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Malawi Community Schools Project
Review and recommendations on the most appropriate and cost-effective means of providing safe water points

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EXECUTIVE SUMMARY

By the start of the new school year in January 1998, 100 new primary schools each with its own water point will be completed for disadvantaged, mainly rural communities. This report reviews and makes recommendations on the most appropriate and cost-effective means of providing safe water at the Community Schools. It is based on a country visit made between 22 April and 3 May 1996, and was submitted in draft in time for the Project Review held on 22 May 1996.

Groundwater availability in large parts of Malawi is sufficient to maintain hand pump supplies of between 0.2 and 2.0 $l\ s^{-1}$. The groundwater is obtained, for the most part, from the fractured basement aquifer which lies beneath the saprolite, the latter may also be saturated. Groundwater is least available in the escarpment area, most abundant in the alluvial aquifers of, for example the Shire Valley, and available in moderate quantities in the weathered basement plateau. Groundwater quality is mostly potable, but fluoride and sulphate create problems for some small areas.

It is essential that the respective water points are surveyed, drilled and tested at each school site before any other civil engineering work is contemplated. The risk of proceeding with construction work and then not being able to supply water to a school is considerable and must be avoided.

Data available to the project include topographic, geological and hydrogeological maps, aerial photographs and Landsat imagery, as well as borehole survey and drilling reports. The surveying work is principally surface resistivity coupled with a hydrogeologists report. EM is not currently used and the new novel technique of Electro Kinetic Surveying is not recommended for use in fractured Basement.

Detailed surveying is recommended for the schools project, and it would be desirable to have a consultant hydrogeologist to 'interpret' the survey reports and rank the sites in order of groundwater availability and suitability of drilling rig type. Surveying amounts to some K10 000 per site, supervision is about K4 500 per day.

Recommended borehole design follows national convention, but an alternative modified design is also recommended for use in specified circumstances. Best available drilling techniques are purchase and deployment through Concern Universal of a new hand portable rig, the Eureka Porta-Rig, for use in shallower boreholes, and contractor operated rotary drilling rigs for deeper boreholes. Recommended contractors are identified. The borehole completion diameter is 110 mm. Recommended cleaning and test pumping procedure included the derivation of a 240 minute specific capacity value and an estimate of transmissivity. Respective costs for a fully tested 35 m deep borehole are: Eureka Porta-Rig K56 000, contractor operated rotary rig, K60 000 to K66 000.

Boreholes should be equipped with Afridev hand pumps, or if the static water level is greater than 35 m by the Climax hand pump. Surface sanitary aprons are required and careful siting of pit latrines is essential.

CONTENTS

1. BACKGROUND

A current Malawi Government initiative will provide free primary school education for all. Towards this ideal, the ODA is assisting with substantial assistance to the Malawi Ministry of Education for its Community Schools Project. It is proposed that some 30 new primary schools be constructed, each with its own water point, for the start of the new school year in January next, 1997. A further 70 primary schools will be constructed with water points for the start of the 1998 school year. These schools will be targeted at disadvantaged, mainly rural, communities.

The Ministry of Education has appointed a Project Implementation Team. The ODA input is managed locally by the British Council, and a consultant construction adviser (PPI Consultants Limited, Capital City, Lilongwe) and an appropriate counterpart (Ministry of Education) have been appointed.

The communities which will be selected for this first year of construction have not yet been identified. It is anticipated that the complete list of 30 communities will not be forthcoming from the various Development Committees until the end of May. However, it has already been decided that the first year of work will be divided three schools to each of ten Districts (see Table 1). Notwithstanding the obvious difficulties of constructing 30 school units in a period of only seven months, there is considerable risk attached to assigning sites and proceeding with construction on the assumption that water can be found later to service them. It is, therefore, essential that the water sources to all proposed school construction sites be located, drilled, proved and established before any construction work is sanctioned. To this end, the surveying and drilling for groundwater sources is of the utmost priority, and is currently pivotal to the entire Primary Community Schools Project. There is no real alternative sustainable source of potable water in most areas.

Given this realisation, the consultant construction adviser requested technical assistance in identifying the available options for proceeding rapidly with the identification and development of suitable groundwater sources. As BGS have a long standing and successful record of work in this field in Malawi, an invitation for a brief consultancy visit to Malawi was made from BDDCA to BGS; this culminated in a meeting between Cadwallader and Robins on 21 March 1996 at ODA in London. The BGS input to the project has been carried out under the existing Resource Centre Agreement between ODA and BGS.

The objectives of the mission are:

to review and make recommendations on the most appropriate and cost-effective means of providing safe water at Community Schools.

The aims of this report are:

to discuss the options for exploration and construction of safe water points at Community Schools with the key players involved in the rural safe water supply sector: Ministry of Irrigation and Water Development; commercial consultants and contractors; NGOs and other donors.

to make recommendations on the most appropriate methods and implementing organisations for the provision of safe water points, including the provision for full and active participation of target communities in decisions relating to the construction and maintenance of water points, and to provide outline programmes and costings.

Given the considerable urgency of the groundwater input to the Community Schools Project, the timing of the BGS activity was requested so that the final report could be available by mid-May. The itinerary for Robins subsequent to the meeting at London was as follows (for personal affiliations see Appendix 1):

Monday 22 April	pm: depart London, travel via Amsterdam
Tuesday 23 April	arrive Lilongwe midday pm: field meeting with Myra Harrison, Steve Packer, Charles Nuttall, Gary Whitby and others at a primary school construction site in Lilongwe Rural District evening, reception for Myra Harrison
Wednesday 24 April	am: meeting with Peter Mtembezeka and others at the Ministry of Irrigation and Water Development pm: meeting with commercial drilling company Scandrill Limited, Lilongwe
Thursday 25 April	am: travelling from Lilongwe to Sharpe Valley pm: field visit to the Concern Universal water development project in Sharpe Valley, and onwards to Blantyre
Friday 26 April	am: meeting with David Hillyard, Concern Universal and thereafter with Mr Schollmeyer at Drilltech and Engineering pm; meeting with Shabir Patel at Contact drillers
Saturday 27 April	travel from Blantyre to Lilongwe
Sunday 28 April	free
Monday 29 April	am: Ministry of Irrigation and Water Development data office, and Airphoto Interpretation Unit of the Ministry of Agriculture pm: meeting with Chief Driller, Ministry of Irrigation and Water Development
Tuesday 30 April	am: discussion with Vincent Gondwe, Education Development Management Unit, and Stanley Chamdimba, Ministry of Education pm: data assembly
Wednesday 1 May	Public holiday. Report preparation
Thursday 2 May	am: discussion with Ministry of Irrigation and Water Development debriefing with PPI Consultants Limited and British Council pm: depart for London
Friday 3 May	am: arrive London via Amsterdam

Briefing from the BDDCA Senior Education Advisor, who was then visiting Malawi, the British Council Project Field Manager and the Project Construction Advisor took place on arrival in Malawi. An initial evaluation of water provision for the community schools has been prepared by PPI Consultants Limited in the form of a briefing note, and this document provides a valuable introduction to the issues involved (Appendix 2). The Construction Adviser and the counterpart Construction Officer facilitated the itinerary.

This report was submitted in draft in time to be considered within the Project Review, held in Malawi on 22 May 1996.

2. GROUNDWATER AVAILABILITY

Rainfall distribution is strongly related to elevation. The plateau area of the Central and Southern Regions receives a mean annual rainfall of between 400 and 1 000 mm a^{-1}, this rises to 2 000 mm a^{-1} in Northern Region. The Lower Shire Valley receives considerably less with rain-shadow effects resulting in less than 400 mm a^{-1}. The variability of the annual rainfall is considerable. Potential evaporation is highest along the lake shore and the Shire Valley and decreases with increased elevation; the range is from 1 100 to 1 700 mm a^{-1}. Groundwater recharge estimates vary from 5 to 100 mm a^{-1} for the weathered Basement aquifers and from 3 to 80 mm a^{-1} for the alluvial aquifers (Smith-Carington and Chilton, 1983). Current groundwater abstraction from wells and boreholes is estimated to be less than 1 mm a^{-1} for rural areas and perhaps 2 to 3 mm a^{-1} for densely populated areas (Kafundu and Laisi, 1991).

The crystalline basement rocks (gneiss and granulite with schists, quartzites and marbles) weather to form a low yielding but very extensive aquifer, typically 15 to 30 m thick. Water may occur in the granular weathering products, the saprolite, and in fractures within the bedrock. Transmissivity rarely exceeds 30 $m^2 d^{-1}$, and permeability is low but variable: mostly in the range 0.05 to 1.50 m d^{-1}, exceptionally 5.0 m d^{-1} (Chilton and Foster, 1995). Storativity lies in the range 0.005 to 0.01; depth to water is normally less than 25 m, seasonal fluctuation is typically between 1 m and 5 m. Dambos are low lying areas of groundwater discharge. On the escarpment area, the weathered material has largely been eroded away and groundwater only occurs in fractures in the weathered rock.

The alluvial aquifers of the lake shore, the Shire Valley and the Lake Chilwa basin are Quaternary lacustrine and fluvial sediments. Clay layers may cause locally confined conditions to occur. Transmissivity values range from 100 to 300 $m^2 d^{-1}$, and storativity from 0.01 to 0.05. Depth to water in the lake shore areas may be less than 10 m, with seasonal variations of between 1 and 3 m. Depth to water increases away from the River Shire and the lake and may exceed 30 to 35 m in, for example, the Bwanje Valley, Rivi Rivi and the Upper Shire.

In summary groundwater availability is least on the escarpment, most abundant in the alluvium (although fluctuating water levels may put some shallow sources at risk from time to time), and moderate in the weathered basement aquifers.

Groundwater is generally potable throughout. However, there are some saline pockets in the alluvium where slow groundwater transport is occurring. There are some high sulphate groundwaters in the Dowa area of the weathered basement aquifer, again where groundwater transport is slow. In the Northern and Central Regions there are isolated areas of high fluoride concentrations up to three times the WHO recommended limit; these waters pose a risk of skeletal fluorosis in humans.

3. DATA AVAILABLE TO THE PROJECT

Topographic maps are available at a scale of 1: 50 000 and geological maps at various scales but covering the whole of Malawi. Aerial photography is available at 1: 40 000 scale (85 mm focal length) for Central and Southern Regions but excluding a portion of western Central Region. Northern Region is covered by air photos at a scale of 1: 25 000 (152 mm focal length). Both sets were flown in 1990 and are available for public scrutiny at the Ministry of Lands and Valuation at Blantyre.

Hydrogeological maps for the whole of Malawi were published in 1987 as a series of nine sheets at a scale of 1: 250 000. Although the mapping does not conform to any recognised international standard, the maps do provide a valuable first pass on likely groundwater conditions in any particular area of the country.

Groundwater level piezometric contours are portrayed wherever data are available; these contours, together with elevation, provide an indication that a continuous water table is likely to exist and the depth at which it is likely to occur below ground level. Boreholes, the location of which was known at the time the maps were made, are shown along with an indication of the salinity of the groundwater drawn from that borehole (as specific electrical conductance). The boreholes are not otherwise identified. The maps subdivide the country into the following groundwater units:

Quaternary alluvium
Cretaceous to Pleistocene sediments
Mesozoic Chilwa Alkaline Province
Jurassic Karoo Volcanic Rocks
Permo-Triassic Karoo
Precambrian to Lower Palaeozoic metamorphic and igneous Basement complex - subdivided between weathered and fractured rock types.

In addition, major faults and the depth to the base of the alluvium are also portrayed. A set of these maps has been deposited with the Primary Community Schools Project office for future reference.

The Ministry of Irrigation and Water Development holds a comprehensive data set of borehole survey reports and borehole drilling journals. It also holds records of, and maintains monthly summaries of, borehole maintenance status according to District. These data provide a valuable insight into where groundwater is obtainable and how sustainable the resource has proven to be.

The borehole survey and journal records are accessed according to the name of the hydrogeologist responsible. The work of Kabuka Banda, for example, is prefixed by the index code 'KB'. This does not help the process of locating relevant data, but a location map is maintained on 1: 50 000 topographic maps which provides a far better means of access. However, this indexing process is not up to date but is claimed to be only about three to four years behind actual data receipts. Furthermore, a great deal of drilling journal reports do not get submitted to the Ministry, but are retained in local project offices. The worst offenders are the NGOs, particularly whilst operating drought relief programmes in the years following the groundwater stress crisis which started in 1992. BGS is currently advising on the digitising of data and its storage on a PC based package such as Microsoft ACCESS. However, this work will not be available in time to benefit the Community Schools Project.

4. SURVEY AND BOREHOLE SITING

For the purpose of serving a primary community school a sustainable yield of not less than 0.2 $l\ s^{-1}$ potable water and exceptionally 0.1 $l\ s^{-1}$ is required. This will service the needs of the school by means of a hand pump and appropriate civil works at the well-head. Nevertheless very careful site selection is required even to attain these modest yields.

There is a Government requirement that drilling contractors should not proceed to drill at a site unless a hydrogeological survey has been previously carried out.

At present, only the Ministry of Irrigation and Water Development offer any comprehensive site survey in Malawi, although it is only a matter of time before one of the NGOs or a private commercial company see this area as a worthwhile and profitable pursuit. It is, therefore, necessary to contract the survey work to the Ministry. For each of the first thirty communities, a survey is required which includes a comprehensive array of electrical resistivity depth soundings with a maximum separation sufficient to identify features in bedrock to depths of up to 50 m, and a sufficient number of arrays to identify an optimum site for obtaining groundwater within the geographical constraints prescribed by the Project (sample reports are appended - see Appendix 3). If the results of the survey suggest that water is unlikely to be found at any location, this must be stated and resort to constant separation traversing may be requested. The hydrogeologist in charge of the survey will have consulted the available records for the area, will have considered aspects such as topography, proximity of dambos, vegetation, local knowledge and should have consulted available air photography. He may be assisted in some of this work (e.g. air photo interpretation) by an outside consultant at the discretion of the Project (see below).

The Ministry hydrogeologists claim a success rate of 66%. The Project should aim for not less than this rate. This may be achieved by resort to additional surveying and evaluation techniques. The EM tool has been used on the Basement rocks of Malawi in the past, but with varying degrees of success. EM surveying has fallen into disfavour with the hydrogeologists at the Ministry of Irrigation and Water Development, but this reflects the diminishing resources which this section endures rather than a rejection of the technique itself. It should be noted that the stress on surveying resources will continue with over 1 000 sites anticipated for the World Bank in the near future as well as normal commitments, coupled with the recent departure of experienced hydrogeologists to posts in UNICEF and Plan International, and the absence of a third person who is on a course of training in South Africa until November. Hydrogeologists are currently deployed one in Northern Region, four in Central Region and three in Southern Region.

One other geophysical technique may provide assistance in borehole site selection. This is the new Electro Kinetic Surveying (EKS) currently under trial with BGS in field conditions in Zimbabwe as part of an ODA TDR Project. As yet the physical processes which this technique is measuring are not fully understood, and to date it has achieved little success in fractured basement (Appendix 4).

