REPUBLIC OF MALAŴI

DEPARTMENT OF LANDS, VALUATION AND WATER

GROUNDWATER RESOURCES OF MALAŴI

December, 1983

OVERSEAS DEVELOPMENT ADMINISTRATION
INSTITUTE OF GEOLOGICAL SCIENCES

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by

A. K. Smith - Carington and P. J. Chilton

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SUMMARY

The development of groundwater resources in Malawi has to date been primarily for rural domestic supplies by the construction of boreholes and dug wells. By the end of 1981 about 5500 boreholes had been drilled, 80 percent of which were equipped with handpumps, 10 percent with motor pumps and about 10 percent were abandoned, primarily because of low yields or poor quality groundwater. At the end of 1981, there were about 1600 protected dug wells, all equipped with handpumps. In 1979 the Government of Malawi incorporated all the agencies responsible for water development into one organisation, the Department of Lands, Valuation and Water. The Groundwater Section of the Water Resources Branch of the Department is now responsible for all groundwater development, including both construction and maintenance of boreholes and dug wells.

The greater part of Malawi is composed of crystalline metamorphic and igneous rocks referred to as the Basement Complex. Younger consolidated rocks are limited to minor occurrences of Karoo sedimentary and volcanic rocks at the northern and southern extremities of the country. The most imposing structural feature is the rift valley, occupied by Lakes Malawi and Malombe and the Shire River. Variable thicknesses of Quaternary sediments occur along the lakeshore, around Lake Chilwa and in the Lower Shire valley.

The rift valley dominates the topography of the country and the major physiographic divisions define the occurrence of groundwater. There are two principal aquifer types, the extensive but thin and relatively low-yielding weathered basement aquifer of the plateau areas and the potentially higher-yielding alluvial aquifers of the lakeshore plains and Shire Valley.

The approach to groundwater development has in the past somewhat obscured the potential of both of these aquifers because of poor borehole design. More recent work has shown that, by the careful application of appropriate borehole design and construction techniques, the weathered zone aquifer will usually support a discharge adequate for a handpump where its saturated thickness is more than 15 m. In most of the plateau areas, therefore, yields sufficient for handpumps (0.25 to 0.5 l/sec) can be obtained without the need for groundwater exploration using geophysical techniques. Higher yields may be obtained where the weathered zone aquifer is thicker, but even where sophisticated exploration techniques are employed to locate sites of greatest potential and the boreholes are properly constructed, yields greater than 3 l/sec are likely to be rare. The potential for irrigation from the weathered zone aquifer is therefore limited. In contrast, investigation drilling carried out in 1980 and 1981 for the National Irrigation Study has shown that yields in excess of 15 l/sec could be obtained from the alluvial aquifers along the lakeshore and in the Lower Shire Valley. In both weathered basement and alluvium, water is generally encountered within 10 to 20 m of the ground surface and only rarely are depths to water greater than 30 m.

Estimations of the available groundwater resources have been carried out, but in both principal aquifers there are problems with the application of conventional methods. In the plateau areas the dambo drainage systems play an important but uncertain role in the movement and storage of groundwater. In the alluvial areas there are difficulties in determining the relative importance of the various sources of recharge and routes for discharge. In summarising the estimates of recharge by the various methods, there is therefore a wide range of figures and additional work is required to define them more closely. Nevertheless, it is clear that there is sufficient recharge to support the relatively low level of groundwater abstraction needed to meet present and future medium-term domestic water requirements.

Groundwater quality is generally acceptable for domestic use. In the weathered basement aquifer the concentration of dissolved solids is generally very low (EC below 750 µS/cm) but there are some areas of highly variable groundwater quality in which there are very localised occurrences of groundwater with EC approaching 4000 µS/cm. The poor quality is principally due to high sulphate levels. The groundwater in the weathered basement aquifer is usually slightly acidic and there are widespread but very localised high concentrations of iron. The alluvial aquifer is also characterised by groundwater of highly variable mineralisation. Overall, the groundwater is generally more mineralised than in the weathered basement aquifer and the highest levels of mineralisation reach an EC of 17,000 µS/cm very locally in the Lower Shire Valley. Where there is groundwater of low pH, corrosion of galvanised pump rods and rising main is common and this may contribute to the problem of high iron levels.

Groundwater development in the present decade will continue to be principally for rural domestic supplies. Only about 10 per cent of the total population is classified as urban and the estimated 1990 rural population will be 7.2 million. Only about 25 per cent of these can be served by the rural piped-water supply programme from protected surface sources, so about 5.5 million people will depend on groundwater for domestic supplies. This represents a total annual demand from groundwater for complete coverage of about 55 million cubic metres from about 25,000 handpumps. The capital and recurrent costs of such an expansion in the level of provision of rural water supplies are enormous. Much of the current efforts of the Groundwater Section of the Department of Lands, Valuation and Water are being devoted to establishing an expanding programme of rural supply projects along the lines of the successful projects currently underway in the Upper Livulezi Valley and Dowa West. These projects are characterised by the close concentration of construction activities in one area to allow efficient and cost-effective implementation to keep down the capital costs, and by the establishment of an effective and reasonably cheap village-based maintenance system to keep down recurrent costs.

CHAPTER 1

BACKGROUND

1.1 SCOPE OF REPORT

This report has been prepared within the Groundwater Section of the Department of Lands, Valuation and Water (DLVW). The data archiving, map preparation and production of the report have been a major component of the terms of reference of the ODA-funded Groundwater Team who have been assisting the Groundwater Section since 1980. The report is to be used for the hydrogeological volume of the report of the National Water Resources Master Plan (NWRMP), the remaining volumes of which are being prepared by a UN master plan team within DLVW.

The preparation of a Master Plan was first recommended by the Water Supply and Sewerage Sector Study carried out by a World Health Organisation/World Bank team (WHO, 1978), after the declaration by the United Nations General Assembly that the 1980s should be the International Drinking Water Supply and Sanitation Decade (IDWSSD). The targets of the Decade are to provide adequate domestic water and basic sanitation facilities for all, and the Malawi Government has adopted these ambitious goals.

This report comprises a summary and interpretation of all available archive hydrogeological data from boreholes and wells, up to December 1981. In addition, information has been obtained from the more recent work of the Groundwater Section, both in its general groundwater development programme and in specific investigations into key aspects of the hydrogeology, primarily aquifer properties and water level fluctuations. The report therefore results mainly from a collation and evaluation of existing records, rather than an extensive collection of new hydrogeological data. Nevertheless, the more recent work has greatly enhanced the understanding of the hydrogeology of Malawi and much improved the interpretation of the large body of existing data.

The report aims to provide an inventory of present groundwater use, existing and projected demands and an evaluation of groundwater resources. This is required, along with the other volumes of the master plan report, to form a sound basis for the careful planning of efficient and economic development of the country's water resources. This report includes details of the availability of groundwater, its quality and its potential for development for rural, urban irrigation and industrial supplies. Associated with this report, a map of the country summarising groundwater potential for planning purposes (1:1,000,000 scale) and a set of nine hydrogeological maps (1:250,000 scale) with brief sheet descriptions have been prepared by staff of the Groundwater Section of DLVW.

1.2 BACKGROUND TO GROUNDWATER DEVELOPMENT

1.2.1 History

Development of groundwater resources in Malawi has been primarily for rural domestic water supplies by the construction of boreholes and dug wells.

Prior to 1979, the responsibility for borehole construction lay with the Geological Survey Department. The first boreholes were drilled in the 1930s under Colonial Development Water Supply Schemes, then from 1947 to 1968 about 100 boreholes were constructed each year. From 1969 to 1972 this rose to nearly 500 each year with large agricultural development projects in the Lower Shire Valley, Salima Lakeshore, Lilongwe and Karonga areas. These boreholes were constructed using contractors' as well as Government drilling rigs. In the late 1970s the construction rate declined again, reducing to about 150 boreholes each year by 1980. There were about 5,500 boreholes in the country in 1981, the vast majority being equipped with handpumps (see section 4.1.3).

The first programme of dug well construction was organised under the Colonial Development Schemes in the 1930s. Over 400 wells were constructed between 1931 and 1939, most of these being equipped with a windlass and bucket, and some are thought to be still in use. There was then little organised dug well construction until 1975 when the "Community Protected Wells Programme" was initiated by the former Ministry of Community Development. This programme now constructs several hundred protected dug wells each year and by 1981 there were about 1600, all equipped with handpumps (see section 4.1.3).

In July 1979, the Government of Malawi reorganised all the agencies responsible for its water development into one organisation, the Department of Lands, Valuation and Water (DLVW). The Groundwater Section of the Water Resources Branch of this Department is now responsible for all groundwater development, including both construction and maintenance of boreholes and dug wells.

1.2.2 Previous hydrogeological investigations

The earliest reports which deal specifically with groundwater are a series of Colonial Development Water Supply Investigation Progress Reports (1931-1940). These give details of the first rural water supply programme of dug well and borehole construction.

There appear to be few other hydrogeological reports published until the 1970s when the Geological Survey (GS) produced a general account of the groundwater resources of Malawi (Wilderspin, 1973) and several regional reports (Bradford, 1973 a -e, Wilderspin, 1974; Pascall, 1973 a, 1973 b; Chapusa, 1977 a-c;Crow,1979;Habgood,1963). These reports provide a useful background to the hydrogeology. The

G S Bulletins, published for most areas of the country (see 2.1), also include brief summaries of the groundwater development.

There are several consultant reports relating to the development of the Shire Valley which include discussions of the hydrogeology but these are not very detailed (Halcrow, 1954; Lockwood 1970; Howard Humphreys, 1975). Much more comprehensive reports were produced by Hunting Technical Services as a part of the National and Shire Irrigation Study (NSIS). The groundwater resources are considered both nationally (NSIS, 1980, 1982) and with particular reference to the Lower Shire Valley (NSIS, 1981). Designs for water supplies for urban centres were proposed by Howard Humphreys (1979). Their investigations included some analysis of hydrogeological data, but the information used was limited and some of it is considered to be unreliable.

In 1978, Wright (Institute of Geological Sciences/Overseas Development Administration) visited Malawi to examine the state of groundwater development and identify topics for further hydrogeological investigations. As a result of his report, a three month visit was made by Chilton (1979) to make a preliminary assessment of groundwater availability and the scope for further groundwater development. The main recommendation arising from this visit was that it should be followed up by a long term assignment. This began in December 1979, with the setting up of the Groundwater Project, under the auspices of the newly formed DLVW, consisting of a team of hydrogeological advisers and professional officers of the Groundwater Section. The objectives of this were to improve all aspects of the groundwater development programme and to produce the hydrogeological volume and maps for the National Water Resources Master Plan (NWRMP).

Catchment studies have been carried out to investigate in detail the hydrogeological conditions in the Bua Catchment (Smith-Carington, 1983) and in the Salima-Nkhotakota lakeshore area (Maulnka, 1983). Test drilling to determine the irrigation potential of some of the alluvial areas for the NSIS (1982) was also supervised by Groundwater Project staff, and provided an excellent opportunity for training in construction and testing practices for higher yielding boreholes. Considerable improvements have been made to borehole designs, local handpump production and groundwater development programmes; full details are given in a comprehensive manual produced by DLVW (1982).

1.2.3 Old records

The data presented in this report have been abstracted from numerous files and reports of varying ages now housed within the Groundwater Section of DLVW (Table 1.1). Many of the records are incomplete and some of the data is suspected to be unreliable. Often the records are sole original copies, some over 40 years old, and they are commonly torn or illegible. Some of the original records have been lost. Data has been compiled from the old records, and it is recommended that all those not required for routine use be archived to avoid any further losses or deterioration.

The old records file data in a variety of ways and it is difficult to assess all the available data for any particular area without a lengthy search. The Groundwater Project thus, as a first priority, sought to establish a subdivision of the country into groundwater units and secondly to establish a readily accessible borehole data system.

TABLE 1.1 <u>LIST OF FILESUSED FOR DATA COMPILATION</u>

1. Borehole construction files (listed by siting geologist)

2. Summaries of borehole details (listed by siting geologist)

3. Annual borehole construction records (listed by date of siting)

4. Borehole fund accounts construction records for invoicing (listed by date of submission)

5. Borehole maintenance records (listed by siting geologist)

6. Borehole geophysical siting files (listed by siting geologist)

7. Colonial Development Water Supply Schemes (listed by date of construction)

8. Water chemistry analysis files (listed by local sampling area)

9. Water chemistry laboratory analysis (listed by Water Resource Unit)

10. Borehole location maps (sited at 1:50,000 scale)

11. Borehole test pumping records (listed by area)

12. Dug well construction reports (listed by project area)

13. Dug well location maps (sited at 1:50,000 scale)

14. Dug well maintenance inspection reports (listed by project area)

15. River discharge records (listed by Water Resource Unit)

16. Rainfall data (listed by map sheet)

1.2.4 Water resource units

A system of 'Water Resource Units' has been adopted dividing the country into 17 physiographic regions (Figure 1.1). These have been modified from the groundwater units proposed by Wilderspin (1973) and Chilton (1979) in order that surface water and meteorological records can use the same data storage system. This facilitates resource studies and more effective water management. Each water resource unit comprises a single large catchment or compatible group of small catchments. Each unit is divided into sub-units which join at a river confluence and either comprise small catchments or clear physiographic divisions. There are a total of 66 sub-units. Each unit is indicated by a number and each sub-unit by a letter.

1.2.5 Revised borehole numbering system

In order to allow borehole numbers to convey information on location, a revised numbering system has been adopted to replace the old Geological Survey (GS) system, based on the initials of the siting geologist. The boreholes are now categorised according to water resource sub-units, and are numbered in chronological order of drilling. For example, 5F148 is the 148th borehole constructed in sub-catchment F (Rusa) of the Bua unit (number 5). Abandoned boreholes have a suffix letter X, cleaned boreholes have a suffix C, and rehabilitated boreholes have a suffix R. A full list of the known existing boreholes for which records are available (some 5500 in total including abandoned holes) together with locational details and cross reference with old G S numbers is being prepared. It is likely that there are an additional small number of boreholes which have been omitted from this list, either because the original construction records are missing, or because they were drilled privately by a contractor and no information about location or construction details is known. If these boreholes can be located in the field, the listing can be updated.

1.2.6 Borehole data compilation

A borehole data cardex card (Figure 1.2) was designed by the Groundwater Project in order to record all available data for each borehole on one record card for easy reference. This was a prerequisite for the map preparation in the water resources work, and has proved valuable in the assembly of borehole data for other purposes such as project planning. Metrication of all existing records was undertaken at the same time as the transfer of information and a virtually complete set of cardex cards is now available for consultation in the Groundwater Section of DLVW. The cards are designed so that the borehole number, test discharge, rest water level, specific capacity and electrical conductivity can be seen at a glance within the storage files. As new boreholes are drilled or rehabilitated, cardex records will be made and added to the system. A full data scrutiny is being

FIGURE 1.1 WATER RESOURCE UNIT BOUNDARIES

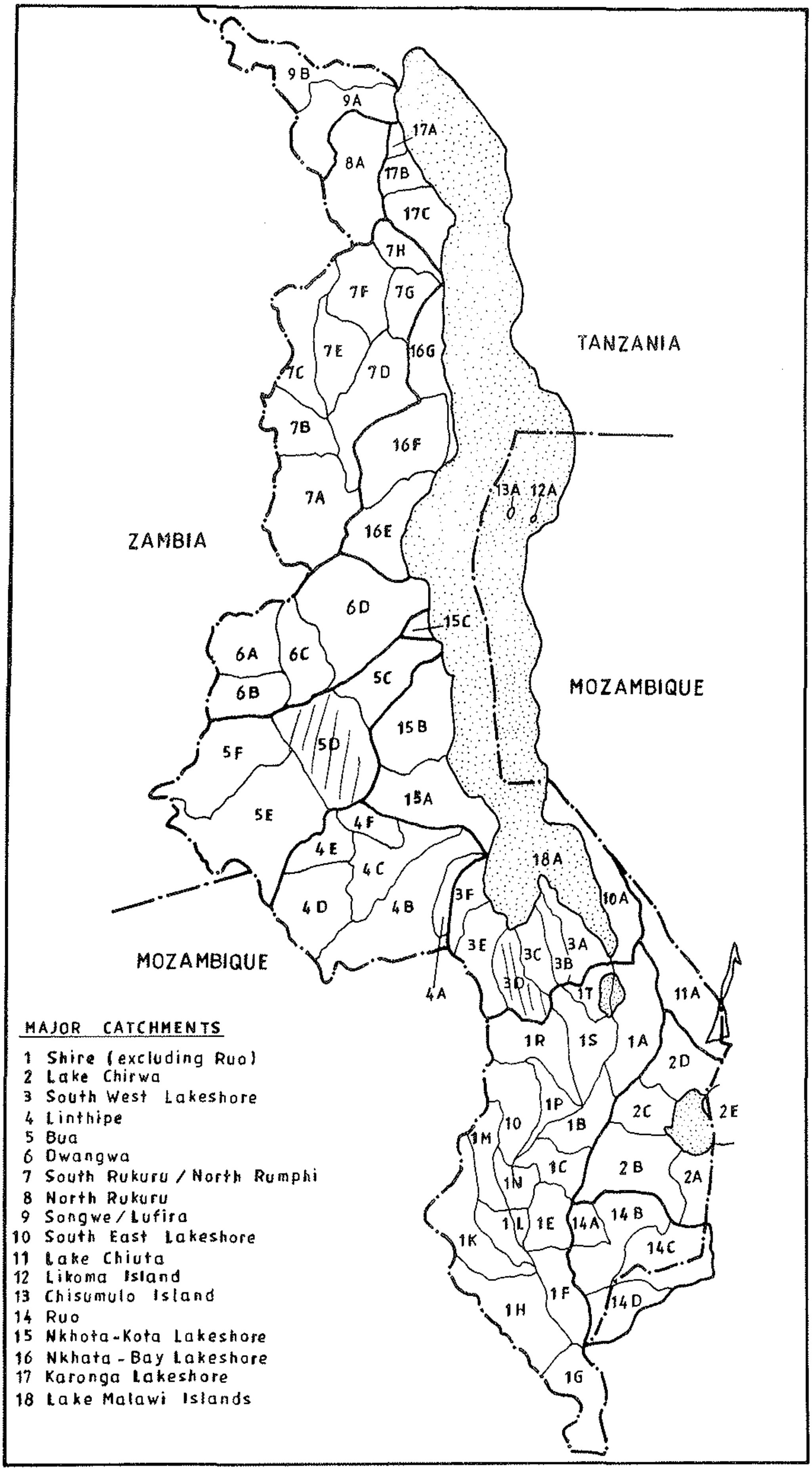

Figure 1.2 Cardex Record of Borehole Information

a) Front

BOREHOLE DATA FORM BDF1

DESCRIPTORS

Locality	Chisuzi Village
Grid Ref.	WIV 513 818
Map Sheet	1333 C2
Depth b.d. (m)	45.75
RWL (construction)(m)	9.15
Datum altitude AOD (m)	1128.5
RWL AOD (avg min)(m)	1119.5
RWL AOD (avg max)(m)	
District	Lilongwe
Client	LCDP

Detailed Geology

0-32.9 Colluvium

32.9-45.7 Basement gneiss

G.S Ref No	D P 1 1 1
Borehole No.	5 E 1 9 9

CONSTRUCTION

Driller/Contractor	WCL Josia
Drilling Method	Percussion
Start	23 03 72
Drilling Finish	05 04 72

Drilling	diam (mm)	from (m)	to (m)
1	203	00.00	33.55
2	152	33.55	45.75
3			

Water Struck (m)			rising to
1	22.20	rising to	9.15
2		rising to	
3		rising to	

Casing		diam (mm)	from (m)	to (m)
Plain	1	152	00.00	21.35
	2			
Slotted	1	152	21.35	33.55
	2			

Casing Material: Plain	MS	Slotted	MS
Slot Size (mm)		Open Area %	
Pump: Type	Climax	Suction (m b.d)	37
Filter: quantity (m^3)	1.5	d50 (mm)	9.5

PERFORMANCE

Driller's Pump Test

5 hour yield (l/min)	136.8
5 hour drawdown (m)	6.10
5 hour Spec. Cap (l/min/m)	22.4

Detailed pump test

Transmissivity (m^2/d)	
Storativity	× 10⁻
See file no.	N/A

SITING

Geologist	D Pascall
Date	06 03 72
CST Spacing interval (m)	22.9
(10 Ωm) Point resistivity	10.2
DP: ρ1 (10 Ωm)	14.0
ρ2	2.5
ρ3	
Depths	6.1 m; m
Recommended: drill to (m)	61.0

Q	RWL bd	SC	EC		

Figure 1.2 Cardex Record of Borehole Information

b) Reverse

5		E	1	9	9	C

PLUMBED DEPTH and WATER LEVEL 1		
Date	Depth (m)	W.L. (m)
07 04 72	45.75	9.15
23 09 76	45.75	5.19
11 11 76	45.75	8.54
11 10 79	45.45	4.58
13 03 80	45.45	3.66
21 09 80	30.50	4.88
09 11 80	30.50	3.36
03 02 81	45.75	4.27
16 05 81	44.23	3.66
04 01 82	44.23	5.49

PLUMBED DEPTH and WATER LEVEL 2.		
Date	Depth (m)	W. L. (m)

CHEMISTRY					
Date	10/72			Date	EC (μS)
Ion	mg/l	mg/l	mg/l		
Ca	30				
Mg	11				
Na	22				
K	3				
Fe	1.8				
HCO_3	152				
SO_4	70				
Cl	10				
NO_3	<1				
F					
TDS	268				
EC					
pH	6.00				
T°C	25.0				

NOTES

Checked. [signature]

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carried out by professional hydrogeologists to ensure that the manual system is free from errors. This checking has largely been completed, although there are still likely to be a few mistakes and omissions.

The cards have also been designed with future computer storage in mind so that the data can easily be transferred. When this stage has been reached it will be very easy to call up locations of boreholes, water level data, water chemistry and other information required for water resources management decisions. It will also be easier to locate and correct any remaining errors using computer listings of data input.

1.2.7 Hydrogeological maps

Hydrogeological information from the cardex cards has been used to compile a master set of maps for each Water Resource Unit at a scale of 1:100,000. For each unit, maps have been produced to show the following :-

a) borehole location and number

b) borehole test yields and specific capacity (where available)

c) minimum rest water level with piezometric form lines

d) depth to bedrock (for alluvial aquifers)

e) electrical conductivity of groundwater (where available)

Groundwater Section staff are using these maps to prepare a set of nine hydrogeological maps at a scale of 1:250,000 for publication. In addition a 1:1,000,000 hydrogeological map has been prepared to show groundwater potential for planning purposes.

1.2.8 Dug-well data

There is only a limited amount of information available for most of the existing protected dug wells. Data recorded at the time of construction includes the following :

a) well number

b) village

c) grid reference

d) depth of well

e) diameter of slab

f) depth of water in well

g) date of construction

h) type of handpump

i) depth of pump suction

j) diameter of rising main pipe

k) length of outlet pipe

l) date of pump installation

The wells are constructed according to two standard designs (see section 4.3.6). They are either brick lined or lined with concrete rings at depth and backfilled to ground surface. Local variations in the well designs and dimensions have not been recorded, nor is there any indication of the lithological succession.

A new dug-well construction report has been designed to ensure that more hydrogeological data is collected (Figure 1.3), and this will be used for all future wells. In future, the recovery of water levels within the well after pumping it dry will also be monitored for a period of several hours, and this data will give some idea of well performance.

Monthly maintenance reports give details of any repairs carried out on dug wells and the materials used. The well depth and water depth are also recorded at the time of these visits.

The wells have been numbered by project area, usually recommencing each year with a new number one, thus there is often confusion when referring to different wells, especially as the numbers are not marked on them in the field. The numbering system is being revised, so that all the wells will be categorised according to the water resource sub-unit, in a similar form to the boreholes (see section 1.2.5).

1.3 TOPOGRAPHY AND DRAINAGE

1.3.1 Physiographic zones

Malawi is situated at the southern end of one limb of the East African Rift Valley System which dominates the topography of the country. There is a wide range in relief, which has a great influence on the climate, hydrology and occurrence of groundwater; thus the Water Resource Units (see section 1.2.4) were defined largely based on the topography. The distribution of the population, and hence the demand for water supplies, is also largely controlled by the topography.

Malawi can be divided into four main topographic zones (Figure 1.4) :-

FIGURE 1.3 DUG WELL CONSTRUCTION REPORT

FORM A1 front

WELL Nº P 28

OFFICE OF THE PRESIDENT AND CABINET
DEPARTMENT OF LANDS, VALUATION AND WATER
(GROUND WATER SECTION)

DUG – WELL CONSTRUCTION REPORT

District DOWA
T. A CHAKHAZA
Locality BISWICKI
Grid reference WA726110
A. O. D. 3790'
Moved from BLAIR
Moving to MBOBO

Client KADD
Address BOX 92 LILONGWE
Well supervisor H.K. Crew Nº I
Digging started 3.10.83
Digging finished 10.10.83
Final completion 17.10.83

1 DAILY RECORD

Date	Digging time	From (m)	To (m)	Other work (hrs)	Remarks
		0	1.8		VILLAGE DUG
3.10.83	5 HRS	1.8	2.1	DIGGING	
4.10.83	7 HRS	2.1	2.5	"	
5.10.83	6 HRS	2.5	2.95	"	
6.10.83	6 HRS	2.95	3.25	"	HARD ROCK AT 3 METRES
7.10.83	6 HRS	3.25	3.6	"	

2. DETAILS FOR COSTING AND CHARGING

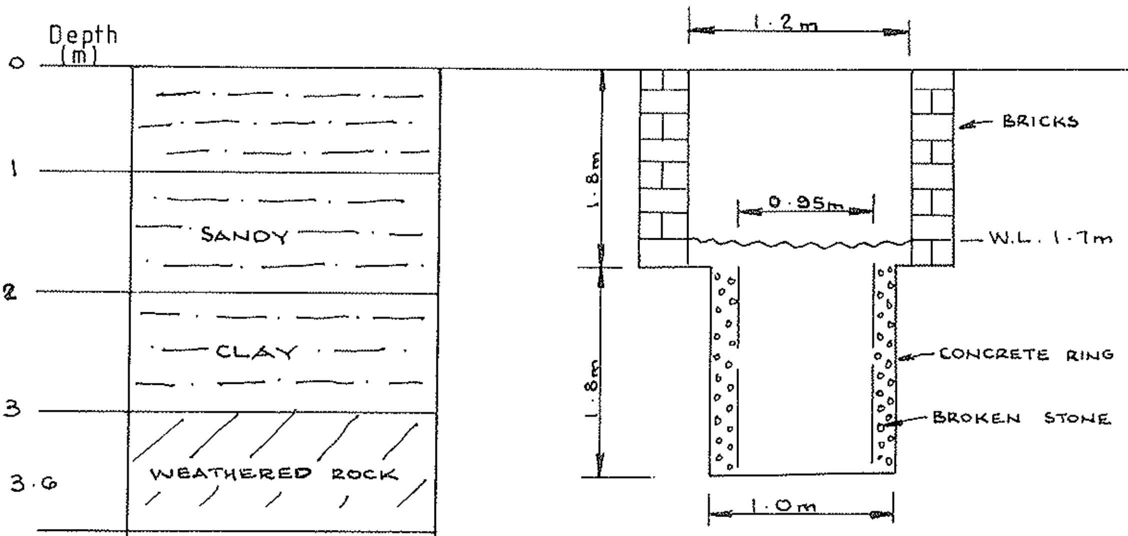
A. CONSTRUCTION DETAILS

Diam 1000 mm, from 1.8 m, to 3.6 m
Total depth 3.6 m
Rest water level 1.7 m

B CONSTRUCTION MATERIALS USED

Concrete rings no 2
Bottom slab no –
Top slab no 1
110 mm guiding PVC pipe m –
63 mm PVC rising main pipe m 3.1
25 mm PVC pump rod m 3.1
Foot value no 1
Plunger no 1
Solvent cement tin 1/2
Cleaning fluid tin 1/2
Filter stones sum VILLAGE PROVIDED
Cement pkt 4+5
Pumphead no 1

3. LINING DETAILS



RECOVERY OF WATER LEVELS AFTER PUMPING DRY

TIME	WATER LEVEL (m)	TIME	WATER LEVEL (m)
0:00	4.47	0:25	3.77
0:01	4.30	0:30	3.70
0:02	4.27	0:45	3.43
0:03	4.24	1:00	3.22
0:04	4.21	1:30	2.93
0:05	4.19	2:00	2.74
0:06	4.17	2:30	2.60
0:07	4.15	3:00	2.50
0:08	4.12		
0:09	4.10		
0:10	4.07		
0:15	3.98		
0:20	3.90		

a) plateau areas

b) upland areas

c) rift valley escarpment

d) rift valley plains

a) plateau areas

The plateau areas are extensively peneplained, gently undulating surfaces with broad valleys and interfluves. They are ancient erosion surfaces lying at altitudes of 900-1300 m above sea level (see 2.1.2) and cover particularly extensive areas in the Central and Northern Regions. The surfaces tilt away from the escarpment zones as a result of uplift along the rift valley. Rejuvenation has kept pace with these earth movements and rivers largely drain towards the rift valley; as a consequence the valleys become more incised towards the escarpment. The plateau areas are drained largely by "dambo" which are broad, grass-covered, swampy valleys that are liable to flooding and have no well-defined channels.

b) upland areas

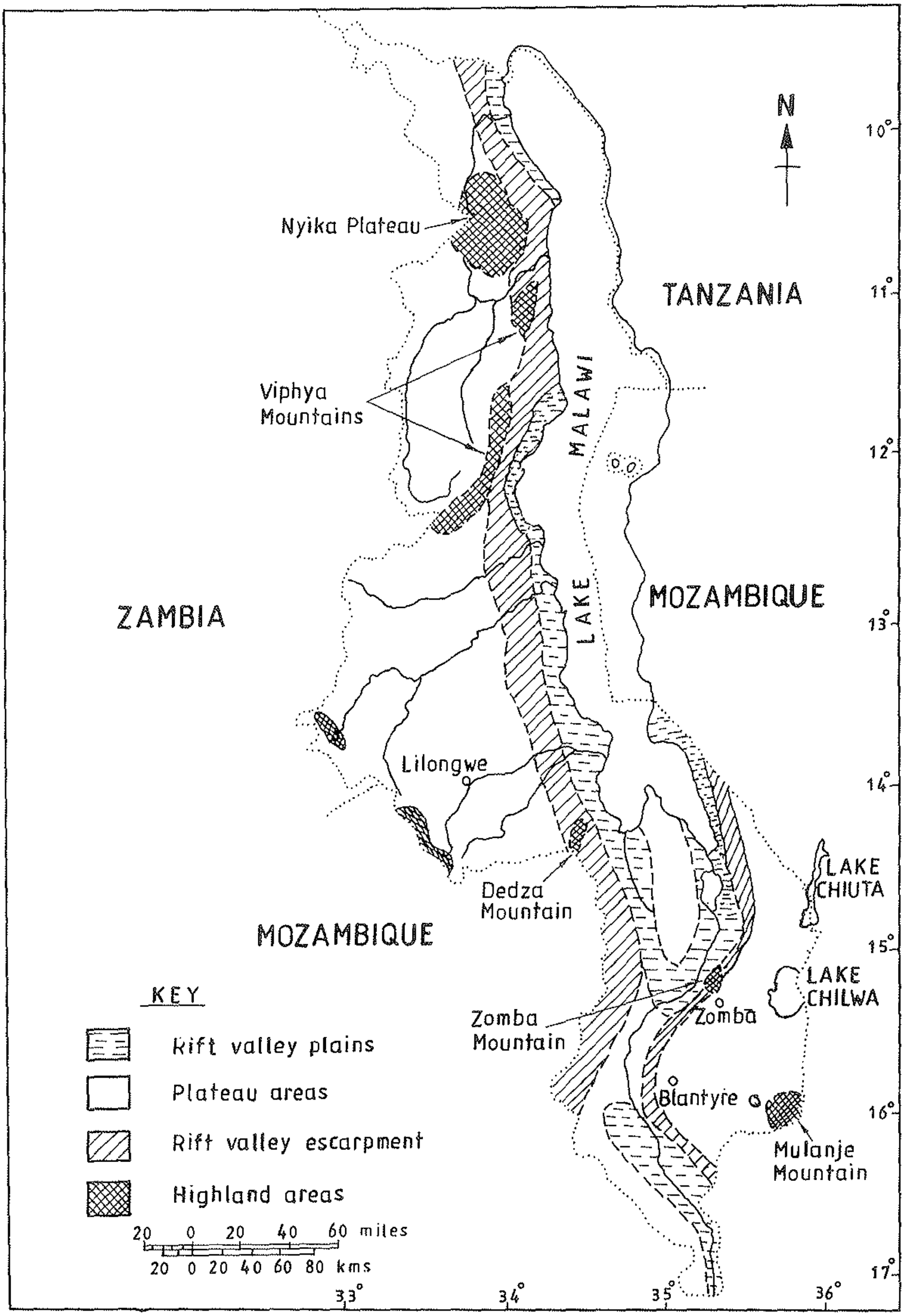
The flat surface of the plateau areas is broken by occasional inselbergs rising abruptly and steeply from the plains. These are small isolated residuals where the bedrock is more resistant to erosion.

There are also several extensive highland areas rising from the plateau which represent remnants of the post-Gondwana erosion surface (see section 2.1.2). The mountains of Mulanje, Zomba and Dedza, and the Viphya and the Nyika plateaux are the most prominent uplands, reaching altitudes of 2,000 - 3000 m above sea level. They are formed mainly of granitic or syenite intrusions which are more resistant to erosion. Slopes are steep and the topography is often very dissected.

c) rift valley escarpment

The rift valley escarpment falls steeply from the plateau areas, and slopes are commonly very dissected. The "en echelon" faulting commonly results in the land surface falling in a series of steps down to the rift valley floor. Bedrock occurs at or near the surface because active erosion strips away any products of weathering processes as fast as they can form.

FIGURE 1.4 MAJOR PHYSIOGRAPHIC ZONES



d) rift valley plains

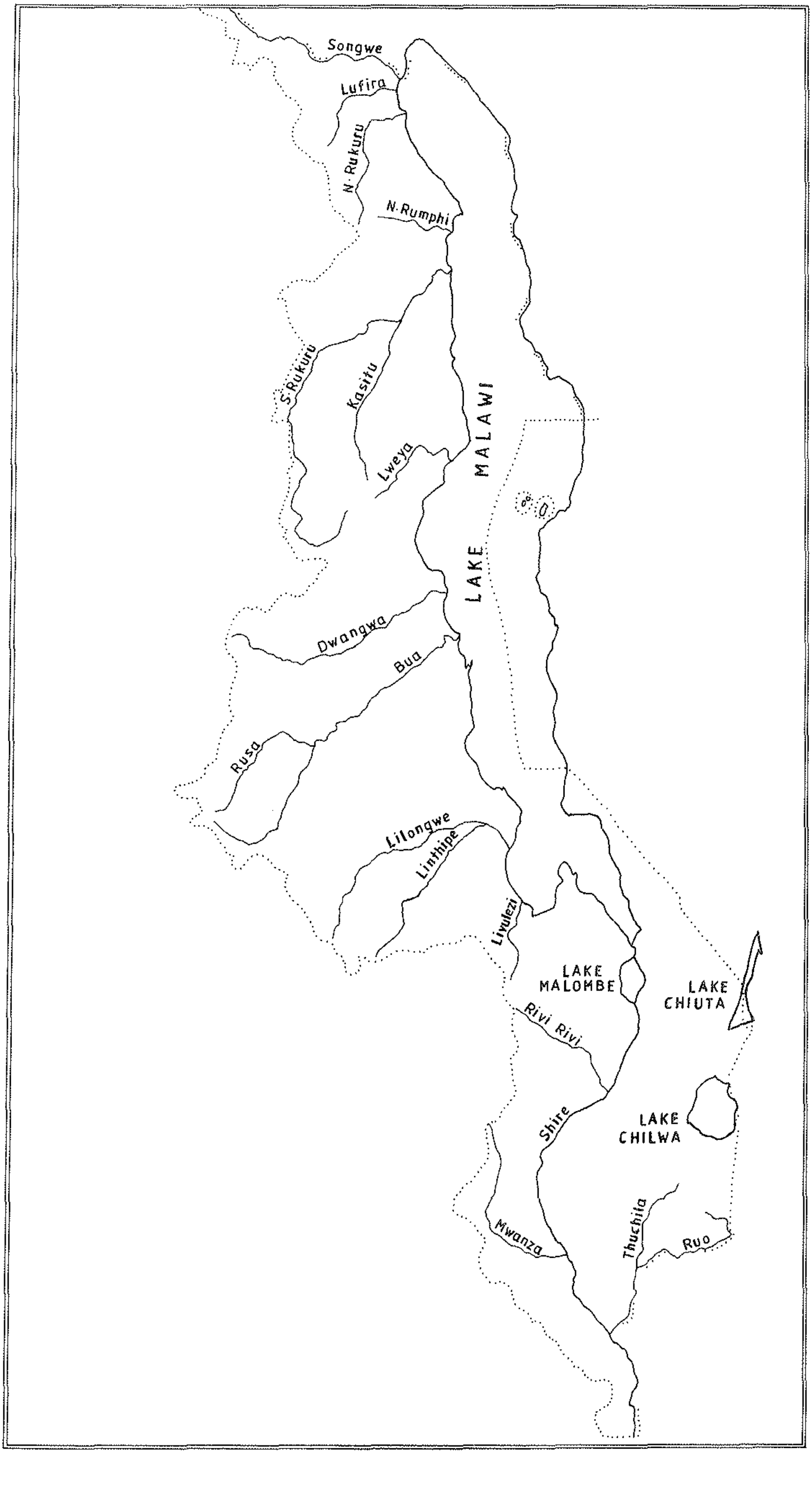
The plains of the rift valley floor are gently sloping and of very low relief. They extend along parts of the lakeshore and Upper Shire Valley at levels of less than 600 m, and fall to less than 100 m above sea level in the Lower Shire Valley. The plains are areas of deposition, where sediments derived by erosion, particularly from the escarpment zone, are deposited.

1.3.2 Major drainage systems

The major drainage systems are clearly dominated by Lake Malawi (Figure 1.5). The River Shire is the largest river and it is the only outlet for Lake Malawi; it follows the rift valley southwards to join the River Zambesi. The Upper Shire Valley is a flat alluvial plain separated from the broad lowlands of the Lower Shire Valley by a series of gorges, rapids, and falls. Its major tributaries are the Ruo draining the Mulanje Mountain area and eastern Shire Highlands, and the Mwanza from the Kirk Range. The principal rivers draining into Lake Malawi are the Linthipe, Bua, Dwangwa and South Rukuru. These have numerous tributaries, and the drainage pattern appears to be frequently controlled by structural weaknesses. These rivers nearly all have extensive areas of dambo on their upper tracts on the flat plateau areas. The dambo may occupy up to 25% of the total land area (Hill and Kidd, 1980) and these have a distinct hydrological regime which is not clearly understood, but is important in relation to water resources (see section 3.4.2). The broad, poorly defined channels and slow flow of water through the grasses result in very low erosion rates and the plateau landforms have been stable for a very long period of time. The major rivers all have deeply dissected valleys where they have cut through the upwarped edge of the rift valley escarpment. In between them are many smaller rivers having their headwaters in the dissected escarpment. There are often gorges with rapids over the fault sections.

On entering the rift valley plains the gradient becomes very gentle and, as a result, much of the river load is deposited. There is annual flooding in the wet season in these sections, and river channels frequently change their course. This is well observed in the Bwanje Valley. Rivers frequently lose much or all of their flow into the alluvial deposits especially where they debouch from the escarpment zone. Further downgradient the discharge may increase again with a contribution of groundwater discharge. It is clear that the hydrology is complex. The intense rainfall during the wet season can give rise to extremely high flood flows, however the long dry season leads to ephemeral flow in most streams except the largest rivers and streams rising in the highland areas (Drayton, 1980).

FIGURE 1.5 MAJOR DRAINAGE SYSTEMS



All drainage systems discharge to Lake Malawi or the Shire River with the exception of the catchment of Lake Chilwa. This is a shallow, internally-draining basin where inflow is balanced by high evaporation losses. The lake is saline and periodically dries up due to excessive evaporation. The surrounding areas tend to be swampy during the wet season. The lake is fed by rivers which cross the Phalombe Plain originating from Zomba and Mulanje mountains, and from Mozambique. Many of these rivers are seasonal.

1.4 CLIMATE

1.4.1 Introduction

The climate of Malawi is markedly seasonal and rainfall is largely associated with the migration of the Inter-Tropical Convergence Zone (ITCZ) and the associated Equatorial Troughs which bring the region alternately under the influence of the SE Trade winds and the NE monsoons. However climatic conditions are complex due to the very varied topography and the influence of Lake Malawi. Generally speaking the plateau areas have warm climates with moderate rainfall, and the rift valley has a hot climate which may be semi-arid in places.

The climate can be divided into three main seasons. The "hot wet" season usually extends from November to March; rains start slightly later in the north but may last until April or even May. The dry season is divided into "cool dry" extending from about May to August, followed by a "hot dry" season with progressively increasing temperatures and relative humidity from September to November.

1.4.2 Winds

During the dry season the prevailing winds are the SE Trades which are relatively dry and produce clear or fair-weather cloudy conditions. With the migration of the ITCZ south over Malawi, the winds tend to become more northerly, as the influence of the NE monsoons increases, the temperatures rise and the relative humidity increases. The wet season is associated with the convergence of air towards the ITCZ. The winds are generally light during this period and usually from the north, north-east or north-west. The strengthening of the SE Trades again drives the ITCZ north and brings the wet season to an end over most of the country, although the escarpment and other slopes exposed to the south-east continue to receive orographic rain by forced convection.

1.4.3 Rainfall

The rainfall distribution is strongly related to topography (Figure 1.6), with the highlands and areas with exposed slopes facing the prevailing winds having much higher rainfall than those in the rain-shadow and those in the lowlands. Over 90 percent of the country has a mean annual average of more than 800 mm. Mulanje Mountain, Zomba Mountain and the exposed Nkhata Bay lakeshore (with steeply rising escarpment behind) have an annual average of more than 1800 mm. The low rainfall areas are restricted to parts of the lakeshore (South Karonga, Salima and Mangochi areas), the lowlands of the Shire Valley, and other protected rain-shadow areas (for example the South Rukuru Valley).

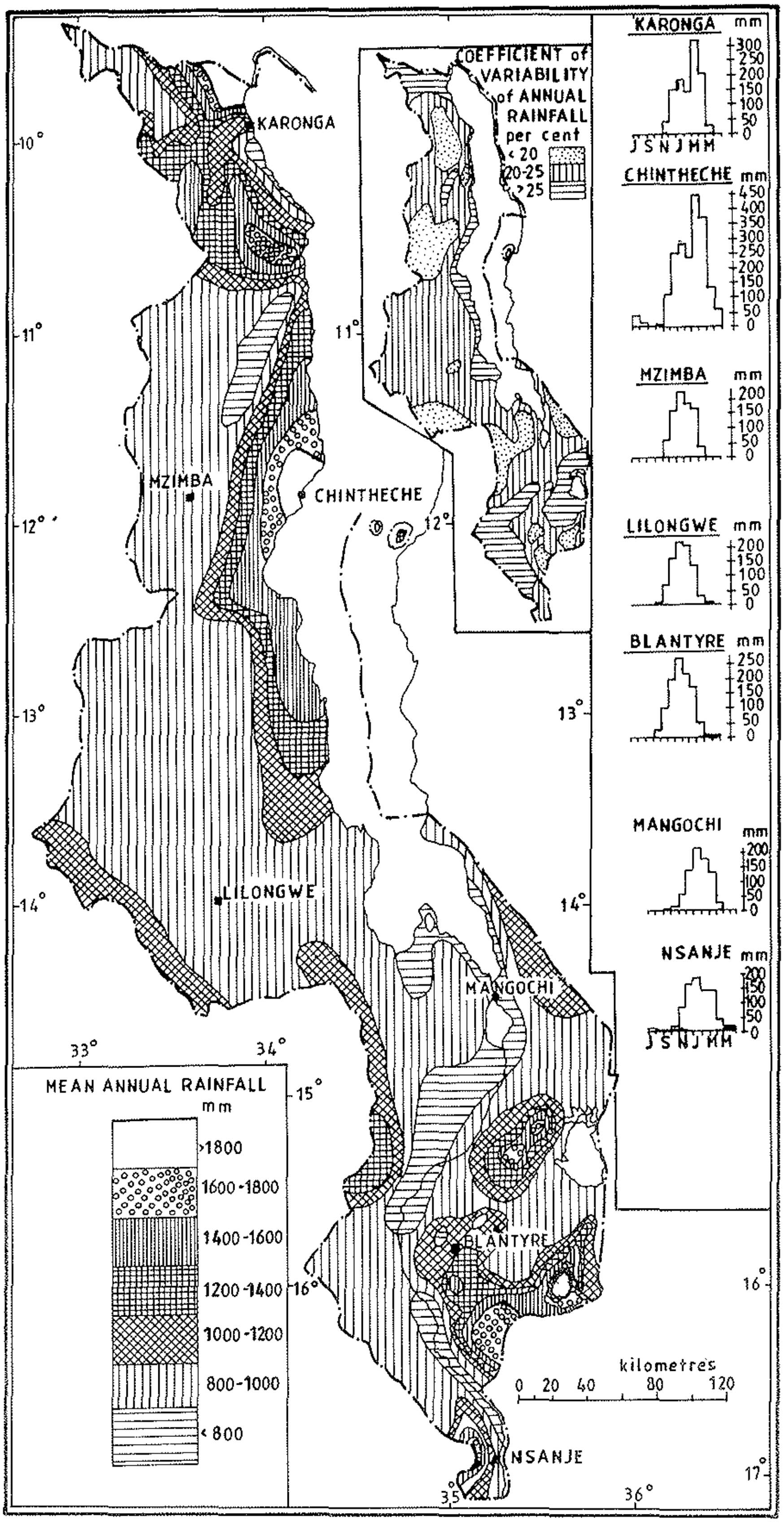
Annual rainfall varies greatly from year to year with a tendency for a number of wetter than average years to be followed by a number of drier than average years, but there is no predictable pattern. Normally the lower the rainfall the greater is the variability and vice versa. The seasonal nature of the rainfall is shown by the bar charts in Figure 1.6. The initial rains of the wet season are usually intermittent, but they become more continuous and heavier reaching a maximum in about January. After this they tend to decline in frequency and intensity. The tropical storms are produced by convergence associated with the ITCZ and the high temperatures causing strong convection which may be aided by topography forcing the air to rise. Rainfall can be very heavy and records of over 20 mm/day are quite common. There is very large spatial variability in tropical storms, even over short distances. However on an annual basis, the total rainfall at any one site is probably reasonably representative of rainfall over the area.

