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FINAL REPORT: GROUNDWATER MANAGEMENT IN DROUGHT-PRONE AREAS OF AFRICA

N S Robins, R C Calow, A M MacDonald, D M J Macdonald, B R Gibbs, W R G Orpen[1], P Mtembezeka[2], A J Andrews[3], S O Appiah[4], and K Banda[2]

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2. Ministry of Irrigation and Water Affairs, Lilongwe, Malawi
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EXECUTIVE SUMMARY

In Ghana, Malawi and South Africa, as in much of Africa, groundwater development is seen as the only cost effective way of meeting dispersed and growing rural demands. While this realisation has underpinned rural water supply initiatives in Ghana and Malawi for some time, in South Africa the realisation is relatively new. Here, the need to satisfy the basic water needs of some 12 million people neglected under old policies has given groundwater a new role. Against this background, the importance of groundwater, particularly in rural areas where the resource is typically the only perennial source of supply, cannot be overestimated. As recent experience in Southern Africa has demonstrated, however, groundwater supplies cannot always be relied upon when other sources fail.

In all three countries, major changes in the approach to service provision, from top down paternal approaches to bottom up participatory ones, are occurring. In Ghana and Malawi, this transformation is well established, and South Africa has much to learn from their experiences. In all cases, however, the change throws up important questions regarding groundwater management, particularly with respect to monitoring programmes and the maintenance of national databases.

While the more immediate impacts of drought on food security have received much attention in recent years, longer term effects on water security have received much less attention. Not surprisingly, policy responses to drought have concentrated on food needs - most recently on access and entitlements to food - and it has often been difficult to mobilise resources for water sector activities. This is despite the fact that recent droughts, certainly in Southern Africa, have had major impacts on water security. In Malawi, for example, the 1991-92 drought left an estimated three million mainly rural people without access to adequate water supplies as shallow wells and some boreholes failed. One consequence was the use of unprotected sources for drinking water supplies, often shared with cattle, and outbreaks of diarrhoea, cholera and dysentery accounted for many lives.

Experience indicates that the chain of events linking meteorological drought to groundwater drought may be far from clear, and that groundwater sources may fail for a variety of different, though often related, reasons. This has highlighted the need for long term tracking of hydrological *and* hydrogeological conditions, and the need for timely, reliable and comprehensive information on the status of groundwater supplies, the nature of water supply problems, and community access to water. Typically, such information is not collected, or is fragmented amongst the different water sector actors. The reasons include: the low priority given to monitoring and 'information management' programmes by government, donors and NGOs; reluctance on the part of donors to commit money to long term projects with hard to quantify results; institutional upheaval and the trend towards decentralisation (see above) and, related to this, the piecemeal, project-based approach of much rural development work.

The project highlighted the deficiencies of present policies with regard to groundwater drought. In all three countries, policy interventions occurred only after the emergence of crisis conditions, with no action taken to prevent crises occurring in the first place. Furthermore, the effectiveness of emergency relief programmes was questionable, with resources often poorly targeted and arriving too late. Typical problems included poor/non-existent information on the status of rural water supplies; related to this, unfocused 'blanket' responses (usually emergency drilling programmes); rushed and uncoordinated planning; high cost; and diversion of resources away from other programmes. In addition, question marks over the longer term sustainability of relief infrastructure indicate that relief programmes may not only fail to relieve immediate water stress, but may also fail to address longer term supply needs.

In Malawi and South Africa, where experience of relief is more recent, programme structures were dismantled once crises were deemed over, with little or no evaluation of relief efforts undertaken. One result is the loss or fragmentation of much useful information which could have been used to inform non-drought programmes and future crisis prevention/mitigation efforts. This loss of institutional memory applies to both government, donors and NGOs. In Malawi, for example, recent efforts to

launch a large shallow well project met with community resistance; while communities had taken on board lessons from the 1992 drought, when most shallow wells dried up, the donor obviously had not.

Given the shortcomings of reactive, crisis management, the attractions of a more proactive framework aimed at *crisis prevention* are considerable. Shifting the emphasis from crisis management to crisis prevention entails action on two fronts: the 'drought proofing' of rural water supplies, and the development of contingency plans which incorporate early warning systems to give timely notice of emerging problems and initiate appropriate actions.

Drought proofing involves treating drought as a normal and recurring event that can be planned for. Examples include the sinking of drought relief boreholes in pre-drought periods, sited in the most favourable hydrogeological areas. Such boreholes could be uncapped during emergencies and used by households from different villages, or used as sources for tankering operations. Another strategy might involve leaving additional construction materials with villages after new wells or boreholes have been sunk. In Northern Ghana, extra concrete rings are cast and left at the well head to facilitate deepening at some time in the future should the need arise. Well/borehole deepening should be a routine component of rehabilitation programmes in vulnerable areas.

Vulnerability maps for Ghana, Malawi and South Africa have been prepared by the project as management tools. Though these vary in complexity and data usage between countries, all are based on a common conceptual framework that brings together indices of physical resource potential (physical vulnerability), with indicators of supply coverage and demand (human sensitivity). Collectively, these factors indicate at a broad scale those areas that may be most prone to groundwater droughts. The Malawi and South African maps correlate closely to recent drought experience, in that they highlight areas badly affected in the early 1990s. In the Northern Province of South Africa, for example, the most vulnerable areas are the former homelands. The map for Northern Ghana was based on very little data, but indicated that areas underlain by the Voltaian Shales were most at risk.

Vulnerability maps could be used in a number of different ways. For example, one use would be in identifying critical monitoring areas - areas where the monitoring of groundwater conditions and access would seem particularly important. In addition, they could be used to target drought proofing measures, such as those listed above. More generally, such maps could provide useful focal points for sector planning, particularly in relation to the prioritisation of different areas for water developments and technological choices. In South Africa, sector planning maps under development are likely adopt some of the features of the drought vulnerability map developed for Northern Province.

In terms of groundwater drought *prediction* in space and time, there is a need to develop national drought plans which include groundwater resources assessments, and incorporate simple early warning systems to warn of supply problems. Here, developments are very much tied to progress made in establishing long term monitoring and assessment programmes; reliable early warning systems depend on reliable data and long term tracking of meteorological and hydrogeological trends.

1. INTRODUCTION

Groundwater drought can be regarded as the final stage of a drought progression in which surface waters are the first to be affected. During a groundwater drought when some wells and boreholes dry up, water scarcity may quickly overtake crop failure as the single most important and politically visible problem, and local, regional and national impacts can be severe. Causal factors, other than the reduction in recharge associated with drought, include rising groundwater demands. Groundwater demand may fluctuate seasonally, increasing when surface water sources dry up, and increases in the long-term with population growth and economic change.

The effect of drought upon groundwater has received little attention. However, the impacts of groundwater drought are many and costly. Prediction and planning for drought enables better use of resources which can be targeted at vulnerable area in pre-drought periods.

1.1 Project scope

The project was operated as a partnership between:

- The British Geological Survey, Hydrogeology Group
- The Malawi Ministry of Irrigation and Water Development
- The Ghana Water and Sewerage Corporation
- The Department of Water Affairs and Forestry in South Africa
- The UK Institute of Hydrology

The Project Goal was to *alleviate the impact of groundwater drought on vulnerable communities*, and the Purpose of the Project was to *identify ways in which the management of groundwater in drought-prone areas of Africa could be improved in order to mitigate the impacts of groundwater drought.*

The main deliverables from the project were:

- evaluation and reporting of the regional experiences of groundwater drought in the three partner countries;
- drought sensitivity analysis for areas within each country;
- a system for predicting the occurrence and impact of groundwater drought;
- groundwater management plans;
- an international project workshop and dissemination.

The network of collaborators was widened to include other government departments, non-government organisations (NGOs), and external support agencies (ESAs). After the workshop, the interest in and influence of the project was widened still further.

Following literature reviews and country visits, inception reports were prepared for Ghana, Malawi and South Africa. Each report provides information on: the water resources base and the role and importance of groundwater; recent drought experience with particular reference to groundwater supply; spatial and temporal aspects of groundwater drought incidence and impact; the policy response of government, NGOs and ESAs; and suggestions for ways groundwater management might be improved, with particular emphasis on contingency planning.

The drought sensitivity analysis concentrated on the development of groundwater drought vulnerability maps and an investigation of how different groundwater sources, in different hydrogeological environments, behave under 'stress' (reduced recharge and/or rising demands).

Drought vulnerability maps were prepared for the Northern Province of South Africa, Malawi, and the Northern Region of Ghana. Maps were created with varying amounts of data: South Africa the most, and Ghana the least. All are based on a common conceptual framework that incorporates both physical predisposition to groundwater drought, using geological and rainfall indicators, and human sensitivity to groundwater drought, using demographic and water supply coverage indicators.

An examination of the causes of water level decline in wells and boreholes was carried out. Modelling indicated that although decline could be caused by a regional lowering of groundwater levels, in low transmissivity aquifers, which underlie much of the African continent, the decline in water levels in wells and boreholes can often be due to steep cones of depression that develop around sources in response to pumping. These problems are exacerbated in drought times as the demand on groundwater sources is likely to increase as surface water supplies dry-up.

Drought management strategies were discussed with project partners, each with the purpose of alleviating the hardship of groundwater drought. These ranged from 'drought proofing' measures to the development of outline drought plans and early warning systems.

Dissemination includes the three country inception reports, two technical reports, and a major international workshop which was held in Lilongwe, Malawi, in February 1997. A number of papers are currently in preparation for the international technical literature.

The Lilongwe workshop was attended by over 60 delegates from nine African countries. The objectives of the workshop were:

- to provide a direct means of disseminating the findings of the project to those operating in the field of water security for rural communities in Africa;
- to discuss concepts, strategies and ideas with the key players involved in sustainable rural water supplies;
- to develop the network of individuals and organisations concerned with groundwater management in drought-prone areas;
- to advise Donors of the benefits of funding proactive management strategies.

1.2 Background

In the dryland regions of Africa, groundwater is typically the only perennial source of water supply. The importance of groundwater has long been recognised by indigenous communities, typified by the care commonly afforded to a village well or spring. Indeed proximity to water - either surface water or readily accessible groundwater - has historically been a primary determinant of settlement patterns.

