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NATURAL ENVIRONMENT RESEARCH COUNCIL

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Overseas Geology Series

Visit to undertake groundwater development studies in Tabora region Tanzania (July-September 2000)

J Davies and B Ó Dochartaigh

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Executive Summary

(i) Water supply is a major problem in the Tabora Region of Tanzania. During the June to October dry season surface water supplies are scarce and often contaminated. Locating sustainable groundwater sources to supply the region's growing population is therefore vital. However, groundwater development is constrained by uncertainty over the geological controls on groundwater availability. Limited quantities of groundwater occur in the near-surface weathered zone and in younger unconsolidated sedimentary aquifers, as well as along fractures within the Precambrian crystalline basement rocks that underlie the region. These resources can be developed using properly constructed boreholes and hand-dug wells.

(ii) The complex nature of the geology of the Tabora Region was apparent from detailed desk studies of maps, reports and digital remotely sensed data carried out prior to fieldwork. The results of these studies enabled the selection of appropriate methods for field investigations to provide the necessary data for preliminary evaluation of the hydrogeological resources of the region. The Tabora region is underlain by three main rock types:

(i) High grade Precambrian age gneisses, schists and granites of the Tanzanian craton;

(ii) Lower grade Cambrian age amphibolites, phyllites, meta-sediments and meta-volcanics of the Nyanzian series;

(iii) Late Tertiary age lacustrine sediments and associated ash deposits preserved within small scale graben structures associated with the southern extension of the major rift systems to the north.

Groundwater occurs in specific aquifer types within each of these main lithological groups and appropriate techniques need to be used to evaluate each.

(ii) The BGS team spent three weeks in the Kabale area of Nzega District where seven boreholes were sited and drilled; and a week at three sites in Tabora District where dry borehole sites were resurveyed and previously constructed boreholes tested. Tanzanian counterparts included a senior geologist (DDCA), a geophysicist (Ministry of Water), engineers from WaterAid and the Anglican Church, a consultant hydrogeologist and village water committee members, all of whom fully participated in field work activities. During these studies the BGS team carried out 25 km of EM34 surveys. Detailed geological data, including penetration logs and rock chip sample logs, were collected during the drilling of each of 7 boreholes to assess the lithological characteristics of the main geological formations penetrated. Twenty simple bail and Whale pump tests were carried out to evaluate the hydraulic characteristics of these formations. Twenty-eight water samples for hydrochemical analysis were collected from boreholes and hand-dug wells. All data collected were digitised and managed using spreadsheets and ArcView, a desktop geographical information system (GIS). A preliminary digital base-map of the region was compiled using digital satellite images and topographic maps.

(iii) The initial results of these studies were disseminated to members of the village water committees in the field, to counterparts both in the field and during regular meetings throughout the visit, and to district and regional political leaders and representatives of their administrative staff in Nzega and Tabora. Three seminars sessions were undertaken with: local NGO and regional governmental personnel in Tabora; representatives of the Ministry of Water Hydrogeology Section, Regional Ministry of Water office and DDCA in Dodoma; and representatives of the Ministry of Water, DDCA, University of Dar es Salaam, NGOs and commercial drilling companies in Dar es Salaam. The country representative of Water Aid

and the Engineering Advisor to DFID in Dar es Salaam were also briefed. From the results of the field work and from discussions held during the seminars the following issues were identified:

(iv) Decentralisation has had significant impact on the system of water supply provision and the collection and collation of hydrogeological knowledge in Tanzania. Institutions at local level – local government and NGOs – now undertake the majority of rural water supply provision and must provide technical and social support for community-managed services. While this change has many benefits, in particular with regard to consideration of the socio-economic issues and the sustainability of rural water supplies, it has been to the detriment of national hydrogeological databases, national expertise and control over borehole drilling and construction standards. The Ministry of Water has overall responsibility for collecting, processing and disseminating data, but finds it difficult to carry out its duties in this regard due to a lack of appropriate resources. Data sets collected by individual projects are fragmented between different institutions and government levels, including central, regional and district Ministry of Water offices, central and regional DDCA offices, NGOs and external agencies. The overall understanding of groundwater resources in Tanzania is not being improved, and without an increased understanding, organisations such as WaterAid who are undertaking water supply work risk making poorly informed decisions.

(v) The main source of hydrogeological information for the Tabora Region is the Tabora Regional Water Master Plan, a comprehensive compilation and analysis of groundwater occurrence in the region as of 1980. However, much of the analysis was based upon spot information from a restricted number of boreholes, and the Master Plan needs to be upgraded if the groundwater resources of the Tabora Region are to be more effectively developed. Increasing the hydrogeological knowledge base need not be prohibitively expensive: the most cost-effective method is to maximise the quality and quantity of data collection and collation from ongoing drilling programmes. A far greater number of boreholes have been completed in the Tabora Region since the Water Master Plan was carried out than were drilled for the sole purposes of the Master Plan. If basic hydrogeological data from these boreholes had been routinely collected, verified, collated and analysed, the current understanding of groundwater occurrence in the region would be much more advanced, for relatively little added investment.

(vi) Current water supply policy is focused on providing village boreholes, for which communities need to invest significant funds, in order to ensure a feeling of 'ownership' and therefore responsibility on the part of the communities. Although in some villages NGOs are constructing new hand-dug wells as well as, or instead of, boreholes, this approach could be usefully expanded. In many areas it may be sufficient to upgrade existing hand-dug wells at less cost and with less possibility of adversely affecting traditional behaviour. There should be increased awareness of traditional water supply strategies and of what communities will find acceptable as alternative supplies, in terms of cost, location, quality and durability.

(vii) A borehole has a finite life, due to corrosion and wear of component parts controlled by water chemistry as well as intrinsic material qualities. The ongoing replacement of redundant boreholes should be taken into account in water supply planning and user communities informed of the likely life span of their boreholes.

(viii) Groundwater protection and management is an important concern even for low-yielding hand-pumped boreholes. At present there is little understanding of seasonal, inter-annual or long-term fluctuations in groundwater quantity or quality. Issues such as the impact of latrine provision on shallow aquifers should be considered. The drying-up of many shallow boreholes by the end of the dry season may be a seasonal response to groundwater recessions, or may be exacerbated by the current extended dry period. Collection of spatial and temporal climatic and hydrogeological data could help identify areas at risk of quantity or quality

problems for future planning purposes. The lack of resources at NGO and government level means that communities may need to be involved in data collection and self-monitoring of their water resources.

(ix) Potential borehole sites are identified by the communities (generally close to village centres) and then investigated using basic resistivity techniques. There is little or no initial hydrogeological surveying and no use of topographical maps, aerial photography or other geophysical methods.

(x) Borehole drilling success rates are often the only criteria used to evaluate and compare drilling programmes, but caution should be used in interpreting such statistics, as the definitions of 'success' may vary. The benefits of drilling relatively low-yielding boreholes in less productive areas may be greater than a more 'successful' drilling programme in an area where aquifers are more productive, and therefore easier to develop. These benefits will only be realised if adequate data are collected and used to expand the knowledge base. There is a need for increased awareness of the limitations of the groundwater resource within particular lithological units, both in terms of quantity and quality. This will enable user communities to be given realistic estimates of borehole yield and of likely seasonal or longer term fluctuations in water quantity or quality. This may mean that the current blanket standard for the number of people supplied by a single borehole – 250 persons at a rate of 25 litres/head/day – should be replaced by more flexible criteria.

List of Acronyms

BGS	British Geological Survey
DDCA	Drilling and Dam Construction Agency
DFID	Department for International Development
GIS	Geographical Information System
GPS	Global Positioning System
KaR	Knowledge and Research
LRDC	Land Resources Development Centre
l/s	litres/second
mbgl	metres below ground level
NGO	Non-Governmental Organisation
ODA	Overseas Development Administration
PRA	Participatory Rural Appraisal
TAHEA	Tanzanian Home Economics Association
TSh	Tanzanian Shillings
WHO	World Health Organisation

1. INTRODUCTION

From July-September 2000 a team from the British Geological Survey carried out work in the Tabora Region of Tanzania to investigate the occurrence of groundwater in different geological environments. The BGS study was carried out in conjunction with the ongoing WaterAid programme to provide village water supplies in selected parts of Tabora Region. The bulk of work was carried out in a village in Nzega District in the northern part of Tabora Region. Additional work was done in three villages within a 20 km radius of Tabora town. The location of the study area is shown in Figure 1.1.

This investigation forms part of a two-year project aimed at producing groundwater development tools to increase the success of water supply projects in geologically difficult areas of sub-Saharan Africa. The project is funded by the Department for International Development (DFID) under the Knowledge and Research (KaR) programme. In the first year of the project, groundwater development problems facing four WaterAid programmes in Ghana, Ethiopia, Tanzania and Zambia were rapidly assessed. The initial visit to Tanzania is described in Davies and Ó Dochartaigh (1999). The programmes in Tanzania and Ghana were selected for more detailed follow-up work in the second year of the project. Techniques developed during the project will be used to produce groundwater development maps for areas where the siting of sustainable groundwater supplies has proved difficult. A brief introduction to the project is provided in Appendix A.

Two BGS staff, Jeffrey Davies (Hydrogeologist) and Brighid Ó Dochartaigh (Hydrogeologist), visited Tanzania from 30 July to 10 September 2000. WaterAid facilitated the visit. An itinerary for the visit is given in Appendix B. Terms of reference were as follows:

(i) To develop appropriate techniques for assessing groundwater resources in geologically complex areas.