EKS has been field tested in Zimbabwe, Vietnam and Egypt. In Zimbabwe the system has been applied to groundwater studies within Basement rocks for which ground conditions had already been proven. It was found to positively identify usable groundwater within deeply weathered saprolite, but it could not be used so readily to identify water bearing fracture zones in the bedrock itself. The EKS tool is, therefore, of most value in identifying borehole sites in the saprolite or in the alluvium, but is of limited value in detecting water bearing fractures in the unweathered Basement rocks. Its capabilities in Malawi are uncertain but it may be a useful tool in due course.

5. SUPERVISION AND INTERPRETATION OF SPECIALIST ADVICE

The hydrogeological survey reports which are currently being produced by the Ministry of Irrigation and Water Development are often ambiguous. Concern Universal have just completed thirty boreholes at their Sharpe Valley Project. They had a 50% success rate (>0.2 l s^{-1} test yield) using only the work of the hydrogeologist, but were able to increase the success rate to 70% with advice from local people, regard to topography and vegetation and a modest influence from dowsing. Dowsing has a varied record throughout the world, but if it helps to provide confidence in site selection, and if statistics show it to be a positive influence, then it should not be dismissed out of hand.

The survey work is often conducted in two parts. The electrical resistivity team visit the required location and report, sometimes unsupervised, to the hydrogeologist. There is a clear need for the Project to retain a quality control brief over these activities, and this may be done either by employing a well briefed and trusted technician, and/or by employing an outside consultant (see options below). Use of aerial photographs and geophysical techniques other than electrical resistivity can only be carried out by recourse to outside consultancy.

Given the reports of the hydrogeologists, there is a need to collate the information in order to rank the sites according to the likelihood of obtaining water at each community school. It should be noted that only at this stage can the optimum location for the school structure for any given community be identified, and that school site selection should ideally be deferred until the groundwater resource has been proved by drilling and testing. Community ranking will enable the most favourable sites for groundwater development to be treated as priority, so facilitating the construction stage of the Project, and leaving those sites which may require an alternative and additional geophysical technique or other more detailed evaluation until later. It is these difficult sites which may require the drilling of more than one trial borehole, although the economics of drilling more than three failed boreholes at one community are unsound.

The process of collating and of ranking can best be carried out by a consultant. The consultant should also be required at this stage to provide a brief report which should be written in non-technical language for the benefit of the project and which justifies the site selection and ranking procedure. This report should clearly spell out the likelihood of failure, should such be the case, at particular locations. It should also bring together any work carried out in addition to the basic survey work of the Ministry hydrogeologists such as additional geophysics or aerial photograph interpretation. Resort to satellite imagery is not recommended given the resolution of available images and the time constraints of the project.

Costs and timing of the survey work amount to some K10 000 per site (i.e. K300 000 in total) and the work would take eight to ten weeks to complete if done in a continuous block by one hydrogeologist. The break-down of the time required to locate sites at three communities in each of ten Districts according to the prevailing hydrogeological conditions is shown in Table 1.

Table 1 **Ministry Hydrogeologists survey time requested per District (3 community schools each)**

District	Survey days	Comments
Rumphi	7	
Karonga	10	Boreholes may be 60-70 m deep
Salima	5	Boreholes may be 60-70 m deep
Nkhotakota	3	lake-side areas difficult
Lilongwe Rural	10	
Mchinji	5	
Blantyre Rural	7	
Mwanza	7	complex geology
Chiradzulu	7	
Polomba	5	

The cost of providing technician level supervision of the survey work depends on the grade and affiliation of the individual concerned. For example, should the NGO Concern Universal become involved in realising the water points (see drilling options below) they might also provide the required supervision. There are also the Building Supervisors, who will be employed by the Project and will be involved in two to three construction sites at any given time; these people could readily be trained to supervise the surveyors but not so readily the drilling contractors. The services of an external expert consultancy are also desirable, and quotations are available on file from Water Surveys (UK) Limited, amounting to some £200 (approximately K4 500 per day) plus expenses, and mobilised from Botswana, or alternatively BGS could provide a junior hydrogeologist (SO) at a rate of £218 per day plus expenses and mobilised from UK. Alternatively the BGS junior hydrogeologist could arrange to visit Malawi to conduct work on an existing ODA TDR project at a time coincident with the transition from the survey phase to the drilling phase of the Primary Community Schools Project. In this way the preparation of a report on the surveying and the ranking of sites could be achieved without additional travel costs. Wellfield Services, Botswana, offer a similar daily rate.

The total duration of the input of the consultant hydrogeologist in Malawi would ideally be some 45 days, with attendance at critical periods - start, end, survey to drilling transition and as otherwise required. Alternatively the consultant could be present only for the transition phase and an input of 10/15 days would suffice. This would help ease the otherwise difficult transition between the survey and the drilling phases, could provide interpretation of aerial photographs, could coordinate any specialist geophysical input at selected sites, and could prepare an overall survey report in non-technical language ranking sites according to likely success. Given the longer input the consultant would also be required to provide a brief end of project report identifying the data collected during the drilling and identifying improved means of progressing to the year two work which requires a further 70 water points. A combination of consultant hydrogeologist with a local technician offers the most favourable and cost-effective means of progressing. Total cost of this provision amounts to some K200 000 plus the cost of a local technician, or some K75 000 if BGS provide a brief input by a junior hydrogeologist who is already visiting Malawi on other business. With the basic survey costs of the Ministry of Irrigation and Water Development the survey costs amount to some K500 000 plus local costs and expenses.

6. OPTIMUM BOREHOLE DESIGN AND TESTING

The standard Malawi borehole design is shown diagrammatically in Figure 1. The provision of 1 mm slotted 110 mm diameter PVC pipe (with cemented joints) is used wherever a productive zone is encountered, this may be fractures in bedrock, it may be alluvium or the weathered saprolitic material above bedrock. The PVC pipe, complete with a bottom plug, is hung in a 150 mm drilled hole, and the annulus is backfilled with 1 to 3 mm rounded gravel taken from the lake. Under no circumstances should washed quarry dust be used for this purpose as this angular material will eventually compact down to provide an impermeable seal to the productive zone.

Plain 110 mm PVC pipe is used above the slotted pipe, and the top three metres of the annulus is infilled with a 'sanitary seal' of sand and cement. Air flush rigs use air circulation to clean completed boreholes and to develop the gravel pack. A minimum of four hours air flushing, or such time thereafter when the discharge becomes clear, is recommended. As this operation is expensive on diesel, supervision is essential. A fluid flush drilled borehole, where no compressor is available, must be circulated with clean water and developed by surge pumping or bailing until such time as the discharge runs clear. In the event that gravel pack material greater than 1mm diameter appears in the discharge, indicating that the PVC pipe has been damaged or split during installation, the borehole should be abandoned and redrilled.

Under certain hydrogeological conditions the borehole may preferentially be completed to a non-standard design (Figure 1). This design is ideal for conditions in unweathered basement rocks. The plain PVC pipe is first seated into a cement seal at the top of the unweathered bedrock before drilling recommences at reduced diameter (i.e. 100 mm nominal). The cement seal has to cure before drilling recommences, and care is needed not to damage the pipe when inserting and withdrawing the drilling bit. The advantages of this method are cost and better hydraulic contact with the water bearing fractures in the bedrock. It should be noted that

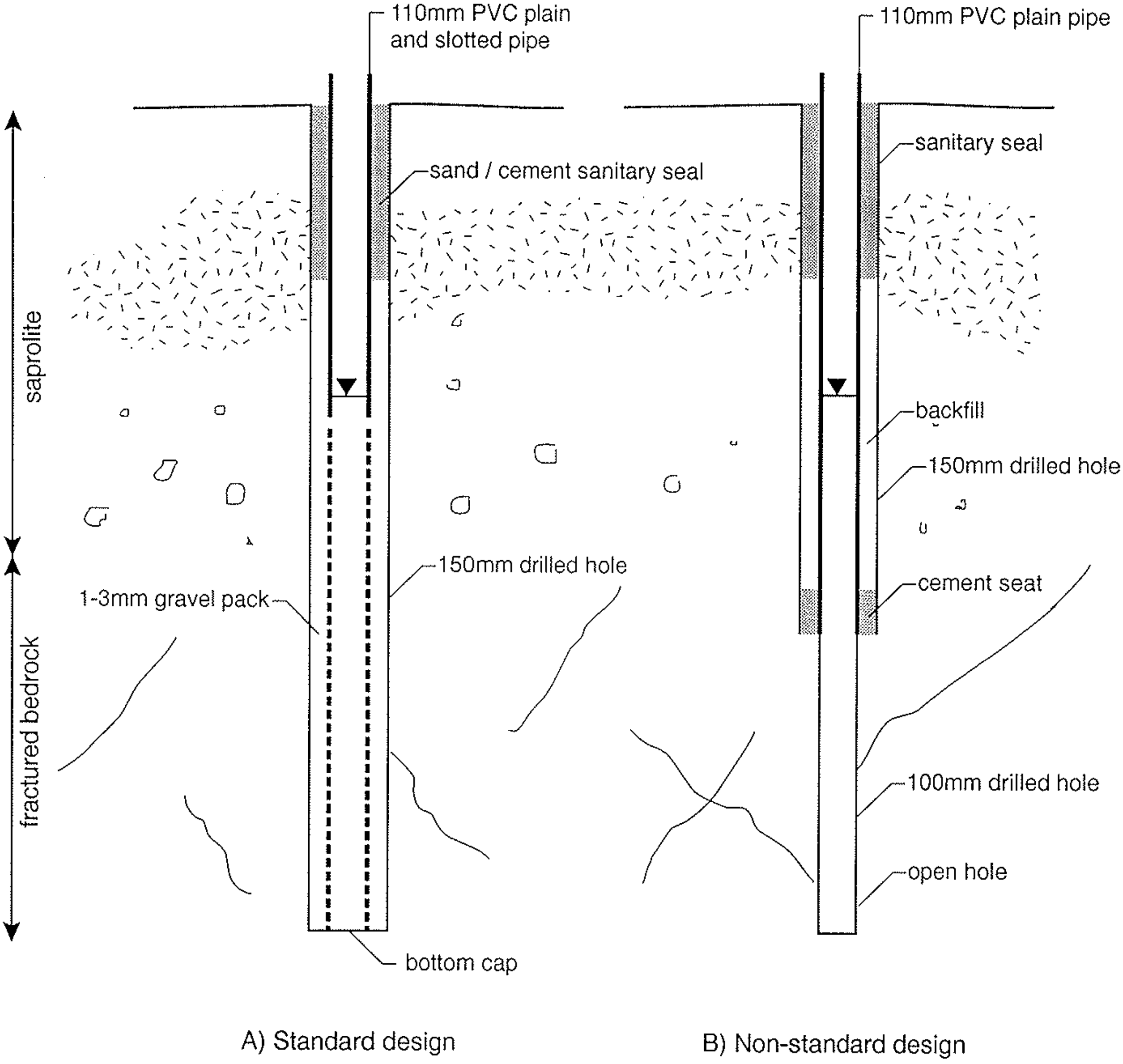

Figure 1. Borehole design

gravel pack, the upper part of which is subject to daily wetting and drying during the normal use of the borehole, is an ideal breeding ground for aerobic bacteria, and absence of gravel pack, although not always possible, is sometimes desirable.

On completion of drilling and cleaning to the satisfaction of the Project's Representative, borehole test pumping may commence. This requires that a test pump (either a small capacity electric submersible pump or a small surface driven turbine pump) is inserted in the borehole to determine the abstraction capacity of the borehole and its likely sustainable yield. This requires that the pump is maintained at a constant rate of discharge for 240 minutes after starting from a static water level (i.e. the borehole had not previously been pumped such that recovery was still taking place). The static water level to a surface datum (e.g. casing top) is recorded, and with elapsed time from the pump starting, the dynamic water level is also recorded. This is done initially at 2 minute intervals to an elapsed time of ten minutes, then at five minute intervals to 120 minutes and thereafter at ten minute intervals. At 240 minutes elapsed time, the drawdown is measured and the pump switched off, recovery dynamic levels are taken at the same time intervals, 2 minutes to ten minutes elapsed time and thereafter at 5 minute intervals and ten minute intervals. These recovery measurements need to span a time of not less than 120 minutes and not greater than 240 minutes depending on full recovery to the original static water level. If full recovery is not attained at 240 minutes then the sustainability of the chosen pumping test yield may be in doubt and even full recovery cannot be taken as a guarantee of sustainability.

The test pumping data should be analysed by the Theis analogue method for transmissivity and the four hour specific capacity value determined (see Glossary). These data will provide valuable comparative information between the respective water points, and help towards the decision whether to equip the borehole as a success or whether to abandon it. If need be, data faxed to BGS Wallingford can be processed in this way and returned.

On conclusion of the testing, the appropriate civil works can be put in place. At the discretion of the Project Representative (perhaps on advice from the hydrogeologist in marginal cases) the pump should be installed. At this same time, the training of a local community committee to maintain the pump and borehole should be well advanced, and that committee should certainly witness the pump assembly and installation process. Indeed community involvement with the whole process of drilling and completion is desirable, although not always possible depending on the technology used and competition from other interests such as, for example, the harvest.

7. AVAILABLE DRILLING TECHNIQUES

The driller, whether a contractor or not, needs to work to an established protocol from the outset. The section above provides the basis of that protocol subject to minor variation depending on the equipment used and local conditions.

In addition to the land dugwell, there are currently four proven levels of drilling technology available in Malawi. These are:

A) the low technology hand driven drilling rig, the attraction of which is high community participation, small capital outlay and low operating and maintenance costs.

B) the small hand-portable power-driven drilling rig, providing some opportunity for community participation, reasonable capital and operating costs and straight-forward maintenance.

C) cable-tool percussion drilling rigs, with limited opportunity for community participation, reasonable capital outlay, operating and maintenance costs.

D) conventional rotary drilling machine, either fluid flush or air hammer, providing no community participation, high capital and operating costs, and associated problems with maintenance costs and availability of spare parts.

Each of these techniques is constrained in some way and it will be demonstrated that the preferred technique cannot satisfy all the prevailing conditions.

At the outset the hand dug well and two of the levels of drilling can be dismissed as viable options for the Primary Community Schools Project due to the imposed time constraints. The drilling techniques are techniques (A) and (C) both of which would take too long in time to produce the required product. Although the obvious educational and ownership benefits of community involvement with technique (A) are clearly attractive, rigs such as the Zimbabwe-built Vonder Rig currently and successfully operated by Concern Universal, are not suitable for the intensive drilling programme proposed by the Project. Besides, the depth limitations of these rigs limit their use to weathered rock where water is known to occur at shallow depths. Penetration may be 2 m d^{-1} using four people to turn and weight the wing-bit at the end of the drilling cylinder, withdrawing the bit at intervals in order to empty the cuttings. Completion of a borehole up to 15 m deep requires between 2 to 3 weeks effort. Any hard rock or the occurrence of a boulder would prevent drilling even to 15 m. Costs per borehole are similar to level (B). Clearly the time constraints of the project prohibit well digging. Perhaps sites in Year 2 could be identified for this method which has obvious attractions for community participation.