In more recent years, development of groundwater resources has increased rapidly as governments, NGOs and ESAs have striven to provide dispersed rural populations with low cost water supplies. A variety of different approaches and technologies have been employed. Many have proved to be unsustainable in terms of government upkeep of a growing population of water points, occasioning a shift in emphasis towards more participatory, demand-driven approaches. In these efforts, groundwater has typically been viewed as a reliable and readily available source of water - a panacea to meeting rural water supply demands.

While many would argue that the emphasis on sustainability is long overdue, recent experience of drought in southern Africa suggests that groundwater wells and boreholes may fail for reasons other than the commonly identified sustainability criteria. One of the principal advantages of groundwater supply arises from the buffering effect of groundwater aquifers in relation to climatic variability and water demands. This buffering capacity is not without its limits. Under certain conditions such as, for example, a combination of rising dry season demand and reduced recharge to aquifers from rainfall, some wells and boreholes may dry up altogether and a *groundwater drought* may result. Such was the case in Zimbabwe when, by the end of the 1988-92 drought, normally reliable wells and boreholes began to dry up, and emergency drilling programmes were hastily initiated. The effectiveness of these reactive measures was in many cases debatable. Boreholes were poorly sited, community participation was negligible and maintenance not prepared for, with the result that within a short space of time, the stock of unsustainable water supply systems was significantly increased.

Droughts, including groundwater droughts, are not random and unpredictable events. Some wells and boreholes, and some areas, are much more vulnerable to groundwater drought than others, and there are essentially predictable variations which are rarely planned for or acted upon. Groundwater drought management strategies are typically formulated in a wider policy framework that still treats drought as a one off event, rather than a 'normal' and recurring hazard. Indeed attitudes and responses to drought are typically concerned not with water, but with food, with the result that other non-food aspects of vulnerability have received much less attention. As Eele (1993) notes:

> The evidence from communities under pressure suggests that the first consideration is to protect productive assets, such as breeding livestock, tools and land. One of the main requirements is for people to remain in their villages and often the first problem faced is not access to food, but rather availability of water.

2. GROUNDWATER AND DROUGHT

2.1 Water scarcity and the nature of droughts

At a continental scale, Africa is significantly disadvantaged in comparison with other continents with regard to its endowment of water resources. The ratio of runoff to precipitation for the whole of Africa is 0.20, just over half the global mean of 0.35. However, significant regional and local variation is apparent: in Malawi, ratios amongst the 38 river catchments vary between 0.04 and 0.54; in Zimbabwe ratios among 108 catchments vary between 0.02 and 0.50.

Temporal and spatial variability in rainfall also creates situations of unpredictability in many countries, and the continent has a long history of rainfall fluctuations of varying lengths and intensities. An obvious expression of this variability is endemic drought. Over the last two decades, understanding of the processes which create drought crises has improved significantly, reflected in better information systems to warn of the impact of drought, particularly in relation to food security (Buchanan-Smith and Davies, 1995). Not surprisingly, policy responses to drought have concentrated on food needs - most recently on access and entitlements to food - and it has often been difficult to mobilise resources for water sector activities (Chalinder, 1994).

Droughts may result in reduced well and borehole yields and the possible drying up of groundwater sources. However, the chain of events linking meteorological drought to groundwater drought may be far from clear, and the spatial and temporal aspects of the relationship remain poorly understood.

2.2 Groundwater resources and behaviour

Groundwater is stored within pore spaces and fractures in rocks. Where the pores and fractures are interconnected water can flow easily and the rocks are said to be permeable. Recharge to groundwater usually occurs annually and is dependent on a large number of factors, including: total annual rainfall;

distribution and intensity of rainfall events; connection to streams and rivers; soil type; and land use.

Much of Africa is underlain by ancient crystalline rocks, typically ancient basement granites and gneisses of igneous and metamorphic origin. Weathering tends to increase shallow permeability creating a mantle commonly 10-30 m thick of sands, gravels and fractured rock known as the regolith. In these areas, the basement forms a minor aquifer known as the *basement aquifer*. Although minor in hydrogeological terms, such aquifers are of vital importance for small scale water supply over a large part of Africa, providing water for villages and small towns in areas where there is often no alternative source of perennial water (Wright and Burgess, 1992).

Many factors determine the degree of rock weathering, and aquifer properties can vary significantly, even at a local scale. This makes careful siting of boreholes and wells important. In general, however, regional over-exploitation of groundwater is a remote possibility as abstraction from individual wells and boreholes is modest: most rural water supply schemes promote simple technologies (boreholes with hand pumps; shallow wells with manual lifting gear), and the physical characteristics of the basement aquifer effectively preclude larger-scale development. As a consequence, the amount of water which can be withdrawn from such aquifers is more a function of the number of access points to the resource (sources such as shallow wells and boreholes) than its overall volume.

If an adequate rate of abstraction cannot be obtained from the weathered zone alone, fractures in the deeper bedrock may be tapped. Other areas are underlain by younger sedimentary deposits and volcanic rocks. Volcanic rocks can have a moderate porosity and may sustain a range of yields. Where sedimentary deposits constitute sandstones and conglomerates, the potential for finding usable groundwater is high. Clays and mudstones, however, are very poor aquifers and finding groundwater resources in these rocks can be extremely difficult. In areas where there is insufficient groundwater to sustain exploitation, for example in basement areas which have not been sufficiently weathered, alternative (surface) water systems such as surface impoundments and rainwater harvesting may be important. More typically, however, major settlement in these areas does not occur, or occurs only when deep boreholes tapping fractures in the rock can be sunk. In the latter case, a conundrum may arise, whereby the poorest are those living in the driest areas where the cost of water provision is highest, the need greatest, but the ability to pay for services is lowest.

A further consideration is water quality. One of the principal advantages of groundwater over surface water is its high microbiological quality, arising from its situation below ground and the natural protection this affords. In some areas, however, groundwater may be brackish and unusable as a source of potable supply. In others, high natural concentrations of fluoride, nitrate or arsenic, or anthropogenic contamination from

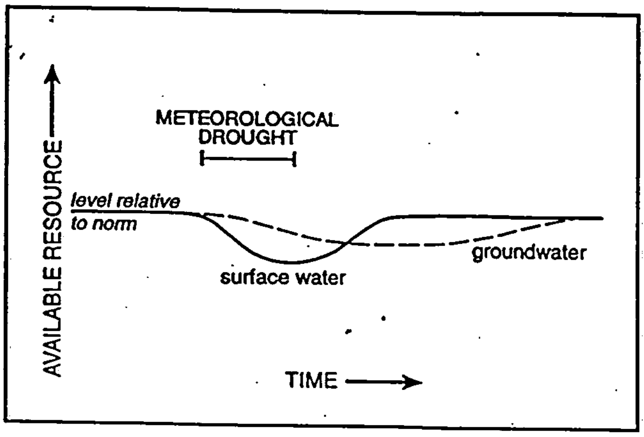

Figure 1 Contrasting response and recovery functions of groundwater and surface water to drought

latrines, may result in health problems.

2.3 The response of groundwater to drought

Perhaps the most significant aspect of groundwater behaviour in relation to drought is the time lag between changes in recharge and responses in groundwater levels and well yields. This contrasts with the relatively flashy behaviour of surface water sources (Figure 1). The result is that, while some wells and boreholes may respond relatively quickly to rainfall variations, problems in others may take months or even years to emerge, perhaps after several years low rainfall. Indeed, it is quite conceivable that a decline in well/borehole yield, or a fall in water level, may only materialise after the rains have returned and the meteorological drought is perceived to be over. This emphasises the need to track the long term effects of drought through hydrological and hydrogeological systems.

The time lag between a meteorological drought and its impact on a groundwater source is likely to depend on many different factors, including:

- severity and duration of the drought episode. Longer periods of low or negligible recharge are more likely to have an impact on groundwater resources and affect well and borehole yields;
- design and siting of the groundwater well or borehole. In general, we might expect shallow, hand dug wells to be more sensitive and responsive to recharge variations than deeper boreholes, and boreholes on interfluves to be more vulnerable than those in valleys;
- physical characteristics of the aquifer. Of particular importance is aquifer storage. In basement aquifers this is highly variable and depends to a large extent on the degree of surface weathering and fracturing which has taken place. However, it is typically much lower than in more productive, unconsolidated aquifers; and
- demands being made on the source. Increasing demand may exacerbate the effects of rainfall failure. Fluctuations in demand may occur over the short term, reflecting for example the drying up of neighbouring wells and boreholes, or over a longer period in response to factors such as population growth and economic change.

While the buffering capacity of groundwater systems confers obvious advantages in terms of the reliability of supply, it also creates certain problems. Firstly, it follows that groundwater also recovers more slowly after drought than surface sources. The result may be complex and seemingly unrelated linkages between rainfall events and their impact on groundwater resources. Secondly, it indicates a need for careful management and continuous monitoring of groundwater supplies. Monitoring and assessment programmes which begin and end with meteorological and agricultural droughts may fail to detect longer term impacts on groundwater, with the result that potentially predictable and manageable problems become emergencies.

2.4 The failure of groundwater sources

The exact cause of the failure of wells and boreholes is not always clear. Sometimes, it is assumed that an aquifer is being overexploited and groundwater resources are being regionally depleted. However, regional over-exploitation is rarely a problem in African basement aquifers and localised depletion, resulting in falling groundwater levels in the immediate vicinity of a well or borehole, is likely to be the principal problem. This is most likely to occur where the demands being placed on a water source are high, and where the permeability of the aquifer is low. In these circumstances, groundwater cannot move sufficiently quickly to replenish the water abstracted from the borehole or well, and a dewatered zone may form around the source (a cone of depression) restricting the inflow of water. Figure 2 illustrates the distinction between source and resource constraints on abstraction.

Increased stress on a groundwater source during drought can also lead to the failure of the pump. Prolonged pumping throughout the day can put considerable strain on the pump mechanism leading to breakdowns, especially if water levels are falling and pumping lifts increasing. The result may be increased demand on a neighbouring source, and thus increased stress (and probability of failure) on that source. And so the cycle continues. The problem may be exacerbated by the cessation of maintenance programmes as relief drilling programmes take priority. The use of poorer quality unprotected sources as water scarcity increases, and the added strain of travelling long distances for water, may have significant health impacts on affected households and communities. This was the experience of Malawi during and following the severe drought of 1991-92.

