The World Bank
United Nations Development Programme
African Development Bank

Sub-Saharan Africa Hydrological Assessment West African Countries

Country Report: Sierra Leone

August 1992

Mott MacDonald International
Cambridge, U.K.

in association with

BCEOM
Montferrier-sur-Lez, France
and
SOGREAH
Grenoble, France

Report Distribution and Revision Sheet

Project: Sub-Saharan Africa Hydrological Assessment
West African Countries

Project Code: 07171B01

Report Nr: 7

Report Title: Country Report: Sierra Leone, Final

Rev Nr	Date of Issue	Originator	Checker	Approver	Scope of Revision
A	25/10/91	R Manley	A Stuck	T Evans	
B	31/08/92	W Bakiewicz	A Stuck	T Evans	Revised in line with comments forwarded by the Client.

PREFACE

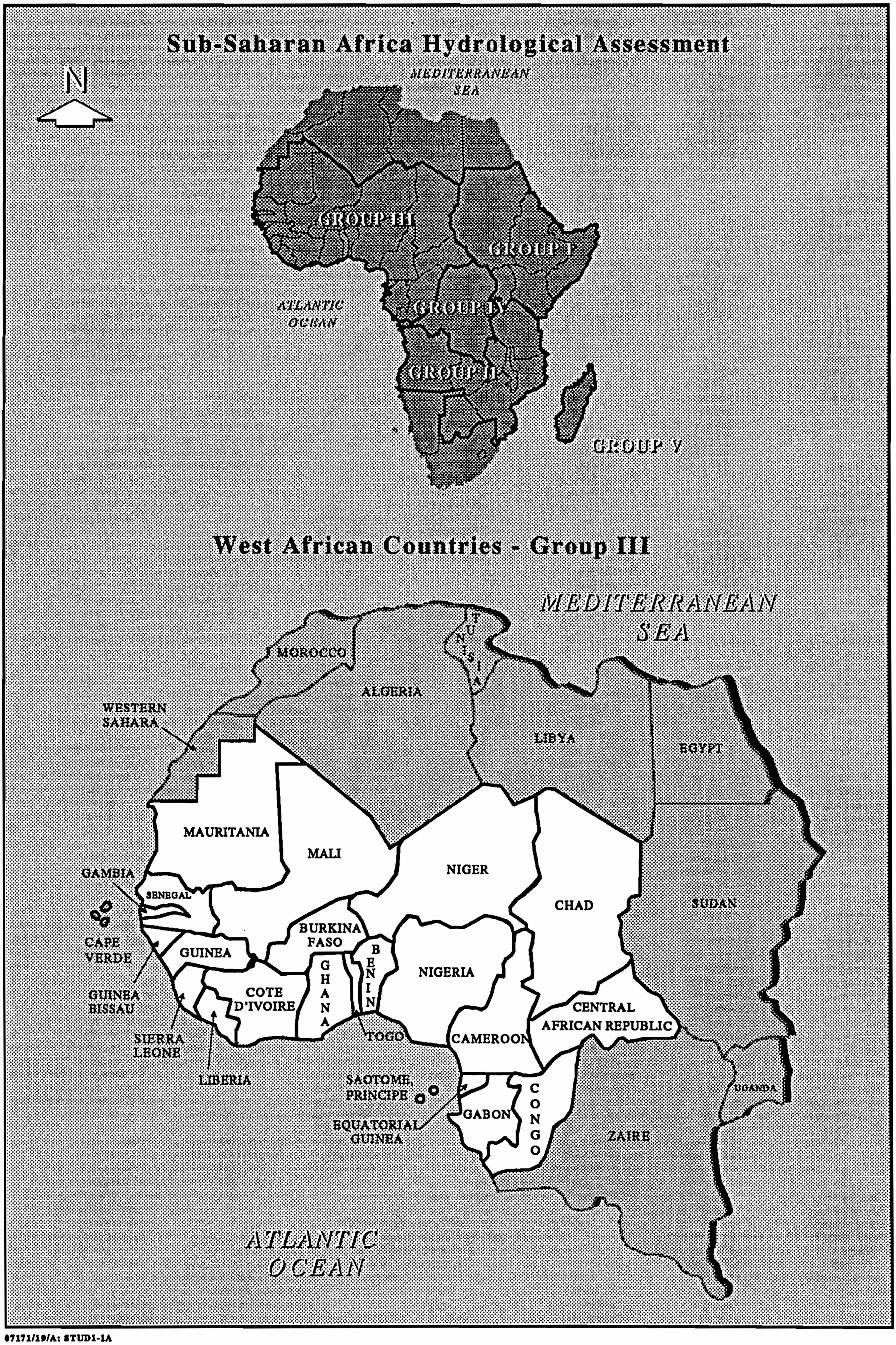
This study is the third tranche of a regional hydrological assessment for sub-Saharan Africa funded by UNDP (Project Nr RAF/87/030), the African Development Bank, and the French Fund for Aid and Co-operation. The study covered twenty three countries in West Africa and started in September 1990. The countries were visited by members of the study team between November 1990 and November 1991. The total time allocation for each country averaged six weeks, of which half was spent in the Consultants home office. In 17 countries the Consultants were assisted by CIEH. The organisation of the study was such that the assessments have been carried out by staff from Mott MacDonald International, BCEOM, SOGREAH, ORSTOM, and a number of local consultants from the region. Every effort was made from the outset to ensure consistency of approach and homogeneity of assessment.

The purpose of the project was to evaluate the status of all existing hydrological data collection systems and to make recommendations to enhance the performance of these systems, the ultimate aim being to assist the countries in the establishment or improvement of a sound hydrological database for the purposes of planning and evaluating water resource development programmes and projects. The goal was to identify those areas where international support would be required, and to develop these recommendations into project proposals in a format suitable for donor financing.

The national assessments, recommendations, and identified project proposals have been published in individual country reports. In addition there is a 'regional' report which supplements the country reports by covering aspects of the study which require assessment at a regional or basin level. It also summarises the common features of the country assessments, and includes a number of project proposals for activities which cover all or part of the region.

This report is based on information obtained and documents collected during a mission to Sierra Leone during the period from 11th January to 1st February 1991. The mission was undertaken by staff from Mott MacDonald International.

We wish to place on record our appreciation of the help of the many people, too numerous to mention, who assisted us during the visit.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ABBREVIATIONS

International

ACMAD	African Centre of Meteorological Applications for Development
ASECNA	Association de Securité de Navigation Aerienne, Dakar, Senegal
CARE	American charity
DARE	Data Aquisition and Rescue Project, International Data Co-ordination Centre, Brussels, Belgium
EDF	European Development Fund
FAO	Food and Agriculture Organisation
IDA	International Development Agency
ILO	International Labour Organisation
IMF	International Monetary Fund
JICA	Japan International Co-operation Agency
KfW	Kreditanstalt fur Wiederaufbau
NGO	Non Government Organisation
OCP	Onchocerciasis Control Project, a WHO programme
ORSTOM	Institut Français de Recherche Scientifique pour le Developpement en Coopération
UNDP	United Nations Development Programme
UNDTCD	United Nations Department for Technical Cooperation and Development
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNICEF	United Nations Childrens Fund
WHO	World Health Organisation
WMO	World Meteorological Organisation

National

Le	Leones
LWDD	Land and Water Development Division, Ministry of Agriculture and Natural Resources
RWSU	Rural Water Supply Unit, Water Supply Department
WSD	Water Supply Department, Ministry of Energy and Power

Technical

DTH	Down-the-hole
GNP	Gross national product
ITCZ	Inter-tropical convergence zone
VLF	Very low frequency
VLOM	Village level operation and maintenance

UN Rate of Exchange (January 1991) US$ = Leones 183

SUMMARY

Sierra Leone is a well watered country with high rainfall and abundant river flows, although there is a pronounced dry season from December to March when flows may be sufficiently reduced to be a constraint to development in the future where storage cannot be provided. Much of the country is underlain by Basement Complex which provides sufficient water for rural borehole supplies where secondary features or deep weathering profiles are developed. The best aquifers are the coastal Bullom Series and alluvial deposits. In general, water availability has not as yet posed a constraint to development and as a result the monitoring of these resources has not been accorded a high priority.

Sierra Leone is at present implementing a 'structural adjustment programme' with the assistance of the IMF. The benefits of this effort are beginning to be realised with a decreasing trade deficit and increased economic activity. The programme requires the holding or cutting of civil service staffing levels throughout government. Those agencies involved in hydrological data collection and processing, which were already experiencing difficulties in recruiting enough suitable qualified staff, have been unable to develop their activities and in most cases are now less active than a few years ago.

The principal department responsible for the collection and processing of climatological data is the Meteorological Service, but such data are also collected by the Land and Water Development Division (LWDD) and by the Guma Valley Authority. There is little or no transfer of information between these organisations. The national meteorological network comprises seven synoptic stations, ten agro-climatological stations, and a further two climate and thirteen rainfall stations; there is also a weather radar system which is not operational at present.

Budget constraints have had a serious effect on equipment. There is no foreign currency allocation for the Meteorological Service to procure replacement equipment, spares parts, or consumables. There is also a shortage of transport for field visits.

The Hydrological Unit of the Water Supply Department (WSD) has only two professional staff and both of these are seconded to the World Health Organisation's Onchocerciasis Control Project (OCP). There is a national river gauging network set up under the auspices of the OCP which has 24 stations. These sites were chosen specifically for their importance to the blackfly eradication programme and the gauges are read only as required by the OCP, actually once a week during visits by OCP fly collectors. The management of this network is contracted to the French organisation ORSTOM. Project records, such as rating measurements, are transferred to Odienne (Côte d'Ivoire), equipment repairs are carried out in either Bamako (Mali) or Ouagadougou (Burkina Faso). The Hydrological Unit are not involved in decision making and there is considerable uncertainty within the WSD as to whether the network and its equipment will eventually be left in Sierra Leone.

The Guma Valley Authority, responsible for Freetown water supply, have records at their dam site for a period of 35 years; this data if processed to yield flows (composite of direct monitoring and

reservoir water balance calculations) would be by far the longest runoff record in the country.

There are three government agencies with an interest in groundwater: the Hydrogeology Unit of the WSD Rural Water Supply Unit, the LWDD, and the Geological Department of the Ministry of Mines. The latter two are almost completely inactive.

There are two major rural water supply projects in progress, the Bo/Pujehun Project financed by KfW, and the Bombali/Kambia Project financed by JICA. The Rural Water Supply Unit has practically no equipment other than that under the control of these two projects. It is estimated that there are about 2 000 dug wells and about 480 drilled wells in Sierra Leone, the majority equipped with handpumps. The total groundwater abstraction is estimated at between 5 and 10 million m^3 which is insignificant compared to estimates of overall recharge. There is no monitoring network for groundwater level measurement and no monitoring of hydrochemical characteristics of abstracted water. This lack of water quality monitoring is a serious deficiency since several project measurements have shown disturbingly high fluoride concentrations. Much of the groundwater is highly aggressive (low pH and negative redox potential) which can cause serious corrosion and maintenance problems unless suitable well components are used.

Five project proposals have been formulated for Sierra Leone. They cover the strengthening of the two national agencies involved in the field of meteorology, and those sections within the Water Supply Department involved in surface and groundwater monitoring and water quality assessments.

CHAPTER 1

GENERAL BACKGROUND

1.1 Geography

Sierra Leone lies between latitudes 7°N and 10°N and longitudes 14°30'W and 10°30'W and has a total surface area of 72 000 km^2. To the west it is bounded by the Atlantic Ocean, to the north and east by the Republic of Guinea, and to the south by Liberia, see Figure 1.1. The country comprises three distinctive physical regions: coastal swamps, interior plains, and the interior plateau. The littoral strip, with a width of up to 100 kilometres, lies below 50 m elevation. Much of this very low lying land is subject to flooding in the wet season, and there are large areas which are affected by tidal flooding where mangroves flourish. Sierra Leone has over 1.1 million ha of swamp land most of it in this zone. Further inland there are the interior lowlands whose altitude ranges from 50 to 200 metres. Here the rivers have wide shallow valleys which flood extensively during the wet season. The generally flat topography is broken in places by isolated inselbergs. The east of the country forms the southern margin of the Guinea Highlands which are the watershed between the southwestward flowing coastal river systems and the Niger Basin. The highest point in the country is Mount Bintimani (1 923 m) in the Loma mountain range. The Freetown peninsula is a separate geographical entity, rising steeply to 900 m above the coastal plain. The shelter provided by the Peninsula Mountains was a major factor in the early development of the port at Freetown.

The main river systems of the country are shown on Figure 1.2. A number of these river systems are shared with neighbouring countries; the Great Scarcies River, or Kolente, to the north forms part of the boundary with Guinea, and to the south the River Mano forms the boundary with Liberia.

Administratively Sierra Leone is divided into three regions and one area; the regions are in turn subdivided into 12 districts as shown in Table 1.1.

1.2 Climate

The climate of Sierra Leone is classified as monsoonal with a single wet season lasting for over seven months. The climate is dominated by the seasonal movement of the ITCZ which forms the boundary between the warm, dry, dusty continental air mass developed over the Sahara and the warm and humid south westerly monsoon air mass. During the dry season harmattan winds from the north-east bring hot, dusty weather. The monsoon air mass predominates over the country from May to November and over 80% of annual rainfall falls in this period. Rainfall is highest near the coast decreasing inland except where this pattern is disturbed by orographic effects, as in the Peninsula Mountains near Freetown.

TABLE 1.1

Administrative Divisions

Area/Province/District	Administrative Headquarters
Western Area	Freetown
Northern Province	Makeni
Kambia District	Kambia
Port Loko District	Port Loko
Bombali District	Makeni
Tonkolili District	Magburaka
Koinadugu District	Kabala
Southern Province	Bo
Moyamba District	Moyamba
Bonthe District	Bonthe
Bo District	Bo
Pujehun District	Pujehun
Eastern Province	Kenema
Kono District	Koidu/Sefadu
Kenema District	Kenema
Kailahun District	Kailahun

Figure 1.3 illustrates the variation of annual rainfall across the country. The isohyets shown are based on those prepared by the MANRF/FAO/UNDP Land Resources Survey Project (SIL/73/002) using data for the period 1951-77.

Annual rainfall can vary significantly as shown by the 5 year running mean of the long term record at four stations, Figure 1.4. The running mean shows a downward trend at two of the stations reflecting the drought conditions which have afflicted the Sahel for the last two decades, however the pattern is not consistent at all the stations which may be a reflection of data quality. The start of the main rains is however quite variable and this has important consequences since much of the country's agricultural production is rainfed.

Daily mean temperature varies little throughout the year. The lowest average temperatures occur in the mid-wet season months of July and August when cloud cover is greatest, the highest temperatures occur in the months of March and April when insolation is high and cloud cover low. At Freetown the average temperature ranges from 25°C in August to 28°C in April. Diurnal variation in temperature is strongly influenced by proximity to the coast, for example being 6°C at Freetown and 18°C at Kabala.

Potential evaporation exceeds rainfall for six months of the year but on an annual basis there is an excess of rainfall.

Figure 1.1

Location Map

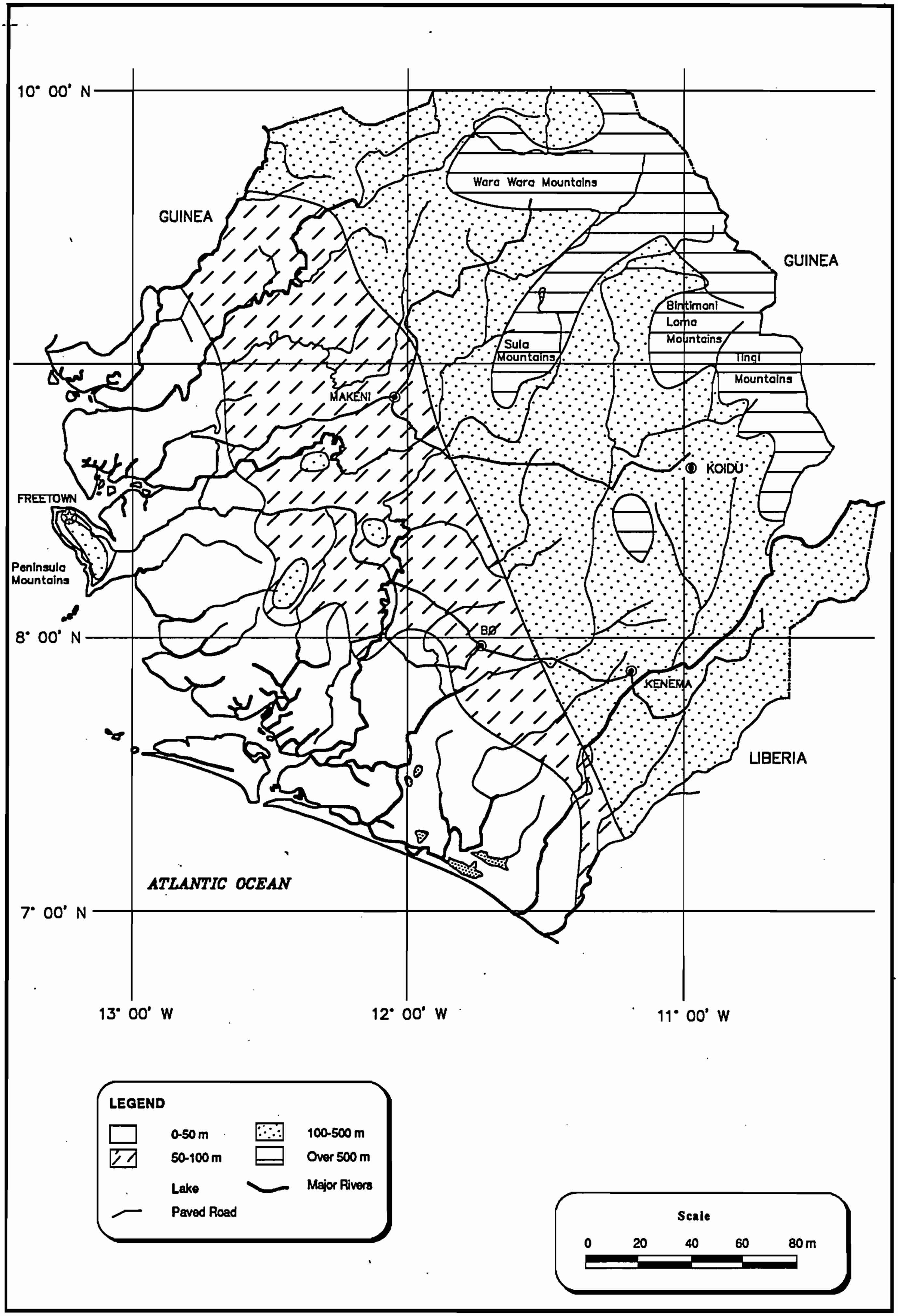
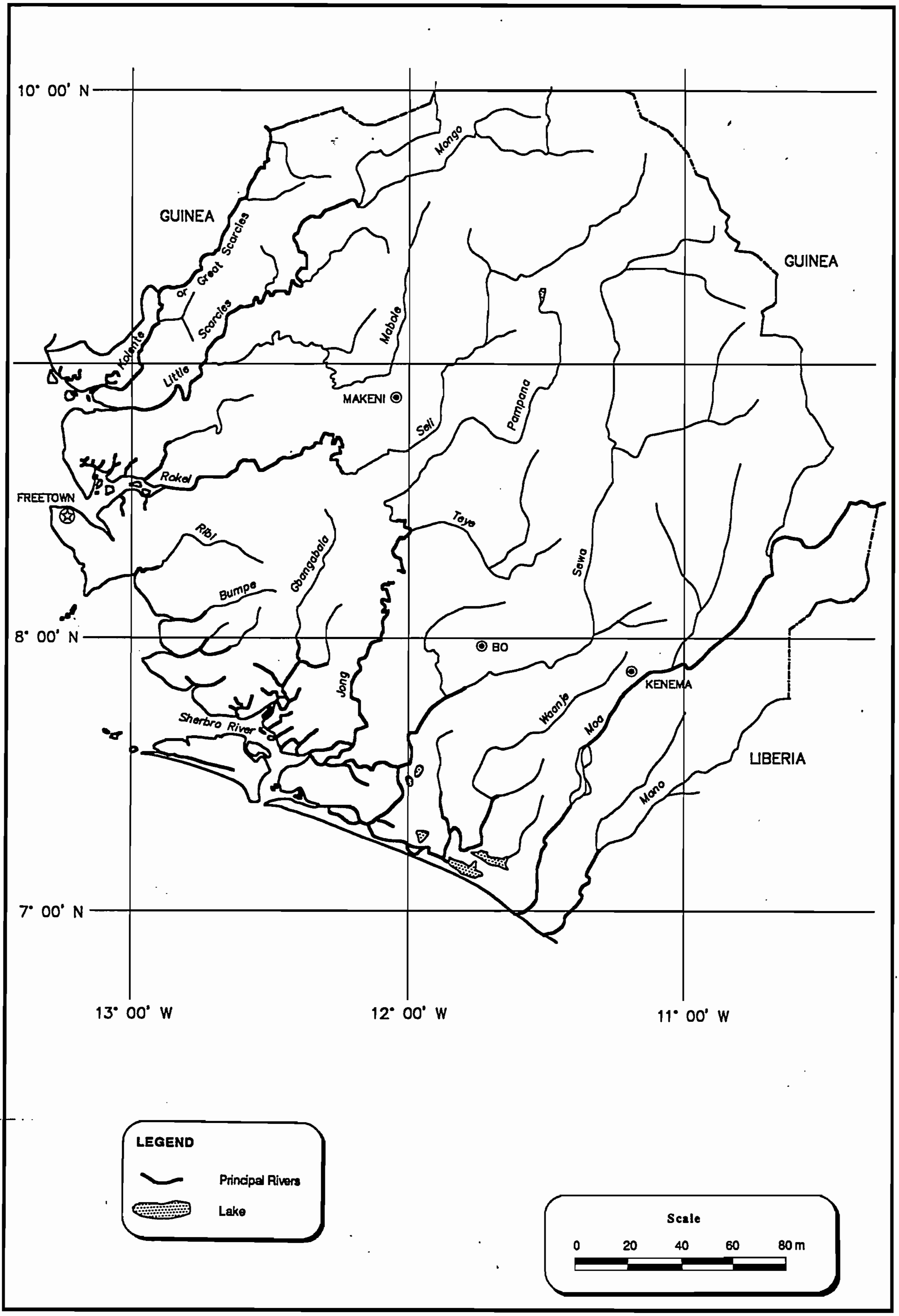
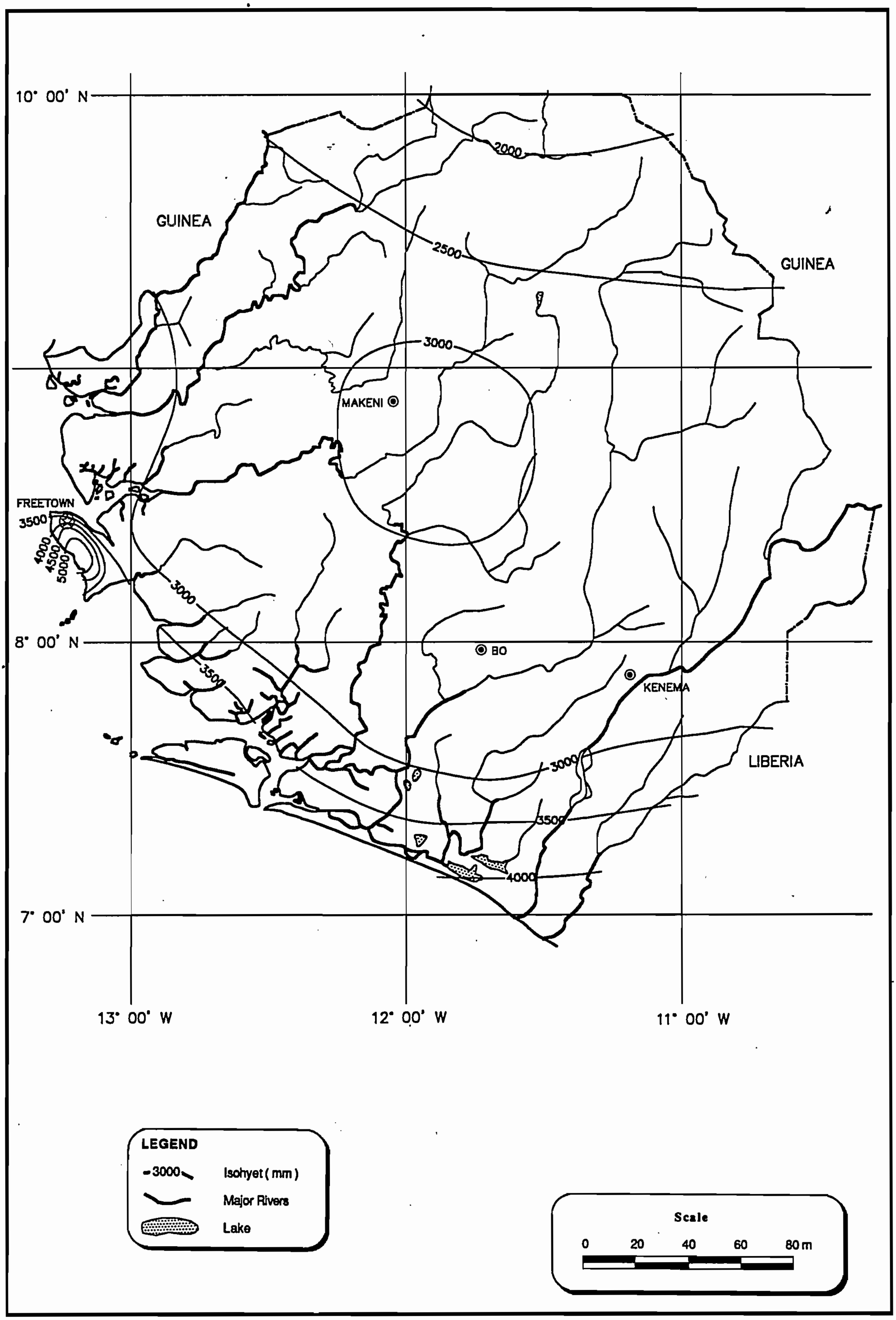


Figure 1.2

Principal Rivers



Average Annual Rainfall Isohyetal Map



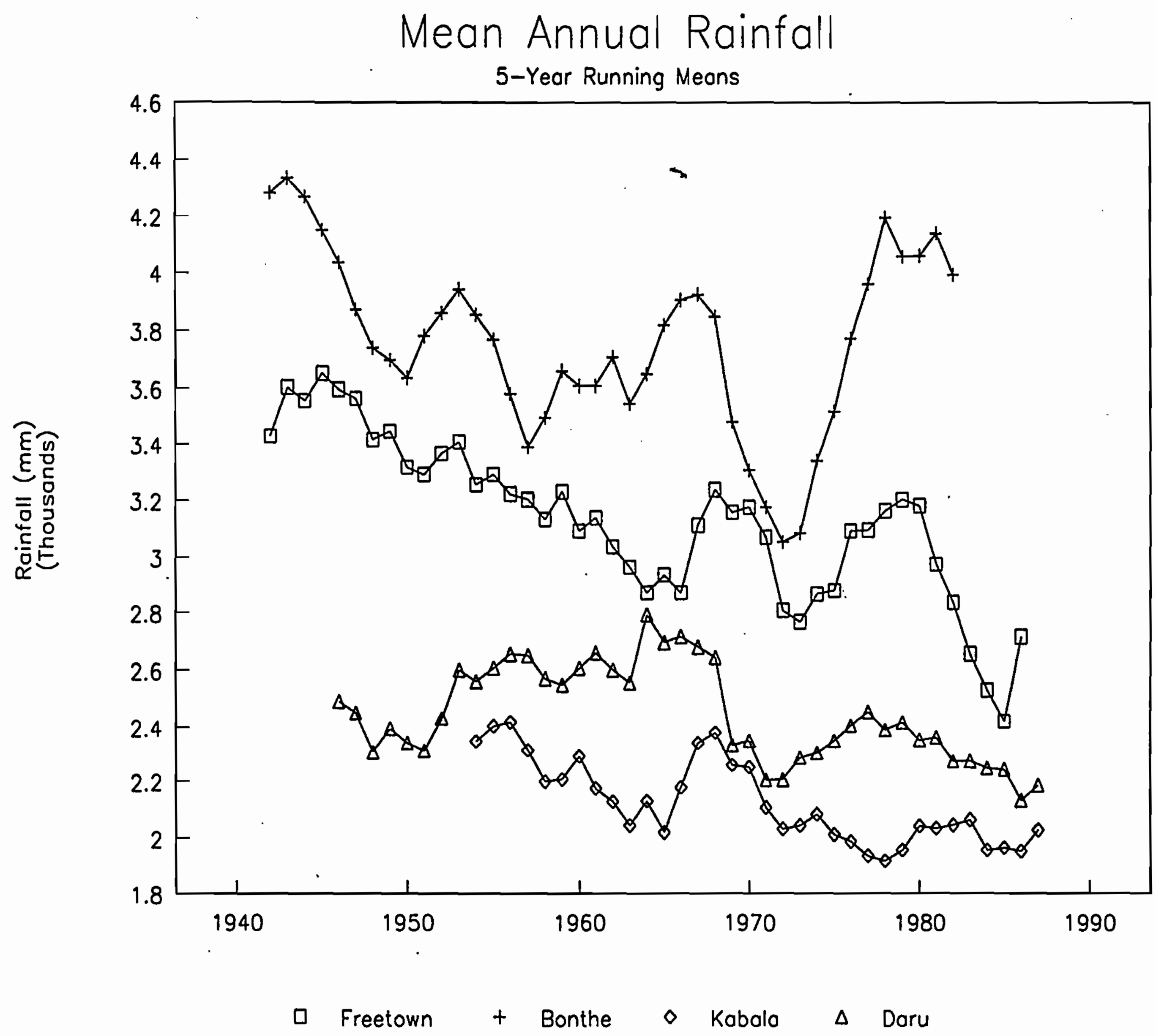


Figure 1.4
Long Term Rainfall Patterns

1.3 Water Resources

In general the country presently has few water resources problems. That this is so is due to the combination of high and well distributed rainfall, and the country's present level of economic development. The dry season is short but this period of low flows may constrain future development options particularly where there is no possibility of storage. There are at present no major irrigation schemes, and the Guma Valley Authority operates the only major storage reservoir for public water supply. One serious problem at present is that areas of the capital city have water shortages during the dry season, and these are due in part to distribution problems linked to power supply rotation within the city.

