would provide very useful hydrogeological information that could be used to flesh out a "big picture" for the Tabora Region. There is a tendency to regard the installation of a borehole as the only opportunity to collect information about the hydrogeology of an area, but much additional information, often the basis of resource sustainability judgements, could and should be obtained through ongoing borehole monitoring.

Hydrogeological database:

The construction of a hydrogeological database, accurately geo-referenced, should be a priority for the region. This will inform future workers, and help to improve drilling success rates. It will also serve to inform the expectations of development workers and communities. A good database can also be the basis for a comprehensive groundwater potential map for the Tabora Region, perhaps using the preliminary maps developed in this project (Appendix 6) as a basis. These maps could show average yields for the different aquifer types, likely depths to groundwater, modes of groundwater occurrence, and water quality information.

5.2 WIDER ASPECTS OF GROUNDWATER DEVELOPMENT IN TANZANIA

NGOs such as WaterAid are leading some of the largest groundwater development projects currently being undertaken in Tanzania. These water supply projects are often the first drilling programmes to be undertaken within remote rural areas, where hydrogeological conditions are little understood. The initial success and long term sustainability of such projects, and of subsequent projects will be improved by the acquisition of appropriate data during the siting, drilling and testing of new water supply boreholes. However, acquisition of the data needed to assess groundwater resources or their long-term sustainability is at times seen as a waste of capital resources and beyond the capabilities of NGOs. It is therefore important that the relevant national institutions should be encouraged to participate in NGO-led water supply projects, to ensure that good quality data are acquired and recorded.

Government institutions such as the Geological Survey and DDCA should be involved with such projects, if only to update their own databases.

Where borehole success rates remain low, or to increase their capacity to provide sustainable water supplies, NGOs should be able to call upon the assistance of local and international experts who are familiar with the local hydrogeological situations. Areas of local expertise relevant to groundwater development in the Tabora Region could include: the University of Dar es Salaam (satellite image and aerial photograph interpretation); the Geological Survey (mapping of rock exposures and logging of rock core and chip samples); the Ministry of Water (borehole test pumping and hydrochemical analysis); the DDCA (borehole construction); and the Land Survey Department (digitised 1:50 000 maps). Other NGOs could monitor water levels, rainfall and borehole operation in association with community groups. These inputs could result in the collection of better quality data to be fed back into central and regional databases, which could be used to inform optimum groundwater resource development. These activities will require extra funding, which should be channelled through the lead NGO who could co-ordinate activities for the greatest benefits to the user community. Some institutional capacity building will also be needed, including the provision of transport, equipment, staff training and operational costs.

As well as the aspects discussed in detail in this report, future groundwater studies could usefully investigate the following:

- the density of abstraction boreholes
- optimum borehole depths
- optimum borehole design
- risk of aquifer pollution
- realistic estimates of borehole yield and resource expectations by communities and planners
- realistic minimum distances between abstraction boreholes and user communities

In conclusion, the following recommendations are made:

- Work on a common database and a groundwater development map for the Tabora Region should proceed as a priority. The techniques used are easily transferable to other areas in Tanzania.
- Conjunctive use of surface, rain and groundwaters needs to be explored, particularly in areas with unpromising groundwater development potential.
- The application of geophysical techniques needs to be better understood, and used more appropriately for borehole siting.
- WaterAid, with the Ministry of Water, should establish a series of long-term monitoring sites in association with community groups, to observe borehole yield, water level and rainfall
- WaterAid will be the local repository for all data collected during this KAR project. The database that accompanies this report, especially the gazetteer of village locations, needs to be field checked and updated on a regular basis. The maintenance of the database will require the full co-operation of aid donors, including funding drilling programmes in the area.
- Representative geological core samples should be obtained from at least a small number of boreholes, in order to determine rock permeabilities and porosities and for lithological analysis.

- This report and accompanying database should be viewed as dynamic documents that can be added to on completion of subsequent drilling programmes to produce an updated statement of the hydrogeology of the Tabora Region.
- Increased co-operation between different stakeholders, such as NGOs and government institutions would be advantageous.
- The view amongst national institutions, consultants and international non-governmental organisations that data are confidential needs to be challenged.

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7 Project outputs

Reports, manuals and papers produced by the project include:

1. MacDonald, A M , Calow, R C and Merrin, P D , 1999. Groundwater from low permeability rocks in Africa. Project report on visit to Ghana to rapidly assess groundwater development issues in the southern Afram Plains (June-July 1999). British Geological Survey.

2. Davies, J and O Dochartaigh, B, 1999. Groundwater from low permeability rocks in Africa (Project No. R7353). Project report on visit to Tanzania to rapidly assess groundwater development issues in the Tabora Region (September 1999)

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8 Glossary

Aquifer - A rock formation that contains sufficient groundwater for water supply.

Borehole - A cylindrical hole, usually about 100 mm diameter and greater than 50 m deep constructed using a drilling rig for abstraction of groundwater from an aquifer.

Conglomerate – A clastic rock made from cemented pebbles, gravels and sands – can have a high potential for groundwater.

Geophysics - Techniques that measure the physical properties of rocks without the expense of drilling boreholes. In certain circumstances results from geophysics surveys can be used to predict the presence of groundwater.

Porosity - The ratio of void space in rock to the total rock volume - expressed as a percentage. Rocks with high porosity can store greater volumes of groundwater.

Permeability - Rate of groundwater flow through a cross section of aquifer. The ability of a rock to transmit water. Permeability is higher when there are interconnected fractures

Pumping test - A test that is conducted to determine aquifer (transmissivity and storage coefficient) or borehole (specific capacity) characteristics.