A preliminary conclusion is that the failure of wells and boreholes during drought is a function of both increased demand on low yielding sources and reduced recharge to the aquifer. Identifying hydrogeological zones that have low permeability, wells and boreholes that are low yielding and areas of high demand might, therefore, help identify areas which are vulnerable to groundwater drought.

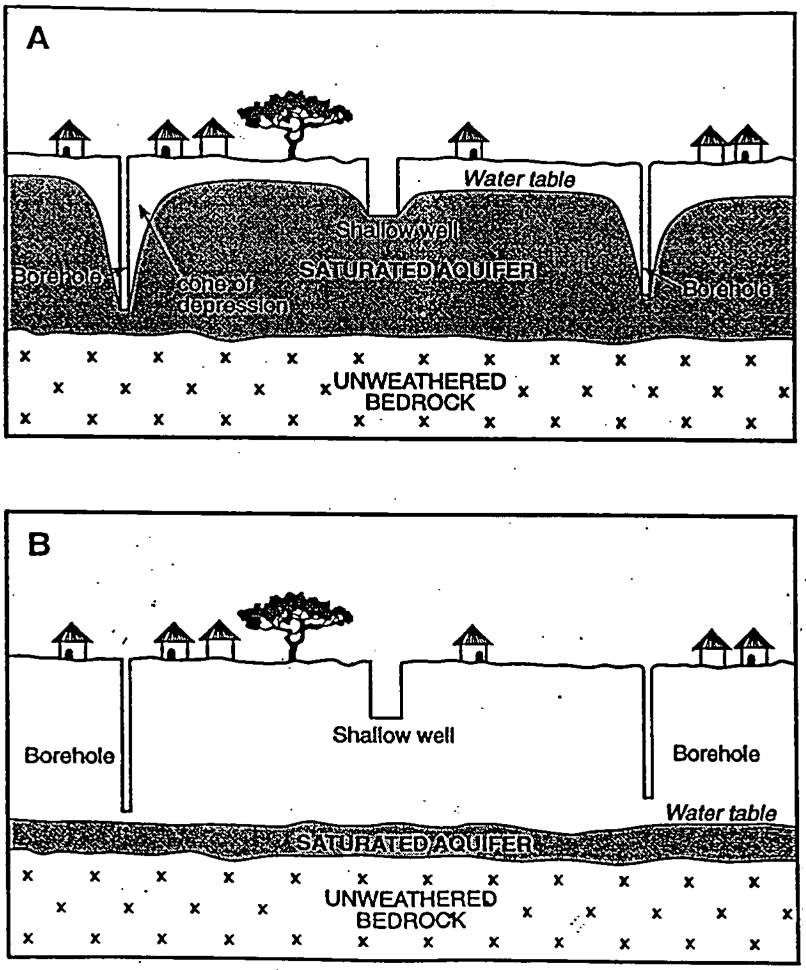

Figure 2 Source versus resource limitations on groundwater abstraction

2.5 The delicate balance between demand and supply

Over the course of a year, demand for groundwater is likely to reach a peak when wells and boreholes are at their most vulnerable, in terms of their yield and ability to provide water. Towards the end of the dry season, alternative sources of water from dams and rivers may disappear, leaving communities dependent on groundwater. At the same time, the number of uses to which water is put may increase as families concentrate on brick making and dry season irrigation of small vegetable plots. The combined effect is illustrated in Figure 3 as a dry season peak in groundwater demand.

Water levels in an aquifer, are naturally at their lowest level at this time, with the result that yields are low. This is illustrated as a dry season yield trough in Figure 3 on the water availability curve. It follows that if a well or borehole can only just meet demand for groundwater in a normal year, water availability and demand curves may intersect during a drought year and demand may exceed the supply capacity of the source. Alternatively, an intersection may only occur after several years poor rainfall, illustrated by the gradual, long term reduction in groundwater availability in Figure 3. The result in either case may be a reduction in water levels, a further decline in yield, and possibly the drying up of the source altogether. Failure of the pump mechanism is also more likely as pumping stresses increase.

Figure 3 also illustrates how long term increases in demand can make a source vulnerable to drought that in the past may have provided reliable and perennial supply. In this instance, seasonal and drought-related fluctuations in demand might historically have fallen well below the water availability curve. A long term increase in demand, however, can eventually put the fluctuations above the curve so that demand will exceed supply.

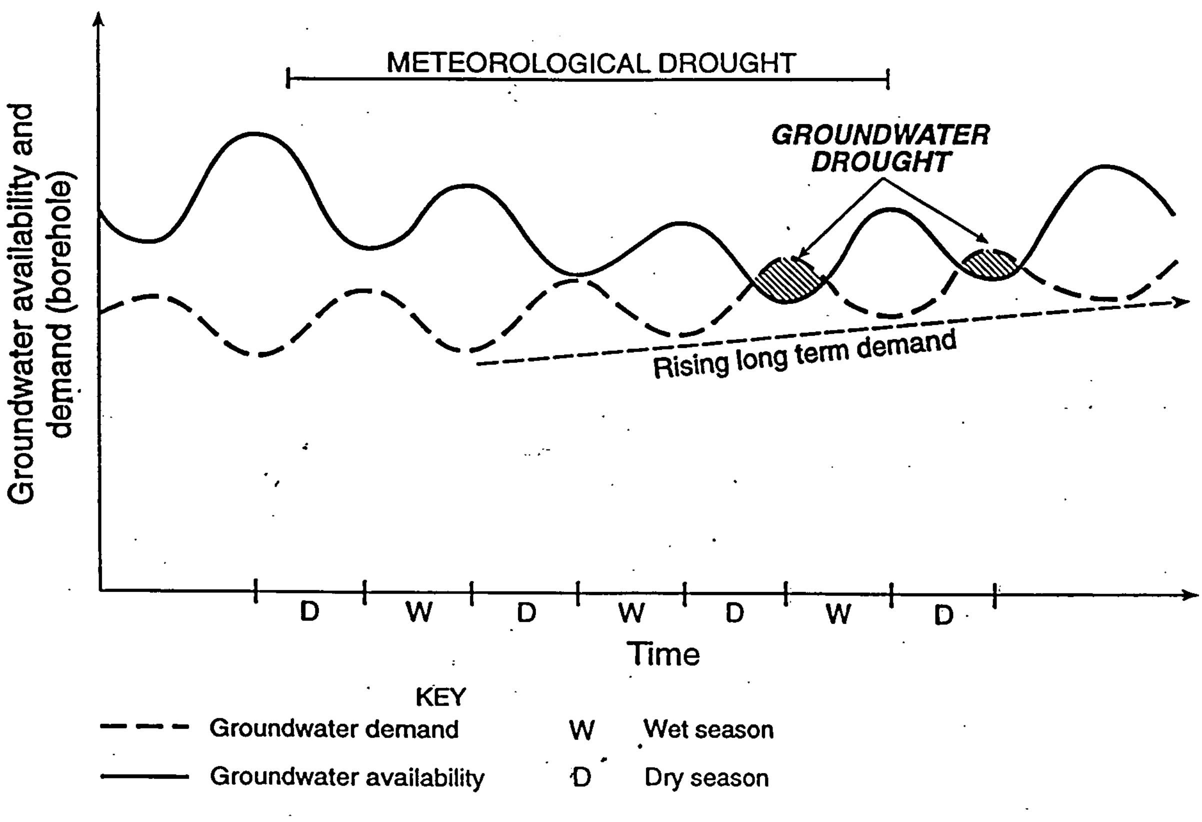

Figure 3 Changes in groundwater availability and demand over time

3. EXPERIENCE FROM MALAWI, GHANA AND SOUTH AFRICA

Three quite different countries were selected, each with its own climatic, geological, socio-economic and institutional controls and influences. Malawi and South Africa have both experienced recent and severe drought in the 1990s, most notably in 1991-92 when low rainfall affected the entire southern hemisphere cropping season. Malawi has continued to suffer, with some relief given by the 1995-96 rains (the effect of the drought is ongoing due to the cumulative effect of successive low rainfall years). South Africa has a low rainfall index and a variability that exceeds that of the Sahel. Here, the 1991-92 drought was reported as being the worst since 1982-83, the latter having been the worst since the 1920s. Ghana is somewhat different and is not generally considered as suffering from recurrent drought. However, although humid towards the coast, conditions become progressively drier inland and the Upper and Northern Regions were badly affected by drought between 1982 and 1984.

3.1 Malawi

Considerable efforts have been made over the last two decades to increase water supply coverage in rural areas of Malawi as a central feature of poverty alleviation and drought relief activities. External assistance has supported much of this work, and Malawi has taken on a mix of multilateral, bilateral and NGO input, as well as committing funds from central government. Much of this support has been targeted on specific projects in the form of capital assistance for borehole construction and hand-pump installation. In more recent years, a change in approach has been occasioned by the inability of the Water Department to service a growing population of water supply sources, and efforts are now underway to promote community based management and participation. The importance of groundwater as a relatively low cost source of potable supply is expected to grow, and groundwater sources already serve the majority of the rural population. However, at any one time it has been estimated that some 25% of wells and boreholes are out of operation, malfunctioning and/or dry because of extended drought (UNICEF, 1995).

Like many other countries in eastern and southern Africa, Malawi suffered the worst drought in over 40 years following the failure of the 1991-92 seasonal rains. The 1991-92 rainfall was the second most severe shortfall of the century, with the highest shortfalls recorded in the south of the country. Coming on top of a refugee crisis and economic and social dislocation, the impact of the drought was severe, exacerbating an already bleak social and economic situation.

The impact of the drought on the nation's water resources was profound. Many rivers and piped water systems dependent on them dried up for extended periods, causing hardship to towns and cities. Perhaps the greatest effects were felt in the many small villages in rural areas, however, where small holders saw their crops fail and where the majority of the population are dependent on groundwater from boreholes and traditional sources such as shallow wells and river dug outs. Here, most shallow wells were reported as drying up altogether; traditionally shallow wells have been dug at the end of the dry season to ensure perennial supply. The result was growing reliance on groundwater where it could be accessed through serviceable boreholes, and use of unprotected water sources (including Lake Malawi) not routinely used for domestic use. With relatively limited borehole coverage at the time, especially in the most densely populated and worst affected south of the country, and with large numbers of boreholes and pumps out of commission because of maintenance problems, villagers (mainly women) were forced to walk long distances and queue for many hours for water. By November 1992, government reports indicated that some three million people across the country had inadequate water supplies, a situation exacerbated by the presence of over one million refugees in the south of the country fleeing war in Mozambique.

