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# The expanding role of the hydrogeologist in the provision of village water supplies: an African perspective

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## Summary

It has generally been assumed that little attention need be given to the design and construction of rural water supply wells as the yield requirements are small and the construction costs low. A different view is presented in this paper, illustrated by examples from several African countries. New thinking is required if limited financial and trained manpower resources are to be used effectively in providing reasonably low-cost but adequate and reliable groundwater supplies. The argument that a substantial hydrogeological input will be expensive is countered by demonstrating that neglect of hydrogeological principles and practices can result in very much higher costs. The need for hydrogeologists and water engineers to be aware of the social and institutional aspects of rural water supply work is stressed.

## Introduction

The United Nations International Drinking Water Supply and Sanitation Decade has focused the attention of governments and donors on the problems of achieving potable water and adequate sanitation facilities for the world's population by 1990. The issue of urban water supplies has received much attention both in engineering development as well as economic studies of tariff structures and cost recovery. However, it is estimated that about 80% of the 1500 million people who do not have easy access to potable water of adequate quality or basic sanitation facilities live in rural areas. The provision of water supplies and basic sanitation in rural areas has therefore become one of the most pressing needs of the Water Decade. As a result of constraints on the availability of water resources and finance, and the need for technically simple and easily implemented water supply schemes, many African countries are developing their groundwater resources by constructing dug and drilled wells equipped with simple, manually-operated pumps. Tens of thousands of such waterpoints have been constructed in the last few years; hundreds of thousands more are planned. There are, however, many problems in constructing and maintaining these waterpoints and the whole programme will be jeopardised if the problems are not resolved. The hydrogeologist has an important role to play in identifying the solutions.

## Background

### History of groundwater development in sub-Saharan Africa

The existence of readily accessible water has always been a very important criterion for settlement in the African interior. The seasonality of rainfall across much of the continent and its effect on the presence of water and pasture has resulted in the existence of nomadic populations in the drier parts of the continent, with fixed settlement occurring only close to perennial surface water or shallow groundwater. In Asia and to some extent in north Africa, sophisticated groundwater engineering practices have been long established. By contrast in much of sub-Saharan Africa, groundwater use was, until more recently, restricted to abstraction from shallow open holes on river banks or in dry river beds.

Formal development of groundwater resources for domestic supply was commenced in many African countries by colonial governments, generally on a small scale, with very limited budgets and often carried out in a piecemeal fashion.

Historically, there have been some differences in approach to groundwater development between British and French Colonial Africa. The former French territories included many of the less arid regions of east and southern Africa which are underlain by crystalline basement rocks. Aquifers in the regolith and fractured bedrock are generally of poor permeability and low storage and, in the latter case, also discontinuous. Development has related mainly to domestic supply and geophysical techniques have been used extensively for borehole siting. The more arid regions of the Sahara and north Africa are underlain by deep sedimentary basins in places containing highly productive aquifers. Deep drilling to groundwater is frequently necessary and analytical techniques for more comprehensive resource evaluation are utilized. Irrigation use has been an important application. Most of the discussion in this paper is confined to east and central Africa.

Within British Colonial Africa, water well drilling programmes were generally the responsibility of the Geological Survey Department or a self-contained Geology Section within a Ministry of Agriculture or Works. The geological input to the provision of groundwater supplies was often restricted to routine well siting, commonly carried out by field survey geologists with little or no formal training in hydrogeology. One of the important outcomes of this was an interest in, but often uncritical use of, geophysical techniques, especially resistivity, for routine well siting, largely irrespective of hydrogeological conditions or water requirements. In contrast to the considerable time and effort (and therefore cost) spent on siting, other aspects of the provision of supplies were largely ignored.

Design, drilling, completion and testing of the wells has generally been carried out by drillers alone, often with no hydrogeological supervision. This arrangement, combined with a common belief (by geologists and drillers alike) that, in basement rocks, boreholes should be cased through weathered material and screened only in the fractured bedrock, resulted in drilling deeper than necessary.

In summary, therefore, the historical view of groundwater development in the region is of extensive but piecemeal well-construction programmes in which there was considerable geological involvement only in the choosing of sites, and very little hydrogeological input in relation to the planning of development programmes, design and construction of wells, choice and installation of pumps or to the organisation of pump maintenance.

## Recent developments

The impetus given to the rural water sector by the increased donor funding in the 1970's has been further reinforced by the Decade (1981–1990). While the targets of the Decade may not be achieved, the increased concern with water supply programmes has had several important consequences.

The desire for improved water supplies is generally found to be high on the list of priorities of development needs, particularly in the rural sector. One of the outcomes of this increased interest in water supplies at the national political level is the strengthening of Government organisations responsible for water development. For example, the Water Development Division of the Ministry of Agriculture in Kenya became a full ministry in 1974, and all government organizations responsible for water in Malawi were amalgamated into the new Department of Lands, Valuation and Water in 1979. This centralization has provided the institutional framework for closer co-ordination between the various sectors engaged in water resource development.

During the past few years, there have been concerted efforts in many countries to identify water resource development options that are suitable to serve widespread rural populations. Large scale surface water development is often constrained by the need for expensive reticulation and treatment, and may be further affected by the markedly seasonal nature of many surface water sources. Across much of Africa, large scale groundwater development potential is limited by the low permeability and storage capacity of the basement rocks of the African shield, although overall storage may be comparatively high.