(ii) To demonstrate improved methodologies of groundwater resource assessment in geologically difficult areas, representative of the Tabora Region, using the techniques developed.

(iii) To demonstrate techniques and guidelines developed at appropriate levels via seminars and workshops.

Figure 1.1 Location of study area.

2. BACKGROUND INFORMATION ON THE TABORA REGION

The Tabora Region is located in mid-western Tanzania on the central plateau, between latitude 3° - 7° south and longitude 31° - 34° east. The region is 76,120 km^2 in extent, representing 9 percent of the land area of mainland Tanzania. Most of the region lies at 1,000-1,500 m above sea level, with two small areas in the north-west and south-east rising to 1,800 m above sea level. The topography over much of the area is flat to undulating with isolated hills and ridges representing outcrops of more resistant basement rocks.

The population of the Tabora Region in 1996 was estimated at 1,226,000, of which 78% live in the rural areas. During the last twenty years the population of the area has increased rapidly. Migrant farmers were attracted by fertile soils and improving infrastructure. Many migrant workers were attracted by the mining of diamonds and gold in the northern part of the region. The Region is divided into six administrative districts, which are further divided into 133 wards and 418 villages. The village is the basic community unit in Tanzanian Governmental structure. A typical village has a population of 2,500-3,000 people, and may cover a large area. Villages tend to be located on ridges and well-drained valley sides. Population density is low, varying from 7 to 45 people per km^2.

The climate is warm with temperatures reaching their peak in September and October, just before the onset of the rainy season. Mean annual temperature is around 23°C, with a slightly cooler period from May to July. (Table 2.1). Rainfall is seasonal, falling almost entirely between November and May. During the June to October dry season occasional showers may occur (Table 2.2). In the west of the region average annual rainfall is over 1000 mm, decreasing to 700 mm or less in the east. Recent climatic data are hard to obtain, but there is abundant oral and observational evidence of a prolonged dry spell since 1997, with little rain during the nominal wet seasons of 1998-99 and 1999-2000.

Rural water supplies consist of piped schemes installed by the Government and shallow wells constructed with the assistance of NGOs. In 1996 there were an estimated 51 piped schemes based on boreholes and 450 shallow wells. Of these, a significant number of the piped schemes are either non-operational or operating below capacity due to lack of funds or groundwater resource problems. Provision is based on the WHO recommended consumption rate of 25 litres/head/day, but WaterAid estimate that during the dry season only 29 percent of the rural water demand in the Tabora Region is being met. This rises to some 36 percent in the rainy season. A water committee elected by the villagers manages each village water supply. Water supplies for Tabora town are derived almost entirely from two surface reservoirs, with a small number of supplementary shallow hand-pumped boreholes. Urban water supply is the responsibility of a municipal water utility provider.

Health problems include cholera that frequently occurs at the onset of the rainy season when surface water supplies become contaminated with effluent. This problem is prevalent within areas of flood irrigation of rice along dambos.

Table 2.1 Mean monthly temperatures at Urambo and Tabora (ºC) for 1964/65 to 1975/76 (From Mitchell, 1984).

Month	Mean Maximum		Mean Minimum		Daily Mean	
	Urambo	Tabora	Urambo	Tabora	Urambo	Tabora
October	32	32	18	19	25	26
November	31	31	18	19	25	25
December	29	28	18	18	24	23
January	29	28	17	17	23	23
February	29	28	17	17	23	23
March	29	28	17	17	23	23
April	29	28	17	17	23	23
May	29	28	16	16	23	22
June	30	28	13	15	22	22
July	30	28	13	14	22	21
August	31	29	15	16	23	23
September	32	31	18	17	25	24

Table 2.2 Monthly mean and minimum rainfalls at Tabora and Urambo (mm) for 1964/65 to 1975/76 (From Mitchell, 1984).

Month	Monthly Mean		Monthly Minimum	
	Tabora	Urambo	Tabora	Urambo
October	16	21	4	5
November	102	105	68	74
December	164	192	110	110
January	96	141	60	84
February	114	176	66	128
March	146	187	96	136
April	101	160	67	80
May	26	35	6	4

The Tabora Region is currently suffering a severe water shortage. In Tabora town, water rationing was initiated mid-way through the 2000 dry season. By early September 2000 one of the town's reservoirs was empty and the other reportedly had less than 2 m depth of water remaining. The Ministry of Water in Dodoma reported that Tabora's water utilities provider had requested an urgent programme to provide emergency boreholes to supply the town, as was carried out in Shinyanga in during 2000. However, the resources of the Ministry of Water do not currently allow for such a programme, which may take place during 2001.

Tabora town is located astride the regional watershed. The west and south west of the region are drained by the Igombe River system, which flows into the Malagarasi swamp area, and by the Ugalla River system flowing into Lake Sagala via the Swangala swamp. The north east of the region is drained by the Wembere River system that drains to the inland Lake Eyasi. The main river valleys tend to be wide, occupied by expanses of mbuga (black cracking clay) soils, and covered by dense vegetation. During the rainy season they are generally wet and may experience flooding. 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.

Where vegetation has been cleared, the flat lying clay soils of the valleys are used for the cultivation of rice during the rainy season. The natural vegetation cover of the region is predominantly Miombo woodland, with Acacia/Cambretum woodland in the drier north-east and east. These woodlands harbour tsetse fly that is the vector for trypanosomiasis (sleeping sickness). However, the region is dominated today by bushed grassland, presumed to be largely a result of the degradation of natural forests through cultivation and overgrazing. A study of the forest reserves of the Tabora Region was completed in 1999 by the Institute of Land Resource Assessment of the University of Dar es Salaam, and a set of vegetation maps covering most of the Tabora Region were acquired for project use. Traditional wet season paddy rice cultivation in Tabora Region has been severely affected during the two poor wet seasons from 1998 to 2000, and the cultivation of cassava, conventionally grown as a drought crop, has been widespread during 2000. A general shortage of grazing has led to large-scale temporary migration among the pastoralists and their cattle herds who make up the bulk of Tabora's rural population, particularly in the northern districts, including Nzega. Migration from the Tabora Region, particularly into reserve areas of protected forests, is believed to be leading to significant environmental degradation, and has reached as far as the Zambian border to the south-west.

Granitic soils, composed of quartz sands and clay minerals occur in well-drained lowland areas and along valley sides. Fine-grained, dark mbuga soils dominate the marshy (dambo) areas. Laterites (oxidised soils formed by tropical weathering) are common across the area, being reddish-brown in colour and comprising quartz pebbles cemented by a ferruginous matrix. Laterites may form a capping layer on granitic sandy soils where they may represent ancient weathering surfaces. The nature of these soils and the water-holding capacity of dambos and their structures have been comprehensively reported in the relevant section of the Tabora Regional Water Master Plan.

The solid geology of the much of the Tabora Region comprises hard crystalline basement rocks of the Dodoman system of Archaean age that make up the central Tanzanian craton. The main rock types are granitic and amphibolitic gneisses (Plate 1), amphibolite and biotite schists, meta-sediments and pegmatitic granites. The Nzega area is underlain by metasediment and metavolcanic rocks of the early Cambrian age Nyanzian system. These include amphibolites, phyllites and banded ironstones. East-west trending graben valleys faulted and eroded into the ancient land surface are associated with the formation of the major rift system to the north. These have been infilled with late Tertiary age lacustrine sediments and volcanic ashes, including aeolian and alluvial sands, calcrete, silcrete and anhydrite. Superficial deposits over much of the Tabora Region clays, detrital sands and lateritic soils of variable thicknesses derived from weathering of the basement rocks. The characteristics of these superficial deposits tend to mirror the underlying solid geology. However, little is currently known about the weathered zone and how it relates to the bedrock geology of the region. Thick sequences of

river sands and gravels are present in major river valleys, often topped by thick black cracking clayey (mbuga) soils.

3. GROUNDWATER AVAILABILITY AND ROCK TYPE

Groundwater availability is dependent on the nature of the underlying rocks. Over much of the Tabora region these comprise a sequence of ancient granitic and metamorphic complexes of low porosity and intrinsic permeability. Groundwater is found only where these rocks are fractured and/or weathered to significant depths. Three water-bearing zones can be identified:

(i) A shallow zone of unconfined near-surface sands and/or nodular-tubular ferricretes, underlain by clay, receiving plentiful wet-season recharge. Water in this horizon is at risk of contamination, in particular from pit latrines. Springs can also occur along the base of valley slopes at the junction between these sands and the valley floor clay-rich 'mbuga' type soils.

(ii) A semi-confined to confined zone beneath the near-surface clay layer, consisting of fractured and weathered basement rock, which may contain significant quantities of groundwater. The thickness of weathering is often greatest along valley sides, thinning towards the central parts of valleys. Permeability in this horizon decreases with depth, often reflected in the declining yields of shallow boreholes as water levels fall during the dry season. Groundwater quality in this zone is largely controlled by interaction with rock minerals.

(iii) Fracture zones within basement rock, which can store significant quantities of groundwater, but which may receive limited recharge. Boreholes constructed within fracture zones often have high initial yields which may decline with time as abstraction exceeds recharge. Water quality may be poor due to excessive mineralisation over long residence times. Valleys generally develop along existing fracture zones, and so this type of aquifer is likely to be found preferentially in valleys. Valley bottoms are generally capped by clay-rich soils, which inhibit recharge.