Although the drought undoubtedly affected the water supply situation in all areas of the country, national figures tend to mask important regional and sub-regional variations in impact. The lack of reliable and comprehensive spatial and time series data inhibits evaluation. In particular, it is difficult to gauge the longer term effects of the 1991-92 drought on groundwater resources and the cumulative effect of successive low rainfall periods. Nevertheless, some important patterns and issues do emerge:

- rainfall is characteristically variable, and even adjacent villages reported starkly contrasting groundwater drought experiences. It seems likely that geological variation may contribute more to differing regional experience;

- relatively few boreholes appear to have dried up completely; those that did were concentrated in hilly and mountainous areas, on aquifers of limited thickness and storage capacity. However, the drought exposed the shortcomings of the government run maintenance programme, and the fact that so many wells and boreholes were not functioning before the drought significantly exacerbated its impact when it did occur;

- determining the cause of failure of boreholes is difficult, and pump failure, silting up of the hole, falling groundwater levels and other problems may all result in an inability to pump water to the surface. Measurements taken from a comprehensive network of dedicated monitoring sites would have allowed technicians to distinguish between resource and source problems, but such a system was not (and is not) in place;

- while the majority of shallow wells were reported as drying up, some wells in areas with shallow water tables (eg in the vicinity of large dambo systems) remained viable.

The social and economic consequences of the groundwater drought are difficult to quantify, but indicators of stress included mounting health problems, long queues for water and inter-village conflicts over water supplies. The health information system in Malawi routinely collects large amounts of data most of which are never analysed, making it difficult to compare data across years and seasons. However, diarrhoeal and cholera outbreaks occurred during the drought, and an epidemic of shigella dysentery began in the Southern Region in early 1992, eventually spreading throughout the country (SADC, 1993). Rural clinics were reportedly inundated with sick infants. Rates of malnutrition, on the other hand, were relatively low, suggesting that the principal health problem may have been water, rather than food related. Drought conditions persisted into the 1992-93 and 1993-94 wet season, with the succession of drought years having a cumulative, though largely undocumented, effect. The result has been a continuation of water resource problems, lasting well beyond the end of the shorter term food crisis.

Reliable information on the status of rural water supplies was unavailable at the onset of the drought, and is a continuing constraint on water sector planning and management (UNICEF, 1995). Instead, the government initiated a series of emergency water supply assessments, with limited support from the donor community, and set up a Water Security Committee. At the same time, and following government appeals, a massive capital programme of well drilling and rehabilitation was launched supported almost exclusively by ESAs and conducted by NGOs. The effectiveness of the emergency drilling programmes in relieving immediate water stress was questionable. In some cases, wells were sunk only after the return of the rains because of logistical and technical difficulties, and one emergency programme designed to address groundwater problems in 1992 was only completed in 1995. Concerns have also been voiced about the sustainability of such programmes, as the nature of the work effectively precludes community involvement in the choice, design, and siting of water points. Follow up funding for the creation of community support structures has also been difficult to obtain for emergency projects once the emergency is perceived to be over.

3.2 Northern Ghana

Ghana is heavily dependent on external assistance in its attempts to increase rural water supply coverage, with development efforts project-based and traditionally focused on the provision of infrastructure. Much of the rural population is dependent on groundwater during the dry season, and *top down* approaches to the provision of services are being substituted by community based programmes in which local people take responsibility for the choice and upkeep of facilities. Ghana is not typically drought-prone, but has experienced severe drought in the past. In addition, large areas of the country have vulnerable, low yielding aquifers which provide unreliable supplies.

During the early 1980s there was a period of reduced rainfall in northern Ghana. In drought-free years, northern Ghana receives rainfall in excess of 1000 mm/year with a 4-5 month dry season. During the dry season of 1983, bush fires raged throughout Ghana causing general damage and exacerbating the effect of the drought. As boreholes began to fail, women had to travel much longer distances for water and in some cases had to pay for using neighbouring wells. In one particular village, Yawn, near the Burkina Faso border, women first had to queue for several hours to use their own well and, as the drought progressed, eventually had to buy water from a village in Burkina Faso.

Two different hydrogeological regions are present in northern Ghana: (a) the Upper Region with moderately yielding weathered basement; and (b) the Northern Region with very poor yielding shales and moderately yielding sandstones. Boreholes and wells in the Northern Region that draw on shales are particularly low yielding and even in non-drought years can be unreliable. In general the boreholes and hand-dug wells within the weathered basement in the Upper Region are reliable in normal years. As a result of the relatively high annual rainfall in northern Ghana there is considerable reliance upon surface waters, both ephemeral streams and larger dugouts and dams. The reliance on surface water in non-drought years put considerable pressure on groundwater sources when the surface water failed.

Long term groundwater level measurements are available at a number of sites in the Upper Region, but none are complete. In particular, records between 1979 and 1984 are missing. The reason for the gap in data is a familiar one: the first phase of an ESA funded project ended in 1979 and the second started in 1984. When the funding ended, so did the monitoring. Sufficient information, however, is available in the hydrographs to show some general points about the response of the aquifer in northern Ghana over the past few years (Figure 4). Several points emerge:

- there appears to be little long term decline of groundwater levels. Measurements in 1993 are roughly similar to measurements in 1976;

- seasonal fluctuations appear greater in boreholes with shallower water tables;

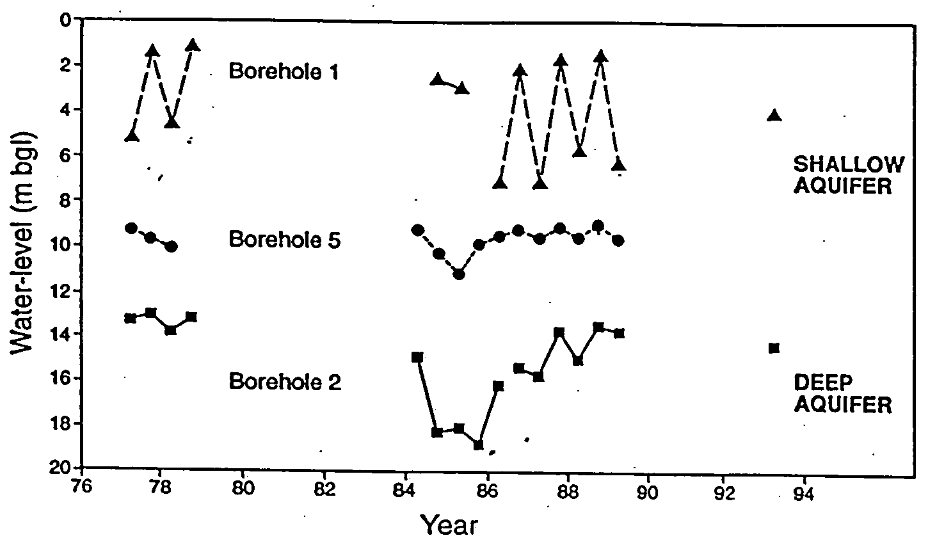

Figure 4 Long term hydrograph for three boreholes in Upper region, Ghana

- water levels in the deeper aquifers were still declining at the end of the meteorological drought in 1984. The lowest water levels were recorded in late 1986;
- shallow aquifers had already started recovering by 1984.

The decline in water levels during the drought was associated with a decrease in the number of operating boreholes, with less than 70% operating in the Upper Region of Ghana by the end of the 1983 dry season. Several contributory factors have been identified, besides the fall of water levels below the pump intake, including heavy silting and pump failure (Wardrop 1987a, 1987b).

3.3 Northern Province, South Africa

One of the first tasks undertaken by the Government of National Unity in South Africa was to set targets for the provision of basic rural water supply and sanitation services. The challenge is a daunting one: it is estimated that over 12 million people (roughly 30% of the population) do not have access to an adequate water supply (Van der Merwe, 1995). Most of these people live in poorer rural areas, neglected under previous policies which favoured commercial agriculture and cities. Not surprisingly, changing government priorities have entailed major institutional upheaval and, like Malawi and Ghana, South Africa is focusing on demand driven approaches to the provision of services which emphasise community mobilisation and participation. At present a variety of different organisations are implementing rural water supply projects, including government, engineering companies, parastatal bodies and NGOs, and efforts are being made to build planning capacity at regional and local levels.

About 80% of South Africa is underlain by secondary aquifers comprising weathered and fractured rocks, generally of low permeability and yield. Groundwater resources assessment and development has hitherto received low priority, reflected in the fact that groundwater only provides around 13% of total supply. Of this, roughly 80% is used for irrigation on large farms which generally overlie the more productive aquifers. Growing competition for surface water resources, however, and the new imperative for meeting the basic water needs of the country's rural population, mean that groundwater will become an increasingly important source of supply. A major difficulty constraining the use of groundwater, however, is uncertainty about yields and demands, particularly outside the main commercial areas. The government is currently undertaking a major mapping and data collection exercise to overcome this problem.

In Northern Province, there is a wide disparity between of levels of provision of water supply with, in general, areas with the highest population densities having the lowest coverage. These areas correspond to the former homeland areas of Gazankulu, Lebowa and Venda, where the proportion of the population with inadequate water supplies is estimated as 95%, 50% and 80% respectively. Groundwater is the most important source of water supply for the majority of the population, with estimates ranging between 80-90% of total supply. Groundwater is supplied primarily from boreholes which, for larger settlements, are generally motorised and feed into reticulated systems with standpipes. Hand pumps are found in less densely populated areas and were installed on emergency boreholes drilled during the drought relief programmes of 1991-95 (see below), but are not an important feature of current coverage efforts. Springs are also an important source of supply. In the central and southern districts of the province, where population densities are high and perennial rivers are few and far between, groundwater is often the sole source of supply. Towards the west, large commercial farms overlying some of the most productive aquifers of the province abstract large quantities of groundwater for irrigation.