Current thinking is tending to favour small-scale, point-source development of groundwater providing a primary protected supply source where people can collect clean water. Supply sources without reticulation are relatively cheap to construct, particularly when assistance from the local community is obtained. No treatment should be needed provided that the source is adequately protected and the very low yield requirements mean that adequate supplies can usually be found over the extensive areas of basement shield outcrop. The hand pump is replacing the bucket and windlass and, with improved design, local community maintenance of its mechanism should be feasible. The full applications of wind, solar and animal-powered pumps have yet to be established. Mechanized pump supply from a groundwater source with reticulation to standpipes and house connections will depend to some extent on the development of more efficient techniques of abstraction, in particular from aquifers of low permeability, and also on the ability to pay for the increased service.

## Current examples

A rapidly growing interest in groundwater development for rural water supplies is occurring throughout much of Africa and a variety of different approaches are being adopted.

Malawi has a remarkable record over 15 years of successful gravity-fed piped-water schemes in rural areas, largely constructed using self-help labour. However, due to the limited number of suitable sources for such schemes, alternatives need to be sought for about 75% of the rural population. Organized groundwater development for rural water supplies dates back to an extensive well-digging programme in the 1930's and was greatly expanded within major agricultural development projects that commenced in the late 1960's. During the early 1970's about 500 wells were being drilled each year. In terms of yield for hand pump installation, the success rate of construction has been high but maintenance costs were proving a heavy burden and operational efficiency was very low, with records indicating perhaps up to 50% of boreholes being inoperative at any one time, mainly because of pump breakdown. A new approach has been adopted in recent years utilizing successful features of the gravity schemes and promoting an integrated programme of drilled and dug well construction, jointly executed by government and community bodies. Aspects of planning, well design, construction methods and maintenance have been carefully reviewed and as a result costs have been very considerably reduced and operational efficiency greatly increased.

Tanzania has seen considerable investments in rural water supply schemes over the last 10 years, with a more recent move away from motor pump and reticulation systems to hand pump programmes. A system of hand-drilling shallow wells has also been developed here and a more unified approach to groundwater development is being adopted in regionally-based projects. Most programmes are funded by bilateral donors, with direct disbursement and contractor/consultant execution. Unit construction costs appear higher than in Malawi and may relate to a lower level of community input. Precise cost comparisons are not available and are difficult to make between countries.

Kenya has a long history of provision of rural water supplies via motorized pumping and reticulation to standpipes but operation and maintenance are posing many problems. In an attempt to identify lower-cost solutions several projects have recently commenced to provide hand-pumped supplies from drilled and dug wells. A clear choice of programme has yet to be adopted.

Zimbabwe has a rural water supply programme which is complicated by the problems of rehabilitation of numerous water supplies destroyed during the civil war, the major population movements consequent upon the war and subsequent resettlement projects, and the effects of the sustained drought. Early plans to provide piped water to all rural communities are being altered as the potential capital and recurrent costs are perceived. Simpler groundwater programmes, utilizing dug and drilled wells equipped with handpumps are being adopted as a first stage in many areas, with reticulation and higher levels of service limited to growth centres, or planned for a later stage.

The Sudan faces a particular problem of dispersed population spread over a vast country, much of which has little perennial surface water. Large hand pump programmes are being implemented in southern Sudan. The difficulties of land access, the regions' remoteness and the overall effects of long-continued civil strife and refugee movements to and from neighbouring countries combine to impose severe constraints on development programmes.

In Zambia, the lack of trained staff, vehicles, funds and spare parts for maintenance of scattered well points in the rural areas has produced a widespread disillusionment with hand pumps in government and village communities. This, together with the escalating costs of drilled wells in a widely-dispersed, piecemeal programme, has resulted in several major projects putting the main emphasis on partially-protected dug wells equipped with bucket and windlass.

Many other countries elsewhere in Africa, notably in West Africa, have rapidly growing programmes of dug and drilled well construction and hand pump installation. The very high investments now being made in 'low-cost' and 'low-technology' groundwater supplies require the establishment of sound principles for every aspect of project planning and implementation. Much research is still needed.

## The role of the hydrogeologist

In early groundwater development programmes, the role of the geologist was often solely to carry out preliminary geological mapping and borehole siting, concentrating on geophysical methods; it was commonly the responsibility of the driller to construct, design, test, complete and equip wells. Even within some of the current large-scale groundwater development programmes for rural domestic supplies, the only perceived role for the hydrogeologist is investigation work during the 'master planning' phase. Despite the huge investments being made in project implementation, it is common to find that no one in project management has significant training in hydrogeology, despite its obvious application in groundwater resource development.

Everyone who has worked in Africa is aware of deficiencies in design and location of borehole and wells in rural areas. Many such deficiencies could have been avoided, had it been considered that the time and effort of a hydrogeologist's input was justified. It is the basic thesis of this paper that much benefit will be gained if the hydrogeologist or groundwater engineer is involved in every aspect of a rural groundwater supply project. The extended role requires an awareness of the technological, sociological and financial constraints of the rural communities in which development is occurring.

### Resource assessment and 'Master Planning'

The advent in the 1970's of 'master planning', either at a national level as in Kenya and Malawi, or at regional level as in Tanzania, heralded a new era. For the first time hydrogeologists, as members of multi-disciplinary teams, have been looking critically at accumulations of information, including well construction, water quality and geophysical data. Additional information is being collected by investigative drilling in an attempt to identify hydrogeological conditions on a regional or national basis.