The higher altitude areas also receive orographic rainfall and mists, known as "chiperoni", during the dry season.

1.4.4 Temperature

Temperatures are closely related to altitude and the latitude effect has much less significance. Van der Velden (1979, 1980) showed that the mean monthly temperature ranges from 10-16°C in the highlands of Nyika, from 16°-26°C on the plateau areas of the Central Region, 20-29°C along the lakeshore and 21-30°C in the Lower Shire Valley. The actual maximum temperatures rise to as high as 40°C during October and November in the Lower Shire Valley while on the high plateau areas this value is about 30°C. The absolute minimum temperatures fall to about freezing level in the highlands in June and July but only to 4-6°C on the plateau areas and remain above 10°C on the lakeshore. The ameliorating influence of Lake Malawi is clearly seen at stations along the lakeshore, where the annual range in temperatures is subdued.

FIGURE 1.6 MEAN ANNUAL RAINFALL



After Agnew and Stubbs, 1972

1.4.5 Evaporation and transpiration

Pan evaporation can also be closely related to topography (Van der Velden, 1979). The average annual pan evaporation ranges from 1500-2000 mm on the plateau areas and is highest along the lakeshore and in the Shire Valley (2000-2200 mm).

Estimates of open-water evaporation (E_o) and potential evapotranspiration (Et) have been derived by the Meteorological Office using the Penman method for several sites from 1972 onwards (Dandaula, 1979). The estimates of Penman E_o are similar but slightly lower than those of open pan evaporation showing the need for a "pan factor correction". The mean annual Penman potential Et ranges from 1100-1700 mm depending on altitude, but the actual Et is likely to be much less than this because of the moisture deficiency which builds up during the dry season. Over much of the country, with the exception of some valley bottoms where conditions remain moist, it is suspected that actual Et rates fall to zero or almost zero by the end of the dry season. This will vary significantly on a local scale depending on land use and soil conditions.

Actual Et has been estimated as an average of 780 mm over the total plateau area of the Bua catchment based on a consideration of vegetation types and moisture conditions although there will be large spatial variations depending on topographic position (Smith-Carington, 1983). Further details are given in section 3.4.5 where a catchment water balance is considered.

1.5 SOILS

1.5.1 Introduction

Summaries of the soils and land capability are provided by Brown and Young (1962 and 1965) which discuss the physical environments of the Northern and Central Regions. These are each accompanied by a map of natural regions and areas at a scale of 1:500,000, and there is an additional map for the Southern Region. Various soil surveys have been carried out by the soil survey unit of the Ministry of Agriculture, and the data in reports and maps is available, though unpublished. The soils of the alluvial plains are described by the National and Shire Irrigation Study (NSIS, 1980).

There are 4 main soil types based on the classification by Brown and Young (1965) :-

a) Latosols

b) Lithosols

c) Hydromorphic soils

d) Calcimorphic soils

1.5.2 Latosols

Latosols are formed by the prolonged weathering of clays and downward leaching of exchangeable bases and silicates. They are found mainly on the gently sloping areas of the plateau and are generally reddish-brown and yellowish-red acid soils with relatively free drainage. They are predominantly fine textured, ranging from loamy sands to clays, and the clay content usually increases with depth. In general the more basic parent materials result in more heavily textured, darker red soils. The soils are commonly deep (often 1-3 m) and are generally more permeable than the hydromorphic soils of the valley bottoms, though drainage may be impeded where massive laterite layers are well developed. The soils appear to have relatively low infiltration capacities and often the lower soil layers are dry even after prolonged rainfall. Soakaway pits from boreholes are commonly very poorly drained confirming the low permeability. Most variations in texture can be broadly related to topography and are determined by the extent of erosion, leaching and relative position of the water table. The latosols are moderately fertile and often heavily cultivated especially where the textures are lighter.

Latosols can be divided into 3 broad types :-

a) ferallitic soils which are strongly leached with an advanced state of clay mineral weathering (mainly kaolinite). These generally have poor nutrient status and often have associated laterite layers.

b) ferrisols are less acid and less leached than the ferrallitic soils.

c) ferruginous soils are found where the weathering of parent materials is even less advanced and the soils are relatively weakly leached.

The physical characteristics of the soils in relation to groundwater recharge are described by Smith-Carington (1983) with reference to the Bua Catchment.

1.5.3 Lithosols

Lithosols are shallow, immature and stony soils found on the steep slopes of the rift valley escarpment and highlands rising from the escarpment. They are usually saprolites, i.e. developed in situ. Deep soils have not had the chance to develop because of rapid erosion in the dissected sloping areas. There is little horizon differentation and any weathering of parent material is balanced by losses through slope wash or soil creep. Drainage may be rapid, but the shallow profile results in low moisture retention.

1.5.4 Hydromorphic soils

Hydromorphic soils are waterlogged for all or most of the year; these are found in dambo areas on the plateau, and valley floors on the alluvial plains. They are usually black or mottled swelling clays, with a high organic content and a very heavy texture, and they have low permeability.

Vertisols, (black cotton soils), for example those of the Ngabu area of the Lower Shire Valley and around Lake Chilwa, are alkaline clays which are very sticky when wet and crack strongly on shrinking when they dry out.

1.5.5 Calcimorphic soils

Calcimorphic soils are derived mainly from alluvial parent material and are found largely along the lakeshore plain. They are grey or brown soils and the texture varies widely, with alternating layers of clays, silts and sands. The clays are strongly swelling but do not usually crack on drying out due to the high proportion of silt. Drainage is impeded where the water table is high and the lower horizons may be mottled as a result. The soils have variable but generally high permeabilities on the old river flood plains. They are usually relatively deep.

1.5.6 Soil associations

A distinct soil catena sequence often occurs from the interfluve crest to the valley centres, especially in the plateau areas. Here there are commonly latosols on the uplands grading through colluvial, sandier soils which have been transported downslope to the valley margins, to hydromorphic dambo clays in the valley floor. This sequence is modified by geology and in detail the pattern of soil types is complex. In other areas, two soil groups often occur in close association, for example lithosols with latosols on the dissected steeply sloping areas.

Termite mounds composed of fine, low-permeability clays are found all over the plateau area and rift valley plains except where waterlogging is permanent. They tend to be large domes on the interfluves and low mounds at the dambo margins.

1.6 LAND USE AND AGRICULTURAL POTENTIAL

1.6.1 Land use

Land utilisation in Malawi is changing rapidly as the country develops. There has been a very rapid increase in the areas under cultivation since the 1930s, and associated reduction in the areas of natural vegetation, which was predominantly deciduous woodland and scrub vegetation. The effects of these changes in land use patterns have yet to be evaluated in detail, but it is possible that they have significant impact on the hydrological regime. The removal of permanent, deep rooted vegetation and introduction of cultivation could have resulted in increased soil erosion and incision of drainage channels, increased total runoff and peak flood flows, and a decrease in dry season river flows.

A study of land utilisation was carried out in 1980 (Table 1.2). Agriculture is the most important sector of Malawi's economy and it employs about 85 percent of the population. The figures suggest that the gross potentially cultivable land amounts to nearly 60 percent of the total land area, the highest percentages being in the Central Region, and the lowest in the Northern Region where there are large areas of rugged topography. A national average of 60 percent of the potentially cultivable land has been utilised at sometime and nearly 40 percent was cropped in 1980, the rest lying fallow or untouched. This is unevenly distributed, with by far the greatest pressures on the land being in the Southern Region. In parts of this region there is little possibility for agricultural expansion and virtually all the available land is being or has been recently cropped, for example the Phalombe Plain. The same applies to the central parts of the Central Region, but in peripheral areas and the whole of the Northern Region there is scope for considerable expansion and even immigration.

Malawi's agricultural production comes from two subsectors, smallholdings and estates. The former accounts for over 85 percent of all agricultural production, mainly growing subsistence crops but with some surplus for export, and it supports the bulk of the country's population. The estates occupy only about 10 percent of the gross cultivable land but produce about 70 percent of the country's agricultural exports.

The National Parks, Game Reserves and Forestry Reserves occupy 20 percent of the total land area (Figure 1.7) most of these being in locations where the slopes are steep and soils are thin, and the land would be largely unsuitable for cultivation anyway.

Other areas which are non-cultivable were delineated by Land Husbandry Department using aerial photographs to define areas of steep slopes (greater than 12 percent) and saturated dambos. It is possible that some of the marginal areas of dambo soils could be cultivated, and indeed there are already many "dimba gardens" which make use of the moist conditions throughout the dry season in these areas. However, if the permanently waterlogged areas of the dambo were drained, this would be likely to upset the hydrological balance. The probable results would be increased erosion, and the formation of well defined drainage channels, higher flood peaks and earlier cessation of flow in the dry season.

TABLE 1.2 LAND UTILISATION (1980)

(based on Ministry of Agriculture Survey data)

Land use	Northern Region (Km^2)	Central Region (Km^2)	Southern Region (Km^2)	Total (Km^2)
Total land area	26,900	35,600	31,600	94,100
National Parks & Game Reserves	4,000	3,900	2,500	10,400
Forest Reserves	3,000	2,900	2,800	8,700
Urban areas and infrastructure	800	1,400	1,300	3,500
Non-cultivable (steep slopes & dambos) 1*	7,600	2,200	3,700	15,500
Gross potentially cultivable land 2*	11,500	25,200	19,300	56,000
Cropped by smallholders in 1980	2,300	7,000	7,300	16,600
Fallow but cropped by by smallholders in last 5 years	2,500	5,200	4,300	12,000
Agricultural estates	1,100	2,500	1,300	4,900
Potentially cultivable but unused	5,600	10,500	6,400	22,500
Total area which has been used at some time	5,900	14,700	12,900	33,500
% of potentially cultivable land which has been utilised at some time	51%	58%	67%	60%
Area cropped in 1980 3*	3,400	9,500	8,600	21,500
% of potentially cultivable land cropped in 1980 3	30%	38%	45%	38%

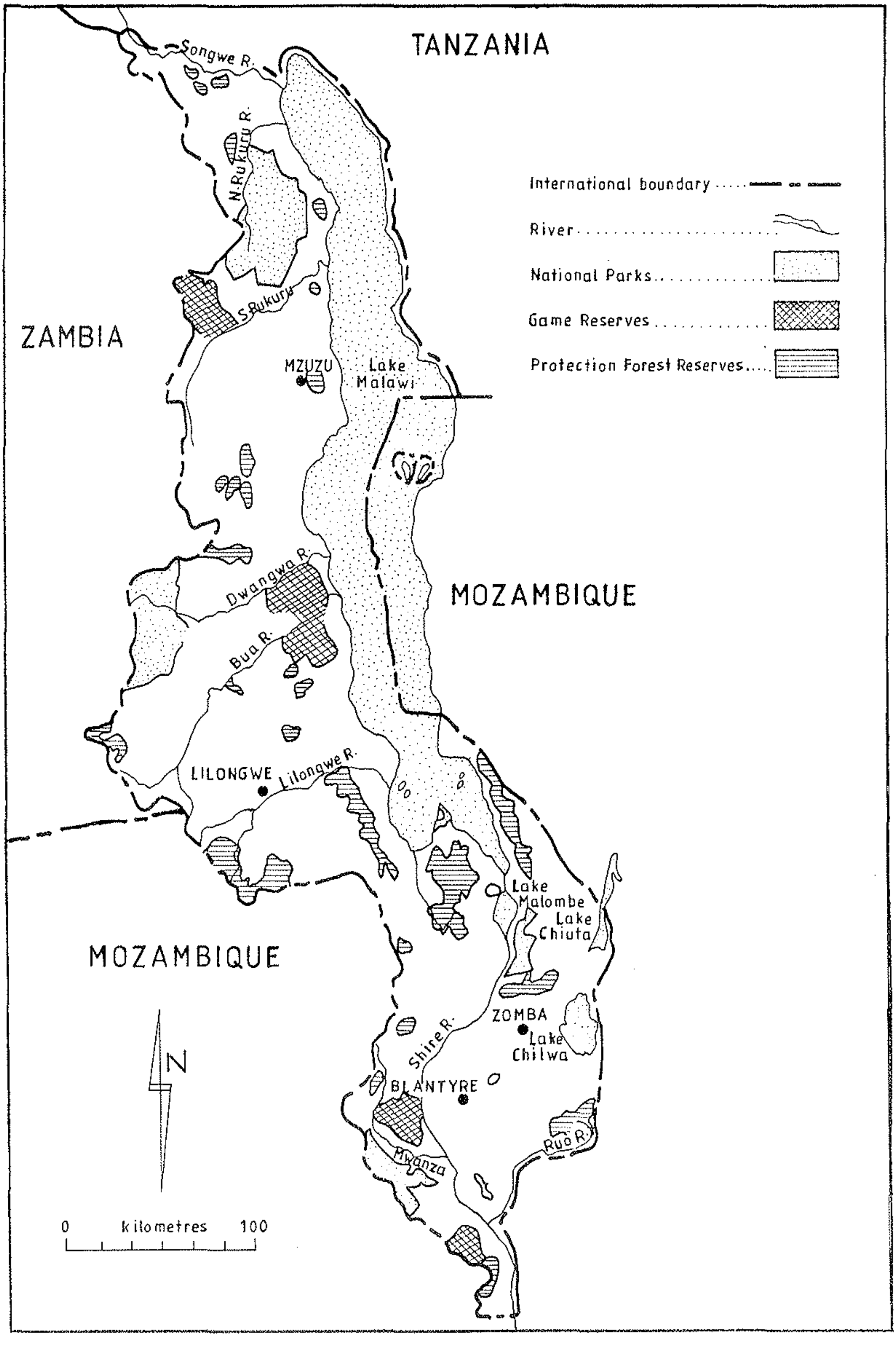
Notes:

1* Outside National Parks, Game Reserves and Forest Reserves

2* Total land area minus National Parks, Game Reserves, Forest Reserves, urban areas and non-cultivable areas

3* Likely to be overestimated as not all estate area is cropped

FIGURE 1.1: MAP SHOWING NATIONAL PARKS, GAME RESERVES AND FOREST RESERVES



The greatest areas of steep slopes are found in the Northern Region, but there the pressures on the land are much less severe. In the Southern Region where the population densities are much greater and smallholding sizes are much less, many of the unsuitable areas are now being encroached upon, resulting in increased soil erosion and declining soil fertility.

1.6.2 Agricultural potential

The agricultural potential is closely related to climate, particularly rainfall and to a lesser extent the temperature, which helps to define which crops are suitable. Most soil types are relatively fertile but this appears to be less important than rainfall in determining the productivity. Most of Malawi has sufficient and fairly reliable rainfall for successful dry land farming, and a variety of food and cash crops can be grown. Brinn and Bunning (1981) give an assessment of crop suitability for different areas. Only limited areas of the country, in the lowlands of the Upper and Lower Shire Valley, parts of the lake-shore and areas of rain-shadow such as the South Rukuru Valley, receive less than 800 mm. These areas are best limited to certain crops e.g. sorghum and cassava, as they always have the risk of severe droughts.

Most of the farmland has medium agricultural potential, but there are some areas with high potential where there is high rainfall and fertile soils. These are principally in the districts of Mulanje, Thyolo, Nkhata Bay and Northern Karonga, and also in the higher altitudes of Dedza, Dowa and Ntchisi. Crop yields from these areas are higher than those from the rest of the country. However there is scope for improvement in all areas to intensify crop returns by better farm management, suitable crop rotations and the use of fertilisers. There is also potential for increased yields, and even for double cropping, by the use of irrigation in some areas, provided that the increased levels of technology and management required are given.

1.6.3 Smallholder agriculture

The smallholder cultivation on customary land covers an area about six times that of the commercial estate sector. The average farm size is estimated at 1.5 ha and the average farming family has five members (World Bank 1981).

Maize is the most important subsistence crop, grown on more than 70 percent of the total land under cultivation, and it is the staple diet of the majority of the population. Rice is regionally important along some areas of the lakeshore (Karonga, Nkhata Bay, Salima), around Lake Chilwa and in the Lower Shire Valley. Cassava is also locally important especially along the lakeshore. Groundnuts are grown on 10 percent of the total cultivated area, and are most important in the Central Region. Smallholders grow tobacco as a cash crop, although to a much lesser extent than the estates. Cotton is also grown as a cash crop, particularly in the Chikwawa district of the Lower Shire Valley and the Salima district. Potatoes are grown locally, especially in the higher land of Dedza district.

The livestock population of Malawi is low compared with other Eastern African Countries. It is found mainly associated with smallholders, particularly in the Central and Northern Regions. Chickens, goats and cattle are the main types of livestock. Some large herds of cattle are found in the Lower Shire.

One of the Government's aims in agriculture since independence have been to maintain self sufficiency in food staples and improve rural incomes. Under the National Rural Development Programme (NRDP) smallholder production is designed to be increased through the provision of agricultural extension, seasonal credit for inputs, and better infrastructure. Various projects are encouraging rural development within the eight Agricultural Development Divisions covering the country. Under NRDP, cultivation of new land is discouraged and emphasis is put on improving productivity of already cultivated areas. Land use planning, maintenance of soil fertility and afforestation have become increasingly important. Rural water supplies are also usually a component of the improved infrastructure which is included in the NRDP programme.

1.6.4 Estate agriculture

The estate sector is heavily concentrated on three commodities; tobacco, tea and sugar. Cultivation is efficient and geared towards export. Tobacco estates are the most important, accounting for 80 percent of the total estate area, although much of the tobacco estate areas lie fallow or are planted with other crops. The tobacco growing areas are concentrated mainly in the Central Region especially in the districts of Kasungu and Mchinji. Tea is grown on well established estates, particularly in Thyolo and Mulanje districts of the Southern Region. Sugar is grown on two large estates, Sucoma in the Lower Shire Valley and Dwangwa Estate on the lakeshore.

1.7 POPULATION

The 1977 census (NSO, 1980) showed a national population of 5.5 million with an average intercensal (1966-1977) growth rate of 2.9 percent per year. The growth rate is unlikely to fall in the near future because of the very young population with 50 percent under the age of 15. The census showed that the population was predominantly rural with only 9 percent living in urban centres and 65 percent of these being concentrated in Blantyre and Lilongwe.

The rural population densities are very variable in different districts (Table 1.3). The highest densities of population are in the Southern Region, and some areas have such dense populations at present that the carrying capacity of the land is

TABLE 1.3 RURAL POPULATION

District	1977 Census Population	1977 Census average density (head/Km)	1966-1977 intercensal growth rate (% per annum)	Projected 1990 population
Chitipa	69,200	17	1.6	92,700
Karonga	91,000	32	2.0	140,500
Nkhata Bay	100,600	26	1.9	142,100
Rumphi	58,400	11	2.5	89,400
Mzimba	275,400	29	2.3	423,600
Northern Region	594,600	24	2.1	888,300
Kasungu	187,900	25	6.3	399,700
Nkhotakota	82,100	22	2.8	133,800
Ntchisi	85,800	53	2.5	122,500
Dowa	238,700	81	2.7	346,800
Salima	126,000	60	3.8	206,700
Lilongwe	600,600	114	2.1	882,100
Mchinji	155,900	47	5.9	317,400
Dedza	292,600	82	2.3	355,400
Ntcheu	222,300	66	2.9	324,500
Central Region	1,991,900	60	3.0	3,088,900
Mangochi	294,600	48	2.3	420,700
Machinga	331,500	57	3.6	527,900
Zomba	325,300	137	2.0	375,300
Chiradzulu	175,600	230	2.0	214,700
Blantyre	186,900	203	3.9	238,700
Mwanza	68,100	31	3.9	125,300
Mulanje	473,300	138	1.6	563,700
Thyolo	314,800	188	2.0	381,200
Chikwawa	183,900	41	1.5	252,500
Nsanje	100,100	56	1.5	108,300
Southern Region	2,454,100	87	2.3	3,208,300
National	5,040,600	59	2.6	7,185,500

almost fully utilised already e.g. Chiradzulu District. The lowest densities are found in the more inaccessible and mountainous northern region. The uneven distribution results in an areally disproportionate demand for domestic water supplies at present, though this could even out in the future if migration occurs.

The rural growth rate varies considerably from one district to another. Kasungu and Mchinji showed particularly high 1966-1977 growth rates because of the large scale development of estates creating job opportunities and encouraging migration of labour from other rural areas. However this high growth rate is not likely to be sustained and the future growth rate is more likely to be around the national average figure. By contrast the intercensal growth rates in Mulanje and Nsanje were low, probably due to agricultural pressure on the land and consequent migration. In Chitipa district the low growth rate is thought to be due to its remoteness and limited infrastructure. The large agricultural Rural Development Projects (RDPs) which started in the late 1960s and early 1970s in Lilongwe, Karonga and Lower Shire Valley areas do not show any significant effect on rural population growth rates.

The availability of cultivable land must control the population growth rate to a certain extent. There is the possibility that migration will occur to the underdeveloped areas, and there is some evidence that this could be commencing (NSIS, 1980) although there will be difficulties due to tribal and language diferences. Economic circumstances and the development of infrastructure will also affect the growth rates. The National Physical Development Plan (NPDP), a UN funded project, has made preliminary population projections but these may be subject to revision following their detailed survey of the country. Based on their studies, the 1990 rural population (Table 1.3) and urban population (Table 1.4) have been estimated.

The urban growth rate (intercensal average 6.5 percent per year) is much greater than the national average because of the migration from rural areas. Some towns are likely to grow faster than others for reasons of location, infrastructure, agricultural potential, and some rural centres may soon be considered as small towns. Many factors are involved and it is difficult to predict future urban populations with any accuracy.

The urban population figures given in Table 1.4 include some centres which are small at present but which may be classed as market centres by 1990. The NPDP project is conducting surveys to gain local information on factors contributing to urbanisation, and the number of centres and the projected populations are subject to revision.

Using the above estimates, the national population of Malawi is likely to be in the order of 8.3 million by 1990, of which 7.2 million will be living in rural areas and 1.1 million in urban centres.

TABLE 1.4 URBAN POPULATION

Urban centre	1977 Census population	1990 projected population
Mzuzu	16,100	34,000
Karonga	12,100	23,000
Mzimba	5,400	10,000
Rumphi	4,000	7,000
Chilumba	3,900	7,000
Nkhata Bay	4,000	6,500
Chitipa	3,100	5,500
Katete	1,500	2,500
Loudon	1,500	2,500
Chinteche	1,200	1,900
Edingeni	500	800
Ekwendeni	500	800
Euthini	500	800
Northern Region	54,300	102,300
Lilongwe	98,700	217,200
Kasungu	6,500	13,000
Nkhotakota	10,300	16,000
Salima	4,700	10,000
Dedza	5,600	10,000
Mponela	3,400	6,000
Ntcheu	3,100	5,500
Dwangwa	2,000	4,000
Dowa	2,000	3,500
Mchinji	2,000	3,500
Nambuma	1,800	3,000
Nathenje	1,800	3,000
Madisi	1,700	3,000
Namitete	1,700	2,600
Ntchisi	1,700	2,500
Chipoka	1,600	2,500
Kasiya	1,300	2,100
Mkanda	1,000	1,600
Sharpevale	1,000	1,600
Central Region	151,900	310,600

(Continuation) TABLE 1.4

Urban Centre	1977 Census population	1990 projected population
Blantyre	219,000	557,800
Zomba	24,200	52,000
Nsanje	6,400	11,000
Balaka	5,600	11,000
Ngabu	4,800	8,500
Liwonde	3,700	7,000
Luchenza	3,400	6,500
Thyolo	3,900	6,500
Monkey Bay	3,200	5,500
Chikwawa	3,000	5,500
Mulanje	3,000	5,500
Mangochi	2,800	4,500
Nchalo	2,600	4,500
Bangula	2,300	4,500
Mwanza	2,400	4,500
Domasi	2,000	3,000
Namwera	1,700	2,600
Mpemba	1,500	2,500
Phalombe	1,200	1,900
Machinga	1,000	1,600
Neno	1,000	1,600
Namadzi	800	1,300
Lirangwe	700	1,100
Chiradzulu	600	1,000
Southern Region	300,800	711,400
National	507,000	1,124,300

CHAPTER 2

GEOLOGY AND GEOMORPHOLOGY

2.1 GEOLOGY

2.1.1 Introduction

The greater part of Malawi is underlain by crystalline metamorphic and igneous rocks of Precambrian to Lower Palaeozoic age referred to as the Basement Complex (Figure 2.1 and Table 2.1). These rocks are overlain unconformably by younger sedimentary and volcanic rocks which are mainly found in small outcrops in the north and south of the country. They include the Permo-Triassic Karoo sedimentary series, Jurassic Karoo Stormberg volcanics, and Cretaceous to Pleistocene sedimentary beds. Intrusive rocks of Jurassic-Cretaceous age occur at several locations in southern Malawi and are assigned to the Chilwa Alkaline Province. Along the lakeshores and large parts of the Shire Valley the bedrock is covered by unconsolidated Quaternary alluvium.

A summary of the geology of Malawi is given by Carter and Bennett (1973) and this has especial relevance to this report. Geological maps covering most of the country at a scale of 1:100,000 (some 40 in total), have been published by the Geological Survey (G S) and these are each accompanied by a bulletin giving local geological details. In addition there are some other G S bulletins which deal with specific aspects of the geology of Malawi. A general geological map at a scale of 1:1,000,000 was issued in 1966 although this has been updated for the Atlas of Malawi (in Press).

2.1.2 Geological history and structure

The Basement Complex rocks have been subjected to several phases of deformation and metamorphism affecting large tracts of Africa (Cannon et al, 1969). The Rusizi-Ubendian orogeny affected the extreme north of Malawi and this was followed by the Irumide orogeny, also affecting the north of the country. The later Mozambiquian orogeny affected a vast area, with high grade metamorphism in the south of Malawi together with brittle deformation of already metamorphosed rocks in the north. Structural trends therefore follow several directions, the most common being NW-SE and NNE-SSW. The strata are generally folded isoclinally, often intensely and are usually steeply dipping. Igneous intrusions occurred at various stages during these orogenies.

FIGURE: 2.1 GEOLOGY

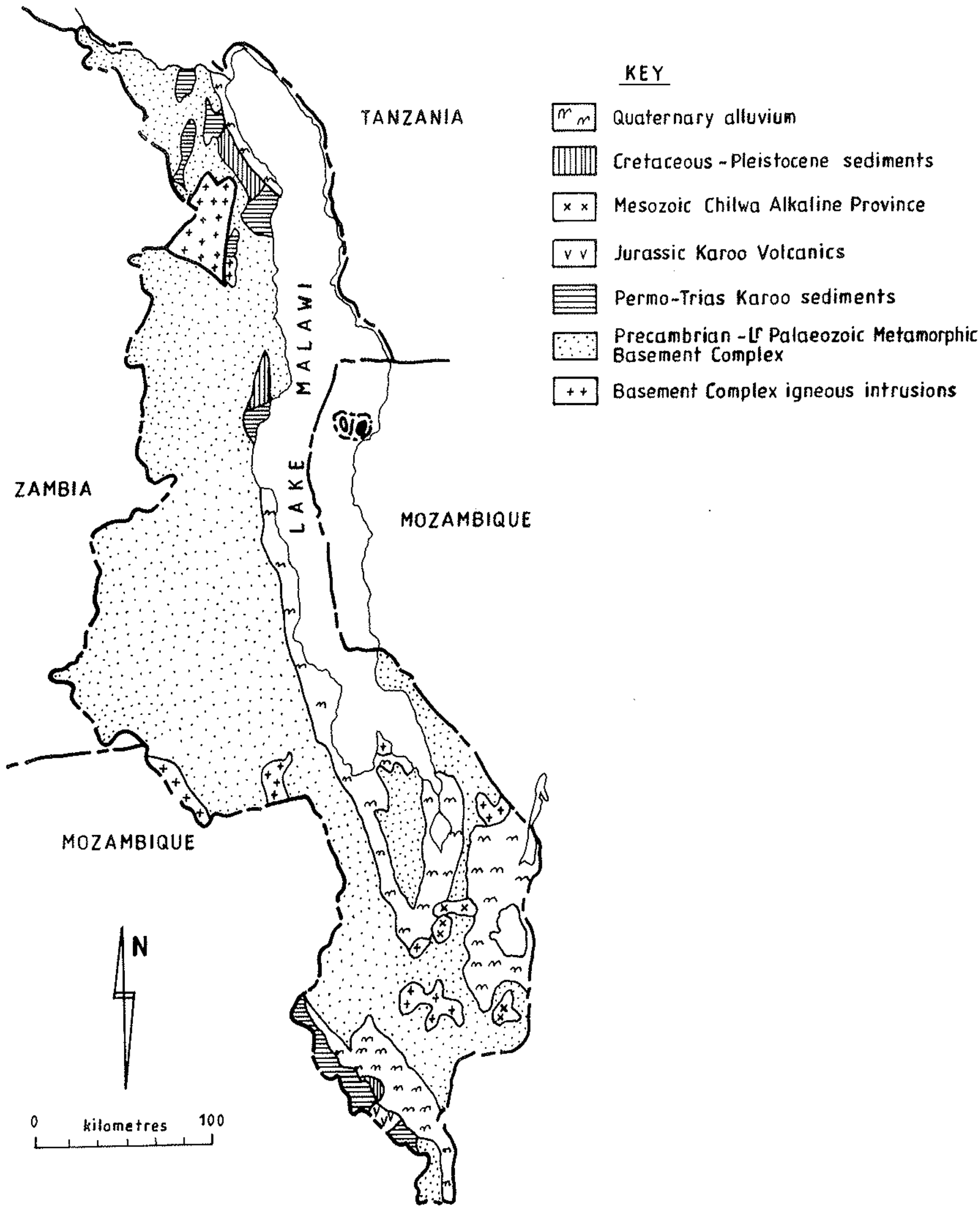


TABLE 2.1 GEOLOGICAL SUCCESSION

Age	Formation	Dominant lithologies
Quaternary	Alluvium	clays, silts, sands and occasional gravels
Cretaceous to Pleistocene	Sungwa, Chiwondo and Chitimbe beds Dinosaur beds Lupata series	sandstones, shales, marls and conglomerates
Jurassic	Chilwa Alkaline Province	syenite-granite plutons
Jurassic	Karoo Stormberg volcanics	basalt
Permo-Triassic	Karoo sedimentary Series	sandstones, conglomerates, shales with coal seams
Precambrian-Lower Palaeozoic	Basement Complex	gneisses and granulites with granite and syenite intrusions

The post Basement Complex structural history of Malawi has been dominated by crustal warping and orogenic movements, interspersed with periods of prolonged erosion, and peneplanation. Several distinct erosion surfaces can be distinguished at different topographic levels (Lister 1967) :

a) the Gondwana and post-Gondwana erosion surfaces of Jurassic-Cretaceous age are found as remnants at the summits of the highlands reaching altitudes of 2,000-3,000m above sea level (see section 1.3.1).

b) the African surface of late Cretaceous-Miocene age lies at altitudes of 900-1300 m above sea level and forms the very extensive 'plateau areas'. These old shield surfaces extend into Zambia, Mozambique and Tanzania.

c) the post-African surface of the lakeshore plain is a Quaternary age surface, lying at altitudes of 475-600 m along the shores of Lake Malawi in the bottom of the rift valley. The plains of the Lower Shire Valley are also surfaces developed on the rift valley floor.

The most imposing structural feature is the rift valley. This was formed by down-faulting during the late Mesozoic and Cenozoic and remains seismically active today. Even the Quaternary alluvium has been affected by faulting. The rift valley is one of the southern limbs of the extensive East African Rift System, which runs in a discontinuous fashion through Africa from the Zambezi River to the Red Sea. In Malawi, it is a single linear zone of extensive "en echelon" down-faulting, occupied by Lake Malawi, Lake Malombe, and the River Shire. The major faults trend N-S or NNW-SSE and most of them show normal displacement. There is also associated upwarping and tilting of erosion surfaces at the top of the rift valley escarpment. The post Basement Complex sedimentary sequences were probably deposited in a series of tectonically-controlled basins which have been affected by subsequent warping, faulting and erosion. The most recent Quaternary alluvial material has been deposited in the bottom of the rift valley and lies unconformably on older strata.

2.1.3 The Basement Complex

The Basement Complex comprises mainly gneisses and granulites which have been highly metamorphosed and deformed. Biotite and hornblende gneisses are most commonly encountered, although other rock types are often interbanded with them.

These include various other types of gneisses (for example quartzo-feldspathic and calc-silicate gneisses), granulites, schists, quartzites and marbles. The gneisses are commonly rich in graphite and frequently also contain sulphide minerals, notably pyrite and pyrrhotite. A sedimentary origin for most of these gneisses is likely (Bloomfield, 1968). Mineral sizes vary from fine to coarse, however the recrystallisation during metamorphism results in low primary porosity and permeability.

The Mafinga and Mchinji groups (in the north and west respectively) are low-grade metamorphic rocks which originated as mudstones, sandstones and conglomerates; these occasionally have cross-bedding and other sedimentary structures preserved in them. Various intrusions are associated with the Basement Complex. These include the Nyika granite in the north, the Dzalanyama granite on the western border with Mozambique and the Lake Malawi Province granites and syenites at Senga Bay, Cape Maclear and Likoma Island. Syenites are found near Blantyre, Dedza, East of Lake Malombe and in numerous smaller outcrops. The Basement Complex rocks are also often cut by a variety of minor intrusives including pegmatite veins and dolerite dyke swarms.

2.1.4 The Karoo sedimentary series

The Karoo sedimentary rocks outcrop in the north of the country in a number of N-S trending basins, and on the SW side of the Lower Shire Valley. They lie unconformably on, or are faulted against the underlying Basement Complex. The basal beds of the succession are conglomerates and sandstones, which are overlain by sequences of sandstones, mudstones, shales and coal seams. The upper part of the succession comprises grits, arkose sandstones, sandstones, shales, mudstones and marls. The sequence is variable and there are significant lateral facies changes from basin to basin. The upper sandstones and marls become increasingly red in colour. The Karoo sediments are well cemented by calcite and indurated; the primary porosities are thus low, and any more permeable horizons are related to secondary fracturing or enlargement along the well developed bedding planes. In the south, the thickness of the sequence has been estimated as exceeding 3,500 m (Bradford 1973), and Karoo sediments probably underlie much of the Lower Shire alluvium.

2.1.5 The Karoo Stormberg volcanics

The Stormberg Volcanics represent the upper part of the Karoo system, and outcrop on the SW side of the Lower Shire Valley. They comprise a series of basaltic lava flows with occasional thin bands of tuff and sandstone (Habgood, 1963). They are most permeable in the more porous layers between successive lava flows.

2.1.6 The Chilwa Alkaline Province

The Chilwa Alkaline Province of southern Malawi consists of a number of syenite and granite intrusions and various minor dykes and volcanic vents. The most important intrusions are the Zomba and Mulanje plutons, however they have little hydrogeological significance because of the steep slopes, low primary porosity, low permeability and poorly developed weathered zone.

2.1.7 The Cretaceous to Pleistocene sediments

Small outcrops of sedimentary rocks occur in several narrow, elongated rift basins, parallel to the lakeshore in the north of the country. These consist of friable sandstones, unconsolidated sands, sandy marls, clays and conglomerates. There is also a small outcrop of a sedimentary sequence overlying the Karoo Series in southern Malawi. This is reported to be mainly desert sandstones with abundant traces of evaporites within a calcareous matrix. Porosities and permeabilities are likely to be relatively high.

2.1.8 The Quaternary alluvium

Deposits of colluvial, fluviatile and lacustrine type are well developed along the shores of Lake Malawi (particularly near Karonga and between Nkhotakota and Salima) and also around Lake Malombe and Lake Chilwa. There are also extensive alluvial deposits in the Upper and Lower tracts of the Shire River Valley and in the Bwanje Valley.

The alluvial sequences lie unconformably on older strata and the junction is often fault-bounded. The deposits are unconsolidated and have been formed by deposition from rivers debouching from the rift escarpment and, along the lakeshores, also from lacustrine sedimentation. The deposits interdigitate therefore, and the resulting sedimentary successions comprise highly variable sequences of clays, silts, sands, and occasional gravels. There are considerable areal differences in the occurrence of sand and clay over short distances because of the complex nature of alluvial deposition in outwash fans, river channels and flood plains. The overall impression is one of fine grained sediments predominating in most areas. The sediments would be expected to be coarsest at the edge of the escarpment, becoming finer down gradient, but the lithological data for existing boreholes is not good enough to confirm this. The mineralogy of rock fragments in the alluvium show that the deposits have been derived from the strata at the sides of the rift valley.

The sediments in the Lake Chilwa Basin appear to be dominantly very fine-grained; this is probably related to the very low energy environment of deposition with internal drainage to the lake. One would expect that there may be some coarser sediments derived from Mulanje or Zomba Mountains deposited in river channels, but these are not apparent from lithogical records for existing boreholes except in Domasi Valley where there are some coarse sands.

Along Lake Malawi the thickness of the alluvial sediments is very variable due to the uneven surface of the underlying bedrock but, in general, appears to increase towards the lakeshore, where thicknesses of over 60 m have been recorded. The Bwanje Valley and Upper Shire Valley both have thicknesses of alluvium commonly 40-80 m deep in the centre of the valleys. In the Lower Shire the thickness of alluvium varies from zero to over 150 m, with the deepest parts of the basin occurring on the eastern side of the valley. The full thickness of the sequence in the centre of the basins is unknown because boreholes do not penetrate to the bedrock beneath.

2.2 WEATHERING OF BASEMENT COMPLEX ROCKS

Weathering is the breakdown or decomposition of rocks which can take place by both chemical and physical processes. There are many factors affecting the type and extent of weathering, including climate, geology, topography, vegetation and time. In tropical zones, chemical weathering is usually dominant, and the development of a thick weathered zone (saprolite) is common. The high temperatures allow relatively rapid chemical reactions, and infiltrating water allows the removal of soluble weathering products and acts as a reagent for further chemical weathering. The processes operate near the surface, and considerably alter the water-bearing character of the upper layers of rock. This has a profound influence on the occurrence and availability of groundwater (see section 3.1.).

The majority of rock-forming minerals are silicates, such as ferro-magnesian minerals, micas and feldspars which decompose to form various clay minerals. There are pronounced differences in the rate of breakdown of individual minerals. Quartz is an exception in that it is resistant to chemical decomposition and persists as a residual primary constituent.

The textural nature of the weathered zone depends very largely on the parent rock composition and the crystal type and size. The weathered basement can be broadly considered as one aquifer regardless of parent lithology as the finalweathering products for gneissic and granitic rocks are always clay minerals with residual quartz fragments. However the best aquifers appear to be found where the parent rock contains abundant quartz. Metamorphic rocks with a higher proportion of feldspars and mafic minerals, and basic igneous rocks, tend to have poorer water-bearing qualities when weathered because of the greater dominance of clay minerals (Table 2.2). Coarse grained parent materials also appear to give rise to better aquifers than fine grained ones.

Since the saprolite develops "in situ", it is stratified with a distinct sequence of materials which increase in their degree of alteration from the fresh bedrock upwards (see section 3.1.2).

The principal reaction which takes place during chemical weathering is hydrolysis. This involves the replacement of the metal cations in the silicate lattice by H^+ ions, and the combination of these cations with OH^- ions to form soluble products which can be removed from the system by leaching. The most mobile metal cations are calcium and sodium. Potassium and magnesium are also readily mobilised but they commonly recombine to form new clay minerals. The least mobile cations are iron (in a ferric state) and aluminium which tend to remain as residual products as sesquioxides. Detailed descriptions of the chemical reactions which take place are given by Thomas (1966) and Acworth (1981).

Circulating groundwater is a very important reagent of chemical weathering. It provides a source of hydrogen ions and removes the soluble products, which would otherwise build up to an equilibrium condition, inhibiting further chemical breakdown. The depth of the weathered zone and extent of decomposition is thus also related to the amount of rainfall which infiltrates.

The character of the weathered products will depend on the weathering environment. The pH of infiltrating water is usually just less than 7 (slightly acid) due to the presence of dissolved CO_2 derived from the atmosphere and from the organic material in the soil zone. The release of cations during reactions with rock minerals raises the pH of the solutions, but the leaching of cations which combine with OH^- ions generally leaves an excess of H^+ ions giving pH valves commonly in the range 5-7. Acidity is also promoted by the presence of organic acids (principally humic and fulvic acids derived from plant decay). These have a marked effect on the solubility of certain elements released during weathering, particularly iron, which form organic complexes called "chelates". The mobility of iron and some other cations is also affected by the redox potential (Eh) of the groundwater.

TABLE 2.2 <u>WEATHERING OF SOME COMMON METAMORPHIC AND IGNEOUS ROCKS</u>

Parent rock	Texture	Jointing	Weathering products	Depth of weathering	Water bearing capacity
Gneiss	coarse grained	moderate	clay minerals Quartz persists	moderate to deep	good
Schist	foliated	cleavage	clay minerals	deep	poor
Quartzite	fine-coarse grained	strong	mechanical weathering	shallow	poor to very good
Granite & Granodiorite	coarse grained	strong	clay minerals Quartz & some mica persist	deep	good
Syenite	coarse grained	moderate	clay minerals	moderate	poor
Gabbro	coarse grained	little	clay minerals	moderate	poor
Dolerite	fine grained	strong	clay minerals & iron oxides	moderate to deep	poor
Basalt	fine grained	strong	clay minerals & iron oxides	moderate to deep	poor

Bioturbation processes can contribute significantly to the weathering and further breakdown of rock material especially in the soil zone and upper layers of the saprolite. The mixing and reworking of soils by termites over a long period is considered by some writers to result in the formation of "stone lines". These comprise mainly quartz fragments which cannot be moved and tend to accumulate at the base of the soil zone. They are commonly seen in latosol profiles on the old erosion surfaces of the plateau areas where these are exposed in roadside cuttings.

The presence of faults and dykes tends to allow greater access of groundwater to the rock surfaces and hence deeper weathering. The original joint spacing in the parent rock is also an important factor controlling the ease with which water can obtain access to the rock surfaces, and is thus a determinant of the depth and rate of weathering. The size and spacing of subsequent joints formed as a result of pressure release appears to be a complex interaction between rock chemistry and crystal size (Acworth, 1981). Gneisses tend to form a large number of closely spaced joints, and chemical weathering is rapid. A granite tends to form joints at more widely spaced intervals with larger fracture blocks which are broken down more slowly by chemical weathering. The higher proportion of minerals more resistant to chemical breakdown also retards chemical breakdown. As a result granites tend to form inselbergs. Schists tend to break down most rapidly of all the Basement Complex rock types because joint blocks do not form at all, and the microfissuring between adjacent crystals opens up a very large surface area which is susceptible to chemical weathering. A small variation in feldspar chemistry may result in a large change in the density of jointing and therefore weathering rate.