South Africa is afflicted by severe and prolonged droughts, often terminated by severe flooding. South Africa's average rainfall of 500 mm is well below the world average, and the timing and distribution of rains is unreliable, particularly in the summer rainfall region in the north. Over the last two decades, the country has suffered two major droughts, most recently in 1991-92. While the effects of the drought were felt country-wide, the Northern Province was particularly badly hit. In Pietersburg, for example, average rainfall for the 1991-92 season was some 470 mm less than average, with the deficit increasing to over 1500 mm in the Nebo area of the former Lebowa homeland (du Toit, 1995).

In contrast to earlier drought relief efforts, which focused almost exclusively on cities and the commercial agricultural sector, attempts were made to mitigate the worst effects of the drought in the former homeland areas. As in Malawi, however, the lack of reliable and comprehensive information on the status of rural water supplies and the impact of drought constrains evaluation. Nevertheless, it is possible to draw some tentative conclusions:

- the drought exacerbated the already inadequate water supply situation prevailing in rural areas, causing widespread water stress. Reports of people travelling distances of 10-15 km to fetch water were not uncommon;

- lack of pre-drought monitoring, communication and coordination problems, and community involvement in water supply made it very difficult to determine the precise cause of water supply difficulties. However, reports indicate that both surface water and groundwater systems failed, either because of poor operation and maintenance, or because sources dried up altogether. Those involved in relief efforts suggest that the principal problem was one of pump failure and fuel shortages with, in particular, the drought exposing a backlog of maintenance problems;

- although absolute water scarcity may not have been the principal problem, it seems clear that there was a widespread reduction in spring flow and groundwater levels. Indeed falling groundwater levels and borehole yields may have contributed to the technical difficulties noted above. Areas experiencing problems of absolute groundwater scarcity included the southern districts and north western areas of the former Lebowa homeland, where groundwater resources are poor and the success rate for borehole drilling low;

- longer term demographic trends may have exacerbated the effects of the drought, with rapid population growth in rural areas leading to rising demand and increased pressure on groundwater sources. In addition, du Toit (1996) suggests that the high rainfall of 1974-76 led to the expansion of spring-side settlements above and beyond the supply capacity of the sources.

The relief programme was handicapped by the lack of pre-drought information on rural water supplies, and by the urgency of action forced upon participants. As du Toit (1996) noted:

> The massive mobilisation of DWAF and other role players to supply emergency water had all the signs of crisis management. The rushed field surveys and borehole siting, despite the good success rate, resulted in the drilling of many unsuccessful or unnecessary boreholes. This contributed to the perception of unreliability of groundwater amongst the engineering profession in South Africa

Hazelton et al (1994) supported this conclusion:

> For the rural subsistence inhabitants there have been no formal structures to monitor drought and to provide relief. Often the structures have been set up on an ad hoc basis, often when drought has reached disaster proportions.

The programme proved extremely costly in terms of both equipment and manpower, and necessitated the diversion of financial and human resources away from longer term programmes. Du Toit (1996) estimates that the overall programme cost DWAF alone in excess of $20 million, with large sums of money also spent by ESAs and NGOs.

The government is now urgently addressing some of the problems highlighted above. In particular, the collection of baseline information on rural water supplies and the communities they serve is seen as a particular priority. Specific data needs identified include the names and locations of rural villages, demographic features, water supply coverage levels by technology type, and basic hydrogeological data, including information on water quality. A comprehensive database of borehole information, including at least the location, yield and depth of boreholes already exists for other areas, and this has been used to produce *safe abstraction maps* delineating areas limited by yield or storage. It is anticipated that, once baseline information has been assembled for the poorer rural areas, similar manipulative processes can be applied to the data. This may go a long way towards regional drought sensitivity analysis.

4. DROUGHT SENSITIVITY ANALYSIS

Drought sensitivity maps can be developed on a common conceptual framework. This brings together indices of physical resources (physical sensitivity) with indicators of supply coverage and demand (human sensitivity). Together these factors highlight those areas which are most at risk of groundwater drought (Figure 5).

The maps can be used for a variety of purposes. They enable resources to be targeted at the most vulnerable communities so that drought proofing measures can be implemented at pre-drought periods. They can also be used to identify critical areas for monitoring water levels and water source status. More generally, they can be used to provide foci for sector planning, particularly in relation to programme and project prioritisation and choice of technology.

4.1 Physical sensitivity

The ability of an aquifer to provide water throughout a drought period depends on several factors. Firstly the aquifer has to have sufficient storage for water to be available. Secondly, there needs to be reliable recharge in non-drought years to provide a sustainable source of water. Finally, groundwater must be sufficiently *mobile* to move from the aquifer to the wells and boreholes; this is governed by aquifer permeability.

Resource storage is a function of the aquifer thickness and the storage coefficient of the aquifer. Aquifer thickness throughout much of Africa is equivalent to the depth of weathering. Long term pumping tests with observation boreholes are required to accurately determine the storage coefficient, but this is rarely done. However, estimates of the storage coefficient can be derived from the geology.

Recharge to an aquifer is difficult to determine accurately and reliably, but many estimation methods exist (Lerner et al, 1990). These include the use of fixed proportions of the annual rainfall, the baseflow index from river hydrographs, or chloride concentrations in groundwater. More accurate methods rely on measurement and modelling of soil moisture content. The variability of rainfall from one year to the next is also important in drought vulnerability. If the long term average recharge in an area is quite high, but rainfall is unreliable from year to year, then the vulnerability is higher than in an area with the same average recharge, but spread more evenly from year to year.

Data on aquifer permeability are not usually available, but a more common measurement is specific capacity, which relates the drawdown in a borehole to the pumping rate. If no specific capacity data exist, an estimate of the yield of a borehole can be used to approximate permeability. If no hydrogeological data exist at all, a field hydrogeologist must estimate permeability using a geology map as a guide.

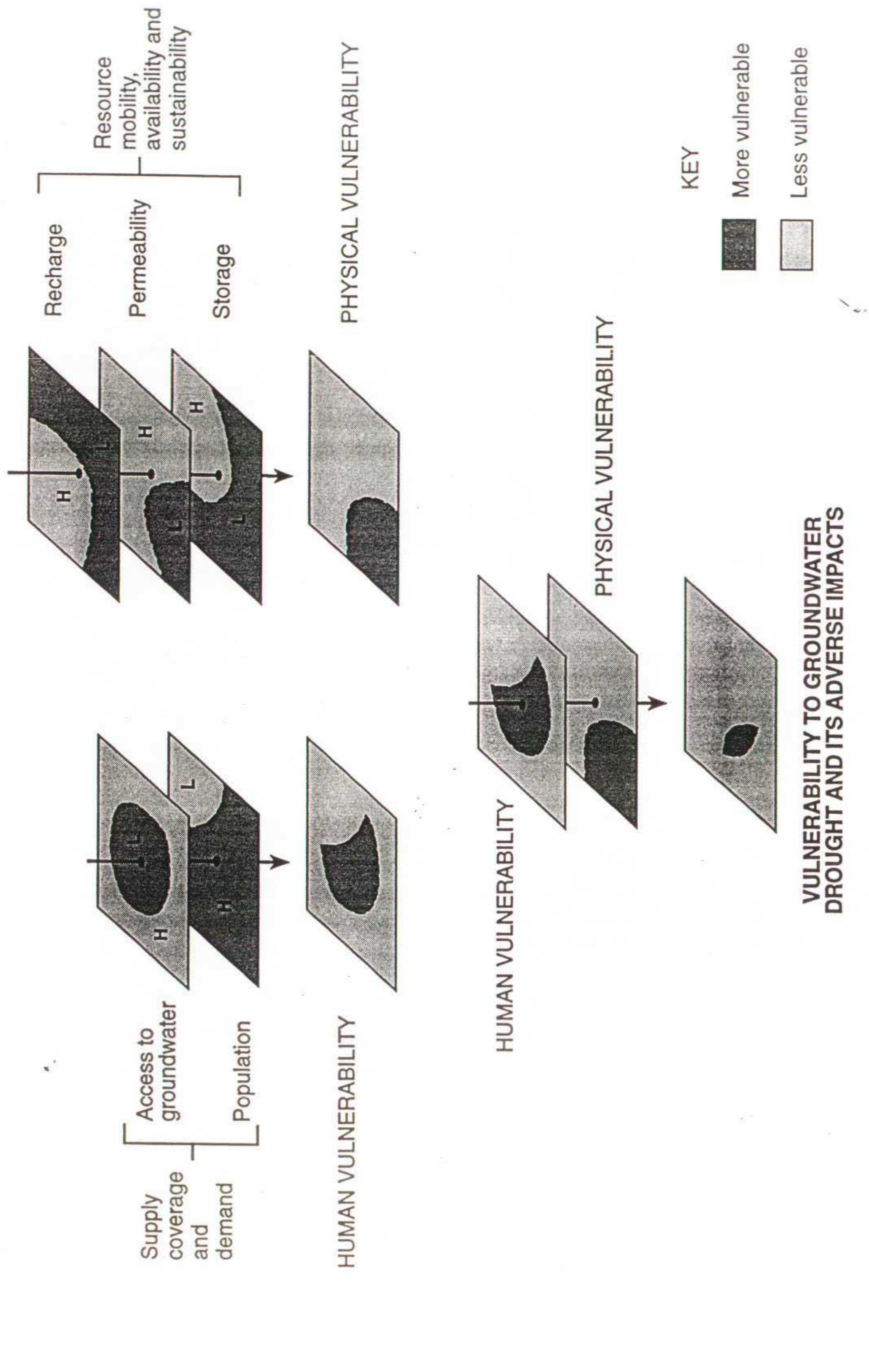

Figure 5 Conceptual framework for groundwater drought vulnerability mapping

4.2 Human Sensitivity

Groundwater drought sensitivity is not determined solely by physical factors; some communities will be more predisposed to drought hazards than others. The sensitivity of human settlement to groundwater drought depends on a number of different factors, some of which are more amenable to quantification than others. However, a preliminary conclusion is that in areas where groundwater supply coverage is low, there are few reliable surface water alternatives, and population density and water demands are high, the impacts of drought on water security will be particularly severe.