In parts of the Nzega district the rocks found at the surface are younger lacustrine, alluvial, aeolian sediments and interbedded volcanic ashes. These sediments can have significant intrinsic permeability and form reasonably good aquifers.

In major river valleys, such as the Manonga valley north of Nzega, thick sequences of alluvial sands and gravels have accumulated which often form a reasonable shallow aquifer system, but may contain brackish to saline water at depths below about 30 m.

4. CURRENT PRACTICE – METHODS AND APPROACHES

Traditional wet season sources of water in the Tabora Region are rivers, ponds, hand-dug wells and pits. These sources are frequently contaminated by effluent carried by surface runoff or leaking from latrines dug into permeable ground, and can form breeding grounds for mosquitoes. Diarrhoeal diseases and malaria are the major causes of mortality in the region, and are most widespread during the wet season. In most parts of the region, surface water virtually disappears during the dry season, and only a small proportion of hand-dug wells and pits continue to supply water. Water levels are generally only a few centimetres above the base of such wells and pits. A number of springs were observed along the base of mbuga-filled valley sides, occurring at the junction between alluvial sands and the clay-rich mbuga soils. Many of these springs appear to flow all year round, and are used by local communities for domestic water supply and small scale irrigation. As yet there are no schemes to protect any of these springs or to install piped distribution systems.

Current Tanzanian Government policy on rural water supplies emphasises cost sharing with villagers to achieve a feeling of community ownership of water sources (Regional Steering Committee, 1996). All NGOs have adopted this concept in the implementation of water supply projects. Projects are initiated with the involvement of the village and component sub-villages. Water committees are set up to liase with WaterAid and its partner organisations. The village committees are required to accumulate funds to cover at least part of the costs of the project and the ongoing maintenance of water supply points. Sanitation and hygiene awareness education programmes are carried out prior to installation of hand pumps.

Groundwater resources in the Tabora Region are being developed by the Ministry of Water, NGOs including WaterAid, TAHEA, World Vision, the Moravian and Anglican Churches, and private concerns. In the Nzega area, a recently opened gold mine (Resolute) is developing groundwater supplies for its industrial operations, and has provided three boreholes for use by the community in Kabale village, where WaterAid are currently working and where the largest part of the current BGS investigation took place. WaterAid and its partners are the major rural water supply provider in the Tabora Region. Most of the NGO water supply program is focused on providing boreholes. In some villages hand-dug wells are being upgraded or rebuilt to augment or take the place of boreholes.

WaterAid's borehole siting and construction programme is carried out in a number of stages. Initially, the village water committee specifies three potential borehole sites, in order of preference. These sites are then surveyed using geophysical methods to investigate the vertical distribution of soils and weathered and solid basement rocks. Resistivity surveying is done by a team of sub-contracted Ministry of Water staff, with community assistance. Current practice is that only resistivity surveying is done, although magnetic surveying equipment is available. In the majority of cases a single resistivity depth survey (or vertical electrical sounding - VES) is done, using an ABEM Terrameter with a Schlumberger electrode array. Analysis is done by curve matching techniques. From the results of the geophysical surveys, the three sites chosen by the village committee are ranked in order of interpreted groundwater potential and maximum drilling depths are recommended. If none of the sites shows potential for groundwater supply a further three sites are selected and surveyed. No use is made of topographic maps or aerial photographs to accurately locate possible water-bearing lineations prior to field surveying.

Drilling is contracted out to a DDCA crew, and supervised by a consultant hydrogeologist. Drilling is done using truck-mounted, air-operated Schramm rigs. Borehole formation samples are currently taken at 2 m intervals and at major lithological changes, and recorded by the site hydrogeologist. The drillers and hydrogeologist often do not have access to stopwatches or water level dippers. Boreholes are drilled to the depth recommended from resistivity analyses unless the hydrogeologist decides otherwise. If the borehole is considered by the drillers and the hydrogeologist to yield insufficient water during drilling, it is abandoned. The hydrogeologist, with the head driller, designs the casing and screen construction. Following the installation of casing, screen and gravel pack the borehole is air lifted to both develop the borehole and provide an indication of yield. No quantitative measurement of borehole discharge during drilling or air lifting is carried out, and borehole yields are therefore unknown. A borehole completion form is filled out and copies forwarded to WaterAid and the central DDCA office.

Test pumping of boreholes is supposed to be carried out by the DDCA after completion, but appears to have been rarely, if ever, undertaken during the WaterAid programme in Tabora.

5. AVAILABLE INFORMATION AND EXPERTISE

Contacts made with members of government departments, NGOs and other organisations within Tanzania are listed in Appendix C. A bibliography was compiled of international papers and reports

describing aspects of the geology and hydrogeology of Tanzania. Copies of maps and reports obtained by the project are listed in Appendix E.

Published topographical maps at 1:50,000 scale are available for purchase. Topographical maps at 1:50,000 scale are also held at the Ministry of Land Use, Tabora regional office.

Published geological maps at 1:100,000 and 1:125,000 scale are available from the Geological Survey, Dodoma, for parts of the Tabora Region, as well as a 1:5000,000 scale map of the Lake Victoria gold fields. Where sheets have been surveyed but not yet published, hand-coloured die-line copies can be purchased, with accompanying field notes. Aeromagnetic survey maps at 1:100,000 scale are available for most of Tanzania.

Other maps of the Tabora Region, including maps of land use, administrative boundaries and vegetation type, are available from the Ministry of Land Use, Tabora regional office.

Aerial photographs at 1:50,000 and 1:25,000 scale are available for purchase from the Department of Surveys and Mapping, Dar es Salaam, and to view at the Geological Survey, Dodoma and the Ministry of Land Use regional office in Tabora.

Demographic, economic, social and environmental data on the Tabora Region are available from the Planning Commission in Dar es Salaam (The Planning Commission, 1996).

Copies of borehole completion forms for the whole of Tanzania are meant to be collected by the Ministry of Water and by the DDCA. No routine or long-term water level monitoring of boreholes is done. The Hydrogeological Section of the Ministry of Water, in Dodoma, holds rock chip samples from boreholes drilled in the Dodoma Region.

Initial hydrochemical analysis of borehole water samples, where these are taken, is done by Ministry of Water regional laboratories, and full analysis by the Water Laboratory Unit of the Ministry of Water's Dar es Salaam office, who also store hydrochemical data. There is no routine or long term monitoring of groundwater chemistry. WaterAid has a Hatch kit which can be used to provide a preliminary water quality analysis, but this is shared between the Tabora and Kiteto offices and so is not always available.

The Ministry of Water is responsible for long term water sector planning and for water quality. The Ministry holds resistivity and magnetometer equipment, and has staff who can carry out geophysical surveys using this equipment.

The DDCA, formally part of the Ministry of Water, is now a semi-autonomous organisation involved in borehole drilling and construction across Tanzania. The DDCA main office is in Dar es Salaam. Drilling equipment and support vehicles are dated and in need of upgrading. DDCA drilling teams do not always have sufficient funds made available to them from the central offices to purchase fuel and equipment, which can lead to delays in drilling.

WaterAid are currently the lead NGO for groundwater resource development at community level in the Tabora Region. Their work is 50 % funded by the DFID. There are also Tanzanian WaterAid programmes in Dodoma, Dar es Salaam and Kiteto. The retired Regional Hydrogeologist for Tabora now acts as a part time consultant hydrogeologist to the Tabora WaterAid programme. WaterAid's main partner NGOs in the Tabora Region are TAHEA, a high profile organisation which works mainly with women's groups, and the Anglican Church.

6. WORK DONE DURING BGS VISIT, AND PRELIMINARY RESULTS

The BGS team spent three weeks carrying out work in Kabale village in Nzega District, where a DDCA drilling crew were installing seven boreholes as part of WaterAid's ongoing programme. Investigations in Kabale included EM34 surveys, rock chip sample collection and logging during drilling, initial test pumping of new boreholes, on site measurement of basic water quality indicators and the collection of water samples for full hydrochemical analysis. The team then spent one week carrying out work in three villages close to Tabora town. In two of these, Mtakuja and Lunguya, EM34 surveys were carried out in areas where dry boreholes had been previously drilled and abandoned, in order to identify sites for re-drilling. In the third, Ibiri, EM34 surveys were carried out in previously un-surveyed areas in conjunction with resistivity surveying carried out by Ministry of Water staff. Initial test pumping of six boreholes in Ibiri and one in Lunguya was carried out. Basic water quality indicators were measured on site and water samples taken for full hydrochemical analysis from boreholes in all three villages. After field work was completed, three seminars were held, in Tabora, Dodoma and Dar es Salaam, to describe the techniques and methodologies used to relevant personnel in NGOs, private consultancies and regional and central government institutions and to disseminate preliminary results from the investigations in Nzega and Tabora Districts.

Engineers from WaterAid's Tabora and Dodoma programmes and from the Anglican Church, a geophysicist and his team from the Ministry of Water, and a senior geologist from DDCA assisted with field work and had practical instruction in all techniques which were used. The consultant hydrogeologist employed by WaterAid was present during the drilling exercise in Kabale and also observed some of the demonstrated techniques. Members of the village water committees and other community members assisted in geophysical surveying and borehole bail testing.

Detailed desk studies of maps, reports and digital remotely sensed data were carried out prior to field work. These material described aspects of:

(i) The geology and hydrogeology of Tanzania and the Tabora Region in particular.

(ii) The geology and hydrogeology of low permeability rocks, and the nature of tropical soils.

(iii) The use of geophysical survey methods for locating structures likely to contain groundwater.