An important component of a master plan should be to identify the occurrence of available water sources, whether ground or surface water, and to provide cost comparisons of development options. Groundwater resources are generally more difficult to quantify than surface water, particularly when dealing with geologically complex aquifers and when account must be taken of the potential advantages of a widespread occurrence. The difficulties of quantification of a groundwater resource tend to favour selection of a surface water scheme even though there may be high costs associated with sophisticated engineering requirements, widespread reticulation and probable water treatment needs. Investigations allowing proper comparisons might demonstrate that the groundwater resource would be more cost effective to develop, possibly with other advantages, such as lower environmental impact.

Master plans are too often regarded as final statements instead of provisional planning documents requiring updating and modification on the basis of results obtained as programme implementation progresses. This is particularly true where groundwater supply programmes are greatly increasing the available hydrogeological information.

The hydrogeologist has an important role in the master planning process and its progressive updating, especially in the selection of the most appropriate and cost effective method of groundwater development. Many factors must be balanced in this selection, including water demand, the hydrogeological environment, water quality, optimum drilling and abstraction methods, the availability and suitability of local construction materials and the feasibility of community involvement.

## Project identification, design and preparation

Most of the rural population of Africa has yet to be provided with potable water supplies of adequate quality. Few countries have a service coverage for their rural population that exceeds 30% and many have considerably lower service levels. The selection of areas to be served may relate less to need than to other factors, such as political benefit or agricultural potential. The selection of water supply option is clearly a function of water resource availability, linked with the economic, social and technical considerations of each option. There is a strong move away from high capital- and recurrent-cost water supplies, particularly those requiring motorized pumping and treatment. Many large and impressive piped schemes in Tanzania, for example, are known to be non-operational much of the time due to the shortage of fuel. Many schemes in Kenya have to supply untreated river water due to an interrupted supply of chemicals. Alternative options such as gravity-fed piped schemes from river or protected spring sources, rain water catchments, or boreholes and wells with hand pumps might be perhaps more reliable because of their simplicity and therefore would be more appropriate and certainly less costly. The last option may well prove to be the most appropriate way of supplying much of the rural population of Africa with a basic water supply.

In planning a project of groundwater abstraction with hand pumps, decisions or information on the following design factors will be needed.

(a) *Per capita* water consumption and the maximum acceptable walking distance for collection.

(b) Total numbers of people to be served (by extrapolation to a planning horizon usually 5–10 years ahead) and their distribution; required numbers of water points can then be calculated.

(c) Types of water point, whether dug or drilled well (in accordance with hydrogeological conditions).

(d) Optimum pump design for easy maintenance and long life.

(e) Plan for maintenance operational procedures and funding.

(f) Recommended level of community involvement.

Projects involve a wide range of activities from field survey to community organization. In certain areas a small scale pilot project in advance of a major scheme may be merited.

## Equipment

In view of the scale of current and planned development for rural water supply programmes the design of appropriate equipment merits more attention than it has previously received. Equipment should function efficiently and be as simple as possible. It should be relatively cheap and, wherever possible, of local manufacture.

Drilling rigs currently used on rural water supply projects in Africa range from locally-fabricated hand-operated units which can drill to a few metres in unconsolidated formations to large, multi-purpose rotary rigs capable of drilling to more than 1000 m in any formation. Rural water supply projects have a very large number of people to serve on a very limited budget. Ideally, therefore, a drilling rig needs to be fast and efficient, simple and cheap to operate, robust and reliable as well as easy to move and maintain.

Drilled wells for hand pump installation require a minimum internal diameter of approximately 100 mm to accommodate a hand pump cylinder. The wells will often be less than 30 m deep, rarely over 60 m deep and only in very rare cases reach or exceed 80 m (beyond which pumping by hand is not feasible).

Drilled formations will range from unconsolidated (and caving) sediments through semi-consolidated formations (such as weathered crystalline rocks) to hard consolidated rocks. If it is planned to screen unconsolidated to semi-consolidated formations, a 50–75 mm thick gravel pack is desirable, requiring a hole diameter of 200–250 mm. Open hole completion of 100 mm diameter may be adequate in hard rock. An ideal rig will drill 200–250 mm holes fast and efficiently in soft rock and 100 mm holes in hard rock to a maximum depth of 80 m, together with the ability to drill both soft and hard rock in the same hole. For drilling rigs to be used exclusively for rural water supply projects a capacity beyond these requirements is unnecessary and in other respects possibly disadvantageous.

In Table 1, the relative merits of various types of drilling rigs are listed. The most suitable drilling method for rural groundwater supply wells will depend on local circumstances but drilling technology could be improved to produce rigs better suited to drilling small diameter, shallow wells in remote areas with semi-skilled crews.

Similar attention needs to be given to other items of rural water supply hardware, such as well screens and hand pumps. Types of well screen in use range from asbestos-cement pipe with 12 mm drilled holes or mild steel pipe with torch-cut slots to more expensive, but less commonly used, wire-wound stainless steel. The use of locally-extruded and slotted PVC pipe is becoming more common and has advantages in its relatively low cost, ease of installation and range of slot sizes. Experience in Malawi has indicated that hand pump failure can most frequently be attributed to sand pumping consequent upon poorly-designed gravel packs or incorrect well screen slot size. Major savings are to be anticipated from improved borehole design in respect to this single issue.