Sierra Leone has considerable potential for hydropower development utilising the steep sections of rivers draining from the interior plateau, although there are limited possibilities for water storage at these sites. It is understood that the proposed hydropower scheme at Bumbuna could ultimately include storage although initially it is to operate as run-of-river.

Mining is a key sector in the economy, see Section 1.7, and a feature of this industry in Sierra Leone is the importance of working alluvial deposits (for diamonds and rutile). The mines use substantial volumes of water, primarily for washing, and it is understood operate several dams. The quality of the water returned to the rivers in certain locations seriously impairs the overall water quality.

The groundwater resources of Sierra Leone have not been extensively or intensively studied, but exploitation is sure to be limited in most regions. Yields from wells are likely to be suitable for domestic supplies for small communities but insufficient for large towns or for irrigation. Nevertheless groundwater is of great importance from the point of view of providing hygienic water supplies for the rural population of the Republic.

Groundwater quality is generally characterised by low overall mineralisation with low pH (often 5 to 6.5) and consequently high concentrations of heavy metals, particularly iron; the iron problem has been exacerbated in some areas by using inadequately protected mild steel well and pump components. Groundwater of high salinity occurs only at the coast and is of the high chloride type; its mode of occurrence and composition testify to the marine influence. There may also be a local fluoride problem in some regions, but this contention needs checking and confirmation.

Though groundwater abstractions for rural supplies are always small and seldom, if ever, result in resource depletion on a regional scale, some attempts have been made at estimating the annual replenishment or recharge. GKW (1988) have identified watertable oscillations of 2 to 10 m between the dry and the wet seasons in the Bo and Pujehun Districts, such fluctuation suggests an active groundwater system, with considerable recharge. Based on computations by Jalloh (1979), annual recharge may amount to as much as 10 000 million m^3, which is several orders larger than total groundwater abstractions.

1.4 Population

The population is 3.8 millions. The population growth rate was 2.4% for the period 1980-85, 2.5% in 1986 and also 2.5% in 1987. The main centre of population is the capital city Freetown whose population is estimated at 630,000. Other large towns are Koidu 86,000, Bo 81,000, Kenema 52,000 and Makeni 53,000. (The basis on which the population figures have been calculated is given in Section 2.3.1.) The population is predominantly rural with 63% of the population living in villages of less than 1 000 inhabitants, 17% in communities of between 1 000 and 10 000 inhabitants, and the remaining 20% in towns and cities of population greater than 10 000 persons.

The average fertility rate is 6.5 babies per woman. That this high rate does not give rise to a higher population is due to a high infant mortality rate.

1.5 Health

Life expectancy at birth is 41 years, one of the lowest in the whole of Africa. Sierra Leone is among the five highest countries in the world in terms of infant mortality (death in the first year) and also death within the first five years. Seventeen percent of all babies die in the first year with a further 10% dying before their fifth birthday. Of these premature deaths one-third are neonatal (within one month of birth) with malnutrition, respiratory infections, diarrhoeal diseases and malaria accounting for most of the later deaths. The average Sierra Leonean child suffers 6 bouts of non-fatal diarrhoea each year.

It is estimated that, up to the present (February 1991), only 20% of the rural population of Sierra Leone has access to safe water (Bicego, 1990). This clearly demonstrates the huge scope for further groundwater development.

1.6 Education

Some published figures suggest that overall rates of enrolment in primary education are relatively high at 65%, but other sources give a lower estimate of 39% for boys and 20% for girls in rural areas and 68% and 62% for boys and girls respectively in urban areas. The net result is a high level of illiteracy which can reach 98% among rural woman. Of the children who start school 27% go on to secondary school and 3.5% go on to University.

The universities consume a significant proportion of the resources available for education, accounting for only 0.4% of all enrolments but 11% of the budget. Half of foreign aid in the education sector goes on graduate level education either in the country or abroad. University education is carried out at Fourah Bay College (founded in 1827 and closely associated with the University of Durham, Great Britain, since 1867) and Njala University College. The two colleges collectively form the University of Sierra Leone. The degrees awarded, which include engineering and scientific subjects, are recognised by overseas institutions for the award of post-graduate fellowships.

1.7 The Economy

The country's Gross National Product (GNP) has stagnated at 1 000 million US dollars (1980 dollars) throughout the 1980s. This, coupled with a growing population, has led to reduction in the per capita GNP, which fell by 2.2% in 1987. In recent years the country has adopted an IMF led structural adjustment programme for the economy which has resulted both in a dramatic change in the country's exchange rate (from parity with the US dollar in 1980, to Le 34/$ in 1987 and to Le 183/$ in January 1991), and also to a reducing trade deficit which was only US$ 5 million in 1986 (the last year for which figures are available). The main contributors to the economy (by value added) are agriculture 43.0%, industry 21.2 %, and services 34.1%. In 1987 the main exports (by percentage of value) were rutile (30.5%), diamonds (22.8%), bauxite (15.3%), cocoa (9.9%) and coffee (9.0%). Rutile, the ore from which Titanium is derived, had risen from only 5.5% in 1980.

CHAPTER 2

WATER RESOURCES

2.1 Surface Water Resources

2.1.1 River Systems

There are nine main river systems flowing through Sierra Leone as shown in Figure 1.2. In general the rivers flow from north-east to south-west. Some of the rivers have more than one name, for example the Great Scarcies or Kolente, reflecting the fact that they flow through areas inhabited by different ethnic groups who give the river a name in their own tongue. Of these nine major rivers three, the Great Scarcies, the Little Scarcies, and the Moa, are shared with the neighbouring territory of Guinea, and two, the Moa and the Mano, with Liberia. There are in addition many minor catchments which are entirely contained within Sierra Leone. Table 2.1 gives the catchment areas of the various river systems and shows the proportion of each located in either Guinea or Liberia.

TABLE 2.1

Major River Systems in Sierra Leone

River System	Catchment Area (km^2)		
	Sierra Leone	Guinea	Liberia
Great Scarcies	2 260	3 660	-
Little Scarcies	12 600	5 400	-
Rokel or Seli	10 200	-	-
Coastal catchments	5 500	-	-
Gangbaia	2 920	-	-
Jong	9 000	-	-
Sewa	13 600	-	-
Waanje	2 900	-	-
Moa	10 700	7 600	150
Mano	2 400	-	5 600

2.1.2 Surface Runoff

The main physiographic regions of Sierra Leone are the coastal swamps, the interior plains, and the interior plateau, see Section 1.1 and Figure 1.1. The coastal plain, with its complex pattern of drainage, is a product of the drowning of an earlier pattern of drainage, a type of coastline referred to as a 'ria'. The tidal range in the Freetown area is some 4 m but is less further south. Significant areas of the low lying coast are flooded at high tide resulting in vast areas of mangrove swamp. In the wet season these flat lands are also subject to extensive riverine flooding.

Given the lack of information on river flows and the almost complete absence of a hydrometric network, problems discussed in Chapter 4, it is difficult to estimate the surface water resources available to the country. However, an approximate figure can be obtained by using the limited flow data available and by comparing it with rainfall recorded over the catchment in the same years to develop rainfall runoff relationships for parts of the country. These relationships can then be extrapolated to cover the whole country using the isohyetal map presented in Figure 1.3. On the basis of such an approach an approximate estimate of mean annual surface runoff for the country is 70 000 million m^3.

No master plan has been produced for the water resources of the country. Given the shortage of hydrological data, discussed elsewhere, it would at the present be difficult to produce such a plan.

2.2 Groundwater Resources

2.2.1 Introduction

The use of groundwater resources for rural water supply is a recent development. In contrast to the surface water resources of the country, which are widely used but poorly monitored or documented, the recent water supply projects utilising groundwater have resulted in a substantial body of information. Accordingly, in order to give a balanced view of the country's overall resource which is dominated by surface water, the description of groundwater given here is only brief and a detailed description has been included in an appendix (Appendix G) to allow a full discussion of the on-going groundwater development projects.

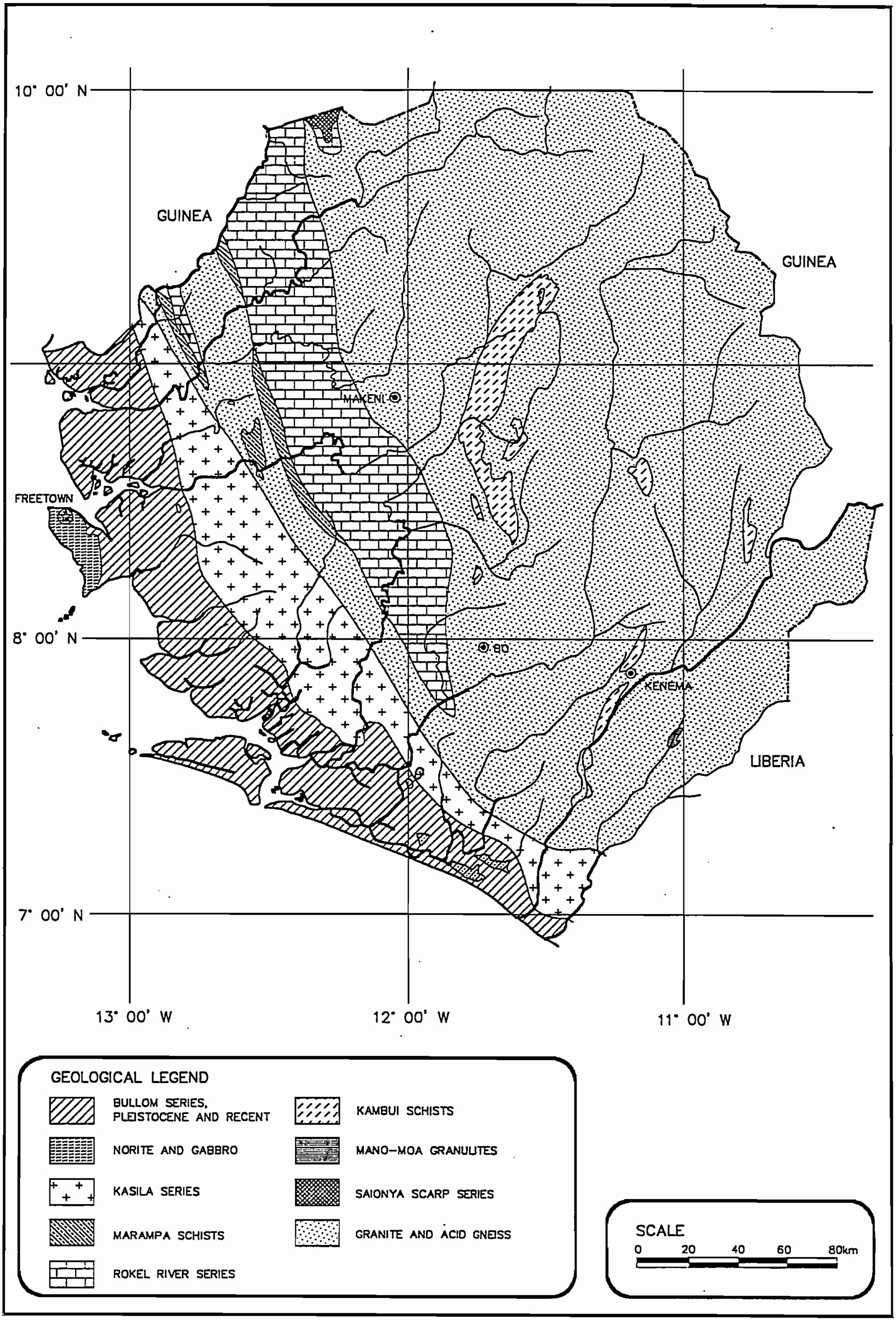
2.2.2 Geology

Sierra Leone is located mainly on the Guinean craton, a tectonically stable region comprised of ancient, highly deformed, crystalline rocks, in places overlain by younger volcanics and sediments. At the coast, the basement dips rapidly towards the Atlantic continental shelf and the coastal belt is covered by Tertiary to Recent sands and clays. The full stratigraphic sequence is shown in Figure 2.1

Apart from the coastal zone and the Rokel Trench (Figure 2.1), virtually the whole of Sierra Leone is underlain by ancient crystalline rocks, consisting predominantly of granitoids, but including

Figure 2.1

Geological Features



amphibolites and other greenstone facies. This Precambrian Basement is cut by many fractures and minor intrusives. The Rokel River Group which is also of ancient age, includes sediments and volcanics, but all of these are strongly indurated, cemented and sometimes recrystallised. Lastly, the Tertiary Bullom Series comprise unconsolidated sands, clays and lignites. This whole succession forms a series of erosion surfaces, the oldest of which have been dissected into mountain and hill ranges.

2.2.3 Groundwater Occurrence

The Basement rocks, which cover much of Sierra Leone, have no primary porosity or permeability in the unaltered state; groundwater in small but exploitable quantities is found mainly in near surface secondary features such as joints, fractures and the zone of weathering. The variation in yield of basement wells testifies to the non-homogeneity or even discontinuity of this near-surface aquifer.

The Bullom Series, though consisting predominantly of clays and lignites, contain coarse, uncemented clastics, which possess primary porosity and permeability; these are generally considered as the most productive aquifers in the country. The maximum well depth recorded in these strata is 110 m and the maximum production rate from a drilled well in these deposits is reported as 15 l/s. The Bo/Pujehun Project has used dug wells in this aquifer, in an attempt to maximise diameter and limit depths in order to avoid salt water intrusion. No detailed records are as yet available.

2.2.4 Water Quality

The available hydrochemical data are scarce with only one project (Bombali/Kambia) routinely reporting extensive chemical analyses at all completed wells. The major quality problem appears to be with heavy metals, particularly iron, though in some cases this may partly be due to the use of inadequately protected steel well components, which react with the typically highly aggressive groundwater. There may also be a fluoride problem with almost 20% of the Bombali/ Kambia wells showing concentrations of 5 mg/l, which is totally unacceptable for potable supplies. However, the analyses are crude and not entirely internally consistent, and need checking. The organic contamination of water wells appears to be adequately addressed with routine checks and disinfections if needed. Further, more detailed, information is given in Appendix G.

2.2.5 Recharge

Groundwater recharge conditions in much of Sierra Leone seem advantageous. The average rainfall is high and normally exceeds potential evapotranspiration in the period from April to November; most of the country has a rolling plains topography with relatively gentle slopes; the soils are often coarse with high potential infiltration intake. The fact that the groundwater system is active rather than static, is reflected by the seasonal oscillations of the watertable; the Bo/Pujehun Project recorded fluctuations of 2 to 10 m between the dry and the wet seasons.

Quantification of the annual groundwater replenishment is difficult; most of the methods used to evaluate recharge make use of generalisations and approximations and often give only a rough indication of the available resource. In most of Sierra Leone this is not very important, because the main constraints to groundwater development are related to the poor transmission properties of the aquifer and the consequent low productivity of wells installed in it. Regional depletion of groundwater resources by wells with hand pumps in Basement aquifers is not normally a serious risk.

There may be a risk of over exploitation of the coastal Bullom series aquifer, which reportedly contains high permeability layers; in addition to recharge limitation this aquifer is at risk of sea water invasion, if overpumped.

Recharge is discussed by Jalloh (1979). On the basis of annual river hydrographs at four stations recharge was estimated to be between 420 and 1 200 mm, while a much lower figure was obtained by an overall water balance for the northern half of Sierra Leone, as follows:

Average annual precipitation	2 550 mm
Average annual actual evapotranspiration	1 550 mm
Average annual surface runoff	908 mm
Average annual groundwater recharge	142 mm

This second value of recharge seems more realistic; adopting it for the whole of Sierra Leone gives the annual recharge of about 10 000 million m^3. Comparing annual recharge of 142 mm with the seasonal water level fluctuations of 2 to 10 m, suggests a range of storage coefficients of 1 to 10%, which agree with the expected order of magnitude.

2.3 Water Demands

2.3.1 General

The main centres of demand are Freetown whose population is estimated as 630 000, Koidu - 86 000, Bo - 81 000, Kenema - 52 000, and Makeni - 53 000. The location of these towns are shown in Figure 1.1. These estimates are only indicative as the preliminary report of the 1985 census does not give a breakdown of urban populations. They were obtained by taking the 1974 census figures, increasing them by the same proportion as that of the most densely populated chieftainship in the relevant district (which it was assumed would approximate to the urban area) and then assuming that the annual percentage growth rate which had occurred from 1974 to 1985 had continued until 1991. In these centres almost all the demand is domestic and there is only a negligible industrial consumption of water.

There is much mining in the country and whilst this uses a lot of water for washing it is a largely non-consumptive use. It does however cause serious pollution in certain cases.

2.3.2 Irrigation and Agriculture

Sierra Leone has over 1.1 million ha of swamp, of which approximately 200 000 ha are under cultivation for rice. The potential for increasing output from 'swamp rice' cultivation is considerable both in terms of increased area and enhanced productivity. There is a rice research station investigating the potential of this type of cultivation at Rokupur on the lower Great Scarcies. The most productive areas at present are the extensive floodplains of the Little Scarcies, Sewa, and Waanji rivers where flooding can be up to 2 m deep in places. The type of rice cultivated is the so called 'floating' rice. At present there is only a low level of water control associated with the cultivation of swamp rice.

Upland rice is also a major crop which is grown as a rainfed crop without supplementary irrigation. The annual rainfall in many areas of the country is sufficient for two crops to be cultivated.

The country however is not able to produce all its own food and it is possible that the introduction of irrigation might help to increase yields particularly in the drier parts of the country.

2.3.3 Domestic and Municipal Water Supply

Where surface water is used for water supply it is normally taken from rivers or swamp areas. Apart from the capital, Freetown, there are reported to be no operating urban water supply schemes. In the early 1980s water distribution and treatment schemes were installed in 30 of the largest towns but few of these systems have ever been fully operational - due to lack of funds for fuel and chemicals. Another reason for the failure of some schemes is that they need electricity and most towns have inadequate or unreliable power supplies.

The only surface water reservoir for potable supplies is for the city of Freetown. This is the Guma Valley dam which was constructed in 1961/62 and has a capacity of 21.8 million m^3 and a yield of 76 million litres per day. This reservoir is operated by the Guma Valley Authority (formerly the Guma Valley Water Company) and, despite severe financial restraints in recent years, appears to be well run and to provide water of an acceptable quality. Most urban residents in other towns resort to wells of doubtful quality, or get water from bowsers.

Around 80% of the rural population obtains water from surface sources, usually streams and pools. In recent years several villages have received supplies of gravity fed water from protected surface water catchments through projects undertaken by the British charity Water Aid.

Though Sierra Leone is a country of high annual rainfall and has a dense network of rivers and streams, it experiences a pronounced dry season from December to March, when surface water may be difficult to obtain, at least in some areas. Hence traditionally some villages and towns have relied on groundwater from dug wells for their potable supplies. More recently groundwater sources have been used for drinking water to limit spread of water-borne diseases; wells and boreholes are relatively easy to protect from organic contamination (bacteria, virus and vector borne parasites) and can provide safe water to small communities, without expensive treatment.

Some villages have relied on dug wells as sources of potable water since ancient times. Groundwater based supplies for larger centres of population are much more recent; nevertheless, according to UNDP (1988), by the early 1980s several towns had water supply systems based on wells and springs as demonstrated by Table 2.2. It should be noted that most of these are located on the outcrop of the Bullom Series.

TABLE 2.2

Groundwater Supply Systems to Towns

Location	Type of source	Water use	Maximum capacity (l/s)	Comments
Lungi Airport	Borehole	Domestic and commercial	6.3	Insufficient yield - replaced by a trench
Milestone 91	Borehole	Domestic	1.1	Discharge declines during dry season
Bonthe	Dug Well	Domestic	13.9	-
York	Dug Well	Domestic	3.7	Insufficient yield
Newton	Dug Well	Domestic and agricultural	17.4	Discharge declines drastically during dry season
Songo	Dug Well	Domestic	13.9	-
Kamiendor	Dug Well	Domestic	4.5	Water level falls during dry season
Gbinti	Dug Well	Domestic	3.7	-
Mambolo	Spring	Domestic	13.9	-
Zimmi	Spring	Domestic	13.9	-

Source: UNDP 1988

Though the first World Bank (IDA) assisted rural water supply project, concerned with the installation of dug wells, started in 1976, it is estimated that only 2% of the rural population of Sierra Leone had access to safe water at the beginning of the UN Water Supply and Sanitation Decade (Bicego, 1990). From 1981 onwards the installation of such wells was greatly accelerated under the

UN co-ordination with standard designs, demonstrated in Figure 2.2 A, adopted. It is however of interest to note that the first four dug wells installed by the Bo/Pujehun Project were of substantially different design (Figure 2.2 B), perhaps indicating imperfect co-ordination, at least at the start of that project.

Since 1976 (but mainly during the Decade) some 1 500 dug wells and 480 drilled wells have been installed and equipped with hand pumps. The average abstraction per well is estimated as 7.5 m^3 per day or about 2 750 m^3 per annum.

The two rural water supply projects concerned with the installation of boreholes, both started in 1987, have adopted substantially different designs, shown in Figure 2.3. In well site selection the Bo/Pujehun Project concentrated on geological appraisal augmented by drilling of shallow holes to discover the thickness of overburden and thus decide whether a dug or a drilled well was appropriate for a particular site. The Bombali/Kambia Project never considered dug wells at all and used geophysics (EM traversing and conventional resistivity sounding) as an aid to borehole siting.

.The KfW assisted project adopted designs using corrosion resistant or chemically inert well and hand-pump components. The JICA project ignored experience in adjacent countries and used some inadequately protected well components (galvanised mild steel casing), probably exacerbating water quality problems with regard to high iron content. In addition this project used stainless steel wire wound well screens, which are unnecessarily expensive for low discharge wells with hand pumps. Lastly, pump tests, chemical analyses of water and reporting are substantially different in the two projects.

At least four different types of hand pump have been used in Sierra Leone, but since 1981, most have been of the India Mark II type, except for the Bo/Pujehun Project which has used the German made Kardia pump. The India Mark II, though reportedly robust and reliable, does not conform to the VLOM (village level operation and maintenance) concept, advocated by the World Bank. The Kardia has a very good all round reputation, but is relatively expensive.

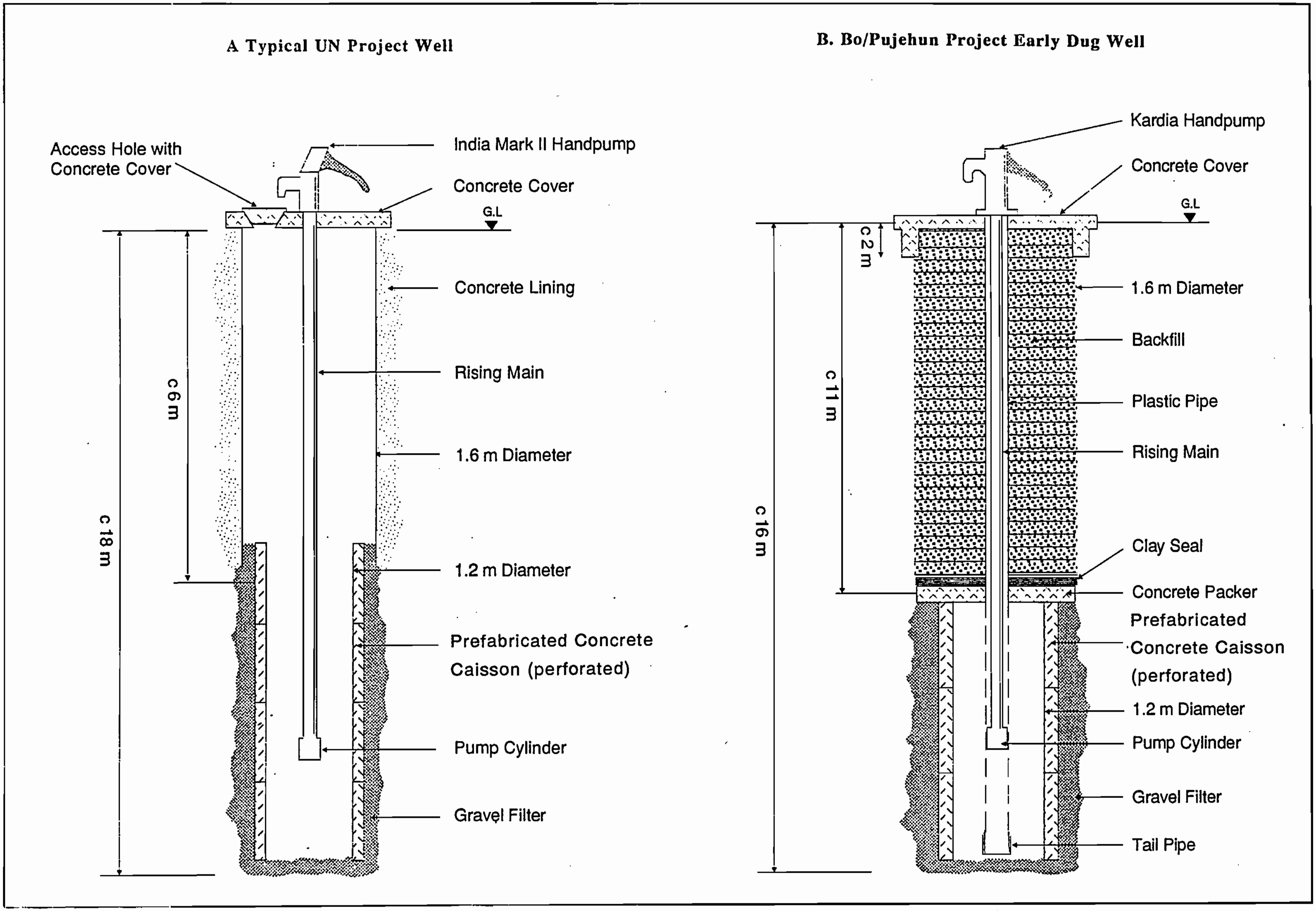
Real costs of various wells are difficult to evaluate. According to UNDP (verbal communication 1991) the cost of a fully equipped dug well constructed under the UN funded Eastern Province Rural Water Supply Project is in the range of US$ 3 000 to 4 000; however, this does not include the costs of the UN personnel. The cost of a Bo/Pujehun Project borehole, also fully equipped, is about US$ 17 000, but this is inclusive of all consultants' costs, including mobilisation of staff and equipment. It is perhaps significant that the latter project no longer installs dug wells; it has found them too slow and too expensive.

The summary of the major developments in rural water supply and sanitation in Sierra Leone up to the end of April 1990, is shown in Table 2.3. This summary is still largely valid as there has been relatively little additional development since then.

