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GROUNDWATER MANAGEMENT IN DROUGHT PRONE AREAS OF AFRICA. MALAWI INCEPTION REPORT

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Collecting water from a village borehole in the Shire Valley

Keyworth, Nottingham, British Geological Survey, 1996

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PREFACE

Almost by definition, drought in drylands means that surface waters are scarce and groundwater is the principal, or only, source of supply. In severe drought, yields from these sources may decline markedly at a time when the demand for groundwater typically reaches a peak. The result may be falling numbers of viable water points, and escalating social and economic costs. Set against longer term demographic and economic changes affecting demand and recharge patterns, the availability of perennial groundwater supplies cannot be assumed, as recent drought experience in southern Africa demonstrates.

The subject of drought in drylands has been extensively researched, particularly from food security, meteorological and sociological perspectives. However, relatively little attention has been focused on the impact of drought on groundwater resources. Drought management strategies reflect this fact. A typical strategy involves an emergency drilling programme in which rigs are imported, international expertise mobilised and large sums of money spent. The execution of these programmes is often poor, however. Wells are poorly sited, community participation is minimal and maintenance of new works is not prepared for. In addition, the response often comes too late, and it is not uncommon to find emergency drought relief wells being sunk after the rains have returned. Within a short space of time, the stock of unsustainable water supply infrastructure is increased, and funds have been diverted from longer-term programmes.

Against this background, the British Overseas Development Administration (ODA) has supported a project entitled 'Groundwater management in drought-prone areas of Africa' (R6233). A key contention of the project is that some wells, and some areas, are much more vulnerable to 'groundwater drought' than others, and that essentially predictable variations are rarely planned for or acted upon. One of the principal aims of the project is therefore to identify ways in which spatial and temporal information on the impact of drought on groundwater resources can be used to improve groundwater management. Ultimately, the project will identify specific strategies that could be adopted or promoted by government and the donor community to (a) improve responses to 'groundwater drought' *within* drought episodes; and (b) improve longer term planning for groundwater drought *outside* drought episodes.

The project brings together institutions from four countries in an equal partnership. The countries (and institutions) involved are: Malawi (Ministry of Irrigation and Water Development (MIWD)); Ghana (Ghana Water and Sewerage Corporation (GWSC)); South Africa (Department of Water Affairs and Forestry (DWAF)), and the United Kingdom (the Hydrogeology Group of the British Geological Survey (BGS) and the Institute of Hydrology (IH)). Personnel from four of these institutions - MIWD, GWSC, BGS and IH - designed the project jointly in 1994. DWAF joined the network in 1996, with support from the British Development Division South Africa (BDDSA). Initially, the project will examine the experience of drought and groundwater drought in each of the African countries, documented in country-specific inception reports. Drawing from this common pool of experience and knowledge, the focus of the project will then shift towards the identification of management strategies. An international workshop will then be held in February 1997 to publicise and discuss findings with the government and donor community.

This report is the inception report for Malawi. It is based on discussions held over the last year with MIWD in the UK and Malawi, and also on information gathered during study tours to Malawi undertaken by BGS and IH personnel in 1995.

ACKNOWLEDGEMENTS

This project represents a partnership between different institutions from different countries. The cooperation and enthusiasm of everyone involved has been instrumental in getting the project up and running and, it is hoped, will contribute to greater awareness of the impact of drought on groundwater resources and the methods by which impacts can be prevented or mitigated.

Thanks are due to all staff at the MIWD, including those at regional and district offices, who assisted in the compilation of this report in June-July 1995. Thanks are also due to Mr Kabuka Banda, formerly Acting Chief Hydrogeologist in the Water Department, who helped design the project and assisted in data compilation, and to the people from the aid and donor community, particularly Save the Children Fund (SCF-UK), who were more than generous with their time.

The authors would also like to thank the innumerable and unnamable others, particularly the villagers from many different areas, who were hospitable and who answered our interminable questions about groundwater, wells and drought with patience and good humour.

1. INTRODUCTION

1.1 Drought, food and water

Like many other countries in East and southern Africa, Malawi suffered the worst drought in over 40 years following the failure of the 1991-1992 seasonal rains. Coming on top of both economic and social dislocation, including the influx of over a million refugees from Mozambique, the impact of the drought on both rural and urban economies was profound. Indeed the effects of the drought were not just felt in 1992, but in the following years as well.

Not surprisingly, the drought had a serious impact on the country's water resources. Many rivers and the piped gravity systems that depend on them dried up, causing hardship to towns and cities. Water levels in Lake Malawi fell significantly, threatening the output of down-river hydroelectric power stations. However, perhaps the greatest effects were felt in rural areas. As the majority of the population are smallholders growing principally for subsistence, failure of the rains had an immediate and profound impact on the livelihoods of the poor. A massive food relief programme was organised, with food and assets distributed to the needy. However, one of the most serious problems for the rural population was access to water. A large proportion of the rural population depend on groundwater for potable supplies, and the drought resulted in the widespread drying-up of hand dug, shallow wells. Many boreholes were also affected by falling water levels, though relatively few appear to have dried up completely. This 'groundwater drought' meant that many rural people had no access to safe water supplies, and in areas poorly served by boreholes, many had to rely on the few remaining rivers, or excavate holes in dry river beds. In Chikwawa District alone, approximately 172 000 people were in need of emergency water. Health problems, including dysentery escalated, and local clinics were inundated with sick infants.

1.2 Drought interventions

The problems experienced in Malawi were by no means unique. In Zimbabwe, a much richer country, groundwater supplies dried up and emergency drilling programmes organised. Experience from these and other drought-prone countries indicates a preoccupation with food and food aid. While food interventions have become more sophisticated, most still presuppose the availability of water. As the experience of Malawi, Zimbabwe and other southern African countries illustrates, however, access to safe water supplies may be of equal concern. Indeed, if more sophisticated policy responses to drought aimed at protecting productive assets such as breeding cattle, tools and land are to be successful, one of the main requirements is for people to remain in their villages. This is unlikely if local water sources have dried up.

1.3 Groundwater management in drought prone areas

A key contention of this project, then, is that groundwater drought, and its impacts and mitigation, is a neglected area of research. The ODA-funded project 'Groundwater management in drought-prone areas' is designed to address this need by:

(a) evaluating how drought in Malawi, Ghana and South Africa has affected groundwater supplies and the people dependent on them;

(b) examining the approach taken by government and the donor community in dealing with drought and its impact on groundwater and, in particular, the nature and targeting of drought interventions;

(c) identifying areas and groups of people most vulnerable to groundwater droughts; and

(d) suggesting ways in which the impact of groundwater drought can be reduced or mitigated.

This Malawi Inception Report is one of three such reports produced for the project; others will be produced for Ghana and South Africa. The aim of each report is to provide a resource of background information which can be drawn on for the remainder of the project, focusing principally on (a), (b) and (c) above. As such, each report is a working document designed to raise issues and questions, rather than a polished end-of-project report with considered conclusions. Taken together, the reports will provide a common pool of knowledge from which generic issues and groundwater management strategies can be identified.

This report focuses on groundwater drought experience and management in the rural areas of southern Malawi. In rural areas, reliance on groundwater as a low cost source of potable supply is greatest, and efforts are being made to accelerate supply coverage. The report concentrates on the experience of the south as this is where the impact of recent drought events was reported to be most severe.

The report begins by introducing some important drought concepts (Section 2), and then presents background climatic, water resources, supply coverage, institutional and economic information (Section 3). Section 4 describes the recent experience of drought in Malawi, concentrating on the events of 1991-92, and including government and donor responses to the problem. Section 5 summarises the main findings and discusses issues arising.

The report has three appendices. Appendix A discusses different drought indicators, the ways in which they could help identify when and where groundwater drought is likely to occur, and how they could be combined to produce drought vulnerability maps indicating areas likely to be worst affected.[2] Appendix B describes and lists the water resources data holdings available to the project. It also provides a list of references used for the report.

[2]The term vulnerability is used in this report to describe vulnerability to the adverse impacts of groundwater drought, and not in the hydrogeological sense of vulnerability to contamination.

2. DROUGHT DEFINITIONS

2.1 Definitions and concepts

The subject of drought in drylands has been extensively researched, particularly from meteorological and food security perspectives. Typically, however, the work of natural and social scientists remains separate, with drought definitions varying accordingly.

Definitions vary according to professional standpoint, and according to whether impact is incorporated into the concept (Box 1). Definitions which incorporate some notion of impact are often termed operational definitions. Operational terms may frame impact either in very broad terms (e.g. as a general water deficit), or according to specific sector impacts (e.g. 'agricultural droughts'). Operational concepts begin to capture the idea of drought as a product of a natural system (the physical environment) and a set of human activities and responses. Notions of vulnerability then have to be explored to answer fundamental questions of why certain areas and groups of people may be disproportionately affected. Table 1 (discussed in Box 1 below) illustrates how droughts have been defined in Africa according to meteorological criteria.

Box 1 Definitions of drought

From a *meteorological* standpoint, drought exists when rainfall is abnormally low, i.e. less than a critical precipitation that defines initiation of drought (Bruwer 1990; Solanes 1986). Area-specific definitions abound. For example in South Africa, Chavula (1994) defines drought as occurring when rainfall in any particular period is 70% of normal, becoming severe when this occurs over two or more consecutive seasons. In Table 1, a similar meteorological definition is used to qualify incidence of drought on an Africa-wide basis. It should be noted that such tables, and the definitions underpinning them, can be misleading, as they fail to capture important factors such as the seasonality, intensity and spatial distribution of rainfall.

In *hydrological* terms, drought has been defined as occurring when actual water supply falls below the minimum required for 'normal' operations, reflecting a deficit in the water balance (Bruwer 1990; Solanes 1986). A similar definition, encompassing supply in broad terms in relation to demand, is offered by Hazelton *et al* (1994), when they state that drought occurs when there is a deficit in water, including surface and sub-surface water runoff and storage, as well as rainfall. This brings us to the rather catch-all definition of drought, of arising when demand exceeds supply.

Notions of supply and demand introduce a range of operational definitions of drought. For example, *agricultural drought* can be defined as occurring when soil moisture is depleted to the extent that crop and pasture yields are considerably reduced (Bruwer, 1990; Solanes, 1986).

From the above, it is apparent that drought is a relative concept, defined in terms of a deviation from the norm and/or a notion of requirement. Needless to say sufficient data must exist to help describe the *normal* conditions of any system.

This project introduces the concept of groundwater drought. In exploring this concept, it may be useful to distinguish between *access* and *availability*. Access refers to the ability to actually get water out of the ground in sufficient quantities and of sufficient quality with given technologies (e.g. shallow wells) and states of repair and maintenance, and ease of access by the population in terms of proximity to water points. It follows that access may be hampered if technologies are inadequate to meet demands (e.g. if shallow wells go dry where boreholes do not), and if coverage provided by operational water points is very low, because of poor states of maintenance and/or low overall coverage levels. Availability problems, on the other hand, can be considered to occur when both wells and boreholes in an area go dry because of absolute water shortages. A related distinction can be made between source and resource problems. During drought episodes, individual sources may become stressed as demands increase and yields decline. However, it does not follow that the groundwater resource as a whole will become stressed, or is threatened by over-exploitation.

These definitions and concepts are discussed again towards the end of the report, in the light of recent drought experience in Malawi and its impact on the nation's groundwater sources and resources.

Table 1 Incidence of drought in Africa according to rainfall deficits, 1980-1990. Reproduced from Cleaver and Schreiber (1994)

Country	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
Angola	—	—	—	—	—	—	—	—	—	—	—
Benin	—	—	—	—	—	—	—	—	—	—	—
Botswana	—	—	D	D	D	D	D	D	—	—	—
Burkina Faso	—	—	—	D	D	—	—	—	—	—	—
Burundi	—	—	D	D	D	—	—	—	—	—	—
Cameroon	—	—	—	D	—	—	—	—	—	—	—
Cape Verde	—	D	D	D	D	D	—	—	—	—	—
Central African Rep.	—	—	—	D	D	—	—	—	—	—	—
Chad	—	—	—	D	D	—	—	—	—	—	—
Congo	—	—	—	—	—	—	—	—	—	—	—
Côte d'Ivoire	—	—	—	D	—	—	—	—	—	—	—
Equatorial Guinea	—	—	—	—	—	—	—	—	—	—	—
Ethiopia	D	D	—	—	D	D	—	D	D	—	—
Gabon	—	—	—	—	—	—	—	—	—	—	—
Gambia, The	—	—	—	—	—	—	—	—	—	—	—
Ghana	—	—	D	D	D	—	—	—	—	—	—
Guinea	—	—	—	—	—	—	—	—	—	—	—
Guinea-Bissau	—	—	—	—	—	—	—	—	—	—	—
Kenya	—	—	—	—	D	—	—	—	—	—	—
Lesotho	—	—	D	D	—	—	—	—	—	—	—
Liberia	—	—	—	—	—	—	—	—	—	—	—
Madagascar	—	—	—	—	—	—	—	—	—	—	—
Malawi	D	D	—	—	—	—	—	—	—	—	—
Mali	—	—	D	D	D	—	—	—	—	—	—
Mauritania	—	—	—	D	D	—	—	—	—	—	—
Mauritius	—	—	—	D	—	—	—	—	—	—	—
Mozambique	—	D	D	—	—	—	—	—	—	—	—
Namibia	—	—	—	—	—	—	—	—	—	—	—
Niger	—	—	—	D	D	—	—	D	—	—	D
Nigeria	—	—	—	—	—	—	—	—	—	—	—
Rwanda	—	—	—	—	D	—	—	—	—	—	—
São Tomé and Principe	—	—	D	D	—	—	—	—	—	—	—
Senegal	D	—	—	D	D	—	—	—	—	—	—
Sierra Leone	—	—	—	—	—	—	—	—	—	—	—
Somalia	—	—	—	D	—	—	—	—	—	—	—
Sudan	—	—	—	—	D	—	—	D	—	D	D
Swaziland	—	—	D	—	—	—	—	D	—	—	—
Tanzania	—	—	—	—	D	D	—	—	—	—	—
Togo	—	—	—	D	—	—	—	—	—	—	—
Uganda	—	—	—	—	—	—	—	—	—	—	—
Zaïre	—	—	—	—	—	—	—	—	—	—	—
Zambia	—	—	D	D	D	—	—	—	—	—	—
Zimbabwe	—	—	D	D	D	—	—	—	—	—	—

— Not available.
D Significant rainfall shortfall from long-term average.

3. COUNTRY BACKGROUND

3.1 Social and economic characteristics

Malawi is a small landlocked country in southern Africa, bordering Mozambique to the east, Zambia to the west, and Tanzania to the north (Figure 1). It is also a very poor country, struggling with rapid population growth, an economy dominated by agriculture and therefore vulnerable to natural hazards such as drought, and political and economic instability. The result in recent years has been declining standards of living and health. Administratively the country is divided into three regions: Southern, Central and Northern. Each region is sub-divided into districts (Figure 1). Key indicators of social and economic status (see Figure 2) are outlined below:

- **Income**. In 1993 it was estimated that 50% of Malawi's population lived below the poverty line; more recent estimates suggest a figure of around 60-70% (UNICEF, 1995).

- **Population**. Population was estimated at about 10.5 million in mid-1993. In 1977, the figure was about five million (UNICEF, 1995; World Bank, 1995). Of this, around 85% live in rural areas and depend on agriculture (UNICEF, 1995). Malawi has received large numbers of refugees in recent years, with inward migration reaching a peak of one million in 1991 as people in neighbouring Mozambique fled the war. The overall population growth rate is about 3.3%/year.

- **Health**. The under five mortality rate is one of the highest in the world at 245 deaths/1000. Principal causes of child mortality are: malaria (19%); malnutrition (17%); anaemia (13%); measles (11%); diarrhoea (8%); peri-natal problems (4%) and other disorders (15%) (UNICEF, 1995). Figures will obviously vary from year to year. In drought years, evidence suggests that water-related illnesses increase considerably.

- **Economy**. GNP/capita is among the lowest in the world at around US $200 (1993 figures). GDP growth rates have fluctuated between the positive and negative over recent years, with negative figures recorded in the worst drought years (1992 and 1994 in Figure 2). This is because rainfed agriculture dominates the economy, accounting for around 30% of GDP in 1994.

3.2 The water resources base

3.2.1 *Physiography*

Malawi is dominated by the rift valley, part of the East African Rift System, which runs along its entire length. The country has a surface area of 120 000 km^2 and five main physiographic zones (Figure 3): the 1000 m high crystalline basement plateau in the west with characteristic inselbergs and dambos; Lake Malawi in the east; the rift valley escarpment which bounds the lake; the low-lying alluvial Shire Valley in the south, which flanks the lake's outflowing river; and upland areas which include both inselbergs rising above the basement plateau, and granite and syenite intrusions. The latter are remnants of the post-Gondwana erosion surface, and form the Mulanje, Zomba and Dedza mountains and the 2000-3000 m high Viphya and Nyika plateaux in the north.

Land use

The land use in the south is principally agricultural. This has traditionally been rainfed, although the current view is that the rains can no longer be relied on. In the north there is less agriculture and

Figure 1 Location and geography of Malawi

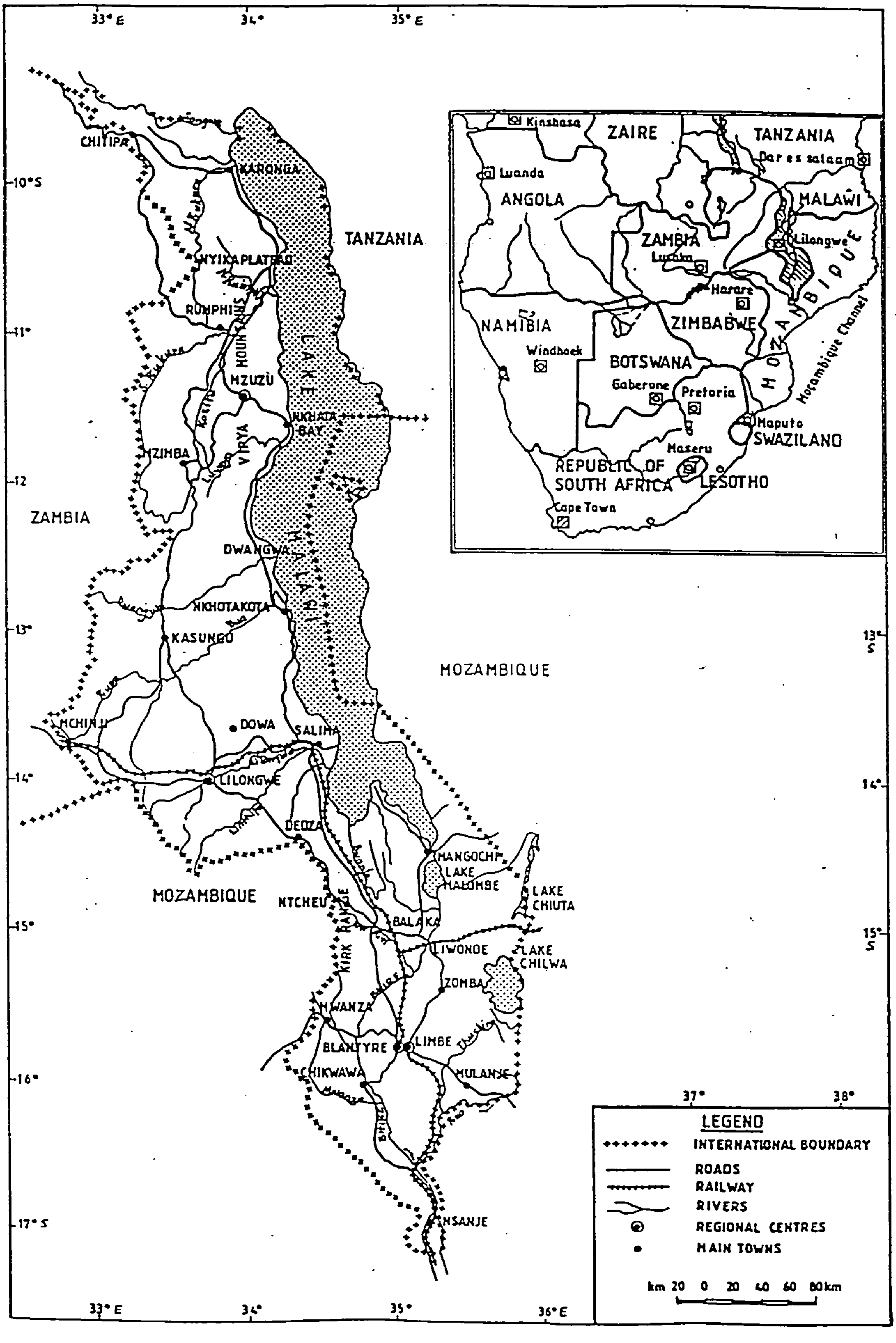


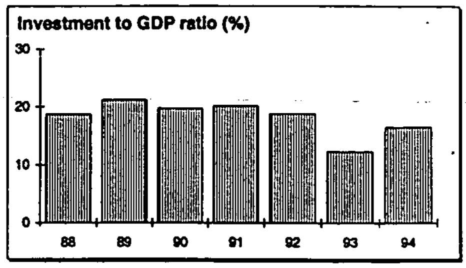
Figure 2 Social and economic indicators. Source: World Bank (1995)

Malawi

Population mid-1993 *(millions)*	**10.5**	Income group: **Low**
GNP per capita 1993 *(US$)*	**200**	Indebtedness level: **Moderately Indebted**

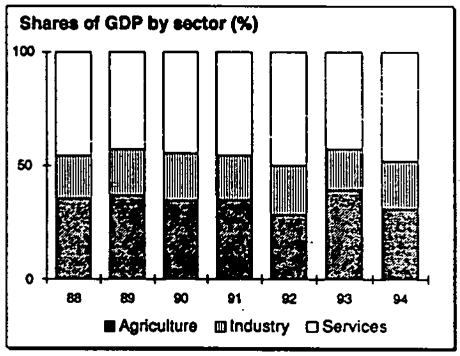
KEY RATIOS

	1985	1990	1992	1993	1994
Gross domestic investment/GDP	18.6	19.7	18.8	12.3	16.5
Exports of goods and nfs/GDP	24.2	24.8	22.5	16.6	31.2
Gross domestic savings/GDP	12.9	9.7	1.9	1.8	-1.7
Gross national savings/GDP	9.1	6.6	-1.1	1.2	..
Current account balance/GDP	-8.5	-8.0	-18.6	-11.2	-20.3
Interest payments/GDP	2.6	1.8	1.6	1.4	2.4
Total debt/GDP	90.0	87.9	91.7	92.3	161.6
Total debt/exports	361.2	347.0	402.1	545.7	499.5



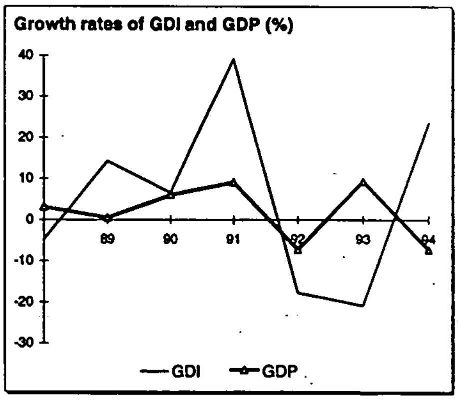
GDP: PRODUCTION

	1985	1990	1992	1993	1994
(% of GDP)					
Agriculture	36.6	34.4	28.3	39.2	30.7
Industry	18.7	20.9	21.7	18.1	21.2
Manufacturing	12.3	14.1	14.6	11.8	..
Services	44.7	44.7	50.0	42.7	48.1
	1985-90	**1990-94**	**1992**	**1993**	**1994**
(average annual growth)					
Agriculture	1.3	-0.4	-25.1	53.4	-29.3
Industry	4.9	0.2	2.4	-7.4	5.3
Manufacturing	4.9	-0.8	3.0	-10.5	5.4
Services	3.8	-0.2	0.8	-5.4	0.7
GDP	2.0	0.6	-7.3	9.3	-7.3



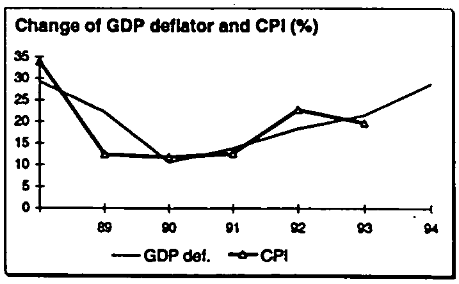
GDP: EXPENDITURE

	1985	1990	1992	1993	1994
(% of GDP)					
Private consumption	69.4	74.6	79.5	81.5	87.7
General government consumption	17.7	15.7	18.5	16.7	13.9
Gross domestic investment	18.6	19.7	18.8	12.3	16.5
Exports of goods and nfs	24.2	24.8	22.5	16.6	31.2
Imports of goods and nfs	29.9	34.9	39.3	27.1	49.4
	1985-90	**1990-94**	**1992**	**1993**	**1994**
(average annual growth)					
Private consumption	4.2	0.2	-8.7	7.9	-6.9
General government consumption	4.7	-4.4	0.7	-3.1	-18.5
Gross domestic investment	-0.8	-2.1	-17.8	-20.9	23.5
Exports of goods and nfs	-0.3	0.1	-2.9	-5.0	7.7
Imports of goods and nfs	4.7	-3.9	-9.3	-21.1	12.6
Gross national product	2.5	0.6	-7.3	9.6	-8.3
Gross national income	1.8	-1.2	-12.2	7.3	-7.2