Sandstone - A rock that is made from cemented sand grains – usually has a high potential for groundwater.

Shallow well - A large diameter (usually greater than 1 m) hole, dug to less than 20 m depth to access groundwater.

Shale – Laminated mudstone– usually has a low potential for groundwater

Siltstones and mudstones - Fine-grained rocks made of mud and/or very fine-grained particles. Usually have a low potential for groundwater.

Success rate (borehole drilling) - Imprecise term, normally taken as the number of successful boreholes divided by the total number of boreholes drilled – expressed as a percentage. Different organisations have different measures for denoting a successful borehole.

Sustainable yield – the yield from a borehole or aquifer that can be continued indefinitely, because the volume of water abstracted from the borehole or aquifer is less than the volume of water recharged from rainwater.

Weathered zone - A layer of rock beneath the soil zone that has been altered by physical breakdown or chemical decomposition.

Yield - The rate of water abstraction from a well or borehole, measured as m^3d^{-1}, $l\ min^{-1}$, $l\ sec^{-1}$.

Appendix 1 Maps and reports collected during BGS field visits to Tanzania

Maps

- 1:2,000,000 scale Tanzania Vegetation Cover Map
- 1:500,000 scale Tabora Region village location map
- 1:50,000 scale topographic maps:
  63/3 – Kahama
  63/4 – Isaka
  64/4 – Ibingo
  79/2 - Bukene
  79/3 – Bukumbi
  79/4 – Bulunde
  80/3 – Utwigu
  80/4 - Ndembezi
  97/2 - Ulyankulu
  97/4 – Usagari
  98/1 - Mambal
  98/2 - Ipala
  98/3 – Ibiri
  98/4 – Uyui
  99/3 – Ndala
  118/2 - Tabora
- 1:50,000 scale topographic maps (reconnaissance level dye line prints):
  97/4 – Usagari
  118/1 - Mabamba
  119/3 - Igoweko
- 1:2,000,000 Geological Map of East Africa 1952, Dept of Surveys and Lands, Dar es Salaam, 1954
- 1:500,000 The Lake Victoria Goldfields, Tanzania 1989, Ministry of Energy and Minerals, Geology Division (MADINI), Dodoma
- 1:250,000 Geological map of the Tabora Region showing boreholes drilled from 1931 to 1988
- Scale 1:125,000 scale geological maps:
  Quarter Degree Sheet 79 – Bukene
  Quarter Degree Sheet 80 – Nzega – published in colour 1956

- 1:100,000 scale geological maps:
  Quarter Degree Sheet 97 – Ulyankulu
  Quarter Degree Sheet 98 – Igombe Dam
  Quarter Degree Sheet 117 – Urambo
  Quarter Degree Sheet 118 – Tabora

- 1:100,000 scale Aeromagnetic maps:
  Quarter Degree Sheet 64 - Shinyanga
  Quarter Degree Sheet 79 – Bukene
  Quarter Degree Sheet 80 – Nzega
  Quarter Degree Sheet 97 – Ulyankulu
  Quarter Degree Sheet 98 – Igombe Dam

Quarter Degree Sheet 117 – Urambo
Quarter Degree Sheet 118 – Tabora

- 1:250,000 scale Land Cover and Land Use Maps, produced by Hunting Technical Services for the Surveys and Mapping Division, Ministry of Lands, Tanzania, in 1996.
  Sheet SA-36-14 KHAMA
  Sheet SA-36-15 SHINYANGA
  Sheet SB-36-1 KASULU
  Sheet SB-36-2 BUKENE
  Sheet SB-36-3 NZEGA
  Sheet SB-36-5 UVINZA
  Sheet SB-36-6 TABORA
  Sheet SB-36-7 IGALULA
  Sheet SB-36-10 NYONGA

- Landsat 5 TM image 170_171-63 acquired 1 and 10 September 1984 georeferenced to Transverse Mercator projection, Clarke 1880 Spheroid and Arc 1960 Datum, bands 5, 7 and 3

Reports

- Geological Survey, Dodoma, 1987. Brief explanation of the geology of Quarter Degree Sheet 97 – Ulyankulu
- Geological Survey, Dodoma, 1987. Brief explanation of the geology of Quarter Degree Sheet 98 – Igombe Dam
- Mashala, N A T, Petro, F N S and Kajara, R S A. 1987. Brief explanation of the geology of Quarter Degree Sheet 118 – Tabora, Geological Survey, Dodoma
- Moses F and Kajara R S A., 1987. Brief explanation of the geology of Quarter Degree Sheet 117 – Urambo, Geological Survey, Dodoma
- Regional Steering Committee. 1996. Tabora Region, Water Sanitation and Hygiene Promotion, Five Year Development plan, 1996-2000.
- Hydrogeology Unit, Regional Water Department Hydrogeological and Geophysical Investigation Report for Ilalwansimba Village, Tabora Rural District

Appendix 2 Summary of VES survey data from previous WaterAid projects in the Tabora Region

Village	VES surveys carried out	Comments
Ilolwansimba	Ihala Ikonola Ilandu Mihama Nsuguzi A Nsuguzi B Ubala	Summary data available
Lunguya	Kalembela Mhogwe B Marudio A	Detailed data available
Mtakuja	Igombanilo Kawekapina Kazana Kikundi A Kikundi B Kiloleni Mtakuja Centre Mtapenda 1 *Mtapenda 2* Tiara A Tiara B1 Tiara B2	Detailed data available for all except Mtapenda 2
Msangi	Block Farm Ibangu Iyombu 1 Iyombu 2 Msangi E Msangi N2 Msangi N3 Msangi W	Detailed data available