The hand pump itself is still a weak link in development programmes due to difficulties of maintenance and much effort is currently being devoted to obtaining solutions. Hand pumps are being developed with the following criteria in mind: ease of maintenance, preference for local manufacture, sturdiness and reliability, and relatively low cost.

## Well siting

Hydrogeological conditions and user convenience must both be considered in well siting. A sense of community ownership is desirable and may be achieved by allowing the community as much involvement as possible in the selection of well sites. The degree to which this is feasible depends on the hydrogeological environment. Where the supply aquifer is within fractured bedrock, the need for detailed geophysical surveys will limit community site selection. Where aquifers occur in extensive weathered formations at moderate depth, the decision may be left almost entirely to the community, bearing in mind the need for protection from pollution.

The well site should be chosen so that an adequate and sustained yield of water of acceptable quality is to be anticipated. For a hand pump, the requirement is between 0.3 and 0.5 l/sec. The well should be situated so that it can serve a population in the range 150–300 people within the design maximum walking distance, which is usually between 0.3 and 1.0 km. The choice of site will to some extent control the well type. If the water level is shallow and the near-surface formations are relatively soft, a dug well will probably be more economic; with deep water levels and hard

TABLE 1. *Comparison of drilling methods*

| | Hand-operated rig | Cable-tool rig | Small-air flush rotary rig | Large multi-purpose rotary rig |
|---|---|---|---|---|
| Capital cost | very low | low–medium | medium | very high |
| Running cost | very low | low | medium | very high |
| Training needs for operation | low | low–medium | medium | very high |
| Repair skills | very low | low–medium | medium | very high |
| Back-up support | low | low–medium | medium | very high |
| 200 mm holes to 15 m in unconsolidated formation | fast | fast | feasible but difficult | very fast* |
| 200 mm holes to 50 m in unconsolidated formation | very slow and difficult | fairly fast | feasible but difficult | very fast* |
| 200 mm holes to 15/50 m in semi-consolidated formation | impossible | fairly fast | feasible but difficult | very fast* |
| 100 mm holes to 15/50 m in consolidated (hard) formation | impossible | very slow | very fast | very fast* |

Based on Chilton *et al.* (1982).
* Constraint is mobilization time.

formations, a drilled well is likely to be preferable. Well storage can be a critical factor. With very low permeability and limited aquifer thickness, large diameter dug wells to significant depths, say 30 m, and even constructed in hard rock using jack hammers and explosives, may be necessary to obtain the minimum yield for a hand pump supply.

The cost effectiveness of geophysical techniques in rural water supply programmes may sometimes be open to question. In Malawi until recently, electrical resistivity surveys were employed routinely for borehole siting. Since it now appears likely that yields for a hand pump can be found almost anywhere from aquifers within the weathered material overlying crystalline basement on extensive erosion surfaces, their use in such circumstances is clearly not justified. Applications are more justified where determination of weathering thickness is critical or in a search for localized fracture zones in bedrock. Improved correlation with hydrogeological conditions of the lower cost geophysical techniques, such as electromagnetic, and perhaps more effective use of satellite imagery in conjunction with air photographs would have obvious advantages in low-cost rural water supply programmes. A more extensive use of sophisticated geophysical techniques would, in many cases, be constrained by the general scarcity of trained geophysicists in Africa.

## Well design, construction and completion

Good well design is fundamental to long-term project success, not least because of the greatly reduced need for hand pump maintenance, due to reduction or prevention of sand pumping. The hydrogeologist is not required to design every well individually; a series of standard designs may suffice but close supervision should ensure that the designs are correctly implemented. Close supervision of a drilling programme is likely to result in greatly reduced costs. All too frequently a well is drilled to 60 m when an adequate yield would be obtained if drilling had stopped at 20 m and screened accordingly. It is even possible that a higher yield and lower drawdown could be obtained from the shallow well screened in unconsolidated surface weathered layers than from a deeper hole in which these are cased out.

The construction of dug wells has an important application in rural water supply programmes but a proper understanding of their behaviour and characteristics is essential to ensure that they are used appropriately. A drilled well draws on storage in the aquifer. In a large diameter dug well the volume in well storage forms a reservoir which can provide water at peak periods at a higher rate than the inflow into the well. For this reason, a dug well can be used in aquifers of very low permeability. In order to ensure a reliable supply the relationship between pumping regime, storage requirement and rate of inflow must be understood so that a general design parameter of target depth of excavation below dry-season static water-level can be established. Further, the amplitude of seasonal and longer-term water-level fluctuations needs to be considered. The current severe drought conditions in southern Africa are putting dug wells out of action in major projects in Zimbabwe and Zambia. While dug wells are invariably more drought-susceptible than drilled wells, their reliability could be enhanced if general designs based on hydrogeological principles were established, much as has been advocated above for drilled wells. Again the role of the hydrogeologist is clear.

An important requirement of well construction is that it should ensure proper sanitary protection to reduce pollution risks. This is especially important for dug wells where water levels are near ground surface. Provision should be made by means of an apron and drain for removal of waste water from the immediate vicinity of the wellhead. A secondary but important factor in encouraging villagers to use the improved source is its general amenity value, which can be enhanced by the provision of facilities for washing clothes.

## Community participation

The importance of community participation must be stressed. There are many examples throughout east and central Africa of projects which have not involved the local communities during the planning and implementation phase, and which have subsequently begun to break down because of the lack of commitment by the villagers.