The rate of weathering is also controlled by the thickness of weathering products; thus on the broader flat interfluves and gently slopes of the plateau areas, where the saprolite is thick and its rate of removal is very low, the rate of weathering of bedrock at depth will be low. By contrast, in areas which are more dissected and slopes are steeper, for example on the escarpment zone, the rate of weathering may be higher. This in turn is in equilibrium with the rate of removal by erosion, which is also higher, thus the slopes continue to be denuded.

The saprolite thickness can therefore be broadly related to topography with negligible weathered zones on steep inselberg slopes, moderate weathering on the gentle slopes, and deeper weathered zones on the flatter interfluve sites and also suspected to occur under some flat valley floors. It should be noted that where there has been rejuvenation, part or all of the weathered zone is likely to have been eroded away, and in places outcrops of bedrock can be seen.

CHAPTER 3

HYDROGEOLOGY

3.1 OCCURRENCE OF GROUNDWATER

3.1.1 Introduction

There are two main aquifer types in Malawi:

a) the extensive, but relatively low-yielding, weathered basement aquifers of the plateau

b) higher-yielding alluvial aquifers of the lakeshore plains and the Shire Valley

There are several other geological sequences which may yield groundwater but their extent is small and/or their yields unreliable.

3.1.2 The weathered basement aquifers

The prolonged in situ weathering of the crystalline basement rocks has produced a layer of unconsolidated saprolite material (see section 2.2.1) and it is this which forms an important source for rural domestic water requirements.

The weathered zone is best developed over the plateau areas where it is commonly 15-30 m thick, and locally even thicker. Towards the crests of the escarpment, the uplift associated with the development of the rift valley has resulted in rejuvenation of the rivers and increased erosion, and thus the thickness of the weathered rock aquifer tends to be reduced in these areas. It also thins towards bedrock outcrops. The saprolite thickness tends to be greatest along fracture zones.

A relatively thick weathered zone may also have built up in the Basement Complex rocks at the bottom of the rift valley; this is sometimes exposed in a zone between the base of the escarpment and the junction with the overlying alluvial sediments.

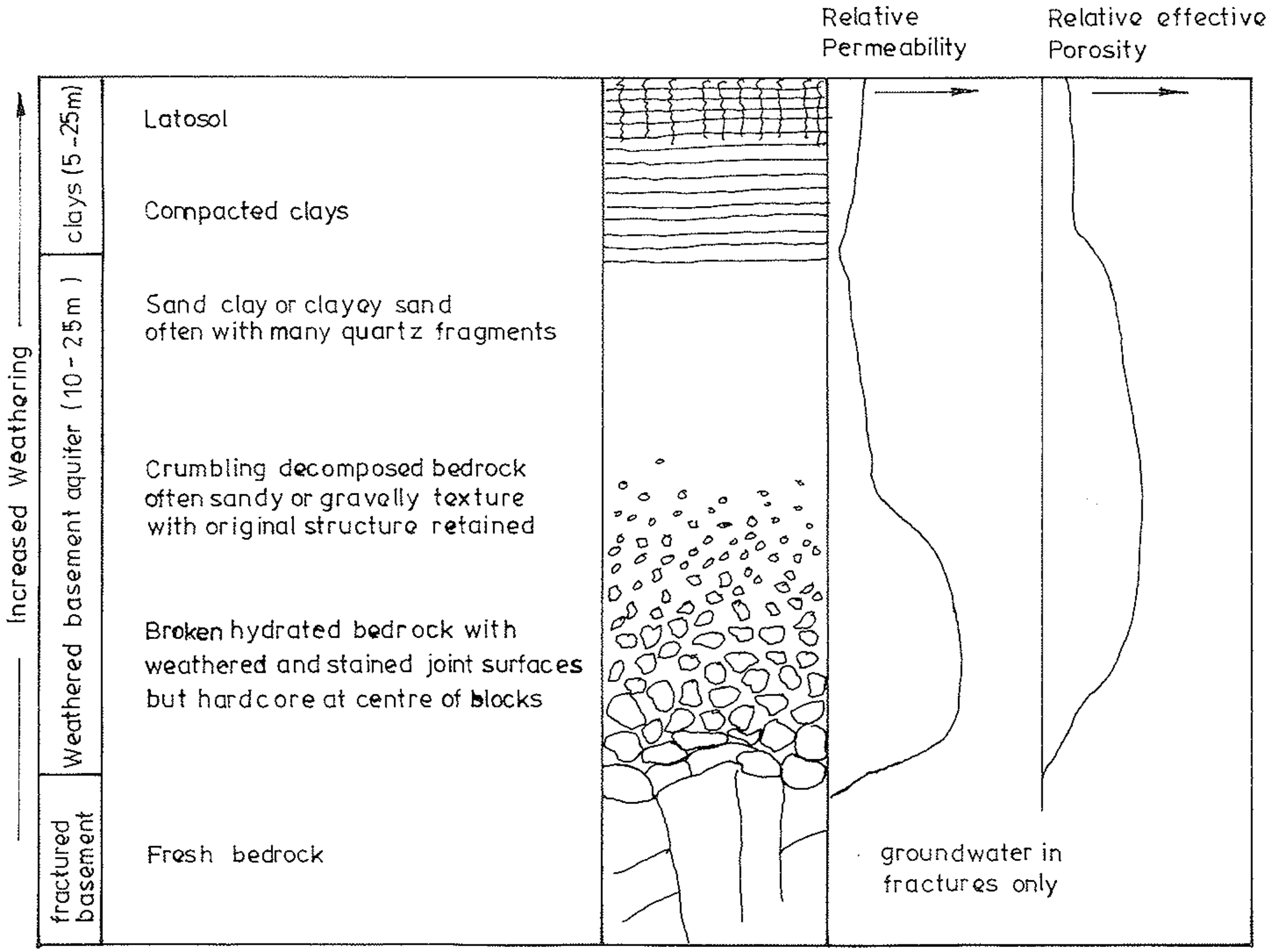
Relatively thick weathered zones are also found on some block-faulted shelves on the rift valley escarpments, for example, the Upper Livulezi Valley shelf. It is possible that there might be significant thicknesses of saprolite on the flatter surfaces on some of the highlands, for example there are bauxite deposits on parts of Mulanje Mountain, but these areas are virtually unpopulated, so the demand for groundwater development is negligible .

When exposed, for example in roadside cuttings, remnants of veins can be seen extending from fresh bedrock up to ground level confirming that the material is "in situ". Relict structural features, for example fractures, are also preserved. The aquifer appears to be more or less continuous, although it can be very heterogeneous in texture even over short distances.

The degree of alteration and unconsolidation increases progressively upwards from the fresh unweathered bedrock. In detail, the character of the weathered zone varies with the parent rock type and texture, and the topography (see section 2.2.1). There can be considerable spatial variability in texture and the more permeable horizons may only have limited lateral extent. The coarser grained parent materials give rise to the best aquifers as they decompose to a more permeable sandy texture.

Most of the lithological logs from old drilling records are very poor with little differentiation of the variable materials within the sequence. Where detailed lithological logs exist, it is clear that a generalised weathered-rock profile can be given (Figure 3.1). Above the hard fresh bedrock there is a zone of broken and hydrated rock where the joint surfaces are chemically weathered but the centres of the blocks remain fresh and unweathered. The first signs of weathering are often brown limonite stains on otherwise fresh surfaces, but gradually the blocks become more weathered around the edges leaving a hard corestone at the centre. This grades into a zone of crumbling and decomposed bedrock which retains the original rock structures such as quartz veins and joint surfaces. Partly decomposed feldspar crystals can often be observed. These lower layers, which are often of sandy or gravelly texture, usually have the highest permeability and effective porosity, especially where the clayey material has been removed or redistributed by groundwater as it is formed. Above, there are commonly pale brown clayey sands or sandy clays, often with many small loose quartz fragments and mica flakes. This whole sequence makes up the aquifer and is commonly 10 to 25 m thick. The aquifer is partly confined by an overlying thickness of 5 to 20 m of red brown clays and latosols, the final products of complete weathering. These surface layers are usually very tightly compacted and have very low permeability.

FIGURE 3.1 TYPICAL PROFILE OF WEATHERED BASEMENT AQUIFER



Groundwater is commonly first struck near the base of the clays, and usually rises (sometimes by several metres) before rest water level is found. The saturated thickness of the aquifer will be a critical factor in determining whether sufficient yields can be supplied, even for rural domestic supplies for handpumps. As a guide, a minimum saturated thickness of 10 m has been taken as a design figure for rural water supply boreholes in the integrated groundwater projects (see section 4.3.3). Where the weathered zone is too thin, or the depth to water is too great (even where there is a deep weathered zone), potential yields are likely to be insufficient. Another important factor is the permeability of the saprolite; even if there appears to be a sufficient saturated thickness of weathered material, a very clay-rich sequence may result in very low permeability and inadequate borehole yields.

Laterites, which are iron oxide-rich layers, are commonly found in weathered bedrock profiles especially where the water table is high and the fluctuations of water level are conducive to its formation. On better drained sites the laterites tend to be indurated and on higher topographic sites they are usually found lower in the profile. Fossil laterites may be found anywhere, even on the interfluve crests. These indurated layers have very low permeability and porosity and thus tend to impede infiltration. Where they are massive and at shallow depth, infiltrating rainfall will tend to be impeded and be discharged as interflow along the top of the laterite layers, unless they are discontinuous or fractured.

Dug wells can be constructed in the semi-confining clays in the valley bottoms; these require sufficient storage within the well for daily use because the low permeability of the clays results in slow rates of refill. The clays are considered to be in hydraulic continuity with the more permeable aquifer material below, and allow slow vertical percolation of water.

The weathering profiles in the dambo areas are largely unknown, and thought to be highly variable depending locally on the various stages of aggradation and erosion in the genesis of the drainage system. Bedrock is seen to outcrop in some sections with well defined channels, yet other dambo areas are thought to be underlain by relatively thick weathered zones, together with some sandy colluvial deposits transported downslope. Dug wells on dambo margins in the Central Region plateau areas show that the sequence is sometimes fresh bedrock directly overlain by thick clays of very low permeability. The sequence is likely to vary even within a single dambo, with changes observed down its length.

In the pediment areas surrounding the uplands rising from the plateau, there may be coarser colluvial material which has been transported downslope. The thickness and lateral extent of these deposits is not well known, but the potential groundwater yields and recharge from surface run off are likely to be relatively high due to the coarser and more permeable nature of the sediments (unless they are very poorly sorted).

3.1.3 The unweathered fractured basement aquifers

The fresh bedrock underlying the weathered zone is rarely a significant aquifer, except where extensively fractured, as the available storage is negligible in the rock matrix and likely to be low in the fractures. Although there are many old boreholes which have been drilled to considerable depths into fresh bedrock on the plateau areas (often reaching 50-70 m) these rely largely on storage in the overlying weathered zone.

Outcrops of fresh rock are found in the escarpment zone, and also where the rocks (usually igneous intrusions) are more resistant to erosion and remain as uplands (for example Mulanje Mountain, Zomba Mountain and Nyika Plateau) or inselbergs. In these areas, both the soil cover and the weathered zone are thin because they are removed by erosion as they develop. Only the lower horizons of saprolite will be preserved. The groundwater storage relies entirely on secondary porosity in fractures which is generally very low.

There is generally low potential for groundwater development in the escarpment zone except very locally when boreholes intersect a well-connected fracture system where flow velocities may be high; however yields are likely to be unreliable because of the low storage. Initially high-yielding boreholes may well decline rapidly in performance because of depletion of groundwater resources; surface runoff from the steep slopes is high and recharge is not dependable. Aquifers are poor and discontinuous, and yields are likely to be unreliable even where fracture traces can be located.

3.1.4 The Karoo sedimentary aquifers

The sedimentary sequences of the Karoo Series are thought to be extremely thick, but the strata are generally strongly cemented by calcite which has resulted in a considerable reduction in primary porosity and permeability (Bradford, 1973). According to the drilling records, the sandstones do not appear to weather much on exposure and groundwater storage is likely to be largely determined by the extent of secondary fissuring and enlargement of joints and bedding planes. These aquifers tend to outcrop in hilly areas which are sparsely populated and are not very suitable for cultivation, so they have not been well developed. There is little hydrogeological data available for the aquifers in the north of the country and only scant information on those in the south (Lockwood, 1970; Bradford, 1973).

The Karoo sequence in the south has been affected by extensive faulting which may either form groundwater boundaries, or alternatively could locally increase the secondary porosity and borehole yields. In the Lower Shire Valley the depth to water is often 20-30 m below ground level, depending on the elevation of the land surface. Borehole yields are generally low and unreliable and some boreholes have been abandoned because of poor production rates. The National and Shire Irrigation Study (1980) considers that the aquifer is likely to behave in a confined manner because of the intense stratification.

3.1.5 The Karoo Stormberg volcanic aquifer

The Stormberg basalts of the Lower Shire Valley are locally water bearing in the more porous and permeable horizons between successive lava flows. The most productive layers are found nearest the ground surface in the zone of maximum groundwater circulation, and deeper zones tend to have porosities reduced by infilling with clay weathering products.

There are several productive boreholes for rural domestic supplies, and these have a wide range of test yields due to the very variable nature of the aquifer (0.25-2 l/sec).

3.1.6 The Cretaceous to Pleistocene sedimentary aquifers

These sedimentary sequences are not very significant in terms of areal extent, and little is known about their hydrogeology. They are thought to be only lightly-cemented with relatively high porosities. Thus, where they are sandy or gravelly, permeabilities should be high and yields should be good wherever they are saturated. Poor quality water however may restrict the use of the aquifers. The outcrop in the Lower Shire Valley has saline groundwater, caused by the solution of calcareous and evaporite minerals in the matrix.

3.1.7 The alluvial aquifers

The alluvial aquifers are fluvial and lacustrine sediments which are highly variable in character both in vertical sequence and lateral extent (see section 2.1.8). They occur in several basins which, apart from Lake Chilwa, are all located along the rift valley floor :-

a) Salima - Nkhotakota Lakeshore

b) Karonga Lakeshore

c) Bwanje Valley

d) Upper Shire Valley

e) Lower Shire Valley

f) Lake Chilwa Basin

There are many boreholes which have been constructed in the alluvial areas, but the geometry of the basins is not well understood, because many of the boreholes do not penetrate the full thickness of alluvium. The maximum thicknesses are probably closest to the lakeshore and in the centre of the alluvial valleys (see hydrogeological maps).

Most lithological records from boreholes give little detailed information on the successions. The overall impression is that clays usually dominate the sequence, and although it is clear that in many localities there are significant thicknesses of sands, these are often poorly sorted. The sedimentary environments likely to produce the highest groundwater yields will be the buried river channels and the littoral (beach and dune) zones of the lakeshore where the deposits are usually coarser grained and well sorted. There may be relatively high yields from some of the coarser outwash fans at the base of the escarpment, although these are often poorly sorted. The deposits interdigitate, and the distribution of the most permeable material within each basin is likely to be complex. The water-yielding strata may comprise most of the succession or could, in some cases, be negligible. Where there are thick clay sequences the aquifers will be semi-confined. Near the base of the escarpment, where the alluvium is thin, groundwater may be derived mainly from the underlying weathered basement aquifer where this is present and in hydraulic continuity with the alluvium. It may be difficult to differentiate between alluvium and weathered basement from the drilling records and in many cases only the lithological boundary with the underlying hard fresh bedrock will be noted.

The Lake Chilwa Basin is somewhat different from the other alluvial areas in that it is not in the bottom of the rift valley, but perched on the eastern side of it. The lithological records from boreholes are poor but suggest that much of the succession is clayey. Two exploratory boreholes drilled for the National and Shire Irrigation Study (1980) penetrated predominantly clay successions, and both were abandoned due to lack of suitable aquifer material and very low yields. It is thought that the fine-grained lacustrine sediments in this basin have been deposited in a very low energy environment, possibly under reducing conditions. There are some occasional occurrences of sands and gravels found in buried river channels, for example in the Domasi Valley, which have produced the highest groundwater yields.

3.2 AQUIFER PROPERTIES

3.2.1 Introduction

Although some information exists for many of the boreholes drilled in Malawi, the records are often insufficient to give more than a crude estimate of aquifer properties. Very few boreholes have been test pumped with detailed monitoring of groundwater levels, and virtually all of these only have measurements within the pumping borehole itself.

Estimates of aquifer properties using tests from old-design boreholes may be very misleading; Figure 3.2 shows that there is a great contrast in borehole performance between those of the old design and those which have been properly designed (see section 4.3.3).

The aquifer properties appear to be extremely variable, often over very small vertical and lateral distances, depending on such factors as the lithology, degree of weathering, thickness of the aquifer material and geological structure.

Very few records of any kind exist for the dug wells, although local information suggests that yields and permeabilities of the clays in the dambo areas of the weathered basement are very low. Some of the wells constructed in these clays regularly dry up during use, because they refill only very slowly and are not deep enough to provide sufficient storage.

3.2.2 Borehole yields

Records of borehole yields are at best the result of short term test pumping by the drillers (commonly 5 hour tests but sometimes 12 hour tests), but for the older boreholes the only indication may be a drillers "recommended yield", the reliability of which may be rather dubious. In many cases the drawdown is not measured, and the test yield gives the only indication of aquifer performance. The drillers "recommended yield" is nearly always the same as the test yield, regardless of whether the discharge rate was clearly too high (with drawdown very quickly to the pump suction) or whether the discharge rate was much less than the productive capacity of the borehole (with very small drawdown during the test). In cases where the drawdown is very large, the initial discharge rate often cannot be maintained because of the reduction in transmissivity as the aquifer is dewatered.

The records show uniformly low yields (mostly less than 2 l/sec) for entirely different aquifers (Table 3.1). It is suspected that these reflect the poor borehole design which has been the same for all hydrogeological conditions. In many boreholes the productive horizons may have been cased out. (See section 4.3.2. The poor construction practices result in high

FIGURE 3.2 COMPARISON OF BOREHOLE PERFORMANCE FOR OLD DESIGN AND PROPERLY-DESIGNED BOREHOLES

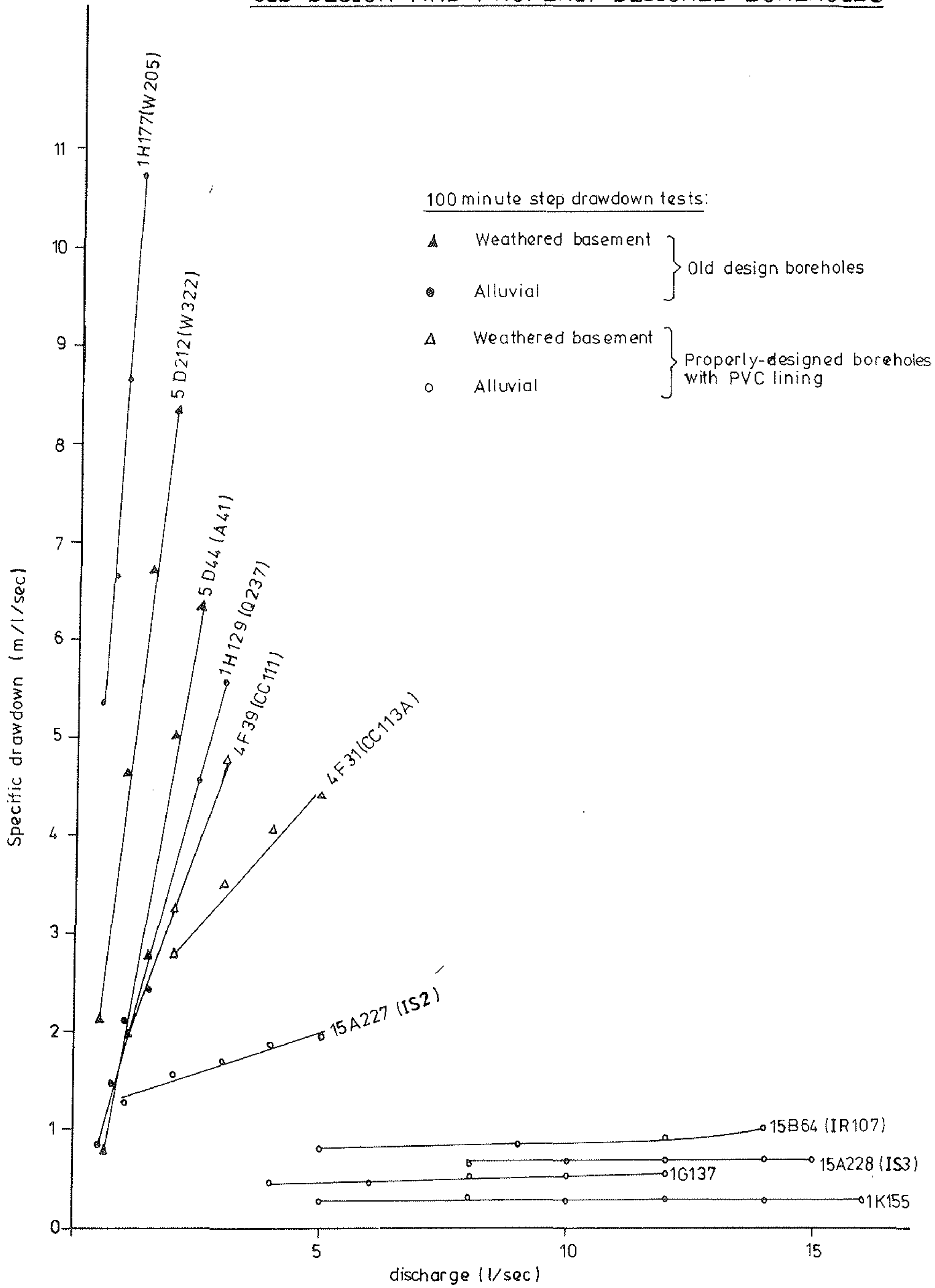


TABLE 3.1 AVERAGE BOREHOLE YIELDS

Area	Aquifer type	Number of boreholes	Average test yield (l/sec)	Source of data: NSIS, 1980
S. Rukuru	Weathered basement	234	0.76	Wilderspin, 1973
Lilongwe area	Weathered basement	403	1.02	Wilderspin, 1973
Lilongwe area	Weathered basement	600	1.2	Stanley International, 1983
Salima area	Alluvium	240	0.91	Chapusa, 1977
L^r Bwanje	Alluvium	104	1.09	Chapusa, 1977
U^r Bwanje	Alluvium	170	0.82	Chapusa, 1979
L^r Shire	Alluvium	260	0.94	Bradford, 1973

Note:

The table shows uniformly low yields regardless of the aquifer type; this is considered to reflect poor borehole design or pump capacity and not the full productive capacities of the aquifers.

well losses and it is likely that many boreholes are very inefficient. It has been noticed in the Lilongwe area that boreholes constructed since 1973 where the weathered zone has at least been partly screened, have significantly higher yields (mean 1.5 l/sec) (Stanley International, 1983). The low yields may also reflect pump capacity, and some boreholes will not have been tested at full productive capacity. It should be noted that yields are usually quite adequate for rural domestic supplies with hand-pumps which only require 0.25-0.5 l/sec.

In the weathered basement aquifer, yields are generally greatest where the saturated thickness of the weathered zone is greatest and the bedrock coarsest. The best yields are likely to occur where the weathered zone is associated with fractures which commonly allows greater depths of weathering (see section 2.2.1). These zones can sometimes be picked out as lineations on aerial photos. Chilton (1979) showed that for the existing boreholes located close to fracture traces in the plateau area of the Bua Catchment a plot of yield against distance from the trace showed no clear correlation. This may partly be explained by the poor borehole designs, but it is clear that there are many other factors controlling borehole yields. Topographic considerations are also important, and it was shown that of those boreholes situated near the dambo fewer have very low yields (less than 0.25 l/sec) and more have high yields (greater than 2 l/sec) than those situated on the ridges. There is however a wide scatter in the plot of yield against distance from the dambo.

Some authors, notably Gear (1951), have attempted to statistically relate borehole yields to borehole depth in tropical shield areas. A consideration of old borehole construction pratices in Malawi (see section 4.3.2) and many of the neighbouring countries shows that this approach is likely to be inappropriate. In many cases, the belief that the fractured rock was invariably the productive aquifer, without considering the potential of the overlying weathered material, led to the latter being cased out. While correlating yield with depth for boreholes constructed in this way may be possible, it could be misleading because productive horizons at relatively shallow depths may have been ignored.

With improved borehole designs, adequate yields for rural water supplies have been obtained from the weathered basement aquifer from boreholes only 15-25 m deep in the Livulezi Valley Integrated Project and 20-40 m deep in the Dowa West Integrated Project. Yields of 0.25 to 0.5 l/sec can probably be obtained from most of the weathered basement areas, without a geophysical survey for site selection, and with smaller drawdowns as well as the boreholes being shallower and cheaper, provided that there is a sufficient saturated thickness of weathered material. If the weathered zone is thin, or most of it is dry with great depths to water, the potential yields are likely to be lower.

The variation in yield appears to be broadly related to the saturated thickness of the weathered zone. This is clearly the case at Lilongwe International Airport, where three properly designed boreholes produced test yields ranging from 1.5 l/sec to 5 l/sec which could be correlated with weathered zone thicknesses of 20 to 29 m, beneath the confining clays.

The highest yields might be achieved using a collector well system in areas where the weathered zone is thickest and laterals are drilled out in the most permeable material.

On the escarpment and on the steep slopes of the highlands, yields from the fractured basement aquifers are usually low, except where there is extensive fracturing and they tend to be unreliable because of the low storage.

In the alluvial aquifers, yields from existing boreholes are very variable but generally low ; it is suspected that productive zones are often cased out and that some boreholes have not been tested to full capacity. Yields should be greatest where the sedimentary sequences are coarsest and well sorted.

Eight properly-designed boreholes (see section 4.3.3) have been constructed by the Groundwater Project and Shire Valley Agricultural Consolidation Project to determine irrigation potential in some of the alluvial areas of the Salima Lakeshore, Bwanje Valley and Lower Shire Valley (NSIS, 1982). These were tested at yields of up to 15 l/sec, the maximum discharge of the test pump unit (Table 3.4), and it is clear that some of these boreholes could sustain even higher discharge rates (Figure 3.6). Low efficiencies of the old boreholes are clearly masking the true, much higher productive capacities of some of these alluvial aquifers. It should be noted that there were also a number of boreholes drilled for the same irrigation investigations which had to be abandoned because of dominantly fine grained and low permeability sequences and thus low yields. There were two unsuccessful boreholes in the fine alluvial clays of the Chilwa Basin, one in the Bwanje Valley and three abandoned in the Lower Shire Valley due to poor aquifers (four others were abandoned because of logistical difficulties during drilling).

3.2.3 Specific capacity and specific drawdown

The specific capacity (SC), which is the yield per unit drawdown, is a measure of borehole and aquifer performance and can be determined where the final water level has been measured during the test pumping. Records are only available for a limited number of boreholes, and these are not strictly comparable since they are not always for a standard time. Also, the specific capacity is likely to be severely non-linear for different yields, with a larger incremental drawdown for higher discharge rates. Nevertheless, they give a better indication of aquifer and borehole performance than the records of yield on their own.

The results of long term test pumping of some of the higher yielding District Water Supply and institutional boreholes are shown in Table 3.2. These nearly all show low specific capacities, regardless of aquifer type, and this is thought to belargely a result of poor borehole design and consequent low borehole efficiency. There does not appear to be any relationship between specific capacity and borehole depth or aquifer thickness for any of the aquifer types. The specific capacities are so low, especially for the alluvial material, that it is considered that they do not give a realistic estimate of the aquifer potential.

Many other boreholes which have been tested for shorter periods (usually 5 hours) confirm this picture of widespread poor borehole performance regardless of aquifer type. Specific capacities are usually less than 0.2 l/sec/m and large drawdowns of over 20 m are often observed. A statistical analysis of data from the Lower Shire Valley (Mainala, 1982) showed no significant correlation between specific capacity (normalised for variations in borehole diameter and the degree of penetration into the effective saturated zone of the aquifer) and lithology or geomorphological factors.

Multiple-rate step-drawdown tests have been carried out on some of the District Water Supply and institutional boreholes. Those in weathered basement show that at lower discharge rates, the specific drawdown (drawdown per unit discharge) increases gradually with pumping rate. However at higher discharge rates, there is commonly a substantial increase in specific drawdown, and even a "breakaway" where there is a very rapid increase in drawdown for a small increment in discharge (Figure 3.3). These effects are due to a reduction in transmissivity brought about by large drawdowns which result in a decrease in saturated aquifer thickness, and also an increase in well losses if the flow of water becomes non-laminar. Operational pumping rates should be chosen within the range of more linear specific drawdown in order to minimise the pumping costs.

Multiple step tests carried out in old alluvial boreholes show that the discharge/specific drawdown relationships are more linear (Figure 3.4). This suggests that the boreholes may not have been tested to full capacity because of limitations on pumping equipment. If, for example, borehole 1H 129 had additional steps performed at 3.5 l/sec, 4 l/sec and even higher discharge rates, it is possible that the specific drawdown curve would have reached a marked "breakaway" point as the borehole efficiency decreased rapidly with the increasing discharge. Although the observed relationships are fairly linear, the gradients are relatively steep (notably so for borehole 1H 77) which suggests poor borehole performance.

FIGURE 33 100 MINUTE STEP DRAWDOWN TESTS, BASEMENT BOREHOLES (old design)

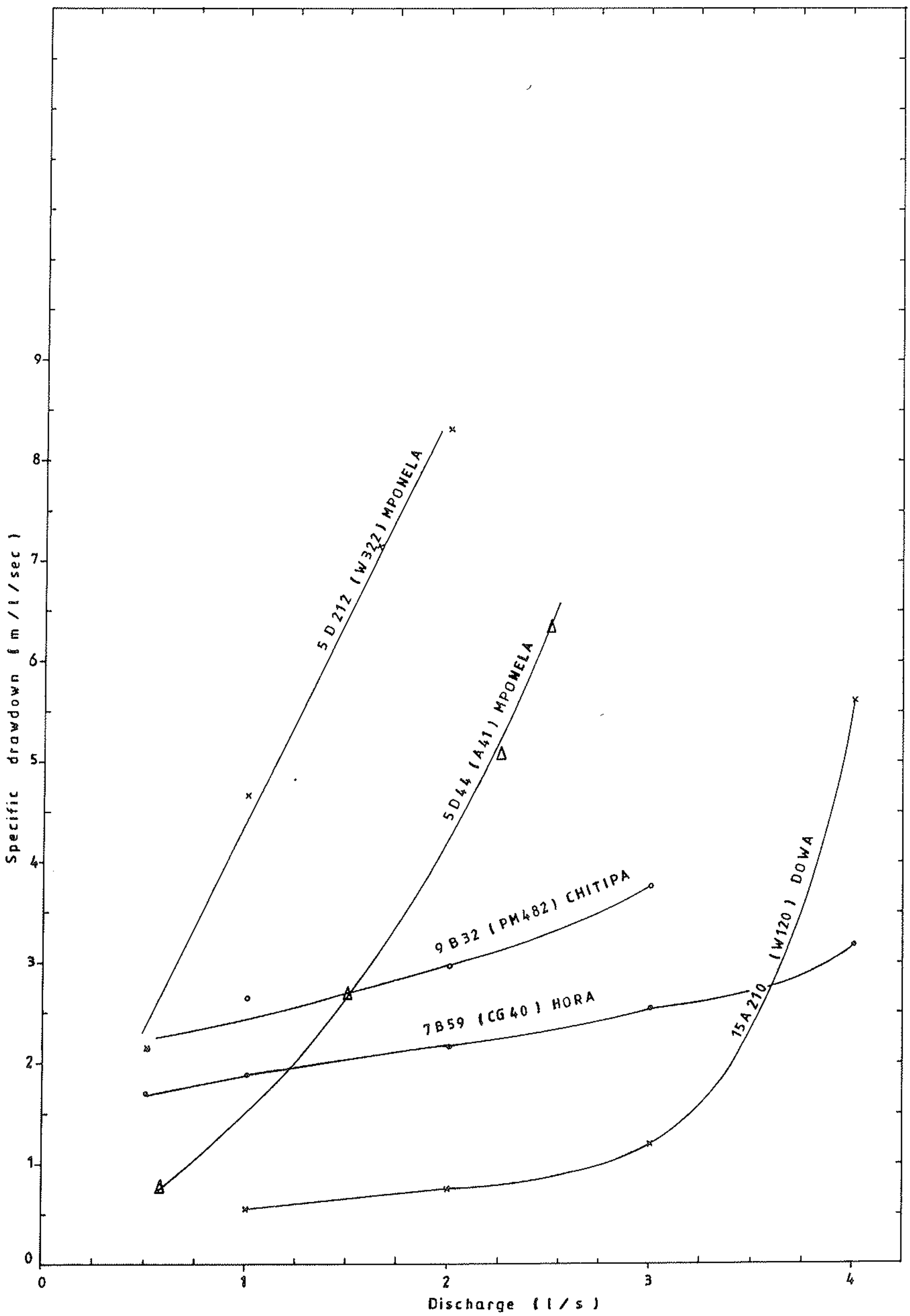


FIGURE 3·4 100 MINUTE STEP DRAWDOWN TESTS IN ALLUVIAL BOREHOLES (old design)

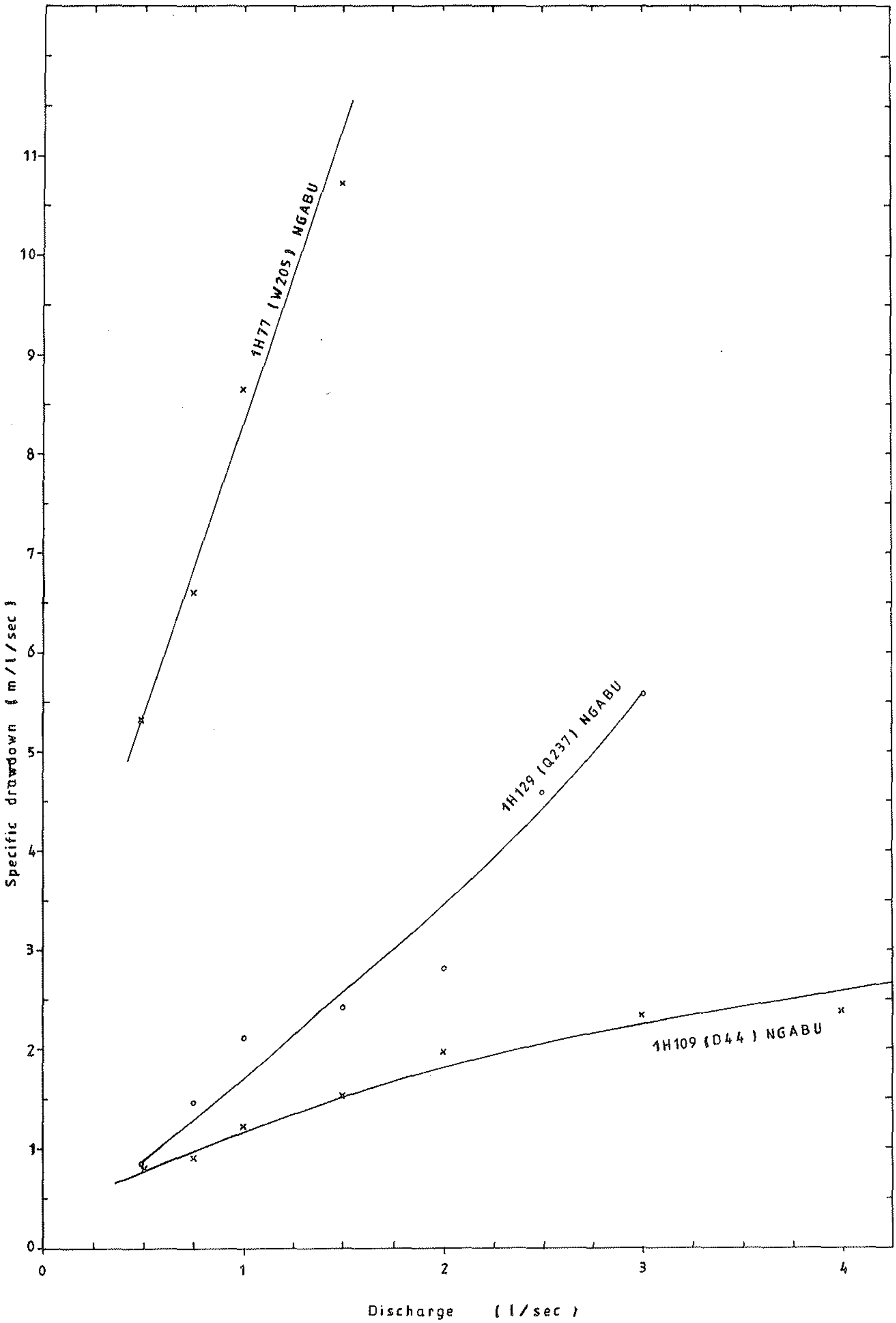


TABLE 3.2 CONSTANT RATE TESTS ON OLD BOREHOLES

Location	Aquifer type	Borehole number	G.S. number	Discharge (l/sec)	Length of test (hr)	Drawdown (m)	Specific capacity (l/sec/m)
Chitipa	WB	9B32	PM482	2.0	72	6.93	0.29
Chitipa	WB	9B68	CC180	1.0	72	14.62	0.07
Chitipa	WB	9B6	H156	0.8	22	13.80	0.06
Chitipa	WB	9B7	H157	1.5	22	15.22	0.09
Hora Farm Institute	WB	7B59	CG40	4.5	72	17.19	0.26
Chiwengo (Nr Kasungu)	WB	5D192	AM15	1.1	29	5.54	0.20
Chiole Mission, Ntcheu	WB/FB	1R129	AM1	1.0	5	27.57	0.04
Chiole Mission, Ntcheu	WB/FB	1R130	AM2	4.0	24	32.55	0.12
Ntcheu Old Hospital	WB/FB	1R84	J101	1.0	8	14.4	0.06
Ntcheu Hospital	WB/FB	1R46	L428	0.58	72	11.34	0.05
Mvera Army Camp	WB/FB	4C96	RK162	0.85	24	16.0	0.05
Mvera Army Camp	WB/FB	4C103	RK161	1.5	24	19.0	0.08
Mponela	WB	5D212	W322	2.0	10	18.18	0.11
Mponela	WB	5D44	A41	2.5	10	15.31	0.16
Mponela	WB	5D224	W176	1.25	5	26.3	0.05
Mponela Road Camp	WB	-	-	1.25	48	17.10	0.07
Dowa	WB/FB	15A210	W120	3.0	4	21.58	0.14
Dowa Red Cross	WB/FB	15A234	-	4.0	72	5.59	0.72
Mpemba	WB	1E72	PM604A	0.75	72	40.23	0.02
Mpemba	WB	1E79	L300A	1.0	24	6.71	0.15
Mpemba	WB	1E1	C162	0.5	24	16.41	0.03
Namwera	WB	11A30	K26	2.0	24	8.10	0.25
Songani	WB	2C22	A21	0.75	72	16.81	0.04

(Continuation) TABLE 3.2

Location	Aquifer type	Borehole number	G.S. number	Discharge (l/sec)	Length of test (h.)	Drawdown (m)	Specific capacity (l/sec/m)
Chiradzulu School	WB	2B220	K2	0.5	25	1.05	0.48
Chiradzulu	WB	2B218	J37	1.25	24	22.91	0.05
Chiradzulu	WB	2B217	J35	1.5	24	33.24	0.05
Thekerani (Lower)	WB/FB	14D28	RK38	0.75	72	21.52	0.03
Chilumba	A	17C46	RK12	0.3	24	19.20	0.02
Chilumba	A	17C47	RK14	0.4	24	16.21	0.02
Salima Militia College	A	15A198	SM361A	1.0	72	3.55	0.28
Salima Militia College	A	15A199	SM362	0.5	72	13.50	0.04
Salima	A	15A212	A57	9.8	15	5.18	1.89
Nkhotakota	A	15B12	W321	3.2	24	4.65	0.69
Balaka	A	1R53	E300	4.0	16	25.64	0.16
Chikwawa School	A	1L10	H164	1.0	24	4.12	0.24
Chikwawa	A	1L6	HD164	2.0	72	6.28	0.32
Chikwawa	A	1L4	T3	0.75	72	3.95	0.19
Chikwawa	A	1L5	HD163A	2.0	72	11.11	0.18
Nchalo Plant 1	A	1H292	RB150	0.5	24	14.85	0.03
Nchalo Plant 2	A	1H291	RB151	3.5	72	19.17	0.18
Ngabu	A	1H109	D44	5.0	72	15.40	0.32
Ngabu	A	1H77	W205	1.25	54	8.56	0.15
Ngabu	A	1H129	Q237	2.75	72	12.51	0.22
Ngabu	A	1H344	A179	1.5	72	17.27	0.09

(Continuation) Table 3.2

Location	Aquifer type	Borehole number	G.S. number	Discharge (l/sec)	Length of test (hr)	Drawdown (m)	Specific capacity (l/sec/m)
Nsanje	A	1G32	T5A	5.0	24	5.15	0.97
Nsanje	A	1G33	T5B	1.5	72	3.82	0.39
Nsanje	A	1G28	K168B	1.1	17	4.27	0.26
Nsanje	A	1G27	K168A	0.6	15	10.61	0.06

Note:

The table shows that specific capacities are usually very low regardless of the aquifer type; this is considered to reflect poor borehole design rather than a true reflection ofaquifer performance.

WB = weathered basement

FB = fractured basement

A = alluvium

Better design can almost certainly improve the borehole performance, which will result in higher specific capacities and more linear, lower-gradient discharge/specific drawdown relationships. Such improvements were confirmed by the testing of properly designed boreholes (Figures 3.2, 3.5 and 3.6 and Table 3.4). This emphasises the dangers of using tests from old boreholes to determine aquifer properties.

The long term behaviour of boreholes in Malawi is poorly documented, and few have been properly test pumped more than once. Those which have been retested usually show significant deterioration of performance with time (Table 3.3), unless the borehole had been redeveloped before testing. The fall in specific capacity could be due to one of several causes:

a) Movement of fine material into the borehole causes infilling and a decrease in the effective depth of penetration of the aquifer. There is much evidence, from maintenance records, of borehole infill by fine material and wear on pump components, especially in alluvial areas. This is generally the result of an ineffective gravel pack in the annulus surrounding the borehole, coupled with large slot sizes in the screen (see section 4.3.3).

b) Corrosion of borehole linings in areas of acid groundwater could result in further ingress of aquifer material or even the collapse of sections of the borehole. Acid groundwater is a relatively common occurrence (see section 3.5) and pump components have to be replaced in some areas every 6-12 months.

c) Incrustation of the gravel pack and screen slots by iron deposits or other materials results in a decrease in permeability. Deposition on the downhole pump components is commonly observed in boreholes in the weathered basement aquifer.

d) Blocking of fractures will cause a decrease in porosity and permeability. A good example of this phenomenon is seen in the fractured basement aquifer at Dowa, where the boreholes are open and do not have any screen, so the deterioration in borehole performance (Table 3.3) is most likely to be caused by the blocking of fractures.