Appendix 3 Drilling system used

The DDCA drilling system used compressed air flush with a Mission high pressure down-the-hole hammer 216 mm (8½ inch) button bit with tungsten carbide inserts, a 150 mm (6 inch) diameter drag bit with 289 mm ($11^3/_8$ inch) reamer, and a 251 mm ($9^7/_8$ inch) rock roller bit with tungsten carbide inserts. Compressed air is supplied by an Ingersol Rand 750 cfm, 300 psi high pressure compressor mounted on a 4x4 MAN truck. Drilling rods were 6.1 m (20 feet) long with 114 mm (4 ½ inch) regular API box pin joints.
The boreholes were drilled by rotary airflush using drag bit through the upper soft horizons, and then reamed using the drag bit reamer and installed with 254 mm (10 inch) temporary steel pipe. Drilling was continued with the rock roller bit or down-the-hole hammer depending on formation hardness, but generally finished using down-the-hole hammer at depth.

Appendix 4 Summary of geological and hydrogeological data from previous WaterAid drilling projects in the Tabora Region

Borehole Name	**Village**	**Lithology**	**Comments**
Mpungu A1	Ibiri	Gravel, weathered pegmatite	Much water
Mpungu A2	Ibiri	Gravel, dolerite	Adequate for hand pump
Mpungu A3	Ibiri	Gravel, dolerite	Adequate for hand pump
Mpungu B	Ibiri	Gravel, dolerite, schist	
Kategile A1	Ibiri	Clayey gravel	Much water
Kategile A2	Ibiri	Lateritic gravel	Adequate for hand pump
Kategile B1	Ibiri	Lateritic gravel, weathered granite	Much water
Kategile B2	Ibiri	Gravel, weathered granite	Much water
Makunguwe B	Ibiri	Laterite, dolerite	Much water
Manyilili	Ibiri	Dolerite, weathered granite	Very little water
Ilolangulu	Chessa		Adequate water.
Nsimba	Chessa	Laterite, weathered pegmatite and granite	RWL below 15mbgl. Only 15 buckets in morning.
Iwombu	Chessa	Coarse sand and pegmatite	Water milky coloured
Uzyungula (Chessa centre)	Chessa	Not recorded/not available	Adequate water.
Ugulala	Chessa	Not recorded/not available	Adequate water. Riser pipe leakage due to cracks.
Chessa Mlimani	Chessa	Not recorded/not available	Low yield. Water taste and colour changes with time.
Ilola	Chessa	Not recorded/not available	RWL below 15mbgl. Only 10 buckets in morning.
Bulima	Chessa	Not recorded/not available	Adequate water.
Iyombo	Msangi	Not recorded/not available	0.55 l/s
Block Farm	Msangi	Not recorded/not available	1.67 l/s
Msangi North	Msangi	Not recorded/not available	2.22 l/s
Ibangu	Msangi	Not recorded/not available	0.69 l/s
Msangi West	Msangi	Not recorded/not available	0.83 l/s
Msangi East	Msangi	Not recorded/not available	2.50 l/s
Mwegelezi A	Lunguya	Pegmatite and gneiss	
Kalembela A	Lunguya	Pegmatite and amphibolite	
Mhogwe B	Lunguya	Gravels, schist and granite	
Marudio "A"	Lunguya	Weathered pegmatite and granite	
Itanana 2	Msimba	Gravels, schist and gneiss	
Msimba Centre A2	Msimba	Gravels and schist	
Msimba Centre B	Msimba	Gravels and gneiss	
Mienda A	Msimba	Gravels and gneiss	

Borehole Name	Village	Lithology	Comments
Mienda B	Msimba	Gravels and weathered gneiss	
Igombanilo	Mtakuja	Gravel, schist, silcrete	Adequate
Kawekapina	Mtakuja	Gravel	Much water
Kazana 1	Mtakuja	Clay	Very little water
Kazana 2	Mtakuja	Coarse sand, gravel, granite	Little water
Kikundi A	Mtakuja	Phyllite, gravel?, schist	Very little water
Kikundi B1	Mtakuja	Gravel, schist, dolerite	Very little water
Kikundi B2	Mtakuja	Gravel, schist, dolerite	Adequate
Kiloleni	Mtakuja	Gravel	Much water
Mtakuja Centre	Mtakuja	Gravel	Adequate
Mtapenda 1	Mtakuja	Sand, schist	Very little water
Mtapenda 2	Mtakuja	Gravel, schist, dolerite	Much water
Tiara A	Mtakuja	Gravel, schist, dolerite	Adequate water
Tiara B	Mtakuja	Gravel, granite	Very little water
Kanala	Nsololo	Gravel, schist, granite	
Mnaisani	Nsololo	Gravel	
Ntalasha	Nsololo	Gravel, granite	
Shuleni	Nsololo	Not recorded	
Misufini	Nsololo	Gravel	