(iv) Background material on rainfall, rivers and other geographic aspects of the Tabora Region.

The collated information provided a first indication of the geological and hydrogeological nature of the areas investigated in detail. Interpreted data from available maps and images were used to produce a preliminary digital base map of parts of the Tabora Region.

Prior to carrying out EM34 surveys in Ibiri, in areas where no previous geophysical work or drilling had been done, stereoscopic pairs of aerial photographs were obtained and examined to identify potentially water-bearing structures.

Short, basic geological surveys were carried out at village sites prior to geophysical and drilling work. A typical survey included:

(i) Discussions with local community members about location of rock exposures.

(ii) Inspection of rock samples from traditional hand dug wells.

(iii) Inspection of near-by river and stream exposures.

Geophysical techniques can be used to investigate the physical properties of rocks in an area without extensive drilling. If appropriate techniques are used, and interpreted carefully, changes in geology or weathering thicknesses can be mapped and faults identified. The BGS team took a portable EM34 system to use during the work in Tabora Region. The EM34 provides a rapid, non-invasive system, requiring only two operators, which can be used to survey relatively large areas of ground in short periods of time. Because there is no direct contact with the ground, it is ideal for use in semi-arid areas where contact resistance problems can be experienced during resistivity surveying.

Prior to the BGS investigation at Kabale, VES surveys were carried out at 6 of the 7 proposed borehole sites. The BGS team, assisted by WaterAid, Anglican Church and Ministry of Water staff, carried out 19 km of EM34 surveys in Kabale, and a further 6 km in Mtakuja, Ibiri and Lunguya villages. EM34 surveys were generally undertaken using a 20 m inter-coil separation, with readings made in both vertical and horizontal orientations. The vertical coil (HD) readings give information about the shallow zone, while the horizontal coils (VD) penetrate deeper. Over areas of interest, such as the immediate area around borehole sites in Kabale, or over anomalies shown by 20 m inter-coil separation measurements, further surveys at 10 m and 40 m inter-coil separations were undertaken. Measurements were usually taken at station intervals of 20 m, except for surveys at 10 m inter-coil separation for which the station interval was reduced to 10 m. The results of these surveys will be correlated with the results of resistivity surveys over the same areas and with borehole geological logs, in order to establish methods of interpreting geophysics in the two study areas.

Seven boreholes were drilled in Kabale village at the sites located by WaterAid. Six of these sites had been previously surveyed by VES, the results from which were used to decide on the depth to be drilled. The exact location for the seventh site was decided following EM34 surveying. Detailed geological and hydrogeological data were collected during the drilling of each borehole to assess the hydrogeological potential of the main geological formations penetrated. Summary details of the boreholes drilled in Kabale are given in Table 6.1.

Table 6.1 Summary information for boreholes drilled at Kabale village.

Borehole ID	Location	Southing	Easting	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		

Drilling was carried out by DDCA using a Schramm T64 truck-mounted rig using compressed air flush. The boreholes were drilled by rotary airflush using a drag bit through the upper soft horizons, and then reamed using the drag bit reamer and temporary steel pipe installed. Drilling was continued with a rock roller bit or down-the-hole hammer, depending on formation hardness, but generally finished using down-the-hole hammer at depth. Parameters recorded during drilling included:

(i) Penetration logs – the time taken to drill 1.0 m intervals was recorded and plotted, allowing relatively hard and soft horizons to be identified.

(ii) Rock chip samples – rock chips produced during drilling were collected at 0.5 m intervals and geologically logged. 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). Representative chip samples, placed in sequence within a sectioned pipe to show changes in colour with depth, were photographed.

An attempt was made to make quantitative measurements of borehole discharge during drilling of certain of the boreholes. This was done by creating a small dam around the casing head which collects water discharged during air flush drilling, and measuring the time taken for the outflow from this dam to fill a bucket of known volume.

After drilling, the boreholes at Kabale were test pumped to give an indication of the hydraulic properties of the aquifer surrounding the borehole. Six boreholes in Ibiri and one in Lunguya, near Tabora town, were also test pumped. Because the boreholes were low yielding, they were tested using simple systems devised for application to low permeability rocks. Two test pumping techniques were demonstrated during the BGS investigations in Tabora Region:

(i) Bail tests – a simple, easy to use test system using a locally made bailer can give a first approximation of aquifer properties immediately surrounding the borehole. This method is based on the slug test developed by Cooper et al (1967). A certain volume of water is abstracted from a borehole over a measured length of time. The water level is then monitored until it recovers to 75 % of its original level. Because water level recovery is logarithmic, water level measurements are taken at short time intervals (e.g. every 0.5 minutes) at the start of recovery, but decrease with time (e.g. to every 10 minutes after 120 minutes of recovery). The resulting recovery curve can be interpreted quantitatively, or analysed using simple, quick techniques and basic criteria to indicate whether or not the borehole can provide a sufficient yield to support a hand pump.

(ii) Whale pumps – a simple test pumping system for low yielding boreholes, designed around the Whale pump for an earlier BGS project in Nigeria (Davies and MacDonald,1999), was also applied in the Tabora Region. However, although the Whale pump system is flexible and ideal for test pumping low yielding boreholes in many areas, the maximum hydraulic lift of the pump is only 18 m. In the Kabale area, water levels in the majority of observed boreholes are 15 m or more below ground level, and so the Whale pump system is not applicable. In addition, the Whale pump, as with any other pump, will not work effectively if gas is present in groundwater, as the gas will accumulate within the pump and cause cavitation and pump failure. This phenomenon was observed in boreholes in both Kabale and Ibiri.

The bail tests carried out at Kabale and Ibiri are summarised in Table 6.2, and the three Whale pump test attempts are summarised in Table 6.3.

Table 6.2 Summary of bail test data from Kabale, Ibiri and Lunguya villages.

Borehole	Village	RWL (mbgl)	time bailed (min)	Effective pump rate (l/s)	Smax (m)	Sc	tWL50	tWL75	Comments
Itonjamandi	Kabale	10.22		0.17	0.78	0.22	3.5	9	Postdevelopment
Kabale	Kabale	25.98	57.00	0.06	1.16	0.05	12	31	Postdevelopment
Kabale	Kabale	26.39	27.00	0.12	2.3	0.05	20	40	Predevelopment
Kasela1	Kabale	29.38	53.00	0.06	4.11	0.01	>109	> 109	Predevelopment
Kasela1	Kabale	25.88	45.67	0.07	4.54	0.02	100	165	Postdevelopment
Kasela2	Kabale	12.645	17.67	0.19	0.775	0.25	2	7	Postdevelopment
Kasela2	Kabale	12.64	27.00	0.12	0.48	0.25	3.5	13	Predevelopment
Lubaga	Kabale	13.87	34.00	0.10	0.75	0.13	13	59	Middevelopment
Lubaga	Kabale	13.977	20.33	0.16	0.799	0.20	8	30	Postdevelopment
Mwagundu	Kabale	15.245	25.58	0.13	0.83	0.16	2	5	Postdevelopment
Kategili A2	Ibiri	3.46	11.33	0.25	7.24	0.03	210	>400	excessive drawdowns obtained: shallow borehole which was bailed dry in c. 10 minutes during test
Kategili B1	Ibiri	4.665	12.67	0.26	2.855	0.09	5.5	13	
BGS Mpungu B	Ibiri	4.38	12.67	0.26	4.35	0.06	> 40	> 75	
Makunguwe B	Ibiri	2.535	12.25	0.27	3.09	0.09	5	8	
BGS Mpungu A1	Ibiri	3.746	14.38	0.23	8.129	0.03	65	>130	
BGS Mpungu A2	Ibiri	2.4	13.25	0.25	5.49	0.05	18	29	
Marudio A	Lunguya	12.165	20.25	0.16	3.275	0.05	29	80	

Table 6.3 Summary of Whale pump test data from Kabale and Ibiri villages.

Borehole	Village	Type of test	RWL (mbct)	Pump rate (l/s)	Smax (m)	Sc	Approximate T (m/d)	Comments
Mwagundu	Kabale	Whale pump	15.555	0.05	0.35	0.14	3.1	Postdevelopment. Aborted after 55 minutes when pump failed due to gas in water.
Itonjamandi	Kabale	Whale pump					-	Postdevelopment. Failed due to gas in water
Makunguwe B	Ibiri	Whale pump	2.885	0.14	3.385	0.04	0.3	Aborted after 55 minutes when water levels fell below pump level

A total of 28 samples (acidified and unacidified) for hydrochemical analysis was collected from boreholes and hand-dug wells. The samples were brought back to the UK for analysis in the BGS laboratories for major and minor ions, including fluoride and arsenic. On site measurements of temperature, pH and electrical conductivity were taken for each of the water samples collected and for a number of hand-dug wells where samples for full analysis were not taken, to give an indication of water quality. Fluoride is known to be present at high concentrations in some groundwaters in the northern part of the Tabora Region, and dental fluorosis was evident in many of the villagers in Kabale.

The data collected were digitised and managed using spreadsheets and ArcView, a desktop geographical information system (GIS). All tabular data for spatially referenced data points (e.g. pH and SEC (specific electrical conductance) measurements for individual boreholes) are stored within ArcView. All of the data collected are spatial in nature, and a GIS is therefore ideal for data display and analysis. The digital satellite images, projected in ArcView, were used throughout the fieldwork as a background map on which data points located using a GPS were plotted. Data points included all borehole sites visited and sites where water samples for hydrochemical analysis were collected, a number of traditional hand-dug wells and pits, and the lines of EM34 surveys. Two particular advantages of a GIS are the ability to easily and effectively produce maps which can be tailored to project needs, and to easily analyse collected data for spatial patterns.