TABLE 2.3

Rural Water Supply and Sanitation Projects in Sierra Leone

Item	Project	Coverage	Period	Foreign funding by	Total foreign funding to date	Targets	Units completed	Remarks
1	Village Wells Component of Northern IADP	Bombali and Tonkolili Districts	1976 - 1984	IDA	$851 400.00 (estimated)	300 dug wells	? 220 dug wells	Project was not under RWSU co-ordination. Phased out in 1984.
2	Village Wells Component of Magbosi IADP	Tonkolili and Port Loko Districts	1980 - 1984	IDA	$1 203 000.00 (estimated)	250 dug wells	? 200 dug wells	Project was not under RWSU co-ordination. Phased out in 1984.
3	Village Wells Component of Eastern IADP	The Eastern Province	1981 - 1985	IDA, UNICEF	$600 000.00 (estimated)	150 dug wells	112 dug wells	Project superseded by project (12) below with effect from Jan 1986.
4	Rural Water Supply Programme (SIL/79/009)	Country-wide	1981 - 1985	UNDP	$1 611 000.00	Establishment of the Rural Water Supply Unit in WSD; Technical assistance on Projects (3) above and (5) below.		Project ended Dec 1985, to be replaced by Project (11) below.
5	Koinadugu Rural Water Supply Project	10 Chiefdoms of the Koinadugu District	1981 - ongoing	UNDP EEC	$1 200 000.00 $300 000.00	300 dug wells VIP latrines	282 dug wells 100 VIP latrines	UNDP funding ended Dec 1986. Since then EEC has been funding the Project as part of Project (10) below.
6	Moyamba Rural Water Supply and Sanitation Project	Moyamba District	1981 - ongoing	CARE, NORWAY	$2 150 000.00	Dug wells VIP latrines	210 dug wells 800 VIP latrines	Project likely to go on until 1993.
7	National Environmental Sanitation Programme	Country-wide	1981 - ongoing	UNICEF	$540 000.00	Establishment of NESS to implement the Environmental Sanitation component of water supply programmes		Project ongoing.
8	Peninsular Rural Water Project	Freetown Peninsula	1983 - 1985	CARE, WATER AID	$250 000.00	4 Gravity-fed units	2 Gravity-fed units	Project phased out in 1985.
9	Village Wells Component of ILO's Rural Works Project	Kambia and Bonthe Districts	1983 - ongoing	DANIDA, ITALY, UNDP	$200 000.00	70 dug wells	51 dug wells	Project ongoing.
10	Port Loko/Kambia Rural Water Supply Project	Port Loko and Kambia Districts	1985 - ongoing	EEC	$3 200 000.00	140 dug wells. Pilot rainwater harvesting units, VIPs	160 dug wells, 28 Rainwater harvesting units, 65 VIPs	Project nearing completion.
11	Strengthening of Rural Water Supply Unit (SIL/85/002)	Country-wide	1986 - ongoing	UNDP	$1 781 516.00	Co-ordination, technical supervision and monitoring of all rural water supply and sanitation activities in the country.		Project is strengthening RWSU established on Project (4) above.
12	Eastern Province Rural Water Supply Project (SIL/84/C01)	The Eastern Province	1986 - ongoing	UNICEF, (UNDP)	$2 495 952.00	250 dug wells, 13 gravity and 8 spring units, 1 050 VIPs	200 dug wells, 8 gravity and 8 spring units, 800 VIP latrines	Superseded Project (3) above. Project nearing completion.
13	Gravity-fed Water Supply and Sanitation Project	The Eastern Province	1986 - ongoing	WATER AID	$3 000 000.00	Gravity/spring units, VIP latrines	100 gravity, 10 springs 1 500 VIP latrines	Project likely to go on until 1993.
14	Bo/Pujehun Rural Water Supply and Sanitation Project	Bo and Pujehun Districts	1987 - ongoing	KfW - West Germany	$9 300 000.00	300 drilled wells, 30 dug wells, VIP latrines	345 drilled wells, 30 dug wells, 180 VIP latrines	Project to continue to mid-1991.
15	Bombali/Kambia Rural Water Supply Project	Bombali and Kambia Districts	1987 - ongoing	Govt of Japan	$9 400 000.00	142 drilled wells, 1 surface scheme	140 drilled wells	Project ongoing.
16	Water and Sanitation component SIL/85/003	Shenge Region Moyamba District	1989 - 1990	UNCDF, UNDP	$400 000.00	19 dug wells, 300 VIP latrines	7 dugs wells, 5 VIP latrines	Project ongoing.
Source: Bicego, 1990			TOTAL		$38 484 868.00			



Typical Dug Well Design

Figure 2.2

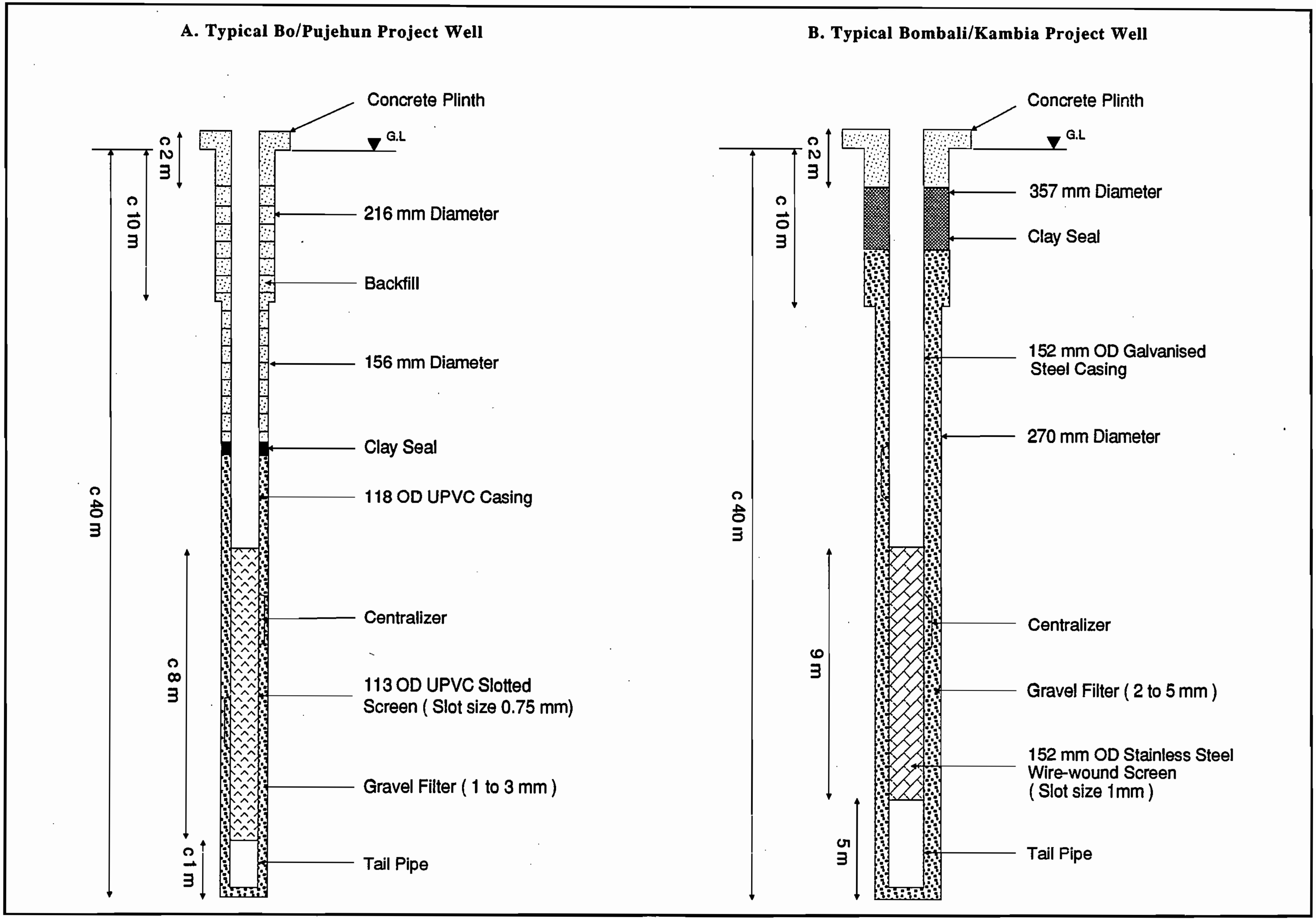


Figure 2.3 Typical Drilled Well Designs

2.3.4 Hydropower

There are presently no commissioned hydropower installations but one scheme is currently under construction at Goma, to the north of Kenema. This will be able to produce 4 MW but as there is no storage its dry season yield is assumed to be only 0.5 MW. It has therefore been necessary to supplement it with an oil fired station which, of course has a negative effect on the overall economic viability.

Work had also started on the access roads to the country's most promising and economically justifiable hydropower scheme at Bumbuna. In recent years however work has been halted due to a lack of funds. This project is planned to be developed in several phases with an ultimate total generating capacity of 305 MW and a planned energy production of 1 250 GWh per annum. This is some five times higher than the total amount of electrical energy produced in 1984 so it is obvious that it would be uneconomic to develop it to its full potential immediately. Initially it will operate as a run of river scheme with a head of 114 m. It is later proposed to provide storage at Yiben. Given the current problems that the country has in obtaining supplies of oil and oil products it would seem that hydropower will become increasingly important if finance can be found. A number of other schemes have been identified and these are listed below in Table 2.4.

TABLE 2.4

Proposed Hydropower Sites

Name	Location	River	Type	Capacity MW	Capital US$[1]	Equalising Discount Rate[2]
Gbangbaia	Mayambe	Gbangbaia	Run of River	1.0	3.4	10.4
Gandorhun	Bo	Sewa	Run of River	20.0	65.4	10.2
Manalho	Kabala	-	Run of River	0.5	3.2	9.3
Benkungor Falls	Kona	Sewa		10.8	22.0	29.5
Betimi Falls	Magburaka	Pamoana	Run of River	3.6	13.5	12.8
Singimi Falls	Moyambe	Gbangbaia	Limited storage	7.2	28.0	20.8
Kambitombo Falls	Komaduyu	Mongo	River diversion	0.8	6.6	5.2

Notes: 1 1985 US dollars.

2 This is the discount rate at which the cost of electricity from the hydropower scheme equals that from fossil fuel generation.

3 The table was prepared from different sources which do not all give the same information.

CHAPTER 3

CLIMATE

3.1 Organisation and Management

3.1.1 The Meteorological Service

The Meteorological Service comes under the Ministry of Transport and Communications. This reflects what is perceived to be its principal function - that of providing forecasts for aviation. The main office is in the centre of Freetown but there is also another office (Tower Hill) on a hill overlooking Freetown. It is in this office that the weather radar is based and also where the Meteorological Service computers are kept.

The structure of the service is shown in Figure 3.1

3.1.2 Other Organisations

Some data have been collected at agro-climatological stations by the Land and Water Development Division (LWDD) of the Ministry of Agriculture and Natural Resources. A network of 10 stations was set up in 1978. Initially the Meteorological Service was able to help LWDD with the running of this network by providing replacement instruments and charts, but since their stocks of both became exhausted this has no longer been possible. It was reported that the Meteorological Service does not have copies of the data.

The Guma Valley Authority has a network of 13 rain gauges. These are normally read on a daily basis but less frequently during the dry season. There is also a climate station which records humidity, maximum and minimum temperature, and hours of sunshine. Data from some of the sites are passed on to the Meteorological Service.

3.1.3 Staff and Training

The number of staff in each of the divisions of the Meteorological Service is shown in Table 3.1, which also shows the qualifications of the staff and their duty stations.

TABLE 3.1

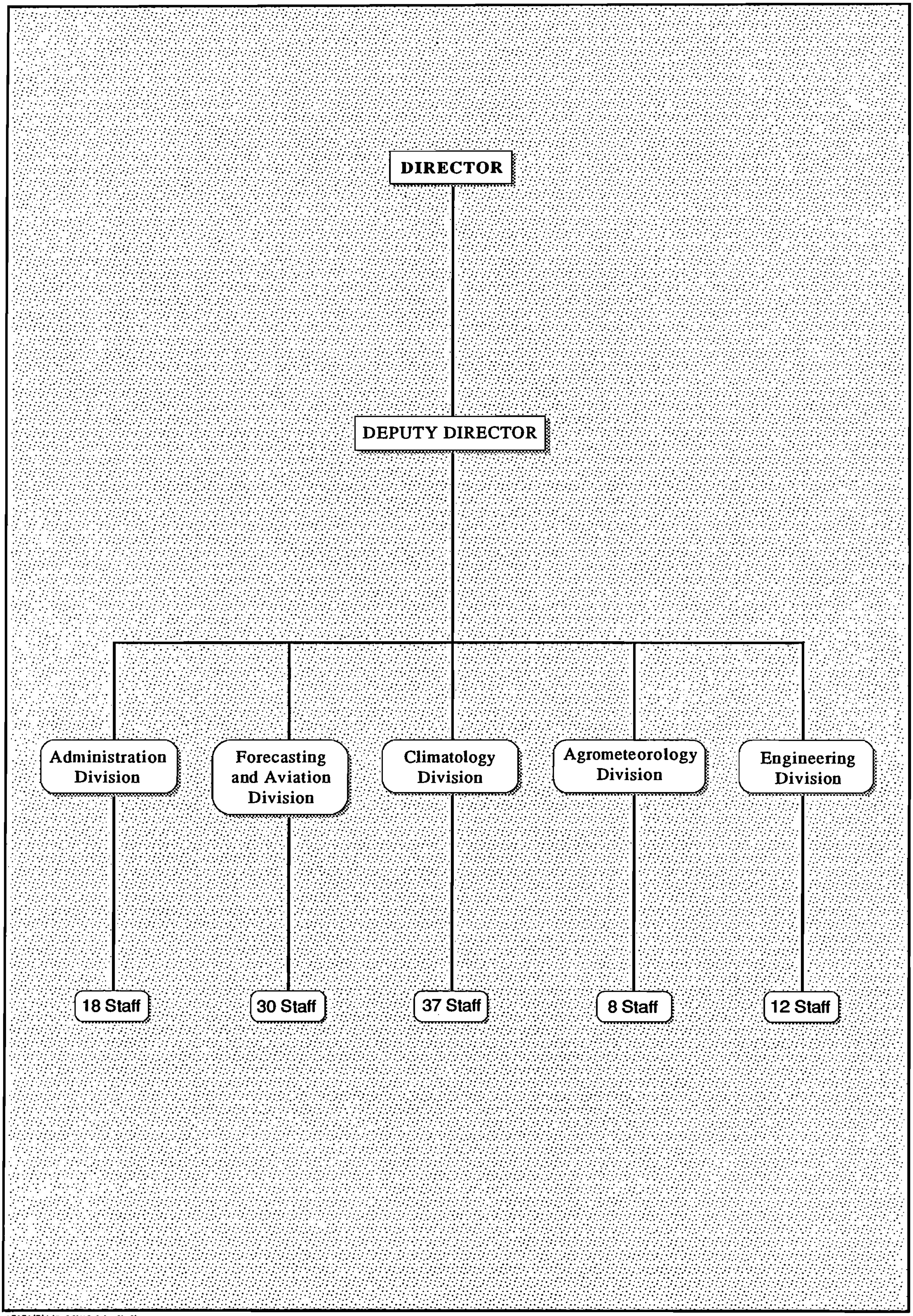
Meteorological Staff - Qualifications and Duty Stations

Divisions Staffing	Administration	Forecasting & Aviation	Climatology	Agro-Meteorology	Engineering
Total	18	30	37	8	12
Qualifications					
Graduates	2	5	1	1	1
O level+	3	12	4	3	6
Other	13	13	32	4	5
WMO Grade					
Class I	-	4	1	1	-
Class II	-	3	0	1	-
Class III & IV	-	23	36	6	-
Duty Station					
Freetown	16	0	13	8	12
Lungi	2	25	0	-	-
Bo	-	-	4	-	-
Makeni	-	-	3	-	-
Njala	-	-	3	-	-
Daru	-	-	2	-	-
Shengi	-	-	2	-	-
Bonthe	-	-	2	-	-
Sefadu	-	-	2	-	-
Kabala	-	-	2	-	-
Falconbridge	-	-	2	-	-
Yele	-	-	2	-	-

Training for Class IV observers is carried out locally. This takes the form of a 12-month course of initial training followed by 12 months of on-the-job training. After some experience the observers are given a refresher course and promoted to Class III. There was a special training centre with full-time instructors at the Tower Hill offices of the Meteorological Service until 1981 when it was forced to close due to economic constraints. There are no facilities in the country for Class II and Class I level training. Staff have been sent abroad to the USA, Great Britain, Kenya, Nigeria, USSR, and Australia for training at this level.

Figure 3.1

Organisation of the Meteorological Service



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3.1.4 Budget

The total Meteorological Service budget for 1990/91 is Le 11 940 844 (at the rate of exchange prevailing in January 1991 this is equivalent to US$ 65 250). This is made up of Personnel, Le 8 615 774, and Other, Le 3 325 070. From the personnel component Salaries account for Le 4.8 million and Education and Transport allowance for Le 1.0 million. Of the 'other' costs major components are Stores and Uniform, Le 0.49 million; contribution to WMO and ACMAD (a WMO sponsored centre), Le 0.60 million; Travel Le 0.65 million and Transport, Le 0.5 million.

The only item for equipment is that under 'Stores and Uniform' which is equivalent to US$ 2 600. This is not adequate for the replacement of equipment. As a consequence of the IMF's Structural Adjustment Programme there was little difference in the official and the parallel rates for the Leone. Even so the budget did not allow for the import of foreign manufactured equipment. The Service had done what it could to minimise the effects of the reduced budget by a number of measures which included the manufacture of Stevenson Screens in the country, the use of ink pad ink for the instrument pens and the printing of recorder charts in the country. In general the only equipment that the Service possessed was that provided under the auspices of internationally financed projects.

The government's published development budget (a copy of which was provided by the Water Supply Department) also includes sums for the Meteorological Service. This budget is equivalent to a capital budget. This includes, from the domestic budget, the sums of Le 400 000 (US$ 2 185) for 'Improvement and Extension of Meteorological Services', Le 600 000 (US$ 3 279) for 'Establishment of Agro-meteorological network' and Le 650 000 (US$ 3 552) for 'Surface wind equipment for Lungi Airport'. The first two of these items are also shown to have associated foreign grants of Le 19 200 000 (US$ 104 920) and Le 39 568 000 (US$ 216 220) but the source of these funds and whether or not they have been disbursed is not shown.

3.2 Climatological Data

3.2.1 Climatological Network

The climate network at present consists of seven synoptic stations, of which one is jointly operated as an agro-climatological station. All of these stations are staffed by observers employed by the Meteorological Service. In recent years the frequency of observations has been reduced, for reasons of economy, from hourly to three-hourly and only during the daytime. Of the seven stations classed as synoptic two are temporarily closed - Bo, due to a fire which severely damaged many of the instruments, and Falconbridge in Freetown, due to difficulty in obtaining a replacement for the observer, who has had to give up for medical reasons. Figure 3.2 shows the locations of these and other climate stations and Table 3.2 gives details of their period of operation.

TABLE 3.2

Climate Stations

Name	Location		Period of operation	Remarks
	North	West		
Synoptic				
Bo	7° 58'	11° 45'	1937-86	
Bonthe	7° 32'	12° 32'	1941-84	
Daru	7° 59'	10° 52'	1944-84	
Falconbridge	8° 30'	13° 14'	1930-85	
Kabala	9° 35'	11° 33'	1933-86	
Lungi	8° 37'	13° 12'	1945-91	International airport
Njala	8° 06'	12° 05'	1933-91	Joint agro-clim station
Climatological				
Batkanu	9° 04'	12° 25'	1933-61	
Bunumbu	8° 10'	10° 52'	1949-76	
F B College	8° 28'	13° 13'	1955-85	
Gambia	7° 23'	12° 11'	1972-82	
Gbangbama	7° 43'	12° 18'	1957-70	
Gbangba	7° 29'	12° 12'	1956-57	
Guma Dam	8° 22'	13° 13'	1974-85	
Hanga	7° 56'	11° 09'	1950-64	
Njaiama	8° 33'	11° 06'	1933-39	
Kailahun	8° 11'	10° 35'	1952-61	Now agro-clim station
Kenema Farm	7° 53'	11° 11'	1951-73	Now agro-clim station
Kissy	8° 28'	13° 11'	1939-54	
WAFRI Kissy Dockyard	8° 29'	13° 11'	1953-59	
Kontobi	8° 14'	12° 10'	1975-84	
Koyeima	8° 15'	11° 42'	1933-77	No record 38-44 and 60-76
Kbwable	-	-	1959-77	
Lumley	8° 28'	13° 16'	1954-84	
Magburaka	8° 43'	11° 57'	1954-59	
Makeni	8° 53'	12° 03'	1941-83	
Makali	8° 38'	11° 40'	1950-55	Now agro-clim station
Marampa	8° 41'	12° 31'	1939-75	
Musaia	9° 46'	11° 33'	1939-75	Now agro-clim station
New England	8° 28'	13° 14'	1959-84	
Newton	8° 20'	13° 00'	1938-78	
Nr 2 River	8° 21'	13° 12'	1948-78	
Port Loko	8° 47'	12° 47'	1954-84	No record 71-79
Pendemba Farm	8° 05'	10° 41'	1962-77	
Pepel	8° 29'	13° 43'	1939-74	
Pujehun	7° 21'	11° 43'	1953-77	
Rokupr	9° 01'	12° 57'	1935-85	
Segbwema	7° 59'	10° 58'	1933-46	
Sembehun	7° 56'	12° 32'	1942-47	
Solon	-	-	1954-68	
Tongo	-	-	1980-82	
Tonkolili	-	-	1957-62	
Torma Bum	7° 25'	12° 01'	1972-80	
Waterloo Town	8° 20'	13° 04'	1939-52	No record 44-49
Wellington	8° 27'	13° 10'	1974-85	No record 77-78
Wilberforce	8° 28'	13° 16'	1957-61	
Wordu	8° 27'	10° 57'	1961-76	
Yengema	8° 37'	11° 03'	1938-83	
Yongibana	8° 26'	12° 13'	1953-61	

TABLE 3.2 (cont)

Name	Location		Period of operation	Remarks
	North	West		
Agro-climatological				
Alkalia	9° 19'	11° 23'	1978-91	
Bendugu	9° 31'	10° 58'	1978-80	Short-term - Observer problems
Kailahun	8° 17'	10° 35'	1978-91	
Kamakwie	9° 30'	12° 45'	1978-80	Short-term - Observer problems
Katonga	8° 50'	12° 56'	1978-91	Rainfall and temp only
Kenema	7° 52'	11° 11'	1978-91	
Makali	8° 38'	11° 40'	1978-91	
Mattru Jong	7° 38'	12° 10'	1978-91	
Moyomba	8° 10'	12° 25'	1978-91	
Musaia	9° 46'	11° 33'	1978-91	
Njala	8° 06'	12° 05'	1978-91	Joint station
Potoru	7° 32'	11° 29'	1978-91	
Roloko	8° 52'	12° 08'	1978-91	

Note: Periods of operation of agro-climatological stations are approximate.

Of the 43 climate stations which have operated at some time in the past very few are now operating and reporting to the Meteorological Service. The only ones which appear to be still operating are those which have been adopted as sites for agro-climatological stations. The data from these stations, operated by the LWDD of the Ministry of Agriculture and Natural Resources, are not sent regularly to the Meterological Department.

All the stations, both synoptic and climate, suffer from lack of spares to replace broken equipment and lack of suitable charts for automatic recorders. Some charts have been printed locally but there have been problems in obtaining the necessary precision. The special card needed for sunshine recorders cannot be produced locally. Another measure which has been taken to reduce the problems of lack of foreign exchange for equipment procurement has been to use rubber stamp ink for the chart pens.

A network of 10 agro-climatological stations was set up in 1978 at: Kailahun, Kenema, Potoru, Mattru Jong, Moyamba, Njala (jointly operated), Rolako, Makali, Alkalia and Mausaia. Two further stations were set up, at Kamakwie and Bendugu, but were only operated for a short time due to difficulties in finding observers. A further station, Katonga, measures rainfall and temperature only. The stations are also plotted in Figure 3.2 and Table 3.2 gives details of station locations.

The parameters measured include maximum and minimum temperature, grass minimum temperature, wind velocity and direction, rainfall, wet and dry bulb air temperature, sunshine duration and the stations were also equipped with a Gunn Bellani solarimeter and an evaporation pan. As well as the climate data the monthly forms also record the agricultural activities in each of the four quadrants for the first and second halves of the month. They also give details of the major crops classed under headings 'annuals' and 'perennials' and describing their state relative to 'planting', 'with fruit' and 'harvest'. Under the heading 'annuals' are included rice, cassava, maize, ground nuts with provision for up to 8 other crops depending on locations. Under the heading 'perennials' there is allowance for coffee, cocoa, oil palm, coconut, kola nut and up to 7 others. The network is still in operation and the observers seem to be conscientious but breakdowns of certain instruments mean that not all the parameters are at present measured.

None of the data appear to have been published but they are held on file in the LWDD offices. None of the data are sent to the Meteorological Service. The network was set up in the context of project AG:DP/SIL/73/002, 'Agro-ecological Atlas of Sierra-Leone'. The project ended in 1982 and it was reported that the stock of consumables (ink, paper for sunshine recorders etc) was exhausted within two years. During their recent visit to micro-film climatological data, the DARE project did not record this data.

Table 3.2 lists all the climate stations and their period of operation. More details on the period of operation and the quality of the data of these stations is given in Appendix E.

Figure 3.3 shows the number of climate stations, and how many of them were synoptic stations for each year since 1930 when the first climate stations were opened. It does not include the stations in the agro-climatological network set up in 1978 and which is still functioning. It will be noted that there has been a gradual decline since the number of stations reached its maximum in 1959 and that in recent years the rate of decline has increased.

3.2.2 Equipment

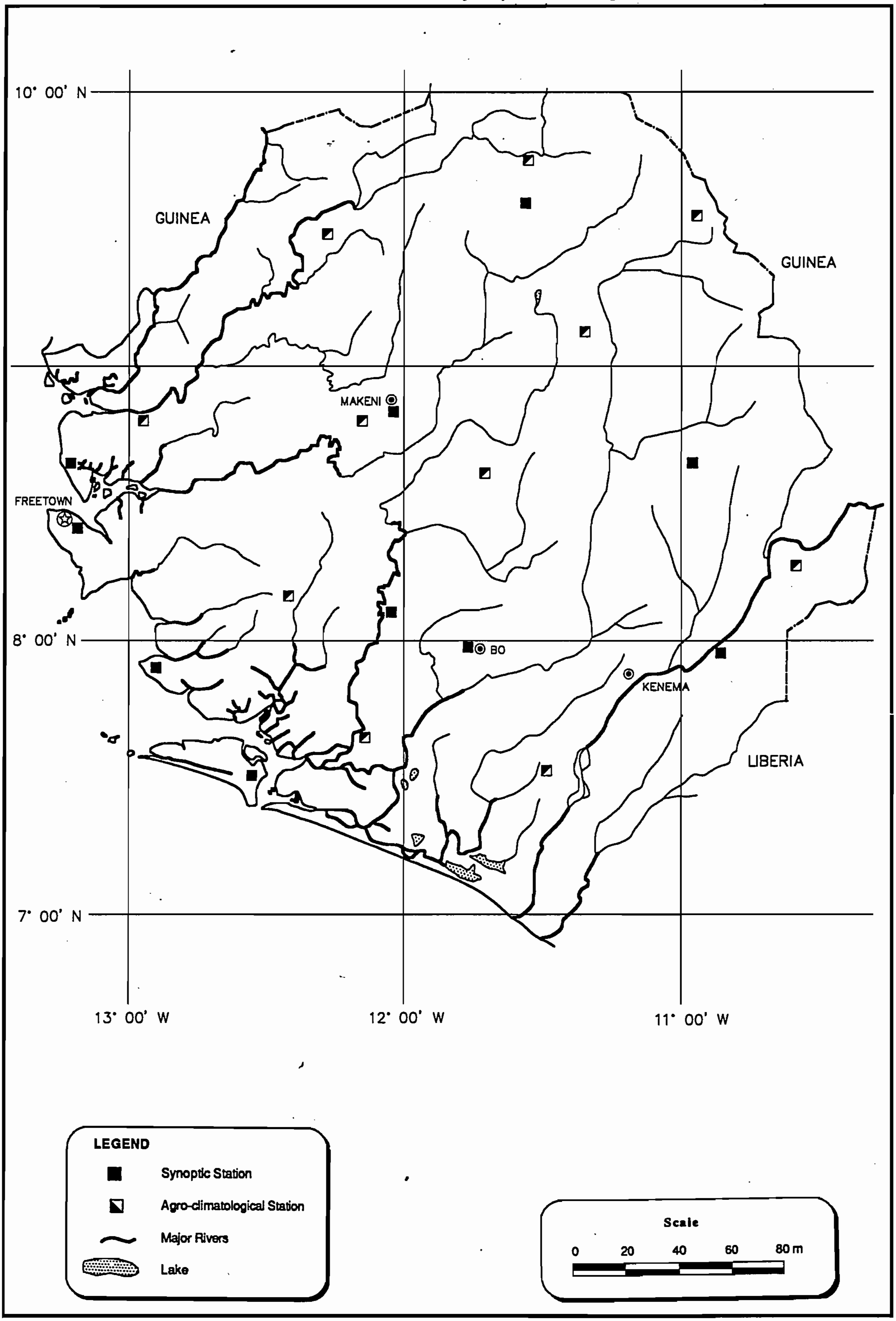
The observation equipment used is almost entirely made by Casella (UK). There is no stock of spare parts and it is not normally possible to replace or repair broken equipment. Barometers are a particular problem in this respect.

The Meteorological Service owns a weather radar, a Mitsubishi RC-5B. The equipment was delivered in 1979 but due to delays in providing a building and mast it was only installed in 1990. The equipment operates at a nominal power of 250 kW and has a range of 300 km, sufficient to cover all the country. However problems, possibly due to low power or degradation as a result of long storage, mean that its range is reported to be only 150 km. During a demonstration of the equipment even on the shorter range no images, even of ground clutter, were visible. The placement of the equipment, on the side of Tower Hill outside the city of Freetown, means that part of the country would be in radar shadow. It was also reported that none of the national meteorologists have specialised training in the use and interpretation of weather radar. A further drawback to the use of the radar is that there is no telemetry network, which would be necessary to give quantitative calibration of the radar.

Enough spare parts were provided to last for 5 years use but only limited training was given in maintenance during the installation of the system. The training was limited partly by the time needed to install the system and partly by the fact that the radar in Freetown is intended to be used as an operational system and its use as a training tool would conflict with that function.

Figure 3.2

Locations of Synoptic and Agro-Climatological Stations



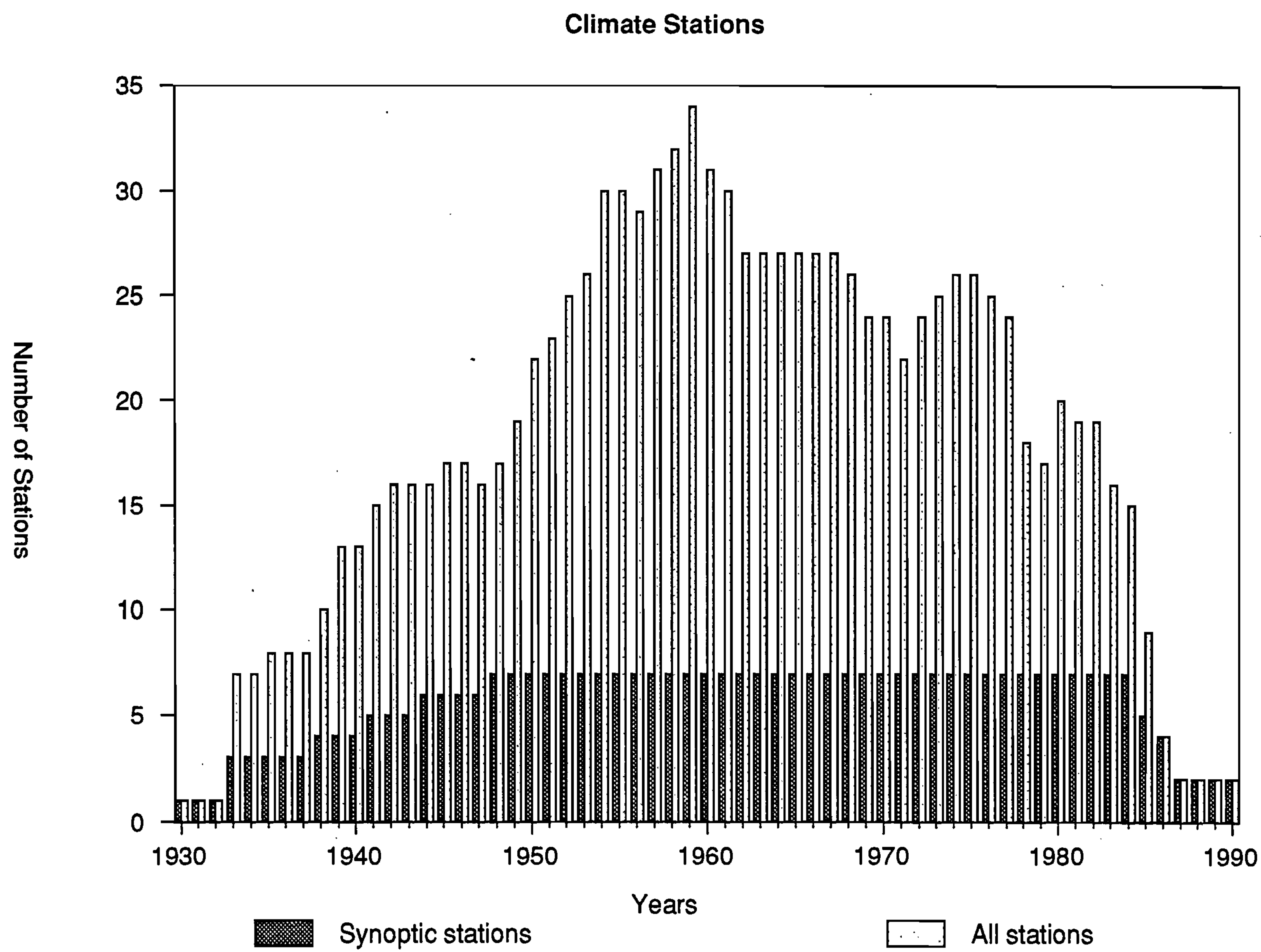


Figure 3.3
Development of the Climatological Network

The agro-climatological station at Njala Agricultural University was inspected during our visit, the station is operated by Meterological Service observers but is also part of the LWDD agro-climatological network. The station appeared to be well maintained with the grass cut, the sunshine recorder with the card correctly aligned, and fresh gauze in the wet bulb thermometer. It was not possible to see the inside of the recording rain gauge. This site had no evaporation tank and also lacked an anemometer so it would not be possible to make evaporation estimates.