Appendix 5 Hydrochemical Analyses

Field No.	**Village**	**Sample Location**	**Geology (where known)**	**Latitude**	**Longitude**	**Date of Sample Collection**	**Field pH**	**Field Temperature (deg. C)**	**Field Conductivity (microSiemens)**
K1	Kabale	Mwagundu borehole	Amphobolite	-4.026167	33.173917	24/08/00	7.17	29.6	1137
K2	Kabale	Busigili hand dug pit	Alluvial sands			24/08/00	6.92	30.8	408
K3	Kabale	Kasela 2 borehole	Lacustrine sediments, siltstone	-4.054566667	33.1616	25/08/00	7.36	27	979
K4	Kabale	Kasela 1 borehole	Phyllite	-4.058567	33.173517	25/08/00	7.06	27	970
K5	Kabale	"Kabale" hand dug well	Calcrete-cemented gravels	-4.016533333	33.19863333	25/08/00	7.41	26.4	478
K6	Kabale	"Kabale" hand dug well	Gravels, phyllite	-4.016533333	33.19863333	25/08/00	8.09	27.9	2850
K7	Kabale	Lubaga borehole	Lacustrine sediments	-3.999900	33.173400	25/08/00	7.17	28.3	911
K8	Kabale	Lubaga hand dug well	Probably ferricrete	-3.998166667	33.17203333	25/08/00	7.68	27.8	1575
K9	Kabale	Kabale hand dug well	Probably ferricrete	-4.017383333	33.19466667	25/08/00	6.05	28.6	164
K10	Kabale	Kabale borehole	Phyllite	-4.014133	33.193150	25/08/00	7.14	28.6	630
K11	Kabale	Itonjamandi borehole	Volcanic ash	-4.018200	33.166517	25/08/00	7.08	28.2	1085
K12	Kabale	Itonjamandi hand dug well	Probably ferricrete	-4.019066667	33.16565	25/08/00	7.39	26.7	1090
K13	Kabale	Mwagundu hand dug well	Ferricrete	-4.028666667	33.17385	25/08/00	6.35	27.3	113
I1	Ilolwansimba	Ubala borehole		-4.892666667	33.11296667	27/08/00	6.41	27.9	5290
I2	Ilolwansimba	Ihala A borehole		-4.904283333	33.09603333	27/08/00	5.23	27.1	125
M1	Mtakuja	Mtakuja Centre borehole	Gravel	-5.1408	32.74625	28/08/00	6.6	27	2250
M2	Mtakuja	Kiloleni	Gravel	-5.157016667	32.7583	28/08/00	5.76	26.1	157
M3	Mtakuja	Kikundi B	Gravel, schist, dolerite	-5.180866667	32.73576667	29/08/00	7.51	28.1	804
M4	Mtakuja	Mtapenda		-5.183266667	32.75171667	29/08/00	5.7	26.6	63
IB1	Ibiri	Kategili A2 borehole	Lateritic gravel	-4.92395	32.60561667	30/08/00	6.82	25.5	1290
IB2	Ibiri	Kategili B1 borehole	Lateritic gravel, weathered granite	-4.929133333	32.59616667	30/08/00	6.47	26.7	595
IB3	Ibiri	Mpungu B1 borehole		-4.915383333	32.57903333	30/08/00	7.25	26.3	969
IB4	Ibiri	Makunguwe B borehole	Laterite, dolerite	-4.89545	32.59443333	30/08/00	5.5	27.8	67.5
L1	Lunguya	Mhogwe B borehole	Gravels, granite	-4.87935	33.04081667	31/08/00	6.41	27.3	792
L2	Lunguya	Marudio A borehole	Pegmatite, granite	-4.862216667	33.00375	31/08/00	10.16	28.7	1210
IB5	Ibiri	Mpungu B2 borehole		-4.918733333	32.59198333	01/09/00	6.03	27.4	195
IB6	Ibiri	Mpungu A(1) borehole	Gravel, weathered pegmatite	-4.912583333	32.56751667	01/09/00	6.7	30.4	153
IB7	Ibiri	Mpungu A(2) borehole	Gravel, dolerite	-4.916483333	32.56883333	01/09/00	6.47	30.5	107