FIGURE 3.5 STEP DRAWDOWN TESTS IN PROPERLY-DESIGNED WEATHERED BASEMENT BOREHOLES

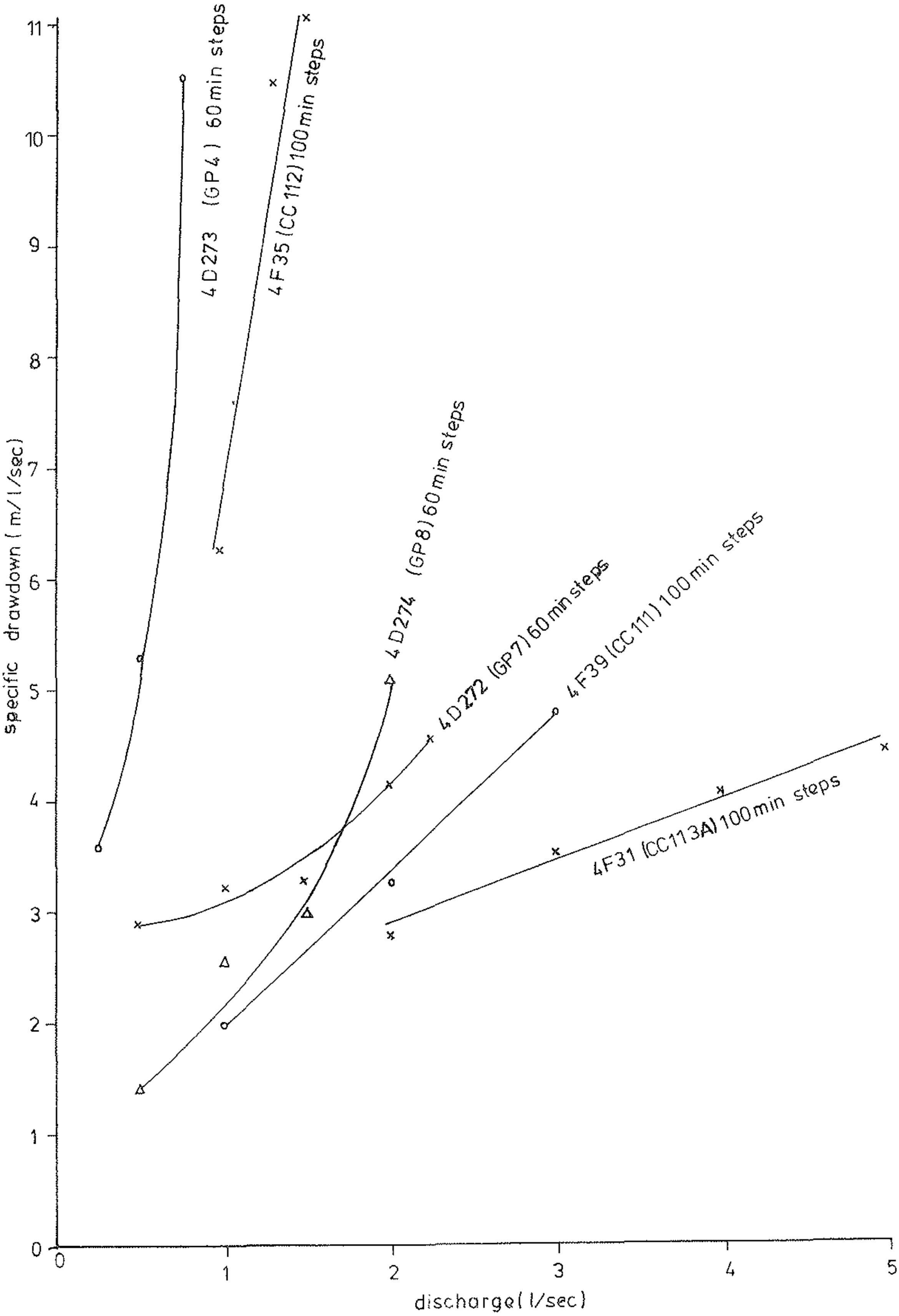


FIGURE 3.6 100 MINUTE STEP DRAWDOWN TESTS IN PROPERLY DESIGNED ALLUVIAL BOREHOLES

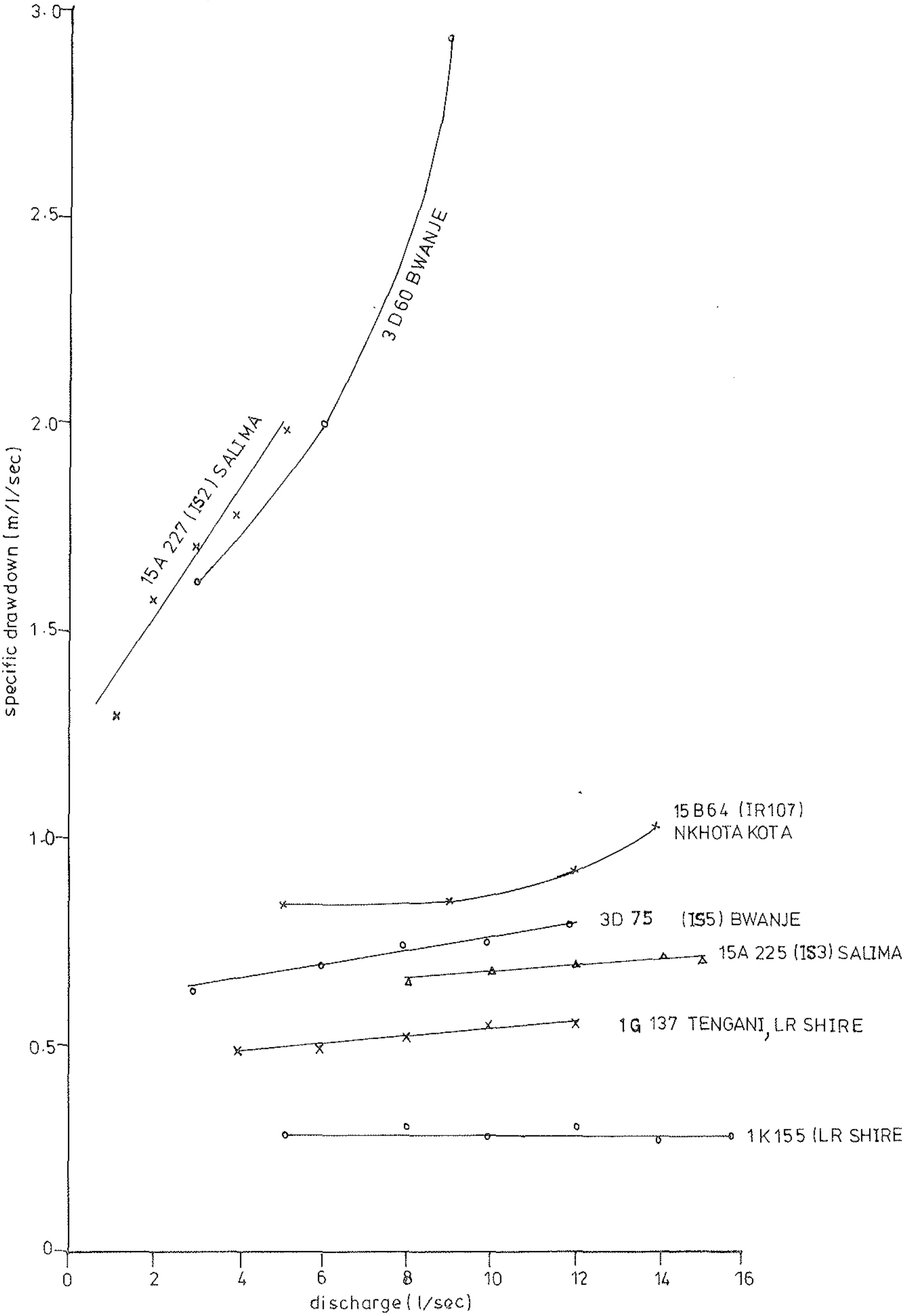


TABLE 3.3 LONG TERM BOREHOLE PERFORMANCE

Location	Aquifer type	Borehole number	G.S. number	Date	Discharge (l/sec)	SC (l/sec/m)	Date	Discharge (l/sec)	SC (l/sec/m)
Dowa	WB/FB	15A210	W120	6/2/78	3.1	0.80	12/7/79	3.0	0.14
Ntcheu	WB/FB	1R129	AM1	20/6/78	1.0	0.10	1 /8/79	1.0	0.04
Ntcheu	WB/FB	1R130	AM2	28/7/78	1.5	0.28	24/8/79	4.0	0.12
Chitipa	WB	9B32	PM482	21/6/78	2.9	0.30	3/6/82	2.0	0.29
Chiradzulu	WB	2B218	J37	21/8/78	1.25	0.06	21/2/80	1.25	0.05
Balaka	A	1R53	E300	11/11/81	3.5	0.22	21/9/82	4.0	0.16
Nsanje	A	1G32	T5A	18/5/78	0.58	0.26	29/4/82	5.0	0.97+
Nsanje	A	1G28	K168B	20/5/78	0.75	0.28	2/8/78	1.1	0.26
Nsanje	A	1G27	K168A	22/5/78	0.6	0.06	31/7/78	0.6	0.06
Mpemba	WB	1E1	C162	24/5/78	0.4	0.03	30/3/80	0.5	0.03
Salima	A	15A212	A57	27/1/78	2.0	0.83	26/1/79	9.8	1.89

+ after development of borehole

WB = weathered basement

FB = fractured basement

A = alluvium

e) Declining groundwater levels would result in a decreasing saturated aquifer thickness. However the abstractions are generally much lower than the annual recharge (see section 3.4) and this is unlikely to be the case except for some of the fractured basement aquifers where recharge is not dependable.

3.2.4 Transmissivity

Transmissivity (T) is defined as the volume of flow through a full section of the aquifer of unit width under unit hydraulic gradient in unit time. It is usually estimated from the rate of drawdown observed during an aquifer test. Most boreholes in Malawi have not been pumped for long enough for detailed analysis, and only relatively few tests have been carried out at constant discharge rates in properly-designed boreholes (Table 3.4).

The long term tests usually have only limited water level measurements taken within the pumping borehole itself. The data are subject to inaccuracies due to surging water, well losses, fluctuations in discharge rate and well storage effects at the start of the test.

Large drawdowns in thin aquifers may result in significantly lower apparent transmissivities because of the reduced saturated aquifer thickness. Corrections should be made for the dewatering effect, unless the drawdowns are small, although in practice this is very difficult because of the vertical variations in permeability. In the weathered basement aquifer the lower part of the sequence is usually the most productive (see section 3.1.2). Despite the large drawdowns, the decrease in transmissivity may therefore not be as significant as appears at first sight.

The interpretation of data from testing of the old-design boreholes in the weathered basement aquifers (see Table 3.2) would be misleading, because it is suspected that the saprolite is largely cased out or lined with screen of very low open area, and the boreholes are only open in the hard bedrock below. The flow routes for groundwater entering such boreholes will be complex. In addition to contributions from fractures in the bedrock, there will also be an unknown contribution from the overlying saprolite by vertical movement through the aquifer down the outside of the borehole casing and in the annulus of disturbed ground immediately around the borehole. These tests may well give a better indication of fractured basement aquifer properties rather than those of the weathered zone. The analysis of the pump test data should be treated with caution since the basic assumptions for conventional pumping test analysis are not satisfied. The differences in borehole performance between old-design and properly-designed boreholeshave already been discussed

(See section 3.2.3 and Figure 3.2) and the dangers of estimating transmissivity from measurements within poorly-designed pumping wells cannot be overstated.

Pumping tests on various old-design boreholes were carried out by Howard Humphreys (1979). Most of these tests were too short and at variable discharge rates, and thus the analysis is rather unreliable. The National and Shire Irrigation Study (1980) gave estimates of transmissivities mainly based on specific capacities. These estimates are also rather dubious given the unreliability of the specific capacity determinations as discussed in section 3.2.3.

Results of more recent testing on properly-designed boreholes with relatively linear specific capacities are presented in Table 3.4. The NSIS investigations (1982) show that the alluvium can be an important aquifer with transmissivities ranging from 50 m^2/d to over 300 m^2/d. However, aquifer properties are likely to be very variable depending on the lithology and thickness of the deposits.

In order to improve the understanding of the weathered basement aquifer, two detailed pumping tests were carried out at Lilongwe International Airport in boreholes known to be properly-constructed and having linear specific drawdown/yield relationships (Smith-Carington, 1983). The water levels were monitored in the pumping borehole and in two small-diameter, properly-constructed observation boreholes at each site (Figures 3.7 and 3.8). The form of the response to pumping is unusual and similar in all boreholes except CC113A, with a steep "shoulder" (probably a barrier boundary effect) followed by a decline in the rate of drawdown. The latter effect could possibly be caused by gravity drainage during dewatering as the water level falls below the semi-confining clays in the case of CC112, but this is unlikely to be the explanation for the response in observation boreholes to CC113A, as the water level remains within the surface clays. Here it probably indicates the intersection of some recharge boundary. The recovery of water levels shows a rather different form with no shoulder effect and the initial rates of recovery are more rapid (Figures 3.7 and 3.8).

The small drawdown and delayed response in the nearer observation borehole (OW1) during pumping of CC113A is thought to reflect the fact that it only partially penetrates the weathered zone. It is suspected from its response that the lower part of the aquifer contributes most of the yield and that there is poor hydraulic connection between the upper and lower layers. This was confirmed by conductivity logging and chemical sampling in the boreholes (see Figure 3.19). The results from this borehole cannot be used to estimate transmissivity because the flow will be predominantly vertical leakage in response to pumping of CC113A. The delayed response is probably due to both strong vertical banding in the aquifer and very low permeability in the most weathered upper layers. Another possibility is that the pumping borehole and OW2 both intersect some fracture trace preserved in the weathered zone.

TABLE 3.4 RECENT AQUIFER TESTS ON PROPERLY-DESIGNED BOREHOLES

Location	Borehole number	G.S. number	Aquifer type	Discharge rate (l/sec)	Length of test (hr)	Drawdown (m)	S.C. (l/sec/m)	T (m^2/d)	Average Kh (m/d)
Salima	15A227	IS2	A	5	72	11.65	0.43	70[+]	3[+]
Salima	15A228	IS3	A	15	72	11.71	1.28	160[+]	6[+]
Salima	15A229	IS7	A	15	72	5.39	2.78	300[+]	8[+]
Nkhotakota	15B64	IR107	A	14	72	18.00	0.78	130[+]	11[+]
Bwanje Valley	3D75	IS5	A	12	72	10.98	1.09	150[+]	6[+]
Bwanje Valley	3D60	3D60	A	7	48	25.32	0.28	50[+]	-
Lower Shire	1G137	1G137	A	12	72	7.54	1.59	200[+]	7[+]
Lower Shire	1K115	1K115	A	15	72	4.83	3.11	330[+]	23[+]
Lilongwe	4E80	CC137	WB	1.5	24	22.24	0.07	-	-
Chilumba	17C54	CC168	A	3.0	72	13.23	0.23	-	-
Lilongwe	4F39	CC111	WB	2.2	72	14.5	0.15	-	-
Lilongwe	4F35	CC112	WB	1.4	72	14.4	0.10	5-35[x]	0.3-1.8
Lilongwe	4F31	CC113A	WB	5	75	24.5	0.20	10-35[x]	0.4-1.2
Chitedze	4D272	GP7	WB	2.0	72	11.68	0.17	12	0.5
Chitedze	4D274	GP8	WB	1.5	49	10.43	0.14	10	0.6
Chitedze	4D273	GP4	WB	0.5	60	4.69	0.11	7	0.2

Notes:
A = alluvium
WB = weathered basement
FB = fractured basement

+ After NSIS (1982)
x After Smith-Carington (1983)

FIGURE 3.7 TEST PUMPING AT LILONGWE INTERNATIONAL AIRPORT CC 112 (4F 35)

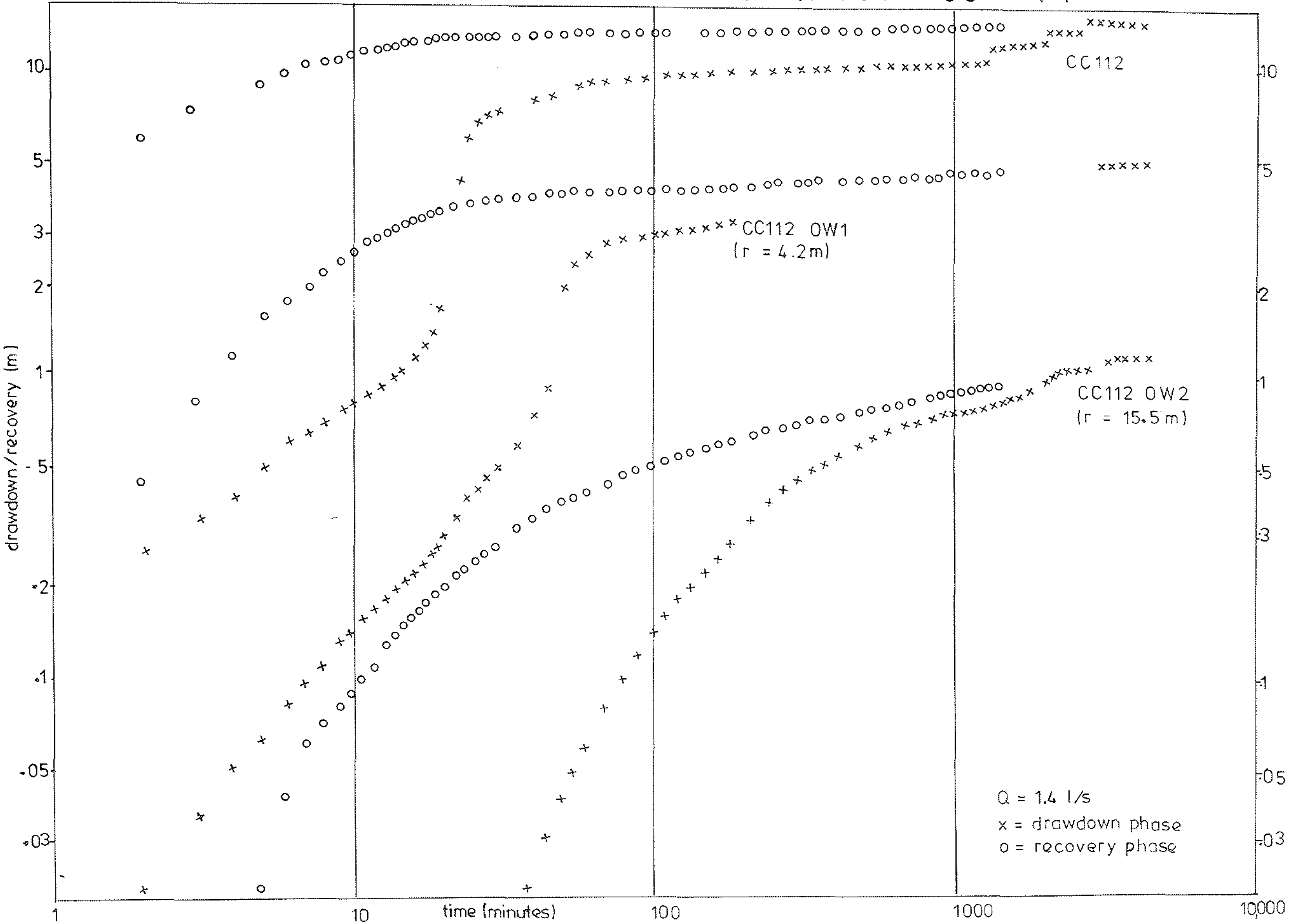
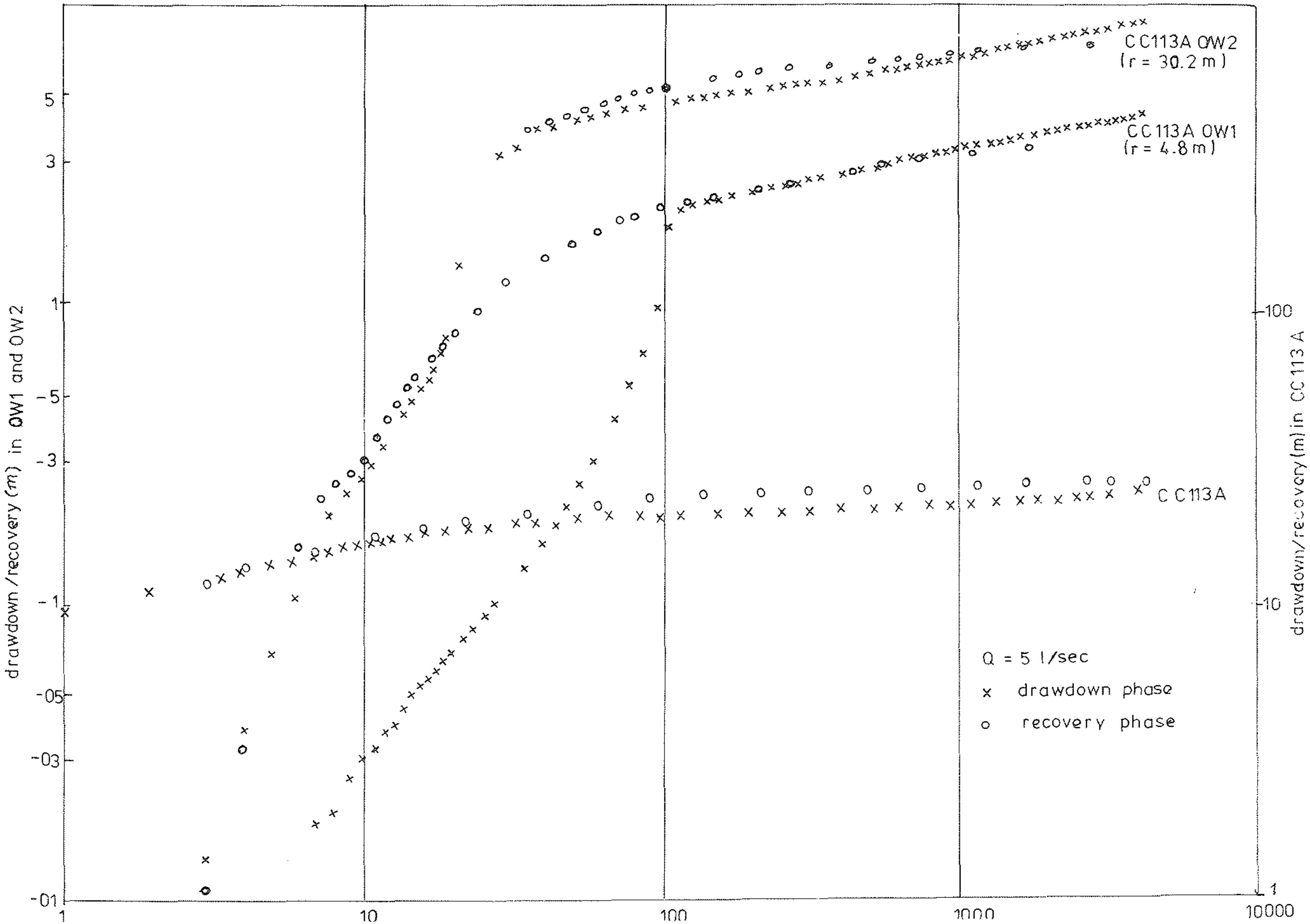


FIGURE 3.8 TEST PUMPING AT LILONGWE INTERNATIONAL AIRPORT CC 113 A (4F 31)



It is clear that the weathered basement aquifer is very complex with the heterogeneity of the material both vertically and laterally resulting in variable flow from different horizons. The early data has been used to estimate transmissivity; it is probably in the range of 5 to 35 m^2/d around CC112 and 10 to 35 m^2/d around CC113A (Table 3.5). However, this will only predict the decline of water levels for a relatively short period before the response to pumping is dominated by complex boundary effects. The late data in such tests is required to help choose the setting of the pump suction, discharge rates and pumping regime, and to make estimates of long term pumping water levels.

The Lilongwe International Airport boreholes are high yielding, and not very typical of the weathered basement. Results from the testing of more representative, lower yielding (0.25 to 1.4 l/sec) but properly-designed rural water supply boreholes in the Livulezi and Dowa West Projects have been tentatively analysed. The tests were short (1 to 5 hours), and the water levels in some cases were very quickly drawn down to pump suction with a consequent reduction in discharge rate for the remaining duration of the test. The interpretation of the data is complicated both by gravity drainage after the aquifer passes from a semi-confined to an unconfined condition, and also by the decrease in saturated thickness resulting in a fall in transmissivity as the aquifer is dewatered, as well as boundary effects. Analysis of the early parts of both the drawdown and recovery phases where there are sufficient data points suggests transmissivities of 1 to 20 m^2/d in the Livulezi Project (Smith-Carington and Msonthi 1983, and Figure 3.9), and 0.2 to 5 m^2/d in the Dowa West Project (Ruxton, 1983 and Figure 3.10). As a result of these very low transmissivities in thin heterogeneous aquifers, there could be a significant decline in yield in some boreholes at times of drought with the lowering of groundwater levels and the loss of important flow horizons.

3.2.5 Permeability

Permeability (K) is defined as the volume of flow through unit area of the aquifer under unit gradient in unit time. It is likely to be very variable, both vertically and laterally, in both alluvial and basement aquifers because of the large range and abrupt changes in lithology.

The frequent occurrence of clays and clay-rich layers in alluvial sequences and in the weathered zone of the basement will ensure that the properties are highly anisotropic, with vertical permeabilities suspected to be much lower than horizontal permeabilities. This effect is borne out by the aquifer tests at Lilongwe Airport (see section 3.2.4) where the small drawdown in the partially-penetrating, nearby observation borehole is suspected to be at least partly due to layering within the weathered basement aquifer and low vertical permeabilities.

Highly variable water quality over very short distances in some areas of weathered basement (see section 3.5) suggests low permeabilities and little mixing of groundwater. On the basis of estimated transmissivities and aquifer thicknesses, typical average permeabilities are likely to be in the range 0.5-1.5 m /d. The most permeable horizons are unlikely to exceed 5 m/d. Groundwater flow will be complex, with the bulk of the flow often from a few thin horizons (commonly veins or fractures) together with a smaller contribution by diffuse flow from the rest of the sequence.

TABLE 3.5 ESTIMATES OF TRANSMISSIVITY, LILONGWE INTERNATIONAL AIRPORT

G.S. number	Borehole	Transmissivity estimate (m^2/d)			
		type curve method		straight line method	
		drawdown	recovery	drawdown	recovery
CC112	4F35	22	3	16	3
CC112OW1	4F26	39	3	*	*
CC112OW2	4F38	19	39	*	*
CC113A	4F31	11	11	11	11
CC113AOW2	4F37	37	25	*	*

after Smith-Carington (1983)

* u is too large for straight line relationship (Cooper and Jacob, 1946) to hold for early data.

FIGURE 3.9 TEST PUMPING, LIVULEZI PROJECT

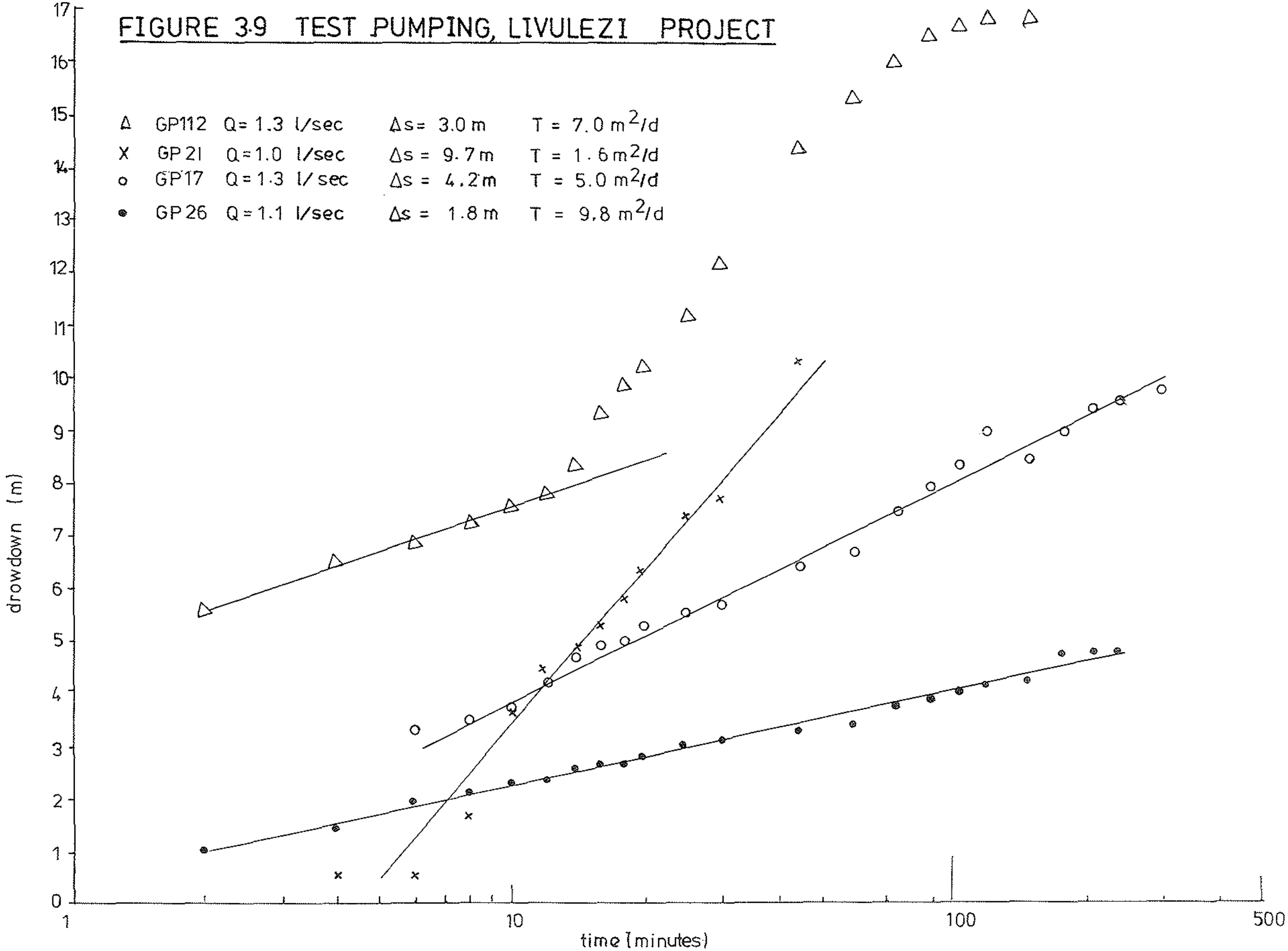
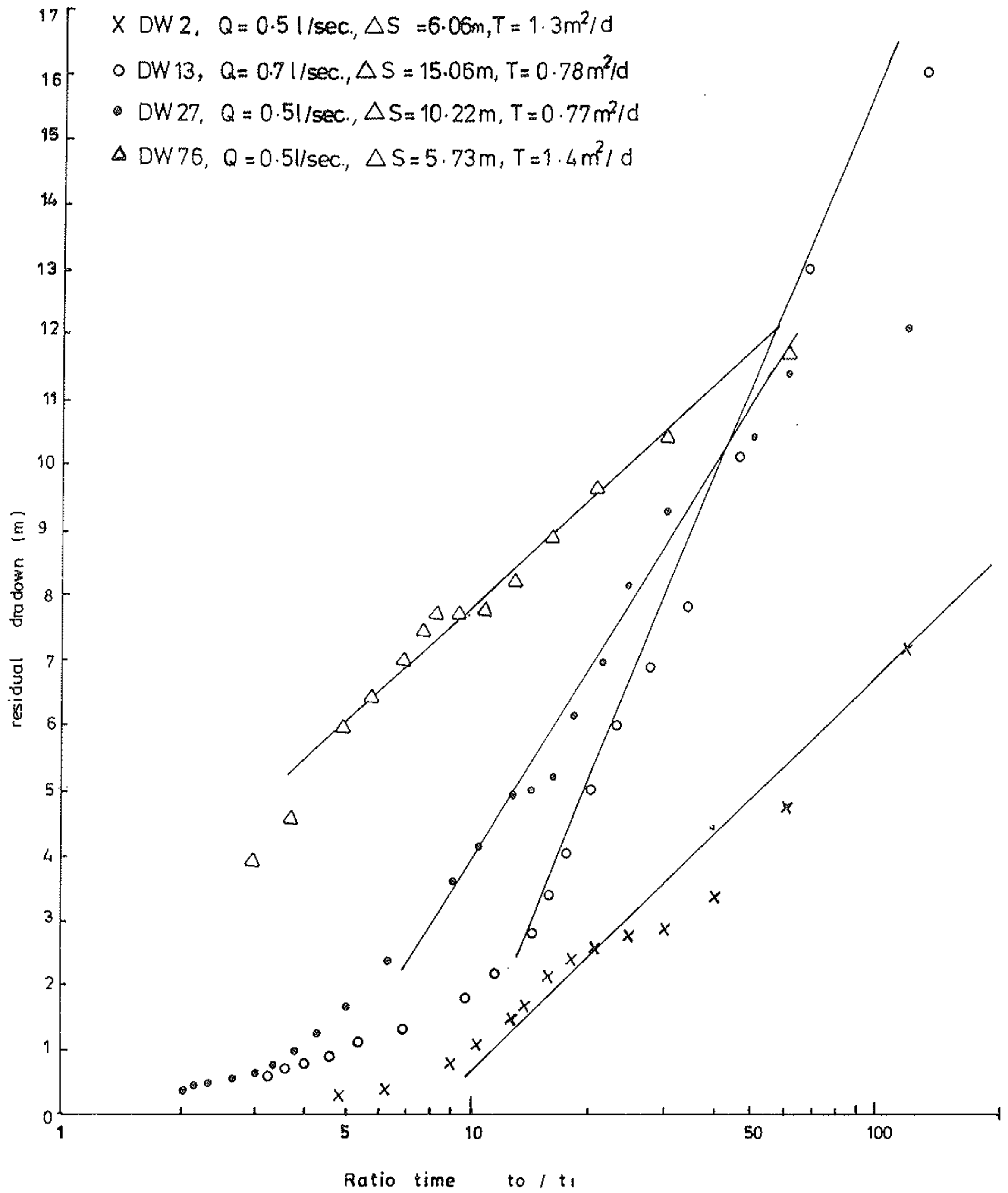


FIGURE 3.10 RECOVERY FROM TEST PUMPING, DOWA WEST PROJECT



In the alluvial aquifers, typical average permeabilities are likely to be in the range of 1-10 m/d. It must be noted that these are only rough approximations and there will be considerable local variations. NSIS (1982) suggest a permeability of about 10-20 m/d in clean alluvial sands and gravels and almost an order of magnitude lower, about 2-5 m/d, in colluvial clayey sands and grits. Groundwater flow will be largely intergranular.

Anisotropic conditions are likely to occur in the well-bedded, strongly-cemented Karoo sedimentary aquifer, where the permeability will be controlled largely by the secondary porosity along bedding planes and fractures.

Permeability in the fractured bedrock will be highly variable and dependent on the extent and intersection of fracture zones. Flow velocities in individual large fractures could be very high, but the overall permeability is likely to be low because of the low porosity.

3.2.6 Storage ooefficient

The storage coefficient (S) is defined as the volume of water which an aquifer releases from storage per unit surface area per unit change in head. There is no reliable information on the storage properties of the aquifers since this requires analysis of data from an aquifer test where the water levels have been monitored in observation wells, and transmissivity estimates are reliable.

The storage coefficient will probably be in the range $5x10^{-3}$ to 10^{-2} in the weathered basement aquifer and 10^{-2} to $5x10^{-2}$ in alluvial aquifers, but it cannot be estimated with any better precision without better knowledge of the strata and more certainty of the transmissivity.

There is an additional complication as the storage coefficient in those aquifers which are semi-confined will vary during pumping, and seasonally, if the groundwater level falls below the semi-confining layers.

NSIS (1980) Estimate the specific yield, Sy (effective porosity) of the weathered basement to be about 5 percent and to lie in the range 3-10 percent for the alluvium, based on lithological records.

3.3 GROUNDWATER LEVELS

3.3.1 Depths to water

Groundwater levels were measured in boreholes at the time of construction, and have been recorded subsequently (since 1971) by Borehole Maintenance Units. The readings are irregular as they are only taken when handpumps are removed for repairs, and in addition many of the measurements are suspected to be unreliable. For both the alluvial and weathered basement aquifers, groundwater is usually struck at a level below its final rest water level, and it then rises, sometimes by several metres. This is evidence of the semi-confining nature of the surface strata. The extent of the rise in water level reflects the degree of artesian pressure and depends on many factors including the lithology, the topographic position, and the time of the year when drilling takes place. The alluvial boreholes may penetrate more than one aquifer, so the difference between struck water level and rest water level represents a composite of the pressure conditions within the several aquifers.

Regionally, the piezometric levels (as shown by rest water levels in boreholes and dug wells) are closest to the ground surface in areas where the rainfall (and hence recharge) is highest. They tend to form a subdued impression of the surface topography being closest to ground level near surface water courses and deeper under interfluves.

Over the plateau areas, rest water levels are generally less than 25 m and commonly less than 15 m below ground level, but they may be deeper towards the rift valley escarpment or in other localised areas. Near the dambo, the groundwater levels may rise to ground level during the wet season.

In the rain shadow area of the South Rukuru Valley, piezometric levels tend to be slightly deeper (commonly 15 to 25 m below ground level). Here the saturated thickness of weathered material may not always be sufficient, even for the low yields required for rural domestic supplies from handpumps, and the depth of weathering in relation to the depth to groundwater may well be critical. In the Upper South Rukuru Valley, there is hydraulic continuity between the aquifer and the river, however groundwater levels are often below the river level in the middle reaches. It is uncertain whether the river loses water into the underlying aquifer or whether there is poor hydraulic connection between the two and the aquifer is confined in this region.

Depths to groundwater in the alluvial basins are again closely related to the rainfall and recharge. They also tend to increase with distance from Lake Malawi and or with topography. Rest water levels are normally less than 10 m below ground surface in the Salima-Nkhotakota lakeshore plain and in the Lake Chilwa Basin, although the depths of drilling required before water is first struck are sometimes considerably more. Water levels are deeper in the rain shadow areas of the Bwanje Valley, Rivi-Rivi Valley, Upper Shire Valley and parts of the Lower Shire Valley, where they may be 30 m or more below ground level. In some parts of the Lower Shire Valley, however, water levels are very close to the ground surface.

Close to the shores of Lake Malawi, the groundwater levels may be controlled to a certain extent by the lake level although this will only affect a relatively narrow zone (see section 3.3.5). Recent lake levels in the late 1970s have been very high and associated with this groundwater levels have been very close to the surface or even rising above ground causing flooding in low lying areas, for example in the Katete dambo, near Salima.

Groundwater levels in the Karoo sediments are usually deep; they depend on the surface topography, and in the Lower Shire Valley are commonly 20 to 30 m below ground.

3.3.2 Seasonal fluctuations

Measurements of groundwater levels taken by the Borehole Maintenance Units indicate that normal seasonal fluctuations are in the range 1 to 5 m in the weathered basement aquifer and 1 to 3 m in the alluvial basins. It must be emphasized that these measurements are very infrequent, likely to be inaccurate, and can only be used as a rough guide in the absence of other records.

Groundwater levels have been monitored with autographic recorders at several sites since 1980. These give a much more accurate indication of seasonal changes in the volume of stored groundwater, and with continued measurements, the long term effects of groundwater abstraction can be evaluated. Diurnal fluctuations in water level of 10 to 50 mm are observed in all the boreholes; these are associated with changes in barometric pressure.

Two boreholes with recorders in the weathered basement aquifer situated on lower valley slopes in the plateau area of the Bua catchment show seasonal water level fluctuations of 2 to 3.5m (Figure 3.11). Another borehole with a recorder at Lilongwe International Airport showed a rise of nearly one metre in 1983, but only one year of data is available (Figure 3.12). Water levels do not begin to rise until two to three months after the commencement of the wet season. Much of the early rainfall is used to satisfy moisture deficits which have built up in the soil and unsaturated zone during

Figure 3.11 SEASONAL GROUNDWATER LEVEL FLUCTUATIONS, BUA CATCHMENT

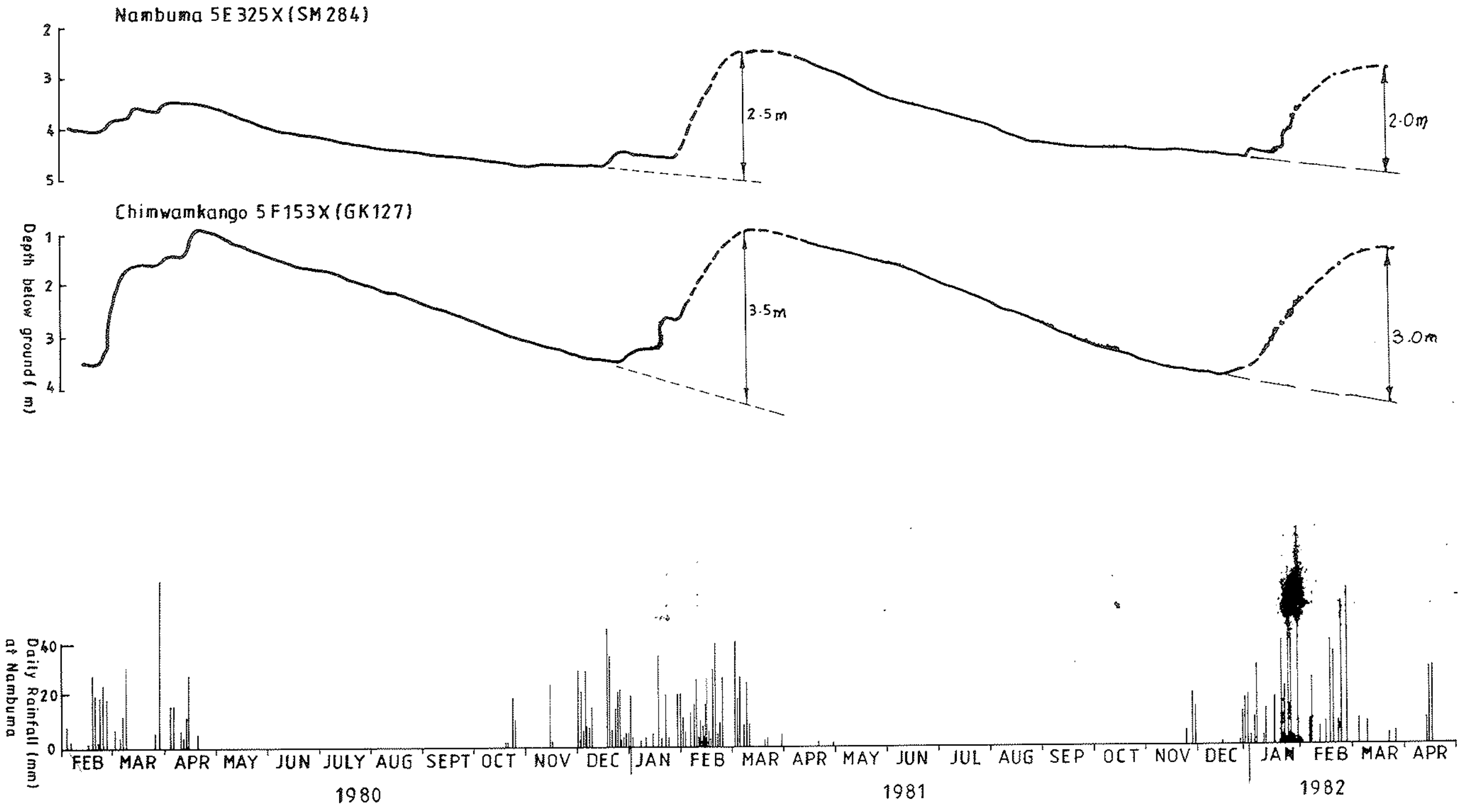
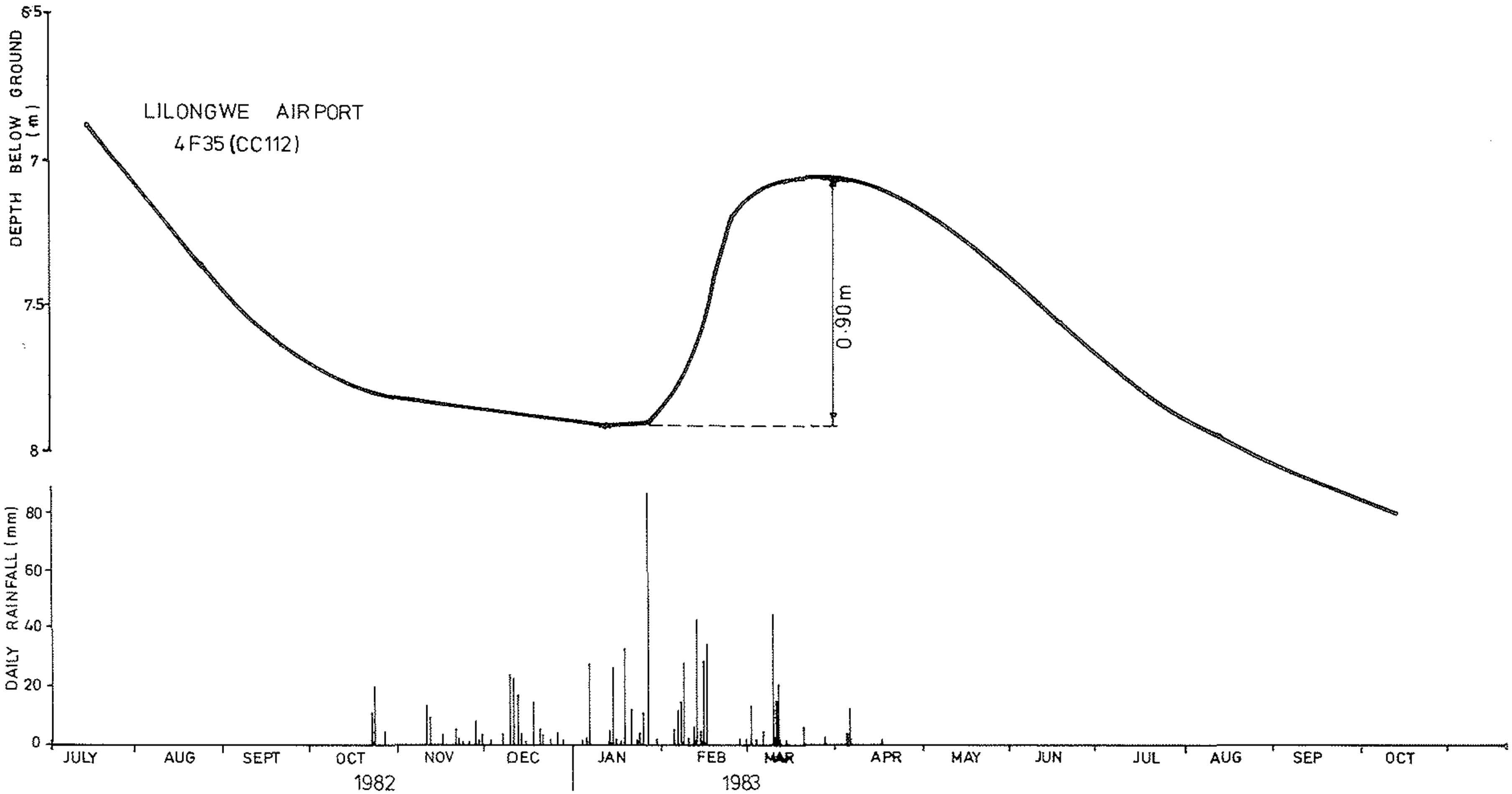


FIGURE 3·12 SEASONAL GROUNDWATER LEVEL FLUCTUATIONS, LILONGWE AIRPORT



the dry season, and little deep infiltration can occur until these have been made up. Maximum groundwater levels occur around March/April, towards the end of the wet season, after which there is a gradual recession of water levels until the minimum is reached between December and February. Variations in the shape of the hydrograph will obviously occur from site to site, and from one year to the next, depending on the rainfall amount, intensity and distribution through the wet season. The amount of recharge and the storage properties of the aquifer will determine the amplitude of the water level fluctuations (see section 3.4.3).