For communication between the headquarters and the synoptic stations the Meteorological Service uses single side band short wave radio. It was reported that some of the radios are not functioning and that there have been problems with the solar panels used to charge the radio batteries. International communication of meteorological information has recently been difficult. Currently the service can receive data from the regional centre in Dakar, Senegal, but are unable to transmit data back due to the closure of the link station at Monrovia since the onset of security problems in Liberia. A request has been made to the WMO for a direct link to Dakar.

3.2.3 Maintenance and Field Support

It was reported that the budget does not allow for an adequate number of field visits. This was felt to be a particular problem in the case of volunteer observers, or organisations who voluntarily run rainfall stations. Some of these have stopped sending data and it was felt that a programme of regular visits would have helped to maintain their enthusiasm.

The lack of field visits is offset to some extent by the fact that staff of the Service are posted to synoptic stations.

3.2.4 Data Processing

The field data are sent to the head-office, in the first instance by single side band short-wave radios. The data are later transmitted by mail. There does not appear to be an established set of quality control procedures, eg by comparing data at one station with that at a nearby station or by checking that data are within certain bounds.

None of the data have been put on computer. The service has a number of micro computers and a range of peripherals. These are listed in Table 3.3 together with details of their current operational status.

TABLE 3.3

Status of Meteorological Service Computing Equipment

Type	Number	Condition (January 1991)
Computers		
IBM PC/AT	3	All have hard disk failures and only one has a working floppy disk.
IBM PS/2 model 60	1	Provided with CLICOM. Both hard and floppy disk problems.
IBM PS/2 model 30	2	One is unserviceable and the other operating normally.
Walters (Germany)	2	Provided for satellite communications, one for Data Collection Platform and the other for Data Receiving Station. Both are operating normally.
VDUs		
IBM mono	3	Satisfactory
IBM colour	3	Two are operating normally but with one the display fades with time.
Walters mono	1	Satisfactory
Walters colour	1	Unserviceable
Printers		
IBM Proprinter II	3	One is satisfactory and two are unserviceable.
IBM Proprinter XL	1	Unserviceable
IBM jet printer	1	Satisfactory
Epson FX-1000	1	Satisfactory
Walters	1	Satisfactory
Other		
TOPAZ 1KVA UPS	1	Unserviceable
Vitron UPS	1	Satisfactory
Generator	1	Unserviceable - broken oil seal.

3.2.5 Data Availability

There is no data inventory. Those inventories which appear in this report were prepared by the consultant sifting through the records stored in 'Kalamazoo' files in the Meteorological Service.

It was reported that some records have been lost in the past. Before the Service was transferred from the airport at Lungi to Freetown a fire destroyed some records. Other records were lost after the transfer when a water pipe fractured. It appears however that only administrative records were damaged and that no data were lost - but this does illustrate the danger of the present method of record storage.

Much of the data has been put on to micro-film by the DARE project who will be producing their own inventory. Not all the data were recorded due to the limited time available for the mission and, during the consultants visit, staff of the Service were using the micro-film camera to record data not previously collected. The staff expressed some concern as to whether they were using the correct procedures for this as they claimed to have had difficulty in understanding the English of the personnel sent to Sierra Leone from the DARE project.

3.3 Rainfall Data

3.3.1 Rainfall Network

An inventory of rainfall stations is given in Appendix D which shows the period of operation of each station. A total of 108 stations have provided rainfall records at some time. The data are normally recorded on a daily basis except in the case of autographic gauges at the synoptic stations where hourly figures are tabulated on the monthly returns. At the present moment the only stations which are fully operational are those at the sites of synoptic or agro-climatological stations and those operated by the Guma Valley Authority (the company which supplies water to Freetown). Figure 3.4 gives year-by-year figures for the number of gauges which are operating. Those gauges which had data for the whole year are differentiated from those gauges which only provided data for part of the year. It will be seen that, as with the climate stations, the number of stations reached a peak in 1959. The decline was arrested during the 1970s but has continued more sharply in the 1980s. Figure 3.5 shows the network of rainfall stations as it was in 1969, the last year for which a year book was published.

3.3.2 Equipment

The rain gauges, both recording and traditional, are Casella type. There do not appear to be any gauges by other manufacturers.

3.3.3 Maintenance and Field Support

The Service is able to provide very little field support due to lack of funds. This has resulted in a reported falling off in the returns of observations from observers at private companies, estates etc who it is felt lack incentive to report when the Meteorological Service is unable to visit them, to check on the state of their equipment and to ensure that the observers follow standard procedures.

3.3.4 Data Processing

As with the climate data, none of the rainfall data have been entered in a computerised database nor does the Meteorological Service have an inventory, or even a list of stations with their grid references available. The monthly rainfall values together with certain statistics are entered in ledgers for all stations since their date of opening up to 1989. The daily observations on the forms used for their original returns are available for inspection and copying.

3.3.5 Data Quality

A double-mass plot for the period 1940 to 1989 for 5 stations is shown in Figure 3.6. The cumulative value of each station is plotted against the cumulative value of the average of the other four stations. The charts show a number of breaks in the linear relationship but these are not too severe. For these five stations, which all have professional observers, the quality of the record seems to be reasonable. A rather more worrying aspect of the data is observed in Figure 3.4 (which shows the number of stations operating). From this it can be seen that a large proportion of the stations have one or more months of missing data during the year.

3.3.6 Data Availability

The data are all stored either in the form of monthly summaries or as original report forms at the head-office of the Meteorological Service in Freetown. These data, as already stated, are not in a computer compatible format, and the only way to use the data for scientific or technical work would be to copy it by hand or by photocopying.

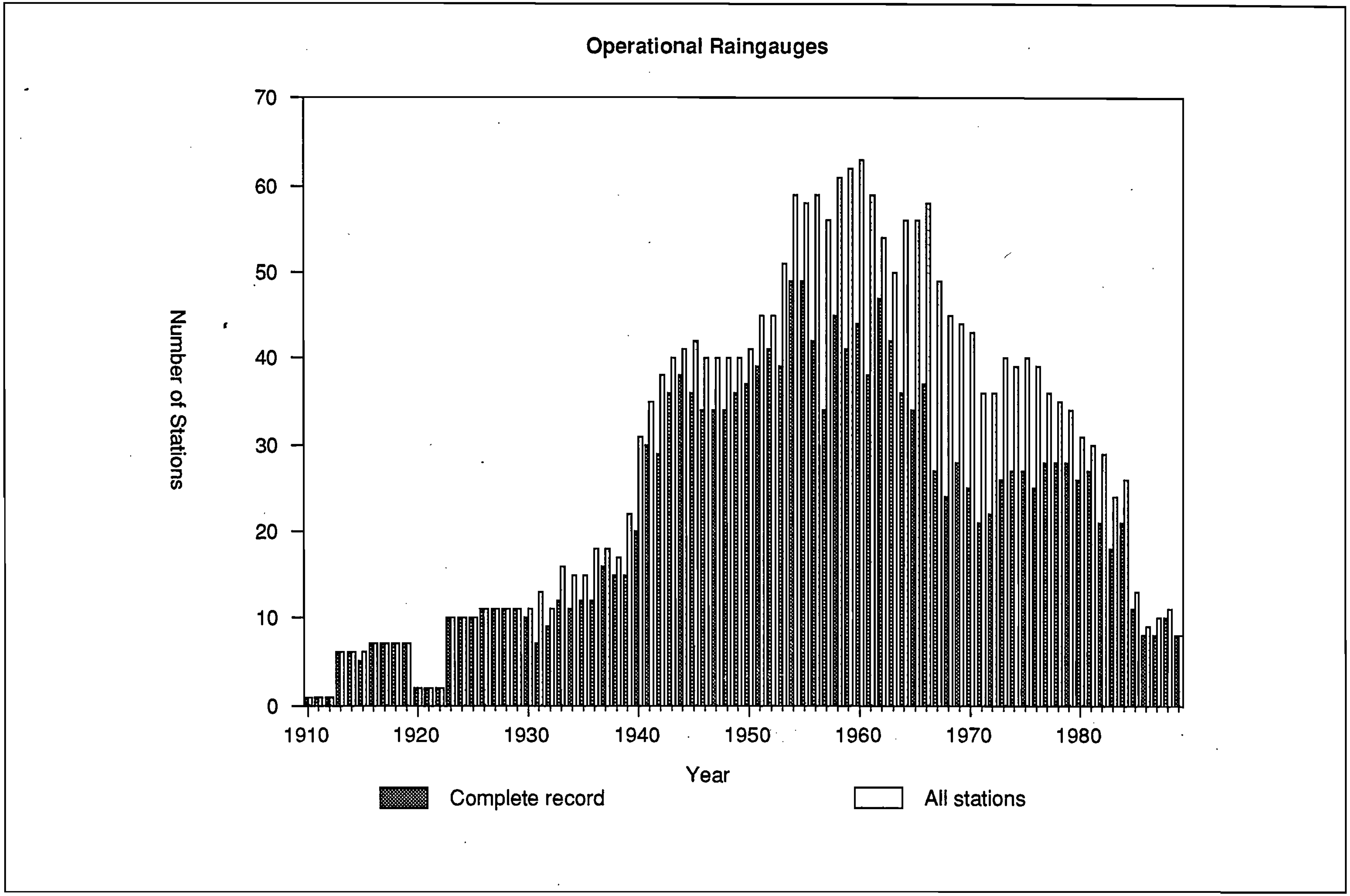
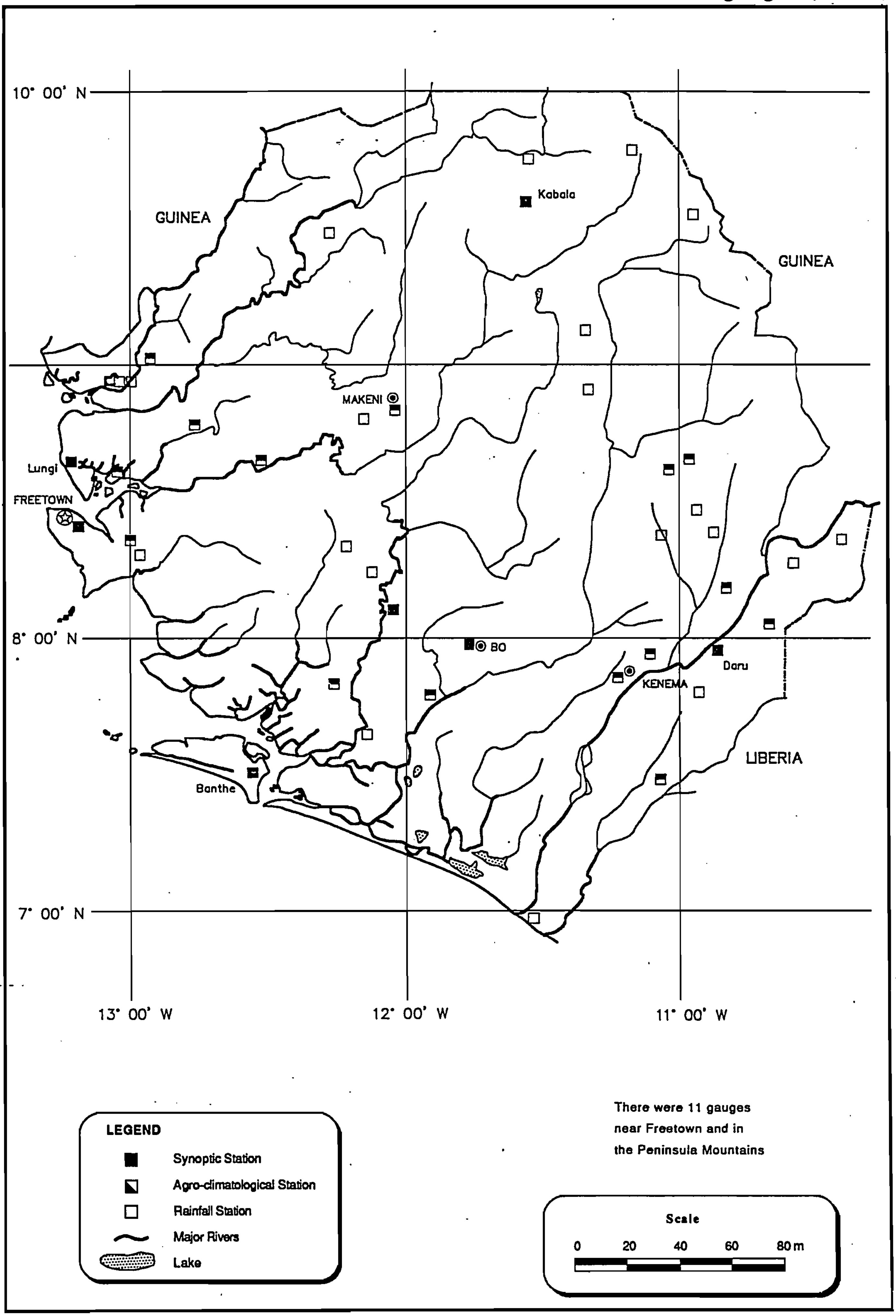


Figure 3.4
Development of the Raingauge Network

Figure 3.5

Location of Raingauges (1969)



There were 11 gauges near Freetown and in the Peninsula Mountains

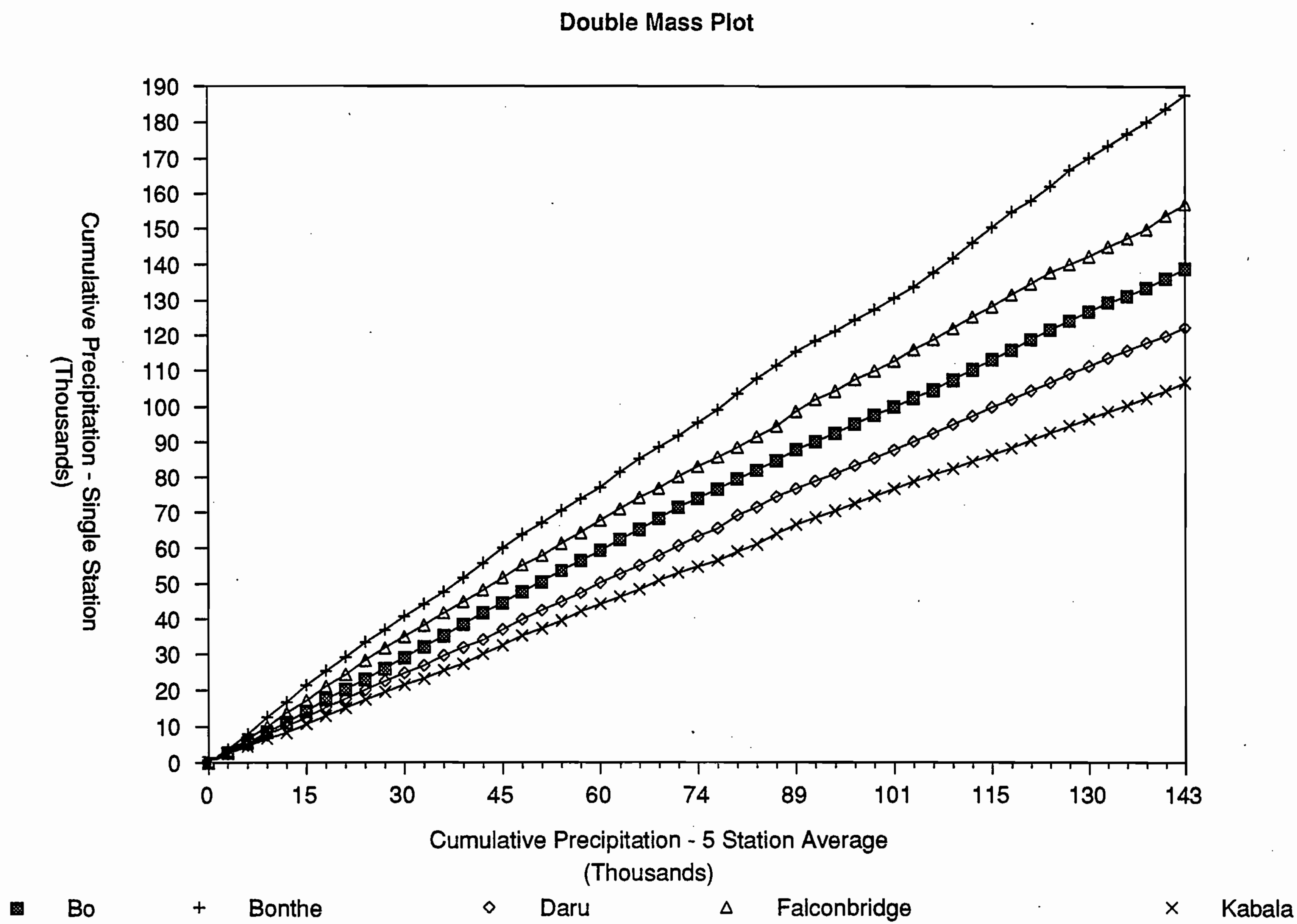


Figure 3.6
Quality Control-Double Mass Analysis

CHAPTER 4

SURFACE WATER

4.1 Organisation and Management

4.1.1 The Hydrological Unit

The Hydrological Unit is attached to the Water Supply Department (WSD) of the Ministry of Energy and Power. An organisation chart is shown in Figure 4.1. This chart represents the *de facto* state of the organisation. A more comprehensive organisation chart was prepared in 1985 but the structure it shows has not been implemented. Given the continuing repercussions of the Structural Adjustment Programme on government finance it is not clear when the new structure will be implemented.

At the present time both the two professional staff attached to the Hydrological Unit are based in Makeni, 126 miles from Freetown. There they are working with a United Nations volunteer running a hydrometric network for the international Onchocerciasis Control Project. This activity is effectively the only hydrological activity in the country at present.

The Onchocerciasis Control Project (OCP) is a United Nations project executed by the World Health Organisation (WHO). Onchocerciasis is a form of river blindness caused by a fly. To eradicate the parasite which the fly carries there is a project to dose the rivers of West Africa where the disease is endemic. To reduce the cost of wasteful application of chemicals and to ensure an adequate dosage a special hydrometric network has been set up in several countries. Most of the hydrological activities for the project are handled by ORSTOM under contract to the WHO. In some countries the existing hydrometric network is used as a basis but in Sierra Leone the OCP network is the only working network in the country. The WHO expect the project to continue until the year 2000. The budget for the OCP was US$ 60 million for the two years 1990 and 1991.

4.1.2 Other Organisations

The Guma Valley Authority has kept records at their dam near Freetown. This includes rainfall and evaporation as well as data on water levels and releases.

Before the construction of the dam started in 1961 a hydrological station was operated from March 1946 to January 1956. The equipment consisted of an automatic water recorder and a weir was constructed. Monthly values of the flow and some information on maximum and minimum flows are held in the offices of the company in Freetown. Other, possibly more complete data, are also held in the archives of their consultants, Howard Humphreys and Partners, of the United Kingdom.

The Guma Valley Authority has also kept regular records of the water level in the reservoir, pan evaporation, rainfall, seepage and draw-off. From these records it should be possible to reconstruct a flow record for the catchment from 1967, when the reservoir came into operation, up to the present. If this was done it would represent the longest flow record in the country.

There have also been flow measurements on the Mano River at Mano Mines, a point where the river forms part of the boundary between Liberia and Sierra Leone. The first staff gauge was installed on 29 August 1958 and the station was at that time called Kavilahun. The gauge was used intermittently from 1959 to 1969 but the data were reported to contain anomalies. In January 1970 the station was put back into service and an automatic water level recorder fitted. A rating curve has been established, which included re-calibration of the staff gauge installed in 1958, and flows have been published (monthly means) for the periods November 1958 to December 1961, January 1970 to April 1971 and September 1975 to December 1979. (Mano River Union - Mano River Basin Development Project, Feasibility Study, Volume 3, Topography and Hydrology, Mano River Union - Sofrelec, March 1981).

In the report entitled 'Strengthening of the Division of Land and Water Development, Sierra Leone: Project Findings and Recommendations' there are references to two documents which imply that other stream-flow measurements have been made. These are: Hammelberg J - 1981 - 'Freetown Peninsula road studies (stream-flow velocity measurements)', and Helmish F and Thirugnanasambanthar S - 'Dry season stream-flows in selected areas of Sierra Leone'.

4.1.3 Staff and Training

The Senior Executive Engineer in the Hydrological Unit (see Figure 4.1) has an MSc in Public Health Engineering. The Assistant Executive Engineer has a BSc in Engineering from Sierra Leone University. The technical staff have Ordinary level GCE or equivalent qualifications. Two of the technicians have been trained as draughtsmen.

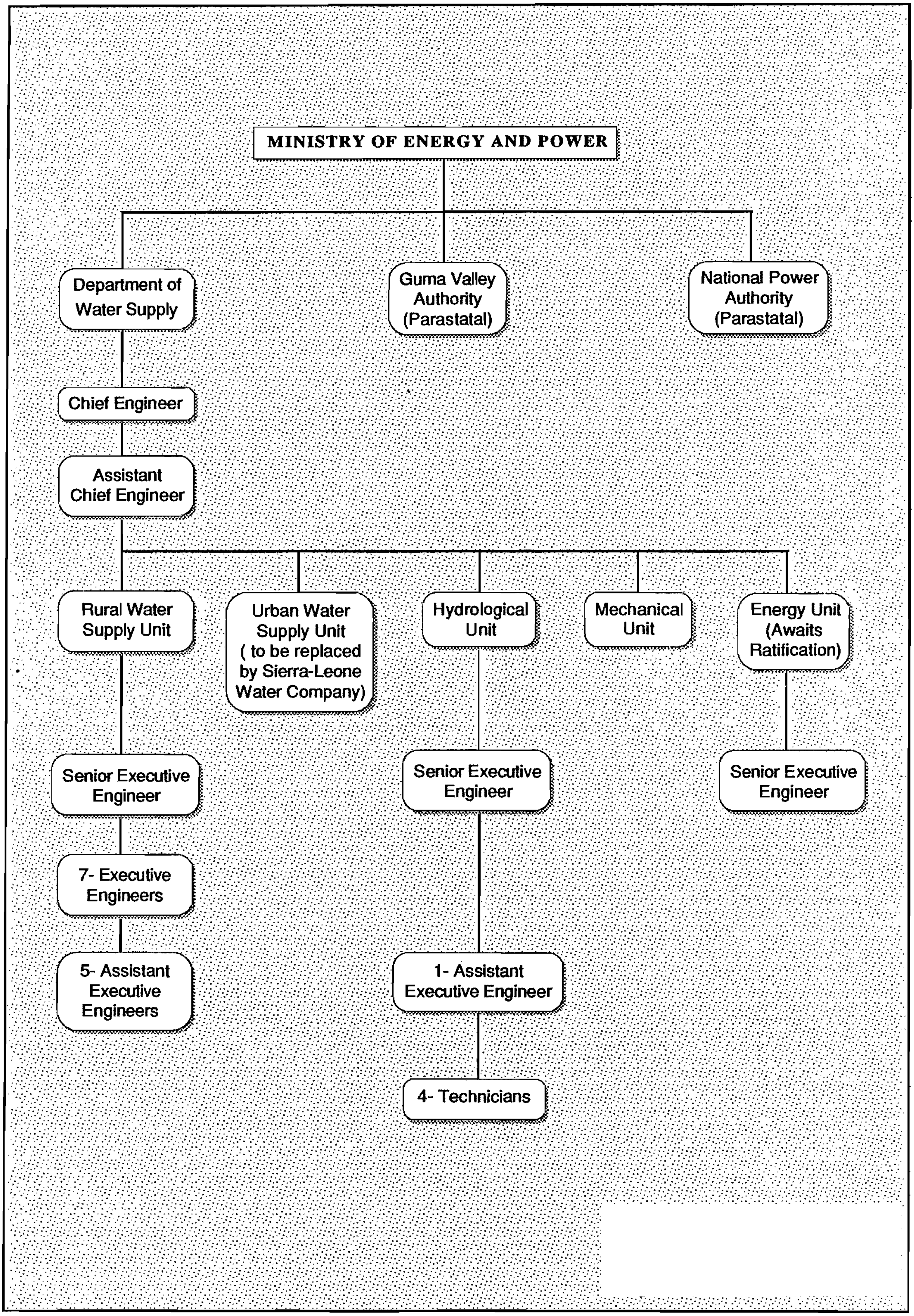
The degrees of the University are recognised for postgraduate training overseas.

4.1.4 Budget

The total revenue budget for the Ministry of Energy and Power (1990/91) is Le 230 201 250. This is equivalent to US$ 1.26 million at the rate of Le 183/$ prevailing in January 1991. Of this figure the largest sum is Le 120 million (US$ 655 750) for the establishment of the Sierra Leone Water Company. This company, for which offices are being built and whose Director is the only member of staff yet appointed, will be responsible for water supply in urban centres outside of Freetown. The total expenditure on 'personnel' is Le 35 201 250 (US$ 191 250) and on 'other expenditures' (excluding the water company) is Le 75 000 000 (US$ 410 000). Of the 'other expenditures' major items are 'transport, fuel and oil' - Le 5 000 000, Stores - Le 6 000 000, 'chemicals for fully treated

Figure 4.1

Organisation of the Ministry of Energy and Power



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stations' - Le 10 000 000 and 'fuel water supply stations' - Le 12 000 000. Of this amount only a small proportion is spent on hydrology; from the staff table it can, for example, be estimated that only Le 520 000 (US$ 2 850) is spent on the salaries of the two professional and four technical staff involved in hydrological activities.

The Ministry also benefits from a 'development' budget but no items for hydrology are included.

4.2 Hydrological Data

4.2.1 Hydrometric Network

The initial activities in hydrology in the country began under the auspices of the UNDP project SIL/69/509, Strengthening of Sierra Leone Electricity Corporation. Within the context of that project the UN OTC appointed Motor-Colombus Consulting Engineers Inc of Baden in Switzerland, as sub-contractors, to carry out a study of hydropower potential and power market potential. For this study the consultants used river flow information from Guinea and Liberia as at that time no hydrological data was available in Sierra Leone. This project set up 5 gauging stations equipped with staff gauges.

In 1972 a follow-up project, SIL/72/007, Pilot Project for the Determination of the Surface Water Resources of Sierra Leone, was started. The principal aims of the project included providing data for the design of the Bumbuna Falls hydro-electric scheme and for the Dodo micro-hydro-electric project. Data were also provided for potential irrigation projects. The project added extra stations and fitted automatic water level recorders at 5 stations. It also produced improved rating curves for all the stations.

Within this project there was a network of 12 hydrological stations. The details are shown in Table 4.1 and in Figure 4.2. Further details are given in Appendix F. The information is taken from 'Hydrological Year Book of Sierra Leone' containing data from May 1970 to March 1976 and published in October 1976 .

The hydrological network set up under these two projects was initially maintained by the Sierra Leone Electricity Corporation with some assistance from the Ministry of Works. In January 1975 the Hydrological Unit was created and took over responsibility for the network under the Ministry of Energy and Power.

Some of the stations continued to operate for a few years after the project finished but a hydro-electric study in 1982 for the Mano River Union felt the later data were of unknown accuracy and used only the published data. In addition to the hydrological data there was also a rain-gauge (Casella) and a Class A land pan supported above ground.