Construction is only the beginning of the life of a water supply point. Operation will hopefully continue for many years afterwards but it is during construction that a sound basis of effective maintenance must be established. The importance of the community participating in as many decisions and activities as possible during planning and implementation cannot be overemphasized. It is only in this way that a sense of commitment and feeling of ownership by the community can be built up to allow the successful establishment of a maintenance system in which the villagers themselves play a large part.

## Operation and maintenance

A major cause of failure of rural water supply projects all over the world is the inadequate attention to the organization and funding of maintenance. By their nature, rural water supplies are often widely dispersed in remote areas and provide for the poorest sector of the community. The experience of many countries is showing that a centralized government maintenance organization is rarely able to provide adequate service, because of high costs of operation and unwieldy bureaucracy. This can result in pumps being out of action for long periods. Villagers may become disillusioned with an 'improved' but unreliable supply and return to traditional, polluted sources. Problems would be compounded with an increasing scale of development.

In such circumstances, more effective maintenance may be possible in which responsibility is devolved wholly or in part to the community using the well. For preventive maintenance to be possible, a simple hand pump is required in which ease of maintenance is the prime consideration. If the communities' responsibilities are to be extended to routine replacement of below-ground components, these too must be simple and easily removed from the well. Where government and community are to share responsibility for maintenance, a tiered structure is to be recommended. The first tier of village caretakers could keep the well and surroundings clean and carry out preventive maintenance. Successive tiers of area mechanics and maintenance assistants leading up to district teams could provide the capability to carry out more difficult repairs, maintain a supply of spare parts and supervise each tier below.

While useful information and ideas can be drawn from other programmes, solution of the maintenance problem and the proportions and details of government and community responsibilities are likely to be specific to each country. Different solutions will depend not only on technical considerations but also on the social and administrative structure, economic factors and the general degree of self-reliance of people in the rural areas. There may be a need for sociocultural studies to provide guidance in the design of a maintenance system. In any case, the hydrogeologist planning and implementing rural water supplies needs to be aware of all the factors affecting maintenance capabilities in the area in which he is working. This is in addition to his own professional responsibility of seeing that the maintenance burden is minimized by the correct construction of properly designed boreholes. A sand-free discharge is so important in prolonging pump life that there may be scope for improving the performance of existing drilled wells by rehabilitation measures. These could include cleaning out infill, placing a new inner lining and gravel pack, redevelopment and re-testing to obtain a sand-free discharge and, finally, completion with a new hand pump so that new and existing wells can be incorporated into the same maintenance structure.

## Health education and sanitation

In a water supply project a considerable amount of effort and funds go into providing a supply of good, clean water. Nevertheless, the resultant impact on health may be minimal if health education and improved sanitation are ignored. Whilst an adequate supply of clean drinking water is a prerequisite for good health the mere provision of such water supplies does not necessarily reduce the occurrence of water-related diseases.

In broadening his role in the provision of rural water supplies, the hydrogeologist must become aware of the links between water and health, and of the importance of a complementary health education and sanitation programme. He may need to carry this awareness as far as initiating and promoting co-operative programmes where there are separate organizations responsible for water and health. Where both wells and pit latrines are being constructed in the same programme, the hydrogeologist will have to draw on his own professional training and experience to give guidance on their siting to avoid potential pollution hazards.

## Training

The effect of the Water Decade in stimulating governments to strengthen their organizational capability to undertake accelerated rural water supply programmes has already been referred to. Having established the institutional framework, there follows a great need for institution building by the training of staff at all levels.

Governments may take different approaches to the implementation of rural water supply programmes. The responsibility for implementation may rest with a Government Ministry through its central headquarters or regional or district offices. Elsewhere, there may be a parastatal rural water corporation or, alternatively, implementation may be in the hands of private contractors and consultants at a major commercial level or private contracting in the form of skilled well-diggers and artisans at village level. Often there is a combination of several or all of these. In all cases there will be a need and an opportunity for the hydrogeologist to pass on his own professional training and experience, especially to counterpart hydrogeologists, drillers and well diggers.

In undertaking this further broadening of his role the hydrogeologist will have to be aware of local conditions and requirements and take care not to advocate inappropriate techniques. He may also need to develop skills in communicating with people from a wide range of educational backgrounds.

## Costing

It has often been argued that the low unit cost of rural water supply wells makes hydrogeological supervision of construction unnecessary. This can readily be countered by the response that although the unit cost may be low, the total investment may be very high. While rural water supply projects do not lend themselves to the rigorous economic analytic approach commonly applied to large scale irrigation or water supply projects there is a great need for the hydrogeologist to be aware of the cost implications of all aspects of a project.

Costing implications underlie all the activities summarized above, from choosing the supply option at the master planning stage and deciding on design criteria in the preparation of projects, to selection of equipment and materials before the project commences. Once a project is underway costs can be controlled by careful management and supervision. The importance of this in relation to siting is easily appreciated; unsuccessful boreholes are expensive and the need to minimize their number is clear. However, the important cost-savings that can result from supervision of construction need to be emphasised, and are briefly described below as illustrated by results of recent work in Malawi.

## The Malawi Experience

In Malawi, trained hydrogeologists have been involved in the rural water supply programme only since 1980. Before this, separate drilled well and dug well programmes were being implemented without hydrogeological involvement, apart from routine well-siting by geologists. There was little understanding of the occurrence of groundwater, no co-ordination between the two programmes to select the most appropriate abstraction method to suit local conditions, and a lack of supervision of the widely dispersed programme of drilled wells of standard design.