Water levels in the alluvial aquifer are monitored by two recorders near Salima (Figure 3.13) on the lakeshore plain. These show smaller annual fluctuations of about 0.8 to 2.5 m which could reflect the higher storage properties of this unconsolidated aquifer (see section 3.4.3). A delay in response of water levels following rainfall is observed, with the rise not commencing until December-February and peak levels occurring around March/April.

The dry season water levels in the thin weathered basement may be such that the saturated aquifer thickness is very small, and the reduction in transmissivity and storage can lead to supply problems in severe drought conditions.

3.3.3 Long term groundwater level fluctuations

Boreholes with the longest and most frequent records show that there is no evidence of declining water levels over the period 1971-1981, in either the weathered basement or alluvial aquifers. Figure 3.14 shows an example of the type of records available for some boreholes in the Bua catchment. This is not surprising because, although abstraction has increased over this period, the present abstraction from groundwater (see section 4.1.3) is still a very small proportion of the seasonally replenished resources (see section 3.4) and thus aquifer depletion would not be expected in any of these areas. There is scope for considerable further development of groundwater resources without any significant danger of declining water levels.

In the fractured bedrock aquifers of the escarpment however, there may be declining water levels in some areas because of unreliable recharge to the fracture zones. For example at borehole 15A 155(X186) near Dowa, water levels have fallen from 16 m to 23 m below ground level over the period 1971 to 1980.

By contrast, within the Sucoma Sugar Estate in the Lower Shire Valley, which was established between 1964 and 1976, there has been a local rise in groundwater levels in the alluvium caused by heavy irrigation of the area using water from the Shire River (Van der Velden, 1980). Boreholes 1H53, 1H104 and 1H242 had shown rises of 6m, 3m and 2m respectively, by 1979.

FIGURE 3.13 SEASONAL GROUNDWATER LEVEL FLUCTUATIONS, SALIMA LAKESHORE

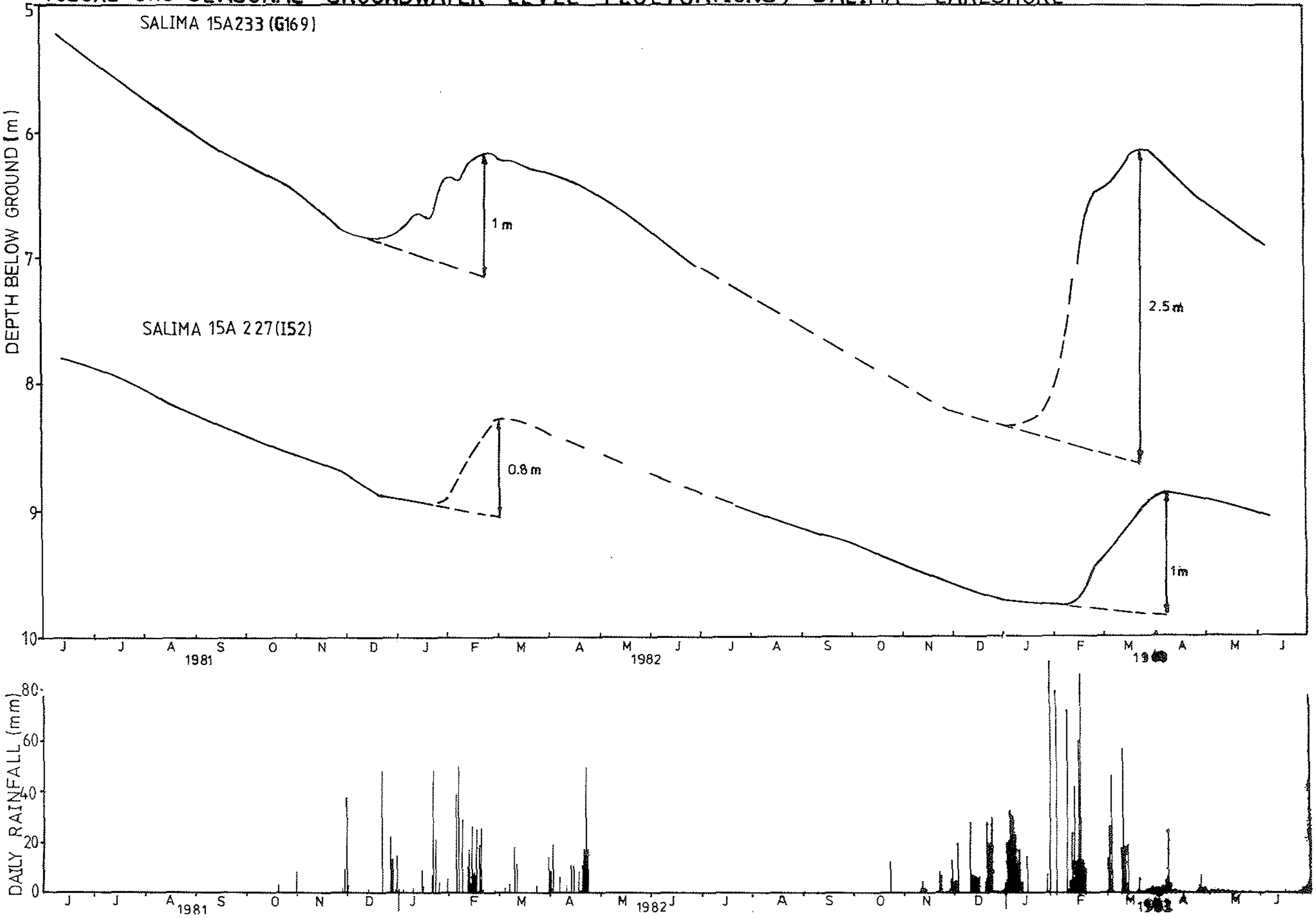
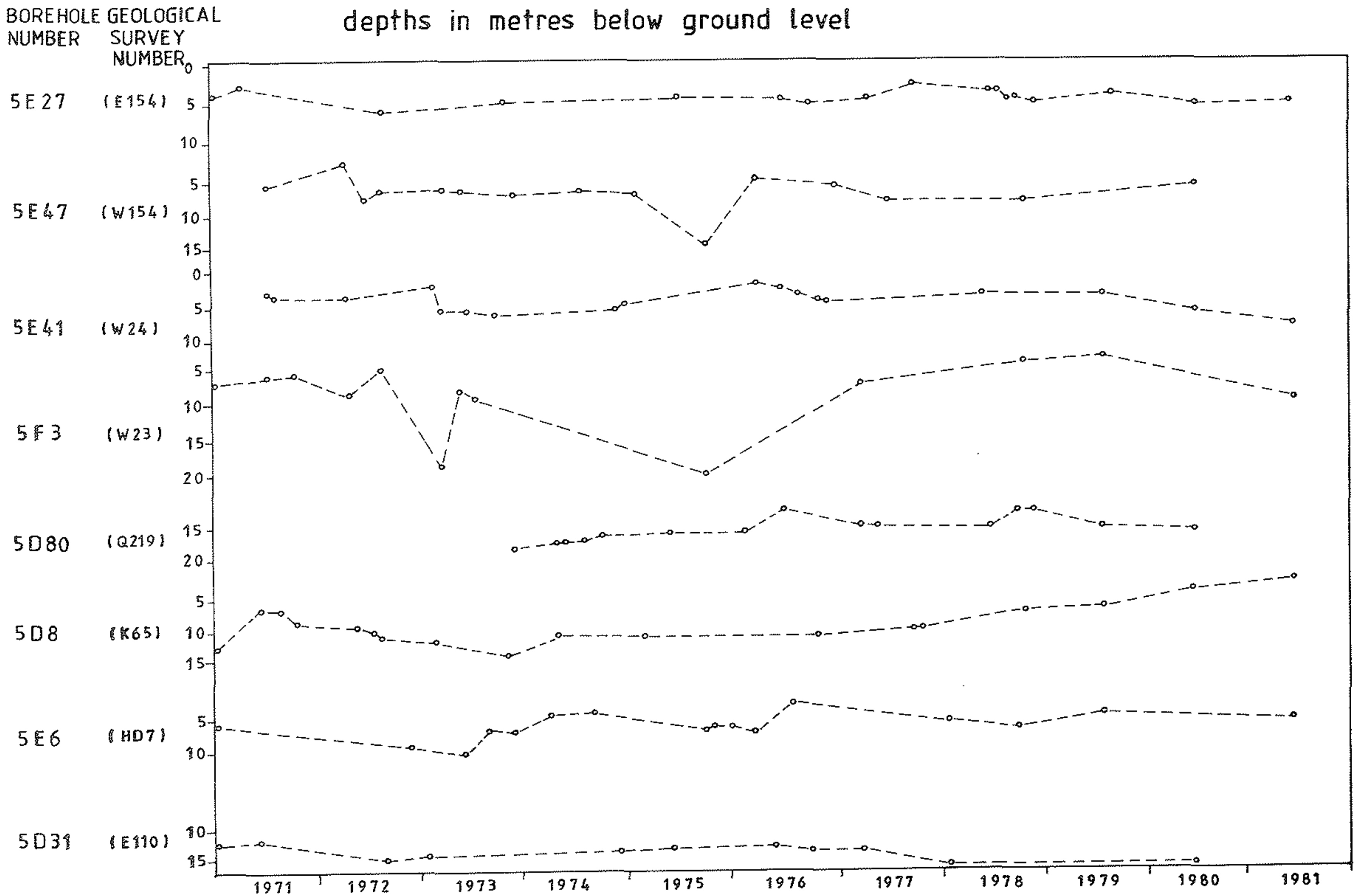


FIGURE 3.14 GROUNDWATER LEVELS FROM BOREHOLE MAINTENANCE RECORDS, BUA CATCHMENT

After Chilton (1979)

depths in metres below ground level



3.3.4 Groundwater movement

Piezometric form lines have been constructed using estimated minimum groundwater level elevations (see hydrogeological maps), and they give a general indication of the direction of regional groundwater movement although there are insufficient data points to construct groundwater contours on a local scale. The hydrology and hydrogeology is dominated by Lake Malawi and the Shire River, and the whole country drains to this system, except for the internal drainage of the Lake Chilwa Basin.

Groundwater movement may be structurally controlled in all aquifer types, but particularly those which are more consolidated and more affected by faulting. The Karoo sediments in the Lower Shire Valley for example, are traversed by many faults, which may form groundwater barriers e.g. Mwanza Fault (Bradford, 1973). The groundwater levels observed at present are a virtually natural condition because the abstraction is so small, and the possible effects of faulting will not be fully felt until abstraction increases.

Direction of groundwater flow may also be controlled by the occurrence of uplands with steep slopes and fresh bedrock; groundwater movement will tend to be deflected around the base of such highland areas.

a) Weathered basement aquifers of the plateau

On the plateau areas, the piezometric surface suggests apparently regional hydraulic continuity, with generally radial flow to the basin centres and local, structurally controlled movement around uplands rising from the plateau. This regional picture may be misleading as the ground surface is so flat that the underlying piezometric surface is also gentle, and a generalised contour map can easily be drawn. On a local scale, however, the direction of groundwater movement is likely to be very variable with flow towards each dambo tributary, and the actual groundwater flow patterns are thought to be complex. The localised flow cells with slow rates of groundwater movement are confirmed by the highly variable water quality within short lateral distances (see section 3.5.2).

The regional hydraulic gradients are very low (often less than 0.005) but these are a reflection of flat surface topography rather than permeability. A detailed altimeter survey to determine the form of the piezometric surface over part of the Dowa West Project area (Figure 3.15) showed that the groundwater contours were a subdued expression of surface topography with average hydraulic gradients of 0.014 to 0.044 (Figure 3.16).

FIGURE 3.15 PIEZOMETRIC SURFACE IN DOWA WEST INTEGRATED PROJECT SEPT, 1983

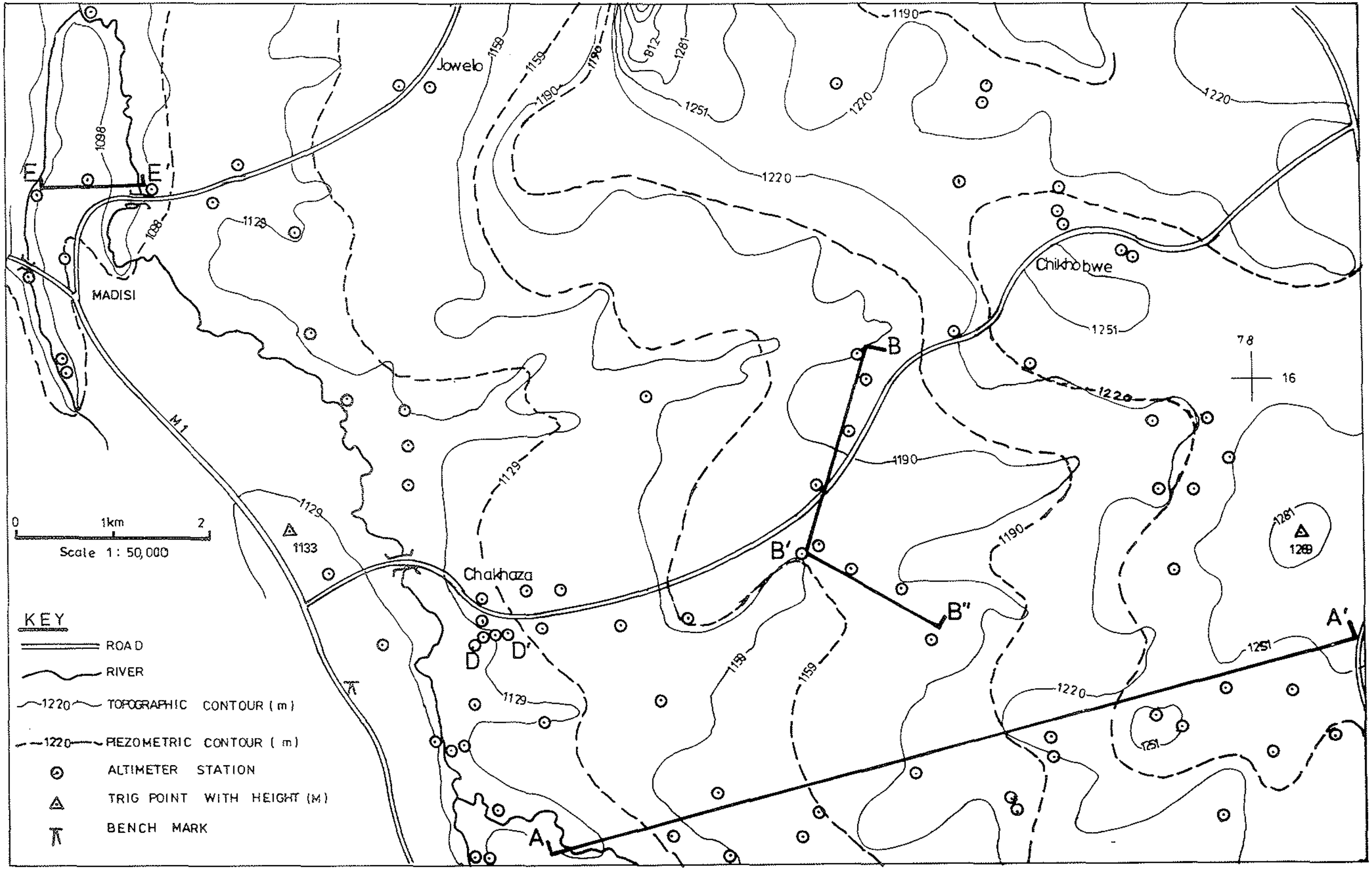
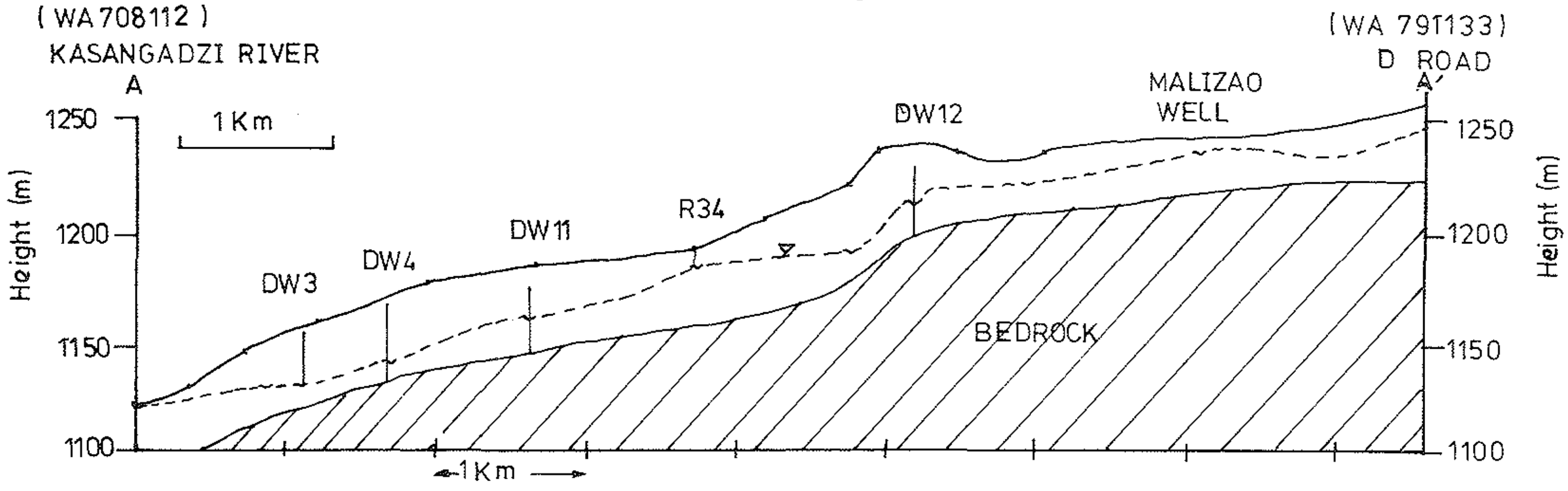
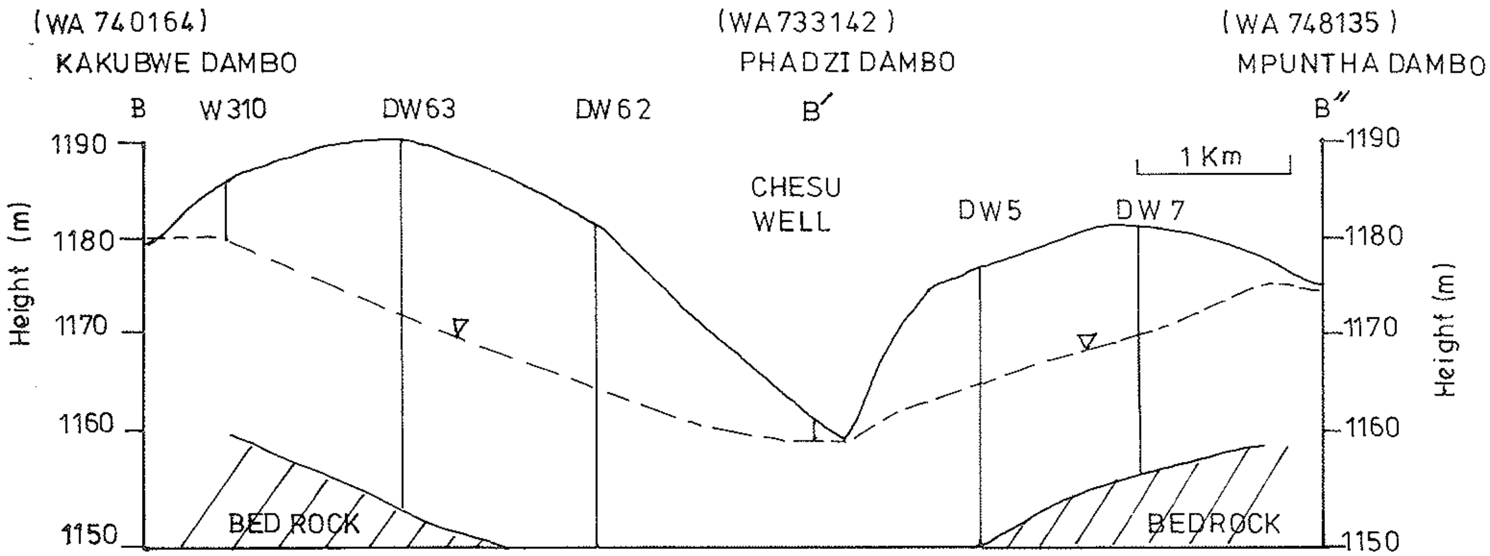


FIGURE 3.16 CROSS SECTIONS THROUGH THE WEATHERED BASEMENT AQUIFER DOWA WEST INTEGRATED PROJECT

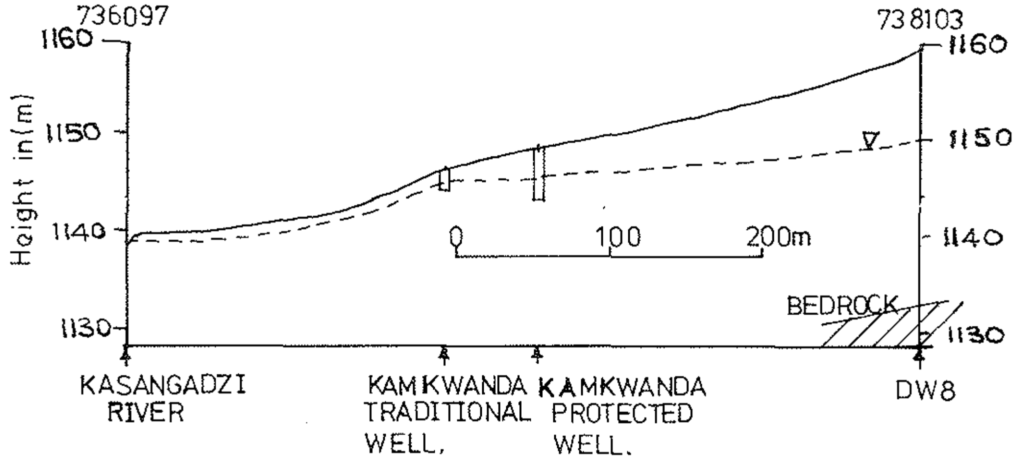
A. Section along length of interfluve



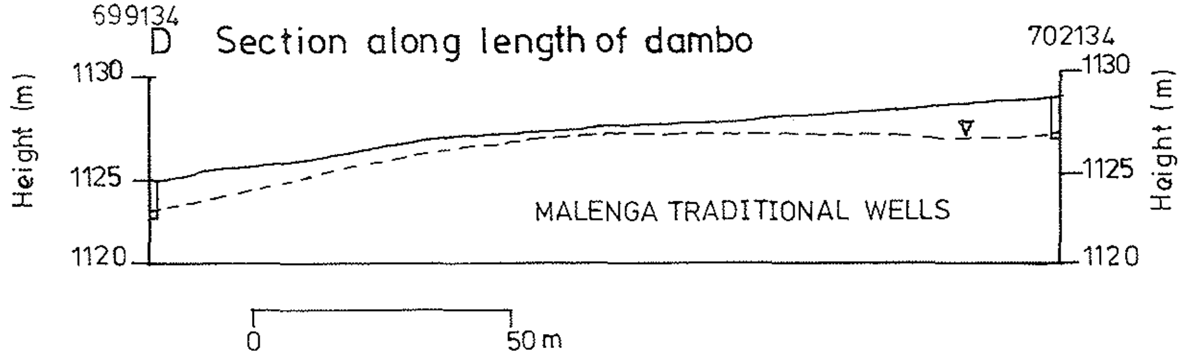
B Section across interfluve



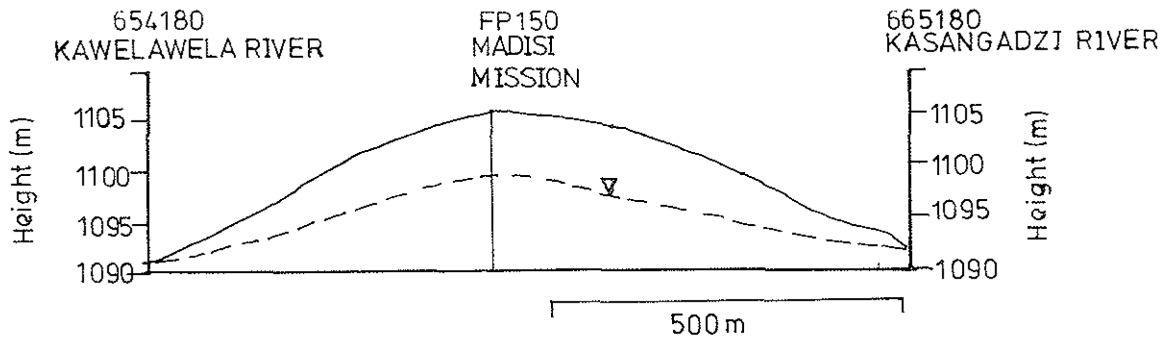
C. Section up river valley slope



D Section along length of dambo



E Section across interfluve



The weathered basement aquifer is likely to be in direct hydraulic continuity with the dambo, and is probably responsible for most of the baseflow in any surface water courses. The actual groundwater discharge to rivers will depend on recharge rates, the extent of impeding laterite and the degree of hydraulic connection with the dambo. In the middle section of the South Rukuru catchment on the plateau, for example, the groundwater contribution will be negligible because water levels are virtually always below the level of the river bed.

Groundwater underflow in the weathered basement of the plateau areas is probably negligible because the zone of weathering is usually thin towards the upwarped escarpment edge, and the natural hydraulic gradients would tend to encourage groundwater movement away from the escarpment edge itself towards the incised river channels in this region.

b) fractured basement aquifers

Groundwater contribution from the fractured bedrock aquifers to the rivers discharging from the uplands and the escarpment is difficult to determine, but is likely to be small. Piezometric form lines cannot be constructed in these zones because of the discontinuous nature of any aquifers. The hydraulic gradient will be large because of the steep topography resulting in rapid drainage.

It is possible that there may be some underflow of groundwater, by deep percolation through the fractures and along fault planes in the escarpment zone, which eventually discharges to the alluvial aquifers or directly into Lake Malawi. This is impossible to quantify, but given the overall low secondary porosity and low permeability, it is likely to be small.

c) Weathered basement and alluvium of rift valley plains

At the base of the rift escarpments, there is commonly loss of water from the rivers, recharging the weathered basement and alluvial aquifers. These two contiguous aquifer types appear to be in hydraulic continuity, both along the lakeshore plains and in the Shire Valley, based on a consideration of groundwater levels. Further down the hydraulic gradient the river discharge usually increases with the addition of a component of groundwater, and the piezometric form lines in the alluvial aquifers usually indicate direct discharge of groundwater into surface water bodies.

The regional hydraulic gradients in the alluvium are generally low (0.001-0.01) and reflect the very gentle surface topography. The variable groundwater quality and heterogeneous lithologies suggest that the small scale flow patterns may be very localised.

There is likely to be a significant amount of groundwater underflow through the alluvium. In the Salima area, the annual discharge towards Lake Malawi is likely to be between 0.13 x 10^6 m^3 and 0.38 x 10^6 m^3 for each kilometre of shoreline, given an estimated transmissivity of 100 - 300 m^2/d and a hydraulic gradient of 0.0035. The total discharge from any alluvial area along the lakeshore will clearly depend on the local aquifer characteristics.

In the vicinity of Lake Malawi it is possible that there is some seasonal reversal of flow with movement of lake water into the alluvium during the wet season, when the lake rises by one to two metres and the hydraulic gradient is away from the shore. This water in "temporary storage" would then be released and flow back into the lake as the lake level subsided (UNDP/WHO, 1976). In the alluvial area by the lakeshore near Salima the hydraulic gradient is about 0.002 at the end of the dry season; a 1.5 m rise in lake level during the wet season would therefore allow penetration of lake water into the aquifer to about 500 m inland (allowing for a certain, though delayed, rise in groundwater level over this period). Assuming a specific yield of 5 percent to 10 percent, the temporary storage in the sands is relatively small, about 0.019 x $10^6 m^3$ to 0.038 x $10^6 m^3$ per kilometre of shoreline. The amount of temporary storage in other areas of alluvium close to Lake Malawi will depend on the local hydraulic gradients and the storage properties of the aquifer.

Piezometric form lines in the Lower Shire Valley indicate groundwater flow towards the central axis of the valley, but the exact relationship between the river and groundwater has not been established (Bradford, 1973; NSIS, 1980; Crow, 1981).

Groundwater contours around Lake Chilwa show that the subsurface drainage converges on the lake as well as all surface drainage. The hydraulic gradient is very low, because of the very gentle land surface.

3.4 GROUNDWATER RECHARGE

3.4.1 Introduction

A knowledge of groundwater recharge is required in order that the groundwater abstraction does not exceed the seasonally replenished resource and long term depletion of resources is avoided. It is also important to identify significant recharge areas, if possible, in order to guide land use policies.

The annual recharge to an aquifer is generally a small component of the total water balance which is difficult to estimate accurately. It is common practice, therefore, to evaluate groundwater resources by several different methods to give more confidence to the results.

Estimates of recharge to the weathered basement and alluvial aquifers have been made by the analysis of hydrographs, groundwater level fluctuations, flow nets and catchment water balances. Recharge over the plateau area of the Bua catchment (Smith-Carington, 1983) and the Salima-Nkhotakota lakeshore plain (Mauluka, 1983) have been evaluated in most detail.

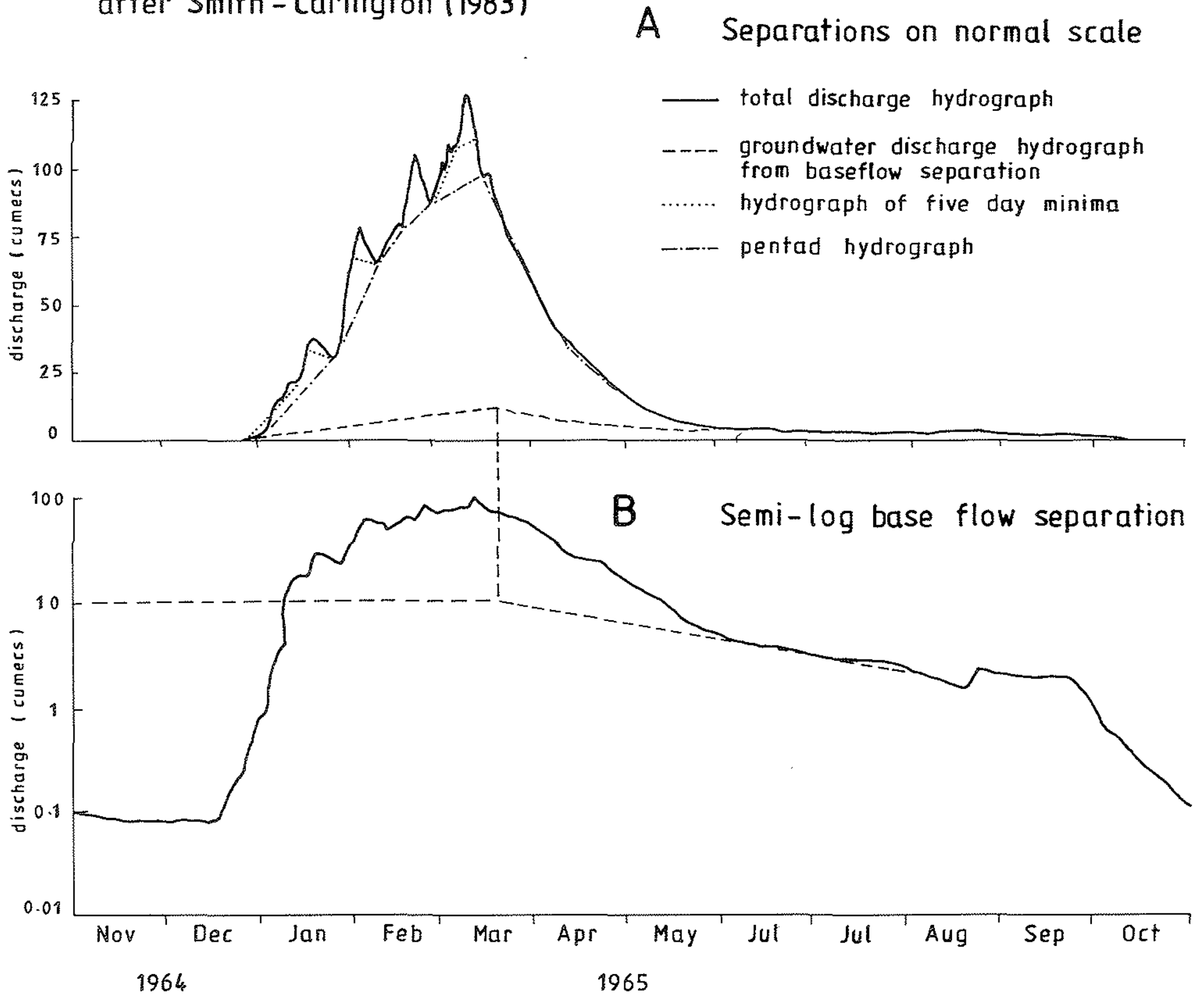
A consideration of the reliability of the different estimates and a summary of the most likely recharge figures is given in section 3.4.6.

3.4.2 Hydrograph analysis

Computer-generated hydrographs of total discharge are available on both arithmetic and semi-logarithmic scales for many gauged rivers in Malawi. The hydrographs can be separated into overland flow and baseflow using conventional techniques (Hall, 1968). On a semi-log plot the last straight line portion of the falling limb represents the baseflow recession. From a backward extrapolation of this line, a continuation of the falling limb of the baseflow hydrograph can be produced. This can be replotted on an arithmetic scale and the rising limb drawn in to intersect with it (Figure 3.17). The annual baseflow discharge can be estimated by measuring the area under the baseflow hydrograph.

Estimates for the gauging stations 5D1 and 5D2 in the Bua plateau area during the period 1959/60 - 1974/75 showed that the annual baseflow, determined by conventional analysis, was mainly in the range 15-30 percent of the total flow and 1-3 percent of annual rainfall (Smith-Carington, 1983). When this is considered over the whole catchment, the implied average recharge is 18 mm and 15 mm for the two stations. The long period of river flow following the end of the rainy season (usually 5-6 months) suggests that the baseflow component is dominantly groundwater discharge, although there may

Figure 3.17 ANALYSIS OF RIVER HYDROGRAPHS, BUA CATCHMENT, GAUGE 5D1, 1964/65
after Smith - Carington (1983)



be a significant interflow component during the rains and continuing for a short period afterwards, when water is diverted laterally along impeding layers such as hard laterite within the weathered profile.

The use of the baseflow hydrograph as an indicator of annual recharge, using the conventional method described above, is considered to be too simplistic for those plateau areas whose drainage is dominated by dambo systems. The dambo occupy up to 25 percent of the total land area and have a distinct hydrological regime; it is thought that the baseflow observed at the gauging station may not give a true reflection of the groundwater recharge to the catchment above the station.

In catchments which are drained principally by dambo the hydrograph form is very flattened with none of the peaks which might be expected to be associated with flashy tropical rainstorms (Figure 3.17). The dambo acts as a storage reservoir which buffers the peaks of irregular rainfall as a result of the slow flow through the dambo grasses in the broad flat valleys. The rising limb of the hydrograph is very steep because rain falls directly over the saturated dambo, which occupy a significant proportion of the catchment, and there is only limited infiltration into the dambo clays. At the end of the wet season, the discharge decreases suddenly, aided by high evapotranspiration over the large dambo area. Baseflow maintains the surface runoff for a period of several months, but the river may dry up before the onset of the following season of rains.

The baseflow analysis should give some idea of minimum recharge, but the observed baseflow component could represent only a residual proportion of the total groundwater discharge. It is possible that a significant amount of groundwater could be discharged to the drainage system upstream of the gauging station and subsequently evaporated or transpired from the dambo before reaching the gauge. This might give a misleading picture of recharge to the catchment above the gauge.

If the dambo vegetation (which is always relatively green and appears to be actively transpiring) were losing water by evapotranspiration at near potential rate throughout the dry season (see section 3.4.5), and if this were derived entirely from groundwater flow to the dambo, the implied volumes of recharge would be very high, perhaps even an order of magnitude higher than that implied by simple baseflow analysis. Other methods of estimating recharge however, suggest that this is unlikely, and the evapotranspiration from the dambo during the dry season must derive at least in part from storage within the clays, with the consequent build up of soil moisture deficits. These deficits would be made up by infiltrating water and interflow after the onset of the rains.

In summary therefore, the minimum groundwater recharge to the weathered basement aquifers in catchments dominated by dambo drainage will be represented by the baseflow derived from simple hydrograph separation, but it could be significantly greater due to evapotranspiration of groundwater from the dambo surface (see section 3.4.3).

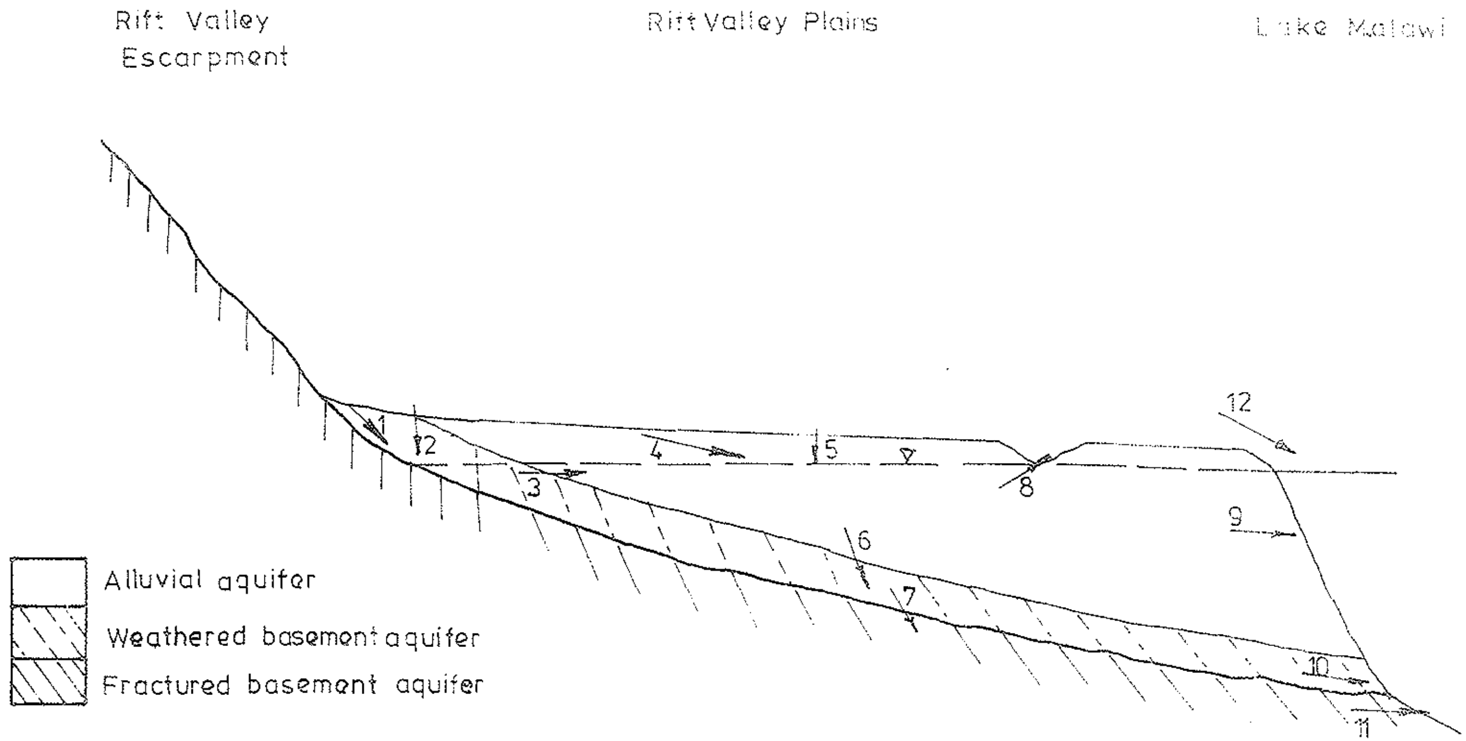
Conventional analysis of hydrographs for the Lilongwe catchment (gauge 4D4) and Upper South Rukuru catchment (gauge 7A3) by Chilton (1979) suggest average groundwater recharge of 39 mm and 20 mm respectively (4 percent and 2 percent of annual rainfall). These are also likely to be minimum recharge figures because of the large proportion of dambo drainage, and actual recharge could be significantly greater as suggested above.

The conventional analysis of hydrographs from the River Livulezi (3B3) over the period 1959/60 to 1964/65 suggests an average baseflow component of 80 mm across this catchment, representing an average of 30 percent of the total discharge and 8 percent of annual rainfall. This catchment is also underlain by weathered basement and has a similar climate to the Bua and Lilongwe catchments, but there is little dambo and the river channels are well defined. The hydrograph form is therefore much more flashy. These baseflow figures might be a more realistic guide to the recharge of weathered basement aquifers, however it should be noted that they will also include an element of recharge from water lost through the river beds at the base of the escarpment as well as widespread rainfed recharge, and the average rainfall (1035 mm) is higher than the average on the plateau areas (800-1000 mm).

The river gauges on the lakeshore plain are all located relatively close to the foot of the escarpment where the alluvium is thin or negligible. Baseflow hydrographs would therefore not represent groundwater discharge from the alluvial aquifer. Baseflow separation for the Shire River would be misleading because of the very large contribution of discharge from Lake Malawi which would completely mask any groundwater contribution.

Analysis of hydrographs over the period 1961/62 to 1973/74 for the Mwanza catchment (gauge 1K1), which is predominantly alluvial, showed a groundwater discharge in the range 3-80 mm (average 19 mm) over the catchment, which represents an average of 30 percent of the total discharge and 2 percent of rainfall. This will not be derived totally from rainfed recharge, but is likely to include a component derived from infiltration through the river beds. In alluvial areas groundwater will also be discharged as underflow through the aquifer and therefore the baseflow component of surface flow will not represent total recharge. It is clear that recharge to the alluvial aquifers and discharge from them is complex (Figure 3.18) and the relative contribution of the different components is uncertain.