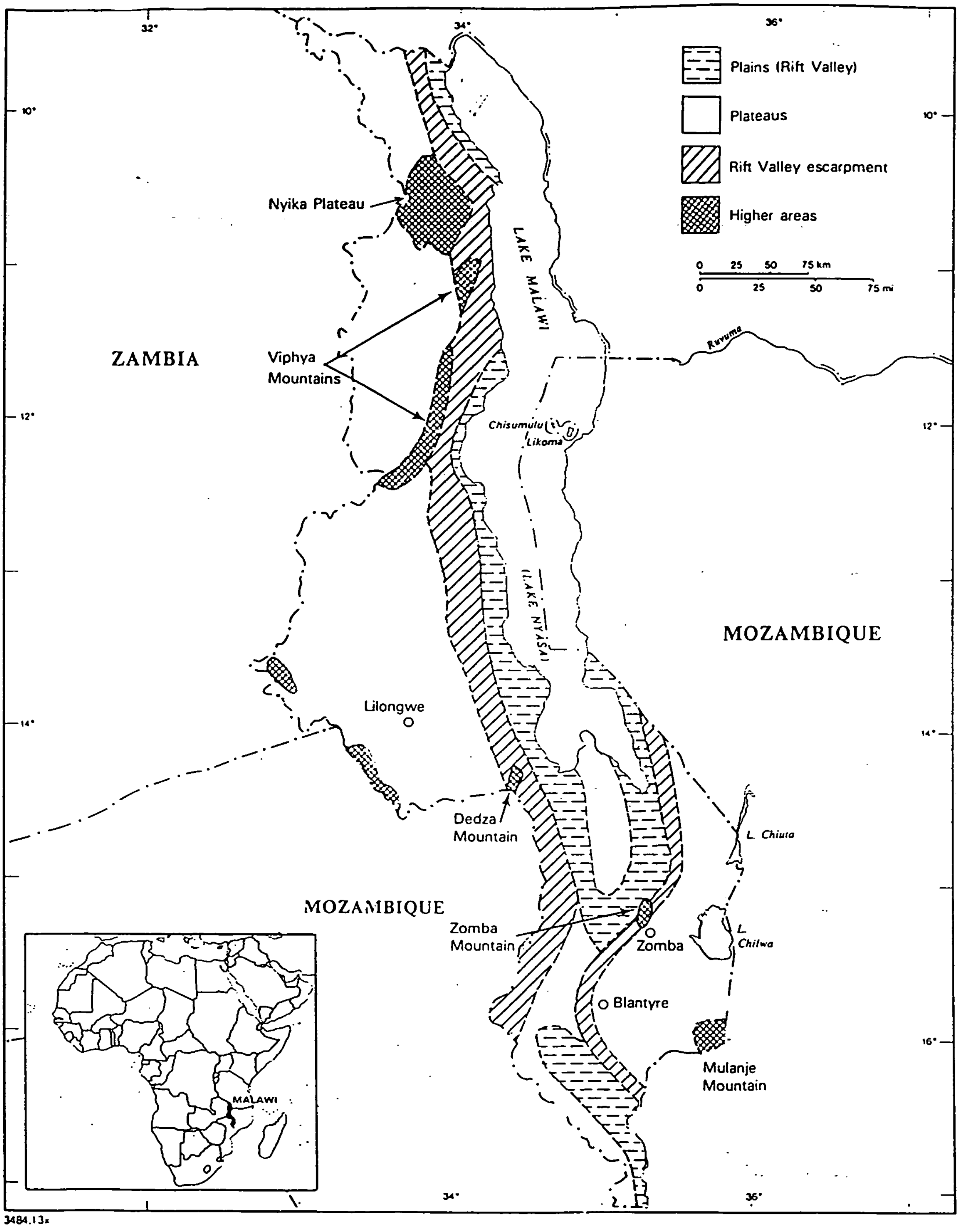
PRICES and GOVERNMENT FINANCE

	1985	1990	1992	1993	1994
Domestic prices					
(% change)					
Consumer prices	10.5	11.8	22.7	19.7	..
Wholesale prices	..	..	..	..	..
Implicit GDP deflator	8.9	10.6	18.3	21.4	28.7
Government finance					
(% of GDP)					
Current budget balance	-0.7	-0.2	-4.3	-3.3	-9.8
Overall surplus/deficit	-6.9	-7.3	-11.6	-8.7	-14.9



Note: 1994 data are preliminary estimates. Figures in italics are for years other than those specified.

Figure 3 **Geomorphological zones. Source: United Nations (1989)**



about 75% of the vegetation is natural. There is significant forestry, particularly in the higher areas. Indigenous hardwoods are being replaced with eucalypts, which have deep tap-roots, high growth rates and correspondingly high evapotranspiration rates. Deforestation without replanting is a growing problem: wood is the national fuel and the sale of hardwoods is lucrative.

3.2.2 *Climate and groundwater recharge*

Rainfall

Climatic conditions are complex due to the varied topography and the influence of Lake Malawi. The plateau areas have a warm climate with moderate rainfall, and the rift valley has a hot climate, which may be semi-arid in places. The rainy season is from November to March in the south, but runs on until May further north. The dry season lasts from June to October, with occasional outbreaks of light rain. Temperatures and relative humidity increase progressively from September to November.

The rainy season occurs with the migration of the Inter-tropical Convergence Zone (ITCZ). Maximum monthly rainfall totals occur during January although the highland and escarpment regions of Malawi exerts an orographic effect particularly on slopes exposed to south-easterly winds. These regions can experience three times the rainfall totals of adjacent areas. This is particularly marked in April with the northwards retreat of the ITCZ bringing with it maximum monthly rainfall totals in some of these regions. Occasional torrential downpours are associated with tropical cyclones from the Indian Ocean and the inflow of cool maritime air causes orographic rain known locally as 'chiperoni'.

Annual rainfall varies substantially from year to year. The lower the annual rainfall, the greater is its variability (Figure 4). The plateaux area of the Central and Southern Regions have mean annual rainfalls of 400-1000 mm/year, rising to over 2000 mm/year in the north. The flood plain of the Lower Shire Valley receives substantially less, with rain shadow effects resulting in means of less than 400 mm/year. Rainfall also varies greatly between years. There is a tendency for a number of wetter than average years to be followed by a number of drier than average years. Chavula (1994) describes a nine year oscillation spell of generally wet and dry conditions in a quasi-cycle of about 18 years, and cites similar results observed in South African rainfall time series. The oscillations can be attributed to interactions between El Nino and the Southern Oscillation phenomena. Figure 5 (p12) shows deviations of national annual rainfall from the country's mean for the last 90 years. Table 2 (p13) presents rainfall and runoff data for each of Malawi's 17 river basins.

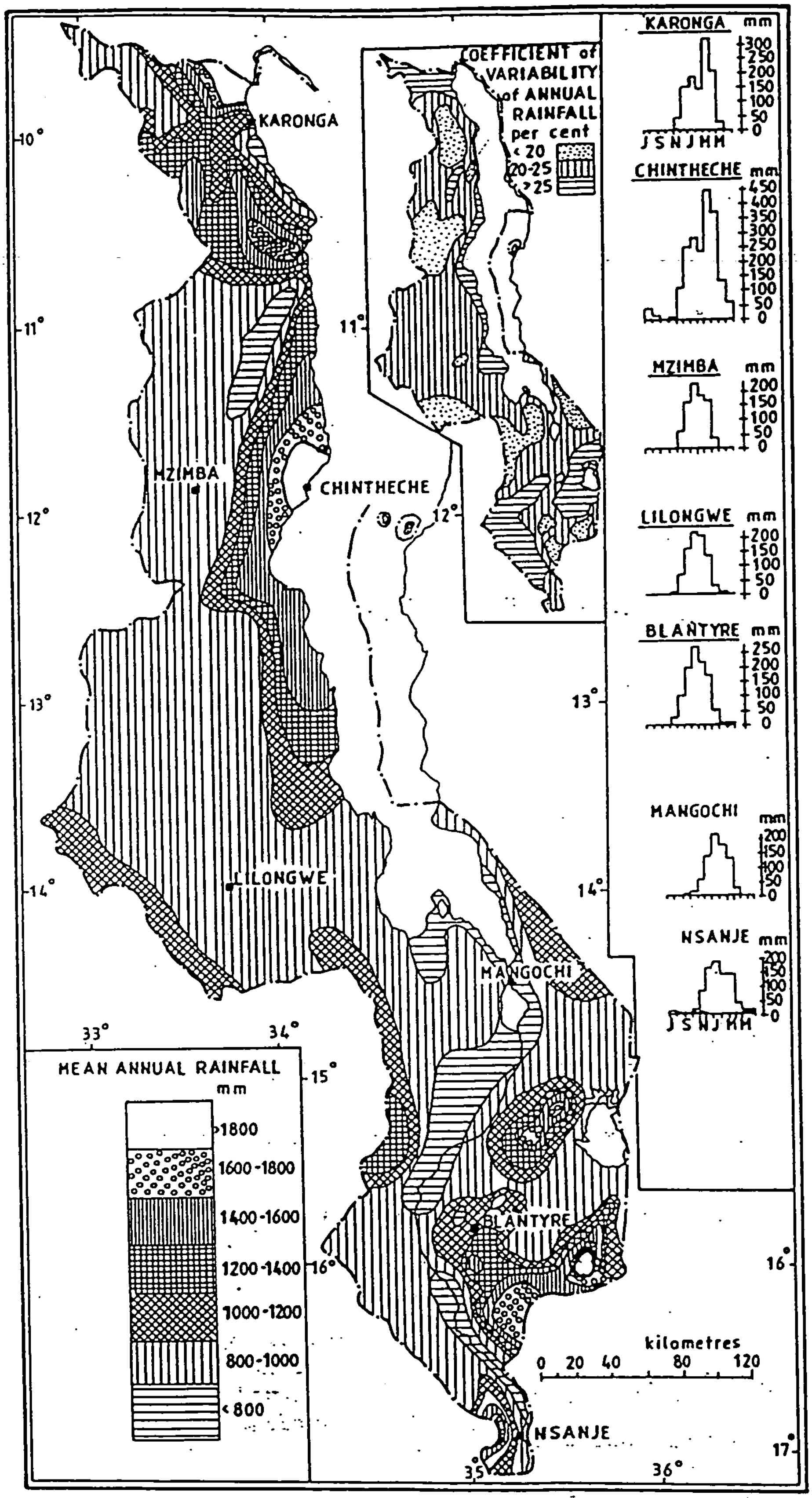
Evaporation

Temperatures typically range from 16-26°C in the plateau areas of the Central Region, and from 20-30°C in the lakeshore areas and in the Lower Shire Valley (Smith-Carington and Chilton, 1983). Potential evaporation (Penman) ranges from 1100-1700 mm/year and decreases with altitude. Rates reach a maximum along the lakeshore and in the Shire Valley. The lowest rainfalls and highest potential evaporation rates occur in the south of the country, in the Shire Valley where population densities are highest (UNICEF, 1995)

Groundwater recharge

In the highlands where orographic rain is significant, recharging waters penetrate scree slopes around the syenite inselbergs (Cosmos Gavarti (MIWD), personal communication). On the weathered basement, the presence of low permeability clays in the weathered superficial saprolite may act as a semi-confining layer. Nevertheless recharge is likely to occur through it regionally by slow direct infiltration (Smith-Carington and Chilton, 1983).

Figure 4 Mean annual rainfall. Source: Smith-Carringtom and Chilton (1983)



Groundwater recharge estimates vary from 5-100 mm/year for the weathered basement aquifers and from 3-80 mm/year for the alluvial aquifers (Smith-Carington and Chilton, 1983). To put these recharge estimates into perspective, current groundwater abstraction from wells and boreholes with handpumps, expressed over the whole catchment, is estimated to be less than 1 mm/year on average, and 2-3 mm/year in densely populated areas (Kafundu and Laisi, 1991).

3.2.3 *Surface water*

Malawi has abundant surface water resources. Average surface runoff is estimated as 196 mm/year (18.5 x 10^9 m^3, or 585 m^3/s) which is equivalent to about one and a half times the average for the whole of Africa. Much of this lies in Lake Malawi and the Shire River. Lake Malawi is the third largest freshwater lake in Africa with an area of approximately 28 000 km^2. It is estimated that approximately 60% of the inflow to the lake is lost by evaporation. Much of the nations power output and irrigation is dependent on lake outflow through the Shire River.

In the plateau areas of the Central and Northern Region rainfall is modest and surface runoff is low, streams are seasonal and extensive areas are covered by dambos. The lake shore areas east of the escarpment zone in the Northern and Central Regions have abundant runoff, perennial streams with significant potential for water supply, irrigation, recreation and hydro-power schemes (see Table 2 with reference to Figure 7).

Each year, Lake Malawi rises during and immediately after the end of the rainy season, and then falls gradually as the dry season progresses. The annual rise is greatest in wet years. The annual fall is more constant, and when successive falls progressively exceed rises, the average lake level falls. Lake level fluctuations over the previous century are shown in Figure 6. Over the period 1953-74, only 29% of catchment rainfall contributed to discharge from the lake into the River Shire, with the rest evaporated from the lake surface or prior to reaching the lake (Drayton, 1979). Rainfall and evaporation are therefore key determinants of lake level and are influenced by changes in vegetation and land use (Calder *et al.*, 1995).

The level of the Shire River is regulated by the Lake Malawi outlet and at the Kamuzu barrage at Liwonde. Flows in the Shire are strongly correlated to the level of Lake Malawi which means that the flow patterns show large persistence. Tributaries to the Shire in the Southern Region have generally lower annual yield with the exception of the Ruo, which drains the high rainfall area around Mulanje Mountain.

Almost all of the power generated within Malawi comes from hydropower installations on the Shire River at Nkula and Tedzani Falls. There are other potential sites on the river which have been identified but not developed, and significant potential for small scale hydropower schemes exists in the north of the country. Water taken from the river for hydropower is returned after use with little overall 'consumption' loss to the system.

The country has been divided into 17 major catchments or water resource units (Figure 7). On a national scale, water resources are dominated by Lake Malawi and the Shire River, with the lake accounting for approximately 70% of the total surface water resource. The flow of the other rivers in Malawi is much more variable than the Shire River and many of the smaller streams are ephemeral. Mean annual runoff rates vary between 10% and 45%, with the response of a river to rainfall events dependent, in part, upon the proportion of the catchment covered by dambos. An indication of the water resources of the 17 major river basins is given in Table 2.

The average annual runoff expressed as a proportion of the average annual rainfall varies from 4-54%. The lower runoff totals occur in the lower rainfall parts of the plateau, where streams are ephemeral. Higher runoff occurs in the highlands where streams are perennial (Drayton *et al* 1980).

Figure 5 **Deviations of national average rainfall from mean values, 1922-1992. Source: Chavula (1994)**

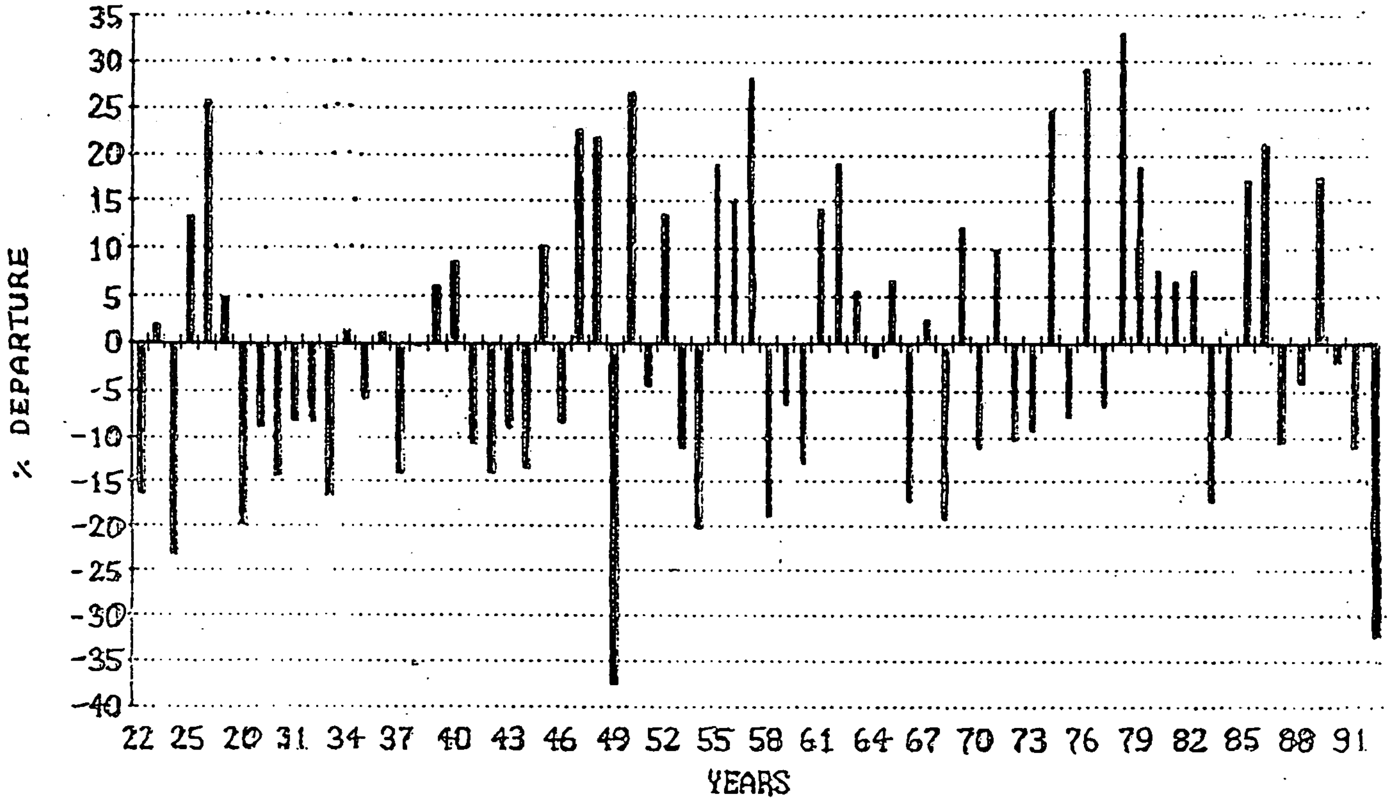


Figure 6 **Annual rainfall and water levels for Lake Malawi, 1896-1994. Source: Kamdonyo (1992)**

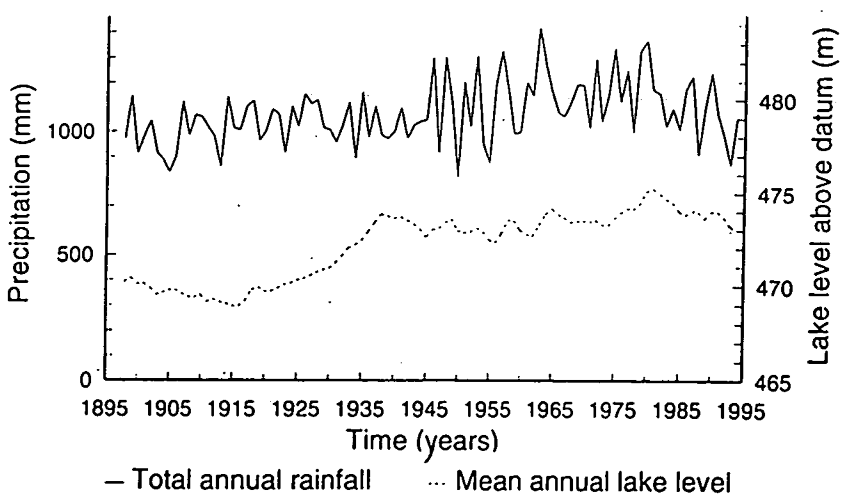
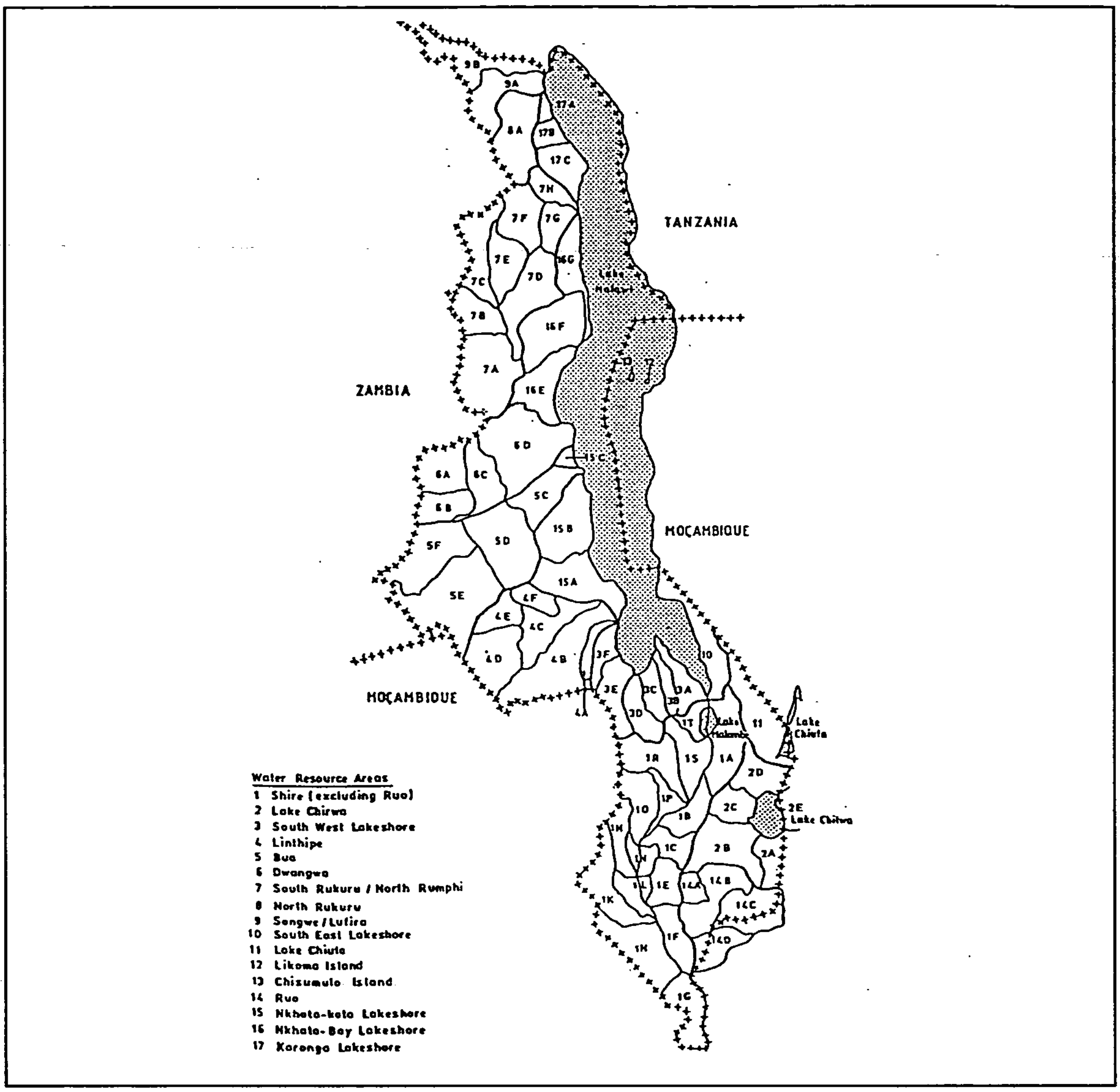


Table 2 **Mean annual rainfall and runoff from river basins. Source: World Bank/UNDP (1990)**

WRU	River Basin	Area (km^2)	Rainfall (mm)	Runoff (mm)	Runoff (m^3/s)	Runoff (%)
1	Shire	18945	902	137	82	15.2
2	Lake Chilwa	4981	1053	213	34	20.2
3	South West Lakeshore	4958	851	169	27	19.9
4	Linthipe	8641	964	151	41	15.7
5	Bua	10654	1032	103	35	10
6	Dwangwa	7768	902	109	27	12.1
7	South Rukuru	11993	873	115	44	13.2
	North Rumphi	712	1530	674	15	44.1
8	North Rukuru	2091	970	252	17	26
9	Lufira	1790	1391	244	14	17.5
	Songwe	1890	1601	327	20	20.4
10	South East Lakeshore	1540	887	201	10	22.7
11	Lake Chiuta	2463	1135	247	19	21.8
12	Likoma Island	18.7	1121	280	-	-
13	Chisumulo Island	3.3	1121	280	-	-
14	Ruo	3494	1373	538	60	39.2
15	Nkhotakota Lakeshore	4949	1399	260	41	18.6
16	Nkhata Bay Lakeshore	5458	1438	461	80	32.1
17	Karonga Lakeshore	1928	1028	361	22	35.1
TOTAL/AVERAGE		94276	1037	196	588	18.9

Figure 7 Major water resources basins



3.2.4 *Groundwater*

Aquifer systems

The different physiographic regions have different aquifer systems associated with them. Two types dominate: the weathered basement aquifer, and alluvial aquifers. Yields are universally low, typically less than 2 l/s.