TABLE 4.1

Hydrological Stations 1970-76

Name	Catchment area km^2	Maximum flood (m^3/s)	Minimum flow (m^3/s)	Average runoff (mm)	Recorder	Rating curve quality
Moa	17 150	2 942	9.6	788	Yes	Good
Sewa	6 870	730	4.8	909	No	Fair
Palima	361	160	0.24	1 431	No	Unknown
Dodo	57	16.7	0.07	1 383	No	Good
Pampana	2 407	511	0.50	1 410	No	Unknown
Badala	2 525	503	1.2	702	Yes	Approximate
Bumbuna	3 990	1 164	1.5	898	Yes	Approximate
Mador	9.5	NA	NA	NA	NA	None
Magburaka	4 710	NA	NA	NA	NA	None
Marampa	NA	NA	NA	NA	NA	None
Mabole	NA	NA	NA	NA	NA	None
Mange	17 230	NA	NA	NA	NA	None

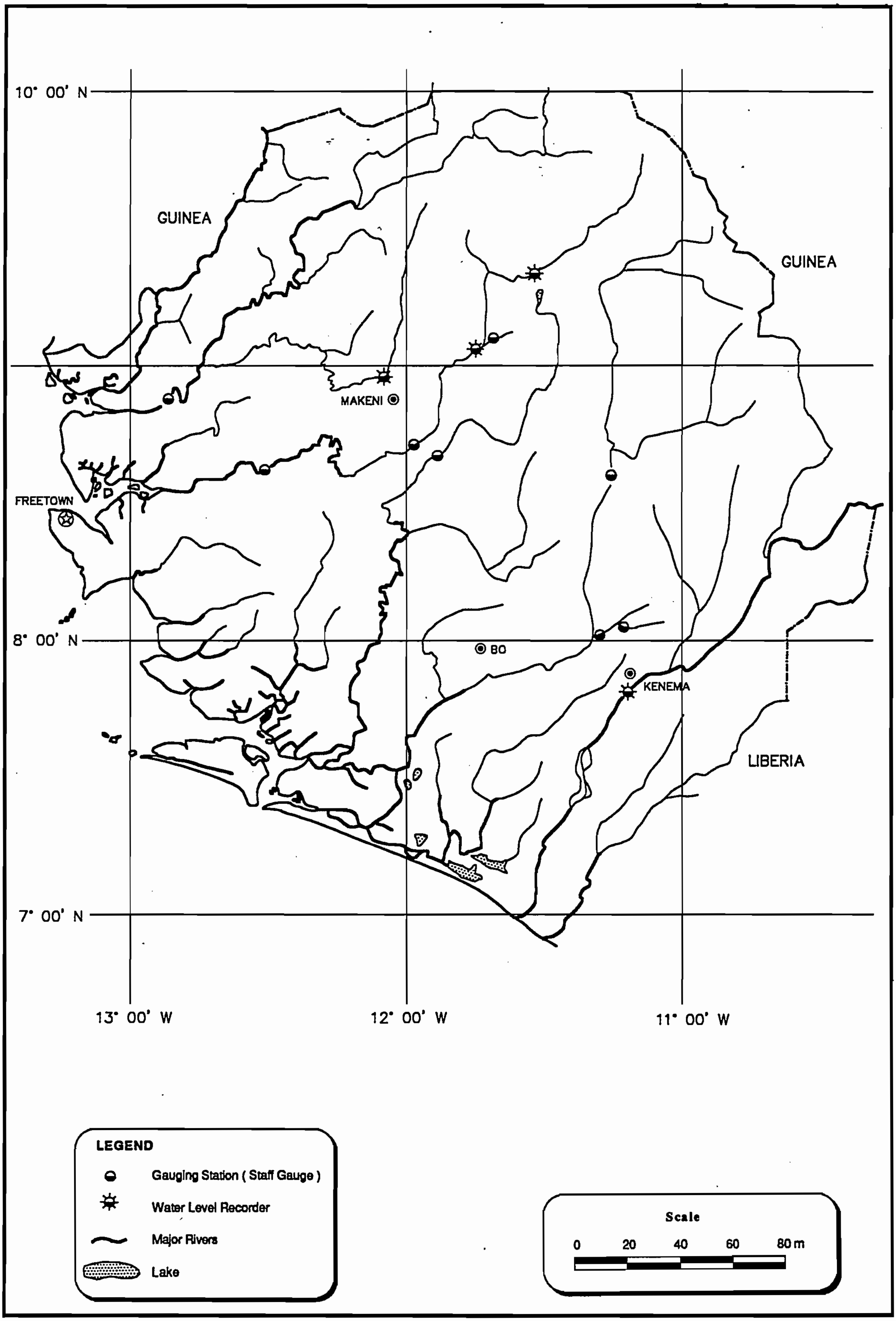
At least some of the charts are still available in the offices of the WSD. During the Consultant's visit 44 charts were counted. They were three-month charts so they contain some 132 station-months of data. In the published year book there are 200 station-months of data from stations with charts. The charts seen were all in a good condition and well annotated with time on, level at start and notes of any changes to levels etc. In particular there appeared to be most of the charts for the station at Bumbuna, which given its potential for hydro-electricity could be useful.

There is also the network of 24 hydrological stations which have been installed in the context of the Onchocerciasis control programme of the WHO. The staff gauges were installed by hydrologists from ORSTOM on short visits to the country. During their visits they also carried out some flow gaugings. Since the aim was to install the gauge boards during the driest period of the year these are mainly low flow gaugings. Other gaugings have been carried out by staff of the WSD and by the United Nations volunteer attached to the project.

The level data are measured at the staff gauges during weekly visits by the fly-catchers or on the occasional visits of the gauging teams. These data are sent to the head office of the OCP in Ouagadougou (Burkina Faso). Copies of the levels are held in the field office in Makeni.

Figure 4.2

Location of Gauging Stations (1976)



There are two teams who carry out gaugings. The gaugings are sent to Odienne (Côte d'Ivoire) for processing by ORSTOM staff using the HYDROM computer program. No rating curve has yet been published for any of the stations. Some details of the stations are given below in Table 4.2. Further details are given in Figure 4.3 and in Appendix F. The stations are intended to be capable of measuring a full range of flows.

TABLE 4.2

Gauging Stations - Onchocerciasis Project

Station	River	Date installed	Nr of gaugings	Remarks
Outamba	Kaba	June 1988	15	
Kaba Ferry	Kaba	April 1988	13	
Musaia	Mongo	April 1988	16	
Kunshu	Mabole	April 1988	26	In earlier network as Mabole
Mabanta	Mabole	April 1988	10	
Arfania	Seli	April 1988	15	In earlier network as Badala
Bumbuna	Seli	April 1988	18	In earlier network with same name
Magburka	Seli	May 1988	28	
Marampa	Seli	May 1988	16	
Matotoka	Pampana	April 1988	20	In earlier network as Pampana
Yifin	Bagbe	April 1988	13	
Yima Ferry	Bafi	April 1988	11	
Njaiama	Sewa	April 1988	18	In earlier network as Sewa
Yele	Teye	May 1990	8	
Taiama	Taia	April 1990	8	
Mokasi	Gbangbaia	April 1990	5	
Mokele	Jong	April 1990	6	
Bumpe	Tabe	April 1990	10	
Lembema	Sewa	April 1990	4	
Bandajuma	Waanje	April 1990	6	
Bandasuma	Moa	May 1990	3	
Gofor	Moa	May 1990	7	In earlier network as Moa
Masahun	Male	May 1990	4	
Batiwa	Moa	May 1990	5	

It is anticipated that Argos platforms with solid state automatic water level recorders of the pressure transducer type, will be installed at five of the sites listed in Table 4.2 before the end of March 1991 under the OCP. These will give hourly values of water level which will be transmitted to the master receiving station. It is also expected that the UN volunteer will leave the project in June 1991. What will happen when he leaves and whether the portable hydrometric field equipment and vehicles will be left in the country or returned to the project head-office for use elsewhere has not be decided.

4.2.2 Methods of Discharge Measurement

The field teams have two OTT current meters and one pygmy meter. Gaugings are carried out by wading or from a boat. Some of the gaugings were carried out by ORSTOM staff who visited the country to install the staff gauges. As the gauges were installed at the end of the dry season when flows were at their lowest, these gaugings were for the low end of the flow range. Other gaugings have been carried out by staff of the Hydrology Unit working with the UN volunteer. Initial calculations for checking of flows are done in the country using a calculator but the definitive calculations are done at Odienne using the HYDROM program. Copies of the results of the program are sent to Sierra Leone. This can sometimes lead to a long delay - in one example the calculations were done two months after the gaugings.

The number of vertical points used is variable and even for relatively shallow depths, 0.5 m, as many as 5 points are used. The program can handle up to 9 vertical points.

As far as the hydrological staff working in Sierra Leone are aware there have been no rating curves produced so far.

4.2.3 Equipment

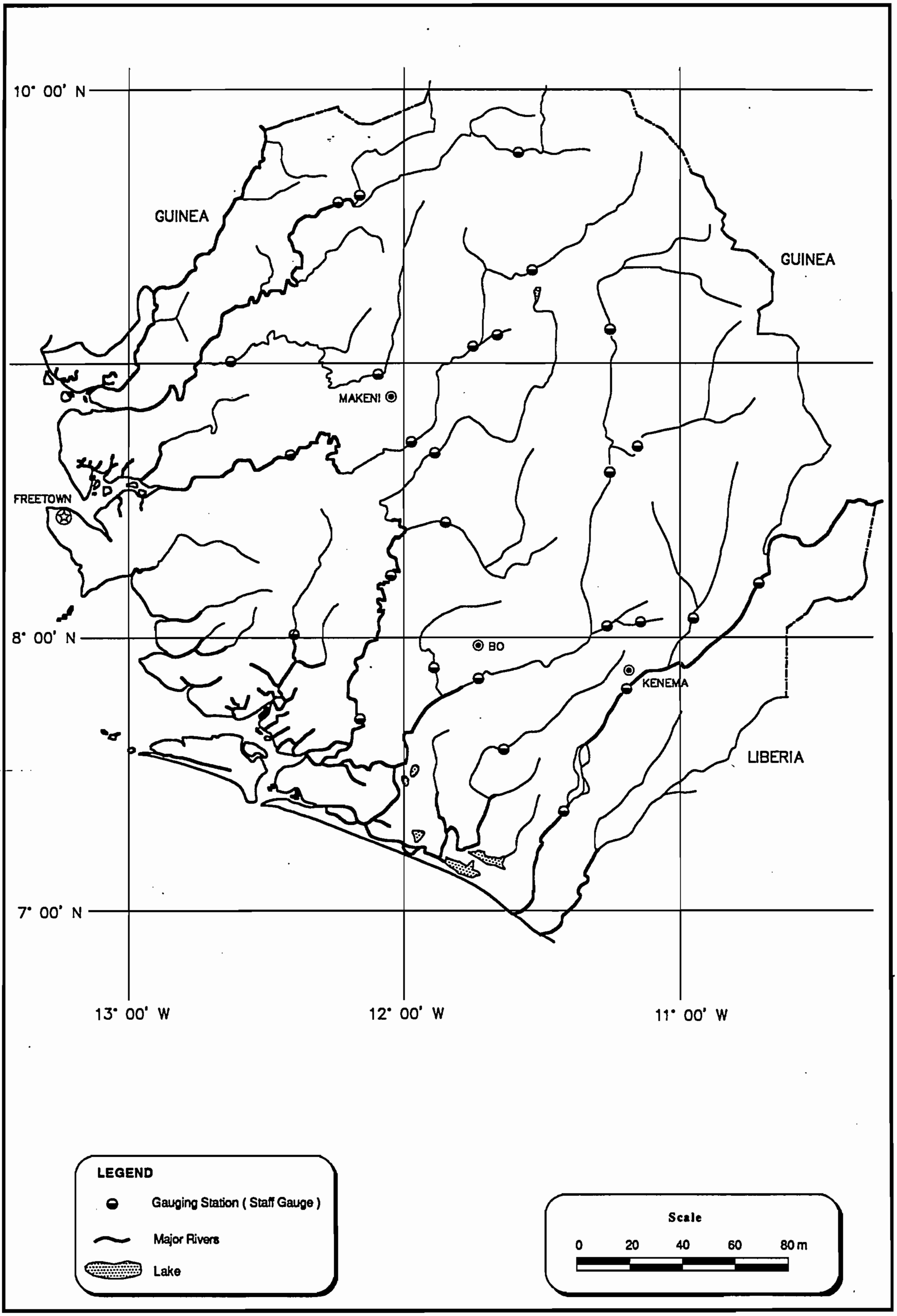
Apart from the current meters, the equipment used for gauging consists of three Zodiac rubber dinghies with outboard motors, one of which is awaiting repair, and two vehicles. All the equipment is the property of the Onchocerciasis Project and the vehicles have not been registered in Sierra Leone. Any equipment repairs are carried out in one of the offices of the OCP project in Bamako, Mali, or Ouagadougou, Burkina Faso. When one of the vehicles was damaged in an accident it took 5 months to be repaired and returned to the project. It is not clear what will happen to the equipment in June 1991 when the UN volunteer leaves the project.

The previous automatic water level recorders are reported to be beyond repair but it is believed that the stilling wells could be put into service again if new equipment was to be installed.

4.2.4 Maintenance and Field Support

Since, apart from the staff gauges and the gauging equipment, there is no field equipment no visits will evidently be carried out. Similarly there are no permanent observers at the sites, only the OCP fly catchers who go from station to station visiting each weekly.

Location of Gauging Stations (1991)



4.2.5 Data Processing

There is no computerised hydrological data base in the country. The earlier data is available in the Hydrometric Year Book of which only one copy remains with the Hydrology Unit. Copies of the recent gaugings and the water levels are held at the OCP project office in Makeni but these data have not been collected into a data base.

4.2.6 Data Quality

Because of the very limited data available no checks on the quality of the data were possible. Figure 4.3 shows the daily flow for Bumbuna for the water year 1975/6, a year which was close to the average for that station. Figure 4.4 shows the recent current meter gaugings for the River Sewa at Njaiama plotted on the same graph as the published curve for the equivalent station which existed from 1970 to 1976. Apart from a difference in the datum the new gaugings are close to the earlier rating curve except for the highest range of flows.

4.2.7 Data Availability

There is no inventory of data nor is there any organised system of filing gaugings with details of station location, data of construction, gaugings carried out etc. The station information presented in this report was obtained from notes prepared for the visit by Sierra Leone staff and discussions to clarify certain points.

The Water Supply Department has one copy of the hydrological year book for 1970-76 which gives daily flows or levels for all stations which were operating at that time and additionally includes rating curves and rainfall and evaporation data. Other copies of this report may be consulted in the UNDP documentation centre.

4.3 Solid Transport

There is no monitoring of solid transport. The project SIL/72/007 procured sediment sampling equipment and laboratory equipment including an oven and balance for sediment measurement but there is no records of this equipment having been used.

There are reports that many of the rivers carry a high silt load but during the Consultant's visit no data have been found to corroborate this.

4.4 Water Quality

Some water quality measurements have been made in the context of small rural water supply schemes but this data appears not to have been published nor inventoried.

The University has a small laboratory, which was funded by UNICEF, to carry out tests of the bacteriological quality of water. There is also a current project supported by the IDRC (International Development Research Centre, Canada) which is looking at the bacteriological quality of water in small streams and ponds in the northern part of the country. This area was chosen as it has the longest dry season. The project is being undertaken at Njala Agricultural University where the analyses are also carried out.

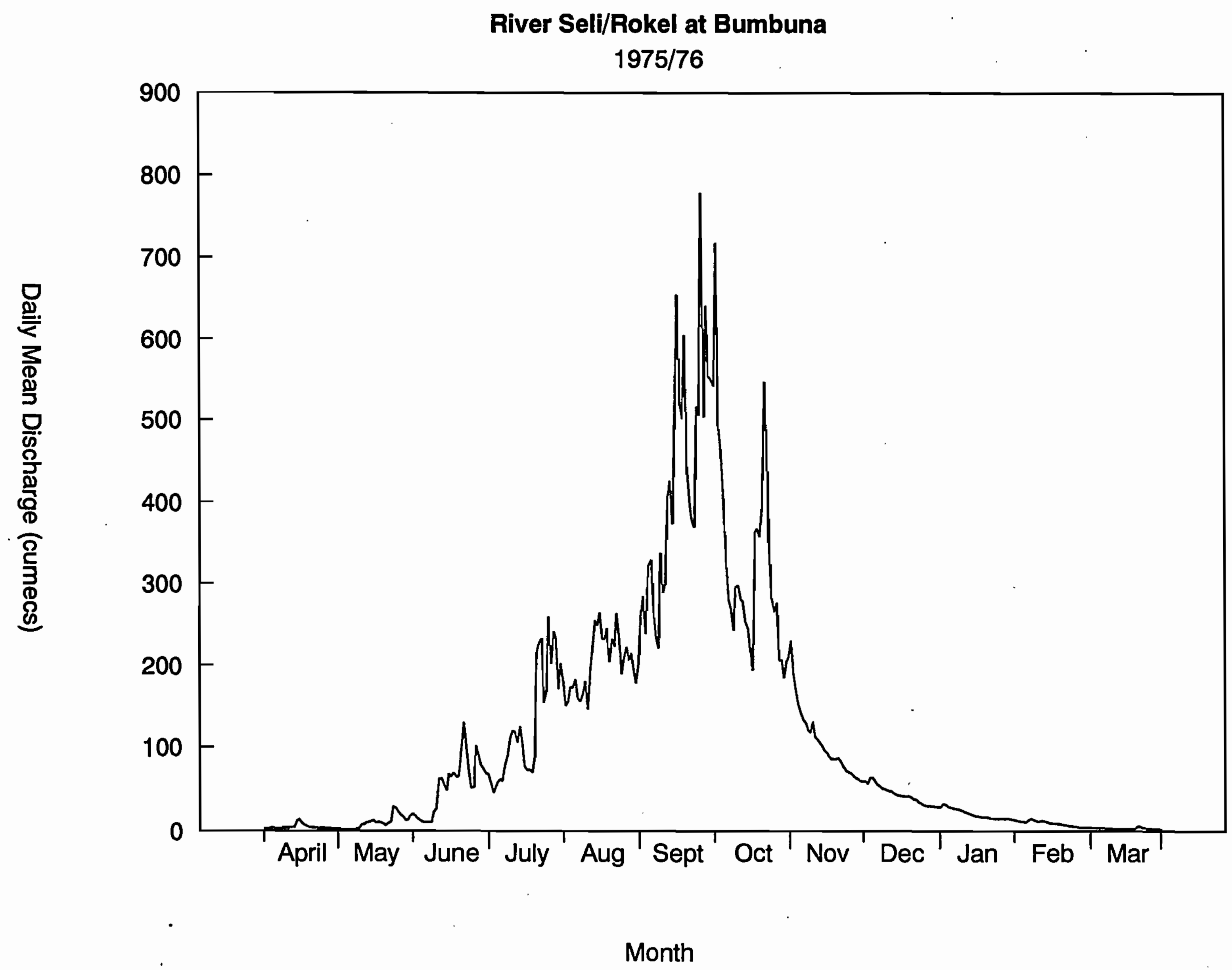


Figure 4.4
Typical Flow Hydrograph at Bumbuna

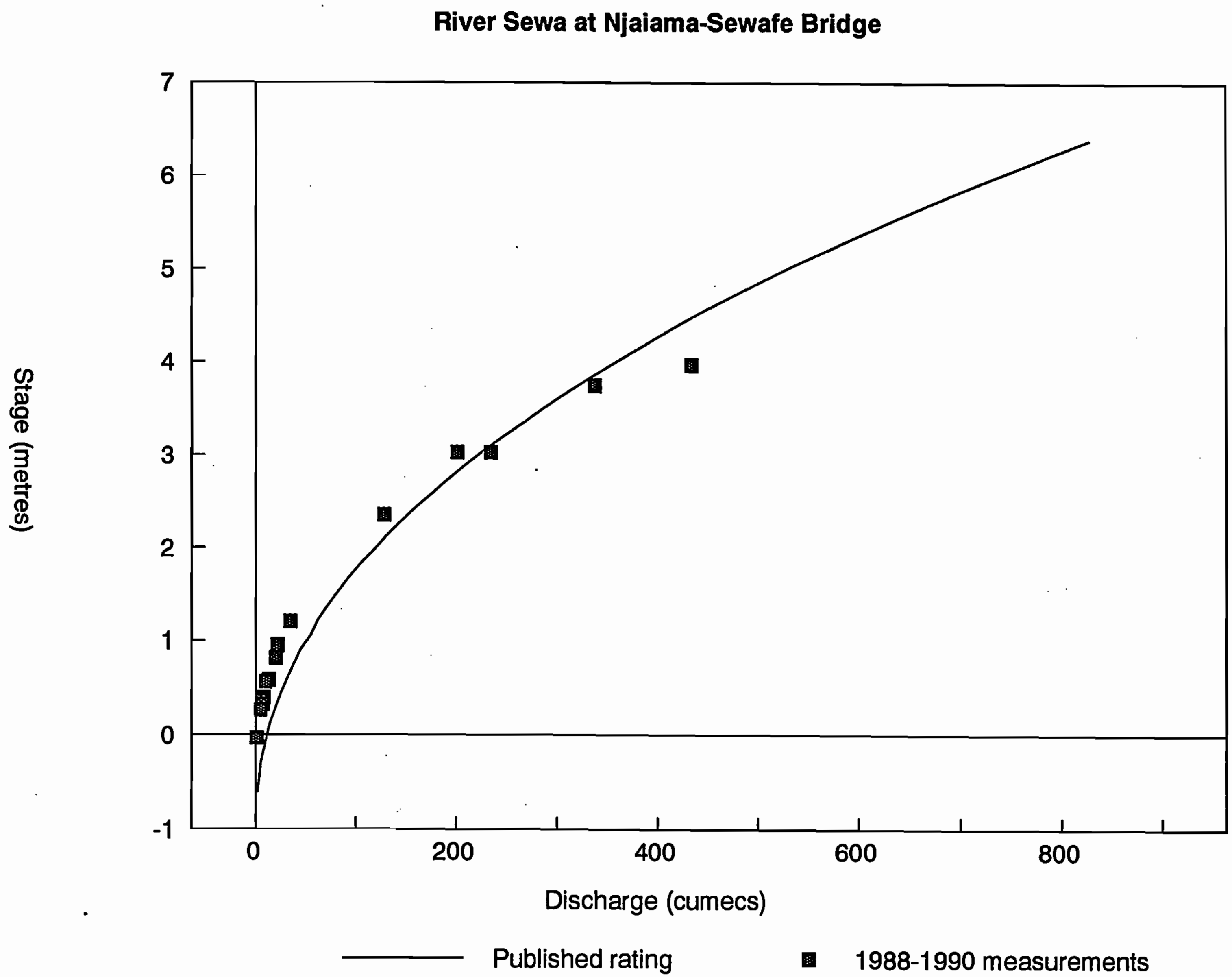


Figure 4.5 Stability of Rating Relationship - River Sewa at Njaiama

CHAPTER 5

GROUNDWATER

5.1 Organisation and Management

5.1.1 The Hydrogeology Service

There are three government agencies with an interest in groundwater, namely the Water Supply Department (WSD) of the Ministry of Energy and Power, the Land and Water Development Division (LWDD) of the Ministry of Agriculture and Natural Resources, and the Geological Department of the Ministry of Mines. The position of these agencies within their respective ministries is shown in Figures 5.1 and 5.2. The intended division of responsibility between these organisations is difficult to evaluate as two of them are almost completely inactive.

The Geological Department of the Ministry of Mines is the descendant of the old Geological Survey of Sierra Leone, which in the pre-independence days took some interest in groundwater. However, now as then, the main objective of geological work is the discovery and evaluation of commercial minerals for mining and export. (The main exports at present are diamonds, rutile and bauxite). The Hydrogeology Unit consists of one geologist offering advice to various organisations in need of water on how to obtain small amounts of groundwater by means of wells. Though the Ministry is fairly well equipped (including for exploration drilling), the Hydrogeology Unit has no equipment at all under its jurisdiction and has had no access to the Ministry's pool of equipment, except for transport for occasional field trips.

The Hydrogeology Unit of LWDD was set up in 1981 as a research oriented organisation. Initially its aim was data collection and compilation, providing services to the WSD and training of technical staff. It collaborated with the FAO Training Mission in the early 1980s. In 1982 an expatriate hydrogeologist financed by the Commonwealth Fund for Technical Cooperation was attached to the Unit; amongst his activities were geophysical surveys for well siting for WSD and for other interests. He was later transferred to the Japanese aid assisted Bombali/Kambia Project, under the jurisdiction of WSD.

At present the Hydrogeology Unit of LWDD consists of one hydrogeologist (MSc Hydrogeology, University College, London) with no support of any kind. No equipment, not even transport, is now available to her; the geophysical apparatus left behind by the FAO Training Mission is now defunct. Her main activity is providing advice on groundwater, particularly on well siting to other Government and international agencies. Recently, such advice has been required on increasingly rare occasions.

It is apparent that the WSD is the most active government agency involved in groundwater development being responsible for all rural and urban water supply, except for that of Freetown, which is under the control of the Guma Valley Authority.

The WSD was set up in the 1960s to co-ordinate all efforts to supply safe potable water to rural and provincial urban communities. In 1980 UNDTCD provided some assistance in support of the organisation but as its Rural Water Supply Unit (RWSU) became increasingly important in the early 1980s with village well/handpump installation gathering pace under the auspices of the Water Supply and Sanitation Decade, UNDP initiated 'Strengthening of the Rural Water Supply Unit' with provision of staff and equipment. Though that project is now completed, the RWSU remains the most active government agency dealing with groundwater.

The Unit is headed by a Senior Executive Engineer with an MSc in Water and Wastewater Engineering in Developing Countries from Loughborough University in the UK. It employs no hydrogeologists and only one geologist, currently in Italy on a six month course in hydrogeology. In addition, specialists in groundwater related subjects, include one hydrogeological technician and four drillers (two of them undergoing training). The full establishment of senior technical staff is specified in Figure 5.1.

The RWSU has practically no equipment except that under the control of the foreign aid assisted projects. There are only three water well drilling rigs in Sierra Leone. One belongs to the German contractor, Prakla Seismos Geomechanik, and is engaged on the Bo/Pujehun Project financed by KfW; it will be re-exported on completion of that project. The other two have been supplied by JICA for the Bombali/Kambia Project and will remain with WSD when the project ends. All three rigs are of rotary/down the hole hammer (DTH) combination type. It should be mentioned that the Ministry of Mines has several drilling machines used for mineral prospecting, some of which reportedly have water well construction capabilities.

In addition to drilling rigs, the KfW and JICA assisted projects have full complements of ancillary equipment such as mud pumps, compressors, test pumps and supporting transport. The UN agencies have also provided compressors, dewatering pumps and transport for the projects implemented with their assistance. Operational geophysical equipment comprises Very Low Frequency (VLF) apparatus with the Bo/Pujehun Project, and VLF (the ABEM Wadi), conventional resistivity set and wire-line logger with the Bombali/Kambia Project. All the projects have access to minor items of hydrogeological instrumentation including:

- 2 portable chemical laboratories (Hach) with the UN Eastern Province Project;
- portable chemical laboratory with the JICA assisted Bombali/Kambia Project;
- EC meters, pH meters, water level indicators, flow measuring devices, stop watches, etc with most if not all of the projects.