Tabora/Nzega Hydrochemical Analyses															
Major Ions															
Field No.	Date Sampled	Site Location	Lat deg	Long deg	SEC	Temp degC	Ph Field	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO3 mg/L	SO4 mg/L	CL mg/L	Water type
K1	08/24/00	Mwagundu 1	-4.026167	33.173917	1137	29.6	7.17	143	3.3	83.6	14.7	489	11.3	90	NaHCO3
K2	08/24/00	Busigili 1	-3.962700	33.178000	408	30.8	6.92	31.5	3.3	30.8	5.35	172	9.7	14.7	CaNaHCO3
K3	08/25/00	Kasela 2/1	-4.054567	33.161600	979	27	7.36	78.9	2.7	108	15.7	441	7.9	5.5	CaHCO3
K4	08/25/00	Kasela 1/1	-4.058567	33.173517	970	27	7.06	55.5	3.6	137	10.7	392	< 0.2	102	CaHCO3
K5	08/25/00	Kabale 1	-4.016533	33.198633	478	26.4	7.41	9.5	< 0.5	89.5	3.31	305	5	3.9	CaHCO3
K6	08/25/00	Kabale 2	-4.016533	33.198633	2850	27.9	8.09	773	3.9	9.6	2.1	1780	5.6	110	NaHCO3
K7	08/25/00	Lubaga 1	-3.999900	33.173400	911	28.3	7.17	130	2.7	60	14.3	382	15.6	78.5	NaHCO3
K8	08/25/00	Lubaga 2	-3.998167	33.172033	1575	27.8	7.68	337	2.2	33.4	6.4	536	20.7	153	NaHCO3
K9	08/25/00	Kabale 3	-4.017383	33.194667	164	28.6	6.05	22.4	1.2	8.4	1.68	95.9	0.9	13.7	NaHCO3
K10	08/25/00	Kabale 4	-4.014133	33.193150	630	28.6	7.14	53.3	2.8	73.2	10.6	368	< 0.2	11.1	CaNaHCO3
K11	08/25/00	Itonjamandi 1	-4.018200	33.166517	1085	28.2	7.08	161	1.3	73.1	14.1	494	9.1	79	NaHCO3
K12	08/02/00	Itonjamandi 2	-4.019067	33.165650	1090	26.7	7.39	258	1.5	53.6	5.7	669	6.7	90	NaHCO3
K13	08/25/00	Mwagundu 2	-4.028667	33.173850	113	27.3	6.35	23.8	1.4	3.2	0.91	51.5	5.5	6.4	NaHCO3
I1	08/27/00	Ubala	-4.892667	33.112967	5290	27.9	6.41	680	10.2	264	93.5	266	8.3	1770	NaCl
I2	08/27/00	Ihala	-4.904283	33.096033	125	27.1	5.23	29	1.3	6.1	2.15	17	< 0.2	38.5	NaCl
M1	08/28/00	Mtakuja Centre	-5.140800	32.746250	2250	27	6.6	315	4	92	62.2	439	9.3	553	NaCl
M2	08/28/00	Kiloleni M2	-5.157017	32.758300	157	26.1	5.76	29.6	4	6.5	2.78	25.9	0.9	19.5	NaNO3
M3	08/29/00	Kikundi B	-5.180867	32.735767	804	28.1	7.51	196	3.1	5.5	1	409	0.3	56.4	NaHCO3
M4	08/29/00	Mtapenda	-5.183267	32.751717	63	26.6	5.7	12.1	1.2	3.5	1.19	24.9	< 0.2	10.2	NaHCO3
IB1	08/30/00	Kategili A2	-4.923950	32.605617	1290	25.5	6.82	137	3.1	101	27.5	476	7.9	183	NaCaHCO3Cl
IB2	08/30/00	Kategili B1	-4.929133	32.596167	595	26.7	6.47	24.4	6.6	37	37.3	190	4.6	80.9	MgHCO3
IB3	08/30/00	Mpungu B1	-4.915383	32.579033	969	26.3	7.25	115	7	55.2	34.7	433	31.4	92.5	NaHCO3
IB4	08/30/00	Makunguwe B	-4.895450	32.594433	67.5	27.8	5.5	7.8	2.8	3.5	1.56	9.2	6.1	8.9	NaCl
L1	08/31/00	Mhogwe B	-4.879350	33.040817	792	27.3	6.41	142	4.4	40.5	10.6	354	4.9	97	NaHCO3
L2	08/31/00	Marudio A	-4.862217	33.003750	1210	28.7	10.16	210	11.9	34.5	0.69	114	76.9	234	NaCl
IB5	09/01/00	Mpungu B2	-4.918733	32.591983	195	27.4	6.03	41.2	2.7	6.7	1.53	82.6	8.8	19.1	NaHCO3
IB6	09/01/00	Mpungu A1	-4.912583	32.567517	153	30.4	6.7	25	4.7	6.6	2.08	55	2.8	12.4	NaHCO3
IB7	09/01/00	Mpungu A2	-4.916483	32.568833	107	30.5	6.47	14.8	2.4	4.8	1.67	35.9	3.3	7.3	NaHCO3