The crystalline basement, Precambrian and Lower Palaeozoic in age, is composed of gneiss and granulite with schists, quartzites and marbles It weathers to form a low yielding but very extensive aquifer, typically 15-30 m thick. A schematic weathering profile is shown in Figure 8, and hydrogeological properties are described by Chilton and Foster (1995). Transmissivities rarely exceed 30 m^2/d, and permeabilities are low but variable: most are in the range of 0.05-1.5 m/day, and the most permeable horizons are unlikely to exceed 5 m/day. Storage coefficient values are estimated to be in the 0.005-0.01 range (Kafundu and Laisi, 1991). Depths to water are normally less than 25 m and often under 15 m, with seasonal fluctuation of 1-5 m. Dambo areas are formed at natural groundwater discharge sites, where the water table approaches ground level. On the escarpment area, the weathered zone erodes as fast as it is created, and groundwater flows principally in fractures.

The alluvial aquifers of the lakeshore, the Shire Valley and the Lake Chilwa basin are composed of Quaternary lacustrine and fluvial sediments. Clay sequences cause semi-confining conditions. Transmissivities are of the order of 100-300 m^2/day, and storage coefficients are estimated to range from 0.01-0.05 (Kafundu and Laisi, 1991). Depths to water in the lake shore areas such as Salima and Nkhotokota are commonly less than 10 m, and are influenced by the lake level. Seasonal fluctuations are in the order of 1-3 m. (Kafundu and Laisi, 1991). Water level depths increase away from the River Shire and towards elevated areas, particularly in rain shadow areas such as the Bwanje Valley, Rivi Rivi Valley and the Upper Shire, where they may exceed 30 m.

Water quality

Groundwater is generally potable, although there are some notable exceptions. For example, pockets of saline groundwater are found in the Lower Shire Valley alluvium, reflecting varying sediment compositions and regions of slow groundwater movement. In addition, some sulphurous boreholes occur in the Dowa area of the weathered basement aquifer where low permeabilities cause slow groundwater movement. In the far north high fluoride concentrations are found, sometimes exceeding World Health Organisation (WHO) limits by a factor of three. Skeletal fluorosis can ensue, and defluoridation plants are used.

3.2.5 *Boreholes and shallow wells*

Shallow dug wells have traditionally been used in Malawi. These have varying constructions: some are unlined, and others have concrete ring and/or brick linings. The first boreholes were drilled in the 1930s and now number around 9000. Borehole design is described by Smith-Carington and Chilton (1983). Few boreholes penetrate the bedrock beneath the weathered zone of the basement aquifer. Percussion and rotary rigs are now used by most drilling operations, whereas in the 1980s manual 'Wonder' rig drilling was more commonplace. Geophysics (principally constant separation resistivity surveys) is used for borehole siting.

Hand pumps are used for rural water supply. Table 3 lists the types currently in use. 'Afridev' pumps are now the preferred choice for most situations, and have the advantage that they can be taken apart and maintained by villagers. However, they do not provide access for measuring water levels. Handpump types are yet to be standardised for specific ranges of pumping head (UNICEF, 1995).

Figure 8 **Conceptualised hydrogeological model of the weathered crystalline basement aquifer in Africa. Reproduced from Chilton and Foster (1995)**

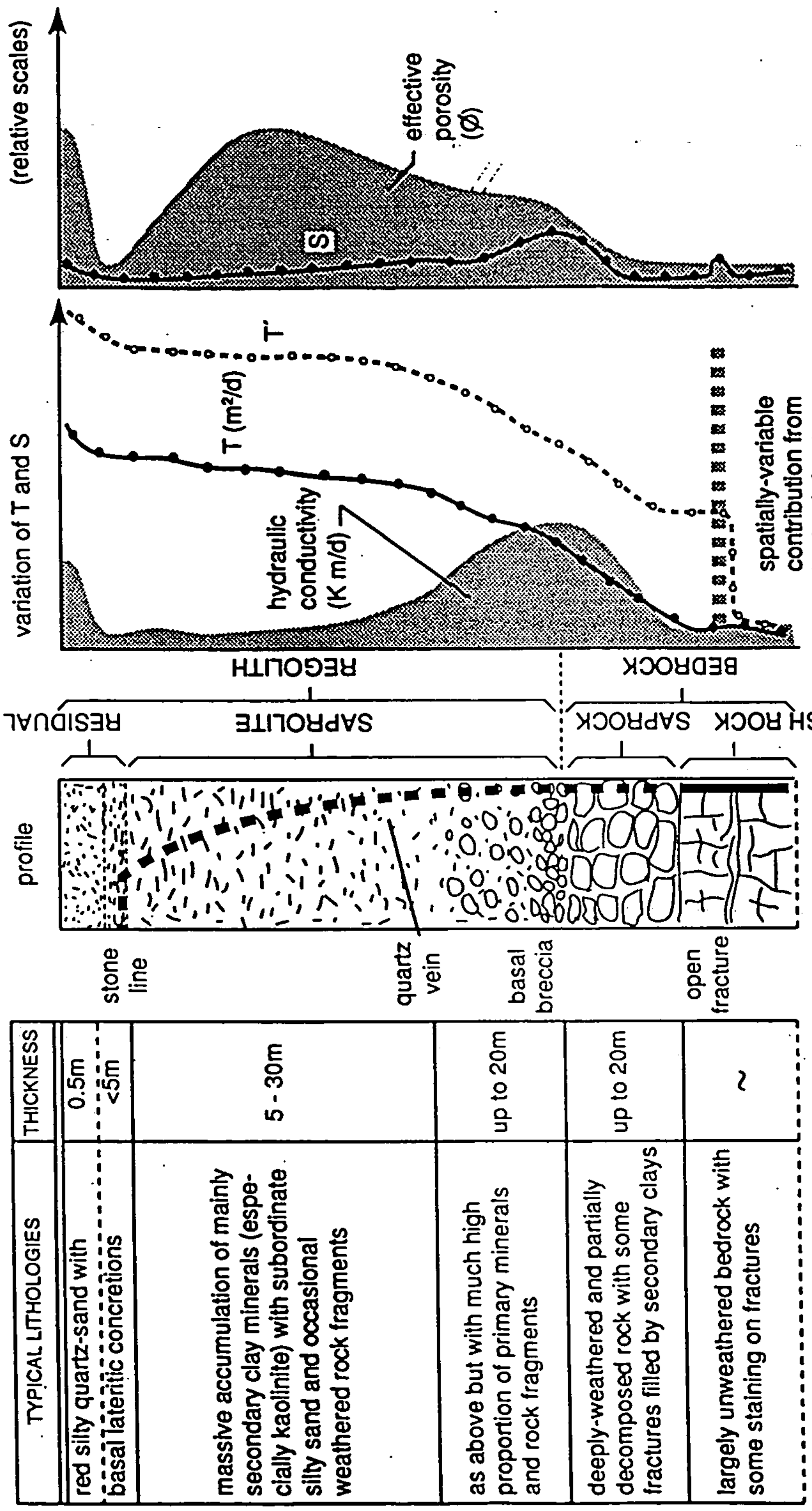


Table 3 **Handpump types currently used in Malawi. Source: UNICEF (1995)**

Type	Standard	Not Standard	Remarks
Afridev Deep Set	●		Standard for all rural groundwater supplies
Afridev Direct Action	●		Being developed for shallow wells and boreholes
Climax	●		Heavy duty for pumping to overhead tanks and for extra deep installations
India Mark II	●	●	For deep boreholes
Bush pump		●	Widely used, being phased out
Maldev		●	Forerunner to the Afridev
Aquadev		●	For deep boreholes installed in refugee areas
Malawi Mark V		●	A shallow well suitable for family use
Shire		●	For shallow wells
Rhumphi		●	For shallow wells
Madzi		●	For shallow wells
President		●	For deep boreholes, being phased out
Vergnet		●	Foot pump for deep boreholes
Mono Pump		●	For deep boreholes
Nira		●	For shallow wells installed mainly in refugee areas
Consallen		●	For deep boreholes

Vulnerability to groundwater level fluctuations.

Changes in water level have important water supply implications, particularly where the aquifers are thin and when drawdowns are large. Water level falls due to low annual recharge can result in the loss of a large proportion of transmissivity. This was observed in escarpment boreholes at Ntcheu in 1983, where the aquifer only has limited fracture storage. Receding water levels resulted from below average recharge in the two preceding wet seasons (Kafundu and Laisi, 1991). Wells with short water columns, for instance shallow wells and partially penetrating boreholes are particularly vulnerable to the effects of falling water levels.

3.3 Water supply and the importance of groundwater in rural areas

3.3.1 *The national context*

In rural areas water is supplied from a mix of surface water, gravity piped systems, and groundwater wells and boreholes. Gravity systems serve towns and larger villages, with wells and boreholes serving remaining areas. A large proportion of the rural population depend on wells and boreholes (see Table 4 and Section 3.3.3 below). The importance of groundwater as a relatively cost effective source of potable supply is expected to grow in future as efforts are made to increase coverage.

The principal urban centres of Lilongwe and Blantyre rely on surface water supply schemes. Water supply to Lilongwe is from the Lilongwe River and Kamuzu Reservoir; Blantyre relies on water pumped from the Shire River and reservoirs on the Mudi River. Zomba, Malawi's third city, relies on groundwater pumped from deep boreholes.

Irrigation is a major consumer of surface water, and large schemes devoted principally to sugar cane and rice are located along the Shire River. At present these schemes cover around 20 000 hectares, but the area under irrigation is expected to increase in future raising concerns over competition for river water between hydropower and irrigation sectors. Groundwater irrigation potential is limited by the low yield of aquifers, and is generally restricted to small vegetable gardens in some areas. However, more intensive groundwater irrigation in dambo areas is being considered.

3.3.2 *Development of rural water supplies*

Malawi's rural water supply is dependent on shallow dug wells, boreholes and piped gravity systems. While groundwater exploitation began under colonial rule with the development of dug wells and boreholes for large scale agricultural development projects (predominantly estate agriculture), it was not until the mid-1970s that low cost schemes focusing on rural water supply were initiated. These schemes included small gravity piped systems (surface water) and shallow well construction (UNICEF, 1995). Shallow well development was concentrated in dambo areas where perennial shallow groundwater circulation could be exploited to provide dry season supplies.

From the 1980s onwards, the expansion of both rural and urban supplies became a dominant feature of poverty alleviation and drought relief programmes, with a mix of central government, multi-lateral, bi-lateral and NGO support. Much donor support has been in the form of capital and technical assistance for borehole and handpump installation in rural areas, typically through projects and programmes in specific areas. Although assistance for shallow well projects was forthcoming in the 1980s (especially the UNDP programme in refugee affected areas of Nsanje), there has since been a shift in emphasis away from shallow wells to deeper boreholes by both central government and the donor community. These can be developed more quickly, are thought to offer better resistance to drought, and provide hygiene benefits.

3.3.3 *Water supply coverage*

National figures

Water supply coverage in Malawi has been estimated at around 62% (Table 4), with 85% coverage in urban areas and 58% in rural areas. Considering rural areas separately, it is estimated that 31% are served by boreholes, compared to 18% served by surface water gravity systems (UNICEF, 1995). UNICEF (1995), presumably quoting government figures, suggest that 9% of the rural population depend on shallow wells, but it is not clear how shallow well coverage can be estimated.[3]

[3]It is difficult to obtain data on the number, distribution and status of shallow wells. Many may have been constructed by local communities with no external assistance. In addition, MIWD maintenance reports from districts only cover borehole data. Some shallow well monitoring data is collected by the Ministry of Health and some NGOs, but this does not appear to be routinely passed on to MIWD.

Table 4 **Water supply coverage estimates. Source: UNICEF (1995)**

District	Total Population (000's) (projected to 1996)	Population Served by Borehole		Population Served by Rural Gravity Systems		Population Served by Municipal Systems		Total Population Served	
		(000's)	(%)	(000's)	(%)	(000's)	(%)	(000's)	(%)
Region North									
Chitipa	134.2	30.5	22.7	89.5	66.7	5.0	3.7	125.0	93
Karonga	205.3	93.75	45.7	64.5	31.4	25.5	12.4	183.7	90
Rumphi	131.6	28.0	21.3	62.0	47.1	12.9	9.8	102.9	78
Mzimba	601.5	153.0	25.4	100.5	16.7	67.5	11.2	321.0	53
Nkhata Bay	191.9	15.75	8.2	7.0	3.6	9.2	4.8	31.95	17
Total (North)	1264.5	321.0	24.66	323.5	33.1	120.1	8.38	764.6	66
Region Centre									
Kasungu	448.6	84.0	18.7	0	0	16.3	306	100.3	22
Nkhota Kota	219.2	59.0	26.9	42.5	19.4	0	0	11.5	46
Salina	262.3	105.0	40.0	0	0	10.6	4.0	115.6	44
Dedza	571.0	171.23	30.0	2.6	0.5	24.58	4.3	198.43	35
Ntcheu	497.5	142.0	28.5	307.0	61.7	5.5	1.1	454.5	91
lilongwe	1354.4	351.0	25.9	0	0	231.3	17.1	582.3	43
Mchinji	346.5	116.25	33.5	37.0	9.2	7.1	2.0	160.35	46
Dowa	447.1	59.25	13.3	0	0	11.5	2.6	70.75	16
Ntchisi	167.6	34.0	20.3	18.5	11.0	3.0	1.8	55.5	33
Total (Centre)	4314.2	111.75	26.0	407.6	11.3	309.88	37.6	1749.23	42
Region South									
Zomba	612.4	60.0	9.8	285.5	46.6	14.27	2.3	365.77	60
Mangochi	688.7	123.25	17.9	18.0	2.6	20.21	2.9	161.46	23
Machina	714.6	120.0	16.8	371.5	52.0	17.75	2.5	509.25	71
Chirazulu	292.5	31.75	10.9	55.5	19.0	15.7	5.4	102.95	35
Blantyre	817.6	51.25	6.3	0	0	550.0	67.3	601.25	74
Mwanza	168.5	35.00	20.8	0	0	8.0	4.7	43.0	26
Chikwawa	439.2	131.25	29.9	60.0	13.7	7.8	1.8	199.05	45
Thyolo	597.9	28.5	4.8	7.8	1.3	19.5	3.3	48.0	8
Mulanje	884.9	49.75	5.6	694.5	78.5	19.5	2.2	763.5	86
Nsanje	283.4	119.0	42.0	0	0	16.0	5.6	135.0	48
Total (South)	5499.7	749.75	16.48	1492.8	21.37	688.73	9.8	2929.23	52
Total National	11 078.4	2182.5	22.38	2223.9	21.92	1118.71	18.59	5443.06	62

These coverage figures are based on the assumption that all water points are operational, and on assumptions concerning the number of people served by different technology types.[4] At any one time, however, a large proportion of boreholes may not be working; 25% has been suggested as a reasonable nationwide, average estimate (UNICEF, 1995), although numbers are likely to vary between areas and over time. The cause may be poor maintenance leading to borehole/pump failure, or drying up of boreholes because of drought. Taking these considerations into account, perhaps only 43% of the rural population has access to an acceptable standard of water supply. The implication of this is that some five million people living in rural areas do not have access to an adequate supply of water.

In light of the above, it is clear that obtaining a reliable snapshot of water supply status is difficult. Additional problems result from: (a) sporadic data gathering in the field (determined in large part by the availability of transport to district officials); (b) extensive donor/NGO involvement in the sector, which makes keeping track of changes in supply coverage difficult; and (c) difficulties associated with determining the precise causes of borehole failure.[5]

Regional and district variations in coverage and technology types

Table 4 illustrates some significant regional variations in coverage and groundwater dependency. In the Southern Region, generally considered the most drought prone and the most heavily populated, a smaller proportion of the population is dependent on groundwater (approximately 16%) compared with Central Region (26%) and Northern Region (25%). Sharp district level variations are apparent, however: in Nsanje, for example, 42% of the population are served by boreholes, and high figures are also recorded for Mwanza and Chikwawa. Relatively low 'groundwater dependency' figures in the Southern Region may reflect the efforts of central government and donors to increase coverage and rehabilitate existing wells and boreholes in this region during and following the 1991-92 drought.

Efforts have been made within MIWD to use coverage figures as a means of highlighting priority areas. Table 5 illustrates how districts can be classified and ranked according to coverage compared with regional and national averages, using an 'equity index' (EI). Districts with a positive index figure have relatively poor coverage.

$$EI = RAC-DC/1-NAC = RAC-DC/0.50$$

Where:

RAC Regional average coverage
DC District coverage
NAC National average coverage

It has been suggested that coverage figures and indices of coverage could be used to help target scarce resources (government and donor) to needy areas. Such data could also be used to help define areas vulnerable to groundwater drought in conjunction with other information (see Appendix A).

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[4]Coverage figures refer to government standards of 'acceptable' supply, based on a minimum consumption of 27 l/c/d at a distance of no more than 0.5 km from a water point. A working borehole is assumed to serve 250 people.

[5]Although maintenance reports do distinguish between groundwater access and availability problems, in practice it may be impossible to identify why a borehole is not functioning. This makes the task of drought assessment based on maintenance returns from the field problematic. In addition, it is not possible for technicians to monitor the status of all district boreholes on a monthly basis.

Table 5 **Ranking of districts according to Equity Index. Source: MIWD Drought File (1995)**

Category/Rank	District		Present coverage (%)	Index	Remarks
1.1	Thyolo	(S)	8	0.90	
1.2	Nkhata Bay	(N)	17	0.86	
1.3	Mangochi	(S)	23	0.60	
1.4	Dowa	(C)	16	0.54	
1.5	Mwanza	(S)	26	0.54	
1.6	Kasungu	(C)	22	0.42	
1.7	Chiradzulu		35	0.36	
1.8	Ntchisi	(C)	33	0.20	
1.9	Dedza	(C)	35	0.16	
1.10	Nsanje	(S)	48	0.10	
2.1	Lilongwe	(C)	43	0.00	
2.2	Salima	(C)	44	-0.02	
2.3	Nkhota Kota		46	-0.06	
2.4	Mchinji	(C)	46	-0.06	80 boreholes under construction from April 1995
3.1	Mzimba	(N)	53	-0.14	Project for construction of 300 boreholes proposed
4.1	Zomba	(S)	60	-0.14	
4.2	Machinga	(S)	71	-0.36	
4.3	Rumphi	(N)	78	-0.36	
4.4	Blantyre	(S)	74	-0.42	
4.5	Karonga	(N)	90	-0.60	
4.6	Mulanje	(S)	86	-0.66	
4.7	Chitipa	(N)	93	-0.66	
4.8	Ntcheu	(C)	91	-0.96	

Note: Positive figures denote relatively poor coverage

N: Northern Region
C: Central Region
S: Southern Region

3.3.4 *Recent government and donor initiatives*

The 1990s have been characterised by efforts to:

(a) increase coverage in rural areas through borehole drilling programmes, with limited shallow well construction. Increasing coverage is seen as fundamental to raising the well-being of the rural poor, with concurrent efforts to improve health and sanitation through integrated development programmes;

(b) rehabilitate existing boreholes and shallow wells to increase coverage;

(c) undertake drought relief programmes in areas worst affected by the 1991-92 drought, with follow up village level operation and maintenance initiatives (VLOM) to ensure sustainability; and

(d) promote community based management (CBM) for new works. At the heart of this new approach is the mobilisation of community support for a system in which communities identify their own water supply needs and take responsibility (away from government) for maintenance.

The role of central government, through the former Ministry of Works and now through the MIWD, has traditionally been all-encompassing, from initial assessment of needs and supplies, to supply development, monitoring and evaluation, and maintenance and rehabilitation. The role of the government in the wider economy, and of the Water Department more specifically, is now changing. It is envisaged that government will in future be responsible for only that work which cannot be conducted efficiently, or with economies of scale and proper coordination, at lower levels. This shift in approach has been prompted by the poor performance of previous investments, donor pressure and financial constraints hampering government's ability to service a rapidly increasing population of water points. Figure 9 illustrates the new rural water supply and sanitation delivery mechanisms, modelled closely on procedures developed on the DANIDA funded Lakeshore project and guidelines drawn up in a 1993 workshop involving government and NGOs.

Regional borehole drilling and rehabilitation projects are funded by donors. Table 6 indicates the extent, nature and targeting of donor funding at the beginning of the 1990s. A clear picture of donor support is difficult to obtain, as there is a great deal of cross-funding. Table 6 lists donor/NGO projects; a list of funders would be much longer, as NGOs such as SCF-UK act as conduits for donor support. Most donor funding is for borehole drilling and rehabilitation, with only limited support for monitoring. Monitoring work which is or has been carried out includes: UNICEF funding for a groundwater quality monitoring programme; Inter-Aide measuring water levels in some shallow wells; and UNDP and UNICEF funding of a drought monitoring exercise in October 1992 (see Section 4).

It is difficult to distinguish between support aimed at increasing long term coverage and sustainability, and shorter term emergency relief. The Water Department raised concerns during the 1991-92 drought that emergency drilling programmes were in some instances poorly targeted, and did not address emergencies at all. The Water Department appear concerned that some NGOs are reluctant to move out of their established zones of influence and deal with problems in other areas.

Donor funding also supports a national programme of capacity building and restructuring. Recent initiatives include World Bank funding for the Malawi Government's National Water Resources Development Plan (NWDP), amounting to some $100 million over five years. Although most of these funds have been earmarked for upgrading and extending water and sanitation coverage in urban and peri-urban areas,[6] about 40% has been set aside for borehole rehabilitation and drilling.

[6]The targeting of World Bank funds, and in particular the emphasis on urban and peri-urban areas, has been the source of some controversy. Other multilateral agencies such as UNICEF and the ODA have indicated that rural water supply and sanitation is being neglected.