The cable-tool percussion drilling rig, technique (C), is the traditional work-horse for deep water borehole drilling throughout Africa, although now largely superseded by the rotary drilling machine. Its advantage is that it can cope with all drilling conditions, its disadvantage is a generally slow rate of penetration according to the hardness of the ground being drilled. Drilling into fractured bedrock could be as slow as 1 m day^{-1}. This type of rig is offered by contractors in Malawi, and although there is opportunity to employ local labourers it is unlikely that a contractor would choose to do so. Because this technique is slow it is also dismissed as a viable contender for the project drilling programme.

This leaves technology (B) and (D), both of which offer advantages and disadvantages to the Project, and which can best be used in combination.

The hand-portable rig (B) offers tremendous advantages in terms of site access and running costs. Access for this type of technology is limited only by the ability to tow a compressor to the drilling site. The available example is the innovative Eureka Porta-Rig, a novel British design, which despite its fragile appearance has already gained a considerable reputation both in Malawi and elsewhere. It offers the facility of a readily portable small rig with an integrated fluid flush tank with settling baffles for the chippings, plus combination facilities for down-hole air hammer. This allows a drag bit to be used in weathered material and alluvium, and an air hammer in hard bedrock. Weight is applied to the bit by hand. This a most versatile piece of equipment and those that have used it (including Richard Carter at Silsoe and Bob Elson at WEDC) speak most highly of its capability.

The Eureka Porta-Rig is capable of drilling and completing a 35 m deep borehole in two days. Its maximum depth in Malawi has so far been 41 m in bedrock using the down-hole hammer and 35 m in alluvium using the drag bit. It is capable of drilling a 30 m deep borehole on only 2 l diesel fuel. Furthermore the rotary drive engine, the fluid pump engine and the test pump engine are all interchangeable ensuring continuity of work should engine problems arise. Concern Universal currently have four trained crews for the Eureka Porta-Rig and would be very pleased to employ this surplus of personnel on a second rig. Delivery time ex-

UK is three months. Each rig is made to order, so any customer modifications can readily be incorporated by the manufacturer.

The opportunity for community participation in this level of technology is small. However, this is a price that must be forfeited in order to produce the water points within the time constraints imposed by the Project.

The conventional combination rotary fluid flush/air hammer rig offers greater depth penetration than the small hand portable rigs. They are also able to deal with all geological conditions. These rigs are operated by Government and commercial contractors, but they offer no facility for community based participation. This is regretted, but under the Project constraints adoption of these equipment for a small number of the school water points is deemed essential. The attraction of contractor operated equipment removes all onus on the client from maintenance of plant and the contractor is required at all times to provide well maintained and operational equipment and to carry out his duties in a workmanlike manner to the satisfaction of the Project representative.

Selection of suitable contractors depends on price and on the suitability of the equipment for the job in hand. It also depends on the contractor's established record for deliverables in terms of both the quality and timing of the product.

8. PROVISION OF DRILLING SERVICES

It is proposed for the reasons described above to purchase a second Eureka Porta-Rig and to place it under the management of Concern Universal. The rig will be dedicated to the Primary Community Schools Project and subsequently released for the exclusive use of Concern Universal. Assuming that the capital cost is distributed between 100 boreholes, and the depth limitation of the rig to all intents and purposes is 35 m, then the average cost per 35 m deep borehole is given as follows based on the quotation on file to drill 100 boreholes (assume 67% success rate, i.e. 33 communities not provided for) submitted to the British Council by Concern Universal in £Sterling and dated May 1996:

1.	Capital equipment, including transport, shipping, spares, etc	83 386
2.	Drilling, including 40% fluid and 60% air circulation, consumables	76 685
3.	Staff costs	53 424
4.	Administration	21 348
5.	Provision of regional depot in north	11 716
	Total	246 559

This amounts to a cost per borehole (already adjusted for 67% success rate and including a 10% annual inflation rate) of some £2460 or approximately K56 000 using the Eureka Porta-Rig.

For this price the Project is buying fully trained staff and supervisory engineering personnel, the knowledge that the work will be undertaken in good faith and without a profit motive, and the consolation that at the end of the Project the ODA funds will have provided, at no extra cost, an additional drilling rig to continue work in Malawi. Given the available commercial drilling costs, the arguments of proceeding in this direction are compelling.

There remains the question of providing water for the 33 communities at which the Eureka failed to drill to a sufficient depth, or at which the groundwater prognosis indicated that water was likely to be too deep for the capabilities of the Eureka. It is assumed that these amount to a total of some 33 sites at 33 communities and that some 8 sites, i.e. 8 communities, have been abandoned as having no water prospect or are already provided by some other source (surface water, reticulation, etc). Resort for the deeper drilling is of necessity dependent on contractors. Available contractors are:

Borehole Drillers, Blantyre: Cable-tool percussion equipment only, and now incorporated in Scandrill Limited.

Contact Drillers, Blantyre: This company is currently employed on large volume contract work for the World Bank and UNDP. It operates four South African made heavy duty truck mounted fluid flush / air hammer rigs on its big contracts but also has two smaller truck mounted Indian manufactured rigs. Equipment visible in the drilling yard suggests a company hard pressed to maintain its contractual obligations, with bald tyres and leaking oil seals much in evidence.

Drilltech & Engineering Limited, Blantyre: This is a small drilling company that has been developed in the last few years as an offshoot of the longstanding enamelling and engineering company Encor Limited. The drilling equipment comprises two compact trailer mounted combination fluid flush and down-hole air hammer rigs manufactured by the mining engineering company Smiths of South Africa. The rigs are versatile and are towed to site behind an agricultural tractor. The compressor is moved in the same way. Company policy is centred on a reputation for good quality work, with a preference for smaller contracts up to 50 boreholes. The company prefers to work south of Lilongwe, otherwise mobilisation can be difficult and expensive. Customers such as Concern Universal certainly speak well of this company: a recent contract for 20 boreholes required that the contractor redrill six of them, this was done without serious difficulty and at the contractors expense. The equipment inspected demonstrates a workmanlike and efficient outfit.

Ministry of Irrigation and Water Development, Lilongwe: The drilling section offers a variety of drilling equipment much of which is idle along with fully trained crews because of lack of funds. The department currently offers three Japanese built, lightweight, compact, truck mounted combination fluid flush and air hammer rigs with integral compressor, three heavier gauge conventional Atlas Copco combination rigs, and five cable-tool percussion rigs. The equipment is well maintained and the department continues a tradition of producing a good quality and workmanlike product. The Japanese equipment (subsequent to the departure of the Japanese aid personnel) recently drilled 75 boreholes for the World Bank. One of the rigs produced 35 boreholes in six weeks. This equipment is well suited to the demands of the Project.

Scandrill Limited, Lilongwe: This company offers three heavy duty truck mounted Atlas Copco fluid flush / down-hole air hammer rigs. This equipment may have site access difficulties. The customer base includes a major programme of work in Kasungu District for Plan International. The company are geared up for the large volume contracts and are clearly poised for the major World bank tenders which are anticipated later this year.

Water Boring Contractors Limited, Lilongwe: This company offers cable-tool percussion rigs only and are not considered further.

Water Well Drilling, Limbe: This company offers heavy duty rotary drilling equipment. Site access may be a problem. Amongst their customer base is Plan International. The output of this company attracts a variable reputation.

It should be noted that considerable stress will be placed on the drilling contractors in the ensuing months due to anticipated demand driven largely by current World Bank loan projects. Ample notice must be given to appointed contractors, and a dialogue struck with them at an early stage. The Project's needs are small by comparison to other work currently on offer.

Cost estimates from contractors have been sought on a like-for-like basis broken down as follows:

mobilisation, per unit
drilling, per metre — to 40 m
40 to 60 m
greater than 60 m
rigging up and rigging down, per unit
provision, installation and extraction of temporary casing, per metre
provision and installation of PVC casing, plain and slotted, per metre
provision and installation of 1 to 3 mm rounded gravel pack, per metre
provision and installation of sanitary seal, per metre
borehole development, per hour
test pumping (and recovery), per hour
provisional - PVC/bedrock cement seal [not quoted], per unit
waiting time (day rate), per hour

Civil works, and the provision and installation of pumping equipment are additional. On this basis approximate costs of a 35 m deep borehole are as follows:

Contact Drillers	K93 000
Drilltech & Engineering Limited	K66 000
Ministry of Irrigation and Water Development	K60 000
Scandrill Limited	K68 000

It is, therefore, recommended, subject to tendering, that the work required over and above Eureka Porta-Rig programme in Southern Region and parts of Central Region be awarded to Drilltech & Engineering Limited and that the remainder of the work in Central Region and Northern Region be awarded to the drilling section of the Ministry of Irrigation and Water Development. Careful and thorough supervision of all contractors activities is essential in order to ensure value for money. The Bill of Quantities should be based on the above listed costing breakdown, and an outline Specification is provided as Appendix 5.

9. PUMPS AND CIVIL WORKS

The Afridev pump, manufactured in India, but now also in Malawi, has been adopted as a standard for heads up to 35 m. The Climax pump is used in addition for pumping heads greater than 35 m. Standardisation encourages the availability of spare parts and the skills to maintain and service. The Afridev is of simple design and the head works can be serviced by the local water committee.

10. SANITATION AND WATER QUALITY

At successful boreholes, the civil works should include a six metre long drain leading away from the well-head towards a stone filled sump. Pit latrines should be sited as far from the borehole as possible, certainly not within 50 m of it, and preferably up gradient from the water point. However, groundwater flow direction may not always be apparent, but an element of common sense is usually sufficient in this matter. Care should be taken to ensure that chosen drilling sites are at least 50 m away from existing pit latrines.

As part of the trial test pumping exercise a sample of the borehole discharge water should be collected in two parts, one part raw, and one part acidified to pH 3 as prescribed by the Ministry of Works Laboratory in Lilongwe. The samples should be submitted to the laboratory for analysis as soon as practicable. WHO recommendations on maximum fluoride concentrations should be respected.

The project should consider the purchase of a conductivity cell which will measure specific electrical conductance and give a useful indication of salinity. It should consider the purchase of a portable bacterial activity kit for use in the field. Examples of such equipment are given in Appendix 6.

11. COMMUNITY EDUCATION AND MAINTENANCE

Training and education and the incorporation of a community Water Committee are vital to the success of the water points. During the drilling the community should be invited to witness the drilling process, and there may be opportunity for their involvement through provision of water and surface works. The Water Committee must be present when the pump is stripped down and prepared for installation, and during the installation process itself.

Once the borehole is completed and tested, the Project should retain a watching brief over the water point for a period of not less than six months. This hand over time enables the yield of the water point to be adequately monitored so that any problems with sustainability can be identified and addressed.

12. FAILURE TO PROVIDE WATER

In the event that the hydrogeological and geophysical surveys indicate that the likelihood of obtaining a satisfactory groundwater source at or near a particular community is small, and that the Project decides to proceed with drilling, the following procedure should be adopted. If the Eureka Porta-Rig is in use, three dry boreholes can be tolerated at any one community, and thereafter the rig should move on to the next site. In the event that a contractors rig is in use, only one dry borehole should be tolerated before the contractor is asked to move to the next community.

It remains likely that out of a total of 100 communities, perhaps some 8 proposed school locations will not have a water point. A judgement is then required on whether to proceed with construction, and consideration should be given to the proximity of reliable water and so on. It must be recalled, however, that demography increasingly requires people (by definition the poorer people) to move to marginal lands, and that as time goes on many of these new communities become unsustainable, or indeed were always unsustainable. Given this realisation, the Project should not promote unsustainablility but should rather concentrate on the more viable communities. People cannot live indefinitely in places where they cannot grow food and have insufficient water even for their own personal needs.

13. PROGRAMME OF WORK

Timetabling is important. The survey work needs to start three months in advance of the commencement of drilling work. Between these two phases a consultant hydrogeologist will interpret the survey reports and translate them into lay terms for use by the Project; at the same time the sites will be ranked in terms of water availability and likely water depth. Once drilling has commenced with the Eureka Porta-Rig, contracts can be put in hand to drill those deeper sites identified in the surveys, and at which the Eureka Porta-Rig has failed to reach water.

There is a considerable need to progress with surveying and drilling in advance of year two. The survey work for the last 70 borehole sites should be completed this calender year and drilling should commence as appropriate.

ACKNOWLEDGEMENTS

The author is grateful to everybody he was able to consult with during his limited time in Malawi. Particular thanks go to Garry Whitby and to Victor Msowoya for so ably facilitating this study.

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GLOSSARY

aquifer: a rock formation which is sufficiently permeable to yield a usable quantity of water to a borehole.

bedrock: the unweathered rock beneath the saprolite and/or alluvium.

constant separation traverse: a form of electrical resistivity survey whereby the electrode array is maintained at a constant separation and the whole array is moved along a traverse or within a gridded area. This method is used to detect vertical rather than horizontal features at a depth which is reflected by the array dimensions.

drawdown; the difference between the rest water level (or piezometric head) and the water level caused by pumping a borehole.

electrical resistivity depth sounding: a geophysical survey technique by which an electrical current is passed through the ground between electrodes, and measured via another pair of electrodes. Electrode separation reflects the depth of observation. Interpretation is by mean of analogue.

fractures: the preferential storage and transport of groundwater in fresh bedrock may best occur in dilated cracks or joints. Water may be fed to the fractures from the granular saprolite above, provided that the saprolite is saturated.

gravel pack: rounded granular material (typically 1 to 3 mm in diameter) placed in the annulus behind slotted borehole casing or screen. It acts as a borehole stabiliser and as a means of promoting water flow into the borehole.

piezometric level: the level to which water will rise in a borehole which penetrates groundwater confined in a fracture or beneath a confining layer such as clay.

recovery: the process which occurs when a pump is stopped and the water level in the borehole is allowed to rise back towards its static pre-pumping level. Incomplete recovery at an elapsed time greater than the total duration of the pumping phase may indicate over pumping.

saprolite: the weathering product that may be present over crystalline basement rocks. It may have a clay rich upper part which inhibits downward percolation of rainwater, and is generally granular, progressing to blocky with depth. It may be a few metres to a few tens of metres thick.

specific capacity: the yield of a borehole divided by the respective drawdown. For interborehole comparison the pumping elapsed time should always be the same (e.g. 240 minutes).

specific electrical conductivity: the unit electrical conductivity of a fluid, which in the case of groundwater reflects the salinity of the water.

storativity: the volume of water that can be released from or taken into storage per unit surface area of the aquifer for each unit change of head.

transmissivity: a measure of the ability of an aquifer to transmit groundwater, being the product of aquifer thickness and aquifer hydraulic conductivity.