At the most basic level, maps can combine some surrogate for water demand, such as population density, with the availability of groundwater sources, such as borehole coverage. These statistics are often available from government departments. Where more data are available, more sophisticated maps can be produced. For example, coverage could be disaggregated by technology type, to give shallow well and borehole dependencies. Data on the availability of alternative surface water sources, such as perennial rivers and lakes, would also be useful.

4.3 Vulnerability maps

Once data on the key determinants of groundwater drought have been collected, they must be combined to produce usable vulnerability maps. It is important to keep the process as transparent as possible so that users can quickly assess how a high or low vulnerability area was identified. For this reason, three maps should be produced for each area: (1) a physical map; (2) a human/social map; and (3) a combined drought vulnerability map. The method lends itself to use on a Geographical Information System (GIS). However, maps could also be compiled using conventional drawing techniques

The physical vulnerability map is produced by combining recharge, storage and permeability indices. Each determinant is divided into three different categories: high, medium or low. The determinants are then combined in a matrix to provide an overall physical vulnerability map. Recharge and storage, measuring the absolute size and sustainability of the groundwater resource, are given twice the weight of permeability, which indicates mobility. The physical drought vulnerability map is also classified into high, moderate and low.

The human/social map is produced in the same manner by dividing both population and coverage into the same three categories and combining them in a matrix. Both are given equal weights. The resulting human/social drought vulnerability map indicates where population is highest and borehole/well coverage is lowest. The map showing the overall vulnerability of an area to groundwater drought can be created by overlying the physical and human/social maps (Figure 5). Together, human and physical factors determine the vulnerability to groundwater drought and its impacts.

4.3.1 Northern Province, South Africa

South Africa is relatively data rich compared with the majority of African countries. During 1995 all available groundwater data were brought together in a National Groundwater Resources Map (Vegter, 1995), and a series of interpretive maps portraying safe levels of groundwater abstraction was produced. From the coverages that were used to produce these maps (prepared using ArcInfo) come two of the constituent layers used in the physical vulnerability maps. The first, *groundwater storage,* combines recommended depth of drilling across the country, based on a statistical analysis of water strikes from borehole drilling, and storage coefficient, related to the rock type. The second is based on the yields of optimally sited boreholes as a surrogate for *aquifer permeability* (no aquifer permeability map is available). The third layer in the physical vulnerability map, *recharge*, was obtained using the output from a soil water balance model called ACRU (Schulze, 1995). This model uses daily rainfall, soil and vegetation type as

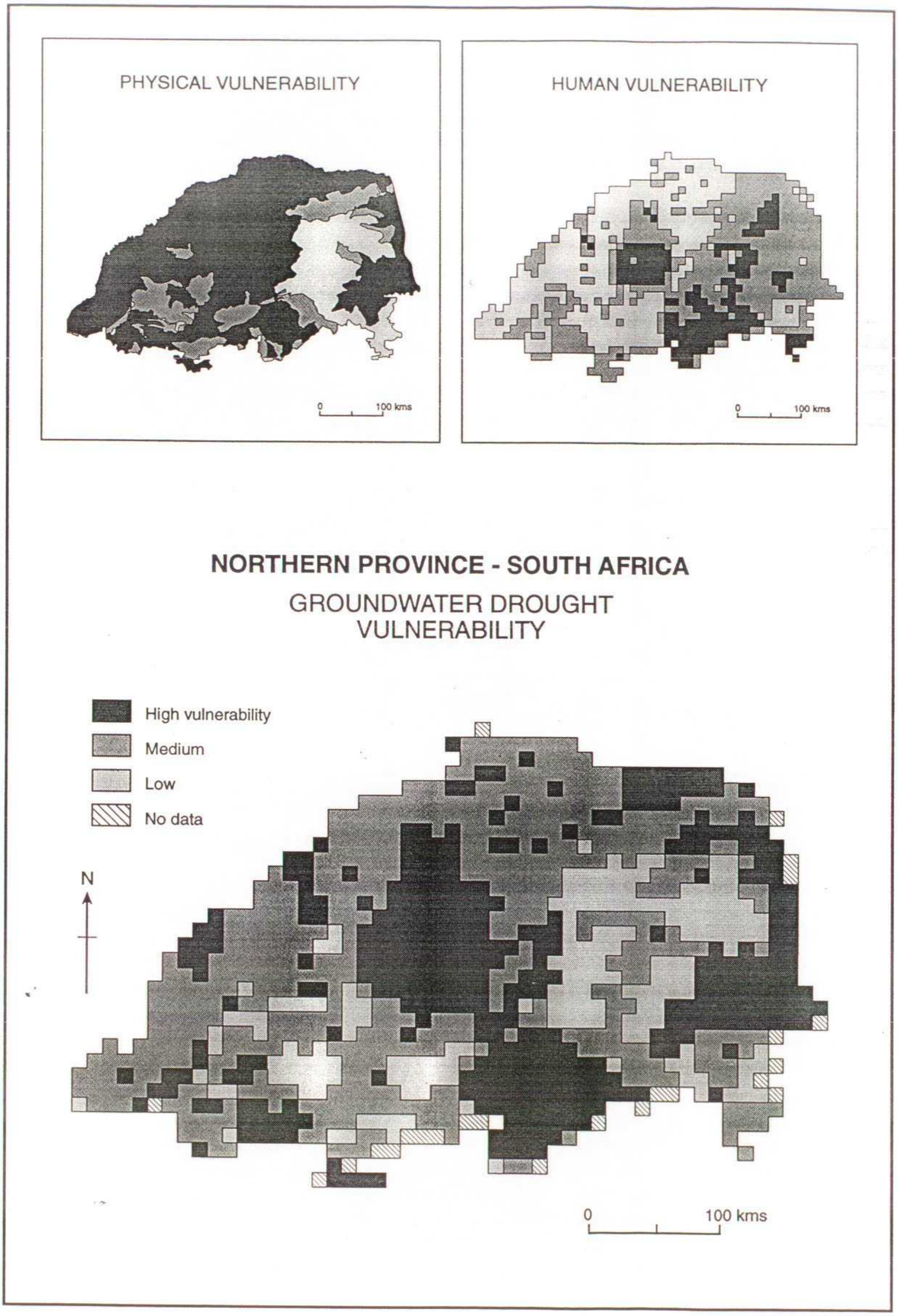

Figure 6 Groundwater drought sensitivity map for Northern Province, South Africa

input and calculates runoff and effective rainfall (recharge). The model had been run for a total of 1946 quaternary catchments over the period 1950-1993. From the model output, coverages of average recharge and recharge variability were calculated for Northern Province. These were combined and input into the physical vulnerability map (see Figure 6). The process of preparing and combining all the layers for Northern Province was carried out using the ArcInfo package.

The data used for the human vulnerability mapping exercise was less comprehensive. Within Northern Province a large proportion of the rural population resides within the former homeland areas. Adequate statistics both on borehole coverage and population within these areas is only now being collated. Acknowledging the inadequacies, borehole data from the National Groundwater Data Bank were used to produce a *borehole coverage* map. The population data were taken from a global data set of gridded population on a 5' by 5' interval (Tobler et al, 1995). This explains the gridded nature of both the human vulnerability and overall vulnerability maps. The latter shows that the zones of high human vulnerability match well the areas of the former homelands. The large areas classed as high within the overall vulnerability map match roughly with the areas that suffered most during the drought of the early 1990s.

4.3.2 Malawi

Fewer data are available for Malawi than for South Africa, and groundwater storage and aquifer permeability maps do not exist at all. Low, medium and high storage and permeability classifications were assigned to each formation based on the knowledge of local hydrogeologists. This process was aided by the digital data held within the Southern African Flow Regimes from International Experimental and Network Data Project (Bullock et al, 1997).

Recharge, as with Northern Province South Africa, was calculated using the ACRU model. This was combined with rainfall variability, based on data from 37 rain gauging stations. The data required for input to the ACRU model was not available over the whole of the country, and data are missing in the south. The impact of this carries through to the physical vulnerability and overall vulnerability maps.

The borehole coverage data in Malawi are detailed, and the low, medium and high categories were set to have roughly equal areas across the country. The 5' by 5' gridded population data were used. The human vulnerability map in Figure 7 reflects the form of the input data. The missing recharge data masks the area in the south that was most affected by the severe drought of the early 1990s.

4.3.3 Ghana

Ghana differs from the other two case studies, South Africa and Malawi, in that there are very few data available for the country. The data that are available are difficult to access; at the moment there is no coherent data collection or databasing for hydrogeological data. In addition, there is no geological or hydrogeological GIS set up for Ghana, so no digital coverages are available for the country. Since the baseline data required to create the vulnerability maps did not already exist, a slightly different approach was taken. However, the underlying system of estimating vulnerability is the same.