Figure 9 **Rural water supply and sanitation service delivery mechanisms. Source: UNICEF (1995)**

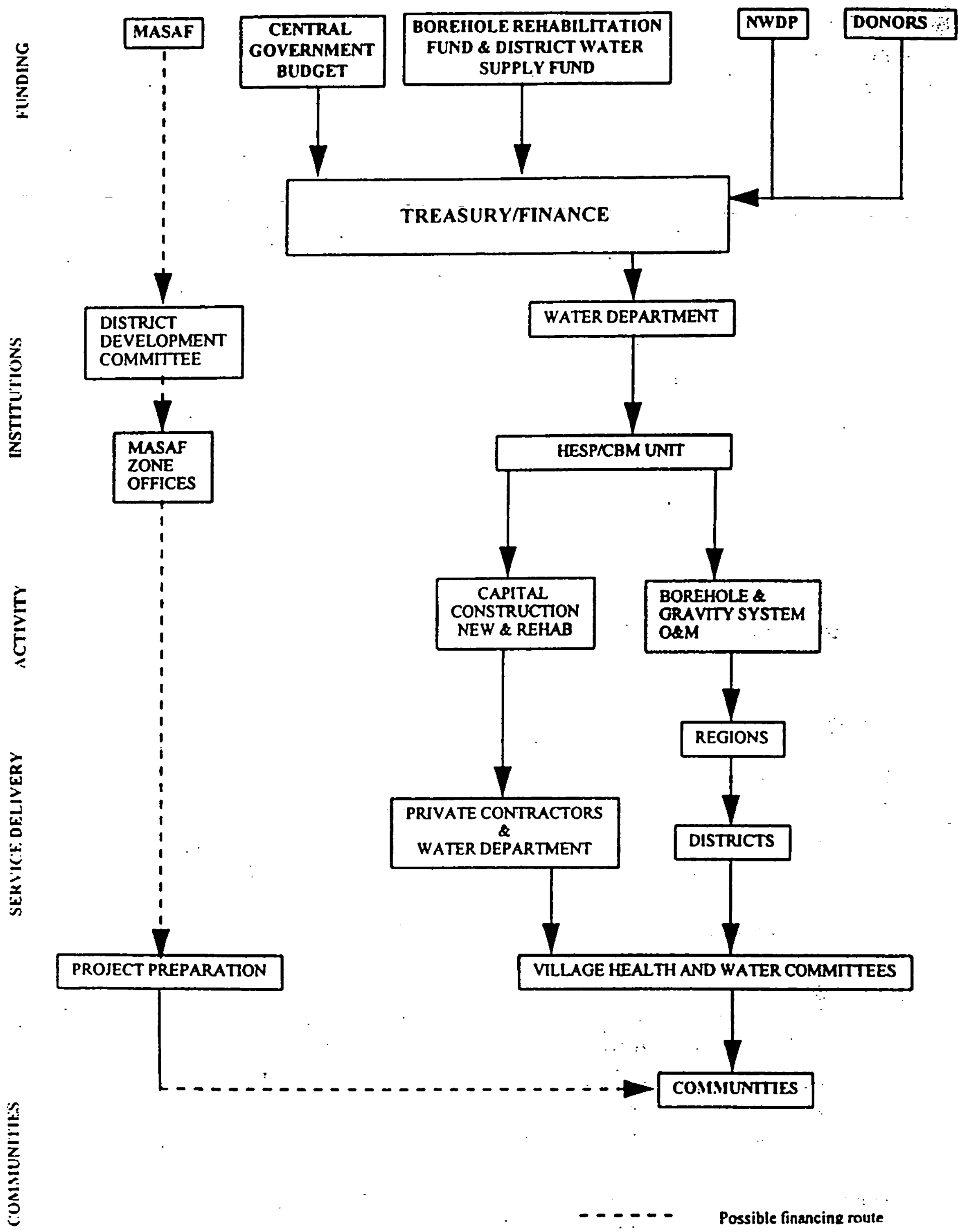


Table 6 **Donor support for rural water supply and sanitation. Source: UNICEF (1995)**

Donor	Nature of support	Period	Remarks
IDA	Rehabilitation of 1450 boreholes in the Northern and Central Region with VLOM	1992-95	Project ongoing, value $US4.3 million
UNCDF/ UNDP	Rehabilitation of 1000 water points in the Southern Region with VLOM and HESP	1994-95	Project in progress. A total of $US6.03 million provided
UNICEF	300 water points in Nsanje. Rehabilitation of 100 boreholes, 100 deep boreholes and 100 shallow boreholes	1992-95	Project extended to 1997 for HESP. A total of $US1.4 million provided
USAID	13 rural gravity schemes and rehabilitation of 2 existing ones in various parts of the country	1992 to present	2 completed 5 on-going 8 about to start
ADB	Zomba South Rural gravity scheme	1993 to present	Project ongoing, value $US4.65 million
JICA	300 boreholes in Mchinji	1993-95	Project to be completed in Sept 1995, value $US6 million.
	164 boreholes in North Kawinga, Machinga	1988-90	Project completed in 1990 and total of $US20 million provided
KfW	231 new VLOM boreholes and 19 rehabilitated boreholes	1995-96	Project in progress
DANIDA	303 VLOM water points in Karonga	1988-94	Project completed
SCF-UK	Construction of water points in refugee impacted areas and drought-stricken districts	1989 to present	Also implementing CBM on national projects
CONCERN Universal	Construction of water points in refugee impacted areas and drought-stricken districts	1990 to present	Also implementing CBM on national projects

4. THE 1990s DROUGHT EXPERIENCE IN MALAWI

4.1 The drought shock of 1991-92: national context

The rain failure of 1992 was the most serious in the country's history since 1949. Coming on top of a refugee crisis and economic and social dislocation, the impact of the drought on the people of Malawi was severe, exacerbating an already bleak social and economic situation.

The chain of events that followed led to national economic crisis. Drought conditions caused real agricultural GDP to fall by 25% in a single year (37% for small scale agricultural GDP), in turn causing an 8% fall in national GDP, or 11% per capita. The drought necessitated large imports of maize. Coupled with the withdrawal of non-humanitarian aid, the result was a substantial balance of payments deficit in 1992. This led to the need to devalue the Kwacha by 40% which, in combination with high maize prices, drove up inflation, leading to the labour unrest still persisting today (Smith, 1995).

The impact of the drought on the nation's water resources was also profound, and undoubtedly had severe economic repercussions. Many of the rivers and piped water systems dried up, as did most shallow wells. This meant that dependence on groundwater, where it could be accessed through boreholes, became even more important. With relatively limited borehole coverage at the time, especially in the most densely populated and worst affected south of the country (see below), people were forced to walk or cycle long distances for water, or to rely on traditional sources. Although it is difficult to quantify the effects in economic terms, it is not unreasonable to assume that the health problems that resulted and the time spent seeking out water supplies at the expense of other activities severely compromised the ability of people to regain economic independence.

The events of the 1991-92 season are the best documented and are the focus of this report. However, lower than average rainfall and drought conditions persisted into the 1992-93 and 1993-94 wet season. The normally perennial North Rukuru, Lilongwe and Bua Rivers dried up not only in 1992, but in 1995 also - a hitherto unheard of phenomenon. This has meant that water resource problems have continued to occur long beyond the end of the food crisis. As far as groundwater resources in particular are concerned, it is recognised that there may be a considerable time lag between periods of low rainfall and effects on groundwater levels, and that several (not necessarily consecutive) periods of low rainfall may conspire to create a situation of groundwater drought. This makes it important to have a continuous groundwater monitoring and assessment programme, with monitoring of groundwater supply status to include periods outside drought episodes defined only by surface water and food security indicators. The focus of this report on the events of 1991-92 rather than, say, 1991-1995, is therefore recognised as a weakness, but reflects the fact that drought monitoring efforts are concentrated in periods defined by indicators other than groundwater status.

4.2 Drought progression: triggers and impacts

4.2.1 *Overview*

The failure of the rains in early 1992 had an immediate and direct impact on the agricultural sector and the lives of smallholders growing rainfed crops. As the dry period continued, surface water flows were affected with adverse impacts on drinking supplies, power generation and irrigated estate agriculture. Lack of rainfall meant that abnormally large soil moisture deficits occurred, with negative effects on groundwater recharge when the rains did eventually come. The earlier than usual drying up of rivers signalled that water tables were falling below river bed levels, and shallow wells began to dry up. The reduction in safe water points then had knock-on effects for health, and outbreaks of water-related illnesses became a serious problem.

In this way a drought progression of triggers and associated impacts can be traced, from failure of the rains and rainfed agriculture, to low flows in rivers and water scarcity, and to the drying up of shallow wells with concomitant health impacts on those with no access to working boreholes. These changes and their impacts are discussed in more detail below.

4.2.2 *Failure of the rains and rainfed agriculture*

Meterological data indicated near normal rainfall in the early months of the 1991-92 rainy season (October to December). Beyond December, however, a sharp decline in rainfall compared to typical years was observed, particularly in the south of the country. The 1991-92 rainfall was 67% of the long term average, the second most severe shortfall recorded this century (Figure 5) (Chavula 1994). The Lower Shire Valley (Chikwawa and Nsange districts in the southern most part of the country), Mwanza, Mangochi, and Machinga Districts recorded the highest shortfalls in rainfall (Table 7), though other areas were also badly affected.

Table 7 Rainfall distribution for February 1992. Source: Kamdonyo (1992)

Station	Rainfall (mm)	Normal rainfall (mm)	% of normal
Chitipa	277.0	221.2	125
Karonga	100.8	164.6	61
Mzuzu	35.9	180.2	20
Nkhata Bay	40.7	194.0	21
Mzimba	189.3	198.6	95
Kasungu	100.2	269.0	37
Chitedze	20.7	199.6	10
Nkhota Kota	38.4	299.4	13
Dedza	66.8	207.9	32
Ntcheu	95.2	234.6	41
Balaka	3.0	177.6	2
Maugochi	2.4	198.9	1
Zomba	69.0	232.0	30
Chichiri	9.0	210.1	4
Bvumbwe	0.4	208.9	0.2
Mwanza	1.8	216.4	1
Makhanga	1.3	123.3	1

The first effects of any drought are in lost agricultural production. In Malawi, where the majority of smallholder production is rainfed and where maize is the dominant (and not very drought resistant) crop, the effects were particularly severe. National crop estimate data collected before the rainfall deficit indicated a good harvest for main staples. However, initial crop estimates of 1.6 million tonnes of maize were reduced to 0.7 million tonnes (56% lower) because of the drought. In February 1992, a rapid assessment of the effects of the drought in the apparently worst affected areas (UNICEF and the Centre for Social Research) concluded that 4.7 million people (including one million children) in

Central and Southern Regions were severely affected and required assistance. Subsequent national registration for food relief distribution raised this estimate to 6.1 million people, approximately 65% of the total population (SADC, 1993). The impact of the drought on crop production varied considerably over the country with the Southern Region, the most densely populated, the worst affected. Reports from Nsanje and Chikwawa also indicated increasing livestock death, the result of both food and water shortages (SADC, 1993).

4.2.3 *Receding river flows and early symptoms of water stress*

The data collected from streams, rivers and lakes indicates that the 1992 drought was particularly severe, with river flow data indicating the lowest flows on record.

Table 8 (from the November 1992 Drought Assessment Report) illustrates flows and water levels at selected river and lake gauging stations.

Table 8 Water resources assessment summary of river flows. Source: MIWD Drought Assessment Report (November 1992)

Name Of River	Measured At	Historical October average flow	1992 FLOWS		
			September observed flow	October observed flow	November estimated flow
		(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
Songwe	Mwandenga	7.670	8.304	6.915	7.02
Lufira	Ngerenge	0.915	0.533	0.178	0.071
North Rukuru	Mwangolera	2.180	1.480	1.015	0.850
Wovwe	Njalayakhumba		1.313	1.124	1.010
Lake Malawi	water levels	474.690	474.060	473.950	473.82
South Rukuru	Kazuni/rumpi	0.303	0.001	0.000	0.000
Chelinda	Rumphi	2.190	1.226	0.979	0.730
Lunyangwa	Mzuzu Sec. S.	0.184	0.085	0.052	0.033
Mzimba	Gausi	0.397	0.000	0.000	0.000
Bua	Malomo	1.260	0.000	0.000	0.000
Lilongwe	Near Mvera	1.140	0.028	0.002	0.000
Mpamadzi	Gumbu/Ntcheu	0.006	TRACE	0.000	0.000
Shire	Chikwawa	590.000	200.000	195.000	200.000
Mulunguzi	Zomba Plateau	0.124	0.072	0.054	0.033
Mwanza	Mwanza Old Customs	0.363	0.000	0.000	0.000
Shire	Liwonde	321.000	210.000	212.000	200.000
Thuchira	Chonde	0.752	0.690	0.323	0.070
Nsuwadzi	Chipungu	4.490	0.318	0.237	0.110

Drawing on this and other data, the report notes the following:

- flows from the Shire River were the lowest on record. This affected downstream power generation, irrigation and navigation;
- by November the effect of drought had spread to Central and Northern Regions. Previously, effects had been confined to the south of the country;
- several major rivers (Bua, South Rukuru, Phalombe and Mwanza), which would normally be perennial water supply sources, ran dry by November for the first time since records began. This was attributed to the fact that groundwater levels were below the river bed, indicating that water levels in the these catchments (and the districts within them) were very low;
- most of the remaining running rivers recorded less than 30% of normal flows; and
- annually drying rivers dried up earlier than usual.

By November 1992 (the end of the 1991-92 rainy season), the situation described above had led to the failure of, or rationing in, 14 rural water supply schemes and five urban water supply schemes.

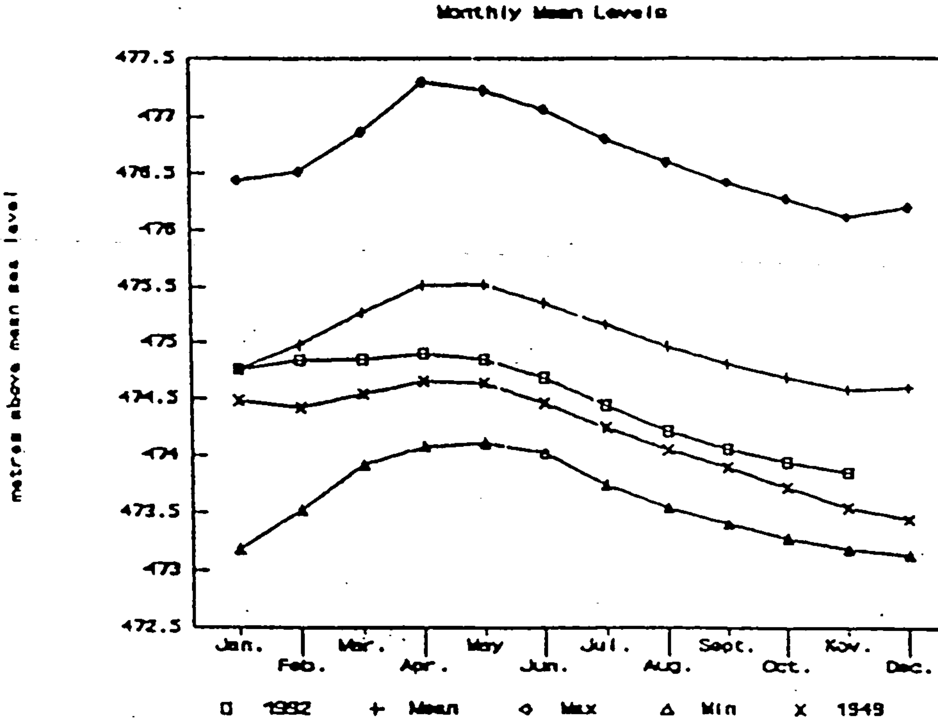
Urban water supplies were adversely affected by the drought. Ntcheu was badly hit: the large gravity-feed scheme taps dried, and the dam level was abnormally low. The importance of dams for supplementing scarce supplies became recognised. A dam was built in Mzuzu in response to the 1991-92 drought. Dams in Kasunga and Zomba have been rehabilitated, as drought-proofing measures. The river supplying part of the Karonga urban area dried and large shallow wells were dug into the dry river bed. The levels of some rivers had to be artificially raised in some places in order for urban supply pumping stations to operate. For instance in 1991-92, abstraction was maintained from the diminishing North Rukuru River by raising its level with sandbags. These measures were again necessary in 1994-95

The effect of the drought on lake levels is shown clearly in Figure 10. By November 1992, levels were approximately 1 m below normal, and at their lowest since 1955. The rise in lake level recorded at the end of the 1991-92 rainy season was the lowest on record, lower even than the rise in the 1948-49 drought-stricken rainy season. The small rise illustrates very low inflows from feeder rivers.

The quality of river water deteriorated during the 1991-92 drought episode. Levels of mineralisation increased in aquifer baseflow-fed rivers, but not in the freshwater lake-fed River Shire. Chavula (1994) suggests that the inadequacy of rainwater to recharge and dilute groundwater resources resulted in increased levels of total dissolved solids (TDS) in groundwaters and associated river baseflow.

Crop failure and deforestation led to reductions in vegetation cover. This, coupled with parched soils (causing more water to runoff rather than infiltrate), led to accelerated soil erosion rates, reflected in a four-fold increase in suspended solids in most rivers (Chavula 1994). Substantial silting of rivers occurred too; relatively low flow rates meant that their ability to carry sediments was reduced, and hence much of their load was rapidly dropped. To the east of the Shire River, 1.5 m of sediment was deposited in stream beds.

Figure 10 **Comparison of recent water levels in Lake Malawi. Source: MIWD Drought Assessment Report (November 1992)**



4.2.4 *Food, water and health*

The impact of the drought on health was severe, and it is here that its effect on the availability of adequate water supplies as well as food becomes apparent.

The health information system in Malawi routinely collects large amounts of data which is never analysed, making it difficult to compare data across years or seasons (SADC, 1993). However, diarrhoeal and cholera outbreaks were observed during the drought period, and an epidemic of shigella dysentery began in the Southern Region in early 1992, eventually spreading throughout the country (SADC, 1993). Rates of malnutrition on the other hand were relatively low, with four separate nutritional surveys indicating coping mechanisms, such as the cultivation of dambo land, seasonal estate labour, food trade with refugees and changes in diet, as being important. This suggests that the principal health problem may have been water, rather than food related. Similar conclusions were reached by the Water Department themselves. For example, the November 1992 Drought Assessment Report compiled by the MIWD Water Task Force (see Sections 4.2.5 and 4.3) states that:

"...the task of drought relief water supply became more challenging as a number of cases of blood diarrhoea and related diseases associated with water shortages were reported throughout the country. The most affected areas were in Mangochi, Machinga, Blantyre and Lower Shire Valley in the south, and Dowa, Lilongwe, Ntchisi, Ncheu, Nkhotakota and Salima in Central Region. Insufficient water supply was expected to reduce hygiene and sanitation practices and encourage water-borne diseases throughout the country. It had been reported that areas where one unprotected water supply source was being used by animals, domestic use was becoming common. It was envisaged that water-borne

diseases like cholera were expected to be prevalent during the early months of the rainy season, due to poor sanitation and scarcity of water."

In light of the above, it is clear that groundwater drought has both quality and quantity dimensions: as the number of operational water points declines, people are forced to use poorer quality water from unprotected shallow wells, rivers, and dug-outs, with obvious health implications. Reports from lake shore areas also indicated that the drying up of shallow wells was associated with an increase in the number of people using lake water for domestic uses. This resulted in an increase in water-related disease (Kabuka Banda (Plan International), personal communication).

It may also be worth noting that the mineralisation of groundwater increases during drought, and that high concentrations of sulphate and manganese can cause diarrhoea (Chavula, 1994). In addition, enhancement of already high fluoride levels can give rise to fluorosis.

4.2.5 *Impact on groundwater resources*

While the impacts of drought are frequently identified in terms of food availability and entitlements, the evidence from Malawi indicates how water scarcity can also become an acute problem. The evidence for this comes from a variety of different sources (government departments, donors, NGOs), and in a variety of different forms (groundwater data, water supply maintenance records, health data, anecdotal evidence, conversations with villagers).

While a broad overview of the effect of the drought on groundwater resources is relatively easy to obtain (most officials in the Water Department painted the same picture), fleshing this picture out in terms of quantitative data is rather more difficult. There are several reasons for this:

- no comprehensive groundwater monitoring system giving reliable information on the status of rural water supplies existed prior to the drought. Emergency assessments were carried out during the drought, but donor funding for nationwide monitoring ended with the return of the rains;

- no overall evaluation of the impacts of the 1992 drought on groundwater supplies appears to have been made. This is in stark contrast to the amount of effort which has gone into evaluating the impact of the drought in terms of food security;

- the Water Department, with its limited financial, technical and manpower resources, did not have the capacity to tackle the water supply problem in rural areas by itself. For this reason, the donor response often side-stepped the Water Department with the result that comprehensive and coordinated data collection and analysis was made more difficult; and

- donor support financed a massive capital programme of well drilling and rehabilitation, but did not finance any *continuous* groundwater monitoring programme.

Nevertheless, it is possible to draw some indicative conclusions from study tours undertaken during the authors' visit and from government and donor records. These lines of enquiry and the information revealed is discussed below.

4.2.5.1 Government reports

With no comprehensive monitoring system in place, government relied on emergency drought assessment surveys and lines of communication between district, region and headquarters in Lilongwe to assess the impact of the drought on groundwater and to formulate responses.

MIWD Water Task Force/Water Security Committee reports describe the status of rural water supplies at periods throughout 1992, 1993 and 1994. Some of these reports are held on file.

The August 1992 report on the effect of the drought states that *common traditional sources of water - streams, dambos and shallow wells - were affected worst by the drought*. Government and donors responded with a large scale borehole drilling and maintenance programme.

The November 1992 Drought Assessment Report based its conclusions on several information sources, including: (a) the results of a 'one-off' national drought survey sponsored by UNDP and UNICEF, and conducted by the Water Department; (b) other government departments, including Agricultural Development Divisions and Regional Health Inspectors; and (c). NGOs and donors.

The report concludes that, *by November 1992, approximately three million people across the country had inadequate water supplies*. It notes reports from some areas (not specified) of widespread suffering from inadequate water supplies, and states that *"...the worst hit areas continue to be the Lower Shire Valley, but the whole of the Southern Region was affected, except traditionally wet areas of Mlanje mountain escarpment and isolated places in Zomba and Thyolo"*.

In describing the impact of the drought, a distinction is again made between boreholes and shallow wells. The report states that *relatively few (perhaps 5% of the 8200 catalogued) boreholes had dried up by November 1992. Dry boreholes were mainly concentrated in hilly and mountainous areas such as Livulezi Valley, where aquifers are of limited thickness and storage capacity*. The report presents water level data from some monitored boreholes which indicates a significant decline in water levels between the period of maximum rise and maximum decline (March-November), if not a total drying up (Table 9). Most of these boreholes are located on basement and fractured escarpment aquifers; no data from the alluvial aquifer was available, and no historical data is available. In contrast, the report states that *most shallow wells (perhaps 70%) were dry by November 1992*, especially in catchments where major rivers (for example Bua, South Rukuru, Phalombe, Mwanza) had dried up. These districts included: Chitipa, Rumphi, and Mzimba in the north; Casing, Dowa, Mchinji, Lilongwe and some parts of Salima, Dedza and Ntcheu in the Central Region; and almost all districts in the south.

In areas where shallow wells were the principal source of potable supply, impacts were particularly severe. Examples quoted in the report include Salima, where all 17 wells dug by the Water Department dried up by September, and Nkhotakota, where 114 out of 169 shallow wells were dry by November.[7] The report goes on to state that "..the drying up of traditional water sources in the north appeared to have seriously affected some parts of Mzimba, Rumphi, Chitipa, Karonga and isolated areas in Nkhata Bay."

[7]Shallow wells in Malawi have typically remained functional throughout the dry season. They are dug in the dry season specifically to avoid problems of drying-up (R. Kafundu (UNICEF), personal communication).

Table 9 **Changes in levels of water table during period between March-November 1992. Source: MIWD Drought Assessment Report (November 1992)**

District	T/A	Bh. No	Water table drop in metres	Period	Type of aquifer
Blantyre	Chigaru	L205	1.3	4/92-10/92	Basement
"	"	RK267	1.6	3/92-10/92	"
"	"	RK23	1.3	3/92-10/92	"
"	"	W241	1.6	3/92-10/92	"
"	"	SK237	0.1	4/92-11/92	"
"	"	L212	0.1	3/92-11/92	"
Chikwawa	Chapananga	FC11	4.2	6/92-10/92	Basement fracture
"	"	K153	0.1	4/92-9/92	"
"	"	CC56	3.0	4/92-10/92	"
"	"	RB176	0.2	3/92-8/92	"
Zomba	Mulumbe	D72	0.4	4/92-11/92	Basement Aquifer
"	"	D74	0.7	4/92-11/92	"
"	"	Y109	0.9	4/92-11/92	"
"	"	S82	2.4	4/92-11/92	"
"	"	FM72	0.4	4/92-11/92	"

4.2.5.2 Field visits

Visits were made to village boreholes and wells, to hospitals and to borehole maintenance teams at various district and regional offices of MIWD to obtain first hand accounts and further records of the 1991-92 drought. It was clear that the impact of the drought varied from place to place. In the Lower Shire Valley, for example, lack of rainfall for crops and low river flows were significant problems. In Mangochi falling water levels resulted in the drying up of shallow wells; this was also a problem in the Lower Shire Valley. Settlements reliant on the fractured basement aquifer experienced drying up of boreholes and shallow wells. In Dowa, the groundwater quality deteriorated so much at certain boreholes that the water became undrinkable.

Nor surprisingly, different people gave different accounts of the 1991-92 drought, even in the same general area. This reflects the localised nature of drought impacts and the varied backgrounds, professions and drought experiences of the people met. [8]

Appendix B contains hydrographs for a few wells based on data collected in the field. Appendix B also contains graphs plotting records of dry boreholes at selected locations over time, using data from maintenance report returns from district and regional MIWD offices.

[8] During the field visits, it was often difficult to gain a clear idea of the impact of the drought from district MIWD sources. Reasons include: non-existent or incomplete records (Malawi has an oral tradition and records, if kept, tend to move with people) and rapid job turnover (people move around frequently; most of the officials met claimed to have been living somewhere else during the 1991-92 drought). Above all, however, district level offices are staffed by maintenance technicians and supervisors with few resources at their disposal.

Alluvial aquifer, Lower Shire Valley

The Lower Shire Valley, containing Chikwawa and Nsanje Districts, was reputedly the region most severely hit by the failure of the 1991-92 rains. Its aquifers are alluvial and flank the Shire River, which flows out of Lake Malawi. In addition to being abnormally low, the rainfall of 1991-92 was locally very variable. Hence adjacent villages and Tribal Authorities within the valley had very different drought experiences, in terms of both severity and duration. Kalambo Tribal Authority of Chikwawa District actually received less rain in 1992-93 than in 1991-92.

Shortage of food rather than water was reported as the most severe problem, with no 1992 harvest in much of the region. Drought was a 'new' experience for the area, and as a result it took a lot of time to mobilise a response. However the response was accelerated because aid agencies associated with the refugee camps were already there. Refugee Camps were at Nsanje, Changamnika in Chikwawa, and at Kunyinda in Ngabu. Good records of their wells and boreholes were kept by SCF-UK and UNHCR, and may be available from their offices.

Ngabu Unit, Chikwawa District - lack of maintenance; drying-up of shallow wells: Chikwawa District is subdivided into two units: Ngabu and Chikwawa. In Ngabu, one borehole usually serves three or four villages. No MIWD borehole maintenance had been carried out for the four months preceding the author's visit due to lack of money.