APPENDIX 1 Contacts made during country visit

Stanley Chamdimba	Ministry of Education
Amon Chirwa	Acting Chief Hydrologist, Ministry of Irrigation and Water Development
Cosmos Gavarti	Deputy Controller (Water Resources), Ministry of Irrigation and Water Development
Myra Harrison	Education Adviser to ODA
David Hillyard	Field Director, Concern Universal
Vincent Gondwe	Project Coordinator, Education Development Management Unit
Hamilton Khoviwa	Chief Driller, Ministry of Irrigation and Water Development
Victor Msowoya	Construction Officer, Ministry of Education
Peter Mtembezeka	Acting Chief Hydrogeologist, Ministry of Irrigation and Water Development
Masauko Mthunzi	Water Engineer, Concern Universal
Charles Nuttall	Assistant Director (Education), British Council
Steve Packer	Senior Education Adviser, BDDCA
Shabir Patel	Managing Director, Contact Drillers
Lucky Penumlungu	General Manager, Scandrill Limited
F Schollmeyer	Managing Director, Drilltech & Engineering Limited
Garry Whitby	Construction Adviser, PPI Consultants Limited

APPENDIX 2 PPI Consultants Limited briefing note 'Provision of Water'

COMMUNITY SCHOOLS PROJECT

Provision of Water

Introduction

It is recommended that the presence of water is ascertained before sites are finally selected and construction begins. The project document indicates that each school should be provided with a water supply. In rural areas this would indicate some form of well or borehole.

This raises the issue of the advisability of hydro-geological surveys. In areas where more sophisticated/complex and therefore more expensive technology to drill would be required, it is recommended that a survey is conducted. Where more basic technology would suffice, such as the vonder rig, the cost of such drilling is minimal, and therefore rarely warrants the cost of a water survey.

Water Surveying

The Water Department conducts surveys with an estimated 60% success rate, at a cost of about K 5,000 per borehole. The time taken to complete the surveys would depend on the locations and distances between sites. Up to three surveys could be conducted in a day, with a two days travelling time. That is about one survey per day on average. It might take time, however, to mobilise the Water Department given the calls on their time. For the Community Schools Project this success rate and timing may inhibit the progress of construction. The technology employed is the resistivity method, whereby electrodes are pegged out in the area in which water is required and resistance measurements are made. This enables the user to plot the depth of possible water.

For the Community Schools project (CoSP) there is a target of 30, a minimum number, of schools to be erected and fully operational for beginning of the academic year, January, 1997. In the phase, 70 schools are to be built and be functional by January, 1998. We have investigated alternatives to the Water Department for the first phase of the building programme for the identification of adequate water. Water Surveys (UK) Limited, for example, initially indicated that a team of hydro-geologists using an EM34 device (which uses electro-magnetic forces to detect water initially with resistivity back-up to help interpret the results) could locate water, at 30 sites, at an approximate cost of £ 28,000.00 exclusive of transport and per diem costs; and, Silsoe College of Cranfield University of Technology has also indicated a willingness to assist with water surveying in the locations identified for Community Schools, but are yet to quote. Water Surveys (UK) Limited have also suggested a lower cost alternative whereby one of their officials comes to Malawi over three visits to train a local team of water surveyors from NGO's and the Water Department. This would cost £6,400 excluding travel and accommodation costs.

Silsoe College have warned of the potential of so-called "experts"who may confuse the situation by blinding the less informed with science, unable to interpret the results with authority backed by experience. They further comment that "*... in the wrong hands geophysics is only a modern technological form of divining-mysterious and something of an act of faith ... in the right hands, geophysics can give useful benefits in terms of improved drilling success rates*". They hold the technical know-how and integrity of Water Surveys (UK) Limited in the highest regard. Water Survey (UK) Limited themselves claim a 90% success rate with their methods.

Borehole Drilling

For physical drilling there are basically three options open to the Community Schools Project:

- *Commercial Companies*: able to drill up to 100m in most conditions at a cost of between K 100,000 to K 110,000 per borehole, whether successful or not.
- *Eureka Porta-Rig*: designed for up to 40m boreholes but able to drill to 45m depending on the geology at a cost of about K 55,500 per successful borehole.
- *Vonder Rig*: designed for a maximum of 20m boreholes in soft and sandy soils. The capital cost is £ 3,000 for the rig, plus transport and minimal daily expenses.

Leading commercial companies in Malawi are Scandrill (Lilongwe), and Drilltech and Engineering (Blantyre). Other with less of a reputation are: Borehole drillers, Water Boring, Contrast Drillers, Whitehead and Jack, and Wells Drilling. All the commercial companies would need professional supervision. The leading companies have a good reputation and ability to manage the process and provide the necessary logistical support, but still suffer delays when this ability is stretched to the limit in times of high demand for their services. Drilltech and Engineering have indicated that they are ready to operate quickly on this project. The experience of NGO's in the field is tabulated below:

NGO	Commercial Companies	Eureka	Vonder	Shallow-well
Concern Universal	✓	✓	✓	
SCF (UK)	✓		✓	
CPAR				✓
Africare				✓
ADRA			✓	
Malawi Red Cross	✓			
Action Aid			✓	
InterAide			✓	✓
Zoa Refugee Care				✓
CSC	✓			✓

A preliminary approach was made to Concern Universal, considered the lead organisation in the field, to undertake the management of the drilling programme at sites for community schools. Their initial costs estimates based on the Eureka Porta Rig are £221,537.00 for 100 holes over the next three years: approximately K 55,500 per successful borehole. This includes the capital cost of the equipment to be used, running costs, employment of a specialised team of drillers, management fees from Concern Universal and their associated support costs (particularly in the Northern Region where they will need to establish a field office specially for this project activity).

Pumping Technology

It appears that Malawi has standardised on the Afridev Pump imported from India at an approximate cost of K 7,500. One company, Scandrill, will install a pump supplied by us for free as a discount on 100 boreholes. Information from WEDC indicates that it is advisable to follow the trend in using the Afridev rather than introduce a new pump because of the need for spares.

Recommendations

Given the building deadlines that have to be met in COSP, we recommend that for 1996/7 a target of 30 schools is agreed, demanding the development of 30 boreholes. For these, we recommend that we identify someone to advise us on a strategy for water surveying, drilling and water pumps to be used. Options include using Water Surveys (UK) Limited to train local practitioners in the methodology used to identify water; and, either using the expertise of Concern Universal be employed to use the Eureka Porta Rig to drill 100 successful boreholes over the next two years or employ a commercial contractor. A compromise will probably have to be made now on drilling for water before construction begins.

APPENDIX 3 Sample survey and borehole siting reports of the Ministry of Irrigation and Water development

18th August, 1991.

Ref. No.

FROM: J.T. BANDA (HYDROGEOLOGIST TRAINEE), REGIONAL GROUNDWATER, P.O. BOX 458, LILONGWE.

TO : KABUKA BANDA (HYDROGEOLOGIST) P/BAG 390, LILONGWE 3.

cc : R.D. Kafundu (Principal Hydrogeologist), P/Bag 390, Lilongwe 3.

: P.I. Mlembezeka (Regional Hydrogeologist Centre), P.O. Box 458, Lilongwe.

REPORT OF CONSTANT SEPARATION TRAVERSE (CST) READINGS SURVEY CONDUCTED AT MPHERERO ESTATES IN MCHINJI DISTRICT

INTRODUCTION

Mpherero Estates are located at the North East of Mchinji Boma. Topographically, the area lies on a peneplain (gently undulating surfaces) with broad valley of Ludzi River. The stream follows the linear fracture and brings fluviatile soils (sediments and dark soil). About two hundred metres from the dambos, the area is covered by a band of lateritic soils, Latosols. However, this does not neglect the fact that the area is of extensively agricultural potential. The main crops grown include maize and fire cured Tobacco which are grown on a commercial basis.

EXISTING WATER SOURCES

Currently the Estates use one motorised Borehole which pumps the groundwater besides that there is motor pump which brings water from the Ludzi River to the Nurseries.

METHOD USED IN GROUNDWATER INVESTIGATION

The existing Borehole shows that previously, site surveying was done. Geophysical and construction data was not generally consulted. Detailed Survey was conducted using Geoelectrical Sounding (Resistivity Survey) Technique (Schlumberger Method) A series of constant separation Traverse were made in the vicinity of the estates. When a good site was indicated by low resistivity readings, a peg was driven into the ground and the team moved on. The Principle governing this method is that groundwater as a mineralised resources, it may conduct electricity. In this respect electrict current was let into the subsurface superficial deposit through two current electrodes and two potential electrodes. However existence of Dambos may be indicative of high watertable besides evergreen vegetation which may also indicate the same.

GEOLOGY AND HYDROGEOLOGY

Mpherero Estates lie in the upper Bua area which is underlain almost entirely by gneisses, granulites, quartzite and schist of Malawi Basement complex. The rock types in Mpherero Estates may have been overlain by thick superficial deposits including residual soils, alluvium and colluvium. No exposures of lithologies were encountered except for lateritic band which was observed about two hundred metres from the dambo area.

Underground water supplies are particularly important in the commercial farm as such. There are prospects of dry season farming in this area and as such the demand for Motorised boreholes is very high. Groundwater is readily obtainable from the thick superficial deposit. Mpherero area receives a generous rainfall and borehole site in fracture zone, in zone of weathered gneiss and in the unconsolidated deposit of the Ludzi River gives yields which exceptionally attain high yields enough for the existing planting system.

Underground water is plentiful over much of the head of the Dambo although seems to be a narrow band, which has given us anomalously low specific resistivity.

The future for water supply in Mpherero estate is good, provided it can be controlled and soilerosion dealt with. Underground water is wide spread under most of the Dambo head and borehole siting is difficult in none Dambo areas.

RESULTS

Three sites required groundwater investigation included Mpherero 1, II and 111.

Mpherero I fig 1, which was regarded as site 3. The low zone was found at the North West and North East of the Estate. However one point with low resistivity was found at the South-South-West. Thus the North west and North East overlies the larger aquifers as there are no greater variations in constant separation constant (CST) readings. The depth probes were done on both areas besides the one done at the South-South-West area. The results on geoelectrical sounding indicated that profile No 3 at 0.14 fig 2 was chosen as a possible site for borehole drilling. Profile No. 5 at 0.19 figure 3 was refered as an alternative.

Mpherero II, fig 4, located at the head of the dambo, four pegs were located for depth probes. The area provides two areas of low zones which are situated at the south and are potentially fit for borehole construction. Out of the chosen as having low CST readings, profile No. 2 at 0.14 , fig 5, gave a possible site for borehole and profile No 3 at 0.12 fig 6 gave an alternative site.

Mpherero III fig. 7 indicates the area with lateritic soils gave high geoelectrical soundings while Dambo area to the South of the estate gave low resistivity soundings. Four pegs were identified as the possible position for better depth probes. The results showed that profile No. 2 at 0.17 fig. 8 was chosen as a site and profile No. 4 at 0.24 fig. 9 as an alternative.

Intially it was suggested that all the three site would be drilled, but the financial position of the organisation running the estates (Press Farming) demands one site to be drilled. Professionally, Mpherero I profile No. 3 at 0.14 was selected as the best site to be drilled. As the report is being written no drilling has been done yet.

Ref. NO. WD/B/C/9 (95)

30th March, 1992.

FROM : THE PRINCIPAL HYDROGEOLOGIST

TO : THE CONTROLLER OF WATER SERVICES

CC : THE CHIEF WATER SUPPLY OFFICER

: THE CHIEF WATER RESOURCES OFFICER

GROUND POTENTIAL AS A SOURCE FOR KASUNGU WATER SUPPLY

REPORT ON SITES VISITS AND GEORESISTIVITY SURVEYS

1. SITES VISITS

Four sites selected from topographical maps were visited by one hydrogeologist accompanied by a hydrogeological assistant (survey TA). During this visit, one site was ruled out for surveying, three were confirmed for resistivity survey, two others were selected for surveying.

The site around NGR 1233D3/5668 (downstream of Ntchema) Chitete Rivers confluence) was ruled out for surveying since the site is very far from Kasungu Township besides being on leased land.

The following sites were confirmed / selected for surveying:-

(i) Kavunguti site

(2) Nguluyanawambe site

(3) Water Supply site

(4) Chilanga site

(5) Kasalika site

2. GEORESISTIVITY SURVEYS

Using an ABEM SAS 300 TERRAMETER

Constant Separation Transverses (cST's) were employed to detect lateral subsurface changes by identifying high and low isresistivity parts. The resultant isoresistivity mapping is given in Appendix 1.

Resistivity depth sounding (Depth Probes) was subesequently employed at grid points of low resisting to detect vertical subsurface changes. A maximum depth of 83m was probed. The grid points that were probed are marked as DP 1, DP 2, DP 3, ... on the isorestivity maps shown in Appendix 1. The resultant geo-resistivity sounding were plotted on log- log paper (apparent resistivity in ohm-metres versus the probed depth). These are given Appendix 2.

3. INTERPRETATION OF THE DEPTH SOUNDINGS

To aid interpretation of the soundings, reference depth probes were taken at the following existing borheoles for which drilling logs were available.

(1) G 6 at Kasungu Poilice Station

(2) G 19 at Late Gogo Jenala's Compound

(3) GM 91 at Mr. Neilod's Compound

The georesistivity sounding and drill logs are given in Appendix 3. The interpretation of the resisting survey results is as follows.

3.1 KAVUNGUTI SITE

Three depth sounding were taken at the grid points marked DP 1, DP 2 and DP 3 respectively on the isoresistivity map.

Weathered formation is implied down to 35m, with a clay-rich overburden of up to 6 m thickness at all the grid points probed. DP 3 however implied changes in formation or degree of saturation of weathered formation at 40m. A saturated fractuters zone may occur between 40m and 60m, at DP 3. DP 3, is the rated as having better potential then DP 1 and DP 2.

3.2 NGULUYANAWAMBE SITE

Three depth sounding were taken at the grid points marked DP 1, DP 2, and DP 3 respectively on the isoresistivity map.

The area appeared to be fault controlled as evidenced by lines of weakness defined by a gully.

There was little difference among the depth soundings. Further CST's using a shorter electrode separation distance was recommended.

3.3. WATER SUPPLY SITE

Three depth probes were done. DP 2 implied a thinner clay rich overburden (less than 3m) than DP 1 and DP 3; a thicker weathered formation is also implied at DP 2. Overall, they shows good potential. While this grid point (DP2) appears to be the best, a Wenner electrode was recommended to minimise effects of lateral inhomegeneities.

3.4. CHILANGA SITE

Three grid points were probed. All appeared to have up to 7m thick day overburdens, perhaps reaching a thickness of 12m. The area is however ranked below Nguluyanawambe and Water Supply site.

3.5 KASALIKA SITE

Low isoresistivity occured downstream (DP 2, DP 3 and DP 4). There appears to be uniform formation at DP's 1, 2, and 3 as the apparent resistivities at these grid points appear to increase with depth at the same rate.

Should there be any interest in this site, a CST using Wenner Electrode Arrangement is recommended around DP 4 ~~is recommend~~.

4. RECOMMENDATIONS FROM INTERPRETATIONS FO DEPTH SOUNDINGS

CST reading emplyoying Wenner Electrode separation were recommended over the Kasungu Water Supply and the Nguluyanawambe sites to the effect that two sites are recommended for drilling (isoresistivity map - Appendix 4).