IDRISI, a simple, inexpensive PC based GIS was used to build the maps. IDRISI is raster based, therefore allowing easy overlaying of coverages (Eastman, 1995). The physical vulnerability map was compiled using the 1:1 000 000 geology map prepared by the Ghana Geological Survey (1955), some borehole yield and specific capacity data from available reports (e.g. Gill 1969, Tod 1981) and a rainfall distribution map. Specific capacity data were mainly used to classify the permeability of the various geological units along with borehole yield data and a little anecdotal evidence. There were no direct data on groundwater storage; geology was again used as a guide and classified using information from other groundwater studies on similar terrains The rainfall distribution map was used to estimate the approximate recharge throughout the country. There are even fewer data available on human vulnerability, with population and coverage

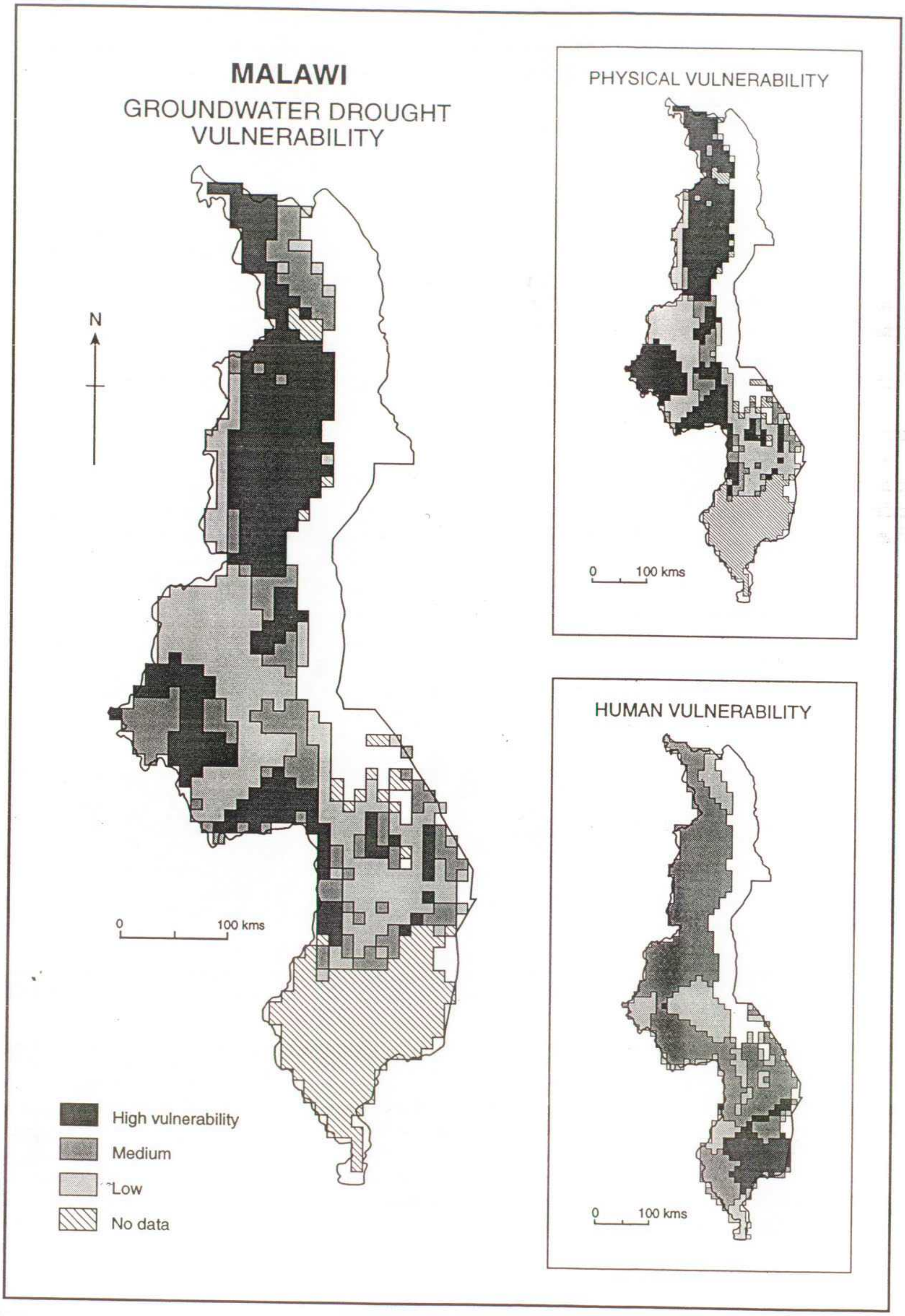

Figure 7 Groundwater drought sensitivity map for Malawi

data only available at a regional scale. The northern Ghana study area only covers two regions at present. Figure 8 shows the physical, human and combined drought vulnerability map for northern Ghana, highlighting the area underlain by weakly permeable shales and the main centres of demand as vulnerability hot spots.

5. GROUNDWATER MANAGEMENT FRAMEWORK

There are a number of ways in which groundwater management in drought-prone areas could be improved. A distinction is made between issues and strategies relating to the longer term management of groundwater resources in pre-drought periods, and those relating to short-term, reactive management during drought, particularly the role and use of emergency drilling programmes.

5.1 Pre-drought proactive management

In all three countries, groundwater development is continuing apace in an effort to meet the growing need for safe, low cost water supply. Much of this development proceeds in an uncoordinated manner, driven by the needs of development projects supported by a wide variety of organisations. In these efforts, groundwater is typically treated as an ill-defined *black box*, with little attempt made to tailor policies and technologies to resource characteristics. Typically, resource assessments are project specific; monitoring programmes, if undertaken at all, begin and end with projects; and drought is rarely planned for despite its routine occurrence. As a result, no comprehensive picture emerges of either the national status of rural water supplies or the status of the groundwater resources themselves, and predictable variations in groundwater drought vulnerability are not accounted for. An a priori conclusion is that, without such knowledge and the policies which reflect it, groundwater droughts will continue to take governments, NGOs and donors by surprise, large sums of money will be spent on emergency drilling programmes, and water supply infrastructure - irrespective of whether it is 'managed' by government or local people - will be subject to predictable failures.

5.1.1 Groundwater monitoring and assessment

The need for a clear understanding of the resource base is essential if development of groundwater is to proceed in an appropriate and sustainable fashion. Similarly, the need for reliable and timely information on the status of rural water supplies would seem fundamental to any form of groundwater drought planning and mitigation. The lack of this information, at least in an accessible and useable form, has been a serious constraint on sector planning and management in Ghana, Malawi, and South Africa. In all three countries, the situation is exacerbated by the fact that data holdings which do exist are dispersed amongst a range of different organisations (government, NGOs, consultants) at different levels (national, regional, local). A typical result is that new projects are designed without the benefit of existing data, the activities of different organisations are insufficiently coordinated, and groundwater development proceeds in an ad hoc manner.

In Malawi, UNICEF (1995) note that up to date compilation of data has been constrained by lack of institutional stability and capacity, and the need to respond to drought and refugee emergencies. In addition, funding constraints and lack of transport are a continuing constraint to data collection at field level; it is not uncommon for district level technicians to be without transport for months, making compilation of regular water supply assessments impossible. The government recognise the need to instigate a comprehensive water level and water quality monitoring and databasing scheme, and to organise existing data (well and borehole records) in electronic form, but attracting donor support for these activities is difficult. Similar issues arise in Ghana, where data holdings are regional rather than national and where many NGOs hold their own databases. In South Africa, efforts are being made to develop a National Water Supply and Sanitation Management Information System to address the problem.

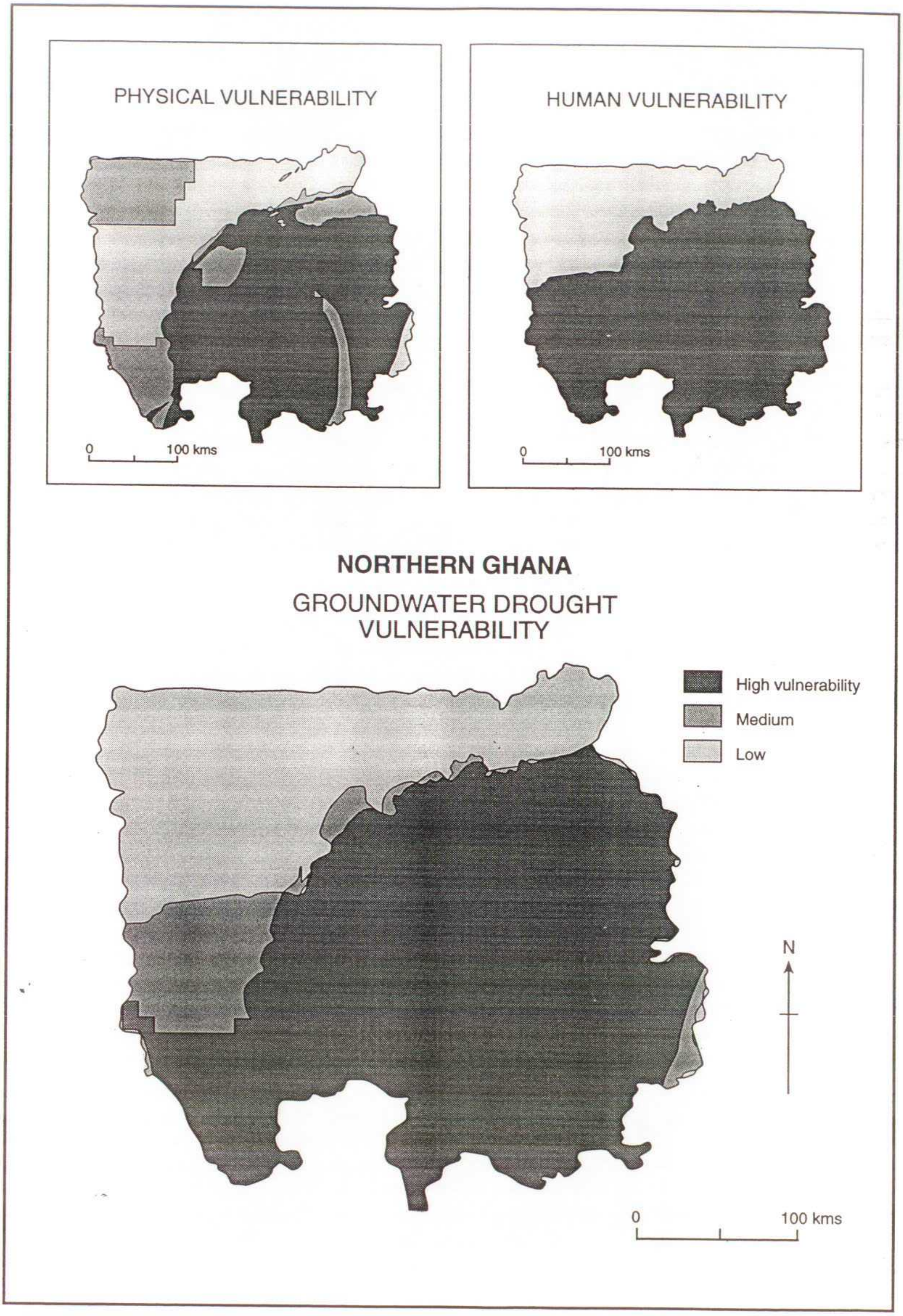

Figure 8 Groundwater drought sensitivity map for Northern Region, Ghana

Appropriate strategies are numerous, but there is an urgent need to:

- recognise the importance of establishing (and maintaining) a sound hydrometeorological and groundwater database that can be used routinely in the planning of new projects and in groundwater drought mitigation. Governments, ESAs and NGOs typically place a low priority on these activities. Reasons include: difficulties in quantifying benefits and verifiable indicators of success, especially over the shorter funding periods now being demanded by donors; a preference for dealing with immediately tangible problems which produce short term results (eg borehole drilling programmes and the installation of hand pumps); and reluctance on the part of hard pressed governments to divert resources away from more pressing, operational issues;

- establish monitoring systems which extend beyond rainfall, surface water and food security indicators to groundwater and groundwater supply status, recognising that antecedent conditions (eg river flows and groundwater levels of the previous year) are essential guides for predicting future hydrogeological (not meteorological) conditions. Ideally, these should be able to distinguish between the different factors contributing to well/borehole failure, in particular, the distinction between source and resource stresses and source/resource and maintenance problems. This indicates a need to collect data on groundwater conditions from a dedicated network of monitoring points;

- ensure that the role of monitoring and assessment is clearly defined within the new institutional arrangements emerging in the region. In Ghana and Malawi, for example, many of the operational tasks traditionally carried out by government are being turned over to local communities. A similar approach is being advocated in South Africa. In theory, this should allow water departments to devote more time and resources to matters such as monitoring and assessment, but tasks and funding arrangements have yet to be clearly defined.