Seasonally wet, 8-9 m deep, unlined dug wells became permanently dry in 1988-89. Only two of a series of 12.5 m deep hand-augured 'Wonder' wells are now in use; most became dry in 1991-92. One hundred and seventy four of the 525 boreholes had yields of under 1 l/minute. Camsax funded the rehabilitation of 70 boreholes which had performed badly in 1991-92 and 1992-93. The outlook for 1995 was reported to be bleak.

Mandega village, Chikwawa Unit - diminishing yields: The village of Mandega was badly affected by the 1991-92 drought, and has an ongoing water supply problem. Mandega has 532 inhabitants living in 125 households (1994 figures). It is supplied by a single low yielding borehole, 'X71'. The CBM scheme has been introduced to the village recently, and four women and six men make up the borehole committee. Each family donates two Kwacha (roughly £ 0.10 at June 1995 prices) each year towards spare parts for the pump. The borehole was rehabilitated in 1992, as part of a routine maintenance scheme. In the process its borehole number, inscribed in its concrete plinth, was obscured.

It takes at least 15 minutes to fill one 20 l bucket (June 1995 situation). Waits of several minutes between pumps of the Afridev are needed to let the water level recover sufficiently for further pumping. A queue of 20 empty buckets is half a day's worth; women sometimes queue overnight, sleeping at the borehole. Many of the villagers walk over 3 km to the next nearest well, which is higher yielding. There is also a shallow well in this neighbouring village too; it is used when the borehole requires maintenance. It is difficult to maintain adequate hygiene in Mandega, due to the shortage of water. Instead of the usual five pails per day per family, families are having to make do with three or fewer buckets each day.

When the rains failed in 1991-92, lack of food was perceived to be a graver problem than the limited water. The villagers relied on government food aid, supplemented with wild fruit, such as seeds of the Mwemba tree. However, some died from malnourishment.

Chikwawa Unit, Chikwawa District - poor coverage, falling groundwater levels, silting up of boreholes, drying up of boreholes: Chikwawa District is subdivided into two units: Chikwawa and Ngabu. In the Chikwawa Unit, there are insufficient boreholes for an adequate water supply. Again, no borehole maintenance work had been carried out in the four months preceding the author's visit due to lack of transport and funds.

There is an average of 450 people per borehole in the area. Although there are 84 boreholes, they do not provide an adequate supply for everybody. Nine irrigation boreholes were abandoned after a 1980s World Bank funded cotton growing project failed. Water levels are typically about 20 m below ground level, hence shallow wells are not usually a practical alternative. The exceptions are privately dug, unprotected shallow wells located on the banks of the Shire River.

There were no dry boreholes in 1992, four in 1993, six in 1994 and six in June 1995. These are at Nyakiphota (PC254), Mati-Mati (FP83), Maperara School (DM 52), Maperara Health Centre (failed during construction), Patro (A214), and Muula in Chapananga (WG34) - which dried in 1994 (personal communication GL Mataula). A combination of lack of rain and silting-up is likely to be the cause of the boreholes drying up. The soil is very sandy, and can enter boreholes from above (depending on the completion), and through the screen (GL Mataula, personal communication).

Eastern Chikwawa receives runoff from the 1000 m high Thyolo escarpment. In contrast, the west of Chikwawa is in the east's rainshadow. Flowing into it, from the 300 m high Marangwe Range, are rivers which have smaller catchments, less rainfall, and which dry up seasonally. The Chapananga area in western Chikwawa is the most drought affected. Streams and rivers there usually dry up in February or March. Instead, people normally rely on rural water supply taps, from gravity feed systems tapping higher reaches of the River Mwanza. Coffee estates in Bandang now take water from upstream of these piped schemes, reducing the water available for them. Hence the piped supply taps in Chapananga are now dry.

In order to cope with the inadequate numbers of boreholes, and the unreliable gravity-fed schemes, the strategy adopted is to dig holes into the sandy bed of the River Mwanza. These pits collapse and fill up overnight, and hence need to be re-excavated daily. Caving-in problems could be alleviated by lining the dugouts with concrete rings.

Dug-out wells, River Mwanza, Chikwawa District - early baseflow cessation: Three men were collecting water from the base of a 1.5 m deep river dug-out. An adjacent 1 m deep dug-out well had been abandoned because it was dry. Collecting water from the river bed is attractive because it takes an hour to queue for water from the nearest borehole. The next nearest one is broken, and has been for a month. The other nearby borehole is too salty to drink willingly. Local people with bicycles or other transport collect water from the river-fed irrigation ditches of the nearby sugar-cane plantation.

When the river flows, water is obtained from holes dug adjacent to the river, as the water is then filtered and cleaner. In 1995, the River Mwanza stopped flowing two months earlier than normal, probably due to a combination of abnormally low recharge and less water retention due to the increasing deforestation. Rains fell and the river flowed briefly in early June 1995. The water level of the river sands has been falling since then. Later in the dry season, when the river sands eventually dry, pressure on the existing boreholes will greatly intensify.

Nsanje District- drying boreholes: Nsanje District is the southern most district in Malawi, and has more shallow wells than any other district. Many were constructed by UNICEF in the 1970s. During the 1991-92 drought, the upland areas were worst off, both in terms of food and water. Boreholes needed deepening. Relief food was available for the refugees.

Records were kept at Nsanje District Hospital from 1991 onwards about wells that had dried. In 1992-93 Nestdale, an Australian NGO, funded a Water and Sanitation 'WATSAN' project. They conducted a borehole survey and found many had dried. An emergency drilling program was carried out where water was scarce. Water levels at the Nsanje hospital borehole fell from 12.60 mbgl in August 1994 to 13.30 mbgl in December 1994. Both shallow wells and boreholes have suffered significant yield reductions between March and June 1995.

Alluvial aquifer, lakeshore areas

Salima and Nkhotakota - falling groundwater levels: There is hydraulic continuity between Lake Malawi and the lakeshore alluvial aquifers, and surface water and groundwater fluctuations are strongly linked. Urban water supply boreholes at Salima and Nkhotakota suffered severe yield losses in 1991-92, when the lake level was also abnormally low. Hitherto the sources had been perennially dependable, but in 1992 they needed supplementing. There are now four boreholes supplying Nkhotakota instead of the original two. The Salima boreholes have been deepened; here groundwater is of paramount importance as it is the town's only source of supply

Malindi, Mangochi District - falling groundwater levels and associated health problems: In Mangochi, falling water levels in dug wells, and diseases related to poor water quality, have been the major drought-related problems. Shallow wells are common in lakeshore and alluvial areas of Mangochi, with some 490 wells in total. Records of both shallow wells and boreholes are kept in Mangochi District Hospital (i.e. not at MIWD). Health workers are monitoring one well's water levels.

Until recently many people in Malindi still used Lake Malawi as a water source, in the traditional manner. Cholera bouts were the norm at the onset of every wet season. Bilharzia was becoming increasingly common, and other water borne diseases were prevalent. As a health initiative in response to calls from the Minister of Health and Community Services, UNICEF commenced a brick-lined shallow well programme in 1991 which was completed in 1993. Wells are typically 10-11 m deep, with a water column 2-3 m deep at construction.

There have been rain short-falls in Malindi in 1991-92, 1993-94 and 1994-95. In 1992-93 the rivers had some water, whereas they dried up completely in the following year. People then had to use water from the shallow wells for washing and brick making.

Blood diarrhoea became prevalent in Mangochi in 1992-93 when the shallow wells were still under construction. Principal causes included inadequate water supplies, poor hygiene, and reliance on lake water as other sources failed. It took time to find an appropriate drug for its treatment. Cholera came when the rains started. Diarrhoea was also a problem in 1993-94, apparently because of poor water supply. It was not as bad as in the preceding year, due to better health education. There were also scattered dysentery and bilharzia cases.

Water levels in the UNICEF shallow wells have been falling ever since construction. Some now have water columns of just one metre with correspondingly low yields. For example in Mtakataka village, it is necessary to wait for an hour between bucketfuls. Others, such as those in Makwinga village, are now completely dry.
UNICEF responded to this drought situation by funding MIWD drilling of 17 boreholes. They are typically 40-45 m deep, with a depth to water of 6-10 m. Most are adjacent to the original shallow wells. For instance at Makwinga, the new borehole is 10 m away from the shallow well; both are 50 m from Lake Malawi.

Some local people still favour water from the lake, which is reported to have a better taste and smell than water taken from the boreholes.

Fractured basement aquifer

Dedza - groundwater availability problems: Dezda's boreholes dried up in 1992-93. Water levels have not yet fully recovered. Six boreholes are currently dry, at: Mauauni, Magunditsa, Madzumbi and Mawale. There are similar problems in Ntcheu, Ntchisi and Dowa. These settlements are all located on hilly rift-valley escarpment areas, where erosion rates are high. The weathered zone is negligible and the majority of the groundwater resource is stored in fractures. The fractured basement aquifers are compartmentalized, and of limited extent. They have low storage, and so are reliant on annual recharge. When this is repeatedly below average, as at present, yields diminish and eventually cease. For example, most of the shallow wells constructed by UNICEF in Bawara, Ntchisi, have dried up. The problem in Ntcheu is similar to a previous one in the early 1980s described by Kafundu and Laisi (1991).

Ngwanda village, Nkhoma - groundwater availability problems: The shallow well at Ngwanda village, Nkhoma, Lilongwe district has a water column of 0.7 m, and has been abandoned. It is one of 60 dug wells in the Nkhoma area, where the French NGO Inter-Aide are based. Nkhoma is on the escarpment, where the weathered zone is thin. Manually deepening these hand dug wells is not possible, as they are already fully penetrating the weathered zone. At Ngwanda, the adopted coping strategy is use of the nearby spring. Ironically, the shallow well was designed to be a substitute for the spring, because the spring is not always reliable. Inter-Aide commenced a monthly shallow well monitoring programme in October 1994.

Weathered basement aquifer

Kasungu - borehole failures: Boreholes in Kasungu District have been affected by the drought. It is a difficult area in which to site boreholes, due to sandy layers giving poor electrical contact for resistivity surveying. Their poor siting increases their likelihood of failing. Overpumping, both on estates and by constant use of hand pumps in big villages, is exacerbating the problem.

Dowa District, Central Region - hydrochemical deterioration: A change in hydrochemistry, and a resultant deterioration in water quality was experienced in 1991-92 in Dowa District. During the drought, abnormally high sulphate concentrations caused laxative effects. Inhabitants of Dowa complained to the Ministry of Health about the quality of groundwater but no chemical analyses were carried out by MIWD.

Drought years are likely to have associated increases in concentrations of groundwaters, due to less than usual dilution with infiltration waters. The effects elsewhere in 1991-92 are unknown as no groundwater hydrochemistry monitoring took place, however no reports of increased salinities reached the MIWD. Analyses of baseflow waters from several rivers showed increases in concentration of sulphate during the drought, by a factor of 22 in the Lunyangwa River (Mrs Lakudzala (MIWD), personal communication).

4.3 Government and donor responses

4.3.1 *Government*

Following failure of the January 1992 rains, the Deputy Minister of Works instituted a Water Security Committee chaired by himself on a monthly basis, with the aim of assessing the status of water resources and supplies. This committee in turn reported to a National Committee for Disaster Preparedness. Several Drought Assessment Reports were prepared using data from various sources, including borehole maintenance returns from district offices, health and shallow well information from other ministries and NGOs, the MIWD's own drought surveys financed with donor money.

According to an August 1992[9] report, a national assessment of water resource status highlighting the most adversely affected areas (including population affected and numbers of boreholes and shallow wells 'available' - see Figures 11, 12 and 13[10]) was prepared by April 1992 and presented to the National Committee for Disaster Preparedness. Decisions were taken on the basis of this assessment to "...accelerate all ongoing water projects", and to "...reschedule and direct new projects, adjust ongoing projects and position the maintenance teams." Most government effort in rural areas appears to have been focused on borehole maintenance, with district office maintenance returns used to target activities. A further drought assessment was conducted in October 1992 with donor funding from UNDP and UNICEF.

Financing for these activities came from the government's own recurrent budget, and also from that portion of donor funding (relatively minor - it was felt that MIWD lacked the capacity to use the resources) channelled through MIWD rather than through NGOs on the ground. Donors channelling money through MIWD included the Chinese government and UNCDF. During the drought, an appeal was launched by the government to donor agencies for the funding of a country-wide initiative to repair all broken down boreholes.

Problems of coordination have been mentioned by government officials, particularly as regards MIWD and NGO activities. A common government complaint is that NGOs are reluctant to move out of their established spheres of influence, whether or not such zones are the most needy. NGO programmes typically involve follow up VLOM programmes, however, and NGOs are typically concerned about spreading their resources too thinly and starting programmes they are unable to nurture on a longer term basis. A further (related) concern is that NGOs select target areas by themselves, or at least 'present' decisions to the government. An NGO response might be that they have a clearer idea about which places are most needy, and are not subject to political interference when it comes to selecting target areas.

It should be noted that MIWD and NGOs now meet on a regular basis to discuss needs and to coordinate strategies, and that SCF-UK publish updates on NGO water and sanitation activities. Reports indicate that these meetings are now poorly attended, however.

Other problems identified by the government during the 1991-92 drought period included lack of equipment (particularly pumps) and spare parts, and a budget over-stretched by problems in urban supply systems as well as rural supplies.

4.3.2 *Donors and NGOs*

In addition to channelling funds through the government, donor funds also helped support (and continue to support) NGO activities on the ground. A number of drought relief water supply projects

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[9] 'A Report on the Effect of the Drought on Availability of Water as end of August 1992'.

[10]These are essentially very simple drought vulnerability maps, which classify districts according to the numbers and proportion of the population without access to water. Category 4 (lowest coverage) areas are concentrated in the south of the country in 1992 but less so by June 1994, perhaps reflecting development efforts in this area during and after the 1991-92 drought.

were initiated during the 1991-92 drought. However, these appear to have been more effective in reducing the likelihood of future water shortages, rather than in alleviating the impact of the 'target' drought.

Figure 11 Water supply situation - August 1992. Source: MIWD Drought Assessment Report (August 1992)

NSANJE (1) (a) 240,000 (b) 121,000 (c) 119,000 (d) 71 (e) 96.	MACHINGA (1) (a) 603,000 (b) 413,000 (c) 190,000 (d) 126 (e) 128	MCHINJI (3) (a) 293,000 (b) 250,000 (c) 43,000 (d) 33 (e) 20
CHIKWAWA (1) (a) 370,000 (b) 198,000 (c) 172,000 (d) 103 (e) 138	MANGOCHI (1) (a) 582,000 (b) 273,000 (c) 310,000 (d) 155 (e) 310	DEDZA (2-3) (a) 483,000 (b) 376,300 (c) 106,700 (d) 60 (e) 94
THYOLO (2) (a) 504,000 (b) 313,000 (c) 191,000 (d) 95 (e) 190	KASUNGU (2) (a) 378, 000 (b) 279,700 (c) 98,300 (d) 60 (e) 77	NTCHEU (2) (a) 420,000 (b) 383,000 (c) 37,000 (d) 27 (e) 20
MULANJE (1-2) (a) 746,000 (b) 638,000 (c) 108,000 (d) 54 (e) 108	NKHOTAKOTA (1) (a) 185,000 (b) 119,100 (c) 65,900 (d) 35 (e) 70	CHITIPA (4) (a) 114,000 (b) 108,000 (c) 6,000 (d) 6 (e) -
MWANZA (2) (a) 143,000 (b) 79,000 (c) 64,000 (d) 64 (e) NIL	NTCHISI (3) (a) 142,000 (b) 120,000 (c) 22,000 (d) 13 (e) 18	KARONGA (4) (a) 173,000 (b) 171,000 (c) 2,000 (d) - (e) 4
BLANTYRE (1-2) (a) 690,000 (b) 553,000 (c) 137,000 (d) 102 (e) 68	DOWA (3) (a) 378,000 (b) 263,000 (c) 115,800 (d) 90 (e) 48	NKHATA BAY (3) (a) 162,000 (b) 132,000 (c) 30,000 (d) 20 (e) 20
CHIRADZULU (2) (a) 247,000 (b) 205,000 (c) 42,000 (d) 21 (e) 42	SALIMA (1-2) (a) 221,000 (b) 165,625 (c) 55,375 (d) 40 (e) 30	RUMPHI (3) (a) 111,000 (b) 88,800 (c) 22,200 (d) 15 (e) 14
ZOMBA (2) (a) 570,000 (b) 458,000 (c) 112,000 (d) 86 (e) 50	LILONGWE (2-3) (a) 1,143,000 (b) 953,200 (c) 189,800 (d) 100 (e) 175	MZIMBA (3) (a) 508,000 (b) 453,000 (c) 55,000 (d) 30 (e) 50

(1) DISTRICT CATEGORY
(a) Total Population
(b) Population with access to water (urban/piped/BW's/surface)
(c) Emergency Target Population
(d) Number of Boreholes
(e) Number of Shallow Wells

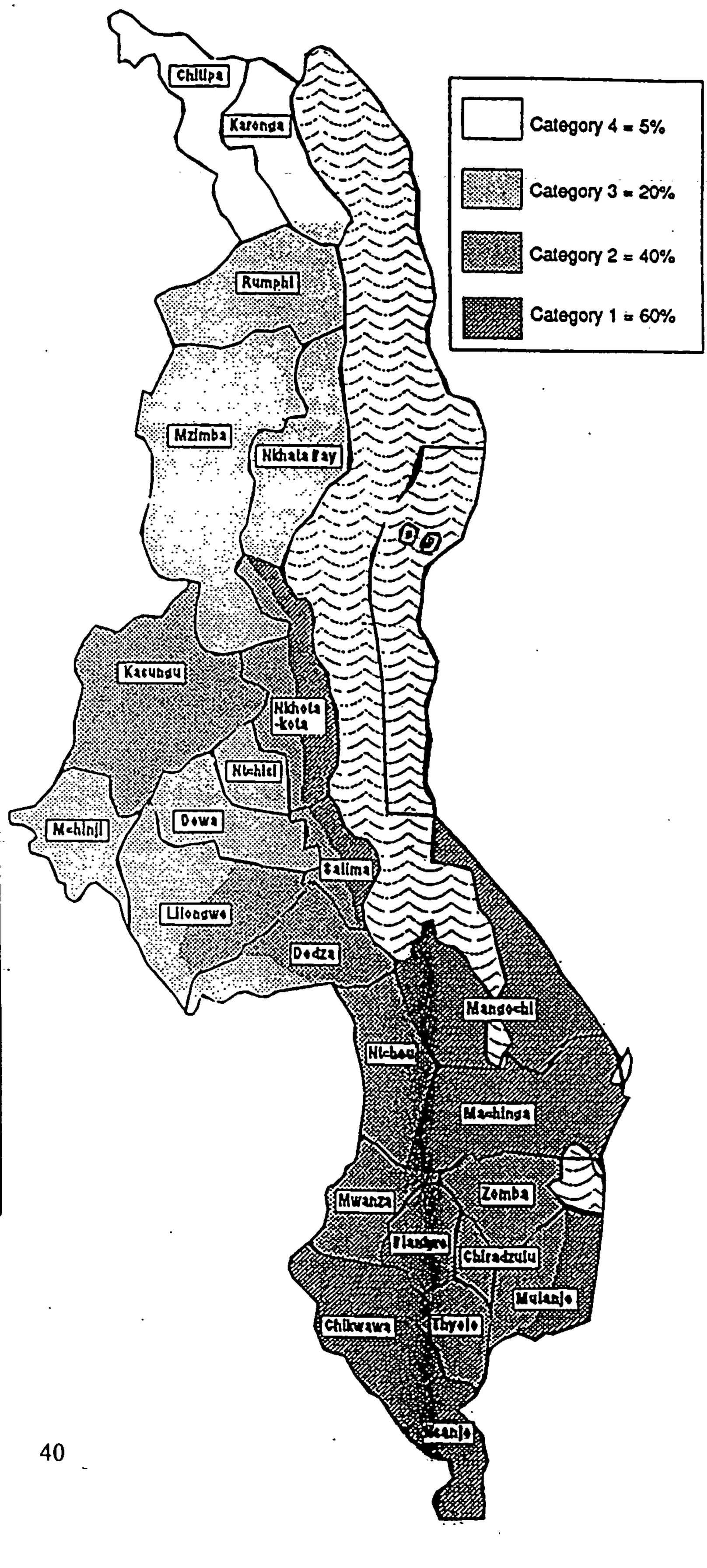


Figure 12 Water supply situation - November 1992. Source: MIWD Drought Assessment Report (November 1992)

NSANJE (1) (a) 240,000 (b) 121,000 (c) 119,000 (d) 71 (e) 96	MACHINGA (1) (a) 603,000 (b) 413,000 (c) 190,000 (d) 126 (e) 128	MCHINJI (3) (a) 293,000 (b) 250,000 (c) 43,000 (d) 33 (e) 20
CHIKWAWA (1) (a) 370,000 (b) 198,000 (c) 172,000 (d) 103 (e) 138	MANGOCHI (1) (a) 582,000 (b) 273,000 (c) 310,000 (d) 155 (e) 310	DEDZA (2) (a) 483,000 (b) 340,700 (c) 142,300 (d) 95 (e) 94
THYOLO (2) (a) 504,000 (b) 313,000 (c) 191,000 (d) 85 (e) 190	KASUNGU (2) (a) 378, 000 (b) 279,700 (c) 98,300 (d) 60 (e) 77	NTCHEU (2) (a) 420,000 (b) 383,000 (c) 37,000 (d) 27 (e) 20
MULANJE (2) (a) 746,000 (b) 659,600 (c) 86,400 (d) 46 (e) 80	NKHOTAKOTA (2) (a) 185,000 (b) 132,280 (c) 52,720 (d) 35 (e) 35	CHITIPA (3) (a) 114,000 (b) 90,000 (c) 24,000 (d) 24 (e) -
MWANZA (2) (a) 143,000 (b) 79,000 (c) 64,000 (d) 64 (e) NIL	NTCHISI (2) (a) 142,000 (b) 98,000 (c) 44,000 (d) 26 (e) 18	KARONGA (4) (a) 173,000 (b) 171,000 (c) 2,000 (d) - (e) 4
BLANTYRE (1-2) (a) 690,000 (b) 553,000 (c) 137,000 (d) 102 (e) 68	DOWA (2-3) (a) 378,000 (b) 204,300 (c) 173,700 (d) 150 (e) 48	NKHATA BAY (4) (a) 162,000 (b) 154,500 (c) 7,500 (d) 4 (e) 7
CHIRADZULU (1) (a) 247,000 (b) 184,000 (c) 03,000 (d) 42 (e) 42	SALIMA (1) (a) 221,000 (b) 154,550 (c) 66,450 (d) 52 (e) 30	RUMPHI (3) (a) 111,000 (b) 88,800 (c) 22,200 (d) 15 (e) 14
ZOMBA (1) (a) 570,000 (b) 402,000 (c) 168,000 (d) 143 (e) 50	LILONGWE (2-3) (a) 1,143,000 (b) 953,200 (c) 189,800 (d) 100 (e) 175	MZIMBA (2) (a) 508,000 (b) 398,000 (c) 110,000 (d) 85 (e) 50

(1) DISTRICT CATEGORY
(a) Total Population
(b) Population with access to water (urban/piped/BW's/surface)
(c) Emergency Target Population
(d) Number of Boreholes
(e) Number of Shallow Wells