Tabora/Nzega Hydrochemical Analyses

Minor Ions

Field No.	Al mg/L	B mg/L	Ba mg/L	Br mg/L	Cd mg/L	Co mg/L	Cr mg/L	Cu mg/L	F mg/L	Fe mg/L	I mg/L	Li mg/L	Mn mg/L	Mo mg/L	Ni mg/L	P mg/L	Si mg/L	Sr mg/L	TON mg/L	Zn mg/L
K1	0.13	< 0.1	0.721	0.256	< 0.001	< 0.003	< 0.002	< 0.008	2.543	0.066	0.101	0.016	0.031	< 0.003	< 0.005	0.1	43.2	1.19	8.9	0.078
K2	0.15	< 0.1	0.552	0.114	< 0.001	0.017	< 0.002	< 0.008	0.672	0.161	0.062	< 0.004	2.64	< 0.003	< 0.005	< 0.1	18.7	0.461	< 0.2	0.035
K3	0.1	< 0.1	1.21	0.224	< 0.001	< 0.003	< 0.002	< 0.008	1.718	0.041	0.142	0.011	0.312	< 0.003	< 0.005	< 0.1	45.2	1.35	< 0.2	0.24
K4	0.08	< 0.1	1.03	0.393	0.001	< 0.003	< 0.002	< 0.008	0.823	0.03	0.083	0.016	0.18	0.003	0.006	< 0.1	41.3	0.888	9.1	0.29
K5	0.07	< 0.1	4.27	0.031	< 0.001	< 0.003	< 0.002	< 0.008	1.141	0.056	0.007	0.007	0.084	< 0.003	< 0.005	< 0.1	55.5	1.63	7.3	0.046
K6	0.59	< 0.1	0.208	0.565	< 0.001	< 0.003	< 0.002	< 0.008	15.261	0.266	2.098	0.039	0.036	< 0.003	< 0.005	< 0.1	57.5	0.233	1	0.024
K7	0.14	< 0.1	1.06	0.433	< 0.001	< 0.003	< 0.002	< 0.008	1.866	0.069	0.089	0.01	0.074	< 0.003	< 0.005	< 0.1	42.6	0.985	9.1	0.166
K8	0.24	< 0.1	0.39	1.125	< 0.001	< 0.003	< 0.002	< 0.008	5.967	0.109	0.140	0.014	0.054	0.003	< 0.005	< 0.1	52.2	0.679	33.9	0.027
K9	4.34	< 0.1	0.391	0.161	< 0.001	< 0.003	0.006	< 0.008	0.779	4.33	0.129	< 0.004	0.253	< 0.003	< 0.005	< 0.1	43.8	0.158	4.2	0.055
K10	0.33	< 0.1	0.853	0.084	< 0.001	< 0.003	< 0.002	< 0.008	1.080	0.194	0.033	0.008	0.183	< 0.003	< 0.005	< 0.1	55.6	0.883	3.9	0.193
K11	0.12	< 0.1	1.01	0.621	< 0.001	< 0.003	< 0.002	< 0.008	2.395	0.06	0.098	0.031	0.073	< 0.003	< 0.005	< 0.1	45.1	1.22	4	0.198
K12	0.2	< 0.1	0.845	0.709	< 0.001	< 0.003	< 0.002	< 0.008	3.933	0.235	0.149	0.016	0.219	< 0.003	< 0.005	< 0.1	55.3	0.825	2.1	0.055
K13	4.07	< 0.1	0.107	0.088	< 0.001	< 0.003	0.004	< 0.008	0.512	2.84	0.020	< 0.004	0.101	< 0.003	< 0.005	< 0.1	18.7	0.061	< 0.2	0.028
I1	0.18	< 0.1	6.33	2.485	0.002	0.004	< 0.002	< 0.008	2.518	0.101	0.149	0.138	0.363	< 0.003	0.009	< 0.1	51.8	4.34	1.4	0.177
I2	2.11	< 0.1	0.246	0.151	< 0.001	< 0.003	< 0.002	< 0.008	0.440	1.35	0.005	0.009	0.034	< 0.003	< 0.005	< 0.1	58.7	0.101	3.1	0.061
M1	0.24	< 0.1	0.986	1.833	0.003	< 0.003	< 0.002	< 0.008	2.083	0.12	0.169	0.354	0.103	< 0.003	< 0.005	0.2	41	1.1	0.5	0.072
M2	1.78	< 0.1	0.148	0.098	< 0.001	< 0.003	< 0.002	< 0.008	0.523	1	0.014	0.027	0.019	< 0.003	< 0.005	< 0.1	49.3	0.0922	9.7	0.043
M3	2.68	0.4	0.193	0.435	0.002	< 0.003	0.003	< 0.008	5.510	0.941	0.110	0.046	0.069	< 0.003	< 0.005	< 0.1	19.9	0.0724	< 0.2	0.073
M4	3.66	< 0.1	0.223	0.078	0.001	< 0.003	0.008	< 0.008	0.490	2.22	0.006	< 0.004	0.062	< 0.003	< 0.005	< 0.1	30.9	0.0556	< 0.2	0.077
IB1	0.3	< 0.1	2.81	0.471	0.002	0.008	< 0.002	< 0.008	1.225	0.281	0.077	0.024	1.32	0.009	0.02	< 0.1	35.5	1.58	0.4	0.124
IB2	0.13	< 0.1	0.682	0.197	0.002	< 0.003	< 0.002	< 0.008	0.369	0.084	0.036	0.054	0.118	< 0.003	< 0.005	0.2	60.2	0.508	1	0.235
IB3	0.11	< 0.1	0.693	0.226	0.001	< 0.003	< 0.002	< 0.008	1.847	0.084	0.070	0.025	0.133	< 0.003	< 0.005	0.2	31.1	0.969	0.8	0.093
IB4	8.23	< 0.1	0.271	0.034	< 0.001	0.004	0.008	0.009	0.790	3.64	0.005	0.007	0.05	< 0.003	< 0.005	0.1	46.9	0.064	0.5	0.137
L1	1.1	< 0.1	1.64	0.504	0.015	< 0.003	0.003	0.014	1.905	0.454	0.040	0.017	0.136	< 0.003	< 0.005	0.1	61.4	0.682	1	0.154
L2	0.3	< 0.1	0.146	0.889	< 0.001	< 0.003	0.062	0.009	0.888	0.127	0.176	0.141	0.006	0.009	< 0.005	< 0.1	38.2	0.283	1.1	0.015
IB5	3.74	< 0.1	0.203	0.147	0.002	< 0.003	0.004	0.01	0.568	1.5	0.046	< 0.004	0.099	< 0.003	0.014	< 0.1	53.6	0.0834	< 0.2	0.071
IB6	1.47	< 0.1	0.149	0.078	0.001	< 0.003	0.003	< 0.008	0.352	1.63	0.034	0.005	0.071	< 0.003	< 0.005	0.3	35.9	0.0766	0.6	0.212
IB7	0.29	< 0.1	0.131	0.064	< 0.001	< 0.003	< 0.002	< 0.008	0.387	0.314	0.020	< 0.004	0.085	< 0.003	< 0.005	< 0.1	34.6	0.0672	1	0.106