Since 1980, a new approach to the provision of rural water supplies from groundwater has been developed, whereby complete coverage of one area at a time is provided by a project team which:

(a) protects suitable existing dug wells;
(b) rehabilitates existing drilled wells where required and when feasible to do so;
(c) constructs new protected dug wells;
(d) constructs new drilled wells; and
(e) establishes a maintenance structure for all water points.

Construction is carried out by up to four drilling rigs and three or four well-digging teams under the supervision of a hydrogeologist. The project designs are based on an understanding of the hydrogeology derived from a review of existing well data and investigative drilling in preparation for Malawi's Water Master Plan.

The Precambrian rocks which underlie much of the country (Fig. 1) have been subjected to prolonged weathering under tropical conditions which has produced a characteristic topography of peneplain and inselberg hills. Several erosion surfaces can be recognized (Lister, 1965), the most important and extensive of which is the late Cretaceous to Miocene African surface, which takes the form of a plateau at an elevation of 1000–1250 m above sea level (Fig. 2). The unconsolidated weathering products on this surface form a shallow, extensive and more or less continuous aquifer. Although thin (generally less than 30 m) it is of great importance as a source of rural domestic water. The unweathered bedrock at depth may have locally high permeability due to fracturing but overall storage is likely to be low. Holes drilled and completed into fractured bedrock will therefore obtain longer term storage from aquifers in the overlying weathered material either directly, if appropriately screened, or indirectly via downward leakage. The character of the weathered zone varies with the parent rock type and texture, but a generalized profile can be given (Fig. 3). The degree of alteration increases progressively upwards from the fresh, unweathered bedrock and the relatively impermeable surface layers of clay produce semi-confined aquifer conditions, with first water usually being struck around the base of these clays. The weathered zone thins towards the edge of the escarpment where uplift associated with the development of the Rift Valley has resulted in increased erosion of the weathered material and it is also reduced towards the bedrock outcrops in inselberg hills.

The potential of the weathered zone aquifer was successfully demonstrated in a small pilot project of twenty-four boreholes, and to date over 250 drilled wells have been completed in the weathered zone aquifer in two major rural supply projects (Table 2). The experience has confirmed that, by the careful application of standard well design and construction techniques, the weathered zone aquifer will generally support a discharge of 0.25–0.5 *l*/sec where its saturated thickness is more than 10–15 m.

Design criteria for the level of service to be provided have been established for the planning and preparation of the projects (Table 3). Design consumption figures have been drawn from the extensive literature on the subject and from comparison with hand pump projects in other parts of the world, allowing a generous margin over current actual consumption (12 *l*/head/day).

Cable tool rigs are ideal for the drilling requirements of the weathered zone aquifer (200 mm holes to 20–30 m). Much of the early pilot project drilling was carried out by very light-weight site-investigation rigs. As anticipated, the rigs proved to be economical, effective, reliable, and also easy to operate and move from site to site. They do, however, lack the greater strength and flexibility of a conventional water well cable-tool rig for pumping, pulling, casing, fishing and overcoming drilling difficulties such as stuck tools. The rigs are kept close together and work through the project area on a village to village basis, supported by a single tractor and trailer for movement between sites, which is very economical. The supervision of

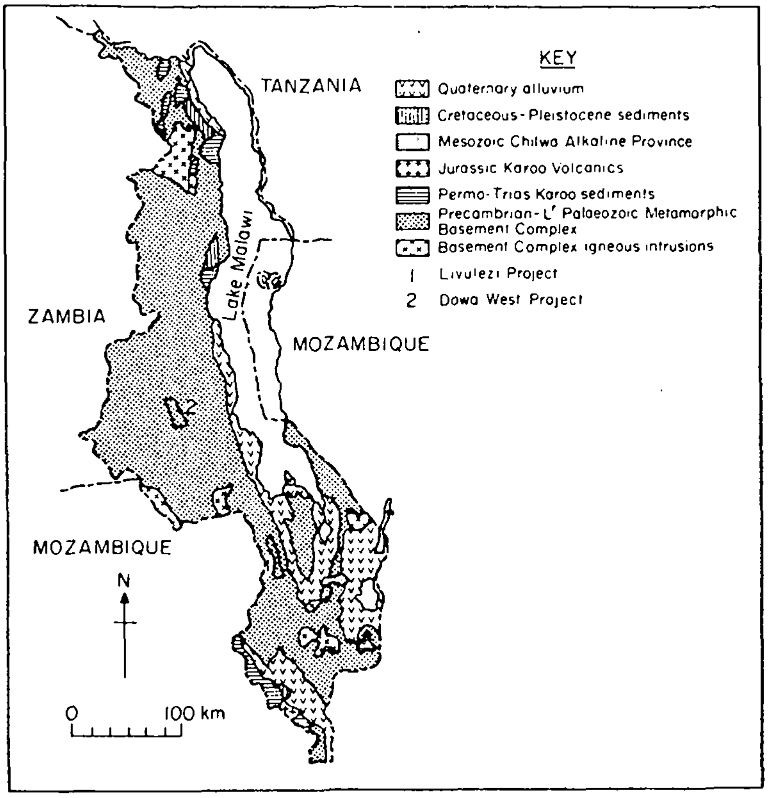


FIG. 1. Geology of Malawi.

construction by project staff using motorcycles is equally economical.