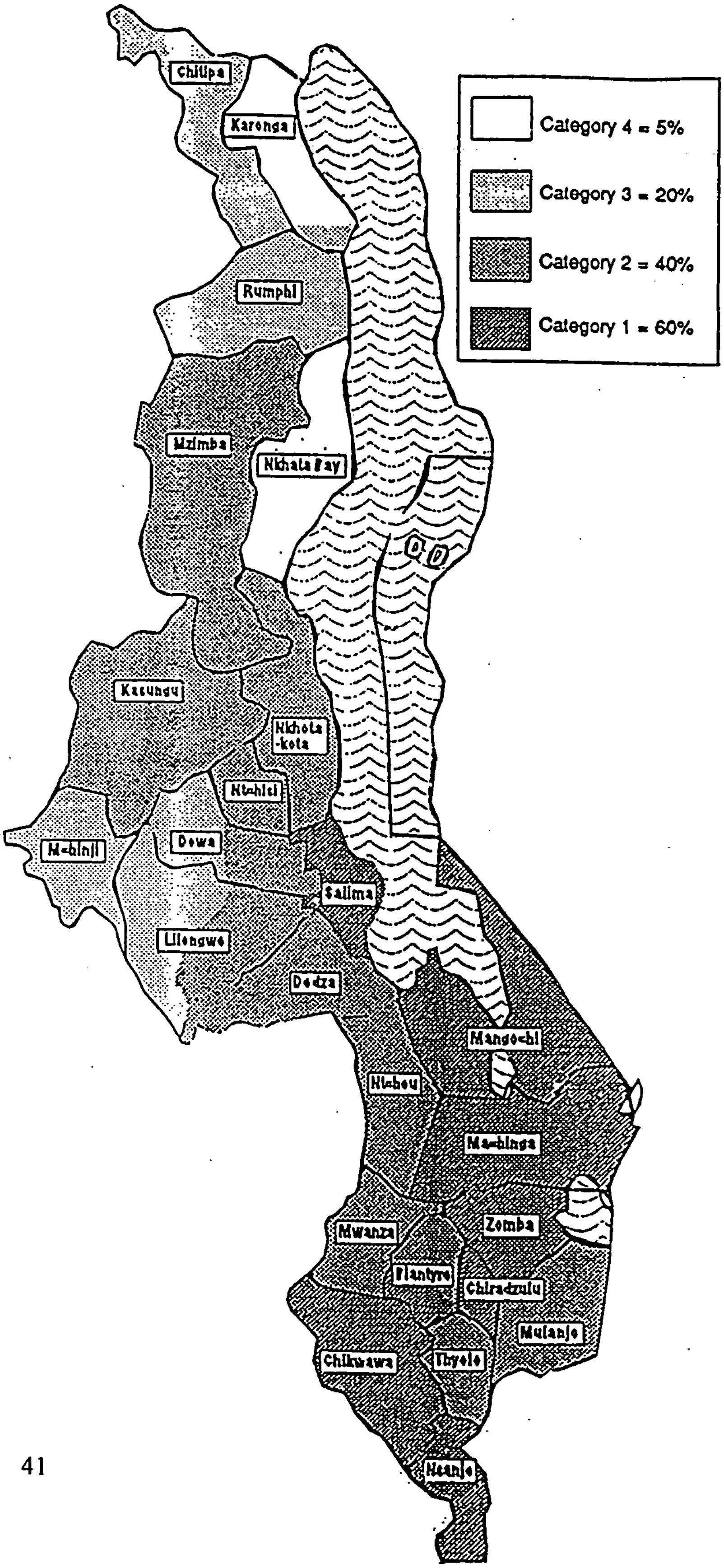


Figure 13 Water supply situation - June 1994. Source: MIWD Drought Assessment Report (June 1994)

NSANJE (4)
(a) 240,000
(b) 234,031
(c) 5984
(d) 6

MACHINGA (3)
(a) 603,000
(b) 520,521
(c) 20,620
(d) 21

MCHINJI (4)
(a) 293,000
(b) 139,900
(c) 8105
(d) 8

CHIKWAWA (4)
(a) 370,000
(b) 201,789
(c) 8853
(d) 9

MANGOCHI (3/4)
(a) 582,000
(b) 209,644
(c) 53,194
(d) 53

DEDZA (4)
(a) 483,000
(b) 177,514
(c) 16,078
(d) 16

THYOLO (4)
(a) 504,000
(b) 61,369
(c) 23,321
(d) 23

KASUNGU (4)
(a) 378, 000
(b) 61,840
(c) 16,640
(d) 17

NTCHEU (3)
(a) 420,000
(b) 356,478
(c) 15,880
(d) 16

MULANJE (3/4)
(a) 746,000
(b) 633,514
(c) 16,009
(d) 16

NKHOTAKOTA (4)
(a) 185,000
(b) 221,642
(c) -
(d) -

CHITIPA (4)
(a) 114,000
(b) 163,470
(c) -
(d) -

MWANZA (3)
(a) 143,000
(b) 35,000
(c) 21,600
(d) 22

NTCHISI (3)
(a) 142,000
(b) 72,584
(c) 17,354
(d) 17

KARONGA (4)
(a) 173,000
(b) 281,465
(c) -
(d) -

BLANTYRE (3/4)
(a) 690,000
(b) 508,220
(c) 25,870
(d) 26

DOWA (4)
(a) 378,000
(b) 132,424
(c) 16,340
(d) 16

NKHATA BAY (4)
(a) 162,000
(b) 106,539
(c) 2,919
(d) 3

CHIRADZULU (3)
(a) 247,000
(b) 106,272
(c) 35,182
(d) 35

SALIMA (3)
(a) 221,000
(b) 150,720
(c) 17,570
(d) 18

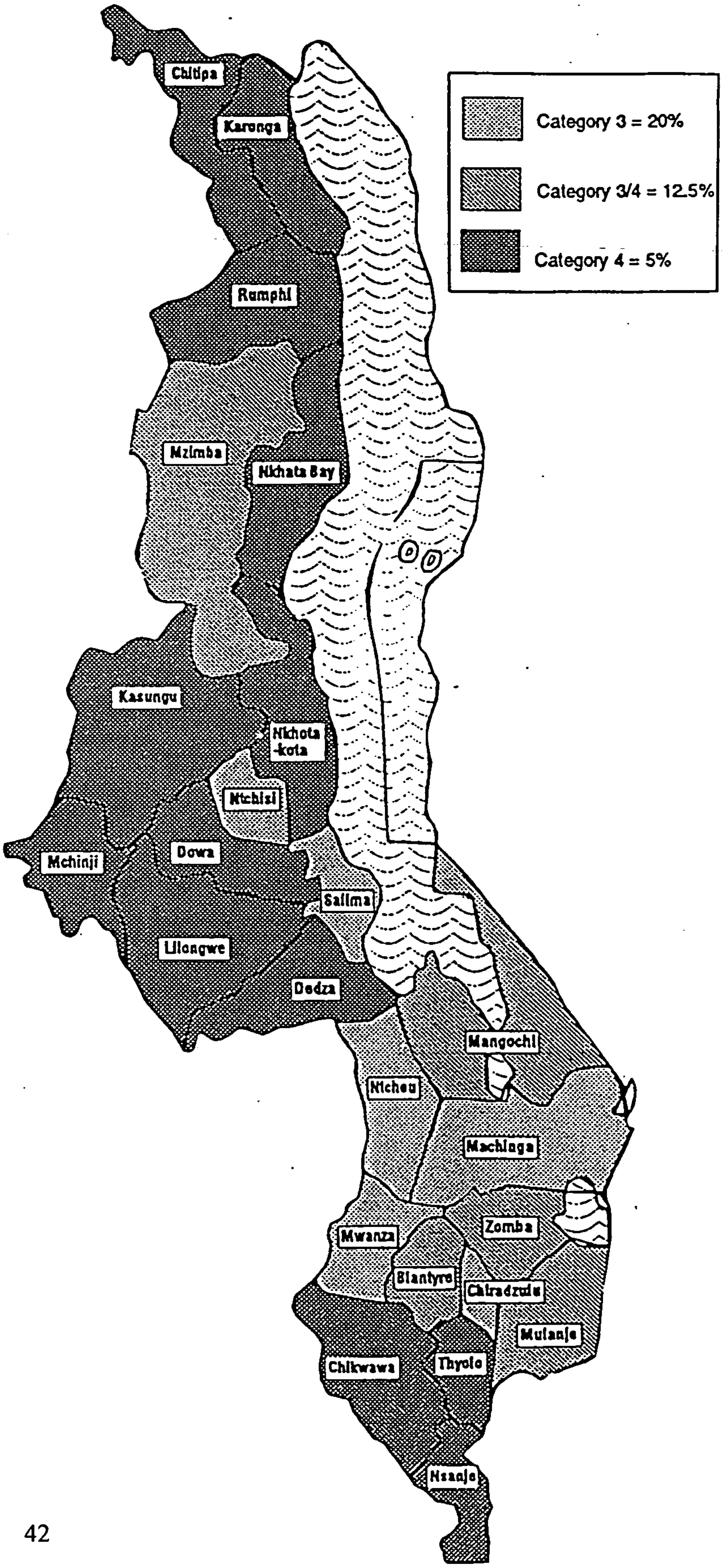
RUMPHI (4)
(a) 111,000
(b) 151,560
(c) -
(d) -

ZOMBA (3/4)
(a) 570,000
(b) 419,351
(c) 21,520
(d) 22

LILONGWE (4)
(a) 1,143,000
(b) 727,855
(c) 21902
(d) 22

MZIMBA (3/4)
(a) 508,000
(b) 403,316
(c) 14,931
(d) 15

(1) DISTRICT CATEGORY
(a) Total Population
(b) Population with access to water (urban/piped/BW's/surface)
(c) Emergency Target Population
(d) Number of Boreholes



While no comprehensive overview of drought related projects was obtained during the authors' visit, the experience of SCF-UK may be representative.[11] In response to the 1991-92 drought, SCF-UK submitted a proposal for assistance to the British ODA for funding of a safe water supply project in October 1992. Following approval and various logistical difficulties, boreholes were finally sunk in the rainy season. Indeed the rains hampered the borehole drilling programme when it eventually got underway. This is not to say that the drilling programme was not justified on developmental grounds (though given the caveats concerning the sustainability of such projects, the justification may be rather weak), but rather that the situation the project was designed to address had passed, as SCF-UK themselves recognised (SCF-UK Drought Report, 1992). Site selection at a macro and micro level was apparently coordinated with MIWD. At micro-level, individual sites were selected according to criteria developed by the MIWD Water Task Force, with priority given to health centres, schools and areas of high population.

Another problem inherent with the provision of emergency water supplies is "... the complete lack of community involvement and consequent inability to guarantee the sustainability of new water points" (SCF-UK Drought Report, 1992). The dilemma is that the aim of drought relief work is to complete it as soon as possible; this tends to preclude community mobilisation and involvement in the choice, siting and design of water points. NGOs such as SCF-UK highlight deficiencies in donor funding arrangements, with funding for community mobilisation and support - if forthcoming at all - arriving too late, and well after completion of water points.

[11]Other NGOs report similar experiences and dilemmas. For example, UNICEF and Concern Universal undertook a drought relief programme in conjunction with the Water Department to rehabilitate and construct 100 boreholes. The project was completed in June 1993, but the initially envisaged community participation, health and sanitation training and maintenance components were not carried out because the work had to be carried out swiftly.

5. CONCLUSIONS AND ISSUES ARISING

5.1 Nature of the 1991-92 drought

The following points emerge from preceding sections:

- the impact of the 1991-92 drought, and hence its local definition, varied from place to place within Malawi. Even at district level, impacts were highly localised. Rainfall is characteristically variable in low rainfall areas, and adjacent villages have starkly contrasting experiences. Geology contributes to differing regional experiences;

- most drought efforts focus on food security. In Malawi, access to adequate supplies of safe water was also a severe problem;

- surface water flows diminished: ephemeral rivers dried up earlier than usual and some 'perennial' rivers stopped flowing entirely. Gravity schemes in many areas failed. Water levels in Lake Malawi were at their lowest since 1955, and the annual rise in levels following the 1991-92 rains was the lowest on record;

- the groundwater drought was more one of access than absolute water scarcity. Except for parts of the fractured basement aquifer, groundwater was usually present. However it could often not be accessed because the water levels fell below the depth of traditional water sources such as shallow wells. Shallow wells in Malawi typically remain viable during the dry season, but were not viable during this drought episode. Partially penetrating boreholes in alluvial areas suffered yield reductions; many needed deepening;

- those boreholes in a good state of repair remained viable in most areas, although water levels fell. However, many boreholes were not working because of poor maintenance when the drought occurred, with the result that many people relied on those traditional, unprotected sources which did have water. Thus poor maintenance compounded the water scarcity problem;

- boreholes may have slower response time to variations in recharge than shallow wells. Any lag effect would reinforce the need for continuous monitoring and assessment of groundwater status;

- outbreaks of disease occurred during drought as people used unprotected, traditional sources. In some cases, animals used the same sources. Diseases also occurred when the rains returned and river flows resumed. Health problems also resulted from groundwater quality deteriorations in localised areas of the weathered basement aquifer;

- no attempt was made in this report to make a full examination of the longer term effects of the 1991-92 drought on groundwater resources, or the cumulative effect of successive low rainfall periods on groundwater resources. The post 1992 situation is one of low groundwater and lake levels. In 1995 perennial rivers stopped flowing and little borehole maintenance was carried out. The longer term picture is of profound importance and should be addressed in further work;

- this report concentrates on events in the south of the country. Follow-up work also needs to consider the effects of drought in Central and Northern Regions.

5.2 Vulnerability to adverse impacts

- some areas are much more vulnerable to groundwater drought than others, and some communities are more vulnerable to the impacts of groundwater drought than others. A combination of factors, including coverage, technology type (well or borehole), geology, hydrology, hydrogeology, and demography conspire to create problem areas. For example, refugee areas where there is shallow well dependency and high population density;

- vulnerability to adverse impacts varies over space and time Experience illustrates how vulnerability is not just a function of geology and technology, but also relates to the ability of communities to access alternative water sources. In Malawi, badly hit areas included those poorly served by boreholes, and areas where many boreholes are not working. These two situations may be related: where demand is high and many people are forced to use only a few boreholes, boreholes are more likely to break down;

- water supply coverage in the south of the country has increased considerably in recent years. This illustrates how vulnerability may change over time, as many areas may be much less vulnerable to drought should it occur again. Ironically, drought relief efforts by government and donors may do little to alleviate the impacts of the current drought, but do much to prevent adverse impacts in future assuming the infrastructure put in place is sufficiently 'drought-proof'.

5.3 Government and donor response

- effective responses depend on reliable, comprehensive and timely information on the status of rural water supplies (both boreholes and shallow wells). This information was not available to government (or, presumably, donors) through the MIWD's existing monitoring system;

- reliable information is essential for any early warning system, but does not guarantee an early response. Experience with early warning systems established to monitor food security indicates how time lags can be considerable. Reasons include the politicised nature of the information generated, isolation of information gathering from the response system and the timing of donor agency and NGO financial years;

- one-off emergency assessments were carried out during the drought, with some assistance from the donor community. Longer term funding of monitoring and assessment programmes - less glamorous than capital construction but perhaps equally important - is difficult to obtain;

- one drought indicator is the demand for more water resources by the managers of urban supply schemes. In 1991-92 these were met in some instances by the provision of dams, and in others by the deepening of boreholes or the drilling of supplementary ones;

- MIWD officials are able to identify potentially vulnerable areas, but a formalised system of communicating this information to donors and NGOs does not appear to exist;

- coordination of government and donor responses may have been hampered by the lack of a forum for discussion. Such a forum has now been established;

- emergency drilling programmes may fail to meet their original objective because of the time lag between project identification, construction and completion. Their contribution to longer term development goals may also be questionable if time consuming sustainability components have to be put to one side. Retrospective funding for VLOM may be difficult to obtain and less effective when it has to be 'tagged on' to a completed project;

- donor response was channelled into borehole drilling and rehabilitation. Other (potentially quicker) responses, such as river bed excavation, were not considered;

- the 'balkanisation' of a country by the donor community is difficult to avoid, but may prevent the most needy areas receiving attention.

APPENDIX A

Groundwater drought prediction and vulnerability mapping

Groundwater management strategies build on knowledge about:

a) which areas are most vulnerable to groundwater drought (prediction over space). This is the subject of vulnerability mapping; and

b) when problems are likely to occur (prediction in time). This is closely linked with (a) above.

In this appendix these two elements are discussed in further detail. The aim is to present preliminary ideas and issues for discussion as a basis for further work in Year 2 of the project.

1. Predictions over space

A number of tools and indices can be used to describe groundwater drought incidence and likelihood. Areal distributions can potentially be combined as a layered groundwater vulnerability (to drought) mapping system.

Rainfall

Areas could be delineated as follows:

- areas of **low** mean rainfall (Figure 5), e.g. < 800 mm/year;
- areas with **highly variable** rainfall, e.g. > 25% coefficient of variability.

Reduced rainfall causes:

- reduced recharge to aquifers;
- reduced runoff into Lake Malawi..

Rainfall indicators could trigger more intensive groundwater monitoring in vulnerable areas

River flows

Stretches of river which normally dry could be identified, with information on how long the period usually lasts.

Rivers flow at reduced rates and/or for shorter periods if:

- rainfall is reduced;
- baseflow from aquifers is reduced;
- dams are built upstream;
- increasing abstraction for irrigation occurs upstream.

When this occurs, demand for groundwater is likely to increase. Low flow indicators may signal potential groundwater problems ahead, and could be used to trigger more intensive groundwater monitoring in target areas.

Change in land use

Deforestation is a significant problem in Malawi. The result may be:

- decreased evapotranspiration;
- higher run-off and more 'flashy' catchment characteristics;
- reduced rates of infiltration and thus recharge.

Replacement of indigenous trees with more water demanding trees such as eucalypts (e.g. Chikangawa Forest, Northern Region) reduces net aquifer recharge. Reductions in phreatophytic evapotranspiration have the opposite effect.

Other land use trends with potential implications for groundwater drought vulnerability include:

- cultivation in dambo areas and attendant changes to their hydraulic regime;
- surface water irrigation developments which may reduce downstream flows and thus surface water supplies, increasing pressure on 'downstream' groundwater resources;
- small scale groundwater irrigation developments, which raise the potential for conflict between agricultural and domestic use.

Wells and boreholes in areas subject to land use change may need to be closely observed.

Geology

Wells and boreholes penetrating aquifers of limited extent and low saturated thickness are the most vulnerable to water level decline. Such aquifers have limited storage volumes and are therefore most reliant on annual recharge. Examples include boreholes on the fractured basement aquifer supplying towns of Ntcheu, Dedza, Dowa, and Ntchisi.

The geological features of a vulnerability map might therefore include:

- thickness, saturated thickness;
- transmissivity, or specific capacity of similarly constructed wells; alternatively yields;
- extent.

Some distinctions can be made between weathered basement and alluvial aquifers:

- the weathered basement is thinner, but the alluvium receives less rainfall;
- the weathered basement has a lower transmissivity and a lower storage coefficient than the alluvial aquifers;

- cones of depression are narrower and deeper in the weathered basement;

- falling water levels will be universal in the alluvial aquifers, but localised in the weathered basement aquifer, again due to their different T/S ratios.

Well and borehole coverage

Borehole/well coverage figures could be used to delineate potentially vulnerable areas. Areas with low coverage (areas with large proportions of people not adequately served) could be considered more vulnerable. Such a system has already been used in Malawi to help indicate which areas of the country should receive drought relief priority (see Figures 11, 12 and 13).

It would be useful to distinguish between:

- water supply technology types, to compare proportions of populations without access to urban or piped or surface or borehole water. Areas heavily dependent on shallow wells might be more vulnerable to groundwater drought than areas with larger numbers of boreholes, at least at the beginning of a prolonged drought episode;

- periods in time, so that figures could be compared over time. Coverage figures may change as projects install new infrastructure or rehabilitate existing facilities, and with demographic changes (e.g. natural population growth; migration between districts and regions). While data on changing infrastructure could be incorporated on a regular basis, population data is likely to be 'given' between different census surveys.

For mapping purposes, readily accessible and up to date information on the locations and status of all boreholes and shallow wells would be required.

Water column height

Data on the length of the water column in wells and boreholes could in theory be used to identify areas vulnerable to groundwater drought. Comparisons between different wells and boreholes would need to be made for the same season, as even in non-drought years there may be significant seasonal variation in water levels.

The length of the water column depends on:

- borehole depth;

- water level;

- degree of silting.

If groundwater levels fall, wells with short water columns will be affected most because:

- they suffer a greater relative loss of yield;

- they are most likely to dry up.

These observations allow us to draw up a well/borehole vulnerability index. In order of increasing vulnerability, we have:

a) shallow wells on interfluves (e.g. Lilongwe East);

b) shallow wells in valleys (e.g. Malindi, Mangochi);

c) partially penetrating boreholes (e.g. Lilongwe District);

d) fully penetrating boreholes; thin aquifers;

e) fully penetrating boreholes; thickest part of aquifer.

Maps of 'initial water column depths' of <u>all current wells</u> could be made from well depth and water level data obtained at the time of drilling, if they were readily accessible.

Maps of initial water column depths <u>pre 1988</u> could be compiled from information in the MIWD GWATER database. The value of this would be limited by the lack of all the post 1988 boreholes and shallow wells.

Dry well/borehole distribution

Proportions of dry wells give an indication of where:

- groundwater levels have fallen;
- excessive silting has occurred;
- abstraction has exceeded recharge;

Areas where wells go dry permanently, seasonally, and not at all could be delineated. Proportions of dry boreholes on a district basis can be obtained from Monthly Borehole Maintenance Reporting Forms, but their reliability is questionable. Resolution on a Tribal Authority basis would be particularly useful, but is not currently readily available. Proportions of dry shallow wells would give a fuller groundwater drought picture.

Borehole/well maintenance reports

When wells and boreholes break down, an 'artificial' groundwater drought may result. Wells may require:

- fishing;
- pump maintenance;
- pump replacement;
- silt removing.

The situation may be protracted if:

- transport for maintenance teams is unavailable;
- spare parts are not available;
- Community based Maintenance Village Committees have not been set up, or if continuing training has not been available.

National borehole status monthly reports give information on non-working boreholes on a district basis but, as noted above, the reliability of the data is questionable.

Water quality and health data

Demand for water relates to quantity and quality. It therefore follows that if water quality is unpotable, a groundwater drought situation may arise. Indicators of groundwater drought could therefore include health data (shigella, cholera, blood diarrhoea, etc) from local clinics. Experience from Malawi suggests that outbreaks of water-related illnesses during drought periods are related to use of unprotected sources, caused or exacerbated by borehole failure.

Hydrochemical factors also affect potability, and drought may increase chemical concentrations in groundwater when recharge is low. If this occurs in places where concentrations are already high, elevated concentrations may render waters harmful or unpotable.

Waters most at risk are those with:

- high concentrations of total dissolved solids (e.g. various alluvial aquifer localities);
- high fluoride concentrations (e.g. 8-13 mg/l in Karonga, Salima, Nkhotakhota and Nkhoma);
- high iron concentrations (some weathered basement aquifer zones);
- high sulphate concentrations (e.g. Dowa West).

2. Predictions over time

The past is a key to the present: knowledge of historical information enables understanding of how the present situation has evolved, and prediction of future events. Analysis of nationwide time series spatial records (e.g. rainfall, dry borehole proportions, dry river frequencies, etc) can cast light on the evolution of a particular drought. These are often available by district, but for local variability detail should be collected on a Tribal Authority basis where possible. Long term records (over 50 years) are confined to rainfall, river flow and lake level data at a few sites.

Rainfall

Rainfall information is described in Appendix B. Cyclic effects are apparent and are analysed by Chavula (1994), who states: "Based on the criterion that drought occurs at 70% of normal rainfall (i.e. 30% departure), the series indicate that severe drought events occurred in Malawi in the years 1948-49 (38% departure) and 1991-92 (33% departure). Moderate drought periods occurred in the following years: 1923-24, 1927-28, 1932-33, 1953-54, 1957-58, 1967-68, and 1982-83. Of the nine years listed, seven were El Nino years."

Chavula quotes from Harrison (1984) that Malawi has a nine year oscillation spell of generally wet and dry conditions in a quasi-cycle of about 18 years. Abnormally warm Pacific Ocean temperatures can be used to forecast rain shortfalls, e.g. 1991-1992.

Recharge

Antecedent soil moisture conditions influence the amount of recharge. It is necessary to consider:

- rainfall in current season;.
- rainfall in the preceding season;
- rainfall intensity (i.e. ideally consider daily data);
- evaporation.

Lake levels

A low rise from the lake level at the start of the rainy season to the lake level peak indicates:

- low rainfall in the entire Lake's catchment;
- low recharge;
- reduced discharge into the Shire River (e.g. 0.3 m rise in 1991-1992 cf more typical 1.2 m rise in 1992-1993).

Lake levels are modelled by Calder *et al (*1995). Past records are simulated and the effect of changing land use has been investigated. The model could be used to predict the effect of repeated low rainfall years, and substantial land use changes on the lake level and the outflow of the Shire river.

River flow (and no-flow) data

Data availability is described in Appendix B. Data could be used to trigger intensive groundwater monitoring in potentially vulnerable areas. Statistical analysis of time series river flow data could include:

- expressing runoff as a percentage of the long term average value over the same period;
- analysis of spells to include duration of spells when discharge remains below a given threshold; deficit volume below the threshold during the period as well as the minimum instantaneous or average discharge over a specified duration;
- analysis of low flows to determine minimum flow values averaged over 'n' consecutive days, including days of their occurrence and the frequency of occurrence;

Frequency of events can be expressed in a number of different ways: simple ranking of driest years; empirical probability of non-exceedence based on sample values; analysis of annual minima series; and expressing the probability in percentage terms as a return period (the average recurrence interval between non-exceedence of the selected low flows). Persistence can be tested for and quantified by computing the first order serial correlation coefficient, or by using statistics of runs.

Groundwater level information

Continuous monitoring of water levels would allow the determination of:

- whether or not they are falling;
- when they start to fall;
- the rate of falling.

If water levels could additionally be compared to water column depths, and aquifer thicknesses, the wider consequences of falling water levels could be predicted:

- which wells will go dry and when;
- when the aquifer will go dry.

Absolute groundwater drought depends on the position of the water table within the regolith.

Well yields

Declining well yields and intermittent pumping can give an indication of falling groundwater levels. But they can also be due to:

- silting up of boreholes;
- encrustation of screen;
- very heavy pumping (e.g. submersible pump, or hand pump in use all day).

3. Vulnerability mapping

Groundwater drought vulnerability maps incorporating some of the indicators and features discussed above might provide useful drought management tools. The nature and number of indicators used would depend on intended use, required resolution and availability of data.