DP 3 at Kasungu Water Works

Dp 2 at Nguluyanawambe site

K. M.Banda

HYDROGEOLOGIST

for / PRINCIPAL HYDROGEOLOGIST

GEOELECTRICAL SOUNDING

Krüger

State: KASUNGU	Area: KAVUNGUTI
Profile no: 1 & 3	Date: 19-02-92
Measured by: FS	Ground elevation:

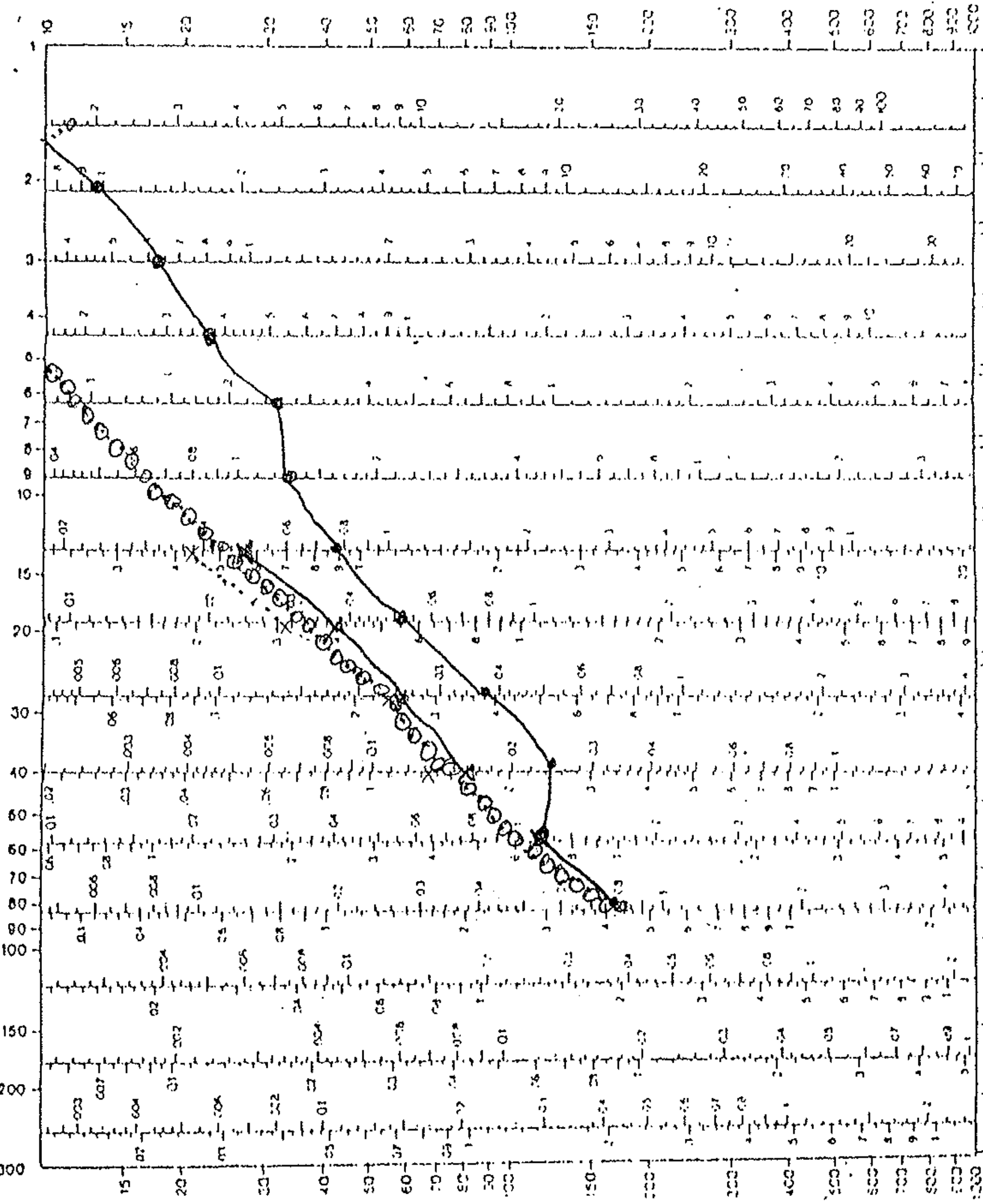
2.1 KAVUNGUTI SITE

DP3 AT 0.37 •—•—•

DP 1 AT 0.40 oooooooo

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.6
3.0	0.5
4.4	0.5
6.3	0.6
9.1	0.5
13.2	0.5
13.2	6.0
19.0	0.5
19.0	6.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
56	5.0
56	25
	5.0
	25
120	6.0
120	25
175	6.0
17[illegible]	25
250	25
250	100



No.	DP1 ρa	DP3 ρa
1	1.74	1.2[illegible]
2	0.70	0.9[illegible]
3	0.26	0.6[illegible]
4	0.15	0.3[illegible]
5	0.091	0.2[illegible]
6	0.063	0.1[illegible]
7	0.044 / 0.45	0.07 / 0.5[illegible]
8	0.031 / 0.31	0.05 / 0.4[illegible]
9	0.022 / 0.24	0.03 / 0.2[illegible]
10	0.015 / 0.17	0.02 / 0.1[illegible]
11	0.10	0.1[illegible]
12	0.083	0.07
13		
14		
15		

... 2 . DEPTH SOUNDINGS

Krüger GEOELECTRICAL SOUNDING

State KASUNGU	Area: NGULUYANAWAMBE
Profile no: 1 & 2	Date: 15-02-92
Measured by: FS	Ground elevation:

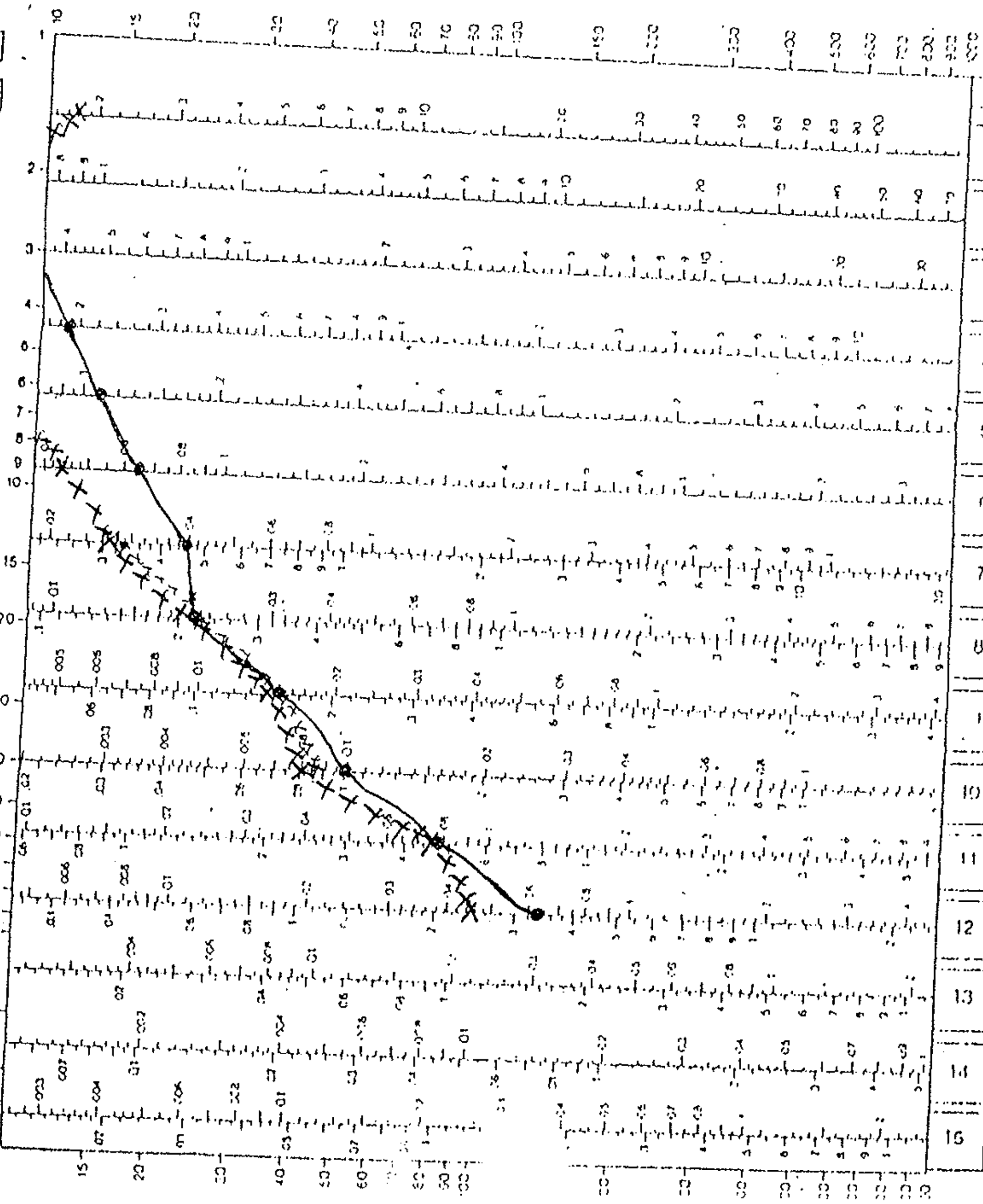
2.2 NGULUYANAWAMBE SITE

xxxxxx DP1 BETWEEN 0.25 & 0.29

•—•—• DP2 AT 0.34

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.5
3.0	0.5
4.4	0.5
6.3	0.5
9.1	0.5
13.2	0.5
13.2	5.0
19.0	0.5
19.0	5.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
58	5.0
58	25
[illegible]	5.0
[illegible]	25
120	5.0
120	25
175	5.0
175	25
250	25
250	100



St	DP1 ρ_{ac}	DP2 ρ_{ac}
1	0.81	0.[illegible]
2	0.48	0.[illegible]
3	0.23	0.[illegible]
4	0.12	0.[illegible]
5	0.072	0.1[illegible]
6	0.042	0.06
7	0.027 0.33	0.04 0.40
8	0.019 0.22	0.02 0.25
9	0.014 0.14	0.015 0.15
10	0.008 0.090	0.10 0.099
11	0.073	0.069
12	0.045	0.06
13		
14		
15		

APPENDIX 2 : DEPTH SOUNDINGS

GEOELECTRICAL SOUNDING

Krüger

State: KASUNGU	Area: WATER SUPPLY WORKS, PLANT
Profile no: 1 & 2	Date: 20-02-92
Measured by:	Ground elevation:

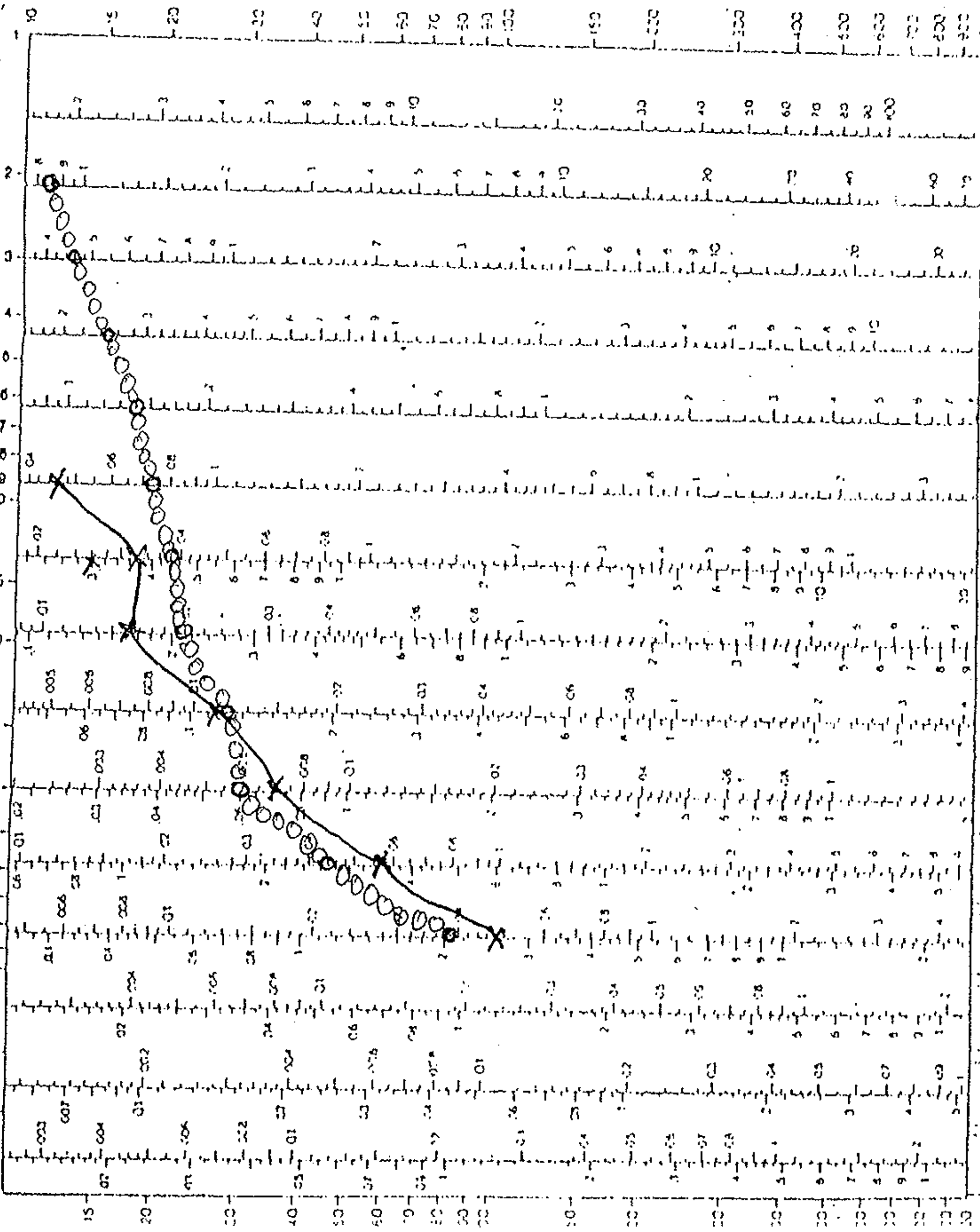
2.3 KASUNGU WATER SUPPLY PLANT

x x x x DP 1 AT 0.26

o o o o o DP 2 AT 0.32

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.5
3.0	0.5
4.4	0.5
6.3	0.5
9.1	0.5
13.2	0.5
13.2	5.0
19.0	0.5
19.0	5.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
58	5.0
58	25
[illegible]	5.0
[illegible]	25
120	5.0
120	25
175	5.0
175	25
250	25
250	100



St	DP 1 ρac	DP 2 ρac
1	0.59	1.3
2	0.39	0.8
3	0.25	0.4
4	0.15	0.2
5	0.072	0.[illegible]
6	0.043	0.0
7	0.026	0.03
	0.30	0.36
8	0.015	0.02
	0.18	0.19
9	0.011	0.012
	0.11	0.12
10	0.007	0.00
	0.077	0.82
11	0.056	0.04
12	0.049	0.039
13		
14		
15		