The techniques and methodologies demonstrated during field work were also described during three seminars held in the final week of the BGS visit, and preliminary results from the hydrogeological investigations in Nzega and Tabora Districts were given. The seminars were held in Tabora, Dodoma and Dar es Salaam with a total of 34 representatives from WaterAid, TAHEA and the Anglican Church and other NGOs, regional and central departments of the Ministry of Water, DDCA, the Tabora Water Authority, universities, and private drilling companies. The seminars took the form of a two to three hour presentation by BGS staff followed by questions and discussion among all participants. Detailed minutes of the discussions were kept. The agenda for the seminars and a list of the participants at each seminar is given in Appendix D.

7. SUMMARY AND CONCLUSIONS

During the BGS visit to Tabora simple techniques to improve data collection were demonstrated in the field and at the series of seminars when their usefulness in the immediate and longer term was discussed. Techniques that need no new equipment include increasing the frequency of rock chip sample collection during drilling, and making semi-quantitative measurements of borehole discharge during drilling and borehole development. Techniques which require new equipment which is relatively easy and cheap to obtain include borehole bail testing and Whale pump testing. The first requires only a locally produced metal bailer and a length of rope, while the second utilises a Whale pump that costs under UK£100, can be ordered direct from the manufacturers in the UK, and needs locally-available rope and hose-pipe. Equipment needed to field test basic water quality indicators is slightly more expensive, but not prohibitively so. All of these techniques can add significant extra value to data collected during ongoing groundwater development programmes for relatively little extra cost or effort. The only technique used by BGS in Tabora that requires significant investment of funds is the EM34 geophysical survey system. This system is needed for the accurate location of water-bearing lineaments in the field.

Basic descriptions of the techniques and methodologies used in the field, and preliminary details of the results of the BGS investigations, were presented at the three seminars held in the final week of the visit. These seminars were well attended by representatives of all of the major parties involved in provision of water supply in Tanzania. The presentation by BGS was followed in each case by in depth discussions of the problems faced in developing groundwater resources in Tanzania. The participants were enthusiastic about the scope and implications of the current BGS project and

expressed keen interest in seeing a further project to extend the current work across wider areas. Such a project would address issues raised during seminar discussions, which included the following:

The process of decentralisation of water supply provision from central to district government and from government to NGOs has had two major consequences for the Tabora Region:

(i) There is a progressive loss of expertise at government levels because government departments no longer have the resources to co-ordinate and carry out groundwater development work: not only water supply provision but also groundwater level and groundwater quality monitoring. They cannot therefore maintain essential staff skills or effectively train young staff. Even where government departments still provide expert services to NGO projects, such as in Tabora where Ministry of Water staff are contracted to carry out geophysical surveys, the lack of resources mean that the most efficient equipment may not be available. The lack of resources at government level also means that there is currently no comprehensive system of national or regional databases to hold information collected during drilling programmes.

(ii) NGOs, who currently undertake most rural water supply provision in the Tabora Region, often do not have the required expertise to effectively and successfully develop groundwater resources. The WaterAid programme in Tabora has contracted out much of the geophysical surveying and analysis, drilling supervision and borehole construction work to government or private institutions. NGOs also do not have the resources, or any institutional obligation, to collect the data required for effective groundwater development planning, either during water supply development and installation or by long term monitoring.

The cost implications of failing to maximise information gathering from existing drilling programmes are significant. To gain the same information that could have been routinely collected during ongoing drilling requires significant investment in exploratory drilling and testing. Simple techniques and methods such as the ones demonstrated during the BGS visit could be used to collect high quality information from ongoing drilling programmes.

The collection, verification, documentation and analysis of quality hydrogeological data derived from drilling programmes would allow those organisations involved in water supply in the Tabora Region to more effectively assess the occurrence of groundwater resources and to develop strategic water resource plans for the region. This could be done through upgrading of the existing Tabora Region Water Master Plan and would allow for the production of water development maps which would aid both immediate and long-term planning needs. Strategic planning will require communication between all stakeholders in water supply, including the village communities, NGOs, government departments, the DDCA, private consultancies and donors.

There is an urgent need for groundwater level monitoring to identify areas at risk of declining yields during normal dry seasons and/or during extended dry periods such as Tabora is currently experiencing. Under present circumstances the most realistic method for realising groundwater monitoring may be to involve the local communities in monitoring the characteristics of their own water sources. This requires first that the communities see a benefit to monitoring, and second, that simple methodologies are developed which can be used effectively at community level and the results passed to NGOs and/or district government. In certain villages where falling borehole yields during the dry season are a problem, the communities already implement basic resource management, restricting use of hand-pumps to particular periods of the day to allow for recovery of water levels. These communities are likely to recognise the need for some form of groundwater monitoring. There is also a need for a regional water quality testing programme to identify areas at risk from natural contaminants such as fluoride (which is known to be present in high concentrations in much of the northern Tabora Region) or from anthropogenic contamination from sources such as mining.

The provision of water supply in the Tabora Region is being affected by the poor rainy seasons since 1998. Although the absence of groundwater level monitoring precludes any reliable conclusions, observational and anecdotal evidence suggests that groundwater levels are falling to lower levels during the 2000 dry season than has occurred in recent years, probably as a result of limited recharge during the last two years. Tabora lies in a marginal environment, where even relatively small and short-term climatic fluctuations, such as at the present time, can have a severe effect on water resources. There is a tendency in the Tabora Region to look on groundwater as an unchanging resource: once a 'successful' borehole has been installed, it is expected to continue providing the same resource unchanged over time. It should be recognised that variations in groundwater yield, and in quality, will occur both seasonally and over longer time periods. If this is not accepted, all those concerned in water supply, from communities to NGOs to government to donors, will become frustrated by the failure of the promised reliable water supplies to live up to expectations. The only way to effectively manage and develop groundwater resources in this situation is to increase the understanding of the spatial and temporal occurrence and variations in groundwater.

8. FURTHER ACTIONS AND RECOMMENDATIONS

Actions to be taken immediately as part of the current project are:

(i) The preparation of a comprehensive report describing the BGS field investigations and associated work in the Tabora Region, including an assessment of the groundwater potential in the main geological lithologies encountered.

(ii) The preparation of field slips incorporating large scale maps and interpreted EM34 curves to assist in the siting of boreholes in Mtakuja, Lunguya and Ibiri in Tabora District.

(iii) The preparation of simple groundwater development maps for the Kabale area of Nzega District and for the Mtakuja, Lunguya and Ibiri area of Tabora District, based on the investigations carried out during the BGS visits.

Future actions which are recommended further to the current project:

(i) An assessment of the groundwater resources of the area immediately surrounding Tabora town, to be carried out before any emergency drilling programme is instigated.

(ii) A reworking of the data held in the Tabora Region Water Master Plan into a GIS, and the incorporation of available borehole data collected since the Master Plan was published.

(iii) Additional support should be given to NGOs to allow them to upgrade traditional water sources, such as hand-dug wells and spring systems, where this is appropriate, before embarking on more expensive borehole drilling programmes.

(iv) Long term support should be given to the Ministry of Water and DDCA to ensure that their field teams can conduct appropriate surveys designed to collect the detailed data required for long term planning purposes. Support is also needed to develop databases at regional and national level.

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APPENDIX A INTRODUCTION TO THE PROJECT

Groundwater from Low Permeability Rocks in Africa

When new wells and boreholes are installed by local organisations, the siting is often guided only by social criteria or simple hydrogeological methods. In areas of complex geology, an unfortunate result is that they are often low yielding or dry. On the other hand, the use of more sophisticated methods of borehole siting bypasses local government and NGOs and alienates local communities. Thus the aim of this project is to adapt well-tried hydrogeological techniques so that they can be utilised by local organisations.

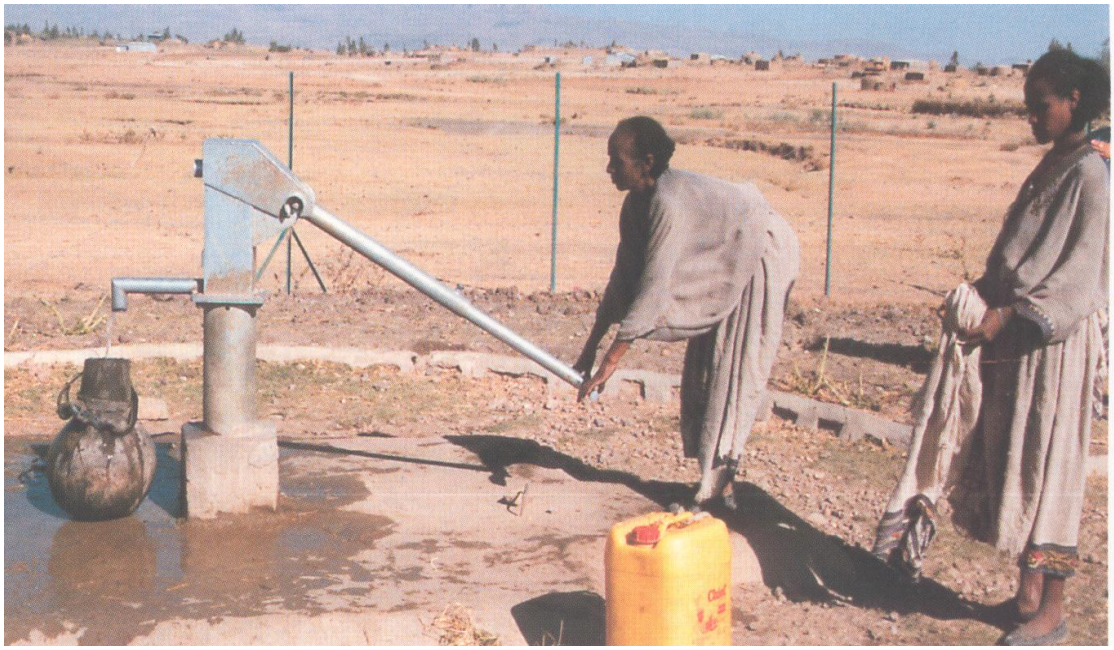
The Project

The project is providing improved understanding of groundwater occurrence, resource limitations and methods of development within geologically difficult areas. The data, maps and knowledge acquired and developed will enable locally based agencies and local government to better target future groundwater developments. The outcomes will be:

- More effective use of often-scarce financial resources
- More sustainable water supplies
- An increase in sustainable well being of poor communities in sub-Saharan Africa

Activities

Reconnaissance visits have been made to four WaterAid projects in Ghana, Zambia, Tanzania and Ethiopia. The objectives of the project and methods to be applied were explained to many stakeholder groups, using the results of the recently completed Oju/Obi Water Supply Project, undertaken with WaterAid in SE Nigeria.



Use of Afridev pump at Hidmo village's borehole, South

- **Ghana** – Water supplies are being provided by the Afram Plains Development Organisation (funded by WaterAid) to recently settled villages within the southern Afram Plains area of East Ghana, an area underlain by very old and low yielding, massive Cambrian age Voltaian sandstones and conglomerates. The drill site selection and the drilling of a series of water supply boreholes were monitored and typical rock exposures examined. The logging of geological samples and test pumping of boreholes have been demonstrated to local staff, as well as the use of a GPS in accurately locating borehole sites (wet and dry). DANIDA have expressed interest in funding future drilling of exploration boreholes using this technique.

- **Zambia** – In the Zambezi Rift valley of southern Zambia, WaterAid are working with the Siavonga D-WASHE committee. The area is underlain by a series of tight fine-grained sandstones and mudstones that often contain brackish water and interbedded conglomerates. Problems have been experienced with the supply of adequate water to groups of Valley Tonga people displaced by the building of Lake Kariba.

- **Tanzania** – Within the Tabora district of north central Tanzania, WaterAid are working with a women's NGO, the Tanzanian Home Economics Association, and two local church-based NGOs to provide water to surrounding villages. Precambrian basement granites and schists underlie the area within which limited water supplies can be obtained from faults and thin near-surface weathered zones. Problems associated with the drilling of dry holes, poor water quality, and seasonally variable yields were encountered.

- **Ethiopia** – Upgrade work for spring sources, hand dug wells and boreholes to the scattered village communities is planned for the Hintalo Wajerat Woreda area of southern Tigray by the Ethiopian Orthodox Church (funded by WaterAid). This rugged area is underlain by Jurassic age limestones, shales and sandstones that have been extensively intruded by basalts and dolerite dykes. Springs issue from the basalt/sandstone contact zones from where they are occasionally channelled into narrow irrigated terrace systems.

Conducting a bail test with the assistance of community members upon a test borehole at Kasela, Nzega District, Tabora, Tanzania

The Future

Although all four areas merit further study, detailed studies will initially be undertaken within the Tabora area of Tanzania and the Afram Plains area of Eastern Ghana. Assessments of the likely water resources of these two areas will be made based upon the integration of remotely sensed data (from Landsat ETM, aerial photographs, topographic maps and geological maps) with data from:

- Geophysical surveys (EM-34 and electrical resistivity),
- Borehole drilling (chip and core sample analysis),
- Borehole test pumping (bailer and Whale Pump tests) and
- Hydrochemical surveys.

Local NGO staff, government hydrogeologists, local government staff and students will be encouraged to participate in all aspects of these studies.

In each case the BGS project work will dovetail into an existing WaterAid drilling programme. The study of available reports and maps of these areas is underway as is the interpretation of Landsat TM imagery. The project aims to provide an initial assessment of the groundwater resource development potential of a limited area at minimal cost. Once established such a system will have application to other projects being undertaken in difficult geological conditions elsewhere in sub-Saharan Africa.

APPENDIX B ITINERARY

29th July Flew from London (Gatwick) at 2215 on flight BA2069 to Dar es Salaam via Nairobi.

30th July Arrived in Dar es Salaam at 1155. Took taxi to Karibu Hotel. Met with Kashi at 1800.

31th July To the WaterAid office. To DFID where discussed project and proposed work programme with George MacDonald. Suggested that we hold a half day seminar in Dar es Salaam before our departure to explain results of the project to local hydrogeologists. Registered at the BHC visa section. Drove to DDCA where had meeting with Drs Mohammed and Mpanda and David Songea (drilling). Agreed that drilling programme in Nzega would proceed to fit in with our programme of work. Also that some DDCA staff would participate in our fieldwork and that DDCA would host a half-day seminar at their offices on our return to Dar es Salaam. Obtained concentrated HNO_3 at chemistry laboratory. To BA office at the Sheraton where changed homeward flight and booked flight to Entebbe. Worked on follow-up KaR project proposal. Met with Mr G K Koda with who discussed community coping strategies.

1st August Obtained maps of the Nzega area at the Survey Department. To the WaterAid office then to Falcon shipping at the airport re clearance of equipment, delayed due to failure of Custom's computer. To central Dar es Salaam to purchase equipment. To the Department of Chemical Engineering at the University where obtained de-ionised water. To the airport but equipment not yet released. To workshops to monitor manufacture of bailer tubes. Met with Kashi to discuss the days events and timing of departure for Dodoma.

2nd August To the airport where received two crates of equipment and documentation from Falcon. To the WaterAid office to collect bailer tubes then to the DDCA to collect concentrated HNO_3 acid. Drove to Dodoma where arrived at 1945.

3rd August To the WaterAid office and then to the Geological Survey where met the Director. Obtained aeromagnetic and geological survey maps of the Nzega area as well as relevant memoirs and reports. To the Ministry of Water where discussed the project with Mrs Mcharo who agreed to attach staff to the project. Returned to WaterAid and thence to the Geological Survey to view aerial photographs of the Nzega area.

4th August Drove from Dodoma to Tabora inspecting typical dambo/ mbuga valley side water seepages on the way.

5th August At the WaterAid office checked air-freight from the UK. Agreed vehicle hire terms with owner of Tsh650 per km. Discussed work programme with Kashi, Muganyizi and Godfrey. To be based at Nzega, geophysical surveys before drilling due to start by 10th August.

6th August Worked on KAR concept note and project report. Discussed groundwater problems of the Tabora region with Americans from Life Water International including Mr Ron Peterson worked with World Vision on evaluation of satellite lineations in the Afram Plains are of Ghana.

7th August Studied parts of the Tabora Regional Water Master Plan. Met Mr Sangija, consultant hydrogeologist to WaterAid. Set up GIS on computer.

8th August Drove from Tabora to Nzega. Drove to Kabale village where met the village water committee chairman who guided us to each of the sub-village sites. At Lubaga met the hydrogeologist and geologist drilling water boreholes for the Resolute gold mine with whom discussed the occurrence of groundwater in the lacustrine sediments of the Manonga valley. Drove to the sub-

villages ending at the southern most, Kasela 1 sub-village, locating each using a GPS. Drilling planned to begin on 10th at Kasela 1 sub-village. Entered sub-village location data onto computer.

9th August Drove to Kasela 1 sub-village site where undertook two 1km EM34 surveys. Entered EM34 data onto computer.

10th August Drove to Mwagundu sub-village where did four 0.5km EM34 surveys. At Itonjamandi sub-village undertook two 0.5km EM34 surveys. Entered EM34 data onto computer.

11th August Drove to Itonjamandi sub-village where did two 0.5km EM34 surveys. To Kabale sub-village where did four 0.5km EM34 surveys. To Kasela 1 sub-village where monitored the start of borehole drilling. Entered EM34 data onto computer.

12th August Monitored drilling at Kasela 1 sub-village. To Lubaga sub-village where did four 0.5km EM34 surveys. To Busigili sub-village where did two 0.5km EM34 surveys. Logged samples from borehole. Decided to let the borehole stand overnight and assess water accumulation the following day. Entered EM34 data onto computer.

13th August Undertook a bail test upon Kasela 1 sub-village borehole. Took 1 hour to bail 40 bails with drawdown of 4m. Rate of recovery was 1m per hour. Erected screen and casing in the borehole. To Busigili sub-village where did two 0.5km EM34 surveys. To Kasela 2 sub-village where did four 0.5km EM34 surveys. Gravel packed the Kasela 1 sub-village borehole and airlifted it. Entered borehole log and EM34 data onto computer.

14th August To the district government office where met Mr D E D Gasembe the executive director of the council. To Kasela 1 sub-village site where airlifted the borehole. To Itonjamandi, Kabale and Kasela 1 sub-villages where did additional EM34 surveys. To Mwagundu sub-village to monitor borehole drilling and log samples. Entered EM34 survey data onto computer. Discussed results obtained to date with Dr Mpanda.