At its most basic level, vulnerability mapping would involve overlaying static maps depicting physical and climatic features such as:

- average rainfall;
- average rainfall variability;
- geology, and places where good yielding boreholes are difficult/impossible to site;
- stretches of rivers which annually go dry, and average no-flow duration
  positions of dams.

Overlaying water supply coverage data on the above might help identify areas most at risk. Coverage data would have to be updated on a regular basis as projects add to existing infrastructure, with estimates made of demographic change. National mapping of this sort could be used to help guide *longer term* planning and targeting of resources.

Coverage data which attempted to distinguish operational from non-operational sources would be much more sensitive to change and would necessarily need to be of a much higher resolution. It could be used to guide *short term*, groundwater drought relief efforts, but an early warning system which could help prevent problems occurring in the first place would need to rely additionally on rainfall, river flow and yield/water level/water quality data, perhaps superimposed on the static map described above. Health data (water-related illnesses) would also be useful. Data needs would be much greater as continuous monitoring, or perhaps targeted groundwater monitoring responding to river and rainfall data, would be essential.

To conclude, national scale maps may be useful for targeting long term development efforts, but would be of questionable use in the targeting of drought relief efforts. Our investigations suggest that groundwater drought problems may be very localised, with effective identification of affected communities dependent on local, site-specific information. The only way of securing the kind of information needed for effective action may be at community or district level (the lowest level at which institutional capability exists), where the problem can be assessed in detail.

APPENDIX B

Project reports, documents and data holdings

1. Reports and documents

From MIWD drought files, Lilongwe

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2. Surface water and rainfall data

Surface Water

The hydrometric network in Malawi consists of about 170 discharge gauging stations and 24 water level stations. The station numbering scheme illustrates in which of the 17 water resource units it is located, the sub-catchment within the unit, and a sequence number. For example: gauging station 07.G.14 on the South Rukuru at Phewzi (Table 1).

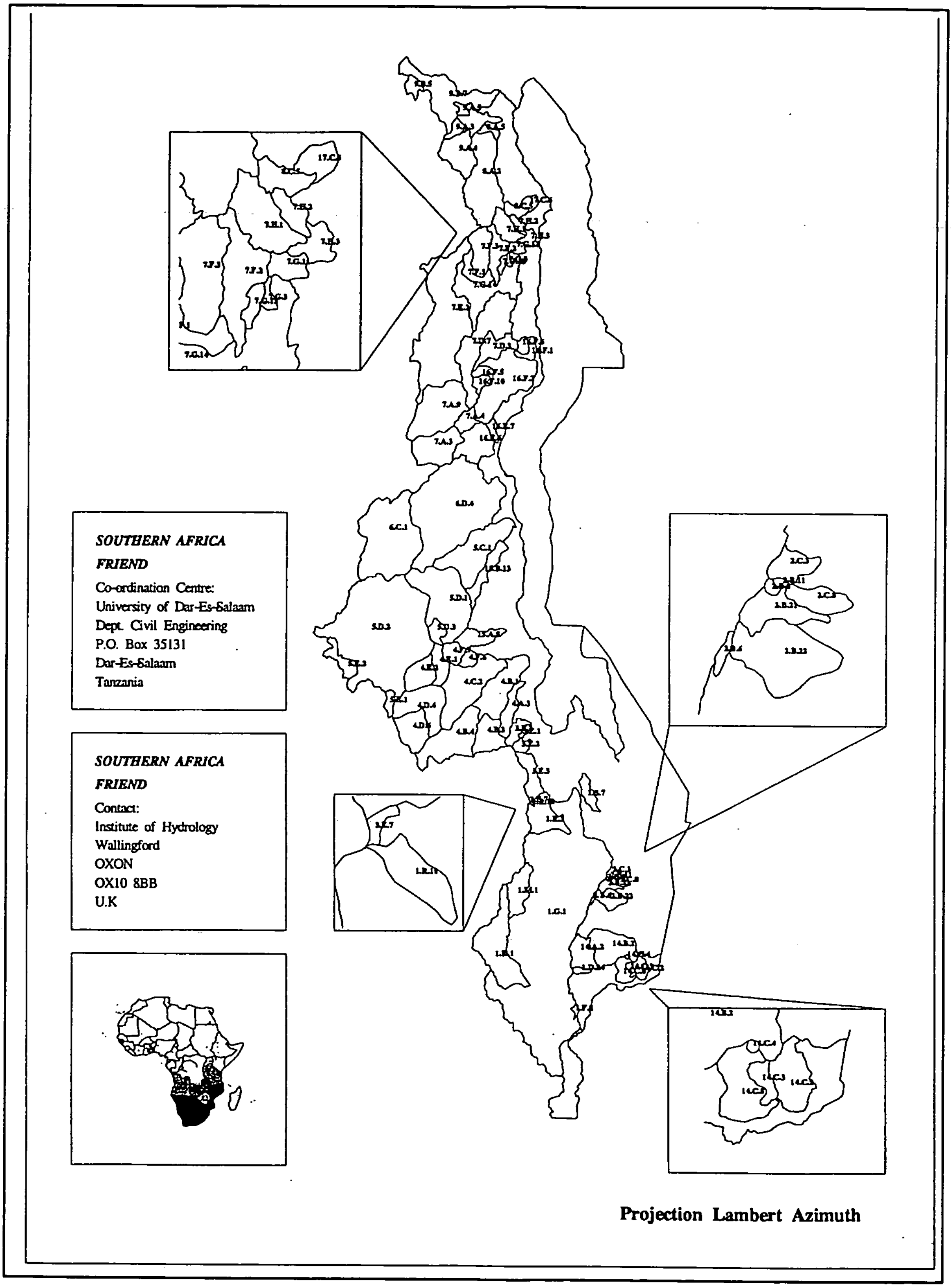
A sub-set of 39 gauging stations were selected for inclusion on the Southern Africa Flow Regimes from International Experimental and Network Data (FRIEND) project. The Southern Africa FRIEND (Flow Regimes from International Experimental and Network Data) project is a contribution to the Fourth Hydrological Programme of Unesco, in which the central theme is hydrology and water resources for sustainable development in a changing environment. One of the objectives of the Southern Africa FRIEND project is the development of hydrological and thematic databases.

Time series daily river flow data from each of the 39 gauging stations has been made available to this project and installed on ORACLE and IH's HYDATA software. Details of the gauging stations are presented in Table 1 and the catchment areas illustrated in Figure 1.

Table 1 Details of selected guaging stations

STATION	RIVER NAME	LOCATION	LATITUDE			LONGITUDE			AREA	START		END	
			D	M	S	D	M	S	km²	MON.	YR.	MON.	YR.
2.B.8	MULINGUZI	ZOMBA PLATEAU							18.1	DEC	1954		
2.B.11	MULINGUZI	WILLIAMS FALLS							7.02	JAN	1956		
2.B.22	THONDWE	JALI	15	29	19	35	28	40	302	DEC	1959		1984
2.C.3	DOMASI	DOMASI TT COLLEGE							72.8	NOV	1957		
1.M.1	MKURUMADZI	MLONGOLA							586	JAN	1953		
14.B.2	THUCHILA	CHENDO							1440	DEC	1951		
1.R.3	RIVI-RIVI	BALAKA	15	2		34	56		748	NOV	1952		1987
1.S.7	NKASI	KALEMBO							236	SEP	1961		
14.C.8	LICHANYA	MILONDE							325	JAN	1960		
14.C.2	RUO	M1 ROADBRIDGE							193	JUL	1962		
14.A.2	LUCHENZA	LUCHENZA	16	0	30	35	17	30	483	OCT	1954		1979
1.R.18	MPAMADZI	GUMBU	14	48	35	34	37	22	7.03	NOV	1963		1988
8.A.5	NORTH RUKURU	MWAKIMEME	9	56	0	33	32	38	1860	NOV	1970		1986
9.A.3	CHAMBO	CHIWONA							150	OCT	1976		
7.H.3	NORTH RUMPHI	CHIWETA							683	SEP	1972		
9.A.4	LUFIRA	CHILANGA							774	DEC	1970		
9.A.5	KALENJE	CHIPWERA	9	51	0	33	32	38	83.4	DEC	1970		1982
9.B.5	HANGA	DAVID KAMEME							188	JUL	1978		
9.B.7	?	?	?	?	?	?	?	?	?	?	?	?	?
7.F.2	SOUTH RUMPHI	RUMPHI	11	3	0	33	49	30	476	JUL	1956		1986
7.A.3	SOUTH RUKURU	CHIMSEWEZO	12	7		33	25		958	MAY	1956		1968
7.A.4	MZIMBA	MUWERU BUKULUTI							269	JUL	1961		
7.D.3	LUNYANGWA	ZOMBWE							513	MAR	1953		
7.F.3	RUNYINA	MJUMA	10	57	14	33	45	32	602	DEC	1970		1985
7.G.14	SOUTH RUKURU	PHEWZI							11800	NOV	1957		
6.C.1	DWANGWA	KWENGWELE							2980	FEB	1953		
16.F.2	LUWEYA	ZAYUKA	11	46	49	34	13	30	2420	DEC	1951		1986
16.F.1	LIMPHASA	TIMBIRI							261	FEB	1953		
16.E.6	DWAMBADZI	NTHANDA							778	OCT	1973		
16.F.10	LUCHELEMU	MAZAMBA ESTATE	11	42		33	54		138	NOV	1959		1974
5.C.1	BUA	S53 ROADBRIDGE	12	47		34	11		###	OCT	1956		1986
5.D.2	BUA	OLD BUA BRIDGE KASESE	13	18		33	34		6790	FEB	1953		1974
5.D.3	MTITI	MTITI							233	MAY	1955		
5.D.1	BUA	BUA DRIFT	13	7	43	33	40	41	9410	NOV	1959		1977
15.A.8	LINGADZI	KANICHE							387	JUL	1961		
4.E.1	LINGADZI	M1 ROADBRIDGE	13	57		33	46		928	NOV	1953		1983
4.B.3	LINTHIPE	LINTHIPE	14	10	44	37	7	28	600	DEC	1957		1981
4.B.4	DIAMPWE	CHILOWA NEW BRIDGE	14	8	11	34	5	18	1460	NOV	1957		1982
4.D.4	LILONGWE	LILONGWE OLD TOWN	13	59	20	33	46	22	1870	OCT	1955		1980
4.D.6	LILONGWE	MALINGUNDE	14	10	9	33	41	22	763	DEC	1962		1986
4.F.6	LUMBADZI	SIMAKUMI							449	DEC	1974		
3.E.1	NADZIPOKWE	MUA MISSION	14	15		34	31		30.1	NOV	1953		1985
3.E.2	NAMIKOKWE	MUA-LIVULEZI F. R.							129	OCT	1957		
3.E.3	LIVULEZI	KHWEKHWELELE	14	26	28	34	32	21	452	OCT	1957		1983
3.E.7	NKANDE	THOBOLA	14	47	32	34	34	50	1.89	OCT	1959		1983

Figure 1 Catchment areas for selected stations



Rainfall

The Department of Meteorology hold all rainfall data on a Honeywell Bull mainframe computer and are currently transferring the data onto the CLICOM package. There are currently 868 rainfall stations and 23 full synoptic stations operating in Malawi. The locations of these stations are illustrated in Figure 2. Monthly rainfall totals are available for 23 synoptic sites located in the vicinity of the catchments shown in Figure 1. The standard period (1961-1990) average monthly rainfall totals for all rainfall stations in Malawi are also available.

Thematic Databases

A full set of topographic maps of Malawi (9 maps) at 1:250 000 scale are available at IH. Only four maps of the Upper and Northern Regions of Ghana were available. The location of the gauging stations has been determined and where possible (primarily for Malawi) the catchment boundary upstream of that point has been drawn following the topographic divides. The catchment boundaries and major hydrometric zones in Malawi have been digitized using the geographic information system ARC-INFO.

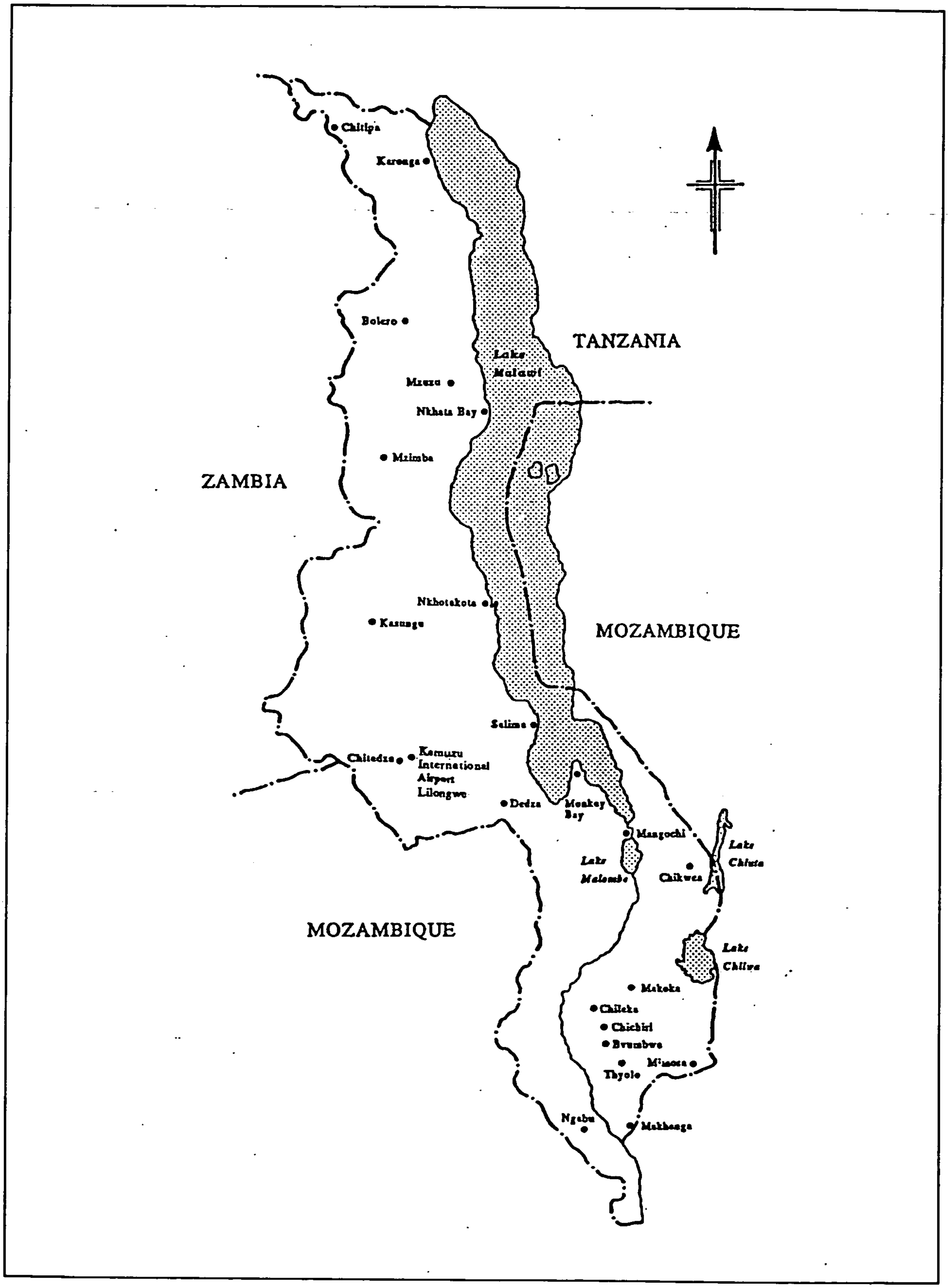
Hydrogeology and geology digital coverage of Malawi at 1:250 K scale have also been digitized using ARC-INFO. T

The SADC-wide soil map in ARC-INFO format which was compiled under the remit of the SADC Food Security programme by the Regional Inventory of Agricultural Resource Base (RIARB) is also available at the Institute. The map presents the soil distributions of the SADC region showing the local nomenclature correlated with the international FAO/Unesco Soil Map of the World Legend. Correlation with the more detailed USDA Soil Taxonomy has also been attempted where possible for the dominant soil in each mapping unit.

Raster coverages of baseline climatologies, average annual rainfall and average annual Penman potential evaporation for Malawi are also available. This data has been supplied to IH by the International Institute for Applied Systems Analysis (IIASA) in Laxenberg in Austria and by the Climatic Change groups at IH and the University of East Anglia in the UK.

Additional ARC-INFO coverages for Malawi and Ghana that have been acquired from IIASA and UNEP GRID in Nairobi are: FAO Africa soil map, political boundaries and major rivers, surface hydrology, irrigation potential, landuse, slope vegetation type and major watershed boundaries which conform to the FAO classification.

Figure 2 Location of synoptic sites. Source: World Bank/UNDP (1990)



3. Groundwater data

Tables 2 and 3 provide an indication of which borehole and shallow well data are available to the project. It is hoped that complete records can be compiled in the near future.

Table 4 is an example of a borehole/shallow well maintenance report, compiled by MIWD on a monthly basis. Maintenance reports, and the difficulties associated with obtaining reliable and timely information on water supply status, are discussed in the main report.

Figures 3-10 present hydrographs and other data from selected locations, plotted using data from MIWD maintenance reports.

Table 2 MIWD borehole maintenance record availability, 1991-1996

Month	Northern Region	Central Region	Southern Region
Mar-91			
Apr-91			
May-91			
Jun-91			
Jul-91			
Aug-91			
Sep-91			
Oct-91			
Nov-91			
Dec-91			
Jan-92			
Feb-92			
Mar-92			
Apr-92			
May-92			
Jun-92			
Jul-92			
Aug-92	R		
Sep-92			
Oct-92	R	R	R
Nov-92		R	
Dec-92		R	
Jan-93		R	
Feb-93	NR	N	N
Mar-93		R	
Apr-93	NR	N	N
May-93	NR	NR	NR
Jun-93	NR	NR	N
Jul-93	R	R	
Aug-93	R	R	R
Sep-93	R	R	R
Oct-93			
Nov-93	NR	NR	NR
Dec-93	R	R	

Month	Northern Region	Central Region	Southern Region
Jan-94	R	R	
Feb-94	R		
Mar-94	R	R	
Apr-94	R	R	
May-94		R	
Jun-94		R	
Jul-94	R	R	
Aug-94	N	N	N
Sep-94		R	
Oct-94	NR	NR	N
Nov-94	R	R	R
Dec-94	R	R	
Jan-95	R	R	
Feb-95			
Mar-95	NR	N	N
Apr-95	N	N	N
May-95			
Jun-95		R	
Jul-95			
Aug-95			
Sep-95			
Oct-95			
Nov-95			
Dec-95			
Jan-96			
Feb-96			
Mar-96			

Key
- (light shading) Complete record
- (dark shading) Partial record
- (blank) Missing record
- N Source - national records
- R Source - regional records

BOREHOLES - WATER LEVELS AT MAINTENANCE

District	Duration	No Boreholes	No readings per borehole	Coord -inates
Ntcheu	1992-1995	20	4	no
Nkhotakota	1992-1994	11	2-4	no
Kasungu	1993-1995	7	3-7	no
Dowa	1992-1995	9	4	no
Mchinji	1992 -1995	9	3-4	no
Ntchisi	1993-1995	20	3-4	no
Lilongwe	1992-1995	20	4-12	no

Table 3 MIWD shallow well maintenace record availability, 1991-1996

Month	Northern Region	Central Region	Southern Region
Mar-91			
Apr-91			
May-91			
Jun-91			
Jul-91			
Aug-91			
Sep-91			
Oct-91			
Nov-91			
Dec-91			
Jan-92			
Feb-92			
Mar-92			
Apr-92			
May-92			
Jun-92			
Jul-92			
Aug-92			
Sep-92			
Oct-92			
Nov-92			
Dec-92			
Jan-93			
Feb-93			
Mar-93			
Apr-93			
May-93			
Jun-93			
Jul-93	░		
Aug-93			
Sep-93			
Oct-93			
Nov-93			
Dec-93			
Jan-94			
Feb-94			
Mar-94			
Apr-94			
May-94			
Jun-94			
Jul-94			
Aug-94	░		
Sep-94			
Oct-94			
Nov-94	░		
Dec-94	░		
Jan-95			
Feb-95			
Mar-95			
Apr-95			
May-95			
Jun-95			
Jul-95			
Aug-95			
Sep-95			
Oct-95			
Nov-95			
Dec-95			
Jan-96			
Feb-96			
Mar-96			

Key
░ Complete record
(blank) Missing record

OTHER DATA - SHALLOW WELLS

Malindi CSDP Shallow wells quarterly status Oct 1992 to June 1995
Bawala Project, Ntchisi - Water level and status at construction

Table 4 Example of borehole maintenance report: National borehole status for the month of February, 1995. Source: MIWD maintenance records (1995)

District per unit	Total in district	Need fishing (B1)	Need new pumps (B2)	Dry (B2)	Broken down pump	Total no working (BT)	Bh repaired	Total working	% working	Remarks
Chitipa	122	-	2	10	8	20	-	102	84	Vehicle not working
Karonga	375	-	-	10	9	19	20	356	95	
Rumphi	112	-	-	-	6	12	17	100	89	
Mzimba	615	6	6	7	52	59	11	556	90	Transport problem
Nkhata Bay	63	-	-	3	2	5	2	58	92	Vehicle in workshop
Totals	1287	6	8	30	77	115	50	1172	91	
Lilongwe	1404	19	200	3	144	166	64	1238	88	
Nkhotakota	236	-	-	1	43	44	1	192	81	Vehicle not working
Dedza	685	13	17	1	38	52	-	633	92	No vehicle
Mchinji	465	2	2	1	40	43	3	422	91	Used clients vehicle
Kasungu	336	2	88	12	28	42	27	294	88	
Ntched	568	5	9	13	38	56	41	512	90	
Salima	420	-	2	-	120	120	2	300	71	No vehicle
Doma	237	5	10	5	72	82	6	155	65	Used clients vehicle
Ntchisi	136	3	10	3	43	49	41	87	64	
Totals	4487	49	338	39	566	654	185	3833	85	
Mangochi	510	6	12	31	68	117	-	393	77	No vehicle
Blantyre	205	4	6	4	50	64	-	141	69	No fuel
Machinga	490	2	8	3	22	35	18	455	93	
Zomba	316	6	2	1	35	44	1	272	86	
Mwanza	140	2	-	6	18	26	-	114	81	No vehicle
Chikwawa	525	7	-	5	15	27	44	498	95	
Nsanje	476	5	-	2	22	29	18	447	94	
Mulanje	199	5	3	4	30	42	29	77	65	
Thyolo	114	4	11	6	26	47	4	67	59	Used DC's vehicle
Chiradzulu	149	4	4	10	25	43	-	106	71	No vehicle
Totals	3124	45	46	72	311	474	114	2570	77	
Grand totals	8898	100	392	141	954	1243	349	7575	83	

Figure 3 **Dry borehole records, Nsanje and Dowa/Ntchisi Districts. Source: MIWD maintenance reports**

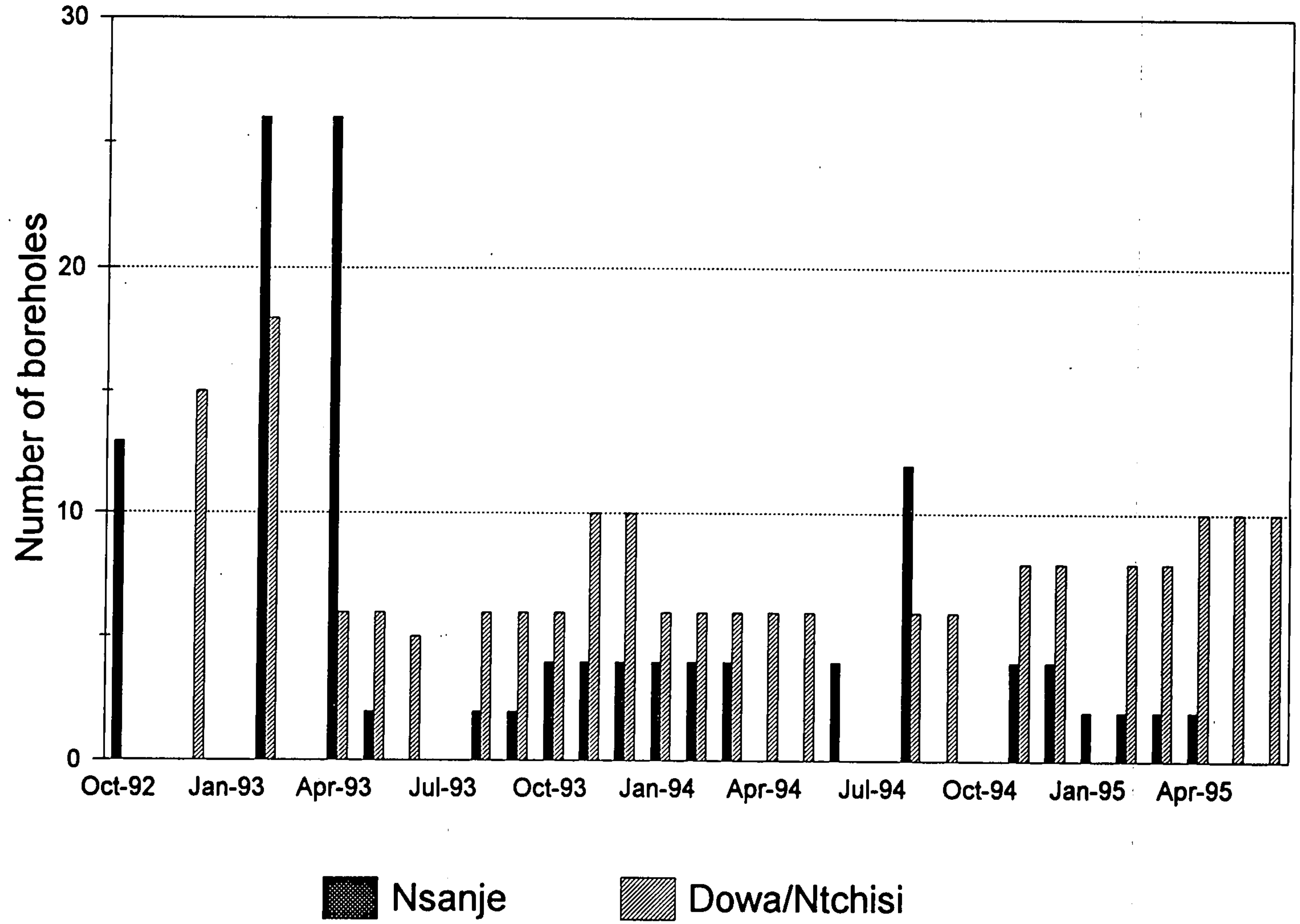


Figure 4 **Non-functioning borehole records, Nsanje and Dowa/Ntchisi Districts. Source: MIWD maintenance reports**