Figure 5.1

Government Agencies with interest in Groundwater-Ministry of Energy and Power

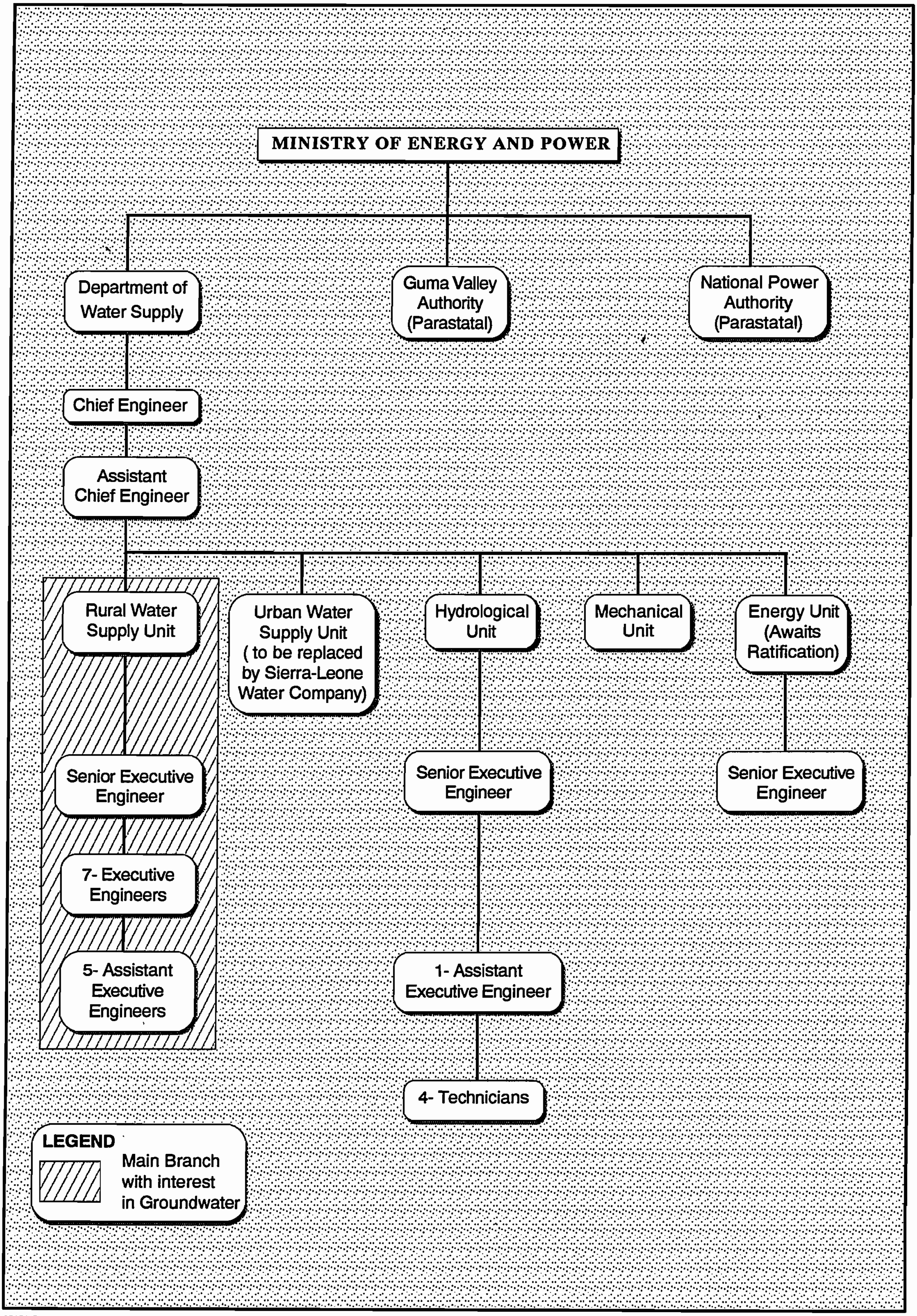


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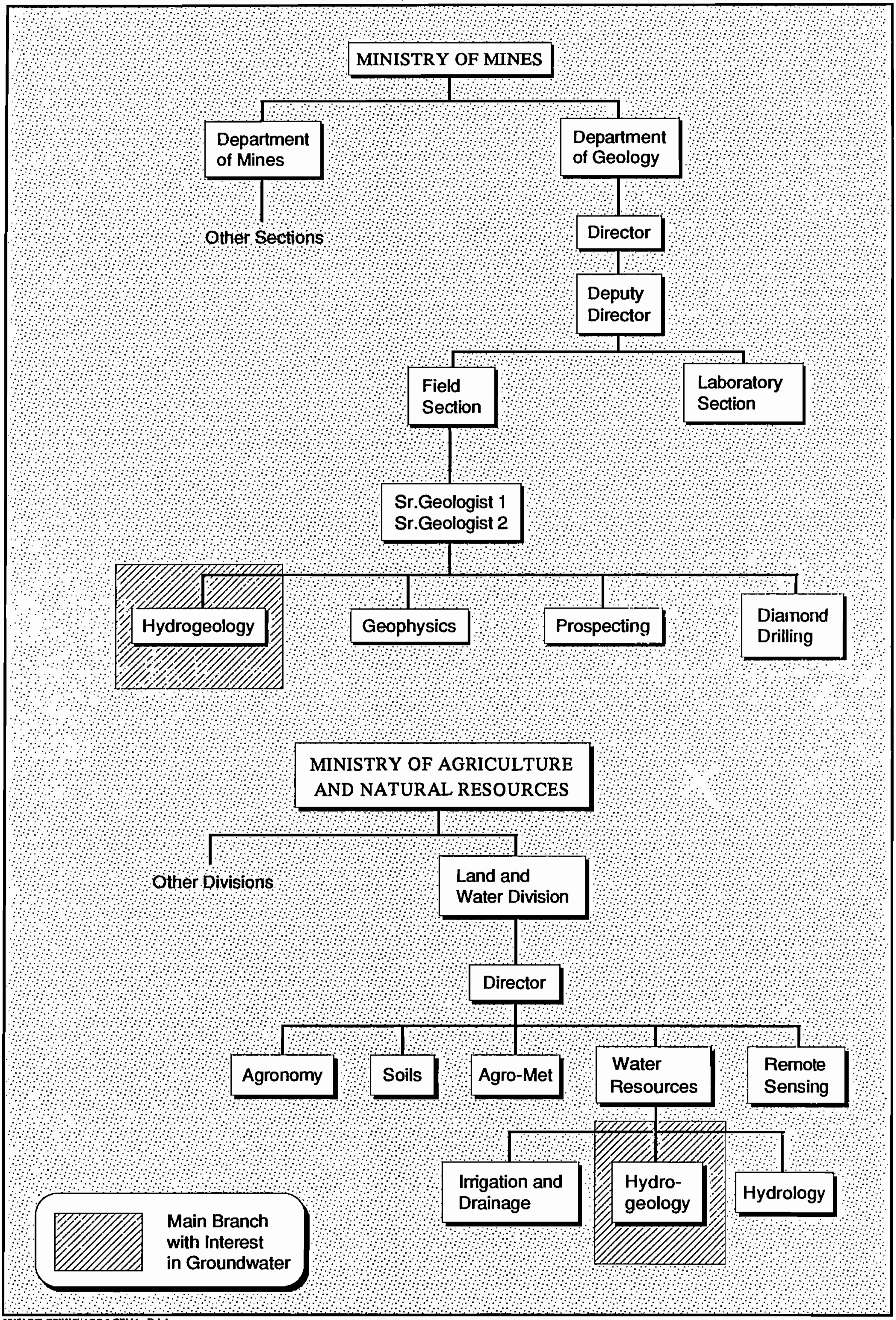
Figure 5.2

Government Agencies with an Interest in Groundwater
Ministry of Mines and Ministry of Agriculture and Natural Resources



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At the end of their 'strengthening' of the Rural Water Supply Unit in June 1990, the UN in the Terminal Reports claimed the following achievements (Bicego, 1990):

A. Construction Activities

(i) Direct Implementation

- Eastern Province Rural Water Supply Programme;
- Water and Sanitation Component of Integrated Development in Rural Fishing Villages, Shenge Region;

(ii) Design, Organisation, Co-ordination and/or Monitoring

- Moyamba Rural Water Supply and Sanitation Project (CARE);
- Port Loko/Kambia/Koinadugu Rural Water Supply Project (EDF);
- Bo/Pujehun Rural Water Supply and Sanitation Project (KfW);
- Gravity-fed Water Supply Project (Water Aid);
- Bombali/Kambia Water Supply Project (JICA);
- Village Well Component of ILO's Support to Rural Works Project.

B. Training

- one 6-month Post-graduate Course in Water Resources Technology at Birmingham, UK;
- one 12-month MSc in Water and Wastewater Engineering in Developing Countries at Loughborough, UK;
- four Fellowships for Middle Level Staff for 10-week Diploma Course 'Community Water and Sanitation' at Loughborough, UK;
- one 2-week Course in the UK on Combustion Engines for Mechanics/Supervisors;

- in-service training for 250 personnel;

- village training of trainers for 200 villagers;

- several study tours/seminars;

- preparation of reports and manuals.

In addition a reorganisation of the Rural Water Supply Unit was proposed with the structure and staff shown in Figure 5.3.

There are indications that the pace of rural water supply activities, which in the last 15 years have relied almost entirely on foreign aid financing, may be declining since the end of the UN Water Supply and Sanitation Decade in 1990.

5.1.2 Other Organisations

There are few other organisations with any interest in groundwater and none with an interest in hydrogeological data collection.

Some of the donors to Sierra Leone's Rural Water Supply Programme have taken a general, but normally inactive, interest in the projects towards which they made financial contributions. These include EDF, Norway, Italy, Danida and non-government organisations (NGOs), usually charity based. At least one of the latter (Water Aid) supplied an engineer to help design the gravity fed systems, which is its main area of interest.

Apart from Prakla Seismos there are no independent drilling contractors in Sierra Leone. Although they currently have only one drilling rig in the country, they are active in several countries of West Africa and have the capability to expand their operations in Sierra Leone rapidly, should the need arise.

There are some contractors in Sierra Leone, willing to undertake the construction of dug wells. One such organisation is Fabra Construction, which provided this service to the German aid assisted Bo/Pujehun Project.

There are also several consulting firms operating in the Republic; most have no hydrogeological expertise but are willing to take up groundwater projects in association with foreign consultants. Only one local organisation offering advice on groundwater problems was identified; this is the Environmental and Scientific Consulting Group, which is an ad hoc association of engineers and scientists, normally working for government agencies, who undertake interesting assignments in their spare time and during leave.

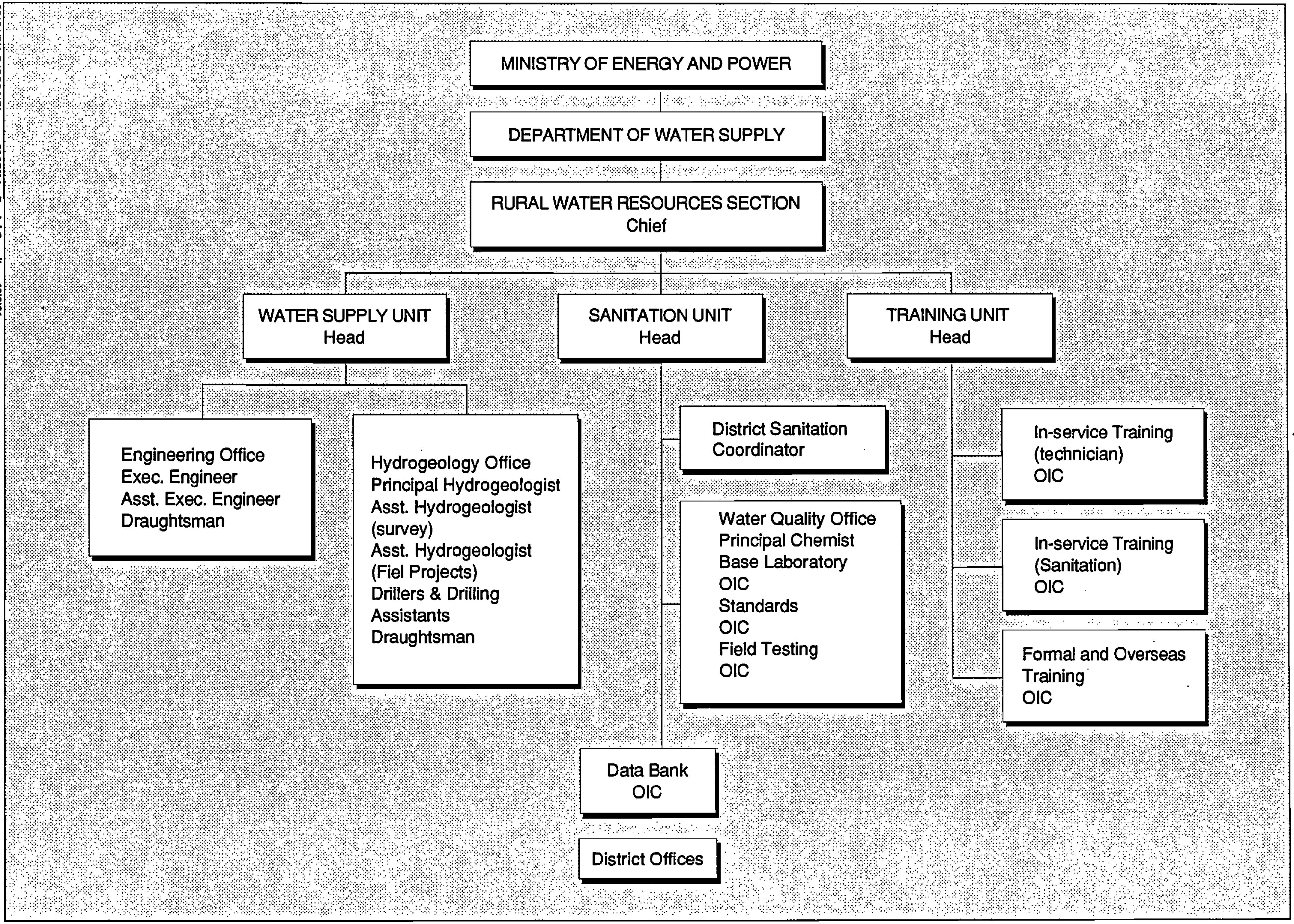


Figure 5.3
Organisation Chart for the Rural Water Supply Unit Proposed by UNDP

5.1.3 Staff and Training

It should be apparent that indigenous groundwater expertise is in short supply in Sierra Leone. As far as it could be ascertained, there are only two qualified hydrogeologists in the country and one of them is no longer active in the discipline (the other one works in the LWDD of the Ministry of Agriculture and Natural Resources).

The head of the RWSU of the Ministry of Energy and Power has an MSc in Water and Wastewater Engineering, but his current functions are largely executive/administrative rather than technical. The one geologist attached to the Unit has been working on the JICA assisted Bombali/Kambia Project and has recently been sent on a six month hydrogeology course in Italy. The rest of the senior staff have engineering degrees from local universities, sometimes augmented by normally short-term training at an overseas institution.

Most of the rural water supply projects assisted by external financing, include training programmes. The UNDP Strengthening of Rural Water Supply Unit Project had the primary aim of training/institution building; its training accomplishments have already been listed in Section 5.2.1. All other projects undertake on-the-job training and some have provided funding for overseas courses. Of particular importance has been the training of water well drillers, since this industry has a very short history in the country. At present three drillers/trainee drillers are attached to Prakla Seismos but the total of WSD employees in this discipline is only four (two drillers and two trainees).

5.1.4 Budget

The total expenditure and personnel budgets for the Ministry of Energy and Power have been given in Section 4.1.4. The expenditure on RWSU staff is not specified separately in the Ministry's budget and is difficult to estimate but the amount spent on the salaries of professional staff will be equivalent to only a few thousand dollars in 1990/91.

Farrant (1990) reported that in 1988/89 the WSD expenditure was about Le 18 600 000. Moreover he claimed that the government spending on the water supply sector was only about 1% of the annual budget as opposed to 6% or 7% in some of the neighbouring countries. It is uncertain from where he derived his figures.

The expenditure on the development of the rural water supply sector is dominated by donor contributions. According to Government estimates the total spending on rural water development in 1990/91 will amount to Le 277 150 000 (US$ 1 514 500) of which some 99.5% will be grants from international and bilateral aid agencies.

5.2 Hydrogeological Data

5.2.1 Maps, Air Photos and Remote Sensing Imagery

The map base for Sierra Leone is reasonably good, with the following maps normally available (some are out of print at present):

TABLE 5.1

Availability of Mapping

Type	Scale	Comment
Road map	1 : 396 000	Published by Shell
Topographic Map	1 : 500 000	1 sheet
Topographic Maps	1 : 250 000	4 sheets
Topographic Maps	1 : 50 000	117 sheets
Air Photos	1 : 40 000	Whole country; stereo pairs; old (1951 to 1964)
Air Photos	1 : 120 000	Coverage of the whole country in monochrome stereo pairs (1975/76 and 1978)
Air Photos	1 : 70 000	Panchromatic, 1978
Infra-red imagery	1 : 70 000	1978
Geological map	1 : 1 000 000 approx	1 sheet
Geological maps	1 : 250 000	2 sheets; north of Sierra Leone (north of 9° latitude)
Geological maps	1 : 50 000	About 40 sheets; black and white; west of 12° longitude only
Geological maps	1 : 50 000	Several sheets; coloured; areas of special mining interest only

The 1 : 500 000 scale topographic map shows elevation in standard colours with contours at 50 m, 100 m, 300 m, 500 m, 700 m, 1 000 m, 1 500 m and 2 000 m. It also shows roads, railways, towns, villages, the drainage system and swamps.

No 1 : 250 000 scale topographic maps were seen. The 1 : 50 000 scale maps have 50 ft elevation contours and show general geographic features. The maps were prepared in the 1970s and are of good quality.

All the aerial photographs are of good quality and have been extensively used for photogeology and geological compilations. Some rural water supply projects have used the air photos (stereo pairs) to identify faults and fractures as an aid to well siting in hard rock terrain.

It is uncertain what purpose was envisaged for the infra-red scan; as far as could be ascertained this imagery has not been used successfully for any practical purpose.

The quality of geological maps is also good. The single sheet at 1 : 1 000 000 scale is too small for any purpose except to give a general picture of the distribution of outcrops of the major formations. The 1 : 250 000 and 1 : 50 000 scale coloured maps have been prepared as aids to mineral prospecting and consequently concentrate on solid geology and on mountainous areas where particular, potentially mineral bearing, rock types occur. From the hydrogeological point of view the black and white photogeological maps are the most useful; these show superficial deposits, dykes and structural features very clearly and should be useful for borehole site selection.

It is understood that another useful geological map may be available in the near future. The Geology Department of the University of Freetown is preparing a 1 : 500 000 scale lineament map from aerial photographs. This may prove useful for borehole siting.

5.2.2 Aquifer Data

The disposition of outcrops of various rock types and the occurrence of visible structural features, possibly relevant to groundwater occurrence, is reasonably well documented, as must be apparent from the previous section of this chapter. However, the situation with the availability and quality of sub-surface information is unsatisfactory.

Records of the geophysical surveys carried out sporadically by various organisations are not to be found. The general UNDP publication (1988) on groundwater in North and West Africa, gives a composite hydrogeological resistivity profile but makes no reference to where the original records may be stored. The only original records available are those of the Japanese aided Bombali/Kambia project (C-ITOH & Co Ltd, 1989) and those of a short survey in the coastal Pujehun District by Jayakaran (1990).

No general data bank of well records exists. Moreover, even the published records of the two borehole projects are difficult to obtain. The dug well data is reportedly available at the regional headquarters of various projects in the form of project files; there are apparently no plans to issue any kind of compilation which might be of use to future workers.

The Bo/Pujehun Project has published well completion reports for 136 boreholes so far, which is less than one third of those completed. The reports are concise and informative, but give very little groundwater quality data and describe all fresh rock penetrated as granite; this is improbable and suggests inadequate geological supervision. Nevertheless, in the main, the records are very good.

The Bombali/Kambia Project has published completion reports for 55 wells which is just more than one third of those completed; no records of unsuccessful drillings are given. The reports are generally very full and excellent all round.

No significant compilations of the water bearing characteristics of the various geological formations appear to exist. It is understood that the hydrogeologist previously attached to the Bombali/Kambia Project, who has now left Sierra Leone, is preparing a hydrogeological map of the whole country at the 1 : 1 000 000 scale and proposes to sell it to the interested parties. It is unlikely that such a map at this scale would be of much practical use.

5.2.3 Groundwater Abstractions

It is estimated that there are about 2 000 dug wells in Sierra Leone, about 1 500 of them equipped with handpumps and about 480 drilled wells, most of them with handpumps. All of these are mainly used for domestic supplies for villages. In addition there are about 10 town water supply systems based on wells pumped with electrically driven pumps.

The rural water supply wells are distributed throughout the country; most of them tap the near-surface weathered and/or fractured zone of crystalline or strongly cemented rock with no primary permeability. Only the Bullom Series outcropping in the coastal belt and containing loose sandy layers form a major aquifer with intergranular permeability. Most of town supply wells are located on the Bullom outcrop. Some recent alluvia occurring along the major rivers are coarse grained and sufficiently thick to yield significant amounts of groundwater. It is reported that mining enterprises, particularly those exploiting alluvial deposits of rutile, obtain their water supplies from such aquifers.

The density of wells and boreholes has not been mapped. During the UN Water Supply Decade well installation took place in all the Provinces; best progress has been achieved by the Bo/Pujehun Project and it is probably those districts that have the highest density of wells (mainly drilled wells).

The total groundwater abstractions in Sierra Leone are estimated at 5 to 10 million m^3 which is insignificant compared to the estimated overall recharge.

5.2.4 Piezometric Data

At present there is no monitoring network for water level measurements. Apparently the LWDD of the Ministry of Agriculture monitors one well (at Rolako near Makeni) at monthly intervals, through the personal interest of the Deputy Director. However, the results of these measurements were not immediately available in Freetown, except for one annual hydrograph reproduced by Jalloh (1979); this shows the difference in groundwater level between the dry and the wet seasons as about 1 m.

GKW Consult reported in the Inception Report for the Bo/Pujehun Project that water levels had been observed in their area in 1980 and 1985. No one in Sierra Leone (including the GKW representative) could produce any further information about this monitoring but the following is the summary given in the Inception Report:

	Average	Standard deviation	Maximum	Minimum
Depth of well (m)	13.1	2.9	19.8	6.5
Height of column of water in the dry season	3.4	1.4	6.0	1.0
Height of column of water in the wet season	6.9	3.2	12.4	1.8

No records of any other monitoring of groundwater levels have been found.

5.2.5 Water Quality

As already described (Section 2.2.4 and Appendix G), hydrochemical data collection associated with well completion, varies from project to project and for some projects is not easily available; in fact in the case of the UN financed projects it is uncertain exactly which chemical parameters are routinely measured. Even the chemical components important from the point of view of public health, are not always measured and are not reported. No monitoring of hydrochemical characteristics of groundwater from wells is being carried out at present.

The bacteriological quality of groundwater from wells is reportedly treated more seriously. Newly completed wells are disinfected with chlorite in all projects. The UN Eastern Province Project claims monthly monitoring of wells for presence of coliform organisms, followed by disinfection, if necessary. Most, if not all, of the other projects do no routine monitoring but respond to the users' complaints with appropriate treatment.

5.2.6 Equipment

Practically all the equipment used in groundwater work in Sierra Leone is attached to individual projects rather than coming under the direct control of the government agencies involved.

Of the three drilling rigs in the country two are Japanese made Tone and one is Prakla Seismos' modification of a basic Gardner Denver (American made) unit. All are top head drive rotary, with down the hole hammer (DTH) capability. The Prakla Seismos rig has a German made compressor mounted on the rig chassis, while the Japanese aided project uses two separate compressors (Atlas Copco). Both projects have a full complement of ancillary equipment including transport.

Operational geophysical equipment in Sierra Leone comprises two sets of VLF apparatus, Swedish ABEM Terrameter, and a Japanese made hand crank borehole logger. Resistivity equipment supplied to LWDD and the Geological Department of the Ministry of Mines by previous groundwater related projects, reportedly went out of use for want of spare parts which could not be procured because of lack of foreign exchange.

The dug well projects financed by the UN and other agencies also have some heavy equipment, including compressors, dewatering pumps and transport, but the exact numbers and the make of individual items are not known.

Water analysis facilities in Sierra Leone are poor. The Ministry of Health reportedly has a small water laboratory; they concentrate on bacterial determination but apparently have some capability for chemical analyses as well. The Ministry of Energy and Power have set up a laboratory at Njala Agricultural University; financial assistance for equipment was provided by UNICEF, who continue to pay for maintenance, repairs and the supply of reagents. This laboratory is equipped for most chemical determinations in water as well as for bacterial counts.

The UN financed Eastern Province Rural Water Supply Project has apparently procured two portable (Hach) laboratories, which can be used for the analysis of water for most of the common radicles. The JICA assisted Bombali/Kambia Project has also provided portable analytical facilities, though the type and make of the equipment is not known. Lastly, most if not all of the projects are equipped for testing water for the presence of bacteria in general and coliform organisms in particular.

5.2.7 Maintenance and Field Support

Maintenance, repairs, spare parts and other supporting services to groundwater related activities are all in the hands of individual projects. Since all the projects are assisted by donor finance, all have access to foreign exchange and are able to procure vital spare parts to keep the various items of field equipment going.

In the past, problems have arisen when on completion of projects, equipment has been handed over to the Sierra Leone counterpart organisations. Local government agencies have difficulties with access to foreign exchange and may not be able to obtain needed spare parts. Consequently, when the equipment breaks down it often cannot be repaired and goes permanently out of use.

5.2.8 Data Processing

Despite two UNDP institution strengthening projects and expenditure of some US$ 3.4 million for this purpose over the last 10 years, there is no central agency in Sierra Leone, that collects, compiles and collates all the groundwater data for the various well installation projects.

The well digging projects collect only limited amounts of data during construction, namely the location of the well, the type of rock penetrated and some groundwater quality parameters. No yield test of any kind is carried out and a well's capacity to sustain the yield of a handpump is judged on the basis of the discharge of the dewatering pump. Such information as is collected is held in files at the regional project headquarters; none of the individual well records, not even in summary, are sent to the Rural Water Supply Unit head office in Freetown or processed further.

The records of the two drilled well projects are much fuller, particularly those of the JICA assisted Bombali/Kambia Project. Both give location, lithology penetrated, casing and screen disposition, pumping tests (step and constant discharge) and some quality parameters; as already mentioned the last item is much more fully treated by the JICA Project, which also makes a fuller interpretation of the pumping tests.

The borehole completion reports, with all the above information, have been compiled and issued in printed volumes, albeit with considerable delay, and delivered to the RWSU in Freetown.

As far as can be ascertained little, if anything, has been done with these data since. No further processing or country-wide compilation appears to have been carried out. No computerised techniques have been used for further data analysis or storage.

5.2.9 Data Availability

As should be apparent from the previous sections groundwater data availability in Sierra Leone is poor. No centralised storage of well and borehole records exists. The most important sources of groundwater data, the rural water supply projects, collect subsurface data at varying levels of completeness and report it in widely different format. The well records are dispersed amongst the regional headquarters of the various projects, where they are kept in files, with no processing; no summaries have apparently been issued on completion of many of the projects.

The accessibility of such records as exist is also poor. Many of the UN papers and reports are for restricted circulation and cannot be obtained by interests unconnected with UN and/or government agencies. Some of the reports issued by consultants, such as that containing the Bombali/Kambia borehole records, seem to have been submitted to the WSD in very few copies (only one copy was found and this is now in Italy with the project hydrogeologist on a training course for six months).

As already mentioned, no systematic groundwater monitoring is being done in Sierra Leone at present. Existence of water level hydrographs is mentioned in some reports and verbally by LWDD staff, but the actual data could not be traced.

No properly indexed library of hydrogeological publications, reports and other information exists. The UN runs a library with unrestricted access but this contains no records of development projects, which are treated as confidential. WSD has most of such material but it is mainly dispersed throughout the offices of staff with special interest in particular projects.

It is uncertain if the records of some of the early well construction projects are still available. However, it is common throughout the world that unpublished data, held in files at provincial government offices, have a relatively short survival record.

CHAPTER 6

EVALUATION AND ASSESSMENT

6.1 Data Needs

Sierra Leone is a well watered country with high rainfall and abundant streamflow. However there is a pronounced dry season from December to March when river flows are much reduced. It appears that one of the main reasons why, up to the present, little emphasis has been placed on hydrometric data collection, is the fact that the country has not as yet experienced any major problems of water resources. On the major rivers the low flow season may however act as a constraint to future hydropower or irrigation schemes which do not provide any storage. Smaller streams may run sufficiently short of water to restrict domestic use. Thirty towns use direct abstraction from a surface water source for piped water supply but the supply of treated water is frequently disrupted. The capital Freetown is presently the only centre with a regular supply of piped water; it derives its water supply from a small catchment draining the steep Peninsula Mountains where a reservoir has been constructed to ensure that supply can be maintained through the dry season.

One of the reasons for the lack of effective urban water supply systems is the shortage of foreign exchange to buy fuel oil. This manifests itself in frequent power cuts in most of the towns which have electricity generation facilities. The country does however have a number of potential sites where hydro-electricity could be generated on a year round basis without the need for large dams to provide water storage. If these sites were to be developed they would help to alleviate the country's power shortage. Indeed the first hydrological stations were installed with hydropower in mind.

Although the country does not practise large scale irrigation it is still not able to produce enough rice which is its staple diet. It is possible that to do this irrigation would need to be practised.

From discussions it has been reported that Freetown does not have a major problem of urban drainage, it is built on the slopes of hills leading to the sea; however the same is unlikely to be true of all the other urban centres. Again as these centres develop and larger and larger areas become paved this is likely to be an increasing problem.

The main use of groundwater, now and in the future, will be for rural water supply. The proportion of the rural population with access to 'safe' water supplies is still low and there is a need to continue the recent investment in drilling programmes.

There appears to be a need to collect data on water quality. There have been reports of many of the country's rivers containing large amounts of suspended sediment, as a result of erosion following deforestation of parts of some river basins, but the Consultant have not seen any data on silt loads. There is also an increasing tendency to equip villages with wells but in many cases little is known of the chemical quality of the water. In the one project which measured the fluoride content, for example, there were levels of fluoride at 5 ppm; a level which can lead to seizure of the joints if it is drunk over a long period of time.

In short, although the country has been able to manage without effective collection of data on surface water resources and in, recent years, a meteorological service which is starved of funds, it is likely that in the foreseeable future there will be a need for hydrological data for development and, unless measures are taken quickly, these data will not be available. The recent groundwater development projects have significantly improved the level of knowledge regarding aquifer potential and well design; however the lack of co-ordination between the projects has seriously impaired the usefulness of the information gathered, and thus data collection particularly on hydrochemistry is still a priority.

6.2 Climate and Rainfall

6.2.1 General Assessment

An FAO/UNDP project in the late 1970s and early 1980s looked into the usefulness of agro-climatological information, amongst other factors, in improving crop yields in Sierra Leone. This demonstrated that there were tangible benefits to be obtained from taking account of weather conditions in determining the best time for sowing and transplanting certain crops. In particular there was a need to differentiate between early rains which were isolated and did not presage the start of the rainy season and the actual start of the rainy season. To this end a network of agrometeorological stations was set up and this network is still to a certain extent functioning. It does however suffer from a lack of spare parts and in many respects it is failing fully to fulfil its original purpose. There is also an apparent lack of co-ordination between the Land and Water Development Division and the Meteorological Service. For example the 10-day bulletin published by the Service does not use data from the agro-climatological stations of the LWDD.

For a number of reasons it is at present difficult to be certain what the effective network of operating raingauges is; there is no inventory of stations, and because of transport and economic problems staff of the Meterological Service work to a restricted time schedule and different correspondents give conflicting information. Table 6.1 estimates the present situation and includes the agro-meteorological stations operated by the Water and Land Development Division of the Ministry of Agriculture, Natural Resources and Forestry. It assumes that the country is humid and that the surface geology is non-sedimentary. The 'recommended minimum' figures in this and the following tables are based on guidelines published by UNESCO/WMO in 1988.

TABLE 6.1

Climatological Data Collection Activity Levels

Element	Recommended minimum density	Actual density
Precipitation stations: non-recording (Number per 10^4 km^2)	40	2.0
Precipitation stations: recording (Number per 10^4 km^2)	2	1.7
Evaporation stations (Number per 10^4 km^2)	3	1.7
Repair and maintenance shops for meteorological equipment (Number per 200 precipitation stations)	1	0
Inspectors of meteorological stations (Number per 100 precipitation stations)	5	-
Superstructure staff meteorology (Number per 100 precipitation stations)	3	-

The table calls for some further explanation. Firstly the number of precipitation stations is well below the norms. Even if one takes the figure as it appears in the last published year book, for 1969, the total number of precipitation stations is 46, which for the country's area of 73 000 km^2 is still only 6 per 10 000 km^2; and this ignores the fact that of those stations 11 are in or near to Freetown. It is also significant that currently there are few precipitation stations reporting to the Meteorological Service other than their own synoptic and climate stations. For recording precipitation stations and evaporation stations the position was somewhat better. There were 24 climatological stations which gives 3.3 per 10 000 km^2. The Service does have a maintenance department but this has few spare parts and cannot be said to function effectively. Similarly the inspectors do not have the funds to visit the stations. To represent the number of superstructure staff per 100 stations would also give a false impression as so few of the stations are operating at the moment.