15th August Additional EM34 surveys conducted at borehole drilling sites. To the Mwagundu sub-village borehole site to log borehole samples during borehole construction and air-lifted. Discussed results with WaterAid staff and Dr Mpanda. Entered EM34 survey data onto computer.

16th August Entered Mwagundu sub-village borehole log onto computer. At Mwagundu sub-village monitored the development of the borehole. To Kasela 2 sub-village where did four 0.5 km EM34 surveys with 40m coil spacings. Experienced problems with the transmitter box. Made up Whale pump test pumping unit. At Itonjamandi sub-village monitored drilling and logged samples. Entered EM34 data onto computer.

17th August Entered Itonjamandi sub-village borehole log onto computer. Test pumped the Mwagundu sub-village borehole. At Itonjamandi sub-village borehole logged borehole samples and produced borehole design. Test pumping test stopped after one hour due to pumping problems, recovery monitored to 75% by 30 minutes. Screen, casing and gravel pack erected in Itonjamandi sub-village borehole. Borehole developed for 2 hours. Entered EM34 survey and test pumping data onto computer.

18th August Entered lithology of Itonjamandi sub-village borehole onto computer. At Mwagundu sub-village conducted bail test on borehole. Itonjamandi sub-village borehole developed by airlift. Monitored start of drilling at Kabale sub-village. Drove from Nzega to Shinyanga where front spring of vehicle was repaired. Drove onto Mwanza where the starter motor of the vehicle was repaired.

19th August Further repairs conducted to front spring and starter motor of vehicle in Mwanza. Drove to the Serengeti.

20th August From Serengeti drove to Nzega via Malampaka where observed a collector well system in a sand river.

21st August Discussed results of surveys and proposed workshop at DDCA in Dar es Salaam with Dr Mpanda and Godfrey. Monitored drilling of the Lubaga sub-village borehole. Test pumping of the Itonjamandi sub-village borehole with a Whale pump failed. Logged samples from the Kabale sub-village borehole. Monitored construction of the Lubaga sub-village borehole.

22nd August Entered Kabale sub-village borehole log onto computer. Undertook a preliminary bail test upon the Lubaga sub-village borehole. Bail tested the Itonjamandi sub-village borehole. Discussed the geology and hydrogeology of the Manonga valley with Bruce Boyes, consultant hydrogeologist to the Resolute Gold mine. To Kasela 2 sub-village site where logged samples from the Lubaga sub-village borehole. Monitored drilling at Kasela 2 sub-village. Bail test undertaken on Kabale sub-village borehole. Gold Mine hydrogeologist and geologist visited the site to discuss results. Entered bail test data onto computer.

23rd August Entered Lubaga sub-village borehole log onto computer. At Kasela 2 sub-village borehole site logged samples. Undertook bail tests at Kabale sub-village and Lubaga sub-village boreholes. Designed and constructed Kasela 2 sub-village borehole. Entered bail test and penetration log data onto computer.

24th August Entered Kasela 2 sub-village borehole log onto computer. Undertook a predevelopment bail test upon the Kasela 2 sub-village borehole. At Mwagundu sub-village borehole realised that the failure of the Whale pumps was due to shall quantities of air coming out of water on depressurising caused cavitation in the pump stopping it pumping water. Obtained a water sample. At Busigili sub-village visited a water abstraction pit dug into river sands and obtained a water sample. Monitored the start of drilling the Busigili sub-village borehole. Discussed results to date with Stanley and Murganyizi. Entered bail test and hydrochemical data onto computer.

25th August To the council offices where met Mr Gasembe, Executive Director of Nzega Council, and his planning officer, Mr D Hella. Briefed them on the results of surveys and limited co-operation with mining company personnel. Also informed them of proposed research on fluoride and relevance of it to groundwater in the Nzega area. At Kasela 2 sub-village undertook a bail test and took water sample. To Kasela 1 where took water sample. Monitored drilling at Busigili sub-village. Water samples obtained from hand dug wells at Kabale sub-village. And from the rest of the boreholes drilled and further hand dug wells. Hammer and drill string stuck in Busigili sub-village borehole at 33m. Discussed the hydrogeology of the area with Bruce Boyes and Mr Sangija. Logged samples from the borehole. Entered bail test and hydrochemical data onto computer.

26th August Analysis of data and packing equipment for move to Tabora. Discussed the results of the Nzega survey and proposed work programme in Tabora with Stanley and Muganyizi.

27th August Entered Busigili sub-village borehole log onto computer. Drove from Nzega to Tabora collecting water samples at Ilolwansimba village. Discussed Nzega survey results with Mr Kashililah.

28th August To Mtakuja village where did a 1.1 km EM34 survey across minor and major east-west lineations. Collected water samples. Entered EM34 data onto computer.

29th August To regional government offices where briefed senior planing officer re results of project to date. To the office of the regional water engineer where briefed him and discussed water supply

problems in Tabora and Nzega. Recognised need to update the Water Master Plan. To the regional office where met the Regional Administrative Secretary and briefed him on water supply problems in Nzega and Tabora. He recognised that to upgrade the regional water master plan was too ambitious at this stage and that he would like to see an extension of work in the present areas. At Kikundi sub-village in Mtakuja village undertook a 1km EM34 survey centred upon a failed borehole drilled into schist. Obtained water samples from two boreholes drilled last year.

30th August To Ibiri village where bail tested three boreholes and undertook a Whale pump test on a fourth. Of three other boreholes that have been equipped with handpumps two have dried up or have very low yields. There has been very little or no rain in this area for the past three years. Entered test pumping data onto computer. Discussed construction of an infiltration gallery on a dambo valley site for a village water supply.

31st August To the regional office where met Mr Kalenza (lands officer). Discussed the availability of maps, Landsat imagery and aerial photography of the Tabora region. Inspected his library of aerial photographs. Demonstrated use of ArcView GIS on laptop computer. Borrowed photographs for two sites at Ibiri village. To Lunguya where did a 1 km EM34 survey at the site of an unsuccessful borehole. Obtained a water sample from a second borehole, and undertook a bail test at a third. Visited the dry Tabora railway dam. Entered EM34 and bail test data onto computer. Studied aerial photographs of the Ibiri village sites, noting lineations and valley structures.

1st September To Ibiri village where attempted to test pump a borehole with a double Whale pump system. Unfortunately, the pumps failed due to cavitation caused by gas produced from the depressurised water. To the valley to southwest of Ibiri village where did a 1.3km EM34 survey past a projected drilling site on a faulted site. At a second site north of Ibiri village did a 0.9km EM34 survey. Bail tests were undertaken upon two boreholes after the failure of the Whale pumping test. Entered EM34 and test pumping data onto computer. Informed that the borehole at Busigili sub-village had been completed successfully.

2nd September Paid for the hire of the 4x4 vehicle. To Mtakuja village where did a 1.2km EM34 survey past a projected drilling site, starting at a dry borehole drilled into schist. Entered EM34 data onto computer.

3rd September Analysis of data and preparations for following days seminar.

4th September Held seminar at the WaterAid office, Tabora with 8 participants. Described the project purpose and results of work undertaken. Discussed problems faced by NGOs and government partners engaged in rural water supply schemes in the Tabora area. Demonstrated the use of ArcView GIS and Landsat images of the area. The discussion that followed included who should cover the cost of dry boreholes, current problems of water supply to Tabora, presence of fluoride in groundwater.

5th September Drove from Tabora to Dodoma. Inspected multi-media presentation system at the WaterAid office.

6th September With multi-media system drove to Ministry of Water where met Mr Lester Kongola, Mrs Mcharo and members of their staff. Presented a seminar that included a description of project and results of works to date, with many pauses to discuss points of information. Most enthusiastic about extending the project areas and relating these experiences to other parts of Tanzania in a sustainable long term fashion. Eight persons attended including the regional water engineer (Mrs Kongola). To the Mineral Resources Department to arrange a permit for the export of rock samples. Samples had to be placed in a cardboard box, tied up with string and sealed with red sealing wax bearing the official seal of the Ministry.

7th September Drove from Dodoma to Dar es Salaam. At the Maji Ubungo office discussed the content of the seminar to be held there the following day with Dr Mpanda. To the new WaterAid office where stored EM34 and equipment boxes. Met the WaterAid country representative, Mr Dave Mather, and Kashililah with whom discussed the results of our visit.

8th September Drove to the Maji Mbongo office where presented a seminar that included a description of project and results of works to date using a multi-media system to 18 participants. There followed about an hour of discussion with a wide range of people including a large group of private drillers. After the seminar discussed the way forward with Kashi and Mpanda. To the WaterAid office where repacked and labelled boxes and produced packing lists. At the hotel briefed George Macdonald on the results of our work and visits. He has requested that funds be made available for future water sector projects. He liked the idea of sustainable low-cost development of local hydrogeology capacity within The Ministry of Water and development of community self-monitoring of water supply systems etc.

9th September Worked on project report. Contacted Major David Burrows of the Salvation Army with who discussed the results of the project. Had further discussions with Mr G Koda re the study of community coping strategies as applied to community self-monitoring of water supply resources.

10th September Davies departed for Entebbe at 0800 on TC772, Ó Dochartaigh departed to London at 1900 on BA2068.