Krüger

GEOELECTRICAL SOUNDING

State KASUNGU	Area:
Profile no: 1 & 2	Date: 11-02-92
Measured by: FS	Ground elevation:

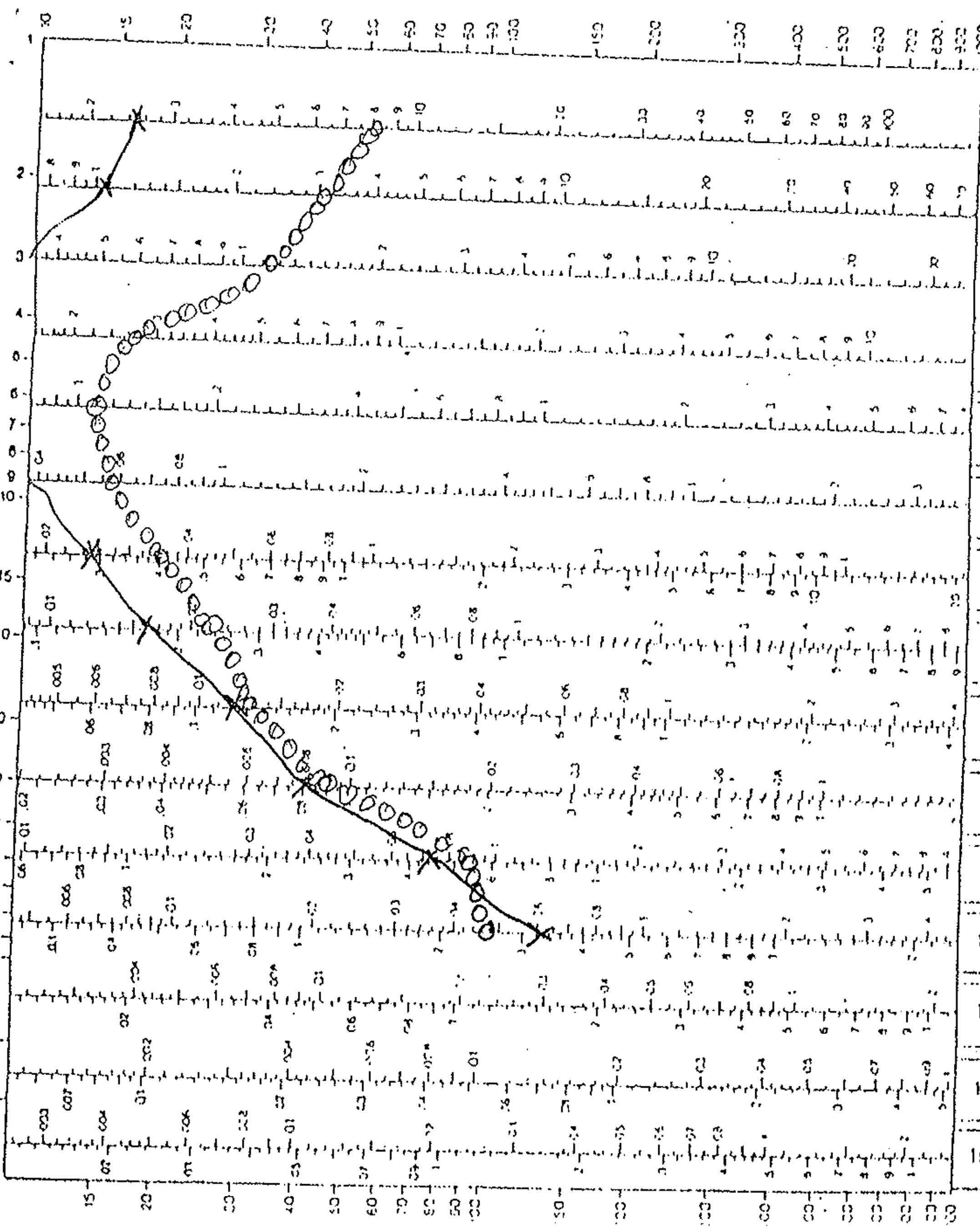
2.4 CHILANGA SITE

x—x—x DP1 AT 0.24

oooooooo DP 2 AT 0.30

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.6
3.0	0.6
4.4	0.5
6.3	0.6
9.1	0.5
13.2	0.5
13.2	6.0
19.0	0.5
19.0	6.0
27.5	0.5
27.5	5.0
40	0.6
40	5.0
56	5.0
56	26
[illegible]	5.0
[illegible]	25
120	6.0
120	25
175	5.0
175	25
250	25
250	100



St	DP1 ρ_{ac}	D[illegible] ρ_{ac}
1	2.55	8.[illegible]
2	1.01	3.[illegible]
3	0.25	1.[illegible]
4	0.088	0.[illegible]
5	0.054	0.[illegible]
6	0.034	0.05[illegible]
7	0.025 0.24	0.03 0.5
8	0.016 0.15	0.0[illegible] 0.2[illegible]
9	0.012 0.13	0.0[illegible] 0.1[illegible]
10	0.008 0.097	0.00 0.0[illegible]
11	0.074	0.06
12	0.060	0.4[illegible]
13		
14		
15		

Krüger

GEOELECTRICAL SOUNDING

State: KASUNGU | Area: KASALIKA

Profile no: 3 & 4 | Date: 09-02-92

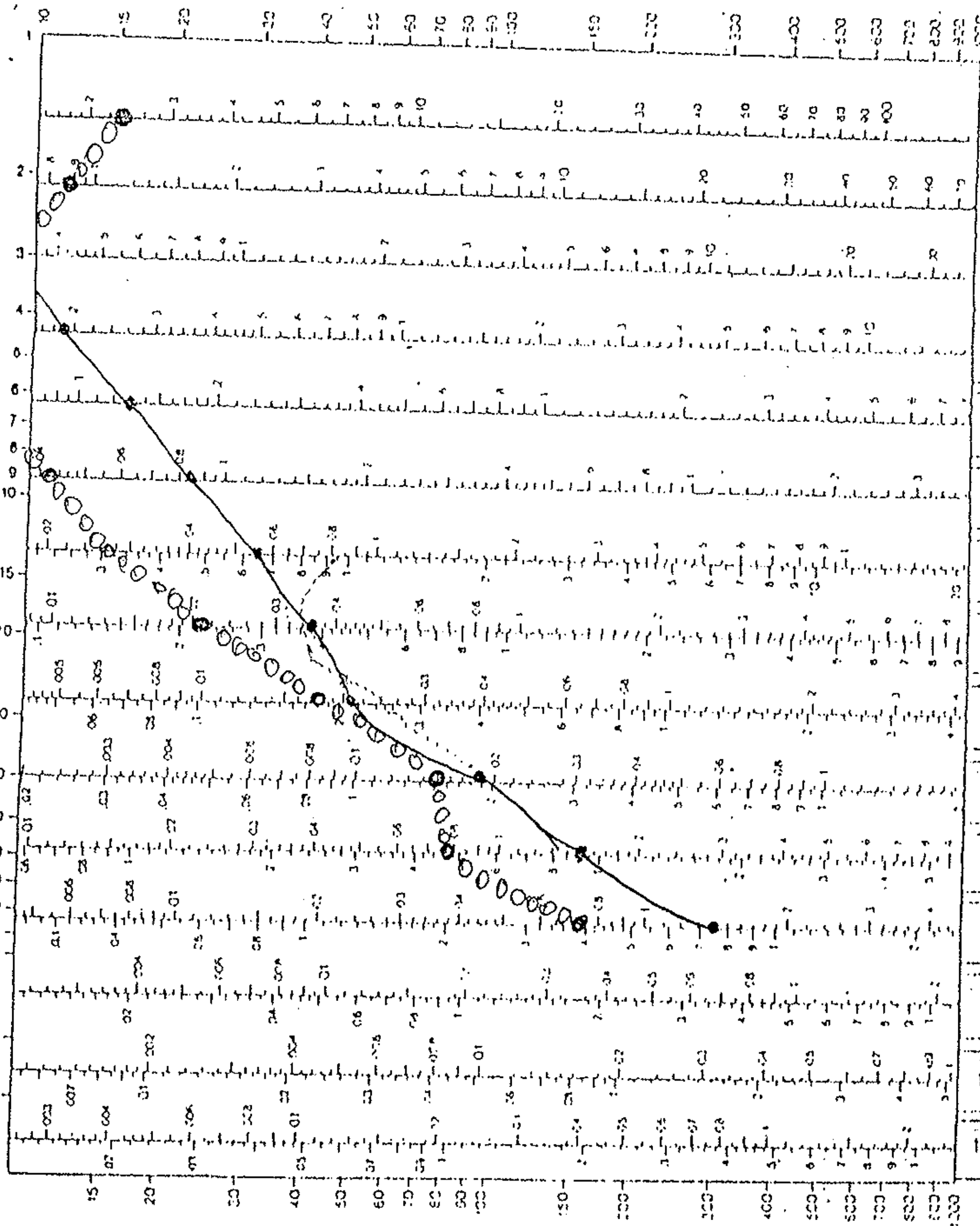
Measured by: FS | Ground elevation:

2.5 o—o—o DP3 AT 0.28

OOOOO600 DP 4 IN BETWEEN 0.47 & 0.54

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.5
3.0	0.5
4.4	0.5
6.3	0.5
9.1	0.5
13.2	0.5
13.2	5.0
19.0	0.5
19.0	5.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
58	5.0
58	25
[illegible]	50
[illegible]	25
120	50
120	25
175	50
175	25
250	25
250	100



	DP3	DP…
Sl	R_oc	R_oc
1	0.88	2.3…
2	0.54	0.8…
3	0.33	0.1…
4	0.19	0.08…
5	0.13	0.053
6	0.084	0.041
7	0.057 0.92	0.02… 0.33
8	0.035 0.037	0.021 0.22
9	0.021 0.24	0.018 0.15
10	0.019 0.18	0.015 0.10
11	0.16	0.078
12	0.14	0.071
13		
14		
15		

APPENDIX 3 : REFERENCE DEPTH SOUNDINGS

Krüger

GEOELECTRICAL SOUNDING

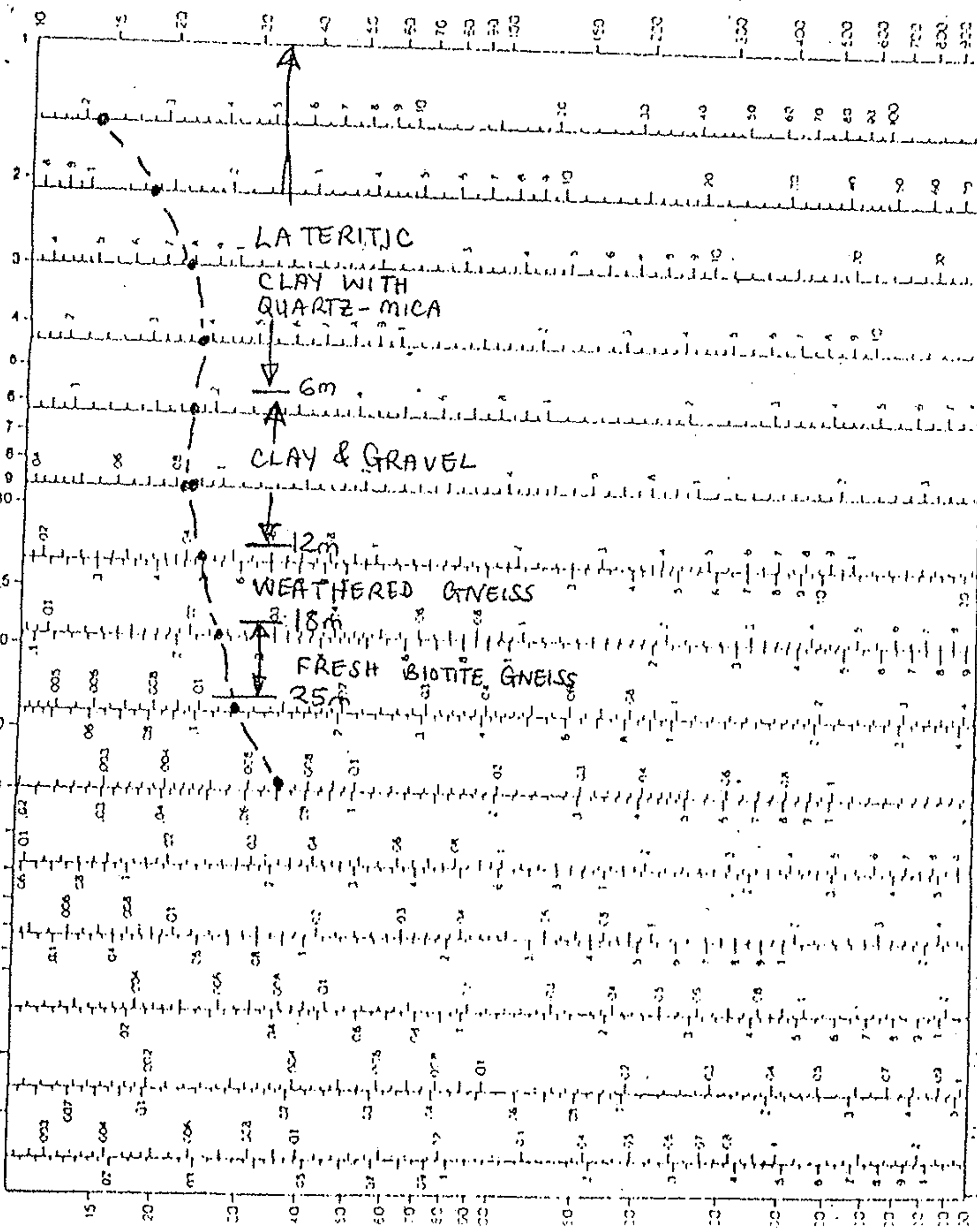
State KASUNGU	Area: POLICE STATION
Profile no:	Date: 20-02-92
Measured by: FS	Ground elevation:

Appendix 3.1 REFERENCE DP AT BH NO. G6

YIELD : 0.5 litres per second

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.5
3.0	0.5
4.4	0.5
6.3	0.5
9.1	0.5
13.2	0.5
13.2	5.0
[illegible]	0.5
19.0	5.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
58	5.0
58	25
[illegible]	5.0
[illegible]	25
120	5.0
120	25
175	5.0
175	25
250	25
250	100