The general design of a drilled well for a hand pump is a 200 mm diameter hole completed with locally-extruded 110 mm diameter PVC casing and screen. The screen is slotted by the manufacturer with 0.75 mm slots, giving an overall open area of 9% externally and 8% on the internal surface. The screen is surrounded by a 50 mm thick gravel pack of 1–2 mm Lake Malawi beach sand. The weathered zone aquifer is of relatively low permeability and as much of it as possible needs to be screened. It is customary to install screen from the depth at which water was struck to the bottom of the well (usually between 9 and 15 m length). The importance of correct screen and pack design is confirmed by the improved cup-leather life in hand pumps on wells producing sand-free water. Twenty-four drilled wells were constructed in the first pilot project from March to June 1981. No cup-leathers needed replacement on any of the hand pumps on these wells until December 1982. Five sets were replaced then, although four were only slightly worn, and one further set was replaced in July, 1983. This compares with replacement on average two or three times a year in existing drilled wells completed with hacksaw-slotted mild steel casing and 6–12 mm crushed roadstone as gravel pack. This improvement helps to reduce the need for, and cost of, hand pump maintenance.

The concentration of drilling rigs permits the supervision of each stage of well construction by appropriate project staff. Whilst it is necessary for the hydrogeologist to be fully involved in well design including decisions on when final depth is reached, the drilling itself should be undertaken by rig headmen and crews with occasional visits from the drilling supervisors. If the rigs are widely scattered in a dispersed programme of well construction, this level of technical supervision is out of the question.

The recognition of the importance of the weathered zone aquifer means that wells should be drilled no deeper than necessary. A well to supply a hand pump can be completed in the weathered zone aquifer and need be perhaps only 20 m deep (Table 2), rather than 45–50 m as was common practice in the past. The hydrogeologist living in the project area is able to receive very regular reports from the rigs and eliminate, by relative rock-hardness criteria (from drilling rate), unnecessary and expensive drilling beyond the weathered zone. Furthermore, a decision to abandon an

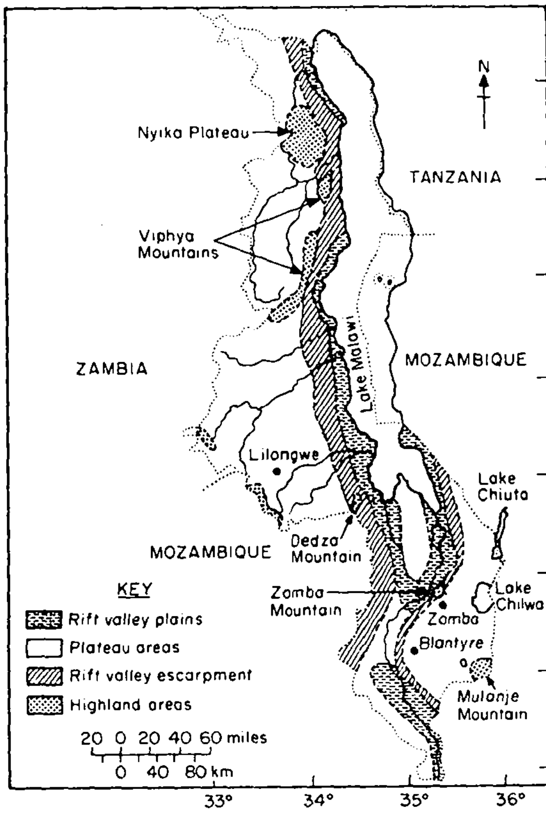


FIG. 2. Major physiographic zones of Malawi.

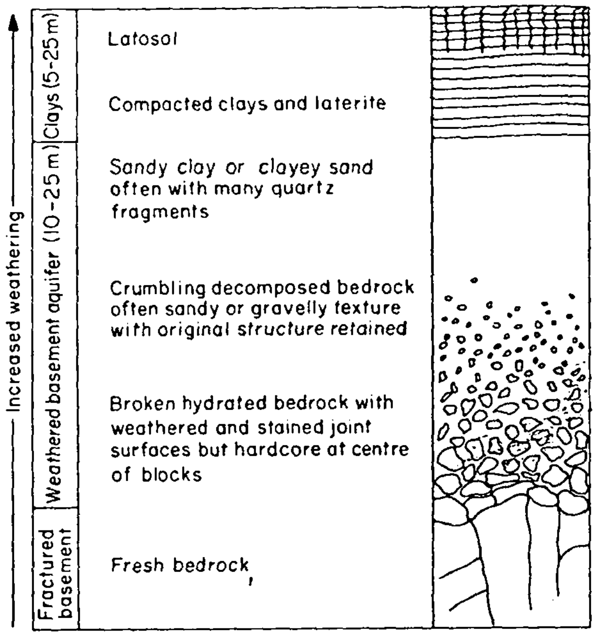


FIG. 3. Typical profile of weathered basement aquifer.

unpromising site can be made at an early stage of drilling and so minimize the cost of unproductive wells.