Tabora/Nzega Hydrochemical Analyses									
Trace elements and comments									
Field	As	Be	La	Pb	Sc	Se	V	Y	
No.	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Comments
K1	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.014	< 0.0003	Borehole pumped for c. 10 minutes using Whale pump then samples taken.
K2	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	< 0.002	< 0.0003	Sample from waterhole dug into alluvial sands between Busigili village & Manonga river
K3	< 0.03	< 0.002	< 0.002	< 0.01	0.0004	< 0.03	0.003	< 0.0003	Sample taken after c. 20 bails.
K4	< 0.03	< 0.002	< 0.002	< 0.01	0.0009	< 0.03	0.003	< 0.0003	Sample taken from single bail.
K5	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.004	< 0.0003	One of 7 hand dug wells, furthest from road, rwl 7 to 8 mbgl, calcrete-cemented gravels
K6	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.026	0.0004	One of 7 hand dug wells, nearest to road, rwl 7 to 8 mbgl, phyllite at base
K7	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.003	< 0.0003	Sample taken from single bail. RWL 14.52 mbct
K8	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.008	< 0.0003	
K9	< 0.03	< 0.002	0.008	< 0.01	0.0014	< 0.03	0.006	0.0036	probably in ferrocrete
K10	< 0.03	< 0.002	< 0.002	< 0.01	0.0004	< 0.03	0.004	0.0006	RWL 26.66 mbct (casing datum 0.5 magl). Sample taken from single bail
K11	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.002	< 0.0003	RWL 10.875 mbct (casing datum 0.7 magl). Sample taken from single bail.
K12	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.005	< 0.0003	WL c 6-7 mbgl. Handug well
K13	< 0.03	< 0.002	< 0.002	< 0.01	0.0005	< 0.03	0.005	0.0008	Hand dug well in ferrocrete; WL c. 2-3 mbgl
I1	< 0.03	< 0.002	< 0.002	< 0.01	0.0006	< 0.03	0.002	0.001	WaterAid Bh, Nira pump,saline during dry season,irrigating from sp down hill
I2	< 0.03	< 0.002	0.005	< 0.01	0.0019	< 0.03	0.003	0.0038	WaterAid Bh, Afridev pump, white opaque water doesn't clear with filtration
M1	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.004	0.0006	WaterAid Bh, Afridev pump, SEC of water in near pits 102 to 187 microS/cm
M2	< 0.03	< 0.002	0.003	< 0.01	0.0005	< 0.03	0.004	0.002	WaterAid Bh, Afridev pump, white water - not as white as Ihala
M3	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.004	0.0005	WaterAid Bh, Afridev pump, pumps 8-9x20l buckets in morning but v little after
M4	< 0.03	< 0.002	0.01	< 0.01	0.0032	< 0.03	0.006	0.004	WaterAid Bh, Afridev pump, white water
IB1	< 0.03	< 0.002	< 0.002	< 0.01	0.0005	< 0.03	0.002	0.0006	Sampled during bailing test. Borehole v v slow to recover
IB2	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.01	< 0.0003	Sampled during bailing test after 2nd bail: water clear but muddy by end of test
IB3	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.003	0.0004	Sampled during bail test after 2 -3 bails; water clear at this point but muddy later
IB4	< 0.03	< 0.002	0.015	0.23	0.0039	< 0.03	0.013	0.0078	Sampled during bail test after c. 3 bails. Water white & opaque
L1	< 0.03	< 0.002	< 0.002	< 0.01	0.0005	< 0.03	0.005	0.0005	WaterAid BH, Afridev pump, SEC of pond water is 130 microS
L2	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	0.039	< 0.0003	Sampled during bail test after c. 5 bails. Water clear at this point but muddy later
IB5	< 0.03	< 0.002	0.006	0.04	0.0014	< 0.03	0.009	0.0052	WaterAid Bh, Afridev pump, only one out of 3 pumps in Ibiri still pumping
IB6	< 0.03	< 0.002	0.006	0.13	< 0.000	< 0.03	0.006	0.003	Sampled during bail test after 6 bails, water grey, turned brown cleared by test end
IB7	< 0.03	< 0.002	< 0.002	< 0.01	< 0.000	< 0.03	< 0.002	< 0.0003	Sampled during bail test after 3 bails, turbid becoming cloudy & brown during test

Appendix 6 Groundwater Potential Maps for the Nzega and Tabora study areas

Appendix 7 Dissemination Seminars

The agenda presented at each seminar, a list of participants, and a summary of the main issues discussed at each of the seminars are presented here.

Seminar Agenda: The same agenda was presented at each of the seminars.

Seminar Title: Groundwater investigation techniques in areas of low permeability rocks: examples from the Tabora Region

Presenters: Jeff Davies, Hydrogeologist, British Geological Survey
Brighid Ó Dochartaigh, Hydrogeologist, British Geological Survey

Agenda:

- Background
- Why carry out this kind of project? Previous work.
- Methodologies
- Overview of carrying out groundwater investigations in areas of low permeability rocks
- Results from studies in the Tabora Region
- Geophysics, geology, test pumping, water quality data
- Discussion

Tabora Seminar, 4 September 2000
Participants:

Eng Herbert Kashililah	WaterAid, Tabora
Eng Godfrey Mpangala	WaterAid, Tabora
Eng Muganyizi Ndyamukama	WaterAid, Tabora
Ms Ester Nzuli	TAHEA
Mr Stanley M N Kayabu	Anglican Church
Mr M E Kuzenza	Regional Water Engineer, Tabora
Mr R Kalingonji	Tabora Water Authority
Mr Andy F Sangija	Groundwater Exploration and Wells Construction Ltd.; former State Hydrogeologist

Main issues discussed:
This seminar focussed on NGO and Regional Ministry of Water concerns specific to the Tabora Region.

- Ministry of Water geophysicists carry out resistivity surveys over potential borehole sites identified by communities, and recommend the most appropriate of these sites. NGOs construct both boreholes and hand-dug wells for abstraction, but are frustrated by the number of boreholes that have low and diminishing yields. Borehole siting needs to be done with more reference to local hydrogeology, for example using aerial photos and maps that are available in the regional government office.
- Data obtained from boreholes are limited to VES surveys (done by Ministry of Water geophysicists) and lithological logs based on samples taken every 1 metre during drilling (made by the consultant hydrogeologist). There is little or no pump testing of

boreholes. The locations of all new boreholes, dry or productive, need to be recorded (using a GPS) and preferably marked on maps for future planning purposes. NGOs need hydrogeological information to give communities a realistic vision of the local groundwater resource.