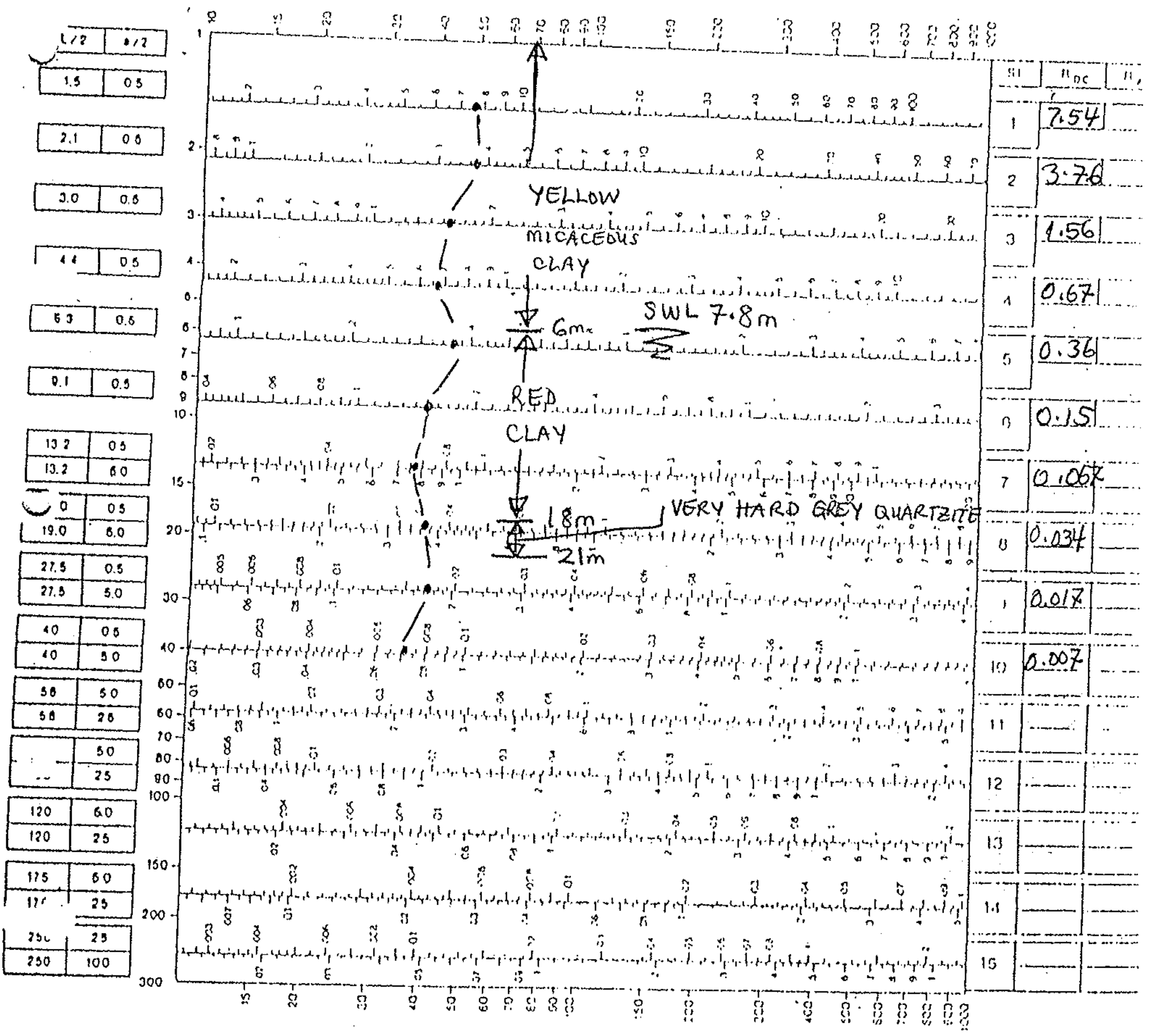


Sl	ρ_{oc}	ρ_{ec}
1	2.18	
2	1.39	
3	0.77	
4	0.38	
5	0.18	
6	0.084	
7	0.042	
8	0.023	
9	0.012	
10	0.007	
11		
12		
13		
14		
15		

Krüger	GEOELECTRICAL SOUNDING	
	State KASUNGU	Area: LATE GOGO JENALA COMPOUND
	Profile no:	Date: 20-02-92
	Measured by: FS	Ground elevation:

Appendix 3.2 REFERENCE DP AT BH № G 19
YIELD 0.3 litre per second.

Apparent resistivity (ohm-m)



APPENDIX 3 : REFERENCE DEPTH SOUNDING

Krüger

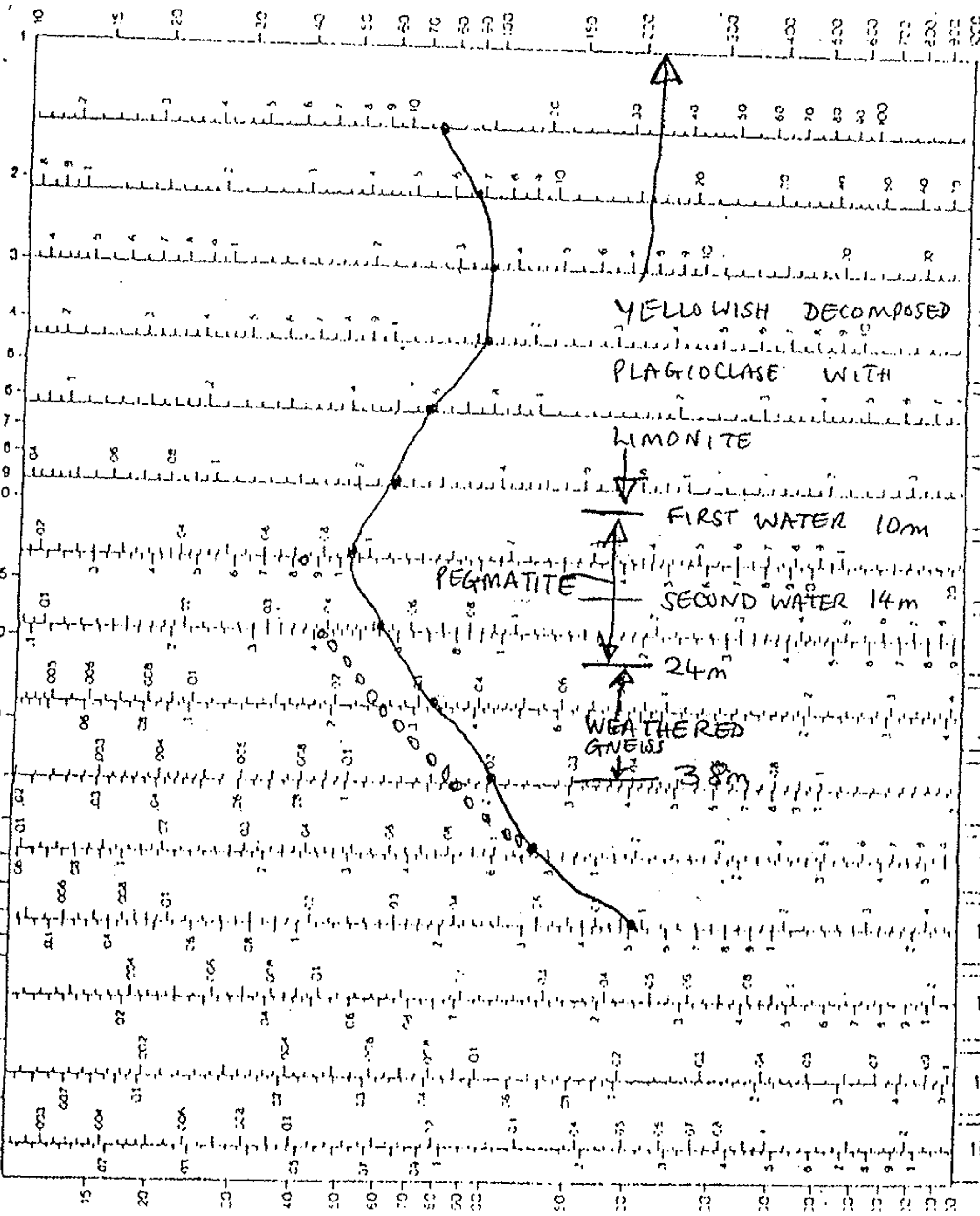
GEOELECTRICAL SOUNDING

State: KASUNGU	Area: Mr NGILODI's
Profile no:	Date: 20-02-92
Measured by: FS	Ground elevation:

Appendix 3.3 REFERENCE DP AT BH No GM91

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.5
3.0	0.5
4.4	0.5
6.3	0.5
9.1	0.5
13.2	0.5
13.2	6.0
[illegible]0	0.5
19.0	6.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
58	5.0
58	25
[illegible]	5.0
[illegible]	25
120	6.0
120	25
175	6.0
17[illegible]	25
25[illegible]	25
250	100



Si	ρa
1	11.93
2	6.76
3	3.53
4	1.57
5	0.58
6	0.22
7	0.091 / 0.83
8	0.057 / 0.41
9	0.32 / 0.26
10	0.020 / 0.017
11	0.12
12	0.093
13	
14	
15	

APPENDIX 2 : DEPTH SOUNDINGS (REPEAT SURVEY)

Krüger

GEOELECTRICAL SOUNDING

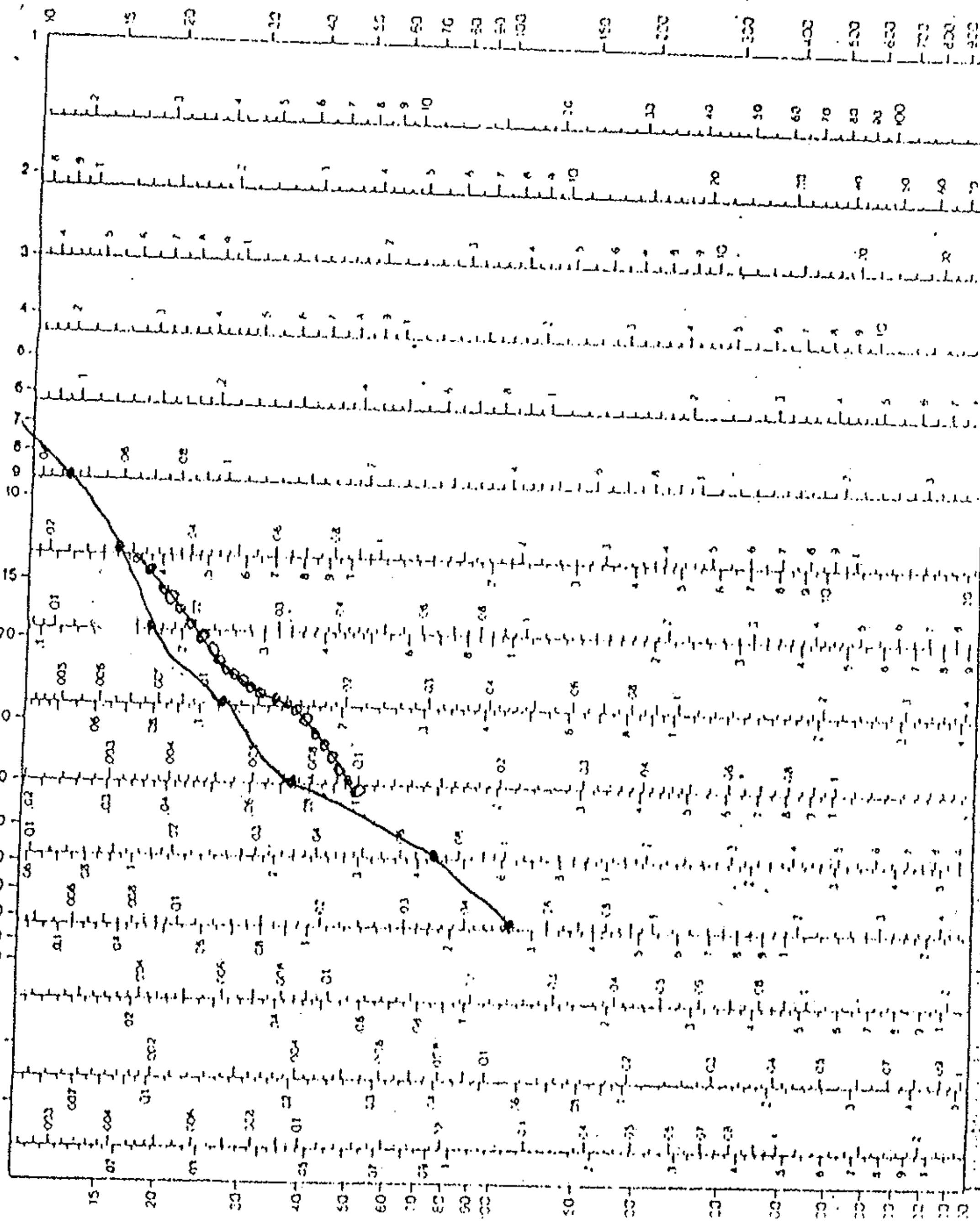
State KASUNGU	Area: NGULUYANAWAMBE
Profile no: DP2	Date: 13/03/92
Measured by: GGC	Ground elevation:

5.1 Depth Probe in Between 0.31 Grid Points

BH № KB 115

Apparent resistivity (ohm-m)

L/2	a/2
1.5	0.5
2.1	0.6
3.0	0.6
4.4	0.5
6.3	0.6
9.1	0.5
13.2	0.5
13.2	6.0
[illegible]	0.5
19.0	6.0
27.5	0.5
27.5	5.0
40	0.5
40	5.0
58	5.0
58	25
[illegible]	5.0
[illegible]	25
120	6.0
120	25
175	6.0
175	25
250	25
250	100



n	R_{oc}	R_{ec}
1	0.81	
2	0.48	
3	0.23	
4	0.11	
5	0.066	
6	0.046	
7	0.028 / 0.35	
8	0.016 / 0.22	
9	0.011 / 0.16	
10	0.0074 / 0.10	
11	0.07	
12	0.05	
13		
14		
15		

APPENDIX … DEPTH SOUNDINGS. (REPEAT SURVEY)