APPENDIX C CONTACTS

Tabora

Eng. Herbert Kashiliah,- Programme Manager, WaterAid
PO Box 409, Tabora, Tel. 255-62-4504, Fax. 255-62-4505, email. Wateraid_tabora@maf.org

Ms Ritta Chizenga - Resident Advisor, WaterAid

Mr Muganyizi Ndyamukama - Engineer, WaterAid

Mr Godfrey Mpangala - Engineer, WaterAid

Mr P A M Chikira -Regional Administrative Secretary Tabora Region, *P O Box 25, Tabora, tel (062)2274 and 4647, fax 4274*

Mr Y E C Masatu - Senior Planning Officer, Tabora Regional Government

Mr Kalenzi - Land Use Development Commission, Tabora Regional Government

Mr M E Kuzenza - Regional Water Engineer, Tabora

Mr Stanley Kayabu - Project Officer, Anglican Church

Mr Christopher Myamuanji - Development Officer, Anglican Church

Ms Esther Nzuli - Project Manager, *TAHEA, PO Box 778, Tabora, Tel. 062-4231*

Ms Alice Shewiyo - Project Officer, TAHEA

Mr Andy Fita Sangija - Senior State Hydrogeologist (ret.), Consultant Hydrogeologist *Groundwater Exploration & Wells Construction Co. Ltd, PO Box 1914, Tabora/PO Box 10781, Mwanza*

Mr R K Mirisho - Soil Scientist, Head of Station, Irrigation Department, *PO Box 1053, Tabora, Tel. 255-62-4166*

Mr Omar - Hydrologist/irrigation specialist, Irrigation Department

Mr Peter - Topographic surveyor, Irrigation Department

Nzega

Mr D E D Gasembe, Executive Director, Nzega District Council

Deogratias P Hella, District Planning Officer, *PO Box 4, Nzega. Tel. 269 – 2349 / 269 – 2301. Fax 269 2366.*

Bruce A Boyes, Groundwater Services PTY Ltd. *8 Tamar Close, Wilson, WA 6107, Australia. Tel. 61 – 8 – 9458 – 3387, Fax 61 – 8 – 9458 – 3391, email* bab@iinet.net.au

Dodoma

Mr P. M. Kenyunko - Assistant Commissioner for Geology (Director), Mineral Resources Department (Geological Survey of Tanzania (Madini site)) *PO Box 903, Dodoma, Tel. 255-61-24945, Fax. 255-61-24943, email. mrd@twiga.com*

Mr Nicodemus Senge - Cartographer, Geological Survey, (drilling site)

Mr Mcharo, Geophysicist, Geological Survey, *email* madini-lab@africaonline.co.tz

Mr Dave Mather, Country Representative, WaterAid, Tanzania, *PO Box 2190, Dodoma, Tel. 255-61-24448, Fax. 255-61-24448, Tel & Fax. 255-61-324246, email. Wateraid_tz@maf.org*

Lister Kongolo, Assistant Director Ministry of Water, Hydrogeology Section, *PO Box 412, Dodoma. Fax 255 – 026 – 2320060* (Also contact via Mr Ruhumbika, DSM)

Mrs Elder Mcharo - Regional Hydrogeologist, Ministry of Water, Dodoma

Mr Issack Komba - Geologist/hydrogeologist, Ministry of Water, Dodoma

Mr Kenny Mpanda - Geologist/hydrogeologist, Ministry of Water, Dodoma

Ms Catherine Kongola, Rural Water Engineer Office, Dodoma

Michael Ruganimkamu, DDCA Central Zone Manager

Dar es Salaam

Ms Dorcas Mathube - Assistant Programme Officer, WaterAid, *PO Box 33759, DSM, Tel. 255-51-700776, email. wateraid-dar@africaonline.co.tz*

Mr George I. Macdonald, Engineering Advisor, DFID Eastern Africa (Tanzania), *British High Commission, Social Security House, Samora Avenue, PO Box 9200, Dar es Salaam. Telephone 255-22-2117659-64/2112953. Fax. 255-22-2112951. Email gi-macdonald@dfid.gov.uk*

Mr Jon Salmon - Natural Resources Adviser, DfID, Dar es Salaam

Ms Carol Rossiter - Consular Officer, British High Commission, Dar es Salaam

Mr David Crawford - Health Projects Abroad, Tabora, *PO Box 886, Tabora*

Mr Frank M Msemo, Water Resources Institute, *PO Box 35059, Dar es Salaam. Tel. 255 – (0) 22 – 2410041. Email.* wri@raha.com

Professor Cauzeni - Forest Resources Management Project, Institute of Land Resource Assessment, University of Dar es Salaam

Dr G. Koda, Senior Lecturer, Mathematics & Computing Dept., Dar es Salaam University

Shadrack Mwakalila, Geography Dept, Dar es Salaam University

Dr Eng. Mohamed - Managing Director, Drilling and Dam Construction Agency, *Maji Ubungo - opposite Tanesco building, Morogoro Road, DSM, PO Box 35066, Dar es Salaam, Tel. 255-22-2451514/2451450, Fax. 255-22-2451450, e-mail. ddca@raha.com*

Dr Samson Mpanda - Geologist, DDCA

Mr David Songea, Deputy Directory, DDCA (Drilling) , *PO Box 35066, DSM, Tel. 255-51-48342, Fax. 255-51-451457, email.* dwr_maji@intafrica.com

Mr Ruhumbika – Director, Water Resources Division (Department of Water Resources?), *PO Box 35066, Dar es Salaam. Email* dwr_maji@intafrica.com

Mr Sayi, Director of Rural Water Supply, (Main Office, street by harbour)

Mrs Judith Mwebezi, Water Laboratory Unit, Ministry of Water, Maji Ubungu

Miss Nadifa Kemikunda - Chemist, Water Laboratory Unit, Ministry of Water

Mr Hassan Mjengera – Water Laboratory Unit, Ministry of Water, *Tel. 255-51-450047, Fax. 255-51-451447*

Dynamic Drillers Ltd - *Libya/Mosque Street, PO Box 72671, DSM, Tel. 255-51-138892/3, Fax. 255-51-133641, email. ddl@afsat.com*

Abdul Bigangika - Digitising Office, Surveys and Mapping Department, Dar es Salaam., *email. abigangika@hotmail.com*

Mrs F. Challe - President, TAHEA, PO Box 1125, Dar es Salaam (within Ministry of Education building), Tel. 255-51-115602. Email tahea@twiga.com

Mr I E Pereira, Managing Director, Falcon Shipping Agents, *DSM International Airport Terminal, PO Box 6839 DSM, Phone & Fax 255-(0)-51 843273*

Precision Air Service - *Box 70770, Ohio Road, Dar es Salaam, Tel. 255-51-130800*

Peacock Hotel - *PO Box 70270, DSM, Tel. 255 – 51 – 114071 / 114126 / 120334 - 40, Fax. 255 – 51 – 117962*

Hotel Karibu - *PO Box 20200, DSM, Tel. 255 – 51 – 667761 / 6680 69 / 668458, Fax. 255 – 51 – 668254*

International

LifeWater International, *15854 Business Center Drive, Irwindale, CA 91706, USA. Tel. 818 – 962 – 4187. Fax 818 – 962 – 6786.*

Ronald C Petersen, Hydrogeology and Geophysics, *email.* Rpete1220@aol.com

Pat Hettingen, *email* pat@lifewater.org

Daniel R Newmyer, Newmyer Drilling Inc. *5522 North Road, 110, Mosca, CO 81146, USA. Email* newmyer@webaccess.net

APPENDIX D AGENDA FOR SEMINARS AND LIST OF PARTICIPANTS AT EACH SEMINAR

AGENDA FOR SEMINARS

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

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

LIST OF PARTICIPANTS AT EACH SEMINAR

Tabora, 4th September 2000, 1000 - 1330
WaterAid office

Eng. Muganyizi Ndyamukama	WaterAid, Tabora
Eng. Godfrey Mpangala	WaterAid, Tabora
Eng. Herbert Kashililah	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 Co. Ltd., Box 1914, Tabora

Dodoma, 6th September 2000, 0900 – 1230
Hydrogeology Section, Ministry of Water

Eng. Muganyizi Ndyamukama	WaterAid, Tabora
Mr Michael Rugaimukamu	Central Zone Manager, DDCA, Dodoma
Mr Lister Kongola	Hydrogeology Section, Ministry of Water, Dodoma
Ms 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

Dar es Salaam, 8th September 2000, 0930 – 1200
DDCA, Maji Ubungu

Dr Samson Mpanda	Technical Support Manager, DDCA
Eng Herbert Kashililah	WaterAid Tabora
Mr F M Msemo	Water Resources Institute, DSM
Mr Hamidu Stanbuly	Bahadele Drilling, DSM
Mr Mohamed Hussein	Bahadele Drilling, DSM
Mr Abdul Karim Mohamed	Bahadele Drilling, DSM
Mr Will Mtulcananje	Concern Tanzania
Mohamed A Nzaro	Geologist, Hydrotech
Mr Stephen Kombe	Hydrogeologist, O.C.I.
Ms Grace Nsanya	Water Resources Dept, MOW
Mr Shadrack Mwakalilah	Geography Dept, UDSM
Mr David S A Msangazi	Geologist, Maji Coast (MOW Coast Region), DSM
Eng A K Kigingi	E-W Manager, DDCA
Mr Petro L L Mollel	Maji Coast (MOW Coast)
Ms N N Lupimo	Hydrogeologist, Ministry of Water (Planning)
Mr Hamisi Matungulu	Civil Engineer, DDCA
Mr Felix K K Karutasigwa	Hydrogeologist, Maji Kagera (MOW Kagera Region)

APPENDIX E MAPS AND REPORTS COLLECTED DURING VISITS

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
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
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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