FIGURE 3.18 SCHEMATIC DIAGRAM TO SHOW RECHARGE AND DISCHARGE IN ALLUVIAL AQUIFERS



1 Recharge to weathered basement aquifer from rivers at foot of escarpment
2 Recharge to weathered basement aquifer from rainfall
3 Recharge to alluvium from underlying weathered basement aquifer
4 Recharge to alluvium from river beds on rift valley plains
5 Recharge to alluvium from rainfall
6 Recharge to weathered basement from alluvium
7 Recharge to fractured basement aquifer from weathered basement aquifer
8 Discharge of groundwater from alluvium to rivers on rift valley plain
9 Discharge of groundwater from alluvium to Lake Malawi as underflow
10 Discharge of groundwater from weathered basement to Lake Malawi as underflow
11 Possible discharge of groundwater from fractured basement to Lake Malawi as underflow
12 Discharge of surface run off (including component of groundwater) into Lake Malawi

3.4.3 Catchment water balance

Using hydrological and meteorological data an attempt to produce a catchment water balance can be made using the general equation :-

$$P = Rs + Rg + Et \pm Ss \pm Sg \pm SMD$$

Where P	=	precipitation
Rs	=	surface run off
Rg	=	groundwater discharge
Et	=	actual evapotranspiration
Ss	=	change in surface storage
Sg	=	change in groundwater storage
SMD	=	change in soil moisture deficit

Assuming a sufficiently long period of analysis the changes in surface and groundwater storage and soil moisture deficit can be considered to be negligible if the balance is carried out over water years, and the equation reduces to :-

$$P = Rs + Rg + Et$$

It must be noted that there are errors in estimating each hydrological component, and thus groundwater discharge estimates should be treated with caution as they can easily be lost within the margin of error of larger components such as rainfall and evapotranspiration.

Considering the catchment to the gauging station 5D1 on the Bua River over a period of 16 years, the average balance equation in mm is as follows :-

$$904 = 58 + 18 + 779 \ (+ 50 \text{ imbalance})$$

A detailed breakdown of the calculations is given by Smith-Carington (1983). The average rainfall of 904 mm was estimated using Thiessen polygons for 8 rainfall stations and is considered to be representative with an error margin of perhaps 10 percent. The total gauged flow from the catchment (Rs + Rg) is also likely to be reasonably accurate although it is clear from section 3.4.2 that the determinations of groundwater discharge by hydrograph separation may well be an underestimate of groundwater recharge.

The estimates of actual evapotranspiration have been made for different types of land use within the catchment and weighted for the area they occupy (Table 3.6). The estimates were determined using the potential evapotranspiration rates for a station at Lilongwe and they depend on the nature of the vege-

TABLE 3.6 ESTIMATES OF ACTUAL EVAPOTRANSPIRATION, BUA PLATEAU AREA

(after Smith-Carington, 1983)

Land use	Cropped or fallow	Woodland	Dambo	Total
Root constant (mm)	140	200	-	-
Annual actual evapotranspiration* (mm)	703	763	1136	-
Proportion of catchment (%)	75-80	5	15-20	100
Evapotranspiration expressed over whole catchment (mm)	533	38	208	779

* annual potential evapotranspiration = 1285 mm

tation (particularly the rooting depth) and the moisture available within the soil. There are no measurements of actual evapotranspiration and the estimates above are subject to large error margins; they are particularly susceptible to error when the soil moisture deficit exceeds the point at which the actual evapotranspiration falls below the potential rate. The evapotranspiration rate from the dambo areas is taken as 120 percent of potential from January to March and gradually reducing to 50 percent of potential by October at the end of the dry season. The dambo vegetation appears to be green and actively transpiring throughout the dry season, and although the transpiring area may reduce slightly, the losses by transpiration are unlikely to be as low as those suggested by Balek (1977) for wooded catchments with dambo in Zambia.

The evapotranspiration from the dambo areas during the period June to November (when any river flow is entirely baseflow) is estimated to be 78 mm when expressed over the whole catchment. As stated in section 3.4.2 this could be derived partly from groundwater discharge as well as a build up of moisture deficits within the dambo clays. The total groundwater discharge could thus be as much as 96 mm/year when the residual groundwater discharge observed at the gauging station (18 mm) is included, although estimates of groundwater flow through the aquifer suggest that groundwater discharge could not be as high as this (see section 3.4.5).

Groundwater levels can fall to a depth of about 2 m below ground in the dambo by the end of the dry season, with the build up of moisture deficits in the clays above. The total water storage which could be available to plants (between saturation and tensions of 15 atmospheres) in 2 m of heavy clays is about 400 to 450 mm, depending on the pore size distributions (Doorenbos and Pruit, 1977). Expressed over the whole catchment, this represents a possible store of 60 to 68 mm, which would be sufficient to supply most of the dry season evapotranspiration from the dambo, but the relative contribution from this store and from groundwater are uncertain.

The 50 mm imbalance in the equation could be entirely due to underestimates in the determination of evapotranspiration, and errors in the determination of other hydrological components, It could also represent a component of groundwater underflow through the weathered zone, or deep percolation through fractured bedrock, although these are unlikely to be very large given the low permeability and fracture storage available.

The absence of any reliable data for surface runoff, groundwater discharge and actual evapotranspiration, and the complexities of the hydrological cycle in the alluvial area (Figure 3.18) precluded the attempt to carry out a catchment water balance for the Salima lakeshore area.

3.4.4 Groundwater level fluctuations

Seasonal fluctuations of groundwater levels can be used to estimate recharge wherever the storage coefficients of the aquifers are known. Accurate measurements of groundwater levels are only available for those boreholes with autographic recorders, but reliable estimates of the storage coefficients and their possible temporal variation with changing water levels cannot be made from the available data.

An estimate of 5×10^{-3} to 10^{-2} has been used for the storage coefficient in the weathered basement aquifer in the Bua catchment where the groundwater level remains within the confining clays. The observed seasonal fluctuations of water level are 2.0 to 3.5 m including an extrapolation of dry season recession rates during the period of water level rise (Figure 3.13). This would imply a recharge in the range 10 to 35 mm, although it cannot be refined to give any more precise estimate because of the inadequate data available. If the groundwater level falls below the confining clays, the storage coefficient will increase as the aquifer passes from semi-confined to unconfined conditions. As a result of these complications, this method of determining recharge cannot be used with any confidence.

The observed seasonal fluctuation in groundwater levels in the alluvial aquifer at Salima are 0.8 to 2.5 m including a component for extrapolated dry season recession. Using storage coefficients ranging from 10^{-2} to 5×10^{-2}, an annual recharge of between 8 mm and 125 mm is implied; the smaller water level fluctuations probably reflect a higher storage coefficient, thus the very wide range of recharge estimates can probably be reduced to 10 - 50 mm. Better estimates cannot be made because of the lack of detailed knowledge of the aquifer storage properties.

3.4.5 Groundwater flow

Regional flow nets can be constructed on the plateau areas and rift valley plains because of the very flat ground surface and therefore very flat piezometric surface beneath, however the local groundwater flow patterns are thought to be complex. There are insufficient data points to construct detailed flow nets on a local scale.

It is thought that any interpretation of groundwater flow through a regional flow net will be misleading because of the very large areas of dambo to which groundwater discharges, the uncertain but variable transmissivities and hydraulic gradients and the complexities of local flow cells.

In the Dowa West Integrated Project area, the close proximity of the water points and the large number of traditional wells near the dambo has enabled the construction of a more detailed map of piezometric levels (see section 3.3.5 and Figure 3.15). The hydraulic gradients are low, ranging from 0.014 to 0.044 during the dry season, and would be unable to steepen much even in the wet season because of the very gentle surface topography. The average transmissivity of the weathered basement in this area is estimated to be 0.3 to 2.2 m^2/d (see Table 3.7 and Section 3.2.3).

Using the equation :

$$Q = TiW$$

Where Q = groundwater discharge (m^3/d)

T = transmissivity (m^2/d)

i = hydraulic gradient

W = width (m)

the groundwater flow to the drainage lines (many of them being dambo margins) has been calculated (Ruxton, 1983 and Table 3.7). In the long run, the annual groundwater discharge will be balanced by recharge, thus the flow estimates were used to estimate recharge over the areas contributing to each discharge line (Table 3.7). Using this method, the annual recharge ranges from 4 to 36 mm. It is assumed that there are no evaporative losses directly from the water table over the interfluve because of the semi-confined nature of the aquifer, and that downward leakage to the bedrock beneath is negligible. It must be noted that the transmissivity estimates determined from test pumping of the boreholes are very low and may not be reliable (see section 3.2.4), and thus the recharge estimates could be rather low.

The annual groundwater discharge to Lake Malawi through a one kilometre wide section of the alluvial aquifer in the Salima area was estimated to be 0.13 - 0.38 x $10^6 m^3$ (see Section 3.3.5). This implies a minimum recharge of 13 to 38 mm over a ten kilometre length of outcrop of alluvium. There will, however, be an additional component of groundwater discharge to surface flow (which cannot be quantified as data is not available), and an unknown contribution to flow through the alluvial aquifer derived from or lost to the underlying weathered basement aquifer (see section 3.4.2 and Figure 3.18).

3.4.6 Summary of recharge estimates

The estimates of recharge derived using different methods are summarised in Table 3.8. There is a wide range of results, some of which must be treated with scepticism, but it is clear that recharge is difficult to define accurately. There are limitations to all the methods, but the most reliable estimates can probably be obtained from analysis of river hydrographs, provided that these are interpreted with caution especially for catchments which are dominated by dambo drainage. These will at least be able to give some idea of the minimum likely recharge. The estimates of recharge based on groundwater flow in the Dowa West Integrated

TABLE 3.7 RECHARGE ESTIMATES FOR DOWA WEST INTEGRATED PROJECT BASED ON GROUNDWATER FLOW THROUGH THE AQUIFER

Area	Length of discharge perimeter (km)	Average hydraulic gradient	Average transmissivity (m^2/d)	Annual groundwater discharge (10^3 m^3/yr)	Recharge area (km^2)	Estimated recharge (mm)
A	13.3	0.025	2.2	267	10.6	25
B	9.0	0.025	1.4	115	4.6	25
C	3.4	0.023	0.6	17	1.6	11
D	2.9	0.044	1.4	65	1.8	36
E	21.4	0.016	1.8	225	19.6	12
F	10.1	0.019	1.5	105	6.1	17
G	16.2	0.022	0.5	65	11.4	6
H	10.4	0.018	0.8	55	6.0	9
J	2.4	0.031	1.3	35	2.1	17
K	8.3	0.023	0.3	21	5.1	4
L	16.3	0.014	1.3	108	11.1	10
mean	10.3	0.023	1.2	98	6.4	16

Project are also likely to be fairly reliable, because of the large volume of accurate data available for a small area, unless the transmissivity estimates are too low. Less confidence can be given to the other methods of estimating recharge, and it is recommended that further work is carried out in this field, especially for the alluvial aquifers.

The recharge appears to be directly related to the annual rainfall, and it is therefore likely to be greatest in areas where the rainfall is highest. As a guide, the recharge is likely to be in the range 1-5 percent of annual rainfall for the weathered basement aquifers, and in the range 1-7 percent of annual rainfall for the alluvial aquifers. This is only a crude guide as this approach considers large areas, and boreholes and dug wells obtain water from relatively small areas, therefore local conditions may often be more important than regional conditions. It should be noted that the present groundwater abstraction for rural supplies is only a small fraction of the likely recharge (see section 4.1.3).

TABLE 3.8 SUMMARY OF RECHARGE ESTIMATES

Method	Recharge to weathered basement aquifer (mm)	Recharge to alluvial aquifer (mm)
Hydrograph analysis	15 - 80 (minimum)	3 - 80 (minimum)
Groundwater level fluctuations	10 - 35	10 - 50
Groundwater flow	4 - 36	13 - 38 (minimum)
Catchment water balance	18 - 96	-

3.4.7 Recharge to the weathered basement aquifers

Despite the semi-confining nature of the surface clays, it is likely that recharge occurs regionally by direct infiltration of rainfall leaking slowly through the clays. The recharge is likely to be recent, and this is confirmed by the generally low mineralisation of groundwater and the dominance of bicarbonate ions (see section 3.5). However, it is probable that the recharge on a local scale is very variable and occurs preferentially along specific zones.

Preferential flow routes may be along relicts of fratures, and along broken quartz or pegmatite veins where these remain preserved in the weathered profile and extend to the ground surface. Recharge will also occur preferentially around the bases of inselbergs and higher ground where the colluvial pediments have higher permeability, although this will occur only over relatively small areas. Surface runoff from the highlands may also recharge sediments in these areas.

The recharge to the aquifer by leakage through the surface clays is likely to be slow. This is confirmed by the very low infiltration rates observed in soakaway pits for waste water from boreholes and also by the delay of several weeks before any rise in ground water level is observed after the onset of rains (although the first infiltrating water will be used to satisfy moisture deficits).

It is possible that there is also some recharge via cracks in the dambo clays at the beginning of the wet season, but this must be of limited extent before the clays swell and seal and the water table rises close to the ground surface.

Infiltrating water may be diverted laterally by impeding layers in the weathered profile, such as massive laterites, and could be discharged as interflow to the dambo areas without penetrating to the water table. This is suspected to be the case in some areas of Mchinji and Kasungu Districts where laterite is very extensive and found at shallow depths below the surface. If the laterite is discontinuous, nodular or fractured, vertical drainage may be possible although it will be impeded. Stone lines may also provide preferential routes for interflow.

The network of burrows in the soil beneath termite mounds could be routes for any infiltrating water reaching them possibly via interflow from up slope, although the surface of the termite mounds tend to be structureless clay with low intrinsic permeability.

3.4.8 Recharge to the alluvial aquifers

The rainfed recharge will be very variable spatially depending on the permeability of the surface deposits, and will obviously be greater in the coarser, well sorted, more permeable materials. Recharge will also occur by seepage from the beds of rivers where they are significantly permeable and the hydraulic gradients are suitable. This will tend to occur where streams debouch from the escarpment zones. In addition recharge will occur by slow downward leakage through clay layers to those aquifers which are semi-confined, and from the underlying weathered basement aquifer. The relative importance of these different components is uncertain.

3.4.9 Evaluation of permanent resources

The permanent groundwater resources can be determined by a knowledge of aquifer geometry and physical properties. A lack of detailed data on specific yield and variation in saturated thickness of aquifer material preclude any accurate estimate of permanent resources.

As a guide, typical permanent resources in the weathered basement would be in the order of 150 mm across the catchment (for a saturated aquifer thickness of 15 m and specific yield of 1 percent) and those of alluvial aquifers would be 1500 mm across the catchment (for a saturated aquifer thickness of 50 m and specific yield of 3 percent) although it is recognised that there will be considerable variation from one location to another. The permanent resources should not be confused with the seasonally replenished resources which are available for abstraction.

3.5 GROUNDWATER CHEMISTRY

3.5.1 Background

The existing data on groundwater quality is mainly major element chemical analyses (some only partial analyses) carried out by the Geological Survey during the 1970s. This archive is considered to provide a useful indication of general water quality but individual analyses cannot be taken as completely reliable. This is evident where there is serious imbalance between cations and anions.

Caution must be taken in interpreting the analyses as the samples were probably collected without filtration, some of the analytical techniques may not be reliable and sampling/storage conditions are likely to have been poor. Unstable parameters (pH and bicarbonate (HCO_3) are particularly likely to be erroneous since they were not measured in the field. Nevertheless the records are valuable in the absence of any other analyses.

A DLWV water quality laboratory was set up in Lilongwe during 1982-1983 with facilities to make more accurate and reliable chemical analyses. This is equipped to analyse the major and secondary constituents and some trace elements present in groundwater.

Some local details of groundwater quality are given in various G S regional reports (Bradford, 1973; Chapusa, 1977; Pascall, 1973 and Wilderspin, 1973). Groundwater quality and its evolution was investigated in several water resource units by Bath (1980), and his report should be referred to for fuller details. A limited number of groundwater samples from the Lower Shire Valley were taken for isotope analysis, and the results indicate that isotopic compositions may be a useful tool to distinguish between groundwater of different ages and/or provenance (Bath, 1981).

On a national scale groundwater quality is generally acceptable for domestic water supplies, but there are some sizeable problem areas where water quality is not suitable for human consumption, and some local problem areas which are hard to define (these are identified as far as possible in the sheet descriptions accompanying the hydrogeological maps).

The areas with unsuitable water quality for drinking can usually be delineated, in the first instance, by electrical conductivity (EC) of higher than 3000 µS/cm (see Table 3.9) though high concentrations of individual ions may result in some waters being unacceptable despite the EC being less than 3000 µS/cm. It is generally considered that the World Health Organisation (1973) limits for drinking water standards are too strict and inappro-

TABLE 3.9 STANDARDS FOR DRINKING WATER IN ARID REGIONS
(modified from Schoeller, 1937, 1955)

	Suitability for permanent supply			
	Good	Fair	Moderate	Poor
Electrical (uS/cm) conductivity	0-750	750-1500	1500-3000	3000-6000
Na (mg/l)	0-115	115-230	230-460	460-920
Mg (mg/l)	0-30	30-60	60-120	60-120
Hardness (as mg/l $CaCO_3$)	0-250	250-500	500-1000	1000-2000
Cl (mg/l)	0-180	180-360	360-710	710-1420
SO (mg/l)	0-145	145-290	290-580	580-1150

priate for untreated rural groundwater supplies where any alternative source is likely to be highly polluted. The standards given in Table 3.9 are considered to be a more realistic guide to the desirable and achievable water quality standards in Malawi. The main drawback for domestic use is the widespread occurrence of high iron concentrations (see section 3.5.6) which are not dangerous on grounds of health, but make the water unpalatable and cause staining.

3.5.2 Groundwater quality in the weathered basement aquifer

The available chemical data suggests that the total mineralisation of groundwater in the plateau areas is generally very low, indicating that the weathered zone is highly leached of soluble minerals and the groundwater is likely to be derived from relatively recent recharge.

The electrical conductivity (EC), which is indicative of the concentration of total dissolved solids, is generally very low, usually less than 1500 µS/cm and commonly below 750 µS/cm. However, there are very local erratically distributed areas where the EC is greater than 3000 µS/cm which may be related to variations in bedrock mineralogy, or mineralisation in fault zones. Those areas towards the rift valley escarpment often have water of higher EC, which could be a function of more extensive faulting and a thinner, less leached zone of weathering. The weathered basement at the foot of the escarpment also tends to have water with higher conductivities.

The water quality can be very variable even over short distances which is evidence of low aquifer permeability, slow groundwater movement and little mixing. For example several samples from waterpoints in the Dowa West Integrated Project area have saline water with EC approaching 4,000 µS/cm whereas fresh water with EC less than 1,000 µS/cm can occur sometimes only a few hundred metres away. The poor quality is principally due to high sulphate levels (see section 3.5.6) and there can be considerable differences between waterpoints even within one village. A survey of water quality in existing boreholes and dug wells in the area before the project commenced did not reveal any particularly high conductivities and on the basis of these results the water quality problem could not have been foreseen without more detailed investigations. The impression of water quality was distorted because the non-functioning boreholes, which were not sampled, were subsequently found to have fallen into disuse largely because of saline water. The distribution of saline water does not appear to be easily related to differences in bedrock composition, and it could be due to mineralisation along fault zones. Very localised but significant variations were also shown by investigations at Timadzi, near Lilongwe (Bath, 1980).

It is suspected that there is often quality layering within the aquifer. Conductivity logging and analysis of samples from different depths in several boreholes located close together at Lilongwe International Airport revealed both distinct layering and considerable lateral variation (Figure 3.19). The chemical analysis of samples from CC113A observation well 2 show that as well as increased dissolution down the profile, there is mixing of at least two groundwater types of different chemical composition (Smith-Carington, 1983).

The groundwater of the plateau area is classified predominantly as calcium-bicarbonate type and a common range of compositions is shown in Table 3.10. In some cases cation exchange may have occurred and magnesium or sodium ions are the dominant cations. In the more mineralised waters sulphate levels may be high but chloride is usually very low. The few reliable field measurements show that the groundwater is usually slightly acidic (pH 5.5 to 7). The low pH together with dominance of the bicarbonate ions suggests that the infiltration is recent and that the water quality is controlled by solution processes in the soil and weathered profile.

3.5.3 Groundwater quality in the alluvial aquifers

The main feature of water quality in the alluvial aquifers is the extreme heterogeneity in the extent of mineralisation and in the chemical composition even over short distances. This is probably caused by enhanced mineralisation along fault zones and the very variable nature of the sediments, and the slow groundwater movement will allow sufficient residence time for local processes to dominate. The variable quality cannot be easily correlated with borehole depth, geology or piezometric level. Quality layering within the aquifer is suspected. Overall, the groundwater is generally more mineralised than that of the weathered basement aquifer (Table 3.10) and a significant number of boreholes have been abandoned due to high salinity, notably in the Lower Shire Valley and the eastern part of the Bwanje Valley.

Where electrical conductivities are low (EC less than 1,000 µS/cm), the composition is usually calcium-bicarbonate type implying recent recharge and processes of solution and hydrolysis of silicate minerals controlling the quality. With higher mineralisation, sodium ions tend to become dominant through cation exchange with the calcium and magnesium ions on clay surfaces in the alluvial sequences. The more saline groundwaters, with EC exceeding 2,000 µS/cm (and sometimes reaching as high as 17,000 µS/cm) usually have high concentrations of sulphate and/or chloride which dominate the anions. These are thought to derive from dissolution of evaporite minerals such as gypsum ($Ca\ SO_4$) or common salt ($NaCl$), and possibly from oxidation of sulphides such as pyrite (Fe_2S). High salinities are also caused by evaporative concentration from shallow water tables, for example in parts of the Lake Chilwa Basin and in parts of the Lower Shire Valley. The very high salinity of groundwater suggests that the hydraulic continuity

FIGURE 3.19 CONDUCTIVITY LOGGING OF BOREHOLES AT LILONGWE INTERNATIONAL AIRPORT

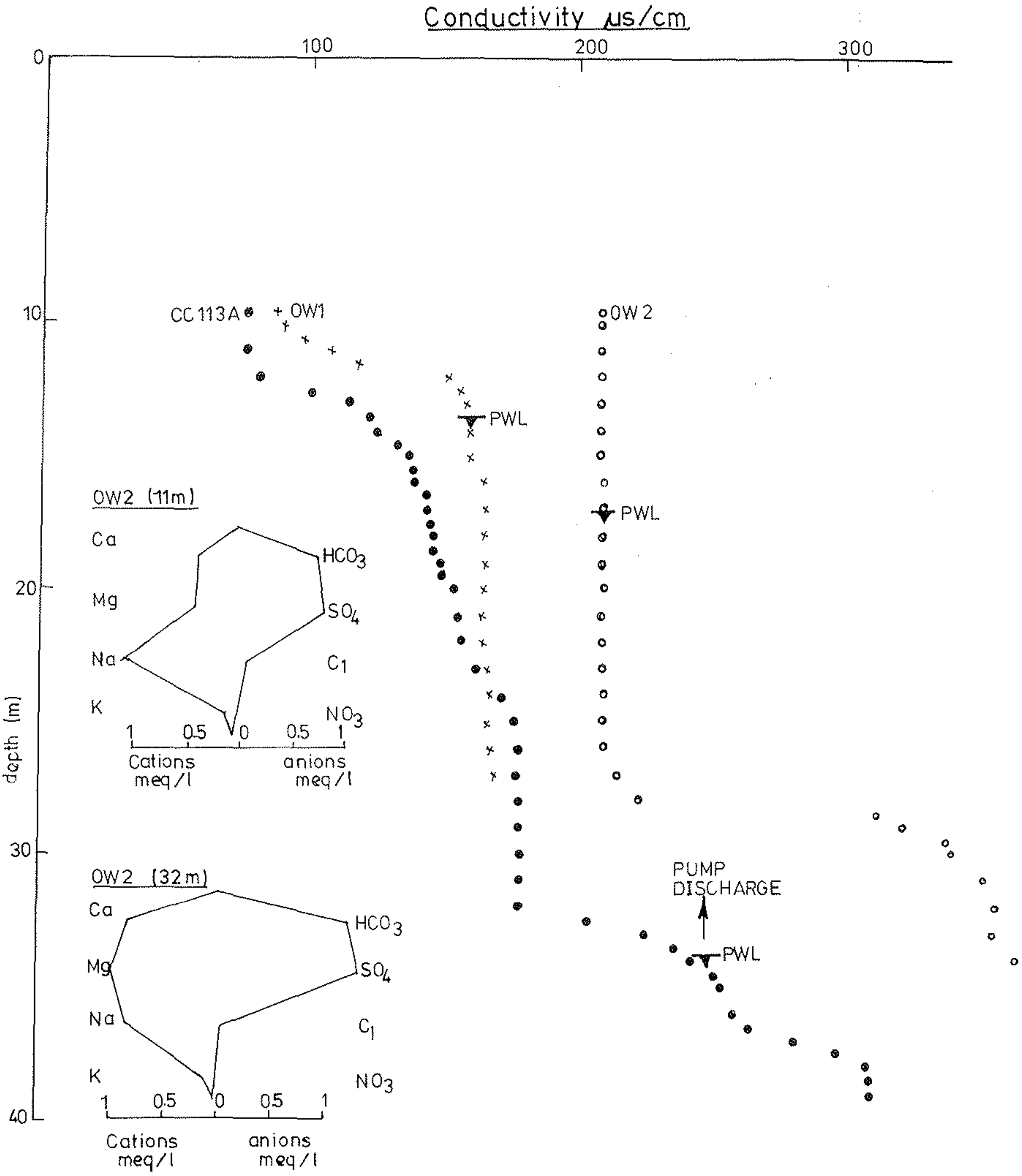


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TABLE 3.10 COMMON RANGE IN WATER QUALITY OF GROUNDWATER

		Weathered basement aquifers (plateau area)	Alluvial aquifers
Electrical conductivity (EC)	µS/cm	100–1,000	500–3000
Total dissolved solids (TDS)	mg/l	60–600	300–1800
Calcium (Ca)	mg/l	10–100	50–150
Magnesium (Mg)	mg/l	5–50	20–100
Sodium (Na)	mg/l	5–70	20–1500
Potassium (K)	mg/l	1–6	1–6
Total Iron (Fe)	mg/l	1–5	1–5
Bicarbonate (HCO_3)	mg/l	100–500	200–1000
Sulphate (SO_4)	mg/l	5–1000	20–2000
Chloride (Cl)	mg/l	less than 20	20–2000
Nitrate (NO_3–N)	mg/l	less than 5	less than 5
Fluoride (F)	mg/l	less than 1	2–10

between the alluvial aquifer and the Shire River may be poor in these areas. However there is localised fresher groundwater where there is loss of flow from ephemeral rivers which recharge the aquifer, for example from the Nyakambo River near Ngabu.

Along the alluvial plains in the Salima-Nkhotakota basin there is a tendency for the water quality to become less mineralised towards the lake; this is thought to reflect recharge to the alluvium from direct infiltration of excess rainfall and also by influent flow from rivers which lose fresher water into the sediments as they flow across the plains. This usually counteracts any natural tendency for salinity to increase by solution of minerals in the alluvium during the slow groundwater movement in the direction of the lakeshore. There may also be a relationship between groundwater quality and aquifer permeability, with the more permeable clean sands and gravels containing the fresher water.

By contrast this does not appear to be true for the Lower Shire Valley. Here there seem to be some large areas of poor quality water regardless of the lithology. There is also a tendency for a gradual increase in total dissolved solids down the hydraulic gradient away from the valley sides, possibly due to increased solution with movement through the aquifer matrix and/or evaporative concentration where the water table is shallow.

There are localised areas of highly mineralised groundwater associated with hydrothermal activity and upflow of thermal water along fault zones, for example along the Namalambo and Mwanza faults, in the Lower Shire Valley, and at the thermal springs near Nkhotakota (Kirkpatrick, 1969).

3.5.4 Groundwater quality in the Karoo sediments and volcanics

The groundwater quality in the Karoo aquifers of the Lower Shire Valley is highly variable ranging from relatively fresh water (usually calcium-bicarbonate type) to extremely saline water (sodium-chloride type). The sulphate concentrations are also highly variable. There is little information on the water quality in the Karoo aquifers in the north of Malawi.

3.5.5. Groundwater quality in the Cretaceous sediments

In the Lower Shire Valley, the Cretaceous sediments are calcareous and contain evaporite minerals; dissolution of these results in groundwater quality being generally poor and saline. Little is known about the water quality in other outcrops of Cretaceous sediments.

3.5.6 Individual problem ions

a) sulphate

There are some areas where high concentrations of sulphate occur. In the Dowa West Integrated Project area, for example, samples from boreholes very frequently exceed 400 mg/l and often exceed 800 mg/l; the latter figure is now under consideration as a country limit. Waters with high sulphate content, especially when in combination with magensium, are unsuitable for human consumption because of the laxative effect they will have, although local inhabitants are likely to have a higher than average natural tolerance.

In the Dowa West Project area the high sulphate levels can not be easily related to differences in bedrock composition, and it is possible that they could have been derived by upward leakage of mineralised waters along fracture zones. Conductivity logging and chemical sampling show that the concentrations increase with depth down the boreholes. Epsom salts ($MgSO_4$) and gypsum crystals ($CaSO_4$) have been found in dried up surface water courses and in pits dug in the dambo clays at the end of the dry season, and where there are heavy deposits, these are usually a good indication of poor quality groundwater in the surrounding catchment. It is thought that the high sulphate levels may be a result of the progressive oxidation of sulphide rich parent material, probably pyrite and phyrrotite in veins producing sulphuric acid, and the subsequent reaction with minerals containing magnesium or calcium. There may be associated high iron concentrations which could have been released into solution by the acidic conditions produced by sulphide oxidation. The situation is very complex and further studies are being made in an attempt to determine the origin of the sulphate and to predict the occurrence of poor quality groundwater.

High sulphate levels can also be produced by the dissolution of evaporite minerals such as epsom salts or gypsum, with associated high levels of magnesium or calcium. This situation is commonly found in the alluvial aquifers.

b) iron

The occurrence of high iron concentrations in waters from the weathered basement aquifer is widespread, and the problem is also quite common in some of the alluvial deposits. Concentrations are very variable, but high levels, commonly up to 5 mg/l are widespread.

This is far in excess of the WHO advised limit of 0.1 mg/l and maximum permissible limit of 1 mg/l. The iron is not damaging to health, but it leads to problems of acceptability of water because of the bitter taste and discolouration of laundry and food. There is thus a danger that people will use alternative unprotected water sources, possibly containing disease-producing bacteria and viruses.

The iron is most likely to be derived from ferro-magnesian minerals during weathering, and the presence of organic fulvic acids may result in complexing and increased mobilisation of the iron. These soluble complexes may precipitate out due to oxidation after prolonged standing or boiling. Iron deposits are often observed on the downhole components of handpumps when they are removed for maintenance; it is thought that these have been precipitated out because of the aeration caused during pumping. Corrosion of the borehole lining and handpump components by acidic groundwater may also contribute to the iron problem; this corrosion is commonly encountered and can result in the need to replace rods and rising main as often as every two years. The routine use of PVC lining and rising main may help to reduce this problem.

The causes of high iron concentrations and their apparently random occurrence are not yet fully understood. If necessary, the iron could be removed by aeration, but the process is inconvenient, problematic to maintain, and there is a likelihood of biological pollution.

c) manganese

High manganese concentrations (above 1 mg/l) present similar problems to iron because of objectionable taste and discolouring, but this problem is less common. The Rukuru Valley is an example of a badly affected area.

d) chloride

High chloride concentrations are a problem in the alluvial groundwaters particularly in the Lower Shire where concentrations frequently exceed 500 mg/l and are often over 2,000 mg/l in some areas. This is probably caused by evaporative concentration from shallow groundwaters and dissolution of evaporite minerals. High salinity has led to abandonment of many boreholes in favour of unprotected surface water sources. There are however some areas where water is consumed with very high chloride concentrations because there is no alternative source. Very little is known about the tolerance of people to saline water and its effect on health, but reduced consumption due to unpalatability is suspected.

Chloride concentrations are generally extremely low in the weathered basement aquifers (usually less than 20 mg/l).

e) fluoride

There are localised areas associated with fault zones and hydrothermal activity in the rift valley where fluoride contents are considerably in excess of desirable limits for potable supplies, for example the thermal springs in Nkhotakota (Kirkpatrick, 1969). If concentrations are between 2 to 10 mg/l consumers are subject to dental fluorosis, and if they are greater than 10 mg/l skeletal fluorosis is likely.

f) nitrate

The generally low nitrate concentrations (mostly less than 5 mg/l expressed as nitrogen) indicate that groundwater pollution is usually minimal. It is likely that the clay soils offer considerable protection to the aquifers from surface contamination derived from faecal matter and/or chemical fertilisers by absorbing ammonium compounds. In water-logged clays, conditions are likely to be anaerobic thus nitrification would not occur. Where water points have been properly completed, higher nitrate levels would only be expected where the weathered zone is thin, where fractured bedrock is near the surface, or in deep sandy aquifers where there is a sufficiently thick unsaturated zone below the nitrate source for nitrification to take place by biological oxidation.

The nitrate levels are likely to be highest in water sources in the middle of villages, but the health risk is relatively low, especially when compared with the alternative, traditional unprotected sources which are likely to be a much greater health hazard due to microbiological pollution.

The most likely risks of groundwater pollution from nitrate will be where the borehole or well surrounds are poorly constructed and it is possible for surface contamination to run directly into the water sources.

g) microbiological pollution

Water sources can be contaminated by excreta containing pathogenic bacteria and viruses etc, which can cause many types of infections. Bacteriological tests which show the presence of faecal coliforms can be used to indicate that disease producing pathogens may be present. Tests for total coliforms do not necessarily indicate faecal pollution as some of these will occur naturally as harmless soil bacteria, and waters without any total coliforms are rare.

Waterpoint construction practices are the single most important factor determining whether or not contamination will occur. Bacteriological examination of properly-constructed boreholes with good sanitary completion has shown that, on the whole, the water quality is very good with faecal coliforms usually less than 5/100 ml and commonly zero. Poorly-constructed boreholes are often highly polluted because it is possible for waste water to gain access to the boreholes. Covered dug wells are more difficult to protect because of the larger area of disturbance, and there are commonly 10-100 faecal coliforms/100 ml, the situation tending to be worse in the wet season. However this is a very considerable improvement from the bacteriological quality of unprotected sources where 10^2-10^3 faecal coliforms/100 ml is typical. Nevertheless, even where water is drawn from protected sources, tests on samples taken from collection buckets and storage pots in the home show that the water is often severely contaminated after collection. This emphasises the need for health education to preserve the water quality.

Water points should be sited well away, and preferably up gradient, from pit latrines and cattle kraals to minimise the pollution risks from pathogens, and also from nitrates (see section 4.3.1). This is, however, no substitute for good construction practices.

3.5.7 Chemical suitability of groundwater for irrigation

The relationships between water quality and its suitability for irrigation are complex and several factors need to be considered. Where groundwater is relatively fresh, with EC less than 1500 µS/cm, it will usually be suitable for irrigation. More saline waters can sometimes be used for irrigation provided that the soil is well drained, but special practices will probably be required.

The Sodium Adsorbtion Ratio (SAR) indicates how much free sodium is available and is defined as follows :

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where the ion concentrations are expressed in meq/l.

In moderate salinity groundwater, an SAR of less than 10 will usually be acceptable to prevent damage of soil structure and reduction in permeability by deflocculation, but an SAR of up to 18 may be acceptable if the salinity of the water is low with EC less than 250 µS/cm (Hem, 1970).

There may be an additional hazard connected with high residual sodium carbonate (RSC) which is defined as follows :

$$RSC = 2 \ (HCO_3 + CO_3) - (Ca + Mg)$$

where ion concentrations are once again expressed in meq/l. The RSC should be less than 2.5 meq/l and preferably less than 1.25 meq/l for safe irrigation.

Minor element concentrations, e.g. boron, require consideration with respect to crop tolerances. If irrigation schemes are planned, chemical surveys should be carried out in advance to determine whether the water quality is suitable for the crops required.

The water from the weathered basement aquifers appears to be mainly suitable for irrigation, except for parts of the South Rukuru Catchment where there is a salinity hazard, but the yields which could be supplied are small. Large scale irrigation using groundwater would be feasible on parts of the alluvial plains, but detailed preliminary investigations will be required to confirm the extent of suitable irrigation water because of the patchy salinity. In the Lower Shire Valley the highly saline groundwaters around the Elephant Marsh will not be suitable for irrigation. In the Salima area, the SAR values appear to be low but the overall salinity may be a problem at some locations. It should also be noted that field experience around the world has shown soil and management practices are far more important than the chemistry of the irrigation water.

CHAPTER 4

GROUNDWATER DEVELOPMENT

4.1 WATER DEMANDS AND EXISTING GROUNDWATER SUPPLIES

4.1.1 Introduction

The present demand for groundwater is largely for domestic purposes, and a summary of the supplies existing in 1981 is given in Table 4.1. Agricultural consumption of water is relatively small and usually obtained from surface water resources (rivers and dams), although there is a small demand for groundwater at some tobacco estates for the nurseries. It is likely that the demand for groundwater for irrigation will increase in the future, with the encouragement of higher crop productivity and even double cropping. Water requirements for industrial purposes are almost negligible at present, although they are likely to become significant in the future with the further development of the country.

TABLE 4.1 BOREHOLES AND DUG-WELLS EXISTING IN 1981

Boreholes with handpumps	4,275
Boreholes with motorpumps	577
Abandoned boreholes with lining	254
Abandoned boreholes without lining	428
TOTAL	5,534
Protected dug-wells	1,582
Open dug-wells (Colonial Development Schemes)	455
TOTAL	2,037

4.1.2 Rural domestic demands for water

Patterns of water use are complex and depend on a variety of factors including distance from the source, reliability of supply, water quality, and whether health education has encouraged increased water use. As a result of improved, protected supplies the water use may increase considerably, especially if the sources are nearer to the homes and more reliable. It is generally taken that water use remains very low (less than 10 l/head/day), unless there is a reliable source within a few hundred metres when water use will be moderate (10-to 25 l/head/day), and only increases dramatically to more than 40 l/head/day, if there are individual house connections (White et al, 1972; Feachem et al, 1978; Cairncross et al, 1980). Rural supplies in Malawi are "primary", i.e. a relatively simple supply which involves water collection from source rather than individual connections, and thus the demand is relatively low.

An evaluation of rural water use in the piped-water schemes (Msukwa and Kandoole, 1981; Ettema, 1983) and a preliminary study of the pilot groundwater project in the Livulezi Valley (Mauluka, 1981) both suggest that the actual consumption is commonly 10 to 15 l/head/day in rural areas of Malawi. A design consumption of 27 l/head/day for rural domestic supplies, has been used for both integrated groundwater schemes (see section 4.4 and DLVW, 1982) and piped-water schemes (Robertson, 1977), and this is in line with similar supplies in other parts of the world.

In 1977, the rural population of Malawi (5.0 million) thus presented an actual water supply demand at 15 l/head/day of about 27 x 10^6 m^3/year, though with improved supplies (27 l/head/day) the design consumption would be 49 x 10^6 m^3/year. The demand at design consumption will rise to the order of 71 x 10^6 m^3/year by 1990 with an estimated rural population of 7.2 million. The uneven distribution of population throughout the country obviously has implications for supplies and those areas most in need of improved supplies have been identified (see section 4.2.2).

4.1.3 Existing rural water supplies

Protected water supplies are obtained from boreholes, dug wells and piped-water schemes in rural areas. The 1977 census returns showed that a total of 1.28 million people, which was a quarter of the rural population, professed to have access to safe water supplies (Table 4.2). It is estimated that about 2.06 million people were served in 1981 and the total amount of water drawn was about 12.5x10^6 m^3/year. The total design capacity of the existing schemes is about 22.4 m^3/year which should be compared with

TABLE 4.2 EXISTING PROTECTED WATER SUPPLIES FOR RURAL DOMESTIC PURPOSES

	1977 population served (million)	Approximate number of water-points in in 1981	Estimated 1981 population served[2] (million)	Estimated supply in 1981[3] ($10^6 m^3$)	Estimated design capacity[4] ($10^6 m^3$/year)
boreholes with handpumps	0.82[1] (boreholes with handpumps and motorpumps together)	4,300	1.08	5.9	10.6
boreholes with motorpumps		550	0.14	2.0	3.5
protected dug wells	0.02	1,600	0.20	1.1	2.0
piped-water schemes	0.44[1]	4,000	0.64	3.5	6.3
TOTAL	1.28	10,450	2.06	12.5[5]	22.4[6]

NOTES:

1. 1977 census returns
2. 1 borehole serves 250 people, 1 dug well serves 125 people, 1 tap serves 160 people
3. Actual water use estimated to be 15 l/head/day for all sources except motorised boreholes which are estimated to be 40 l/head/day
4. Design water use, 27 l/head/day
5. Compare with actual water demand of $27 \times 10^6 m^3$/year in 1977 and $30 \times 10^6 m^3$/year in 1981
6. Compare with 1990 water demand of $71 \times 10^6 m^3$/year at design consumption

the projected 1990 demand of 71×10^6 m^3/year (see section 4.1.2). It is clear that there is an urgent need to improve water supplies in rural areas, as many people are still using unprotected sources such as rivers and open wells.

a) Boreholes with handpumps

In 1981 there were about 4300 boreholes equipped with handpumps providing clean, safe, but untreated water for rural domestic supplies (Table 4.3). These included some 3200 in villages, about 900 at institutions (such as schools, agricultural centres, health centres) and about 200 private boreholes (for example at trading centres and on estates). The institutional and private boreholes will be used for domestic supplies by employees and also by local rural communities. The vast majority of these boreholes with handpumps are maintained by DLVW, and very few are maintained privately. The District Councils are financially responsible for the village boreholes and also for some of those at institutions, though there are plans for Central Government to take over this responsibility. Some boreholes which are marked as operational in the master cardex records are actually abandoned in the field. Boreholes are located all over the plateau areas and rift valley floors, with the greatest concentrations being in the more densely populated Southern and Central Regions, especially in areas where there have been agricultural development projects (see hydrogeological maps).

The number of people served by each borehole is very variable. Some are hardly used, and others probably supply more than 500 people, which is many more than desirable, and queues of women waiting to collect water can be observed, especially during the peak hours of the early morning or late afternoon. There are often very large walking distances from the dwelling places, and it is clear that the existing boreholes are insufficient in number and too widely spaced to meet the demand. As a very rough estimate, perhaps 250 people on average might be served by each borehole and thus about 1.1 million people were served in 1981. It should be noted that at any one time there are a significant number of boreholes which are not operational. If handpump breakdowns are frequent and long periods elapse before repairs are carried out, it is suspected that the local community may lose confidence in the protected supply and cease to use it altogether.