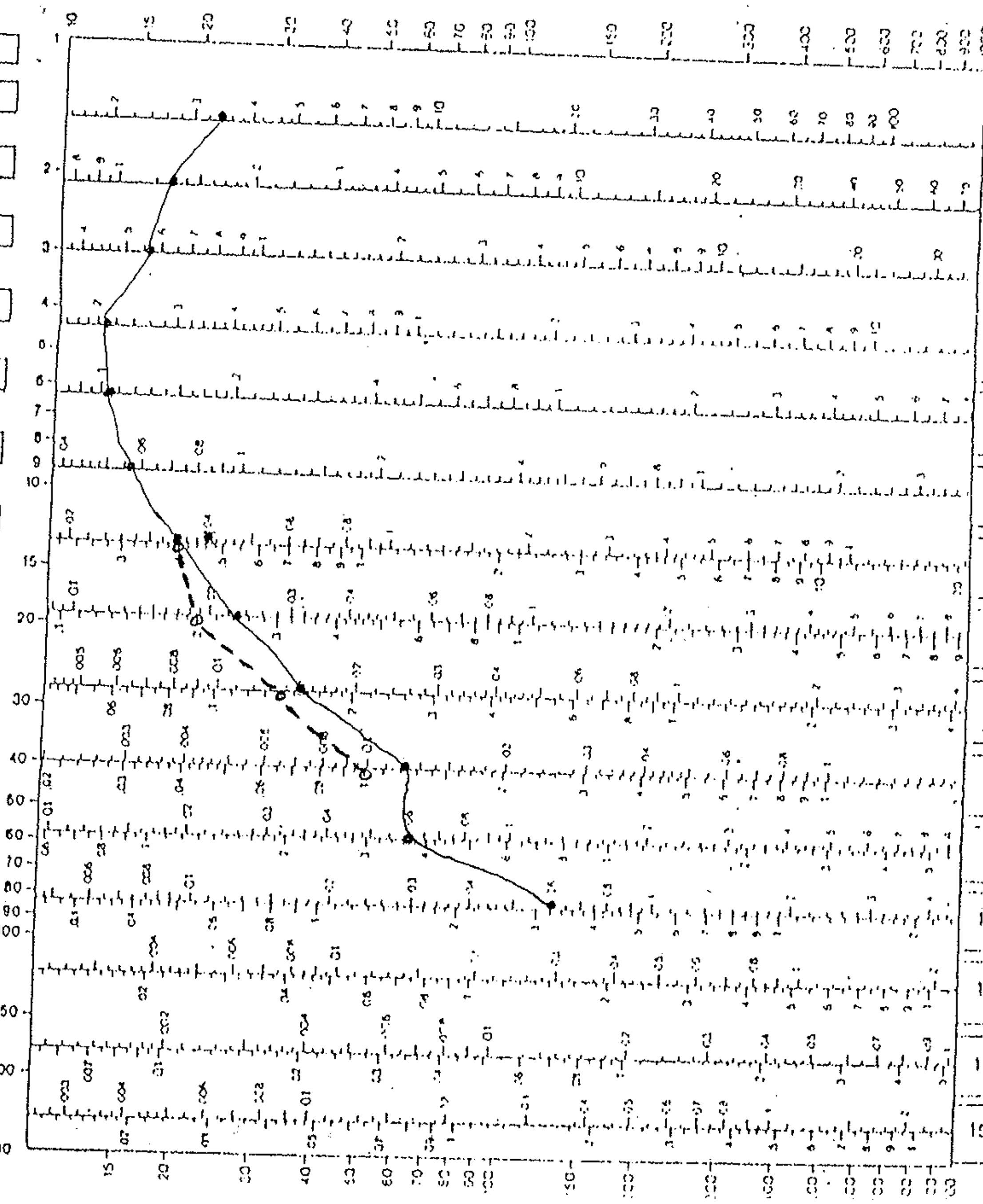
Krüger

GEOELECTRICAL SOUNDING

State KASUNGU	Area: KASUNGU WATER WORKS
Profile no: DP 3	Date: 11/03/92
Measured by: GGC	Ground elevation:

5.2 Depth Probe at 0.30 BH № KB116

Apparent resistivity (ohm-m)



Nr	L/2	a/2	
1	1.5	0.5	3.27
2	2.1	0.5	1.33
3	3.0	0.5	0.56
4	4.4	0.5	0.21
5	6.3	0.6	0.11
6	9.1	0.5	0.056
7	13.2 / 13.2	0.5 / 6.0	0.034 / 0.40
8	19.0 / 19.0	0.5 / 6.0	0.023 / 0.20
9	27.5 / 27.5	0.5 / 5.0	0.015 / 0.14
10	40 / 40	0.5 / 5.0	0.012 / 0.10
11	56 / 56	5.0 / 26	0.060
12		50 / 25	0.060
13	120 / 120	50 / 25	
14	175 / 175	50 / 25	
15	250 / 250	25 / 100	

British Geological Survey

Engineering Geology and Geophysics Group

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FAX MESSAGE

To: Jeff Davies
From: Roger Peart
Date: 10 May 1996

Total sheets: 4

MALAWI PRIMARY COMMUNITY SCHOOLS PROJECT

(Geophysical exploration for groundwater supplies)

Outline of the Electro Kinetic Surveying (EKS) technique
EKS is the most recent hydrogeophysical technique and it is currently being researched by BGS who have undertaken field trials in the UK, Vietnam, Zimbabwe and Egypt. The method offers exciting possibilities since it is the only surface technique that responds directly to the presence of moveable groundwater.

The physical principles of the method, which can be considered a hybrid of the seismic- and galvanic electrical techniques, can be readily understood. Electric charge separation occurs naturally in porewater where ions (usually anions) are attracted preferentially to the surface of the mineral grains constituting the aquifer matrix. Thus the porewater exhibits a net charge and when caused to move relative to the containing rock matrix an electric field is established instantaneously. Such porewater movement is induced in practice by a down-going compressional seismic pulse generated by a surface impact, usually a sledgehammer blow on a steel plate. The resulting oscillating electric field is measured across two pairs of grounded electrodes placed symmetrically about the steel plate on the earth's surface. The plot of the time-varying electric potential (of amplitude typically a few millivolts) across both pairs of electrodes (measured over a total interval of about one fifth of a second from system triggering) can indicate the water table depth, the depth and thickness of saturated permeable zones, a measure of the permeability of individual horizons and hence potential groundwater yield, and the depth to impermeable bedrock. These events in time can be converted to depths by incorporating known or typical seismic velocities for the various horizons encountered. In electrically quiet conditions with good seismic coupling, depths of 70m can be examined using a hammer and plate source.

Added advantages of EKS are the lightweight and compact nature of the equipment (the complete kit can be carried in a small suitcase), its speed of operation (some 50 observations comprising 300 "shots" can be completed in one day) and its straightforward, computer-based data capture, processing and interpretation routine.

BGS experience to date

We are confident that EK is a real and measurable phenomenon and have observed consistent large amplitude signal over saturated alluvium and nil responses over thick clays and impermeable bedrock. The determination of water table depth is less straighforward while permeability (and hence cumulative flow) determinations will require calibration in each new hydrogeological environment.

EKS has served to map both permeability variations in the fill of sand rivers and the bedrock profile and additionally appears to have outlined zones of thickest saturated regolith. The results in fractured basement have been generally disappointing, presumably because EK is largely a surface area phenomenon. To date we have not established a relationship between EKS response and water quality.

Suggested input to this Project

The technique and its interpretation are still at the experimental stage and thus any initial EKS involvement would best be in the form of an early trial (in those environments where the technique is most likely to succeed - see section above) with immediate follow-up drilling. Ideally such a trial would be confined to target zones of areal extent no more than a few acres, highlighted on the basis of air photo examination and/or reconnaissance geophysics (resistivity/em). Such a trial, involving say 6 to 10 sites, could be undertaken as part of our current ODA TDR project (subject to the Government of Malawi and ODA's approval (re change of venue)) and would therefore be gratis. If the trial proved successful then we could continue to survey (at cost) those remaining sites comprising suitable hydrogeological targets (ie excluding deep fractured basement).

This routine phase would require a single BGS operator, a driver/labourer and a suitable vehicle.

Additional comments

The routine application of electrical soundings (VES) (as described in your report) is not appropriate for locating deep fractures in basement. EM techniques are logistically far superior to galvanic resistivity and I cannot understand why they are apparently unpopular in Malawi (except in those areas where the "ambient" resistivity exceeds about 1000 ohm.m ie exposed basement).

Roger Peart
BGS Keyworth
10 May 1996

With best wishes

Yours sincerely

Roger Peart

APPENDIX 5 Draft specification for drilling contracts

Drilling sites will be prescribed by the Project representative.

Boreholes will be drilled to a completed cased diameter of 110 mm. The drilled hole may be 150 mm in diameter. Rotary drilling is preferred, and a drag bit is recommended above bedrock, and thereafter a tricone. Air flush is preferred but water flush will be accepted. Under no circumstances is bentonite or cement to be circulated, but degradable drilling fluids may be used with the written consent of the Project Representative.

The drilled depth will be prescribed by the Project Representative; it will be not less than 35 m and generally not more than 60 m. Chipping samples will be collected from the drilling return dust/slurry and bagged at 3 m intervals; approximately 500 gm is sufficient. Samples will be retained by the Project. On completion of drilling, 110 mm PVC pipe will be hung in the borehole to a configuration prescribed by the Project Representative. A bottom cap will be used, and lengths of 1 mm slotted and plain pipe inserted as instructed. The annulus will be infilled with rounded 1 to 3 mm pea gravel collected from the lake shore. It will be inserted as evenly as possible to a depth 5 m below ground level.

Borehole cleaning will comprise blowing the borehole with a 25 mm air line. The air line should be raised and lowered to best effect and not less than 4 hours pumping should be undertaken. Further blowing will be continued at the discretion of the Project representative. Care shall be taken to ensure that the discharge is carried away from the borehole annulus.

On completion of cleaning, the gravel pack shall be topped up to its original level, and a sand and cement seal shall be placed over the gravel pack. A piece of old sacking tamped down over the gravel pack is recommended. Well head and civil works will be carried out as described elsewhere.

A small capacity test pump capable of sustaining yields of 0.2 to 2.0 $l\ s^{-1}$ for 240 minutes shall be installed. The static water level will be recorded. During pumping the water level in the borehole shall be measured and recorded at 2, 4, 6, 8 and 10 minutes elapsed time. Thereafter it will be measured and recorded at 5 minute intervals. The pump will be switched off at 240 minutes and the same sequence of observations made for the next 240 minutes. The pump yield will be measured by timing a known volume. The pump yield will be set at the maximum likely yield based on the earlier blow cleaning test.

All data derived from drilling will be the property of the Project.

APPENDIX 6 Sample analytical equipment

HANNA, Conmet Stick Conductivity Meters

Simple to use and calibrate. Conmet stick conductivity meters provide quick, highly accurate readings with ATC. The replaceable probe is robust and easy to keep clean and uses the 4-ring measuring system for immunity to hostile environments. Supplied in carry case complete with calibration solution and screwdriver.

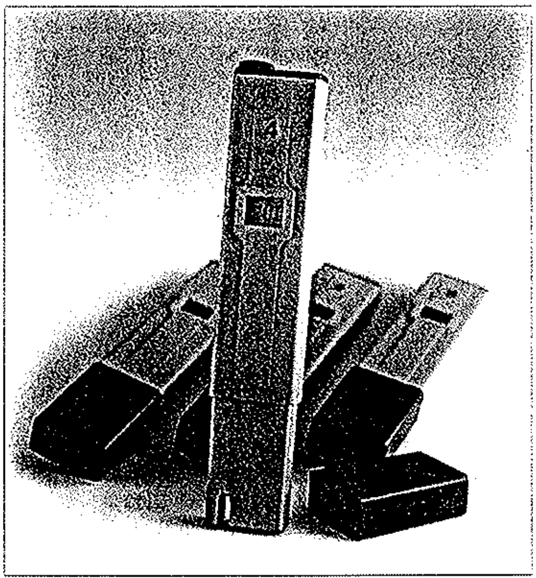
- Compact and robust
- ATC from 0 to 50°C

Specifications

Model	Conmet 1	Conmet 2	Conmet 3
Electrode	HI 3291	" 3292	" 3292
Range	0 to 1999µS/cm	0.00 to 19.99mS/cm	[illegible]
Resolution	1µS/cm	0.01mS/cm	[illegible]
Accuracy	2% of full scale	2% of full scale	[illegible]
Calibration	Single trimmer for 1 point slope calibration		
Temp. compensation	Automatic from 0 to 50°C (32 to 122°F)		
Battery type	4 x 1.4Volts	4 x 1.4Volts	[illegible]

Cat. No.	Description	Price
223-032	Conmet 1, stick conductivity meter	£105.00
223-033	Conmet 2, stick conductivity meter	£105.00
223-034	Conmet 3, stick conductivity meter	£105.00
223-041	Batteries, 1.4V, pack of 12	£6.40

HANNA, Dist WP Conductivity/TDS Tester



Hand held pocket testers for conductivity/TDS measurements housed in a water proof (IP65) case to protect against rain, dust or oven immersion.

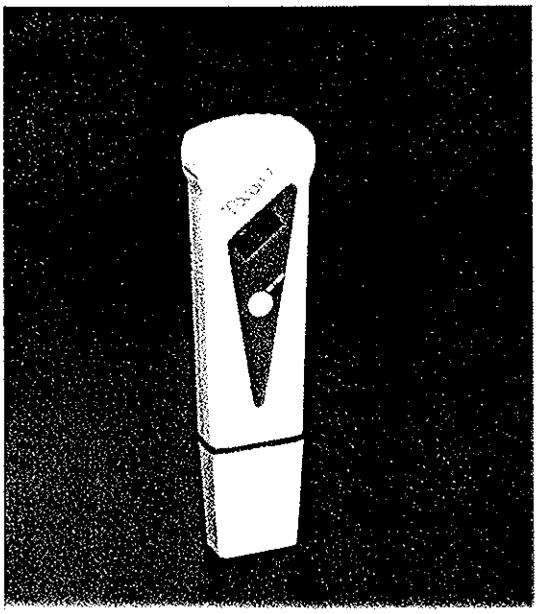
- Waterproof to IP65
- Automatic temperature compensat[illegible]
- Easy to use and calibrate
- Pocket size

Specifications

Model	Dist WP 1	Dist WP 2	Dist WP 3	Dist WP 4
Range	1990ppm	10000ppm	1990µS	[illegible]
Resolution	10ppm	100ppm	10µS	[illegible]
Accuracy	2%FS	2%FS	2%FS	[illegible]
Calibration	One point through adjustment trimmer			
Temperature	Compensation — automatic from 5 to +50°C with [illegible]			
Battery life	200 operational hours (approx)			
Dimensions	150x30x24mm	150x30x24mm	150x30x24mm	[illegible]
Weight	85g	85g	85g	[illegible]

223-035	Dist WP 1, conductivity/TDS tester	£45.00
223-036	Dist WP 2, conductivity/TDS tester	£45.00
223-037	Dist WP 3, conductivity/TDS tester	£45.00
223-038	Dist WP 4, conductivity/TDS tester	£45.00
223-041	Batteries, 1.4V, pack of 12	£6.40

TDScan, TDS and Conductivity Testers NEW



A pocket size total dissolved solids (TDS) or conductivity tester with full scale readout. It is particularly useful in pollution control, water treatment, water hardness testing, aquarium water, hydroponics and fertilizer or chemical concentrations.

- Full scale readout
- ±2% full scale accuracy
- Large LCD
- Splashproof membrane keypad
- Outlasts test kits
- ATC
- Surface mount technology
- Stainless steel electrode system
- Reinforced plastic construction
- Flip-up battery compartment

Model	TDScan 1	TDScan 3
Range	1990ppm	1990µS
Resolution	10ppm	10µS
Accuracy	±2%FS	±2%FS
Calibration	Against appropriate calibrating solutions	
Operating Temp.	0 to 5°C	0 to 5°C
Power	Four 1.4V mercury batteries	
Dimensions	152x42x23mm	152x42x23mm
Wetted materials	316 stainless steel & glass reinforced thermoplastic polyester	
ATC coefficient	Beta, 2% per °C	Beta, 2% per °C

223-039	EC-TDScan 1, complete with battery and protective box	£49.00
223-040	EC-TDScan 3, complete with battery and protective box	£49.00