5.1.2 Groundwater drought vulnerability analysis and early warning systems

In view of the predictable nature of groundwater drought vulnerability (to incidence and impacts), vulnerability maps can be developed for drought-prone areas (see Section 4). These could be used to help target scarce resources to sensitive areas in pre-drought periods, and ensure that appropriate technical choices in terms of drilling methods and the choice and design of wells and boreholes are made in different areas. In the growing number of instances where communities themselves make their own choices from a menu of different water supply options (eg in Ghana), the menu offered could be tailored to ensure that the options on offer are appropriate to local hydrogeological conditions. In addition, such maps might provide a useful focus for coordinating the efforts of the different organisations undertaking water supply projects, prompting discussion and exchange of data and ideas on water supply priorities.

In terms of groundwater drought prediction in space and time, there is a need to develop national drought plans for the water sector to include simple early warning systems to warn of groundwater problems and adverse impacts. Here, developments are very much tied to progress made in establishing long term monitoring and assessment programmes; reliable early warning systems depend on reliable data and long term tracking of meteorological and hydrogeological trends. In South Africa, Hazelton et al (1994) suggest that a key element of any drought plan should be the establishment of a Water Inventory Outlook Committee, whose principal aims would be to (a) compile and analyse data from observational networks operated by government and NGOs, enhancing those networks where necessary; (b) determine user needs in terms of specific data requirements, format and presentation; (c) develop triggers and an early warning system, using a combination of indices to initiate specific and timely actions by different organisations;

and (d) identify drought affected areas for targeting.

An early warning system designed to warn of groundwater drought would need to monitor antecedent meteorological and hydrological conditions as well as groundwater indicators (eg water levels and yields). Thresholds would also need to be established such that once exceeded, actions defined in the drought plan are triggered. Indicators of water stress could also be incorporated, for example incidence of water-related diseases from clinics. In this way, the system could be strengthened through incorporation of data generated by other departments and by other (non-water) projects. Experience from other countries in the region (eg Zimbabwe) indicates that responses need to be flexible and not centrally prescribed; problems may be highly localised, and it is only at lower levels (the lowest level at which capacity exists) that problems can be assessed in the proper context and solutions recommended.

As a caveat, it should be noted that information by itself will not guarantee an early response. Experience with early warning systems established to monitor food security indicate how the response can be too little and too late, despite the existence of a well established warning system (Buchanan-Smith and Davies, 1995). Reasons include the politicised nature of the information generated, and failure to link early warning to response systems.

Possible strategies include:

- groundwater drought vulnerability mapping using various indices and manipulative processes is a potentially useful groundwater management tool. In South Africa the current hydrogeological mapping exercise, when coupled with climatic, demographic and other baseline data, will go a long way towards regional drought vulnerability analysis. It is anticipated that similar systems can be developed for Ghana and Malawi at relatively low cost, using data already held by different organisations. Vulnerability maps can potentially incorporate many different layers of information, reflecting the fact that a combination of factors (physical, demographic, socio-economic) conspire to create problem areas. Useful additions, for example, could include demographic and well/borehole coverage data, so that areas where the impacts of groundwater drought may be most severe can be identified;

- although early warning systems monitoring food security are now commonplace, there is a need to develop drought plans which incorporate water resources assessments, including groundwater. An early warning system for groundwater drought could be based around a combination of indices indicating both occurrence and impact of groundwater drought, and linked to a response system in such a way that, once key thresholds are exceeded, mitigating actions are triggered.

5.1.3 Drought resistance

Much can be done in pre-drought periods to improve the reliability of sources during droughts. Following on from the above, it is clear that sound information on the water resources base and identification of vulnerable areas can facilitate tailoring of water supply developments to local conditions. Ultimately, decisions need to be made on a pragmatic basis, reflecting both the wishes (and increasingly, ability to pay) of local people as well as sound hydrogeological assessment.

Greater coordination and sharing of information between different players in the water sector is also required, especially as the number of NGOs with differing and multiple accountabilities increases (Edwards and Hulme, 1995). Past mistakes need to be avoided, and success stories - for example where the drought-proofing of rural communities has been effective - need to be shared. In addition, the experience of all three countries underlines the importance of effective maintenance arrangements; the impact of a groundwater drought is potentially much worse if a large proportion of water points are already non-operational.

A number of relatively simple measures could be implemented to prevent or reduce the likelihood of groundwater drought occurring. Examples include:

- the Northern Region of Ghana, where shallow wells are completed to a depth of not less than 3 m below the natural water table, and where an extra concrete ring is cast and left at the well head to facilitate deepening at some time in the future should the need arise;

- well/borehole deepening in selected areas as a routine component of rehabilitation programmes;

- the routine sinking of an extra well or borehole in villages where, because of the nature of the aquifer, falling water levels are specific to individual sources;

- the sinking of deep boreholes in the most favourable hydrogeological locations which could be uncapped and used in emergency situations. Such boreholes could be used by households from different villages should local village sources dry up.

5.2 Short-term reactive management

Backup systems still need to be in place to tackle emergencies that do arise. The aim of these should, however, be to relieve water stress in drought affected communities as quickly as possible.

5.2.1 Types of intervention

A broad range of interventions is possible when responding to groundwater drought. In Malawi emergency drilling programmes were organised in response to the 1991-92 drought, and efforts were made to speed up rehabilitation and maintenance programmes. In South Africa, emergency drilling programmes have been supplemented by water tankering operations in the worst affected areas of Northern Province.

In both countries (and elsewhere), the effectiveness of emergency drilling programmes in relieving water stress has been questioned. In Malawi, for example, some drilling programmes did not get underway until after the return of the rains, but hasty organisation left little scope for community mobilisation and follow up work to ensure sustainability. In Northern Province, South Africa, many unsuccessful or unnecessary boreholes were drilled, and it is likely that many of those that did produce water may now have fallen into disrepair, or have been abandoned. Nevertheless, such programmes remain attractive to donors. One of the principal reasons for this is that financial support continues to be much more easily mobilised for emergencies than for longer term efforts aimed at drought-proofing rural communities, or indeed for supporting much needed monitoring and assessment programmes.

Appropriate strategies include:

- the limited effectiveness of emergency drilling programmes needs to be recognised by the donor community, and greater emphasis needs to be placed on longer term pre-drought prevention and mitigation measures;

- the use of temporary, stop-gap measures may be more effective than 'quick fix' solutions aimed at rapid installation of permanent water supply infrastructure. Such measures include assisting communities with the transport of water (eg through provision of water carts and the animals to pull them) and, where institutional capacity permits, the tankering of water by lorry or tractor drawn water-bowsers. In Lesotho, butyl rubber water bags (bladder tanks) were used as reservoirs, facilitating rapid turnaround of tankers;

- ultimately, decisions regarding the appropriateness of interventions need to be made at local level where problems can be assessed in context. Water stress tends to be a much more localised problem than food insecurity as food can be transported further and more easily than water. The challenge is how to identify affected communities. However, this information is rarely available at national level, and there is a clear need to decentralise the response to groundwater drought within the context of a national strategy.

6. CONCLUSIONS

Surprisingly little attention has been paid to the subject of groundwater management in drought prone areas despite recent experience of groundwater drought in Africa. The reasons are many, and include a preoccupation with food rather than hydrogeological aspects of drought, and monitoring programmes which, if functioning at all, focus on immediate cause and effect relationships rather than longer term tracking of the antecedent hydrological and hydrogeological conditions that can lead to groundwater drought.

Groundwater management and drought experiences from Ghana, Malawi and South Africa are in many ways unique, reflecting country specific resource and rainfall characteristics and different groundwater development approaches. Several issues transcend individual country experiences, however, and point to ways in which management might be improved throughout Africa. In particular:

- there is a need to recognise that the processes contributing to groundwater drought occur over the longer term, and there may be great variability in the timing, nature (quantity and quality) and magnitude of impacts. These processes and variations are potentially predictable but rarely accounted for in water sector planning;

- a prerequisite for more effective management of groundwater resources and drought prediction is reliable, comprehensive and timely information on the status of rural water supplies. However, low priority is given to monitoring and assessment activities by governments and donors. Water departments are typically concerned with more pressing operational issues, and ESAs seem reluctant to support long term programmes which do not produce short term, tangible results;

- research is needed to determine how cost effective yet reliable monitoring networks can be established and maintained. In addition, monitoring responsibilities for both data collection and data analysis need to be clearly defined as institutional structures and responsibilities change;

- pre-drought mitigation strategies which help to *drought-proof* rural communities and target resources to vulnerable areas may be much more effective than reactive, quick-fix interventions undertaken during (or often after) droughts. Emergency drilling programmes prove popular with ESAs, but evidence from Malawi, South Africa and elsewhere indicates that they may sometimes do little to relieve water stress and may put in place an unsustainable infrastructure;

- over the last decade numerous early warning systems have been set up to monitor food security, particularly in relation to drought. There is now a pressing need to develop systems which help predict groundwater droughts, detect early symptoms of water stress and trigger appropriate responses: to this end the concept of groundwater vulnerability maps is a beginning.

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