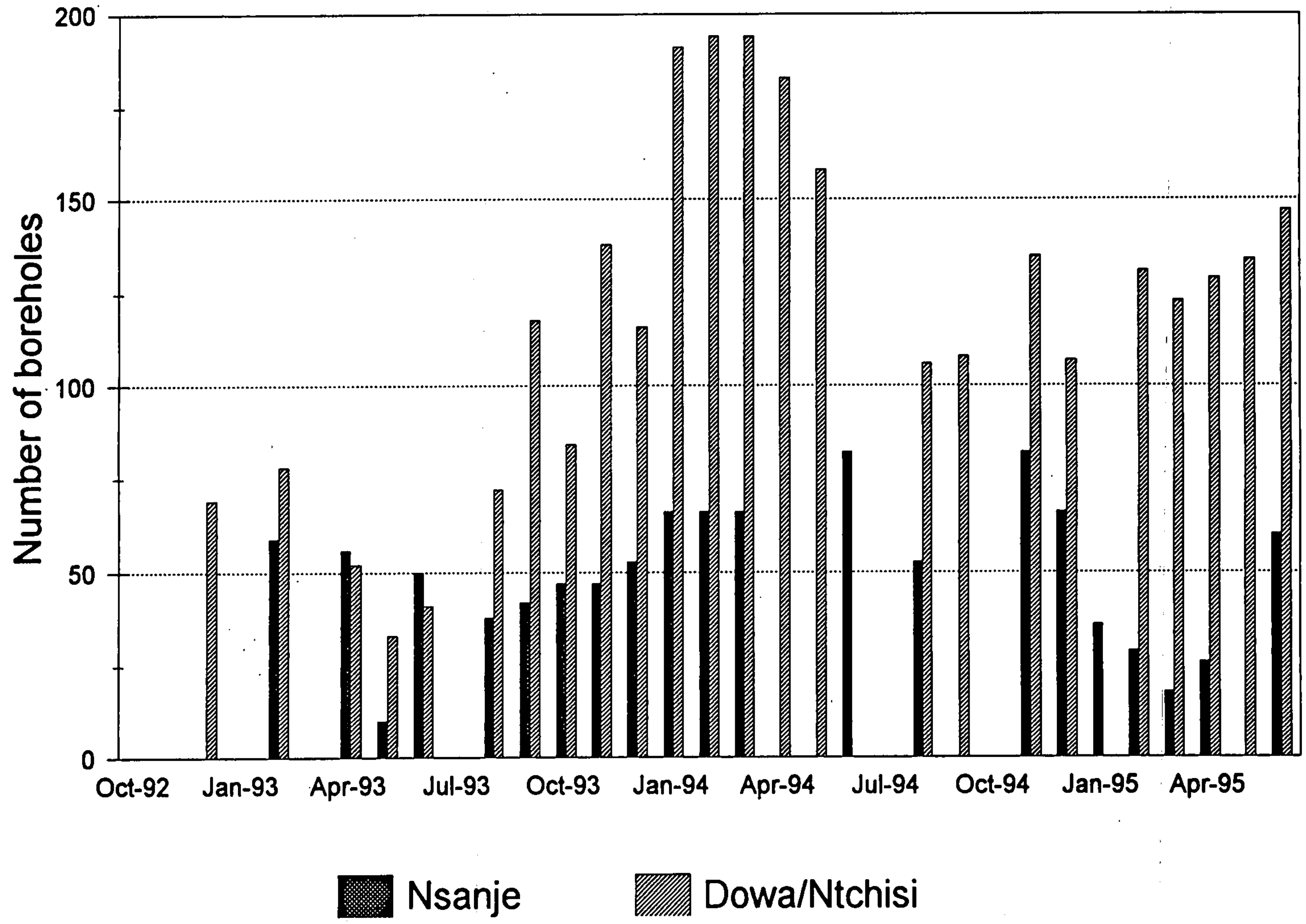


Figure 5 Water level records, various. Source: MIWD maintenance reports

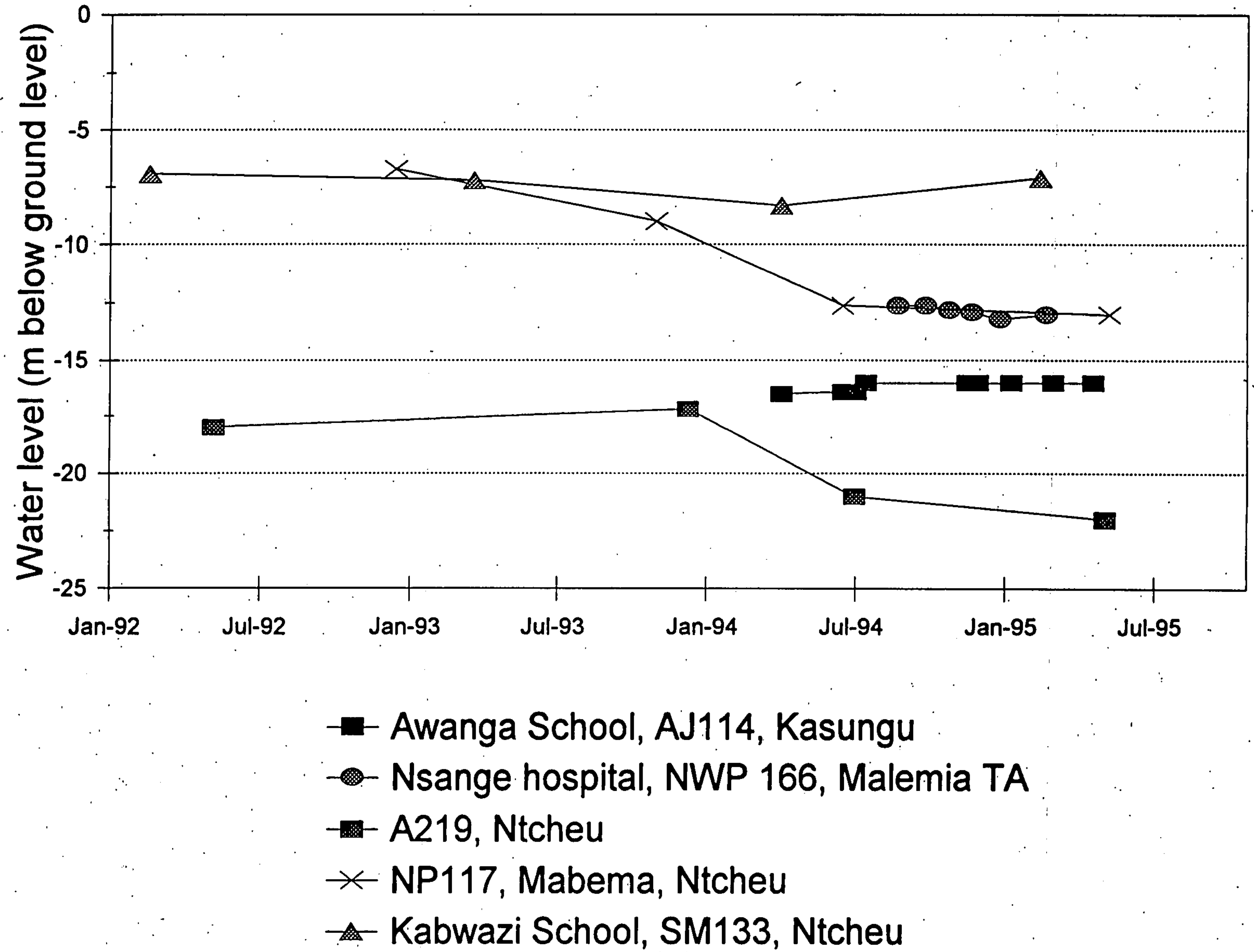


Figure 6 Borehole status, Lilongwe District. Source: MIWD maintenance reports

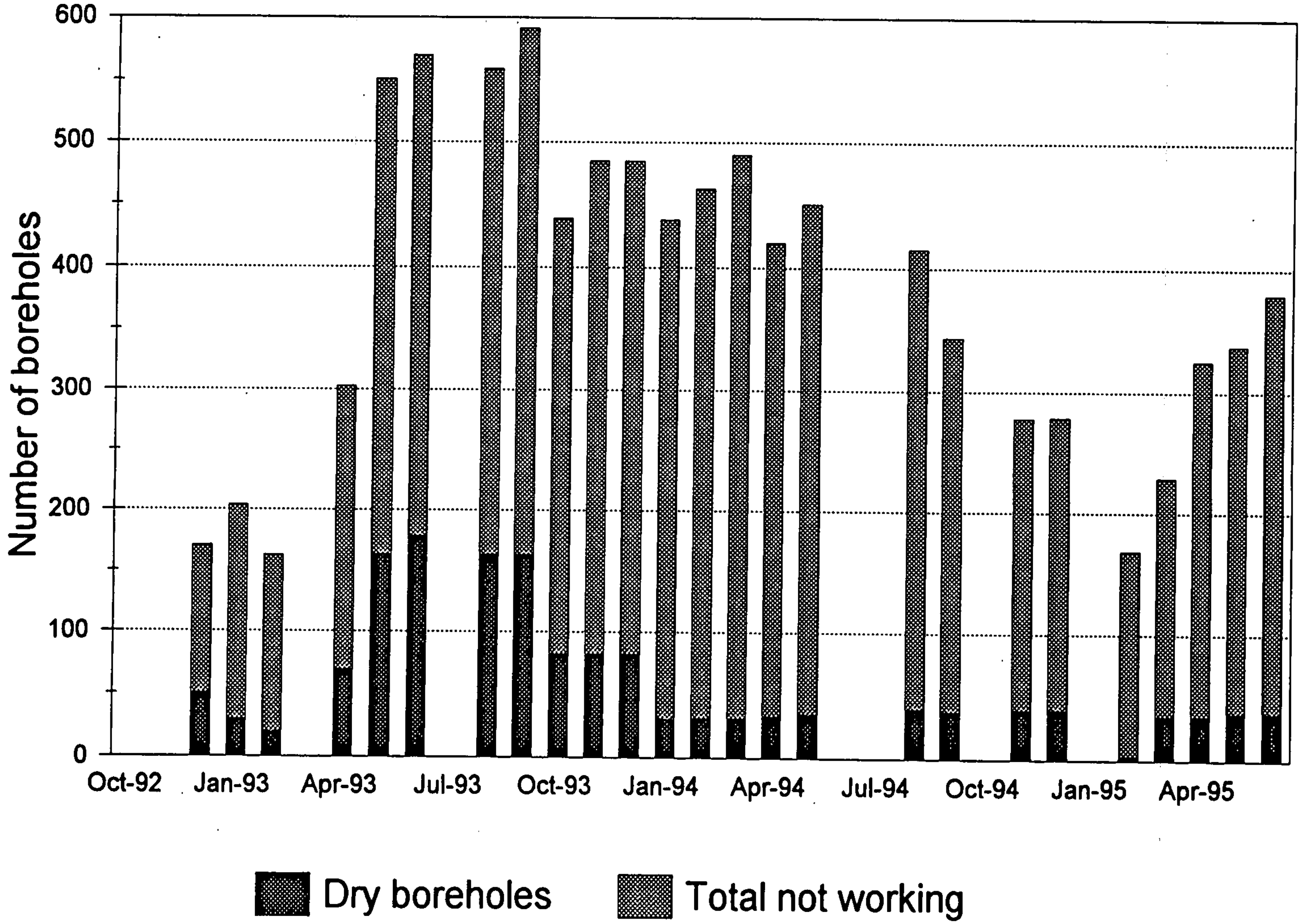


Figure 7 **Borehole water level record for Dzenza School, Lilongwe District (G104). Source: MIWD maintenance reports**

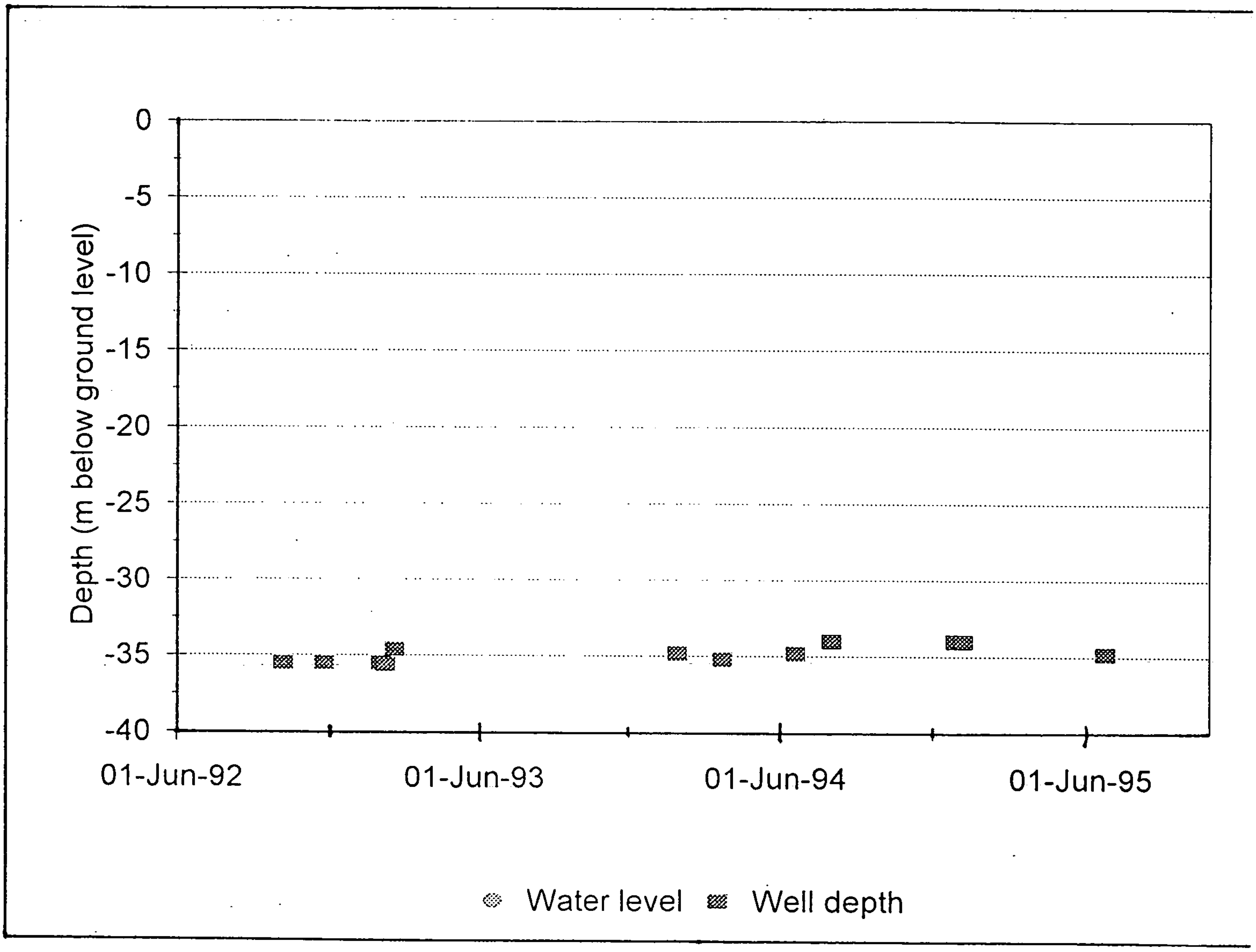


Figure 8 Borehole water level record for Awanga School, Kasungu District (AJ114). Source: MIWD maintenance reports

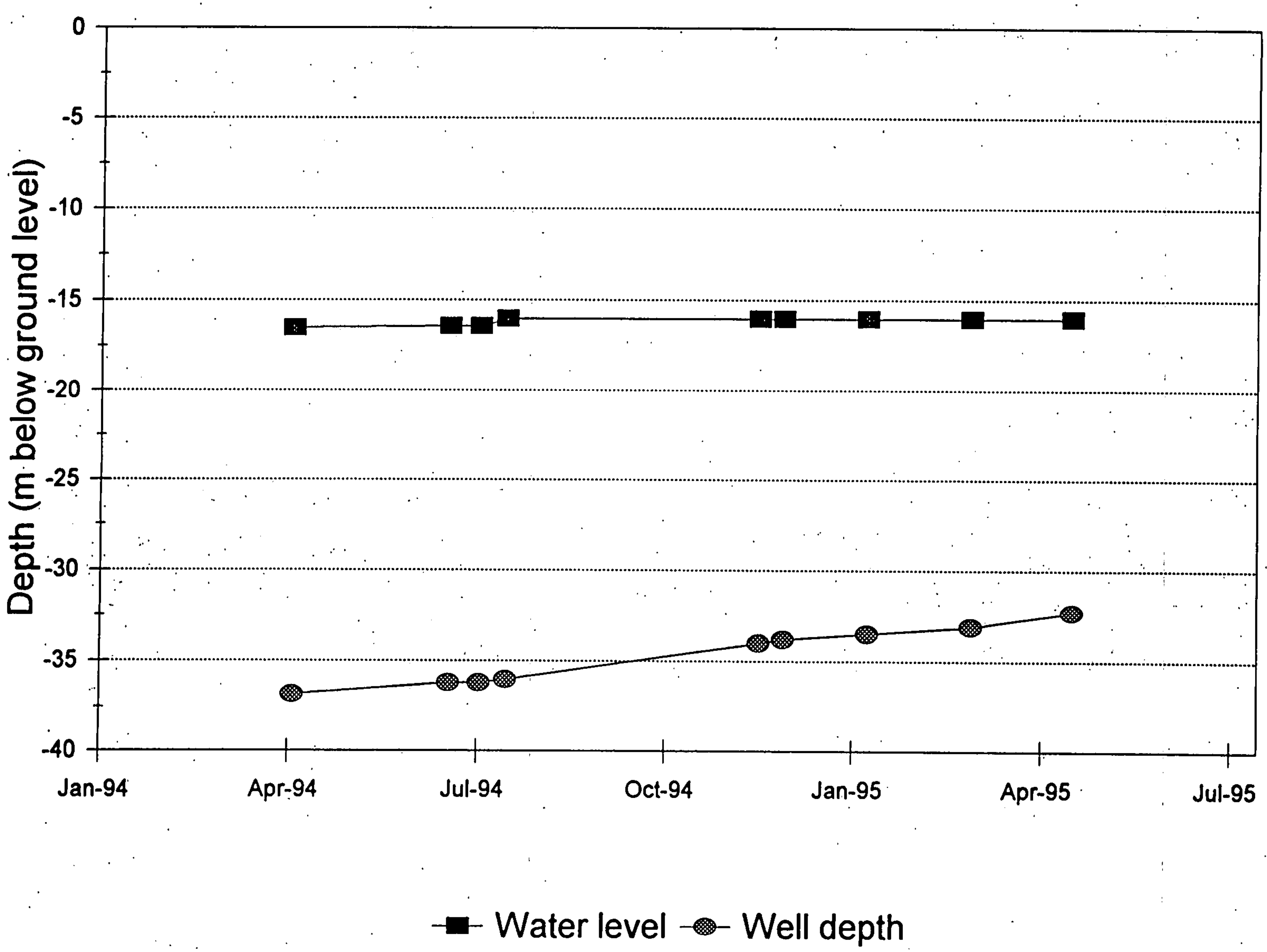


Figure 9 Shallow well status, Malindi District. Source: MIWD maintenance reports

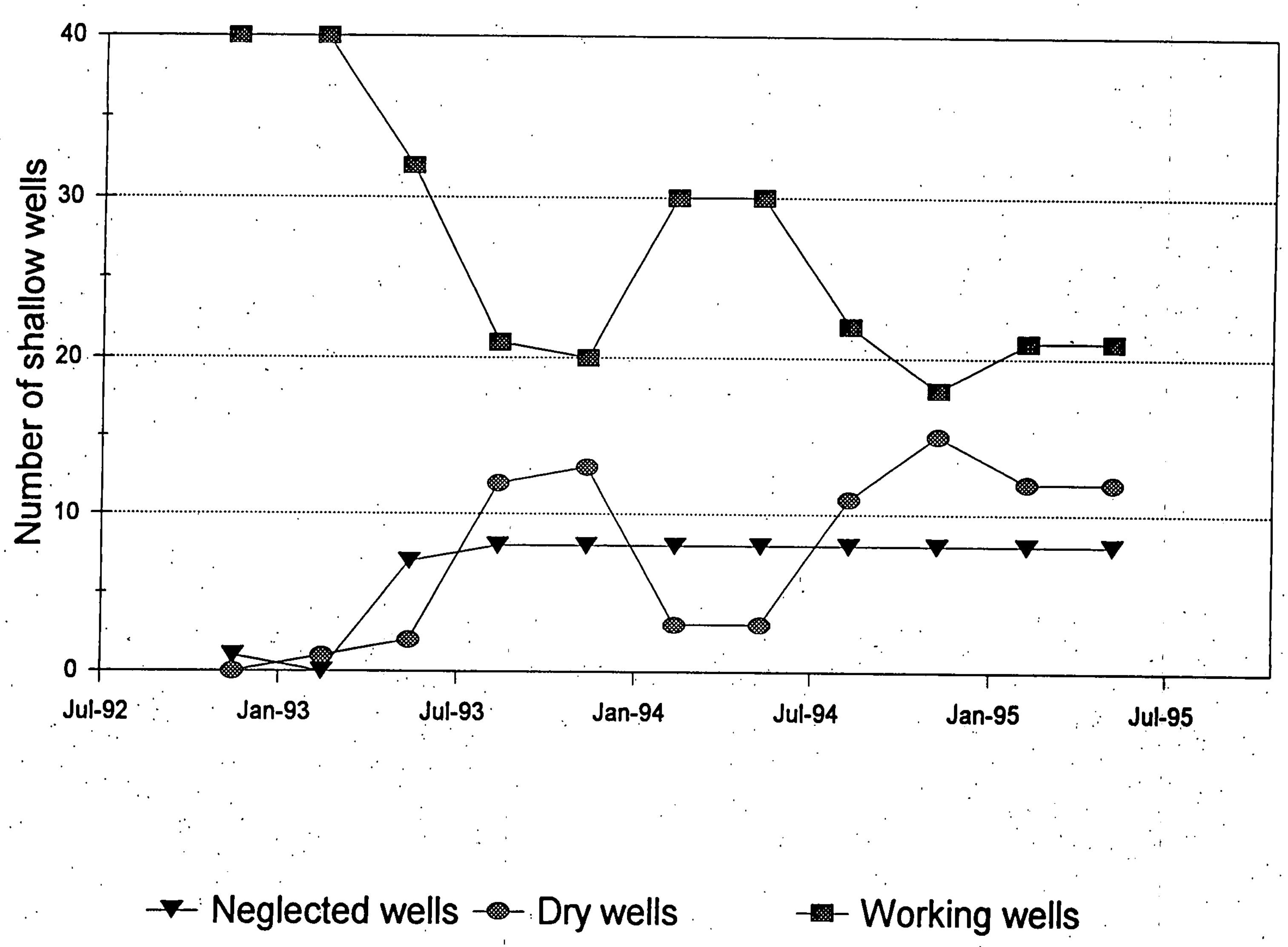


Figure 10 Shallow well status, Nkhoma area. Source: Inter-Aide