Based on a consumption of 15 l/head/day with an average service level of 250 people per borehole, the total annual abstraction of water was in the order of 5.9×10^6 m^3 in 1981. Each borehole with a handpump produces an average discharge of perhaps 700 l/hour or 4 m^3/day. These abstractions of groundwater represent only very small quantities when expressed over the total ground surface, and are only a very small proportion of the annual recharge (see section 3.4). Abstraction of groundwater from boreholes (with both handpumps and motorpumps) was estimated to be equivalent to 0.3 mm/year over the Lilongwe catchment (Chilton,

TABLE 4.3 BOREHOLES EXISTING IN 1981

WR No.	Handpump				Motor Pump				Abandoned with lining	Total
	Village	Institution	Private	Total	Institution	Private	District Water Supply	Total		
1A	25	7	-	32	3	-	-	3	3	38
1B	71	11	-	82	1	1	-	2	-	84
1C	49	28	3	80	1	2	-	3	-	83
1E	24	32	1	57	9	3	4	16	1	74
1F	74	10	1	85	1	-	-	1	6	92
1G	113	12	2	127	1	3	4	8	15	150
1H	249	8	5	262	-	5	7	12	74	348
1K	104	25	3	132	6	1	-	7	3	142
1L	21	-	-	21	1	3	3	7	5	33
1M	6	2	-	8	-	-	-	-	-	8
1N	6	-	-	6	-	-	-	-	-	6
1O	25	9	5	39	-	1	-	1	-	40
1P	37	6	2	45	1	1	-	2	1	48
1R	75	30	8	113	5	7	3	15	-	128
1S	41	14	3	58	1	1	-	2	4	64
1T	15	3	1	19	-	-	-	-	-	19
2A	59	4	-	63	-	-	-	-	3	66
2B	150	33	7	190	6	17	3	26	4	220
2C	32	20	1	53	-	3	-	3	3	59
2D	31	11	-	42	-	4	-	4	1	47

(Continuation) TABLE 4.3

WR No.	Handpump				Motor Pump				Abandoned with lining	Total
	Village	Institution	Private	Total	Institution	Private	District Water Supply	Total		
3A	13	2	3	18	-	-	-	-	-	18
3B	8	-	-	8	-	-	-	-	-	8
3C	28	5	-	33	-	1	-	1	-	34
3D	48	10	9	67	1	2	-	3	4	74
3E	52	12	5	69	-	3	-	3	2	74
3F	46	10	6	62	2	-	-	2	1	65
4A	11	-	-	11	2	-	-	2	-	13
4B	134	35	2	171	5	3	1	9	8	188
4C	103	22	-	125	15	1	-	16	-	141
4D	220	23	7	250	14	6	4	24	2	276
4E	116	20	1	137	15	6	-	21	5	163
4F	15	4	-	19	14	3	-	17	6	42
5C	7	4	1	12	2	12	-	14	3	29
5D	115	44	20	179	8	26	5	39	6	224
5E	205	42	18	265	2	3	1	6	2	273
5F	31	12	31	74	5	84	-	89	3	166
6A	9	4	-	13	-	-	-	-	1	14
6B	3	5	-	8	4	2	-	6	2	16
6C	32	14	4	50	3	33	-	36	19	105
6D	27	15	4	46	14	11	-	25	10	81

(Continuation) TABLE 4.3

WR No.	Handpump				Motor Pump				Abandoned with lining	Total
	Village	Institution	Private	Total	Institution	Private	District Water Supply	Total		
7A	107	42	1	150	4	1	-	5	2	157
7B	15	29	3	47	2	5	-	7	6	60
7C	14	15	3	32	-	23	-	23	3	58
7D	17	22	4	43	1	7	-	8	5	56
7E	25	16	8	49	1	11	-	12	9	70
7F	23	12	-	35	2	-	-	2	-	37
7G	9	14	-	23	-	-	-	-	1	24
8A	23	10	4	37	2	3	-	5	-	42
9A	16	11	2	29	1	-	-	1	-	30
9B	26	29	-	55	3	2	3	8	5	68
10A	31	3	1	35	-	-	-	-	-	35
11A	18	7	1	26	2	1	-	3	1	30
14A	13	13	-	26	2	2	3	7	1	34
14B	91	21	2	114	5	10	1	16	1	131
14C	8	2	5	15	2	3	1	6	2	23
14D	17	7	2	26	-	-	-	-	2	28
15A	144	37	7	188	10	19	4	33	12	233
15B	47	21	1	69	-	3	2	5	1	75
15C	4	2	-	6	-	1	-	1	-	7

(Continuation) TABLE 4.3

WR NO.	Handpump				Motor Pump				Abandoned with lining	Total
	Village	Institution	Private	Total	Institution	Private	District Water Supply	Total		
16E	8	9	-	17	1	1	-	2	1	20
16F	5	10	3	18	2	1	-	3	1	22
16G	2	1	-	3	1	-	-	1	-	4
17A	22	3	-	25	2	-	-	2	-	27
17B	25	3	-	28	-	-	-	-	-	28
17C	35	12	1	48	2	-	-	2	4	54
TOTAL	3175	899	201	4275	187	341	49	577	254	5106

1979), less than 1 mm/year over the South Rukuru catchment (Chilton, 1979), 0.2 mm/year over the plateau area of the Bua catchment (Smith-Carington, 1983) and 0.4 mm/year in the Salima-Nkhotakota Lakeshore plain (Mauluka, 1983).

The design criteria for rural groundwater supply programmes are 27 l/head/day and 250 people to be served by each borehole (see section 4.4). On this basis, the design capacity of the boreholes equipped with handpumps, existing in 1981 was 10.6x 10^6 m^3/year (Table 4.2).

b) boreholes with motorpumps

There are motorised water supplies at many institutions (schools, missions, health centres, agricultural centres, prisons, police stations, customs posts, etc) with water derived either from rivers or groundwater. In 1981 there were about 200 boreholes with motor pumps at institutions (Table 4.3) of which 56 schemes are maintained by the Water Supplies Branch of DLVW (Table 4.4) and the remainder are maintained privately.

There were also 350 private boreholes equipped with motor pumps for example on estates (Table 4.3). Most of these are used primarily for domestic supplies for employees. Additional private boreholes drilled by contractors are also thought to exist, but the total number and locations are uncertain and there are no borehole records.

The motorised schemes usually have a distribution network to a series of stand pipes or individual house connections, and the water is used mainly for domestic supplies. The consumption per capita is likely to be higher than at boreholes with handpumps because the walking distances are shorter. There are no records of abstraction or per capita consumption but taking an estimate of 10 m^3/day for each borehole (serving perhaps 250 people with 40 l/head/day) the total annual groundwater abstraction from 550 motorised boreholes is likely to be of the order of 2.0 x 10^6 m^3/year (Table 4.2).

c) protected dug wells

In 1977 the number of people served by protected dug wells was about 0.02 million, because only about 170 had been constructed. The dug-well programme has expanded considerably since then, and it is estimated that by 1981 about 1600 covered wells had been constructed and equipped with handpumps. These are largely restricted to specific project areas (see Table 4.5 and hydrogeological maps), but the area coverage is more complete with most villages having a dug well wherever possible. The walking distances thus tend to be lower, and the number of people served by each water point is probably lower than for the boreholes. However there are large areas of the country with no protected dug wells.

TABLE 4.4 INSTITUTIONAL SUPPLIES FROM BOREHOLES MAINTAINED BY WATER SUPPLIES BRANCH, DLVW

NORTHERN REGION	DISTRICT
Meru agricultural centre	Karonga
Karonga airport	Karonga
Mwimba agricultural centre	Karonga
Ngerenge agricultural centre	Karonga
Bwengu agricultural station	Rumphi
Mqocha customs post	Mzimba
Chilumba secondary school	Karonga
Lusangazi (M.B.C.)	Mzimba
M'mbelwa farm institute	Mzimba
Robert Laws school	Mzimba
CENTRAL REGION	
Nathenje agricultural station	Lilongwe
Dzeleka prison	Dowa
Kasungu airport	Kasungu
Kasungu prison	Kasungu
Chilanga primary school	Kasungu
Mchinji secondary school	Mchinji
Chitala agricultural station	Salima
Likasi veterinary campus	Salima
Rusa settlement scheme	Kasungu
State House	Lilongwe
Lisasadzi	Kasungu
Liwaladzi	Nkhotakota
Tembwe agricultural station	Mchinji
Mlangeni police training school	Ntcheu
Salima airfield	Salima
Mvera water supply*	Salima
Bua rice irrigation scheme	Nkhotakota
Lilongwe old airport*	Lilongwe
SOUTHERN REGION	
Lengwe NationalPark	Mwanza
Chiradzulu secondary school	Chiradzulu
Chikwawa secondary school	Chikwawa
Bangwe police station	Blantyre
Mwanza customs/police post	Mwanza
Mbulumbuzi pilot dairy	Chiradzulu
Naminjiwa agricultural centre	Mulanje
Kasinthula research station	Chikwawa
Makhanga research station	Chikwawa
Bvumbwe research station	Thyolo
Namitambo health centre	Chiradzulu
Ndakwera health centre	Chikwawa
Thuchila agricultural centre	Mulanje
Mwanza hospital	Mwanza
Mwanza secondary school	Mwanza
Ndata veterinary farm	Thyolo
Magomero training centre	Chiradzulu
Chilwa approved school	Zomba
Mpyupyu prison farm	Zomba
Mikuyu prison	Zomba

TABLE 4.4. (Continuation)

SOUTHERN REGION	DISTRICT
Nayuchi police station	Machinga
Makanjira police station	Mangochi
Makoka research station	Zomba
Ntaja agricultural station	Machinga
Chiponde customs (Namwera)	Mangochi
Nasawa technical training centre	Zomba
Namwera police post	Machinga

NOTE:

* Institutional supply also operated by DLVW

TABLE 4.5 PROTECTED DUG WELLS CONSTRUCTED BETWEEN 1975 & 1981

District	Number of dug wells
Dedza	267
Ntchisi	74
Kasungu	219
Lilongwe	258
Dowa	602
Mzimba	120
Mwanza	13
Ntcheu	22
Mulanje	7
TOTAL	1,582

Note:

172 protected dug wells constructed between 1975 and 1977

Using an estimate of 125 people per dug well and a water consumption of 15 l/head/day the estimated total annual abstraction of groundwater was about 1.1×10^6 m^3 in 1981. Each dug well probably abstracts about 2 m^3/day on average; yields are low and some wells may dry up with heavy use during the day, requiring a period of several hours for replenishment of storage. Using the design criteria of 27 l/head/day and a service level of 125 people per dug well, the design capacity of those existing in 1981 was 2.0×10^6 m^3/year.

It should be noted that some of the 455 dug wells constructed by the Colonial Development Schemes in the 1930s are thought to be still in use. However these wells are open, and the level of protection from pollution will usually be considerably lower than in the covered wells equipped with handpumps.

d) piped-water schemes

The programme of gravity fed piped-water schemes provided protected supplies for 0.44 million people in 1977, according to the census data. New schemes have opened since that date and the population served by the 31 schemes in 1981 is estimated to be about 0.64 million (see surface water volume 2 of NWRMP). Further projects were then either under construction or planned. These schemes take water from protected upland rivers with perennial flows, and feed it by gravity into a network of reticulation pipes with a tap in each village served (Glennie, 1982).

The schemes are designed to abstract up to a maximum of the five year low-flow from the river intakes. The design capacities are based on a 10 year projected population or the "agricultural carrying capacity of the land" whichever is the greater, and a design consumption of 27 l/head/day (Robertson, 1977). The present consumption of most schemes is estimated to be less than full capacity, as the actual water use is only 10 to 15 l/head/day, although some of the earlier schemes now have reached or even exceeded their design populations. When used to full capacity, the schemes cannot be augmented without the addition of further pipe networks and possibly the identification of a new source. The 1981 water use is estimated to be 3.5×10^6 m^3 with an average of 160 people using each tap and the total design capacity of these schemes is 6.3×10^6 m^3/year (Table 4.2). Any further piped-water schemes are likely to require the construction of dams (to ensure dry season supplies) and/or treatment works (because of the danger of source pollution) which will greatly increase both capital and recurrent costs. It is unlikely that piped-water schemes can serve more than 25 percent of the rural population because of the limited number of perennial protected sources.

e) unprotected supplies

In 1977, three quarters of the rural population (3.8 million) used unprotected sources (including rivers, springs, and open dug wells) because there was no access to safe supplies. These are commonly polluted by bacteria, and other pathogens derived from excreta, which can cause water-related diseases such as diarrhoea, cholera, typhoid and hepatitis if the contaminated water is drunk (see section 3.5.6). These infections are a major cause of disease and infant mortality in developing countries.

It is clearly desirable that this situation be improved as soon as possible with the implementation of protected water supply schemes. Since only about 25 percent of the rural population could be supplied from piped schemes, it follows that about 75 percent will have to be supplied from groundwater.

4.1.4 Urban supplies and demands

The operation and maintenance of the District Water Supplies are the responsibility of the Water Supply Branch of DLVW, with the exception of Lilongwe and Blantyre which have their own Water Boards. Water supplies are derived from either rivers (some requiring storage dams) or Lake Malawi (See Surface Water Volume 2 of NWRMP), or from groundwater (Table 4.6). The source works are coupled to either a motor pump or diesel engine and feed into a central storage reservoir. From here the water gravitates into a reticulation system which supplies communal stand-pipes or individual houses if the owners can afford the connections. Details of individual schemes are given in the Data Book Project Report (1982).

The total annual consumption of groundwater for District Water Supplies was estimated to be 1.3×10^6 m^3 in 1981. These figures were derived from consumer meter readings between October and December 1981, in the absence of meters on the main pipelines, and therefore cannot be taken to be completely reliable. The consumption varies slightly during the year, tending to be highest during the dry season (when it can be about 20 percent above average) falling after the onset of the rainy season. The water consumption per capita is much higher than in rural areas, although accurate figures for water use are not known.

Most of the District Supply Schemes do not serve the entire population of the towns, and many are already stretched to full capacity, especially those relying on groundwater. Boreholes are often pumped close to 24 hours per day with insufficient time for recovery of water levels. Those in weathered basement aquifers are particularly vulnerable to overabstraction because the yields which can be obtained are relatively low. Further details of

TABLE 4.6 DISTRICT WATER SUPPLIES FROM GROUNDWATER
(OPERATED & MAINTAINED BY WATER SUPPLY BRANCH, DLVW)

Water Supply Scheme	Estimated 1982 population	No. of metered connections	Estimated average abstraction (1) (m^3/d)	Estimated abstraction in 1981 (2) ($10^6 m^3$)	Estimated average consumption (1) (l/head/day)	% of population covered by scheme (1)	Aquifer type (3)	Borehole number	G.S. number	Test yield (l/sec)
Chitipa	4,200	192	205	0.073	70	70	WB	9B32	PM482	2.0
								9B5	H156	0.8
								9B7	H157	1.5
Nkhotakota	13,000	161	300	0.114	70	33	A	15B12	W321*	3.2
								15B64	IR107	14.0
Dowa	2,600	63	130(R)	0.047(R)	70	71	FB	15A210	W120	3.0
								15A234	Redcross	4.0
Chitedze (Agricultural Station)	2,500	159	220(R)	0.095(R)	100	88	WB	4D277	W118	2.8
								4D272	GP7	2.0
								4D274	GP8	1.5
								4D273	GP4*	0.75
Salima	7,500	346	530	0.275	100	71	A	15A59	D56	3.0
								15A212	A57(S)	9.8
Mponela	4,500	77	120	0.044	70	38	WB	5D168	SM196	1.25
								5D224	W176	1.25
								5D212	W322*	2.0
								5D223	RK126	3.0
								5D44	A41	2.5
Ntcheu	5,000	132	275(R)	0.100(R)	70	78	WB/FB	1R128	L429	1.4

TABLE 4.6 (Continuation 2)

Water Supply Scheme	Estimated 1982 population	No. of metered connections	Estimated average abstraction (1) (m^3/d)	Estimated abstraction in 1981 (2) ($10^6 m^3$)	Estimated average consumption (1) (l/head/day)	% of population covered by scheme (1)	Aquifer type (3)	Borehole number	G.S. number	Test yield (l/sec)
Kochililia Health Centre	300	-	30	0.011	100	100	WB	-	dug well	1.0
Kabudula Hospital	150	-	15	0.006	100	100	WB	5E49	W155	0.8
Dedza Customs	100	-	10	0.004	100	100	WB	4B20	E52	0.8
Balaka	7,000	136	260	0.116	70	53	A	1R53 1R44	E300 E299(S)	4.0 -
Chikwawa	5,000	124	150	0.055	70	43	A	1L5 1L6 1L4	HD163A HD164 T3	2.0 2.0 0.75
Ngabu	5,500	300	250	0.119	70	65	A	1H266 1H109 1H77 1H344 1H129	Q451 D44 W205 A179 Q237	2.75 5.0 1.25 1.5 -
Mikolongwe Vet.Station	1,200	46	110	0.049	100	100	WB	14A22 14A11 14A37	W112 Q63 K75	- 0.8 0.5
Nsanje	8,000	194	240	0.090	70	43	A	1G27 1G28 1G32 1G33	K168A K168B T5A T5B	0.6 1.1 5.0 1.5

TABLE 4.6 (Continuation 3)

Water Supply Scheme	Estimated 1982 population	No. of metered connections	Estimated average abstraction (1) (m^3/d)	Estimated abstraction in 1981 (2) ($10^6 m^3$)	Estimated average consumption (1) (l/head/day)	% of population covered by scheme (1)	Aquifer type (3)	Borehole number	G.S. number	Test yield (l/sec)
Mpemba Training School	2,000	83	65	0.026	70	46	WB	1E79	L300A	1.0
								1E9	L300B(S)	0.5
								1E1	C162	0.5
								1E72	PM604A	0.75
Nchalo	2,000	21	50	0.019	70	36	A	1H291	RB151	3.5
								1H292	RB150(S)	0.5
Chiradzulu	1,200	88	60(R)	0.022(R)	70	72	WB	2B219	J34	2.5
								2B217	J35	1.5
								2B218	J37	1.25
Luchenza	5,000	54	80(R)	0.026(R)	70	23	WB	14B49	J28	0.9
Muloza Customs	1,200	-	15	0.007	45	30	WB	14C6	E36A	0.9
TOTAL	77,950	2,176	3,115	1.298						

NOTES:

* borehole to be equipped

S standy borehole

R including supplement from river

(1) - records from Data Book Project (1982)

(2) - based on consumer meter readings October-December 1981

(3) - aquifer types WB = weathered basement
FB = fractured basement
A = alluvium

borehole and aquifer performance are given in section 3.2.3 for those boreholes where there has been long term test pumping. Some of the very low yielding boreholes are only used as standby supplies for emergencies.

The District Water Supplies which are most in need of improvement have been identified, and proposals for emergency up-grading of these existing schemes to serve the 1985 demand were put forward by Howard Humphreys (1979) and Ministry of Works (1979). The design consumption was based on housing categories estimated by the Town Planning Department (1977) as follows :

Low density housing	-	300 l/head/day
Medium density housing	-	200 l/head/day
Highdensity housing	-	100 l/head/day
Traditional housing	-	50 l/head/day

In the absence of these figures, design consumption of 100 l/head/day has been taken as average.

The designs which proposed to use groundwater are given in Table 4.7, and most of these schemes were included in Phase 1 of the African Development Fund (ADF) Programme which is currently being implemented.

There are also projects which are currently underway to supplement the existing District Water Supplies with further stand pipes wherever there is spare capacity at the source works. These projects will particularly be of benefit to the urban poor sector. These schemes use a design consumption of 37.5 l/head/day to serve the projected 1990 population of the area. Schemes using ground-water have already been implemented at Mponela and Dowa and are under construction at Nkhotakota and Balaka.

Long term plans for Urban schemes will be made following the recommendations of Phase 2 of the NWRMP. The ADF Project (Phase 2) will implement schemes in a programme such that those centres in most need will have priority. It is difficult to pro-ject populations and water demands far into the future, especially for urban areas where growth rates are high and the aspirations of the population are increasing. The water supply requirements therefore need to be reviewed and updated at regular intervals, preferably every 5-10 years.

TABLE 4.7 SCHEMES FOR IMPROVEMENT OF DISTRICT WATER SUPPLIES (GROUNDWATER SOURCES)

Town	Proposed source	Estimated total 1985 population	Estimated 1985 domestic demand (m^3/d)	Design capacity of scheme (m^3/d)
Mponela (C)	boreholes	3,800	310	400
Mchinji (C)	spring	1,200	90	500
Monkey Bay (C)	boreholes	3,300	350	675
Namwera (C)	boreholes	700	70	150
Balaka (C)	boreholes	8,200	700	900
Mwanza (C)	well points	600	50	250
Ntcheu* (C)	boreholes	4,400	350	600
Dowa* (C)	boreholes	2,100	150	250
Ekwendini (C)	well points	1,700	130	250
Rumphi (C)	river/well points	4,600	400	600
Mpemba (W)	boreholes	1,300	125	-
Nsanje (W)	boreholes	8,400	380	-
Chiradzulu (W)	boreholes	500	60	-
Nkhotakota (W)	boreholes	11,900	870	-

C - design by consultant (Howard Humphreys, 1979)

W - design by Ministry of Works (1979)

* - deleted from ADF programme

4.1.5 Water demands for agriculture

Over the country as a whole, the present demand for water for irrigation is very small. There are however a few large commercial schemes using significant volumes of water for agricultural purposes. Nearly all of the schemes abstract from surface water resources, either directly from perennial streams and rivers or from dams. Groundwater abstraction for irrigation is negligible at present.

The Sucoma Sugar Estate in the Lower Shire Valley and Dwangwa Sugar Estate on the Lakeshore near Nkhotakota are the two largest irrigated schemes, and account for most of the irrigated acreage in Malawi (Table 4.8). There are also 16 small rice schemes (along the Lakeshore, in the Chilwa-Phalombe Plain and in the Lower Shire Valley). There is some supplementary irrigation on 14 tea estates during the late dry season to make up moisture deficits. Some of the tobacco estates in the Central and Southern Regions irrigate limited areas to allow early planting, but expansion is limited by high costs (NSIS, 1980).

Very few of the existing schemes have any means of monitoring irrigation flows and there is little idea of how much is being consumed. As a rule of thumb a discharge of 1 l/sec/ha is required for irrigation. However NSIS (1980) examined limited flow records at Lufira rice scheme and found average flow rates of at least twice that which is theoretically necessary, even allowing for inefficient irrigation.

The boreholes at agricultural centres are not used for irrigation purposes, but entirely for domestic supplies and training courses etc. (see section 4.14). Some of the private estates may use groundwater from their boreholes for nurseries, dry planting and irrigation as well as domestic supplies. Notable examples are some of the estates in Mchinji District growing tobacco and irrigated wheat. The amount of water used is uncertain, but likely to be very small relative to domestic water use.

With a growing population to feed, Malawi is now looking for a means of improving crop yields. It is likely that the demand for irrigation water will rise substantially in the future to enable double cropping to increase agricultural output. Many areas will not be able to use surface water since the flows would not be dependable. Peak demands will coincide with low (or even non-existent) river flows towards the end of the long dry season. There may also be other conflicting demands on surface water use. It is quite possible that substantial irrigation demands in the future could be met by groundwater supplies (see section 4.2.3). A "micro-project" based on groundwater in the Salima area is due to start in late 1983 and continue for four years.

TABLE 4.8 IRRIGATION SCHEMES (AFTER NSIS, 1980)

Sites	Crop	Irrigation sources	Total Irrigated area (ha)
Sucoma (Lower Shire Valley)	Sugar	Shire river	9000
Dwangwa	Sugar	River Dwangwa and Lake Malawi	6000
Lakeshores and Lower Shire Valley	Rice	Rivers	3200
Mulanje, Thyolo and Nkhata Bay	Tea	Rivers and Dams	860
Central and Southern Regions	Tobacco	Rivers and Dams	225

4.2 GROUNDWATER DEVELOPMENT POTENTIAL

4.2.1 Introduction

It is clear that further groundwater development is required to meet even the existing demands for rural and urban domestic supplies, and that there is also scope for groundwater development for irrigation or industrial schemes in some areas.

From the preceeding sections on hydrogeology in Chapter 3 it is obvious that there are two main aquifer types in Malawi, with very different physical properties :-

a) weathered basement aquifers:

These are found largely on the low-relief plateau areas and at the base of the escarpments. Potential yields are low (generally less than 1 l/sec) and broadly related to the depth of the weathered zone but the aquifer is present over most of the plateau area, as there is usually a sufficiently deep saturated thickness of a well-developed weathered zone. The average recharge is thought to be in the range 1-5 percent of annual rainfall, typically 10-50 mm per year. The groundwater quality is generally good, but there are localised areas with quality problems which are difficult to quantify without detailed survey work.

b) alluvial aquifers

These are found on the lakeshore plains and in the flood plains of rivers in the rift valley bottom (e.g. Shire, Bwanje). Potential yields are variable due to the heterogeneous and complex sedimentation, but could be moderate (5 to over 15 l/sec) wherever there are significant thicknesses of sands and gravels in the sequence. The average recharge is thought to be in the range 1-7 percent of annual rainfall, (typically 8-60 mm per year) derived partly by rainfed infiltration and also by seepage from surface water courses at the base of the escarpments where they first pass onto the alluvium. Groundwater is generally more mineralised than in the weathered basement aquifers and there are some areas where the water is too saline for human consumption, for example the eastern part of the Bwanje Valley and parts of the Lower Shire Valley. The water quality may be extremely variable even over short distances.

The unweathered fractured basement found on the steep slopes of the escarpment or the uplands rising from the plateau are rarely significant aquifers because of the low storage and low permeability. These areas are usually very sparsely populated and thus the demand for water is not great, but where it is required, access to the sites may be difficult. There may be local situations where significant yields can be obtained from areas where the bedrock is well fractured but these zones can be difficult to locate and recharge will not be dependable.

The other aquifer types (Karoo sediments and volcanics, Cretaceous to Pleistocene sediments) are less significant in terms of their areal extent but may be important locally.

4.2.2 Groundwater potential for rural domestic supplies

Low yields (0.25 to 0.5 l/sec) are all that is required for handpump supplies. With improved borehole and protected dug-well designs (see section 4.3) it is likely that sufficient yields will be obtainable from the weathered basement over most of the plateau areas (except where there are rock outcrops, shallow bed-rock or insufficient saturated aquifer thicknesses) and from virtually all of the alluvial areas. Chemical quality may eliminate some areas if the water is not fit for human consumption; these locations will mainly be restricted to some of the alluvial areas, for example the eastern part of the Bwanje Valley, but there could be localised areas on the plateau where water quality will not be suitable (see section 3.5). The construction of dug wells by the present approach will be restricted to areas where the groundwater level is shallow, less than about 5 m below the surface (see section 4.3.6).

The rural village demands on groundwater are small and should easily be met in all areas without depletion of replenishable groundwater resources. Taking a worst case example, with an estimated projected 1990 rural population density of 350 per km^2 for Chiradzulu District, and using the design consumption of 27 l/head/day, this represents a total annual abstraction of 3.5 mm when expressed over the whole area. This is well within the annual recharge estimates for both weathered basement and alluvial aquifers (see section 3.4). It should be noted that Chiradzulu District has a population density well above average, and the observed water use in those rural areas which have complete coverage of protected supplies is only 10 to 15 l/head/day.

As another example, the Livulezi Integrated Groundwater Project will serve a 1990 population of nearly 60,000 dispersed over an area of some 200 km^2. The annual abstraction at the same design consumption rate would represent 3.0 mm over the valley floor area, compared with an estimated annual recharge of 80 mm (see section 3.4). It is clear that there is no danger of depletion of these resources with these densities of rural population and water demands from primary supplies.

In the escarpment areas however, yields are likely to be unreliable because they depend on intersection of fissures and recharge will not be dependable. There is little scope for groundwater development and there are likely to be a significant number of abandoned boreholes.

There is also some scope for spring protection at locations where groundwater is discharged to streams. Surveys need to be carried out to determine spring locations and discharge rates. Local information on dry season reliability can often be obtained from villagers, and where possible this can be backed up by flow measurements using a portable V-notch weir tank to give some idea of seasonal variability. Wherever the flow is perennial, and from fairly well defined sources rather than broad seepage zones, it should be possible to protect the sites from bacteriological pollution by the construction of spring boxes. These need only comprise a simple sand filter housed by brick or concrete retaining walls with an outlet pipe set into the downslope face. Such protected springs should require minimal maintenance.

The problem of of poor existing water supplies is at present experienced by a very large proportion of the rural population of Malawi, and there are large areas which are suitable for groundwater development projects. Indeed, there may be no economic alternative other than groundwater for rural water supplies for many of the large areas which cannot be served by gravity-fed piped-water schemes. The large numbers of people to be served mean that there is overall a very large demand for water (see section 4.1.2). The cost of individual water points is low, but the huge scale of requirements means that the overall costs involved are very high. Boreholes and dug wells will be constructed where the people are and where the need is greatest, regardless of the most favourable areas for groundwater development.

There are several major areas of the country with large rural populations but poor existing water supplies, and for which there is little potential for untreated gravity-fed surface water supplies. These areas therefore become priorities for groundwater development and include :-

a) Lower Shire Valley

b) South Rukuru Valley

c) Kasungu Plain

d) Nkhotakota Lakeshore

e) Parts of the Shire Highlands

At the present time the improvement of rural water supplies is strongly linked to other development considerations, particularly those identified by the National Rural Development Programme (NRDP) co-ordinated by the Ministry of Agriculture. Agricultural development projects and all the supporting infrastructure that goes with them are organised by the eight Agricultural Development Divisions of the country. Factors used to determine priority areas for development by NRDP Projects include the following :-

a) areas with high but largely undeveloped agricultural potential

b) areas where considerable initiative is being shown by farmers

c) areas of food deficit

d) areas of ready accessibility

e) areas to maintain an even balance in providing development activities to all regions

Those projects being implemented or at an advanced planning stage which have provision for a water supply component from an integrated groundwater project (see section 4.4.2) are listed in Table 4.9. The total costs estimated at the preliminary planning stage are based on complete coverage of the project area by rehabilitating existing boreholes and dug wells and constructing new waterpoints. Where funding has been agreed, the allocation is not always the full sum estimated for total coverage; in some cases this reflects funding of only part of the project area (for example Ntchisi Project where only NT3 will be served), in others (for example Kasungu Project) only existing waterpoints will be rehabilitated, and in a few cases an integrated approach will not be adopted at all (for example the projects under Blantyre ADD) and the funds will be spent on a small number of boreholes at priority locations determined by the ADD and constructed in the dispersed borehole programme at a much higher unit cost (see section 4.4.2). Possible starting dates for the projects are given in the table, but these will depend on funding availability and the construction capacity of DLVW, and will be subject to the preparation of a detailed implementation plan.

It can be seen from Table 4.9 that, although unit costs of borehole and dug well construction are relatively low (see section 4.4), the total investment required to provide coverage to meet the Decade targets is very large. Many components of rural development are included within the funding of infrastructural works of each NRDP project, and the funds for improved water supplies are often severely limited. In addition, the provision of rural groundwater supplies within the programming of NRDP, as set by the eight different ADDs (and several different major donors) could lead to conflicting demands on the DLVW construction capacity, which the Department could find difficult to meet. There is a need, therefore, for a phased programme of rural groundwater supply projects to be drawn up by DLVW so that additional donors can be approached to assist in areas not adequately covered by NRDP and so that implementation can be planned over several years and kept within the Department's construction capability.

TABLE 4.9 AREAS WITH PLANNING MADE FOR INTEGRATED GROUNDWATER PROJECTS

A.D.D.	Project area	Extension planning areas	1990 projected population	Estimated total cost (K million)	Possible starting date	Status	Funding allocated (K million)
Lilongwe	Livulezi Valley	NCH2,4(parts)	60,000	0.4	1981/2	under construction	0.4
Kasungu	Dowa West	DO1	70,000	0.6	1982/3	under construction	0.6
Lilongwe	Lilongwe NE	LL18-22	229,700	2.10	1984/5	funding agreed	0.99
Lilongwe	Dedza Hills	DE5-8,10	173,000	1.25	1986/7	funding agreed	0.61
Liwonde	Balaka	MGA 1-4	104,500	0.89	1984/5	funding agreed	0.69
Kasungu	Ntchisi	NT 1-3	118,750	1.02	1984/5	funding agreed	0.62
Liwonde	Namwera	MNG1,3,4-9	119,700	1.52	1984/5	funding agreed	0.21
Mzuzu	South Mzimba	MZ8-10	101,100	0.82	1984/5	funding agreed	0.76
Kasungu	Kasungu S & NE	KAS1,2,4-7	224,800	2.76	1984/5	funding agreed	0.42
Blantyre	Chiradzulu	CZ1-5	202,120	2.32	1984/5	funding agreed	
Blantyre	Blantyre	BT1-5,7	289,950	3.91	1984/5	funding agreed	0.22
Blantyre	Thyolo	TH1-10	431,250	5.35	1984/5	funding agreed	
Salima	Nkhotakota	KK1,3,4	121,000	1.03	1985/6	funding agreed	1.62
Salima	Salima	SAL1-4	184,200	1.23	1985/6	funding agreed	
Mzuzu	Mzimba-Rukuru	MZ4-7	69,750	0.66	1986/7	funding agreed	0.42
Mzuzu	West Mzimba	MZ6B, 7A	105,200	1.36	1986/7	funding agreed	
Mzuzu	Henga LrKasitu	MZ2,3,RU4	89,500	0.82	1987/8	funding agreed	1.33
Mzuzu	West Rumphi	RU2-4,MZ1	83,850	0.85	1987/8	funding agreed	
Kasungu	Mchinji	MC1-6	181,500	2.16	-	under preparation	-
Kasungu	Dowa East	DO6-8	123,100	1.60	-	under preparation	-
Mzuzu	Nkhata Bay	NB1-5	134,050	1.62	-	under preparation	-
Ngabu	Nsanje	NS1-5	108,400	1.33	1985/6	funding agreed(UNICEF)	0.81
Mzuzu	Emcisweni	M21	22,500	0.30	1984/5	funding agreed(UNICEF)	0.30

4.2.3. Groundwater potential for urban supplies

Urban supplies require higher yielding boreholes (1 l/sec or greater) because the population is more concentrated and the average per capita demands are greater (100 l/head/day). Much more care is thus required in borehole siting in order to ensure that the aquifer transmissivity can sustain the required yields without excessive pumping drawdowns. More detailed information on local recharge conditions is also required in order that the proposed abstraction does not exceed seasonally replenished resources. With increasing investment in the borehole, pump and surface works, a greater level of site investigation and exploration is justified to increase the probability of obtaining the design yields (Chilton and Grey, 1981).

It is possible that, with optimum siting, good borehole design and careful construction, yields of 1 to 3 l/sec may be obtained from many locations in the weathered basement aquifer. Towards the escarpment, where the saturated thickness of the aquifer may be reduced, the yields will be more unreliable.

Most consumers served by the existing small urban supplies use public standpipes. In some cases the potential groundwater yields and/or local recharge might not support the increase in demand which would result from a significant increase in individual house connections. Because of low individual yields, some towns require several boreholes to meet the demand, which is in itself artificially depressed because of the low yields. Examples of towns where existing groundwater supplies are already stretched to full capacity are Chiradzulu, Chitipa, Dowa and Mpemba. At difficult locations where demand is substantial and several boreholes are required, and where the supply needs to be frequently augmented by drilling additional boreholes, the combined high capital and operating costs may at some point become comparable to the cost of a dam storage scheme. There may be a population or demand cut-off beyond which it is more economic to construct a supply based on dam storage, in spite of the additional cost of water treatment works.

Collector wells with laterals drilled in the most permeable zones from a central shaft might be another solution to provide larger, more reliable supplies for small towns. The higher yields would be achieved by increasing the intersection of more permeable zones by the laterals and provision of greater storage within the main well shaft. An evaluation of each individual site would be required, with an exploratory borehole to determine whether a sufficiently thick weathered zone was present with suitably permeable material in the succession. The local recharge conditions would also need to be evaluated in relation to the proposed abstraction rates.

Collector wells would be technically more difficult to construct and maintain relative to the borehole option, and would involve relatively high capital costs. Pilot installations are planned to determine the feasibility of this option at several sites in Malawi.

In the alluvial areas it is likely that high enough groundwater yields from boreholes for urban supplies could be found in most locations except where the succession is dominantly clay rich.

Fractured bedrock aquifers would usually be unsuitable for town supplies both in terms of potential yields, long term reliability and seasonal recharge. It is likely that there will be difficulties in siting boreholes with adequate yields in these areas.

Chemical quality may restrict groundwater development for domestic supplies in some sizeable areas of the alluvial deposits and smaller pockets in the weathered basement, for example at Madisi in Dowa District.

Several schemes at towns in the alluvial ardas are currently experiencing supply problems e.g. Salima, Ngabu, Nsanje and Nchalo. From the results of the investigation drilling for the NSIS (section 3.2) it is clear that in most cases these current problems are caused by poor boreholes rather than poor aquifers. The provision in each case of perhaps only one properly-designed and constructed borehole of adequate diameter could solve many of the problems.

4.2.4 Groundwater potential for irrigation and industrial supplies

A total of 18 boreholes were drilled for the National and Shire Irrigation Study to determine the irrigation potential from groundwater in the alluvial basins (NSIS, 1982). These were drilled and tested by the Groundwater Project in the Salima-Nkhotakota Lakeshore, Bwanje Valley and Lake Chilwa Basin and by the Shire Valley Agricultural Consolidation Project in the Lower Shire. The 8 successful boreholes, where the succession was relatively thick and sandy (see section 3.2.4), were tested at yields of up to 15 l/sec (the maximum discharge of the test pumping unit). These would be sufficient for relatively large irrigation schemes; an abstraction of 15 l/sec would supply an area of approximately 15 hectares depending on crop type, local climate and soil conditions. The alluvial areas are generally relatively flat and there is much land which is agriculturally very suitable for irrigation.

It must be noted, however, that suitable geological successions for high yielding boreholes are not found throughout the alluvial areas, because the complex nature of deposition in these environments results in very heterogeneous, and often very poorly sorted sequences. One of the pilot boreholes in the Bwanje Valley, three in the Lower Shire Valley and both of those in the Chilwa Basin were abandoned because they encountered predominantly fine grained sequences of very low permeability. If old river channels or littoral laccustrine deposits with coarse permeable sediments can be located, these will offer the most favourable sites for irrigation boreholes. The potential for higher yielding boreholes within the alluvial basins justifies further examination.

The depth to water and the likely drawdowns are important considerations for the economic viability of schemes. Obviously the shallower the static water level and the higher the aquifer transmissivity, the less will be the pumping lift required. The question of drainage may also be important in areas where the rest water level is high. Where drainage is slow, perhaps impeded by low permeability clays near the ground surface, the water level may rise to such a height that it causes waterlogging and increased salinity of groundwater by the solution of salts in the soil zone. This is undesirable, and pilot studies would be required to ensure that drainage is adequate.

The quality of groundwater will usually be suitable for irrigation in those areas where the conductivity is less than 1500 µS/cm provided that the SAR and RSC are low enough (see section 3.5.7). There are, however, large areas of highly saline water which need to be avoided and some areas of highly variable quality.

The recharge is also an important consideration in areas where high yielding boreholes are required, in order that depletion of resources does not occur. Considering an abstraction rate of 15 l/sec for supplementary irrigation of a wet season rice crop and a dry season maize crop over an area of 12 hectares, a total of about 4400 hours pumping per year would be required (NSIS, 1982). The proposed abstraction during August and September represents 24 hours pumping per day which does not allow any time for water level recovery. The total gross water requirement for this cropping pattern represents 1530 mm/year over the 12 hectares. This is clearly well in excess of recharge (for which a conservative estimate would be 20 mm) and in the long term depletion of water levels would be expected with such a pumping regime. The horizontal permeability may be sufficient to allow lateral flow to counteract this to some extent, but this abstraction will need to be balanced by recharge over some 900 hectares, unless the irrigation water is not entirely consumed by the crop evapotranspiration and there are vertical losses to groundwater. Regional development of an irrigation well field, with closely spaced, high yielding boreholes, would need to be very carefully planned and constructed in phases to avoid a fall in regional groundwater levels.

The weathered basement aquifer is unlikely to have sufficient recharge or high enough transmissivity for the yields required for large irrigation schemes. However, small agricultural plots (0.5 to 2 hectares) could be successfully irrigated using boreholes yielding 0.5 to 2 l/sec, and smaller plots could be irrigated from dug wells in the dambo margins. It is unlikely that schemes will be very economic, except perhaps for seed beds, as high pumping costs would be incurred. Because of the low aquifer yields, surface water dams offer better scope for irrigation schemes in the weathered basement areas.

Water supply for livestock is not an important consideration in Malawi where animal populations are relatively low in comparison with other countries in the region. There are, however, large herds of cattle in the Lower Shire Valley which could be provided with water by the construction of troughs close to the rural domestic supply water-points. In most areas livestock can be adequately watered at traditional surface-water sources.

Industrial development may also require high yielding boreholes, and the same considerations will apply as for irrigation boreholes except that the restriction on water quality may not be so severe. The quality requirements will depend on the particular use for the water supply and will need individual consideration.

4.3 GROUNDWATER ABSTRACTION

4.3.1 Borehole siting

Borehole site selection was the major activity of the Groundwater Section when it was within the Geological Survey Department. For the past forty years or so resistivity surveys have been routinely used to locate all borehole sites, regardless of the purpose for which the borehole was being drilled or the yield requirements of the user. In the basement areas, constant separation traverses attempt to locate low resistivity zones which are interpreted as an indication of deep weathering and shallower water tables. Very high resistivity zones are avoided as they are likely to indicate either fresh bedrock at shallow depths or deeper water levels. In alluvial areas, constant separation traverses may be able to locate the occurrence of more sandy or gravelly areas where there is moderate resistivity. Very low resistivities are considered an indication of high clay content in the alluvium and are avoided.

The amount of constant separation traverse (CST) work undertaken at a particular site is variable. Individual lines or a more random approach may be adopted to cover an area which is conveniently situated and where the superficial features of vegetation and topography appear most promising. In more recent years, detailed surveys in which CST are taken over a larger area on a grid pattern with lines 30-100 m apart have been employed at some of the locations where higher yields have been required. The results of these more extensive surveys are contoured to define structural trends and low resistivity zones at which to site expanding arrays. In plateau terrain resistivities of about 25-60 ohm.m are usually taken to be indicative of water-bearing formations and sites with values in excess of 100 ohm.m would be avoided unless the surrounding values were even higher and there was no more promising alternative.

At the most promising site or sites, resistivity measurements are taken with an expanding electrode array using the Cooper method established in the 1950's (Cooper, 1965). The data are interpreted by curve matching to give two and three layer depth profiles. These have been theoretically used to indicate likely depths to bedrock, prominent lithological boundaries and expected water levels, but in practice instructions to the driller were usually not related to interpreted interfaces in terms of maximum depths to be drilled.

Although carried out in a routine way, each siting was treated as an individual exercise unrelated to anything around it. The large body of geophysical and construction data from existing boreholes was not generally consulted. Detailed comparison of archive resistivity data with data from subsequent drilling shows only very poor correlation (Chilton, 1979; Carruthers, 1981). The latter concluded that the drilling logs did not suggest that the quantitative resistivity interpretations defined interfaces of any lithological or hydrogeological significance.

Other geophysical methods for groundwater exploration have been investigated in Malawi (O'Conner, 1973; Carruthers, 1981). The earlier work in the 1970s was a sideline to a major mineral exploration programme in the Geological Survey Department. Magnetometer , electromagnetic and induced polarisation equipment was field tested for hydrogeological investigations near Blantyre and in the Lower Shire Valley, but the potential of the equipment and the survey techniques were not assimilated by the Groundwater Section. Extensive fieldwork with several instruments and techniques was carried out in late 1980 by Carruthers but no universally applicable method was indentified. The reliability of resistivity surveys is lessened both by the presence of laterite which gives anomolously high resistivities at shallow depths, which may mask potentially good sites, and by graphite bedrock or highly mineralised groundwater, giving low resistivities which may be confused with a thick weathered zone. Magnetometer surveys are complicated by the presence of magnetite and ferro-magnesian minerals; changes in depth of weathering may be masked by variations in the original bedrock mineralogy. Electromagnetic surveys may be able to delineate fracture traces but the presence of graphite and surface conductors may again mask features of hydrogeological significance. Seismic refraction surveys were hampered by the heterogeneous conditions, lack of well-defined layering and absence of a simple bedrock refractor.

This last point is perhaps the most important factor in appreciating both the potential and the limitations of geophysical surveying for borehole siting. In the plateau areas, layering in the weathered zone is by its very nature bound to be more or less gradational; sharp interfaces would not normally be expected. In an alluvial sequence, in contrast, there may be frequent, thin and well-defined sedimentary layering; the problem here may be to decide which of them are of hydrogeological importance. If geophysics is to be effectively used, it must be applied in a less routine and more flexible way with an appreciation of the principles under lying the survey methods and their interpretation, and an understanding of the hydrogeology and occurrence of groundwater.

The recent work of the Groundwater Section of DLVW has shown that, if boreholes are properly designed (see section 4.3.3), the moderate to low yields required for rural water supply boreholes for handpumps can be obtained over much of the plateau and alluvial areas without geophysical surveying. The main considerations in choosing borehole sites then become the convenience for the users - the villagers themselves can choose the sites, and the avoidance of localised pollution risks (see below). In areas where bedrock may be close to the surface or where the saturated thickness of the aquifer may be inadequate, resistivity surveys will perhaps be able to locate areas which should be avoided.

For urban, industrial or irrigation supplies much higher borehole yields are required, and the capital costs of borehole, pump and surface works may be high. The extra cost of a detailed geophysical survey to locate a favourable site will be justified particularly in difficult terrain. Where the total capital cost of the water supply and the buildings or plant which are going to be dependent on it (for example the new Kamuzu International Airport) are very high, the application of a full range of geophysical techniques and the drilling of test boreholes is fully justified.

Aerial photographs are very useful for delineating rock outcrops and areas of waterlogged conditions in the dambo, both of which should be avoided. For rural water supply project work, the photos will give a better indication of the settlement pattern than the 1:50,000 topographic maps. The distribution of villages, dambo and existing protected and unprotected sources, particularly dug wells, will greatly assist in the allocation of new dug wells or boreholes to each village. For more intensive requirements for higher yields, the air photos may show fracture traces which could be associated with higher permeabilities and/or greater thickness of weathered material. In these circumstances the photos can be used to define promising areas for geophysical surveys.

Waterpoints should be sited up gradient from pit latrines and cattle kraals wherever possible to minimise the potential pollution risks (see section 3.5.6). A lateral separation of at least 15 m should be adequate for most areas in Malawi where there is a thick clay cover. Risks will be minimal provided that the water table is always more than 2 m below the bottom of nearby pit latrines and the water source has been properly completed for sanitary protection (Lewis et al, 1982). In areas where the surface strata are coarser and more permeable, or more fractured, the separation should be increased to at least 30 m. In situations where old, deep pit latrines already exist, there is a danger that they may be directly discharging to the water table. In these cases, a lateral separation of 100 m is desirable, considering the likely maximum permeability to be 5 m/d, and a 20 day travel time necessary for the elimination of bacteria. In highly permeable materials the separation needs to be increased even further.