Table 6.2 shows how the level of staffing compares with the UNESCO/WMO recommendations.

TABLE 6.2

Evaluation of Staffing Levels - Meteorological Service

Item	Number of staff per 100 stations			
	Professional	Technicians		Observers
		Senior	Junior	
Recommended staffing levels				
- Field operations and maintenance	0.5	2	2	100
- Data processing, analysis and interpretation	1	2	2	-
- Supervision	0.25	-	-	-
Total	1.75	4	4	100
Actual staffing levels[1]				
- Field operations and maintenance	10	20	20	240
- Data processing, analysis and interpretation	-	10	10	-
- Supervision[2]	4	10	10	-
Total	14	40	40	240

Notes: [1] Assuming a nominal network of 10 stations and staff from the Climatological and Agro-meteorology divisions only.

[2] Assuming the Director and his assistant each spend 20% of their time on supervision.

As with the previous table, the numbers in this table are of dubious significance. The actual number of stations and the number of staff effectively employed are both open to question. For example, for data processing the figures have counted the two staff encountered who were concerned with the manual processing of the data. One of these is assumed to be a Senior Technician and the other a Junior - but the lack of a personnel structure plan makes such assignments purely nominal.

The service has had three UNDP support projects in the last decade. These were SIL/78/010 - Assistance to the Meteorological Services, SIL/86/020 - Agro-meteorology, and SIL/87/017-Agro-meteorology II. The first appears to have been of some benefit to the Service in that at least it allowed the purchase of equipment. There seems however to be general agreement that the agro-climatological projects failed to achieve their objectives. Without being able to meet all the parties to the project it is difficult to be specific as to the reasons for the failure but the two main factors seem to have been the quality of the expert and the lack of support which the Service could provide in terms of counterpart staff.

6.2.2 Present Situation

If the present network of synoptic, agrometeorological, and climatic stations was fully functional and if the data from the two collection agencies was combined, then the network, with exception of certain areas in the uplands, would be adequate. Since however these two conditions are not presently met the network cannot be considered fully satisfactory.

The present raingauge network is clearly insufficient for the country's needs. Indeed it may be no exaggeration to say that the country's network is on the point of collapse. The 10-day rainfall bulletin for October 1990 gives data for the month at six stations but indicates that nine stations were operating in the same month of the previous year. It has been reported that one of those six stations has ceased to operate in recent months. The country's network is therefore clearly inadequate to meet even the minimum needs for data for any planning purpose.

6.2.3 Future Needs

In the future rainfall and climatic data are required for the assessment of the country's water resources potential. It is felt that it would be realistic and feasible to re-establish the network of stations which has, until very recently, been operating in the country. Provided that these stations are all fully equipped, and that refresher courses are given to the operators who had previously worked in stations that are temporarily defunct, then this network should be adequate.

Rainfall records assume a greater importance in water resource assessment when flow data are limited. The almost complete absence of flow data for the country's rivers has meant that previous studies for hydropower have used what flow data there is extended by the use of rainfall-runoff relationships. This in turn assumes that there is adequate rainfall data both for the calibration of the method used and sufficient historical rainfall data to extend the runoff record for a period of several years. Similar comments would apply to other studies of water use such as potable water for towns or mine washing. Given the limited areal extent of most convective storm cells and the consequent variability of precipitation from place to place a much denser network of stations than exists at the present is needed. Indeed even the past network was not fully sufficient in many respects.

6.3 Hydrology

6.3.1 General Assessment

The only network of hydrological stations which presently exists in the country is that established for the Onchocerciasis Control Project. This network was established with a very specific aim - that of controlling as accurately as possible the dosage of chemicals which are used to eliminate the parasite which causes the transmission of the fly-borne disease. The network is therefore limited to those rivers where the fly is prevalent. Further, the project at present appears only to have need of data on a weekly basis so readings are not made more frequently. Weekly readings, in catchments whose time of concentration is of the order of a few hours, will only give a very approximate idea of the runoff from those catchments and almost no information on the the flood discharges in those rivers. The position is complicated by the fact that most convective storms occur in the afternoon and therefore the rivers will be peaking during the hours of darkness - when even a regular observer would not be to able record data.

In general terms the network is of a reasonable density. The only major addition which would be useful would be gauging stations on those rivers which form the boundary with Guinea and Liberia (the Great Scarcies and Mano rivers) to enable a just distribution of water should any joint project materialise.

The present level of staffing is adequate to give support to the network of stations used in the OCP project. However once the UN volunteer hydrologist leaves, the Hydrology Unit will be without a professionally trained specialist in hydrology. There is however little present prospect of increasing the level of staffing and therefore the future network will have to be adjusted to be within the capabilities of the present staff.

One side effect of the hydrology component of the OCP being seen only as a means to a greater end rather than as an end in itself, is that virtually all the analysis is done outside of the country. There has therefore been virtually no transfer of technology in this important area of hydrological activity.

The WSD at present has a workshop but does not have adequate funds to carry out maintenance for the network of stations. Indeed at present all the equipment has to be returned to the OCP headquarters, or one of their regional offices, for repair. One effect of this policy has been that there has been no counterpart training in maintenance.

A comparison of the network of hydrological stations with the UNESCO/WMO guidelines is presented below in Table 6.3.

TABLE 6.3

Evaluation of Hydrological Network

Element	Recommended minimum density	Actual density[1]
Surface water level stations: non-recording (Number per 10^4 km^2)	24	3.4
Surface water level stations: recording (Number per 10^4 km^2)	1	0
River discharge stations (Number per 10^4 km^2)	20	3.4
Sediment discharge stations (Number per 10^4 km^2)	3	0
Water quality stations (Number per 10^4 km^2)	3	0
Current meters (Number per 10 discharge stations)	1	1.25
Rating facilities for current meters (Number per 200 current meters)	1	0
Repair and maintenance shops for hydrological equipment (Number per 200 discharge stations)	1	0
Water sediment laboratories (Number per 100 sediment stations)	3	0
Water quality laboratories (Number per 100 quality stations)	3	0
Hydrological field teams (2 to 3 persons) (Number per 10 discharge stations)	1	0.83
Special survey teams surface water (3 to 4 persons) (Number per 10^5 km^2)	1	0
Superstructure staff surface water (Number per 100 river discharge stations)	4	-

Note: 1 Assuming the current network of 24 stations with staff gauges only.

The above figures are largely self explanatory but two points deserve noting. Firstly all the 24 stations in the OCP network have had current meter measurements, since it is necessary to know the flow at a station in order to calculate the required chemical dosage. Secondly, there are effectively no staff at the head office working full time on hydrological activities other than those involved in the field teams.

Table 6.4 compares actual staffing with the guideline levels.

TABLE 6.4

Evaluation of Staffing Levels - Hydrology

Item	Number of staff per 100 stations			
	Professional	Technicians		Observers
		Senior	Junior	
Recommended staffing levels				
- Field operations and maintenance	1	5	5	100
- Data processing analysis and interpretation	2	3	3	-
- Supervision	0.5	-	-	-
Total	3.5	8	8	100
Actual staffing levels				
- Field operations and maintenance	8.3	8.3	8.3	0
- Data processing, analysis and interpretation	0	0	0	-
- Supervision[1]	1.67	-	-	-
Total	10	8.3	8.3	0

Note [1] Assuming the Director and his assistant each spend 20% of their time on supervision.

6.3.2 Present Situation

Since the present network was established for one very specific need, the OCP project, it can be assumed that the network meets that need. Where the network is deficient is in providing data for other planning purposes such as hydro-electric power development.

6.3.3 Future Needs

Given the country's present dependence on imported fuel oil for its energy needs it is likely that once the structural adjustment programme has reached a stage where donors are again prepared to invest large sums of money in the country then hydro-electric power generation will be an important area of investment. At present however there is little recent data on river flows available to enable the efficient design of these systems. Most of the schemes which have been proposed in the past have been run of river schemes - the value and frequency of levels of low flow are therefore critical. To estimate these needs a good accurate network which has been well maintained over a number of years. In particular if a river has an unstable bed then, if this is not compensated for by a programme of regular flow gauging, there will be larger proportional errors in the estimation of low flow than of high flow.

The ultimate cost of the hydro-power scheme most likely to be first implemented, Bumbuna, is US$ 250 million. To design such a large scheme with only sketchy hydrologic data involves a large measure of financial risk. The other proposed schemes have a total value of about US$ 150 million. If the expected return from these stations was 10% per annum and this return was improved by only 1%, a very conservative estimate, then an expenditure of US$ 400 000 per year on operational hydrology would be fully justified.

It is also likely that irrigation will be needed in the future, both to make up the shortfall in the country's rice production and to satisfy the food demands of its growing population. This in turn will make demands on hydrological data.

Finally, it is hoped that the situation with regard to urban water supply will be improved by the creation of the Sierra Leone Water Company. When this is done, it may be found that the growth in population since many treatment works were commissioned in the early 1980's will have outstripped supplies which at that time were sufficient. In that case hydrological studies will be necessary to determine whether the river flows are indeed enough to ensure a reliable supply. The situation in Freetown itself is no longer one of abundance - the Guma Valley Dam, the sole source of supply, has not refilled for several years, and there will also be a need to increase the resources available to the capital.

In many cases the problems of operating the direct abstraction water supply systems were exacerbated by the heavy quantities of silt in the river system. So far there is little if any quantitative information on this problem and so data on sediment levels should also be collected.

There is relatively little information on the quality of the water in many of the sources used for supply and a need for a study of the quality of the water used for drinking.

6.4 Hydrogeology

6.4.1 General Assessment

Groundwater in Sierra Leone has been used mainly for domestic water supply. In much of the country, the available quantities with standard abstraction technologies are only sufficient for rural supplies, though in the coastal zone on the Bullom series outcrop conventional wellfields may produce enough water for urban supplies. There may also be technological developments which might allow small scale irrigation. It is in this overall context that this assessment has been made.

In the opinion of the groundwater technical people and the international, bilateral and Sierra Leone Government agencies, the accelerated rural water supply by wells with hand pumps during the UN water supply and sanitation decade has been an unqualified success and has developed sufficient momentum to continue at a similar pace into the 1990s. As demonstration of this success it is often quoted that only 2% of the rural population of Sierra Leone had access to safe water in 1980 and that at the end of the water supply and sanitation decade in 1990 this percentage has risen to 20% (Bicego, 1990).

However, there have been some dissenting voices. Bah et al (1991), who carried out very detailed studies in two small areas (with 30 and 41 dug wells respectively) conclude:

> 'Only 36% of the improved wells surveyed have been in use in the dry season. The rest were either dry or unusable through operational or cultural difficulties.'

Farrant (1990) in a UN appraisal report questions the future of the groundwater industry in Sierra Leone:

> 'This study has revealed that, in spite of the boom in rural water development during the last 3 years, the underlying water supply and sanitation situation in Sierra Leone is sick. In the rural sector, most of the projects which gave rise to the boom are drawing to a close and there are no firm signs of successors to follow. In the urban sector, water supply service has virtually collapsed.'

Farrant ascribes this state of affairs to lack of government investment in the water sector.

Another indicator that all is not well with the rural water supply development in Sierra Leone is that problems of chemical quality of water seem to have been ignored. Dissolved iron concentrations of 5 to 10 mg/l and fluoride concentrations of 5 mg/l are reported without comment; in our experience such iron-rich water is normally not used if any alternative supply is available; more importantly, long-term intake of fluoride-rich drinking water may seriously damage the health of the consumers.

Since groundwater is rightly included in full hydrological assessments of areas, regions and countries, there have always been attempts at defining the desirable density of points for routine data collection and monitoring, comparable to networks of hydrometeorological and hydrometric stations. Unfortunately groundwater resources do not lend themselves to such treatment; their complexity is too great for such simplified treatment and each case should be treated on its own merit. Moreover, when considering staff levels, in Sierra Leone there are three government agencies with groundwater staff, even if two of them are virtually inactive.

The situation in the Republic is compared with the UNESCO/WMO standards in Table 6.5. The WSD is taken as the relevant agency and it should be stressed that the standards refer to groundwater studies unconnected with any particular development project. Some of the requirements estimated using the UNESCO/WMO standards are quite unrealistic; nevertheless the application of these standards offers some clues for a reorganisation of the groundwater service.

TABLE 6.5

Evaluation of Groundwater Data Collection Levels (according to UNESCO/WMO Standards)

Item	Recommended minimum density	Actual density	Additional minimum number required
Groundwater level stations: non-recording (Number per 10^4 km^2)	0.5	0	4
Groundwater level stations: recording (Number per 10^5 km^2)	1	0	1
Groundwater stations measuring hydraulic characteristics (Number per 10^4 km^2)	0.5	0	4
Groundwater quality stations (Number per 10^6 km^2)	3	0	3
Well drilling sets (Number per 10^5 km^2)	2	0	1
Repair and maintenance shops per well drilling sets (Number per 10 drilling sets)	1	0	1
Special groundwater survey teams (each team of 3 or 4 men) (Number per 10^5 km^2)	2	0	1
Superstructure staff groundwater (Number per 100 groundwater monitoring stations)	4	1	3

6.4.2 Present Situation

The main groundwater activity in Sierra Leone at present is the installation of wells under external aid funded rural water supply projects. These projects have been a valuable source of hydrogeological data but the co-ordination of data collection is still poor; no standard procedures or reporting requirements have been used. The required investigatory work is being done by the projects themselves often using different techniques from one another. The data they obtain is not collected by any central agency and is not processed or stored in a convenient form.

There is no formal active organisation responsible for groundwater monitoring, investigation and research. There are no general well design criteria, though dug wells in all projects are of similar design.

Despite these deficiencies the Rural Water Supply Sector has been reasonably successful over the last decade in terms of well/hand pump installation; nevertheless, the situation regarding co-ordination of data collection, investigations of particular areas and research of particular topics, is inadequate and should be improved.

6.4.3 Future Needs

The main use of groundwater in the future will continue to be for rural water supply. Farrant (1990) estimated that further expenditure of US$ 65 million will be required to complete water supply to the rural population. This is certainly a gross underestimate since the actual rural water demand is reported to be considerably higher than the assumed 20 litres per capita and may be expected to grow in the future.

There may also be some scope for groundwater development for urban supplies particularly from the Bullom series in the coastal zone. At present little is known about the distribution of sands within that formation or about the exact position of the fresh/saline groundwater interface. To make this rural/urban water supply more efficient it is necessary to improve data collection from the ongoing rural programmes, undertake the processing and compilation of these data, review the past experience and records as well as the effectiveness of the various projects, carry out regional surveys in areas in which development is to take place, study various relevant topics such as the relation between groundwater occurrence, hydrochemistry, geology and geomorphology, formulate standard procedures and designs, and prepare a water development master plan.

It would also be necessary to do a certain amount of institutional re-organisation and set up a monitoring network for groundwater levels and quality. Thus, the basic needs for the immediate future of the groundwater industry are financial aid and technical assistance for the following:

- a countrywide groundwater study and development master plan;
- setting up and long term observation of a monitoring network;
- institutional reorganisation to allow the efficient execution of the above.

CHAPTER 7

RECOMMENDATIONS

7.1 Introduction

Given the current constraints imposed on Sierra Leone by the structural adjustment programme which, *inter alia*, calls for a reduction in civil service expenditure, it would be unrealistic to propose any project which called for a significant increase in the size of the establishment. Any proposals should therefore aim at maximising the potential level of activity with the current staff. This in itself need not be too severe a constraint. There are enough staff in the Hydrology Unit for two gauging teams; the Meteorological Service has permanent observers at most of its key stations. This level of activity is of course less than the desirable optimum but if all existing staff were working to their full potential it would mark a significant improvement over the present situation. There are certain areas where an extra commitment from the government is called for - and these are detailed below - however these are not felt to be impossibly onerous.

In the following sections recommendations are made to improve the hydrometric data collected to better serve the country's future water development needs. Some of the recommendations are beyond the capacity of the existing bodies and will require outside technical and financial assistance. These recommendations have been grouped into 'packages' which are detailed in Appendix B. In the case of Sierra Leone five such packages have been identified (shown in Table 7.1).

7.2 Rainfall and Climate

7.2.1 Organisational Structure

It appears to us that at the present moment any proposals to change the structure of the Meteorological Service would not be possible - and indeed there is no pressing need to make any such changes. The one area where additional co-ordination is needed is between the LWDD and the Meteorological Service. It does not seem necessary that the stations operated by the two services should be brought under one organisation - indeed it is possible that having two organisations involved with different levels of funding commitment means that one organisation may be able to compensate for shortcomings in the other at different times. It is however obvious that data should be freely exchanged between the organisations, which does not appear to happen on a regular basis at the moment.

TABLE 7.1

Proposed Project Packages

Ref	Title	Executing Agency	Objectives	Total Duration (months)	Inputs (months)			Costs (US$)			Total $
					Experts	Counterparts	Volunteers	Experts	Equipment	Training (1)	
SIL-1	Strengthening the Meteorological Service	Meteorological Service and Land and Water Development Division	To assist in regenerating the climate and rainfall networks	36	24	?	0	592 720	130 000	55 000	777 720
SIL-2	Strengthening the Hydrological Unit	Water Supply Department	To expand the network, set up data processing, and introduce management procedures for the network	48	40		12	981 420	165 000	85 000	1 231 420
SIL-3	Establishment of Water Quality Baseline	Water Supply Department and University of Sierra Leone (Njala Agricultural College)	Establish a network of monitoring points for surface and groundwater for bacteriological and chemical quality	60	18		12	512 000	160 000	55 000	727 000
SIL-4	Groundwater Resource Evaluation and Development Guidelines	Water Supply Department	To produce an overview of groundwater resources and establish standardised guidelines for its development	30	148	204	0	1 290 780	929 233	58 000	2 278 000
SIL-5	Development of Groundwater Monitoring Network	Water Supply Department	To establish a national monitoring network	60	11	189	0	276 580	55 980	8 000	340 560

Notes: (1) The projects have only a small budget for overseas courses because of an emphasis on 'on-the-job' training; up to 80% of the time of the experts will be devoted to training.

7.2.2 Network Size and Density

If all the synoptic, climate and agro-climatological stations that are nominally in operation were fully functional then the network of such stations would be adequate, both in terms of geographical density and the range of variables measured. The main constraints at the moment are lack of funds to import spare parts and replacements for broken equipment, and also a shortage of funds for certain operational support tasks such as the printing of forms for observers. The financial cost of remedying these problems as part of a project would be small but the benefits would be significant.

One area where the network is deficient is in the number of non-recording raingauges. In 1969 there were 22 such gauges, but apart from those operated in the Freetown area by the Guma Valley Water Company there are few, if any, who now regularly send their returns to the Meteorological Service. It should be possible to find organisations who would be prepared to undertake the task of reading a daily raingauge and who could provide staff who could be trained to do this. Again the cost of the necessary equipment would be beyond the resources of the service but if a project was to be launched this need not be a problem. What would be necessary would be facilities for training the observers, for making visits to check that the observers were performing correctly and that the stations had not suffered any problems, eg overhanging trees which rendered their data unacceptable. It would also be necessary to ensure that suitable forms could be printed and despatched to the observers at regular intervals. Observers might be found in water supply installations, at rural airfields, in mining company offices, or at schools or other training institutions. As a minimum the service should attempt to equip and train staff for 50 such sites.

Another area where urgent action is required is to protect the data that have been collected and to store them in a computer compatible medium. To some extent that task has already been started by the DARE and CLICOM projects but it is far from complete. In the case of the DARE project, it had not micro-filmed all the data in the Meteorological Service nor did it include the data from the LWDD. It is also possible that some data is held by observers which has not been transmitted to the Freetown office. The position of the CLICOM project is that equipment has been delivered but that this is in general no longer in a state where it could be used operationally nor where it could be used for further training. Any future project should work closely with these two organisations to avoid overlap of functions and to ensure the security of the existing data as far as possible.

7.2.3 Personnel

The number of staff in the Meteorological Service - while still short of ideal - could be described as adequate. Similarly those staff who were met seemed to be technically well able to perform their tasks. It would not of course be true to say that no future recruitment would be necessary but it would also be unrealistic to suggest that such recruitment should be undertaken at the moment. What is required however is an intensive programme of on-the-job training, perhaps coupled with short specialised courses, to give the staff the chance to get experience which they have been denied by the shortage of funds for equipment and maintenance.

7.2.4 Equipment

The lack of replacements for equipment which is broken or becomes unreliable is one of the biggest problems facing the Meteorological Service. For example one of the stations which is now out of operation was damaged by a bush fire but it has not been possible to replace its equipment. Any future aid should include funds for the replacement of broken equipment by new equipment of the same type. This latter point is most important to maintain continuity of the observational record.

With regard to the computers it is felt that to repair them may be more time consuming and expensive than to replace them. As most of the computers are IBM, and there is an IBM agent in Freetown, repair should however be tried first. After diagnosis of the problem the client is asked to pay for any spare parts necessary which are then imported by the agent from a regional centre in Ghana. The process takes a week. Given the shortage of funds for the import of equipment, the Meteorological Service has not been able to have any repairs carried out.

For the future, careful consideration has to be given to the choice of equipment. If the IBM agent can successfully repair the faulty equipment then it would reasonable to continue with this brand. Given the frequency and duration of power cuts in Freetown it would be sensible to consider the purchase of portable computers with their battery back-up. If extra batteries and chargers were purchased then this would enable almost continuous work to be done using the computers. The power supplies provided for such portable computers - which can handle input voltages from 100 to 240 V- may also give more protection to the computers' internal power supply units than conventional Uninterrupted Power Supply systems, particularly if such a unit is operated in conjunction with a local diesel generator.

Another area where support is necessary is that of communications, both within the country and externally. Within the country the only effective way of communicating data for synoptic forecasts is by radio but many of the transceivers are not working.

As far as external communications are concerned the situation has been aggravated by the recent loss of the relay in Liberia. Whilst it hoped that a stable long-term solution to the difficulties of that country will be found in the future it would perhaps be advisable if Sierra Leone was to have its own independent method of communicating within the WMO's global network. It is understood that the WMO is currently assessing this problem.

At the present moment the weather radar is not fully operational. A large investment has already gone into this equipment, both in terms of the equipment itself and the building and antenna required for it, but it appears that a further substantial sum would be necessary for it to be fully effective. Funds would be required for a study of why the equipment itself is not performing correctly at the moment, the repairs which may be necessary to remedy it, improved power supplies including a generator to enable the radar to operate continuously, specialised training in the use of weather radar for forecasting staff, and specialised training in maintenance for the Service's engineers and technicians. Given the urgent need for investment in other aspects of the Service to maintain basic levels of effectiveness, it may be difficult to justify this additional expenditure.

7.2.5 Maintenance

The task of maintenance is one of the most difficult and most urgent which has to be tackled. The lack of maintenance, resulting from the absence of financial means to purchase foreign equipment, is one of the major factors leading to a decline in the operational efficiency of the precipitation and climate networks in recent years. It would seem appropriate for any project to address this problem by correcting the current equipment problems, providing a stock of spare parts to enable the network to function for some years after the project has ended, and setting aside hard currency for future purchases until the country's development reaches the stage at which it can itself purchase such equipment. In this context the recent attempts of the Meteorological Service to print its own forms and charts and to construct Stevenson Screens should be encouraged.

7.3 Surface Water

7.3.1 Organisational Structure

At present the Hydrological Unit operates within the Water Supply Department of the Ministry of Energy and Power. There seems to be no reason to change this and no obvious alternative for such an arrangement.

7.3.2 Network Size and Density

The network as installed for the OCP project, although conceived with a very specific purpose in mind, none the less gives good coverage to the country's main river systems. At the moment it is unlikely that funds could be found to support any major enhancement of the network - what is important is that this network be used more effectively than it is at the moment and that funds be found to ensure the continuation of the network after the end of the OCP. To this end it is important that the government tries to find the funds to recruit observers able to make observations on at least a daily basis, or even more frequently, for each of the 24 sites. An extension of the network would however be advisable to introduce monitoring of the international rivers, the Great Scarcies, which forms part of the boundary with Guinea, and the Mano River, which forms part of the boundary with Liberia. There have already been studies of hydro-electric development on the Mano River and it is important that the country has its own database to ensure that its interests are adequately served by any arrangement for sharing resources. A station on each of these rivers is recommended.

During the Consultant's visit a proposal for an expanded network of 41 extra stations was presented. It is felt that whilst, in the long term, such a network may be ideal it can not be justified at present. A lot of effort has gone into setting up the present network, including current meter gaugings at all the sites, and the first priority must be to transfer the operation of this network to the Hydrological Unit. When this has been done successfully, and in particular when observers are provided at all the level stations, then it will be possible in the future to look at the expansion of the network.

7.3.3 Personnel

At the moment there is only a limited number of personnel involved in hydrology - one member of staff with an MSc (in Public Health Engineering), one with a BSc and four technicians. This is sufficient for two gauging teams but it leaves no one spare for tasks such as data analysis and participation in water resources studies. After the recruitment of observers the next priority should be recruitment of staff who could form the nucleus of a data processing and analysis section. It would also be useful if at least one person could study for an MSc or equivalent qualification in Hydrology.

7.3.4 Equipment

At present the Hydrology Unit of the WSD has no equipment of its own. All the equipment presently used for hydrological purposes is that provided by the OCP project. It is not clear whether at the end of that project the equipment will be transferred to the national service or whether it will be returned to one of the OCP regional centres. The present indications are that it will not be transferred. Any project would therefore have to start from scratch in terms of provision of equipment.

At the moment all 24 of the OCP hydrological stations have only a gauge board, but five stations will have Argos satellite data collection platforms installed during the course of 1991 although it is not at present known which. This will of course give a better idea of flows, on those rivers where they are installed. It is however recommended that in addition a limited number of stations be equipped with automatic water level recorders. The seven stations suggested for this are : opposite the Liberian town of Mano (where a gauge was operated by the Liberian service for some years); Gofor on the Moa; Lembama on the Sewa; Matotoka on the Pampana; Magburaka on the Rokel; Kunshu on the Mabole and a station on the Great Scarcies at Kambia or Banguria. These sites, except for those on the Great Scarcies and the Mano, have been chosen for their proximity to Makeni and Bo which could be the base towns for two hydrometric teams.

The WSD at present only has a few computers. These are used mainly for text processing and general purposes. It would therefore be necessary for any project to include the purchase of computers and training in their use. The equipment should include not only computers but also digitisers, for transferring information from charts to a computer compatible storage medium, and printers and plotters, for publishing reports. One important task for any data processing service would be to digitise the charts from the network that operated from 1970 to 1976 to safeguard these valuable data.

7.3.5 Maintenance

At present equipment used for the OCP project is returned to one of the regional centres for repair. This applies to all equipment including vehicles and boats, nothing is repaired within Sierra Leone. There is therefore a need to set up a repair and maintenance facility. It is suggested that at the moment this should largely consist of a stock of spare parts for the hydrological equipment rather than a fully equipped workshop.

7.4 Groundwater

7.4.1 Organisational Structure

A certain amount of institutional reorganisation is considered necessary. The main recommendation in this field is that a Hydrogeology Unit is set up within the Department of Water Supply of the Ministry of Energy and Power, with the overall structure shown in Figure 7.1.

Given the present economic situation in Sierra Leone, there would clearly be difficulties in engaging many new personnel to staff the Hydrogeology Unit, but this problem could be at least partially overcome by transferring groundwater staff from the Ministry of Agriculture and Natural Resources and from the Ministry of Mines. There should also be some scope for staff transfers from the Rural Water Supply Unit.

The new unit would need to be equipped for hydrogeological measurements, geophysical survey and drilling. The necessary equipment might be obtained from the JICA assisted Bombali/Kambia Project when this is completed, but financial provision would be necessary for spare parts and consumable materials.

In the field of drilling capability, the Hydrogeology Unit should start with one rig only and limit its drilling to investigations and research. The second JICA rig might be sold to a private interest to set up a local drilling contractor; it is recommended that in the future all drilled well and some dug well construction be done by sub-contract; the exceptions would be those dug wells which are constructed with a large degree of community participation. It should be stressed here that any local organisation involved in drilling must have access to foreign exchange to procure spare parts; without such access, all the machinery under its control will quickly become defunct and suitable only for scrap.

Geophysical equipment for the new unit might be obtained from the same source as the drilling rig, namely the JICA assisted Bombali/Kambia Project, but again foreign exchange would be required to keep it operational. Some hydrogeological equipment might also be inherited from the current rural water supply projects; of particular interest would be the portable chemical laboratories, but these would certainly need to be refurbished with the required chemical reagents.

Regarding a proper water laboratory, the present arrangement between the WSD, the Njala University and UNICEF seems to be working satisfactorily, but the Njala laboratory should be asked to greatly increase the throughput of routine analyses to accommodate the requirements of the Hydrogeology Unit. It may be that it will require more financial support than UNICEF is providing at present.

Some of the early tasks of the Hydrogeology Unit would be to undertake, with outside technical assistance, a countrywide hydrogeological study, a groundwater development master plan, the setting up of a monitoring network, and the setting up of a computerised data bank for well and borehole records.