One of the main factors contributing to the high cost of pump maintenance in Malawi is the need to lift the pumphead each time repairs are required on the downhole components. This requires a heavy vehicle with a winch and a crew of five. A new pump has been designed so that maintenance is much easier. The foot valve and plunger can be removed from up to 30 m depth, without removing the pumphead, and replaced again by one skilled man and one helper. The pump design work commenced in April 1981 and prototypes were installed on village wells in September 1981. A first set of twenty-three pumpheads was made in March and April 1982 and the first production run of 150 commenced in June 1982. Nearly 200 pumpheads are now installed in rural water supply projects in Malawi. The encouragement of local manufacture is considered very important, so that pumps and spare

TABLE 3. *Design criteria for rural water supply projects from groundwater in Malawi*

(a) Target population—projected to 1990.
(b) Daily consumption—27 *l* per person.

| (c) | Sustained yield (*l*/min) | People served | Daily discharge (*l*) | Equivalent continuous pumping time (hr) |
|---|---|---|---|---|
| Drilled well | 20 | 250 | 6750 | $5\frac{1}{2}$ |
| Dug well | 10 | 125 | 3750 | $5\frac{1}{2}$ |

(d) 500 m maximum one-way walking distance.

TABLE 2. *Summary of drilling results, weathered basement aquifer*

| Location* | Number of wells: Total | Successful† | Depth (m)‡ | Water struck (m)‡ | Water level (m)‡ | Yield (*l*/sec)‡ |
|---|---|---|---|---|---|---|
| Livulezi project | 145 | 134 | 24.1 ± 6.1 | 11.3 ± 5.1 | 7.0 ± 3.8 | 0.78 ± 0.40 |
| Dowa West project | 81 | 67 | 26.7 ± 5.8 | 15.2 ± 6.9 | 10.6 ± 6.9 | 0.47 ± 0.27 |

* See Fig. 1 for locations.
† Successful wells defined in relation to hand pump requirement of 0.25 l/sec minimum.
‡ Mean of successful drilled wells ± standard deviation.

TABLE 4. *Summary of costs in rural water supply projects in Malawi (common schedule of prices, 1983 rates)*

| | | MK |
|---|---|---|
| Dispersed Country Programme | | |
| 60 m well with steel lining and Climax hand pump | | 8000 |
| 45 m well with steel lining and National hand pump | | 6000 |
| Integrated Projects (average costs)* | | |
| (a) Livulezi, 134 drilled wells of average depth 24 m and Malawi hand pump | | 2400 |
| (b) Dowa West, 67 drilled wells of average depth 27 m and Malawi hand pump | | 3100 |
| (c) Dug wells both projects, average depth 6 m and MkV hand pump | | 750 |
| Cost breakdown of integrated projects; drilled wells | | |
| Direct labour and material costs | 33% | |
| Project transport | 33% | |
| Project overheads (supervision, depreciation, camp costs, etc.) | 33% | |

* Costings take account of unsuccessful wells. In Dowa West cost increase relative to the Livulezi project relates in part to lower success rate consequent on water quality or insufficient yield.

1 Malawi Kwacha (MK) = 1 US $ approximately.

parts are readily available. Establishment of local manufacture of the downhole components awaits the outcome of design work using plastic materials, which is still in progress.

Considerable efforts have gone into water point completion design. For both dug and drilled wells a 3-m extension pipe in conjunction with an extensive apron and line drain are used to carry the waste water away from the wellhead. In the case of the drilled well the hand pump pedestal is firmly bedded in a concrete plinth. A washing slab is also provided. The community provides labour and materials for the construction of the apron and slab.

A tiered community-based maintenance system is being established in which both village level volunteers and government employees play a part. The system is still at a very early stage of implementation, but the response from villagers to the caretaker training courses which have been held to date has been very encouraging.

At the outset of the programme, ambitious targets for reducing costs were set and the results have demonstrated that a significant reduction (Table 4) can be achieved in comparison with costs in the previous dispersed construction programme.

## Conclusions

It is clear that groundwater is likely to be the most appropriate resource option for water supplies for a large proportion of the rural population in much of the developing world, especially in arid and semi-arid regions where it may be the only option. Experience from a number of countries in east and central Africa shows that groundwater development can be difficult and costly without a proper understanding of hydrogeological principles and practices. Conversely, recent experience from Malawi clearly demonstrates the benefits that can follow from an appreciation of the occurrence of groundwater in poorly-permeable basement areas.

The number of water points needed for rural water supply schemes and the potential capital cost of the programme are so large that the impact of the hydrogeologist who is sensitive to the technical, social and financial issues could be considerable. The application of his professional training and experience to the selection of the most cost-effective methods of groundwater development will require a consideration of the hydrogeological environment, well designs, equipment and materials, and the methods of drilling and pumping.

Groundwater resource estimation and exploration techniques need review to be better suited to the limited skills available and the large scale of many programmes. Well design principles and materials such as well screens need to be adapted to meet the demands of a low-cost, low-yielding borehole. Simple pumps, particularly hand pumps, need to be developed. Many observations suggest that the single biggest cause of hand pump breakdown in many countries is well, not hand pump, design; this key point alone emphasizes the role of the hydrogeologist.

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## Answers to Questions

*1. T. R. Mitchell, Swindon*

Is the K8 to K20 cost comparison from the Livulezi or latest project area?

*E. P. Wright*

The cost comparison, which refers to *per capita* costs, is based on the Livulezi project. The costs for the latest project area in Dowa West have increased due to a falling success rate consequent upon localized occurrence of poor quality water (mainly high sulphate). Present equivalent costs in this area would be around 10–12 Kwacha per head although it is hoped to improve on this by means of improved siting techniques.