In urban areas the combined effect of many pit latrines in fairly close proximity to water supply boreholes needs to be evaluated. There are several towns in Malawi situated on alluvial aquifers with relatively shallow water tables, and where the public supply boreholes are now well within the built-up areas e.g. Salima, Nsanje. In locations where the pollution risks are highest, i.e. coarse sandy soils and sediments above the water table, it may be a safer practice to site any future boreholes at or beyond the edges of the town with a protected zone of appropriate radius around them, even though this could result in longer reticulation works and higher costs.

The proximity of any urban supply boreholes to each other should be given careful attention when siting, in order to minimise the interference effects between boreholes whilst aiming to keep the length of the reticulation works as short as possible. The optimal positioning will obviously depend on local conditions and cannot be generalised.

4.3.2 Design of existing boreholes

The majority of the existing boreholes in Malawi are poorly designed. Construction costs are high. Most of the boreholes are 40-50 m deep or even deeper, often reaching well into fresh bedrock. The drilled depth of the boreholes often bears little relationship to the lithology. In contrast to the considerable input by geologists to the siting programme, borehole construction was carried out almost entirely by drillers. The borehole design employed has been the same, regardless of aquifer type or yield requirement.

All of the boreholes drilled prior to 1980 were either partially or fully lined with imported steel casing of 150 mm nominal diameter, or much less commonly 100 mm or 200 mm diameter. The pipe is generally slotted in the bottom third or half, torch-cut up to 1976 and manually with a hacksaw to date. The torch-cut slots were vertical, 300 mm long, about 3 mm wide, at 300 mm intervals down the pipe and three slots around the circumference, giving an open area of about 0.8 percent. Torch-cutting was replaced by hacksaw cutting in an attempt to eliminate sand pumping by reducing the slot size. The hacksaw slots are cut horizontally, 100 mm long by about 1.5 mm wide, 300-400 mm apart prior to 1980 and 75 mm apart currently, two slots staggered around the circumference. This gives an open area of 0.1 percent to 0.2 percent prior to 1980 and up to 0.5 percent more recently.

The open area of the screened portion of the borehole is very low. In addition, the more productive levels are often cased out, especially in the weathered basement aquifer and water is forced to pass down to the fresh bedrock before it can enter the borehole. Head losses are likely to be large, the entrance velocity of the water may be high and the boreholes are generally very inefficient. The low specific capacities often reflect this poor borehole design rather than a low yielding aquifer (see section 3.2.3).

The gravel pack material used prior to 1980 comprised a crushed, angular roadstone of 6 to 12 mm size range, most commonly a nominal 9 mm quarry stone. The annular space between the 168 mm OD steel casing and 200 mm borehole would be less than 25 mm (12 mm over the casing collars). Proper gravel emplacement in these circumstances would be impossible, and even if it were possible the "gravel" would serve no useful purpose as a filter. There is no effective filter and since the slot sizes in the screen are large, fine material from the aquifer can easily be drawn into the borehole. Boreholes are therefore liable to infill and there is often excessive wear on pump components, especially handpump cup leathers. Maintenance visits are consequently frequent and costly.

4.3.3 Improved borehole designs

Since 1980 a considerable effort by the Groundwater Project within the Groundwater Section of DLVW has been devoted to improving borehole designs and reducing their costs. This has been achieved by matching an understanding of the hydrogeology and groundwater occurrence with the most economic and appropriate methods of abstraction. The improved designs have already been successfully implemented in more than 200 boreholes. Even so, boreholes are still sometimes drilled that do not produce enough water for a handpump, but with the much closer supervision possible in the projects these can be abandoned during drilling, saving the additional costs of non-productive drilling and completion of the borehole. Overall, the improved designs have probably resulted in a higher borehole success rate and have certainly produced better borehole specific capacities (see section 3.2.3). Full details of the designs and construction practices, which are briefly summarised below, are given in the integrated projects manual (DLVW, 1982).

The recognition that the weathered basement is a more important aquifer than the fractured bedrock below enables boreholes to be drilled to much shallower depths. For rural water supplies a minimum saturated aquifer thickness of 10 m is the target and over much of the country water levels are such that total depths of only 20 to 30 m are sufficient for handpump supplies. Drilling diameter is kept as far as possible to a standard 200 mm. These modest depth and diameter requirements make possible the use of small to medium-sized percussion rigs, relatively lightweight vehicles and small crews. Drilling times and costs can both be considerably reduced.

Borehole designs have been further improved by increasing the open area of the slotted pipe to about 8 percent and reducing the slot size to 0.75 mm. The lower entrance velocities and correct placing of screen together produce increased hydraulic efficiency and improved yields. The use of smaller diameter (110 mm) locally manufactured and slotted PVC lining is considerably cheaper than imported 150 mm steel and probably results in increased borehole life due to its inert nature. It might also reduce the problem of high iron concentration in groundwater, which could be partly associated with the dissolution of steel lining by groundwater with a low pH.

The use of a correctly graded gravel pack has also improved hydraulic efficiency and reduced the influx of fine material into the boreholes. Lake Malawi beach sand at several locations has a suitable grain size distribution. A pack thickness of about 50 mm is achieved by the combination of 200 mm drilled hole and 110 mm PVC casing. The benefits of improved screen and gravel pack are demonstrated by the results from the boreholes drilled in 1981 in the first part of the Livulezi Integrated Project. Twenty four boreholes were constructed between March and June 1981. No cup leathers needed replacement on any of the handpumps until December 1982. Two sets were replaced then although one was only slightly worn and one further set was replaced in July 1983. This compares with replacement on average two or three times a year in existing boreholes completed with hacksaw-slotted steel casing and 6-12 mm roadstone as gravel pack (see section 4.3.2).

The benefits of improved screen and gravel pack can also be extended to the existing boreholes. A programme is underway to rehabilitate many of the rural supply boreholes which have the worst records for infilling and frequency of pump repairs. The boreholes are cleaned out and, where appropriate, an inner lining of 110mm PVC is inserted and a gravel pack emplaced in the surrounding annulus. After re-development and test pumping the intention is that the boreholes should then have improved aprons and surrounds constructed, a new handpump installed (see below) and they should then be incorporated into the new maintenance system.

Borehole surrounds are now carefully constructed to ensure good sanitary completion and thus reduce the risk of direct pollution of groundwater from the surface. The new Malawi handpump (see below) is cemented into the borehole plinth and has a 3 m extension outlet pipe to carry the discharge water away from the wellhead. This is completed with a brick based concrete apron and channel to carry the waste water further away down-slope of the borehole. The development of small irrigated vegetable gardens to use the waste water is being encouraged.

The same range of design improvements in casing, screen and gravel pack and much improved hydrogeological supervision have been incorporated into the urban drilling programme, and have produced some dramatic improvements in performance (Figure 3.2). Urban, irrigation and some of the institutional boreholes require larger diameters to accommodate a motorised pump. PVC casing and screen of 160 mm OD has been used in some recently completed urban supply boreholes, with drilled diameters of 300 mm, reducing to 250 mm. Larger lining diameters are likely to be required for urban supply boreholes where the pumping rate is above about 5 l/sec, and would certainly be required for high-yielding irrigation boreholes. In the plateau areas, boreholes for motor pumps will need to penetrate the full thickness of the weathered zone aquifer to ensure the best yields, with the siting procedures aimed at locating the maximum aquifer thickness.

It is possible in some areas (particularly in alluvial aquifers) that high-yielding boreholes could be used conjunctively with run-of-river piped water schemes. Groundwater could thus be used to supplement the supply by feeding into the reticulation network in the dry season when river flows are low. Pilot projects would be required to determine the feasibility and economics of such schemes.

The feasibility of the construction of collector wells (see section 4.2.3) is being investigated. It is possible that in the low-permeability weathered zone aquifer a collector well system might produce higher yields and smaller drawdowns than a conventional borehole, although there are clearly technical difficulties to be overcome in constructing and dewatering the shaft and drilling the laterals.

4.3.4 Borehole pumps

Most of the existing boreholes are equipped with handpumps. There are several different types of pumphead in use; most are imported and expensive, and all are difficult to maintain. A truck with a winch is required to lift the pumphead before even the most basic repairs can be carried out on the downhole components. Handpump maintenance is consequently a great organisational and financial burden on Government (see section 4.4).

A locally-manufactured and relatively cheap handpump - the Malawi (MALDEV) pump - has been developed with ease of maintenance being the main design consideration. Prototypes were installed on village boreholes in September 1981, the first limited production run of 25 pumpheads was made in March and April 1982 and the first full production run of 150 commenced in July 1982. Nearly 250 are now installed and the pumphead shows considerable promise in terms of both ease of maintenance and reliability. The way is now open for community participation in handpump maintenance (DLVW, 1982) as servicing and repairs should be possible by hand. The next step is the development of cheap and easily replaceable downhole components, a problem which is currently under research in Malawi, by the Consumer Association in UK, by the UN/World Bank Interregional Handpump Testing Project, and many others. These developments and the involvement of the community in preventive maintenance will help to relieve the burden on Government. The frequency of handpump repairs will be considerably reduced by the use of better borehole construction practices (see previous section).

Boreholes for the District Water Supplies and at many institutions and private estates are equipped with motor pumps. The type of pump depends generally on the available power source; electric submersible pumps are used where electricity is available from the national grid, otherwise diesel engines are required.

4.3.5 Dug well siting

In the Malawi rural water supply programme, dug wells are considered to be the appropriate source where groundwater levels are less than 4-6 m below the surface. Although much deeper wells are dug by hand elsewhere (and have been dug in the past in Malawi) digging in the current programme is limited to relatively shallow depths to permit simple, rapid and economical well construction in which the villagers themselves play a large part, and to allow the use of suction-lift pumps for dewatering. In practice this means that, in the plateau areas, dug wells are sited towards the bottoms of valleys and most commonly in the dambo margins.

Aerial photographs and topographic considerations from field visits are the principal means of locating suitable areas for dug wells. Within the suitable areas, communities can then select sites for protected dug wells. The relatively shallow water tables mean that pollution hazards are a prime consideration in choosing dug-well sites. Wells should not be located where there is a possibility of the water level rising in the rainy season to less than a metre below ground level. There is an understandable desire to 'play safe' and locate the well very near to any existing open wells, which are often in the middle of the dambo. However, the existing well may be a serious ready-made source of pollution, and the shallow water table may rise to ground level in the wet season and the centre of the dambo may even be flooded, further increasing the risk of pollution. Providing there are no rock outcrops or shallow bedrock to cause digging problems, wells should be sited towards the dambo margins. The siting considerations in relation to pit latrines and cattle kraals (see section 4.3.1) are even more important for dug wells than for boreholes, emphasising the need for an element of hydrogeological supervision of the communities' site selection process (see projects manual; DLVW, 1982).

4.3.6 Designs of protected dug wells

Dug wells have always been regarded as a simple, unsophisticated and relatively cheap way of providing rural water supplies. They are dug in a somewhat ad hoc way "until there is enough water". Although many dug wells with handpumps have been constructed in Malawi, there are still no general criteria which have been adopted for well depth or yield to guide the relatively unskilled digging crews and their village helpers in constructing a well which is a good and reliable supply source.

Two principal designs are currently employed in the national, dispersed wells programme. Where only limited Government support can be provided by a Project Assistant, a 1.5 m diameter hole is dug by the villagers as far below water as possible. The hole is lined with bricks and mortar throughout its depth, reducing in diameter towards the top to accommodate a concrete top slab. A pump is then installed by the Project Assistant. Where a digging team with a dewatering pump is available, the hole is dug, again with community help, several meters below water level. Two or three porous concrete rings, 1 m high and 0.8 to 1 m in diameter are installed in the lower part of the well, and the upper part is lined either with bricks and mortar or non-porous concrete rings and completed with a top slab and handpump. A variation of the latter method, in which the porous rings are covered by a 'bottom' slab, a PVC guide pipe passes up to ground level and the upper part of the well is backfilled with the excavated material, has been tried in the Livulezi Project. The well is again completed with a top slab and a handpump installed through the PVC guide pipe. This last design is described in some detail in the projects manual (DLVW, 1982) and there is also a discussion of the general principles of dug-well design.

The major technical considerations in a dug well programme relate to two objectives - ensuring the reliability of the supply in terms of quantity and quality. With regard to the former, digging should as far as possible be concentrated in the dry season and the target should be to reach into the aquifer at least 3 m below the dry season water level. This has often not been possible in the national wells programme without the dewatering pumps, and in the current Dowa West Project deepening is invariably a requirement in the rehabilitation works on existing protected wells. Even with this depth target, wells may require deepening from time to time in exceptional drought conditions. The well design incorporating backfilling makes access in these circumstances difficult, and this method of construction is no longer used.

The importance of careful siting in relation to protection of the well from pollution has already be emphasised. In construction, protection measures include the use of a non-porous lining in the upper part of the well, preferably with a clay backfill around it to ensure a watertight seal. There also needs to be a good watertight seal between pump and top slab, and between slab and lining. The surface works are completed by an apron around the well and drain to carry waste water away from the well (see projects manual for details).

The protected wells in both the national programme and integrated projects are equipped with a locally fabricated, direct-action, shallow-lift pump which has passed through several design stages since 1975. The current Mark V handpump has a number of good design features but is still dependent on imported components, and much effort in the wells programme is being devoted to developing a shallow well handpump which can be manufactured locally and can be maintained by village communities.

4.4 COSTS OF GROUNDWATER DEVELOPMENT

4.4.1 Introduction

Economics usually tries to calculate both the costs and benefits of a proposed project or activity. While this is common practice for urban and irrigation supplies, it is generally accepted that it is impossible to quantify and evaluate the benefits of an improved rural water supply. In the latter case, therefore, the approach is one of "cost-effectiveness analysis" - searching for the least costly method of accomplishing a given task. This analysis is concerned with both the initial capital costs and the operating and maintenance costs. Finding ways of keeping down the latter costs in a rural water supply programme is particularly important when there are both severe constraints on recurrent expenditure by Government and a lack of cash in the villages.

4.4.2 The "dispersed" borehole and dug well programmes

The history of groundwater development in Malawi has been briefly described in section 1.2.1. A large programme has gradually been built up in which both borehole siting (see 4.3.1) and borehole construction (4.3.2) have been carried out in a completely routine and standardised fashion. The poor borehole designs - drilling much deeper than necessary and the inadequate screen and gravel pack - were themselves major contributing factors to the high costs of construction and maintenance respectively. The widely dispersed activities of both borehole and dug well programmes were difficult to plan, manage and supervise. High costs and low technical standards were the result. In addition, the large distances between sites resulted in inefficient use of vehicles and high transport costs.

The charging structure employed by DLVW sets a rate (at the beginning of each financial year) for each constituent operation in the construction of a borehole, exactly as would be done in a schedule of prices for a drilling contract. A contractor sets his prices to cover all his operational costs - labour, running of vehicles, materials, supervision and a share of the headquarters overheads, together with whatever rate of profit he sees fit. Each operation of moving, drilling, development and testing is costed on an itemised "per metre" or "per hour" basis, and it is a simple task, once the schedule of prices is fixed, to cost completed boreholes from the drillers' construction reports.

The present invoice charges (1983 prices) for rural water supply boreholes in the national programme range from around K8000 for a 60 m deep borehole with steel lining and Climax handpump, to around K6000 for a 45 m deep borehole with steel lining and National handpump and down to just under K4000 for a 30 m deep borehole with PVC lining and National pump. The introduction into the national borehole programme of some of the technical improvements in borehole construction, particularly reduced drilling depths and the use of smaller diameter PVC lining, is assisting in keeping down borehole costs. There is thus a broad range of borehole costs, depending largely on depth, type of lining material and type of handpump.

The current actual cost of borehole handpump maintenance is difficult to estimate. The annual budget for maintenance in 1983-84 was K645,000, coming from government revenue sources. Dividing this by the total number of boreholes actually maintained, the approximate average annual cost of maintenance is K200 per pump, although there will clearly be great variation from borehole to borehole. The maintenance of these borehole supplies thus places a massive logistical and financial burden on central government, which it will find increasingly difficult to support with the rapid acceleration in the rural water supply programme that the IDWSSD has stimulated (Table 4.9).

The present maintenance organisation comprises 24 units, mainly based at district centres, each equipped with a 5 or 7 ton truck, a superviser and a crew of four or five labourers. The units carry out repairs to handpumps which have been reported as broken down by a postal referral system. The work load this creates and the distances involved mean that there is practically no opportunity for any preventive maintenance. The high cost of maintenance is partly attributable to the high frequency of cup leather replacement; the poorly-designed screen and gravel pack (see 4.3.2) allow the ingress of abrasive fine sand which wears the leathers very rapidly. Another contributory factor is the use of imported handpumps which require the unit's heavy vehicle and winch to lift the pumphead so that the cup leathers can be replaced, and some of which require expensive spares for the pumphead itself. An appraisal of the maintenance costs indicates that transport costs are the major component (60%) with staff costs (20%) and materials and office expenses (20%) being relatively low proportions of the total.

Thus, while the existing borehole maintenance organisation is inefficient, difficult to supervise and relatively costly, it does nevertheless manage to keep most of the boreholes for which it is responsible operating for most of the time. Some improvements are currently being sought by trial use of smaller vehicles and more effective winches, and by changes in the administrative structure to permit closer field supervision and planning of work programmes. In the long term, however, the success of the rural supply programmes from groundwater can only be assured by the local communities taking over a significant proportion of the maintenance burden, especially preventive maintenance, from central Government.

The national dug well programme has also suffered from inadequate supervision and a lack of hydrogeological input to the construction programme. The main results of this are poor well siting in relation to pollution hazards and occasionally in relation to yield reliability. In addition many of the dug wells are insufficiently deep to provide adequate yields throughout the dry season. The dug well programme is concentrated in a relatively small number of project areas, which helps considerably to keep down the transport costs. The funds for the dug well programme come from several sources so it is difficult to establish accurately the actual costs of individual wells in the national programme. Costs in 1983 range from about K400 to K800 depending primarily on depth, level of community participation and whether a dewatering pump has been used.

There is no established formal maintenance system for the dug well programme. Within each area where there is dug well construction in progress, the project assistants are responsible for the maintenance of wells which have been completed. It is not, therefore, possible to separate maintenance costs from construction costs. It is clear from reports from the field and from the detailed monitoring of pump performance in the Livulezi Project that the present Mark V shallow well pump does require frequent maintenance. Development work is underway to produce an improved design of shallow lift pump that is more reliable and more easily maintained at village level.

4.4.3 Integrated projects for rural water supplies

The approach to the provision of rural water supplies by "integrated projects" which has been developed by the Groundwater Section of DLVW is largely a response to the need to find more cost-effective ways of providing groundwater supplies (see 4.4.1). The technical improvements to borehole construction have already been briefly described (see 4.33); the project approach combines both technical and operational improvements to reduce costs. A comprehensive description of the integrated projects is given in the manual (DLVW, 1982).

An integrated project aims to provide complete coverage of an area with improved supplies by rehabilitating existing boreholes and dug wells, by constructing new boreholes and dug wells and by establishing a maintenance system for all of the water points. Thus, having defined an area and target population, a project is planned to provide 27 litres per person per day of clean water within a one-way walking distance of 500 m. Initial planning is based on a dug well serving 125 people or a borehole serving 250 people. The choice between dug well and borehole is made by the project hydrogeologist from local groundwater conditions at each site. Detailed planning and supervision is carried out by the project hydrogeologist, and construction by up to four drilling rigs and four well digging teams, serviced by one or two vehicles.

The concentration of effort by keeping the rigs and digging teams very close together provides for major cost savings by allowing the use of tractors and trailers, light pick-up trucks and motorcycles. The careful management and technical supervision that is permitted by this concentration in one small area also provides for greater operating efficiency, a high standard of borehole and well construction and a high waterpoint success rate. Having the project staff resident in an area for some time also allows the community to be fully involved in the planning and construction of the water points by choosing sites and providing labour and materials. This is an essential prerequisite for the involvement of the village communities in maintenance.

Two such integrated projects are underway at present. In the Livulezi Valley, 133 successful boreholes have been constructed, 5 rehabilitated and 60 protected dug wells have been constructed. Costs of boreholes complete with Malawi pump range from under K1500 for boreholes which are less than 15 m deep to nearly K3000 for those boreholes that are 30 to 35 m deep. The majority of boreholes are between 20 and 30 m deep, the average borehole depth being 24.5m, and average costs about K2400. Thus, for budgetary and planning purposes, the present cost of boreholes in integrated projects works out at just under K100 per metre of depth, complete with all borehole materials and handpump.

A detailed procedure has been devised for keeping account of the actual costs of borehole and dug well construction (described in the projects manual). This enables the invoice cost of the borehole prepared from the schedule of prices to be compared with the actual direct and indirect costs of carrying out the work, and modifications to the schedule can be made where necessary. The detailed accounting of actual costs is also an important management tool in identifying where further efficiencies and cost-savings might be made. In the Livulezi Project, for example, this analysis of actual costs shows that the cost of a borehole can be subdivided into :

a)	direct labour and material costs	33 %
b)	project transport	33 %
c)	project overheads (supervision, depreciation, delivery vehicles, camp costs)	33 %

Even with such a concentrated approach in the integrated projects, still 33% of the construction costs are for transport and there may yet be scope for improved operating efficiency to reduce this proportion further. A reduction in costs may also be possible when the imported rods, rising main and cylinders presently used with all borehole handpumps are replaced by locally manufactured components.

The Dowa West Integrated Project is also currently in progress, serving an estimated 1990 population of 60,000. For the first 81 boreholes an analysis of the actual costs gives an average figure of K3100, including handpump. The costs are higher then those in the Livulezi Project because :

a) the depths to groundwater are greater and consequently borehole depths are greater (average 27.5 m)

b) a private drilling contractor was used rather than the government rigs

c) up to ten of the boreholes may have to be abandoned because of poor water quality

d) ten out of 81 boreholes have been abandoned because of low yields

e) langer development times were required to produce clean, sand-free water.

A similar charging structure has been devised for the dug wells. Using this structure, the average cost of hand-dug wells complete with handpump is similar in both projects, ranging from K650 to K850, the smaller range reflecting the much more limited range of dug well depths.

The cost of maintaining borehole handpumps in the integrated projects will be lower because the improved borehole designs (see 4.3.3) will mean that pumps will break down less frequently. The Malawi handpump does not require a heavy vehicle and winch before repairs can be carried out; transport costs should be greatly reduced. The handpump promises to be very robust and few repairs should be required to the pumphead, especially if preventive maintenance is carried out regularly at village level. If a suitable tiered maintenance system along the lines described in the projects manual (DLVW, 1982) can be established, the likely recurrent cost can be estimated at 5% of capital construction costs (about K100 per annum at 1983 prices). If cheap and easily replaceable below-ground pump components can be manufactured locally and if a high level of community involvement in preventive maintenance and minor repairs can be established, then the target should be to reduce maintenance costs to 2½% of capital costs.

4.4.4 Urban and irrigation boreholes

Urban and irrigation boreholes requiring higher yields will naturally be more expensive to construct than rural water supply boreholes because :

a) preliminary site investigations and detailed geophysical surveys may be required, depending on the yield requirements.

b) greater depths and diameters may be required to achieve maximum yields.

c) larger diameters will be required to accommodate a motor pump - higher drilling costs and materials cost.

d) a greater amount of development pumping, and longer and more detailed test pumping will be required.

e) a greater level of technical supervision will be required.

In the case of urban, institutional or irrigation boreholes the associated capital costs of pumping equipment, pump-house, tank and reticulation works may be very substantial. With this increasing investment a greater level of investigation, including possibly test drilling, is justified to increase the probability of obtaining the design yield. A greater level of professional supervision is also justified to ensure proper construction, development and test pumping.

The cost of a properly designed and constructed urban supply borehole (at 1983 prices) would range from about K6000 for a 30 m hole to about K8000 for a 50 m hole, completed with 160 mm Class 10 PVC casing and screen and inclusive of a detailed site investigation and test pumping (but not test drilling). For a borehole that produces one or two litres per second the additional costs of the pump and surface works would be :

electric submersible pump (1-2 l/sec capacity) assuming power on site	K 3000	to	K4000
pump house, control box, and storage tank			K5000
or			
diesel engine and mono pump (1-2 l/sec capacity)	K4000	to	K6000
pump house for diesel engine, and storage tank			K10,000

giving a total installation cost of K15,000 to K25,000.

The cost of construction and operation of irrigation boreholes was discussed in detail by NSIS (1980, 1982). Their principal conclusion was that irrigation from groundwater could be economic, providing pumping was carried out by electric power and providing the proposed site was within a few kilometres of the existing power grid. The capital costs of an irrigation borehole would depend on the yield required and depth to groundwater. Sample costs were given for a borehole of about 60 m deep to produce a discharge of 15 l/sec (at 1982 prices) :

Borehole construction	K 10,000
Electric submersible pump	K 4,500
Connection to electricity supply	K 5,000
Total (approx.)	K 20,000

The cost of operating the pump was estimated at K0.2 to 0.7 per hour for the range of likely pumping heads found by the investigation drilling for the NSIS.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 DATA STORAGE

5.1.1 The data compilation work on which this report and the associated hydrogeological maps have been based should be seen as a continuing rather than a completed task. If the archives are to remain as an effective source of information to support the planning of groundwater development, then the cardex system and 1:100,000 master set of maps must be completed, checked and continually updated to incorporate the new records coming from the national borehole and dug well programmes, the integrated projects, the borehole rehabilitation programme and the borehole maintenance section.

5.1.2 The ledgers cross-referring for all boreholes new water resource unit numbers with GS numbers and vice versa should be completed, checked and made available.

5.1.3 The cardex data storage system should be extended to the dug wells using a similar numbering system based on the water resource units.

5.1.4 Consideration should be given to the computerised storage and retrieval of hydrogeological data. This would permit the location and correction of many of the remaining errors in the cardex system, and would permit selective access to the data other than by borehole number. Compilations could easily be made according to district, aquifer, yield, water chemistry or other parameters and the application of statistical methods would be greatly facilitated. Consideration should be given to initiating computer storage on a limited trial basis using the Department's existing mini-computer facilities.

5.1.5 To maintain the impetus and carry out the tasks outlined above, the data archiving sub-section established by the Groundwater Project needs to be consolidated and strengthened by the recruitment and training of suitably qualified staff.

5.2. GROUNDWATER RESOURCES

5.2.1 Detailed groundwater resource studies have been carried out for the Bua and Nkhotakota Lakeshore Water Resource Units. These two studies should form the beginning of a series of such reports which should eventually cover all resource units. A phased programme of compiling these studies by the professional staff of the Groundwater Section should be established, and realistic targets set for their completion, bearing in mind the other extensive commitments of the Section.

5.2.2 The evaluation of the hydrogeology of Malawi from the large body of existing data has revealed a number of major uncertainties in the estimation of groundwater resources. These have been the target of the limited amount of additional data collection described in this report. Nevertheless, further studies are required to provide more field data and a better understanding of the following :

a) the hydrological and hydrogeological processes of the dambo systems and their relationships to overall groundwater resources

b) aquifer properties of the alluvial and weathered bedrock aquifers, and in particular the vertical and horizontal distribution of permeability in the heterogeneous weathered bedrock aquifer

c) seasonal and longer term fluctuations in groundwater levels.

More reliable and extensive data on all of these is required to refine the broad range of estimates of recharge given in this report. The collection of long term water level data is particularly important for monitoring and predicting the effect of serious and prolonged drought conditions on the development of the relatively thin weathered zone aquifer. The present very limited monitoring network should be augmented by installing more autographic recorders and by the regular dipping of suitable abandoned boreholes.

5.3 GROUNDWATER DEVELOPMENT

5.3.1 It has been stated several times throughout this report that the main groundwater development requirement at the present time is for rural domestic supplies. Of the estimated 1990 rural population of 7.2 million, perhaps 5.5 million will need to be supplied from groundwater. This is a massive task with potentially huge capital and recurrent costs. Rural domestic supplies from groundwater should remain (as they have always been) "primary" supplies based on a handpump source from which people collect water, rather than "secondary" supplies with motor pumps, storage tanks and reticulation to stand pipes. While the most obvious difference between the two is capital cost (a secondary supply could be 6 to 8 times the per capita cost of a primary supply), this is only one consideration. The difficulty of maintaining the existing handpump supplies has already been described; the operation and maintenance of motor pumps in the rural areas is at present completely beyond the logistical and financial capabilities of either central Government or rural communities. Furthermore, breakdown of a single motorised pump will affect a whole village whereas breakdown of one handpump will have much less effect in a village which has several. People may lose faith in a sophisticated but unreliable supply which they cannot maintain themselves, and continue to use unprotected sources. Finally, as donor funds are limited, the rate at which secondary supplies can be provided is likely to be controlled by the availability of funds, whereas for the much cheaper primary supplies the limitation is more likely to be construction capacity than funds. It is surely better to provide a basic service of protected supplies to as many of the rural population as soon as possible than to provide a superior, but perhaps unreliable service to a few. For all these reasons, it is strongly recommended that rural domestic supplies from groundwater should be primary supplies from dug wells and boreholes equipped with handpumps. An eventually upgraded system with small motorised pumps when water demands and operational capabilities increase should not, however, be ruled out.

5.3.2 Many of the principal features of the groundwater development programme follow on directly from the decision to opt for handpumps for rural supplies. These features are summarised in part 4 of this report and described in detail in the projects manual, and there is thus no need to list them here as recommendations. There is, however, one important point which should be stressed. The modest yield needed for handpump supplies means that the drilling requirements in the two principal aquifers in Malawi are also modest. Boreholes of 15 to 40 m deep and 200 mm diameter, in unconsolidated alluvium and semi-consolidated weathered material, lined with 110 m PVC pipes will be the general requirement except where water levels are very deep. Light to medium duty standard cable-tool percussion drilling rigs are proving highly effective and economical in these conditions. This should without question remain the preferred drilling method for rural handpump supplies in Malawi, although there may be some justification for a rotary drilling capability for deeper, higher cost urban and irrigation boreholes.

5.3.3. Significant groundwater quality problems have been identified in both alluvial and weathered basement aquifers. Further investigations of the distribution (both vertically and laterally) and possible origins of the high mineralisation are required at two levels. Firstly, a better knowledge of the broad scale of likely variations in groundwater quality over a project area is required at the planning and preparation stage. If water quality problems are anticipated, adequate financial provision can be made to cover the estimated extra cost of boreholes or wells abandoned because of poor quality groundwater. In the preparation stage of each integrated project, therefore, a comprehensive water quality survey should be carried out of existing traditional and protected sources. At the end of the dry season, river flow will be largely baseflow and sampling at this time will give a general indication of regional groundwater quality. This should be augmented by pumped samples from boreholes and protected dug wells, and samples from open dug wells and springs. Secondly, a much better knowledge of the very significant but localised variations in groundwater quality is required at the implementation stage. The additional costs from unsuccessful water points can then be lessened as poor quality groundwater may be avoided by an appropriate choice between shallow dug well or deeper borehole and/or by careful siting of the water point. More detailed investigations on a local scale will require water quality logging and depth sampling in boreholes and sampling as drilling progresses. The development of field analytical methods is of particular importance, so that boreholes or wells can be abandoned at an early stage of construction with minimum cost to the project.

5.3.4 The integrated project approach offers the best means of providing properly-designed and well-constructed water points to give clean water throughout the year to the design population at design consumption levels in such a way that the life of the supply will be maximised, all for the minimum necessary cost. The concentration in one area permits both the good technical supervision which ensures a high standard of construction and also efficient and cost-effective implementation. The project approach also offers the prospect of establishing an effective and reasonably cheap maintenance system in which the village communities play an active part. The integrated projects are therefore considered to provide the best hope for achieving the maximum progress towards the Decade's targets. At present, funds are being provided by a number of donors for improved rural water supplies within the infrastructural works of the various NRDP projects. The funds for improved supplies are often severely limited and fall far short of complete coverage. DLVW should therefore draw up a phased national programme of integrated rural groundwater supply projects so that additional donors can be approached to assist in areas not adequately covered by NRDP. Implementation could then be planned over several years and matched to the Department's construction capabilities. The establishment of a clearly defined national rural water supply programme would enable the Groundwater Section to plan its staffing requirements at both professional and technical levels, and would moreover require a clear commitment from Government to provide the administrative and logistical support necessary for the effective implementation of the programme. It would also require the further commitment from Government of the necessary funds to ensure continuing adequate provision for maintenance by the tiered, community-based maintenance system established by the integrated projects.

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REFERENCES

Acworth, R.I., 1981 - The evaluation of groundwater resources in the crystalline basement of Northern Nigeria. University of Birmingham, Geology Department. PhD Thesis (unpublished).

Agnew, S. and Stubbs, M., 1972 - Malawi In Maps - University of London. 143 pp.

Balek, J., 1977 - Hydrology and water resources in Tropical Africa - Elsevier.

Bath, A.H., 1980 - Hydrochemistry in groundwater development: Report on an advisory visit to Malawi - Institute of Geological Sciences, Report No.WD/OS/80/20 54 pp. (unpublished).

Bath, A.H., 1981 - Stable isotope analyses of groundwater samples from Lower Shire Valley, Malawi -Stable isotope technical report no.6 - Hydrogeology Unit, Institute of Geological Sciences (unpublished).

Bloomfield, K., 1968 - The pre-Karoo geology of Malawi - Memoirs of Geological Survey, Malawi, 5.

Bradford, R.B., 1973 - Groundwater reconnaissance study: Lower Shire Valley. Geological Survey Malawi. (unpublished).

Bradford, R.B., 1973 - The hydrogeochemistry of the Mirale area, Upper Shire Valley. Geological Survey Malawi (unpublished).

Bradford, R.B., 1973 - The proposed extension and modification of groundwater abstraction at Ngabu. Geological Survey, Malawi (unpublished).

Bradford, R.B., 1973 - The hydrogeology of the Chingale Terrace. Geological Survey, Malawi (unpublished).

Bradford, R.B., 1973 - The hydrogeology of saline areas in the Lower Shire. Geological Survey, Malawi (unpublished).

Brinn, P.J. and Bunning, S.E., 1981 - Crop suitability assessment. ODA Studentship Scheme Report (unpublished).

Brown, P. and Young, A., 1962 - The physical environment of Northern Nyasaland with special reference to soils and agriculture. Malawi Government Printer, Zomba.

Cairncross, S. et al., 1980 - Evaluation for village water supply planning. WHO-IRC, The Hague, Technical Paper No.15. pp 179.

Cannon, R.T. et al.,1969 - Polyphase deformation in the Mozambique belt, Northern Malawi. Bull. Geol. Soc. America. 80 pp 2615-2622.

Carrol, D., 1970 - Rock weathering. New York.

Carruthers, R.M., 1981 - Report on a visit to Malawi (October-December 1980) to advise on the use of geophysics in groundwater development. Geophysics and Hydrogeology Division, Institute of Geological Sciences Report No.123 (unpublished).

Carter, G.S. and Bennett, J.D., 1973 - The Geology and Mineral Resources of Malawi. Bull. Geol. Surv. Malawi., 6. Malawi Government Printer, Zomba. pp 62.

Chapusa, F.W.P., 1977a - The hydrogeology of the Benga-Chipoka lakeshore plain. Geological Survey, Malawi.(unpublished).

Chapusa, F.W.P., 1977b - Groundwater in the Upper Bwanje Valley and Balaka area. Geological Survey of Malawi, (unpublished).

Chapusa, F.W.P., 1977c - Groundwater in the Lower Bwanje Valley and Cape Maclear Peninsula area. Geological Survey of Malawi (unpublished).

Chilton, P.J., 1979 - Report on a visit to Malawi 29 September 1978 to 6 January 1979. Institute of Geological Sciences Geophysics and Hydrogeology Division. Report No.WD/OS/79/10 (unpublished) pp 90.

Chilton, P.J. and Grey D.R.C., 1981 - The occurrence and utilisation of groundwater in Tropical Shield Areas in developing countries. Paper presented at UNESCO Seminar on groundwater in hard rock areas. Arusha, Tanzania.(unpublished) pp 8.

Colonial Development Water Supply Investigation, (1931-1940) - Annual - Progress Reports. Geological Survey Department, Nyasaland Protectorate.

Cooper, H.H., and Jacob, C.E., 1946 - A generalised geophysical method for evaluating formation constants and summarising well field history. Trans. American Geophysical Union, 27 526-534.

Cooper, W.G.G., 1950 - Electrical aids in water finding. Bulletin No.7, Geological survey of Malawi (revised edition 1965) pp 25.

Crow, M.J., 1979 - Groundwater abstraction and hydrogeology. Geological Survey of Malawi (unpublished).

Dandaula, M.E., 1979 - Mean annual potential evapotranspiration and evaporation in Malawi. Meteorological office, Malawi.

Data Book Project, 1982 - Preliminary report for District Water Supply schemes. Northern Region, Central Region, Zomba Region and Blantyre Region. Water Supply Branch, DLVW HR 46, (unpublished).

DLVW, 1982 - Manual for integrated projects for rural groundwater supplies. ODA-UNDP-Malawi Government. pp 643.

Dixey, F., 1937 - Early Cretaceous and Miocene peneplains of Nyasaland and their relation to the Rift Valley. Geol. Mag. 74 49-67.

Doorenbos, J. and Pruitt, W.O., 1977 - Crop water requirements. F.A.O. Irrigation and Drainage Paper No.24.

Drayton, R.S. et al., 1980 - A regional analysis of river floods and low flows in Malawi. Water Resources Branch, DLVW No.T.P.8.

Drayton, R.S., 1980 - A preliminary survey of the water resources of Malawi (unpublished). Water Resources Branch, DLVW WRB-No.TP11.

Ettema, W., 1983 - The rural piped water evaluation programme. University of Malawi, Centre for Social Research. CSR/26/83.

Feachem, R. et al., 1978 - Water health and development, an interdisciplinary evaluation. Tri-med Books Ltd., London. pp 267.

Flint, R.F., and Skinner, B.J., 1974 - Physical Geology. New York.

Gear, D.J., 1951 - Underground water supplies in the granitic and gneissose rocks of Eastern Uganda. Int.Assoc. Sci. Hydrol., Brussels. pp 252-261.

Glennie, C., 1982 - A model for the development of a self-help water supply program. World Bank Technical Paper No.2. Technology Advisory Group Working Paper No.1.

Habgood, F., 1963 - An account of the geology and groundwater conditions of the Lower and Middle Shire Valley. Geological Survey of Malawi, (unpublished).

Halcrow and Partners, 1954 - The Shire Valley Project. Malawi Government.

Hall, F.R., 1968 - Baseflow recessions - a review. Water Resources Research, 4, pp 973-983.

Hill, J.L. and Kidd, C.H.R. 1980 - Rainfall-runoff relationships for 47 Malawi Catchments. Water Resources Branch, DLVW No.TP7.

Howard Humphreys and Sons, 1975 - Shire Valley Water Resources Study. Design Report. Shire Valley Agricultural Development Project, Malawi Government.

Howard Humphreys & Sons, 1979 - Districts Water Supply Project Design Report and appendices. Malawi Government, Ministry of Works & Supplies.

Jackson, M. - Water Supply and Sewerage Sector Study for Malawi. World Health Organisation/World Bank (unpublished). Report 43 pp and 37 Annexes.

Kirkpatrick, I.M., 1969 - The Thermal Springs of Malawi. International Geological Congress, 23 (19B), pp 111-120.

Lewis, W.J., Foster S.S.D. and Drasar, B.S., 1982 - The risk of groundwater pollution by on site sanitation in developing countries. A literature review. I.R.C.W.D. Report No.01/82.

Lister, L.A., 1965 - Erosion Surfaces in Malawi. Rec. Geol. Surv. Malawi, 7 pp 15-28.

Lockwood Survey Corporation, 1970 - Lower Shire Valley: Irrigation Development Plan. UNDP/FAO.

Mainala, S.M.N., 1982 - A statistical analysis of hydrogeological and geological factors affecting specific capacity of a well and the prediction of yield in a given area, with special reference to fissured Chalk and argillaceous aquifers in Britain and Malawi respectively. MSc Thesis, University of London, UK (unpublished) pp 77.

Mauluka, L.H., 1981 - Livulezi feasibility project - An evaluation study. DLVW, Water Resources Branch (unpublished) pp 11.

Mauluka, L.H., 1983 - Hydrogeological Bulletin for the Nkhotakota-Salima lakeshore area. Water Resource Unit No.15. DLVW

Ministry of Works and Supplies, 1979 - Districts Water Supply Project. Direct Labour Schemes. Design Report. Malawi Government (unpublished).

Msukwa, L.A.H. and Kandoole, B.F., 1981 - Water by the people. An evaluation of the Rural Water Supply Programme in Zomba District. University of Malawi, Centre for Social Research.

National and Shire Irrigation Study, 1980 - Final National Report (Annexe C Groundwater Resources). Hunting Technical Services Ltd., MacDonald and Partners and Ministry of Agriculture and Natural Resources, Malawi Government.

National and Shire Irrigation,Study, 1981 - Lower Shire Report. (draft, unpublished). Hunting Technical Services Ltd., MacDonald and Partners and Ministry of Agriculture and Natural Resources, Malawi Government.

National and Shire Irrigation Study, 1982 - Addendum on Groundwater irrigation potential. Hunting Technical Services Ltd., MacDonald and Partners and Ministry of Agriculture and Natural Resources, Malawi Government.

National Statistical Office, 1980 - Malawi Population Census, 1977. Malawi Government.

O'Conner, M.J., 1973 - Experimental resistivity and IP Surveys for Groundwater Division. Geological Survey of Malawi. (unpublished report).

Pascall, D., 1973a - The Hydrogeology of the South Rukuru catchment area. Geological Survey, Malawi.(unpublished).

Pascall, D., 1973b - Lake Malombe drilling programme. Geological Survey Malawi. (unpublished).

Pike, J.G. and Rimmington, G.T., 1965 - Malawi: A Geographical Study. Oxford University Press. 229 pp.

Robertson, L.H., 1977 - Rural Piped Water Projects Handbook. Ministry of Community Development and Social Welfare.

Ruxton, C.W.F., 1983 - Estimates of aquifer properties and recharge in the Dowa West Integrated Groundwater Project. DLVW (unpublished).

Schoeller, 1937, 1955 - in Groundwater Studies, Geochemistry of Groundwater. UNESCO, 1977. Ed. Brown, R.H. et al.

Smith-Carington, A.K., 1983 - Aquifer tests at Lilongwe International Airport. DLVW (unpublished).

Smith-Carington, A.K., 1983 - Hydrogeological Bulletin for the Bua catchment: Water Resource Unit No.5. DLVW. pp 60.

Smith-Carington, A.K., and Msonthi, F.B., 1983 - Retesting of some boreholes in the Livulezi Integrated Project for Rural Groundwater Supplies. DLVW (unpublished).

Stanley International Ltd., 1983 - Working Paper on Hydrogeology in Lilongwe Region. Lilongwe Water Supply and Sanitation Master Plan.

Thomas, M.F., 1974 - Tropical Geomorphology. A Study of Weathering and Landform Development in warm climates. Macmillan Press Ltd. 290 pp.

Town Planning Department, 1977 - Report on urbanisation policy and housing needs. Malawi Government.

UNDP/WHO, 1976 - A water resources assessment of Lake Malawi. Malawi Government.

Van der Velden, J., 1979 - A summary of rainfall pan evaporation and temperature at pan evaporation stations in Malawi. Water Resources Branch DLVW No. TP3.

Van der Velden, J., 1980 - A summary and review of monthly temperature data in Malawi. Water Resources Branch, DLVW No.TP4.

Van der Velden, J., 1980 - Some aspects of drainage in Malawi. Irrigation Working Paper 30/3. Ministry of Agriculture and Natural Resources, Malawi Government. pp 14.

Water Resources Branch, DLVW, 1979 - Directory of Hydrometric Stations in Malawi current in November 1979. No.TP2.

White, F.G., Bradley D.S., and White A.U., 1972 - Drawers of Water: Domestic Water use in East Africa. University of Chicago. 299pp.

Wilderspin, K., 1973 - A general outline of the groundwater resources of Malawi. Geological Survey, Malawi. (unpublished).

Wilderspin, K., 1974 - The hydrogeology of the Central Region Highlands. Geological Survey, Malawi (unpublished).

World Bank, 1981 - Malawi Basic Needs. Eastern Africa Regional Office. Report No.3461 - MAI. pp53.

World Bank, 1981 - National Rural Development Programme Review. Malawi Government, Ministry of Agriculture.

World Bank, 1981 - Dowa West Rural Development Project, Appraisal Report. Malawi Government, Ministry of Agriculture.

World Health Organisation, 1973 - International Standards for drinking water. WHO, Geneva.

Wright, E.P., 1978 - Report on a visit to Malawi, April 7-April 21, 1978. Institute of Geological Sciences, Report No.WD/OS/78/26. (unpublished). pp 25.