- The water supply provider, generally an NGO, is legally responsible for ensuring the water supplied is of potable quality at village level. Water quality analysis is carried out in Ministry of Water laboratories. There is a moral dilemma as to whether it is better to provide otherwise "clean" water from boreholes that exceeds Tanzanian/WHO guidelines on fluoride, or to allow communities to continue using "dirty" water from traditional wells, which is usually (but not necessarily) lower in fluoride.

Dodoma Seminar, 6 September 2000
Participants:

Dr Lister Kongola	Hydrogeology Section, Ministry of Water, Dodoma
Mrs Elder Mcharo	Hydrogeology Section, Ministry of Water, Dodoma
Mr Emmanuel Nahozya	Hydrogeology Section, Ministry of Water, Dodoma
Mr Kenny Mpanda	Hydrogeology Section, Ministry of Water, Dodoma
Ms Catherine Kongola	R.W.E Dodoma
Mr Makwelle Chali	Hydrogeology Section, Ministry of Water, Dodoma
Eng Muganyizi Ndyamukama	WaterAid, Tabora
Mr Michael Rugaimukamu	Central Zone Manager, DDCA, Dodoma

Main issues discussed:
This seminar concentrated on the regional concerns of the main government departments with a remit for the whole of northern Tanzania.

- Abstraction site location and method selection: the Ministry of Water, and to a lesser extent DDCA, are not making use of the resources available due to a lack of training and especially to a lack of field experience. There is also a lack of appropriate equipment, including EM34 and magnetometer systems. There is a realisation that alternatives to boreholes may be more appropriate in certain circumstances, such as collector wells and rainfall catchment systems, although there is a lack of knowledge and experience of these techniques.
- It is recognised that water quality problems exist, especially within the northern Tanzania area with regard to fluoride in the rift zone.
- Drilling and testing of boreholes and the acquisition and management of data: what are the best methods for acquiring routine field data; merits and practicalities of obtaining spot data from boreholes, including water level and water quality data from a wide series of sites, for long term spatial monitoring. This must involve the communities. How is this data to be managed: for example with ArcView GIS, or in paper files and maps.

Dar es Salaam Seminar, 8 September 2000
Participants:

Dr Samson Mpanda	Technical Support Manager, DDCA
Eng Herbert Kashililah	WaterAid Tabora
Mr F M Msemo	Water Resources Institute, Dar es Salaam
Mr Hamidu Stanbuly	Bahadele Drilling, Dar es Salaam
Mr Mohamed Hussein	Bahadele Drilling, Dar es Salaam
Mr Abdul Karim Mohamed	Bahadele Drilling, Dar es Salaam

Mr Will Mtulcananje	Concern Tanzania
Mr Mohamed A Nzaro	Geologist, Hydrotech
Mr Stephen Kombe	Hydrogeologist, O.C.I.
Ms Grace Nsanya	Water Resources Dept, Ministry of Water
Mr Shadrack Mwakalilah	Geography Dept, University of Dar es Salaam
Mr David S A Msangazi	Geologist, Maji (Ministry of Water) Coast Region
Mr Felix K K Karutasigwa	Hydrogeologist, Maji (Ministry of Water) Kagera Region
Eng A K Kigingi	E-W Manager, DDCA
Mr Petro L L Mollel	Maji (Ministry of Water) Coast Region
Mr N N Lupimo	Hydrogeologist, Ministry of Water (Planning)
Mr Hamisi Matungulu	Civil Engineer, DDCA

Main issues discussed:

This seminar covered more national groundwater development concerns.

- Data collection: the national system of databases requires the input of existing data and the collection of new data from borehole drilling programmes. These data are needed to upgrade the Regional Water Master Plans.
- There needs to be better integration of available national data packages held by other institutions and nationwide projects for better location of groundwater abstraction sites and potential spatial resource potential development based on geological units. National databases held in different offices need to be integrated with those held in regional offices. Communication needs to be improved.
- Water Law and effects of privatisation of government drilling and proliferation of private companies: there is a need to establish common standards of drilling practice and contracts.

This CD-ROM is part of report CR/02/191N ‘Groundwater development in the Tabora Region, Tanzania’ . The CD contains reports and data produced during the Tabora/Nzega Groundwater Study in Tanzania, undertaken as part of the KaR7353 Low Permeability Rocks in Sub-Sahara Africa Project. This study joins the earlier Obi/Oju (SE Nigeria) and Afram Plains (Ghana) studies undertaken by BGS as case studies of rural groundwater supplies form low permeability sediments.
The data files present in Word and Excel formats data generated by this and previous projects in the Tabora/Nzega area. The CD-ROM contents must be accessed using the Microsoft Windows 2000 (or later) operating system.
Additional reports included on the CD are:

- The Manual of Simple Methods for assessing groundwater resources in low permeability areas of Africa (Report CR/01/168N)
- Final report: The groundwater potential of the Oju/Obi area, eastern Nigeria (Report WC/99/32)
- A brief review of groundwater for rural water supply in sub-Saharan Africa (Report WC/00/33)

Some of the reports are in pdf format and can be read with Acrobat Reader. Acrobat Reader version 5.0 has been included on the CD and can be installed by double clicking on **ar500enu.exe**
To read a file: open Windows Explorer and navigate to the CD drive; then double click on the desired file name. To access the main report double click on Main Report, then select the version according to CD drive access letter: D or E. The data files can be accessed either by clicking on the blue underlined hyperlinks within the text of the main report or by double clicking on the relevant Word or Excel file.

This CD was compiled by Jeff Davies and Brighid Ó Dochartaigh from the British Geological Survey.
Comments and queries to jdav@bgs.ac.uk