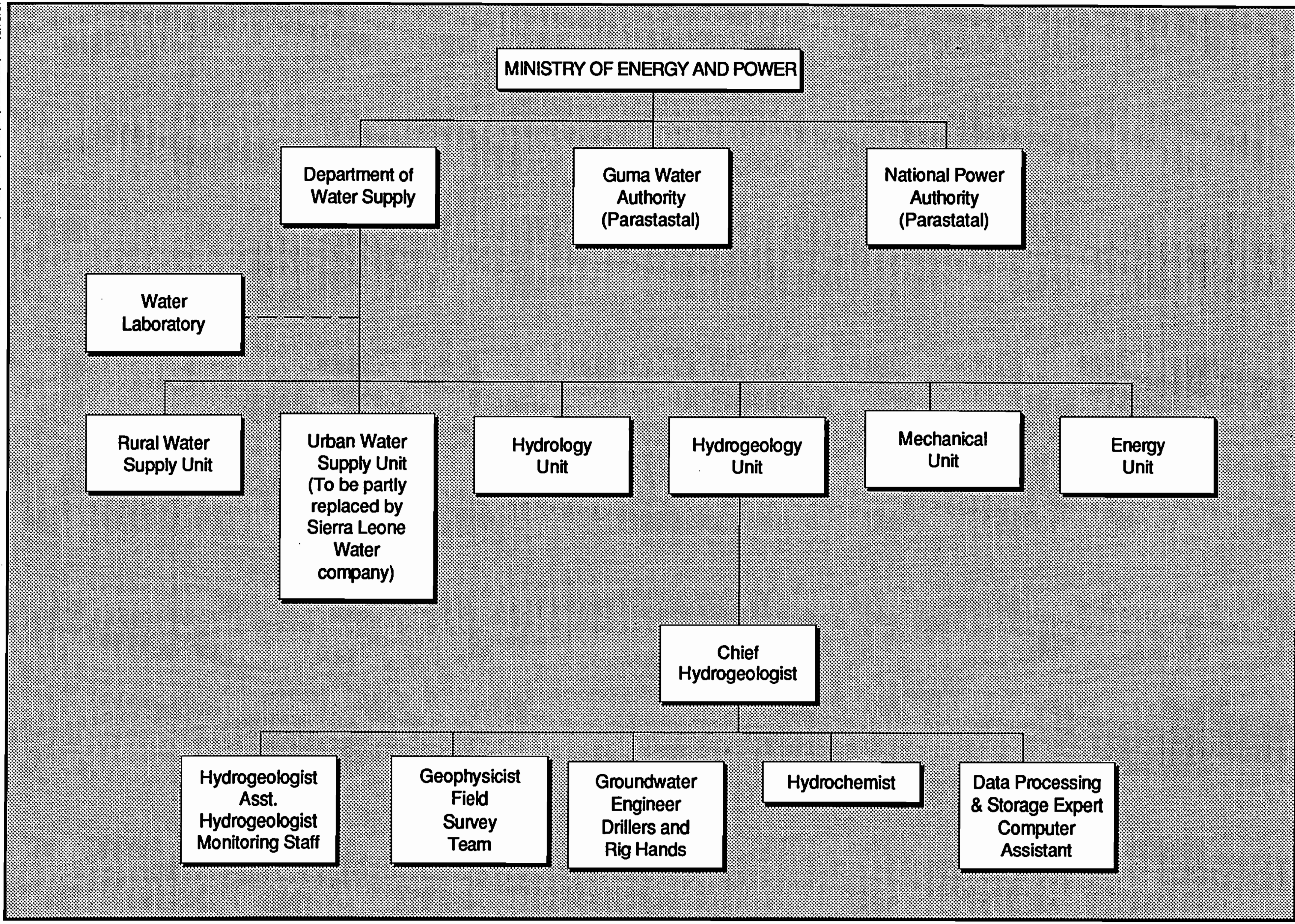
Lastly, it should be mentioned that the reorganisation recommended here is not compatible with the reorganisation of the Rural Water Supply Unit suggested by UNDP (Bicego, 1990) and shown in Figure 5.3. In fact, it is assumed that some personnel would be transferred from the Rural Water Supply Unit to the Hydrogeology Unit. The former's main function would remain the co-ordination of the rural water supply projects and provision of supervisory/liaison staff to that programme.

7.4.2 Network Size and Density

At present there is no groundwater level monitoring network in Sierra Leone, apart from the one well at Relako monitored by the LWDD of the Ministry of Agriculture and Natural Resources. Since providing staff for monitoring network observations is, and is sure to remain, a major difficulty the WSD should try to imitate LWDD's success and, whenever possible, choose monitoring sites at locations where an observer is readily available, as for example near the headquarters of provincial rural water supply projects.

Ideal wells for watertable monitoring are those from which no water is abstracted but which are nevertheless representative of the local conditions. However, these may be difficult to find. If there are no such wells at a convenient location, then measurements can be made in a well which is being used, but at a time when no water has been drawn from it for say, 4 hours (normally the best time is very early in the morning).

According to the UNESCO/WMO guidelines for a country of the size of Sierra Leone, dominated by hard rock geology in a humid climate, the minimum requirement is for five observation stations, four to be measured manually and one to be fitted with a water level recorder. A much more useful target would be ten stations on the Precambrian and Rokel River Series outcrops and another ten in the Bullom Series area. If Bah's (1991) contention that many wells are not being used is correct, suitable points should be easily found, more or less evenly spread throughout the two areas; in areas where no suitable wells exist, special observation boreholes should be constructed.



Recommended Organisation of the Hydrogeology Unit

Figure 7.1

Hydraulic characteristics of aquifers and wells are evaluated on the basis of controlled pumping tests. The two borehole projects have carried out short tests on all successful wells as part of well completion procedures and have done some interpretation of these tests. Fuller interpretation is possible and should be undertaken. The dug well projects (or at least some of them) have not done any pumping tests; in such cases pumping tests should be implemented on suitable existing wells. Though some testing has been carried out on Bullom Series wells (Jalloh, (1979)), gives the results of one such test), because of the complexity of that aquifer system and the occurrence of salt water at depth, it is likely that construction of test wells and full scale pumping tests will be necessary.

As a first estimate it is recommended that:

- full interpretation for aquifer and well characteristics be done on all the boreholes installed under the rural water supply projects;

- about 20 pumping tests be carried out on suitable dug wells spread throughout the rest of the hard rock outcrops and the results interpreted for hydraulic characteristics;

- about 10 wells be installed in the Bullom Series, then test pumped and the data obtained be interpreted by appropriate methods.

The required groundwater quality monitoring network is difficult to define, because of the limited amount of hydrochemical data available at present; a water quality survey of the rural supply wells is urgently required. However, for planning purposes it is suggested that 30 monitoring stations are appropriate, 20 in hard rock areas and 10 in the Bullom Series coastal tract. Initially full chemical analyses should be done but only the parameters either very easy to measure (like EC and pH) or of special interest (eg, chloride, fluoride and iron) should be regularly monitored.

7.4.3 Personnel

The approximate number of staff required for the recommended Hydrogeology Unit have already been listed in Figure 7.1. It is hoped that it would be possible to obtain most of these personnel by transfer of employees from within the WSD as well as from other ministries. However, it is likely that two or three new scientists and/or engineers would have to be engaged.

7.4.4 Equipment

It is hoped that much of the equipment required by the new Hydrogeology Unit can be inherited from some of the completed rural water supply projects. A preliminary list of major items is given below:

- one fully equipped rotary/DTH drilling rig with accessories;
- one compressor (say, 15 kg/cm^2, 25 m^3/min);
- one compressor (say, 10 kg/cm^2, 10 m^3/min);

- one heavy duty truck;
- one water truck;
- five 4-wheel drive pick-ups;
- two test pumps;
- two generators;
- one geophysical borehole logger;
- one set conventional resistivity equipment;
- one set EM (electromagnetic) equipment;
- two portable chemical water laboratories (Hach DREL 5 or similar);
- five EC meters;
- five pH meters;
- four water level indicators;
- 300 m of 150 mm diameter plastic casing;
- 300 m of 150 mm diameter plastic screen.

An attempt has been made to estimate the cost of this equipment, but WSD is much better placed to find out which items might be made available when current projects finish, and which would have to be procured by the new unit.

7.4.5 Maintenance

At present all the equipment used for groundwater development and various associated measurements is in the possession of the rural water supply projects. The projects involving drilling have set up workshop facilities to service and repair drilling rigs, compressors, pumps, generators and transport. It is expected that the Mechanical Unit of the WSD would take over this function in the future.

Once again it should be stressed that to keep the machinery and technical equipment operational, the organisation responsible for the maintenance must have access to foreign exchange so that it can obtain spare parts, any required tools and such consumables as may be needed.

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APPENDIX A

PARTICULAR TERMS OF REFERENCE

APPENDIX A

PARTICULAR TERMS OF REFERENCE

A1 Hydrometeorology

The Consultant shall examine facilities available for the hydrometeorological measurements within the Meteorological Services Department and LWDD of the MANR, and evaluate selected data collected by the organisations to assess their reliability. He shall review existing data transmission facilities and prepare proposals for their improvement. He will then recommend adjustments and/or expansion of the network(s) to cover the entire country. He will also assess the feasibility of limiting the activities in the sector to one of the institutions.

The consultant visited both the Meteorological Service and the LWDD. In both organisations discussions were held at a senior level and with staff who were directly concerned with the data. Attempts were made to visit three climate stations, however the only one visited was that jointly operated by the LWDD and Meteorological Service at Njala. The station at Bo was reported to have been destroyed by fire and the staff from the drilling consultant, based in that town, made enquiries and confirmed that it was no longer functioning. The other site was that at Falconbridge in Freetown; here it was reported that the observer assigned to that station had been unable to work for medical reasons for some months and that a visit would not be useful.

There are no data stored in computer compatible form. To enable a limited check to be carried out data were copied manually from the rainfall data register, entered to a computer, and double-mass curves for five stations were plotted (see Figure 3.5).

Discussions were held concerning data transmission facilities, and the present situation, as it applies both to in-country and international communications, is covered in Section 3.2.2 of the report. Proposals are made in Section 7.2.4. The weather radar installation, mentioned in the 'Background Notes' but not in the 'Particular Terms of Reference', has also been dealt with in the same sections.

The subject of the network(s) is covered in Section 7.2.2. It is recommended that attempts be made to regenerate those climate stations in the network which have recently ceased to function and that efforts be made to recruit extra voluntary rainfall observers. Given the constraints imposed by the current Structural Adjustment Programme it is advised that no expansion of the network should at present be undertaken.

The relative roles of the two organisations who collect climate data, the LWDD of the MANRF and the Meteorological Service, have also been considered. It is felt that there is no pressing need to combine the functions of these organisations. Indeed at a time of financial constraint there could be some advantage in having organisations with budgets from two different ministries. It is however recommended that data be more freely exchanged between the two organisations, such exchange does not appear to happen at present. In the past the Meteorological Service has helped the LWDD by providing replacement equipment. The policy of centralising spare parts for the two services should be continued and this in itself would avoid one of the potential areas of wasted effort and funds.

A proposal for a project to ameliorate the current situation is presented as project SIL-1 in Appendix B.

A2 Surface Water

The Consultant shall review the WHO Report Nr OU/ICP/ODP/106/ON/86 already cited [WHO report by consultant to recommend hydrological network for Onchocerciasis Control Programme] and other relevant information and data to:

- *assess the status of the hydrological network and make recommendations for necessary rehabilitation operations so as to render the network fully operational;*

- *assess the needs for the expansion of the network as to cover the entire country, including the monitoring of surface water flows, swamps, coastal erosion and water quality, and make realistic proposals to this effect;*

- *make recommendations for personnel and material resources necessary to operate the hydrological network covering the entire country. In this regard, the Draft Project Document of 1986 cited above shall be taken into consideration;*

- *make recommendations on the institutional set-up within WSD to continue the activities of the expanded hydrological network.*

Neither the UNDP documentation centre nor the FAO representative in Freetown was able to furnish a copy of the WHO report cited. This is not considered to be a problem as the hydrological network for the WHO's Onchocerciasis Control Programme has already been installed and is in use.

It is felt that the network as installed for the OCP gives adequate coverage of the country's river systems and that, except for two extra stations on those rivers which form part of the boundaries with Guinea and Liberia, no extension of the network should be undertaken. It is however suggested that the WSD recruit permanent observers for all these stations and that automatic water level recorders be installed at a limited number of sites.

The OCP network has 24 stations. The previous network, established by an earlier project in the 1970s, with half that number of stations could not be kept in operation after the project had ended. It would be unrealistic and counter-productive, bearing in mind the financial constraints imposed by the structural adjustment programme, to propose any significant enlargement of the present network.

The one area where institutional change would be advisable would be to set-up a computerised data processing facility within the WSD. This might be done by transferring staff from other units and re-training them if recruitment of new staff should prove to be impossible.

These matters are further discussed in Section 7.3 of the main report and project proposals are detailed in the project SIL-2. The budget for this project is more limited than that of the draft project cited as it is felt that under the present constraints the WSD would be unable to give adequate counterpart support to a large project. Similarly the introduction of a large number of additional stations and automatic water level recorders might result in a network which could not be sustained after the project's end.

It is considered advisable that water quality should be dealt with as a separate project, rather than as a component of another project. Such a project is described in Appendix B as project SIL-3.

A3 Groundwater

The consultant shall:

- *examine the ground water data available in the RWSU and in other institutions, as appropriate; evaluate the data and make recommendations on measures required to fill gaps and weaknesses identified in the data and the method(s) of their collection;*

- *review and make recommendations on the establishment of a centralized system for the compilation and processing of ground water data from all ground water development projects in the country within RWSU;*

- *make recommendations on whether at this stage data collection and processing should apply only to existing ground water development, or whether specific large-scale hydrogeological surveys will be necessary to obtain further ground water data; and*

- *make recommendations for personnel and material resources to operate the centralized groundwater collection and processing system (within RWSU), including proposals for the recruitment and training of personnel.*

These topics are addressed in Chapters 5 and 7.

APPENDIX B

PROJECTS

Country:	Sierra Leone
Date:	February 1991
Project Nr:	SIL-1
Proposed Title:	Strengthening the Meteorological Service
Government Implementing Agency:	Meteorological Service (Ministry of Transport and Communications) and Land and Water Development Division (Ministry of Agriculture, Natural Resource and Forestry).
Estimated Duration:	3 years
Tentative International Contribution:	US$ 777 720
Estimated Counterpart Costs:	To be calculated
Source of Funds:	To be decided

I Development Objective and its Relation to the Country Programme

1 Country Programme

It is one of the country's primary objectives to move towards self-sufficiency in food production. This will mean that its agriculture will have to be more efficient. It has been shown by earlier studies that a network of agro-climatological stations can lead to more efficient agriculture - by, for example, enabling the best seeding and transplanting times to be determined. To optimise agriculture it is also necessary to have a good idea what the evaporative losses are and what the natural rainfall is. For all these purposes it is essential that the country possess a good network of climate and rainfall stations.

2 Project Objectives

At present, due to limited funding, the Meteorological Service, of the Ministry of Transport and Communications, and the Land and Water Development Division (LWDD), of the Ministry of Agriculture, Natural Resources and Forestry (MANRF), are having difficulty in maintaining even a basic network of climatological and rainfall measuring stations. A central problem is that of lack or replacement equipment but this is compounded by faults in data transmission equipment and the lack of a modern computerised system of data collection, quality control and analysis.

The proposed project would tackle all these problems in a systematic way and result in a network which is adequate for the country's needs. The project would also give training in the techniques necessary to enable the service to increase its effectiveness by using computers and other modern techniques.

3 Special Considerations

For several years the economy of the country has been undergoing a structural adjustment programme which has resulted in significant improvements in its balance of payments. The country has also more recently been trying to improve its economic management, particularly in relation to externally financed projects. There are signs that these efforts are beginning to bear fruit and if that is the case then donors, who have been limiting their funding for activities in the country, may once again become more active.

II Major Elements

The project would have two main aims.

The first would be to assemble all the meteorological data which the country has accumulated since the start of this century and to store it in a computer compatible form. This would reduce the danger of the valuable information held on paper forms being lost by deterioration or accidental damage. This aspect of the project would build on those activities already started by the DARE and CLICOM projects of the WMO. It would include provision of suitable equipment and training in the use of computerised data processing.

The second aim would be to regenerate the country's climate and rainfall network which, through a lack of funds in recent years, is now in a parlous state. This component of the project would include the provision of meteorological equipment and spare parts and encourage the country to widen its network of rainfall stations by recruiting voluntary observers.

III Project Strategy

1 Who are the people and/or institutions who would benefit in the first instance from the project's outputs and activities?

The two main organisations who would benefit from the project would be the Meteorological Service and the LWDD. The activities would concentrate on the Meteorological Service but during the course of the project ways would be established in which this service could give appropriate support to the LWDD. This might include, for example, provision of meteorological equipment and data processing of records from the LWDD.

2 Target beneficiaries

At present the country is not self-sufficient in the production of rice, its staple food. There is need for an effective network of climate and rainfall stations to enable the application of methods of agriculture which would increase the efficiency of the agricultural sector. The project could therefore help a wide spectrum of potential beneficiaries.

3 Implementation arrangements for the project

The project would be based at the offices of the Meteorological Service in Freetown but would also work closely with the LWDD. The main office used would be that which houses the computers at present available to the service and which is immediately adjoining the offices of the LWDD who would also participate in the project.

The project would employ two consultants who would spend an initial three months in the country. One of them would make a detailed evaluation of the state of the equipment in the meteorological network and initiate the procurement of new equipment. The second would evaluate the amount of data available to be processed and what the requirements were in terms of computer equipment. Once the equipment had been delivered they would return for a three-month period to, in one case, get the equipment installed and the network operational and, in the second case, give computer training and initiate the procedures for processing the back data.

The total project life would be three years and during that period the consultants would make a number of visits of about one month duration each to help with specific problems.

4 Alternative implementation strategies

One option considered was to have two separate projects - one to set up a data processing system which would initially enter the historic data and then start entering and quality controlling data on a regular basis and a second to regenerate the climate and rainfall network. It was however decided that it would be better to have an integrated approach to these two aspects.

IV Host Country Commitment

1 Counterpart support

The Meteorological Service would be expected to provide office accommodation for the experts and rooms where the computers should be installed and used. They would also be expected to pay for the salaries of field observers.

It is admitted that one of the problems of the previous projects with the Meteorological Service was the lack of suitable counterpart staff. During the consultant's visit staff were however met who appeared to have the necessary background to benefit from the type of project proposed. This matter would have to be clarified before the project started.

Arrangements would also have to be made for the project to have a long transitional phase during which support would be provided in the form of consultancies and provision of spare parts or replacement equipment while the government made arrangements to fully support, in the long term, the activities engendered by the project.

2 Legal arrangements and future staffing

There was not reported to be any major loss of government staff to the private sector. That this was so was due in part to the fact that some staff were able to supplement their government incomes with outside consultancy work while remaining nominally in government service. There is not felt to be a need to introduce legal arrangements to ensure that staff stay in government employ.

V Risks

Care will have to taken to ensure that the problems which resulted in the less than complete success of previous projects are not repeated.

VI Inputs

1 Outline of Inputs

The counterpart organisation would provide two members of staff for training in data processing, two for data analysis and quality control and two for field support. They would also ensure that observers were provided at all synoptic and climatological stations and that data entry operators were available to process the backlog of data.

Two consultants would work in the project. The first would be the Principal Consultant who would be responsible for procuring the equipment needed to re-establish the observational network and training the services staff in field techniques. The second would be responsible for data processing aspects of the project. Both consultants would put in a three-month input at the start of the project and return for missions of varying durations as the project progressed.

A small budget has been included for overseas training but the consultants would be expected to give most of the training themselves in the country. This would take the form both of short courses and on-the-job training. Areas which would be covered would include observational practices and basic and advanced data processing. Specific training in the CLICOM package would be given.

The project would also provide meteorological instruments, partly to replace equipment which had been broken and partly to build up a stock of spare parts. This equipment would be for both the Meteorological Service's network and the Agro-meteorological network under the LWDD. At an early stage in his first mission the data processing expert would decide which of the computers available in the Service would be repaired and what new equipment should be purchased. Consideration should be given to the use of portable computers with battery back-up which would alleviate the problems due to frequent power cuts in the city.

2 Skeleton Budget

Personnel

Item	Duration (months)	Rate (US$/month)	Amount (US$)
Principal consultant	12	20 000	240 000
Data processing consultant	12	16 000	192 000
Flights			70 000
Subsistence			90 720
Sub-total			592 720

Training

Item	Duration (months)	Rate (US$/month)	Amount (US$)
Short courses overseas			25 000
Support to short courses in country			30 000
Sub-total			55 000

Equipment

Item	Duration (months)	Rate (US$/month)	Amount (US$)
Observational equipment			25 000
Computer hardware			30 000
Software			5 000
Communication equipment			50 000
Printing of forms			5 000
Initial stock of computer consumables			5 000
Miscellaneous			10 000
Sub-total			130 000

TOTAL			777 720

3 Policy Issues

It has been admitted that part of the failure of the previous projects was due to a lack of counterpart support. There will have to be clear indication that the government intends to support this project and is in a position to do so before it commences.

Appendix A International Personnel

Consultant in Observational Meteorology

The candidate should have a degree in Meteorology or an equivalent Natural Science from a recognised university. Preference would be given to candidates who also have a postgraduate qualification in Meteorology. The candidate should have at least fifteen years of experience in the use and organisation of meterological networks of which at least five must have been in a position of responsibility. The candidate should also possess experience of work in tropical countries. A good knowledge of English language is required.

In conjunction with counterpart staff the consultant would, during his initial assignment, assess the current state of the network and decide what equipment would need to be procured to bring it to a reasonable operational level. He would also determine what additional stations would be required to give better geographical coverage. During subsequent missions he would help the Meteorological Service to recruit and train observers and to organise their data collection, quality control and dissemination procedures. The first mission would be of three months duration. In the first year three further missions of 1 month each would be carried out. In each of the two following years three missions of 1 month duration would also be undertaken.

Consultant on Data Processing

The candidate should have a degree in Meteorology or an equivalent Natural Science from a recognised university. Preference would be given to candidates who also have a postgraduate qualification in Meteorology. The candidate should have at least 10 years of experience in the use of computers in the processing of meteorological data. The candidate should also possess experience of work in Tropical Countries. In particular the candidate must posses a good knowledge of and experience in the use of the CLICOM data processing package. A good knowledge of English language is required.

In conjunction with counterpart staff the consultant would, during his initial assignment, assess the current condition of the Service's computer equipment and decide what equipment would need to be procured, or what repairs would have to be carried out, to attain a reasonable operational level. During subsequent missions he would help the Meteorological Service to set up a data processing service, to computerise past data, to establish procedures to enter current data on a regular basis and to train staff. The first mission would be of three months duration. In first year three further missions of 1 month each would be carried out. In each of the two following years three missions of 1 month duration would also be undertaken.

Appendix B Training

Item	Amount (US$)
Fellowship in network management	12 500
Fellowship in data processing	12 500
Short course in observational techniques	10 000
Short course in CLICOM	10 000
Support for other training activities (on-the-job training, data entry, etc)	10 000
TOTAL	55 000

Appendix C Equipment

Given the current state of the synoptic/climatological networks the most urgent task would be determine what instruments need replacing and to procure these instruments. It would also be necessary to evaluate the methods of communicating data from the synoptic stations and obtain the necessary transceivers. It is not possible to specify what this equipment would be without a thorough analysis of the present situation. Additional non-recording raingauges will also be needed for an expanded network with voluntary observers.

Similarly it will be necessary to repair and/or procure computer equipment. At present there are only limited facilities for repair of computers in the country and it might be necessary to export and re-import faulty equipment, which could in some cases cost more than replacement equipment. In choosing new equipment consideration should be given to the purchase of portable computers with built-in battery back-up, given the difficulties the country experiences with electricity supplies.

Country:	Sierra Leone
Date:	February 1991
Project Nr:	SIL-2
Proposed Title:	Strengthening the Hydrological Unit, Water Supply Department
Government Implementing Agency:	Water Supply Department, Ministry of Energy and Power
Estimated Duration:	4 years
Tentative International Contribution:	US$ 1 231 420
Estimated Counterpart Costs:	To be calculated
Source of Funds:	To be decided

I Development Objective and its Relation to the Country Programme

1 Country Programme

It is one of the country's primary objectives to reduce dependence on imported oil. This will mean increased use of hydro-electric power. A number of sites have been identified which are believed to be economically viable. There is however a lack of reliable hydrologic data to enable detailed studies to be carried out on the reliability of flows at the chosen sites.

2 Project Objectives

At present the only hydrological data available for studies of hydro-electricity, water supply and irrigation are from a small network of stations operated for some six years in the early 1970s and a more recent network of water level stations set up for the Onchocerciasis eradication programme. The aim of the project is to build on this recent network, which at the moment is not suitable for general hydrologic purposes, to give the country a good network of level and flow measuring stations. The project would also train national staff and provide transport and spare parts, to enable the country to run the network itself for several years.

3 Special Considerations

For many years the economy of the country has been undergoing a structural adjustment programme which has resulted in significant improvements in its balance of payments. The country has also more recently been trying to improve its economic management, particularly in relation to externally financed projects. There are signs that these efforts are beginning to bear fruit and if that is the case then donors, who have been limiting their funding for activities in the country, may once again become more active.

II Major Elements

The main components of the project would be the purchase of a limited amount of equipment and its installation, the setting up of a data processing service and the institution of procedures for running the network on a long-term basis. This would involve a large element of on-the-job training. The project would employ an operational hydrologist, as the Chief Technical Adviser, who would stay in the country for the first year of the project and return at regular intervals over the next three years. The project would also employ a consultant in hydrological data processing.

III Project Strategy

1 Who are the people and/or institutions who would benefit in the first instance from the project's outputs and activities?

The principal beneficiary of the project would be the Hydrological Unit of the Water Supply Department who would, through the project, develop into an effective organisation for the collection and processing of hydrological data. This in turn would bring benefits to other Units of the same Ministry, particularly those concerned with hydropower and with urban water supply.

2 Target beneficiaries

At present the country is experiencing severe problems of electrical supply, due to its reliance on imported oil and the poor state of some of its generating equipment. There are however a number of sites where hydro-electricity could be generated at a lower cost than using oil. To do this efficiently requires good hydrological data. If the schemes were constructed and the data were available the beneficiaries would be those citizens who at present have unreliable electricity supplies or, in many cases, no electric supplies at all. It would also reduce the country's need for foreign exchange to buy the oil, thereby freeing the money for other purposes.

3 Implementation arrangements for the project

The project would be based in the Headquarters of the Water Supply Department in Freetown but one of the aims of the project would be to set up two field teams, based possibly in Bo and Makeni. The Chief Technical Adviser would be responsible, in conjunction with his counterparts, for choosing the sites to receive new equipment, selecting the sites for a limited number of new stations and training the observers to be appointed by the Water Supply Department.

The hydrologic data processing consultant would set up the data processing centre in Freetown, give training in the use of the equipment, initiate the processing of historical hydrologic data and set up procedures for the regular processing of current data.

One of the main elements of the training would be to send someone overseas for postgraduate training in hydrology and a volunteer would be appointed to take his place during his training.

4 Alternative implementation strategies

One option considered was to have two separate projects - one to set up a data processing system which would initially enter the historic data and then start entering and quality controlling data on a regular basis, and a second to build on the existing network of level stations to establish an effective hydrological network. It was however decided that it would be better to have an integrated approach to these two aspects.

IV Host Country Commitment

1 Counterpart support

The Water Supply Department would be expected to provide office accommodation for the experts and rooms where the computers should be installed and used. They would also be expected to recruit and pay the salaries of field observers.

Arrangements would also to be made for the project to have a long transitional phase during which support would be provided in the form of consultancies and provision of spare parts or replacement equipment while the government made arrangements to fully support, in the long term, the activities engendered by the project.

2 Legal arrangements and future staffing

There was not reported to be any major loss of government staff to the private sector. That this was so was due in part to the fact that some staff were able to supplement their government incomes with outside consultancy work while remaining nominally in government service. There is not felt to be a need to introduce legal arrangements to ensure that staff stay in government employ.

V Risks

Care will have to taken to ensure that the problems which resulted in the less than complete success of previous projects are not repeated.

VI Inputs

1. Outline of Inputs

The counterpart organisation would provide two members of staff as counterpart field hydrologists, four technicians for field work, two drivers, one graduate for data processing training in-country, one graduate for an overseas postgraduate course in hydrology and two technician level staff for data entry and digitising charts. They would also ensure that observers were provided at all synoptic and climatological stations and that data entry operators were available to process the backlog of data.

Two experts would work on the project. The first would be the Chief Technical Adviser (CTA) who would be responsible for procuring the equipment needed to enhance the observational network and training the department's staff in field techniques. The second would be responsible for data processing aspects of the project. The CTA would put in a 12-month input at the start of the project and return for further missions as the project progressed. The data processing consultant would start with a 6-month mission and would also return at intervals during the project.

Provision has been made for overseas training but the consultants would be expected to give most of the training themselves in the country. This would take the form both of short courses and on-the-job training. Areas which would be covered would include observational practices and basic and advanced data processing. It is expected that a hydrological data processing package would be purchased and training would be given in its use.

The project would also provide automatic level recorders at six sites and data processing equipment. Consideration should be given to the use of portable computers with battery back-up which would alleviate the problems due to frequent power cuts in the city.

2 Skeleton Budget

Personnel

Item	Duration (months)	Rate (US$/months)	Amount (US$)
Chief Technical Adviser	24	20 000	480 000
Data processing consultant	16	16 000	256 000
Volunteer	12	5 000	60 000
Travel			87 500
Subsistence			97 920
Sub-total			981 420

Training

Item	Amount (US$)
Postgraduate training	30 000
Overseas fellowships	25 000
Support to short courses in country	30 000
Sub-total	85 000

Equipment

Item	Nr	Rate	Amount (US$)
Automatic water level recorders	6	5 000	30 000
Current meters			20 000
Computer equipment			30 000
Software			10 000
Vehicles	2	25 000	50 000
Initial stock of computer consumables			5 000
Initial stock of spare parts and charts			10 000
Miscellaneous			10 000
Sub-total			165 000
TOTAL			1 231 420

3 Policy Issues

There are no specific policy issues to be settled.

Appendix A International Personnel

Chief Technical Adviser in Operational Hydrology

The Candidate should have a degree in Civil Engineering or an Environmental Science from a recognised University. Preference would be given to candidates who also have a postgraduate qualification in Hydrology. The candidate should have at least fifteen years of experience in the use and organisation of hydrological networks of which at least five must have been in a position of responsibility. The candidate should also possess experience of work in tropical countries. A good knowledge of the English language is required.

In conjunction with counterpart staff the consultant would, during his initial assignment, assess the current state of the network and decide what equipment is required to bring it to a reasonable operational level. He would also determine what additional stations would be required to give better geographical coverage. During subsequent missions he would help the Hydrological Department to recruit and train observers and to organises their data collection, quality control and dissemination procedures. The first mission would be of 12 months duration. In each of the three following years four missions of 1 month duration would also be undertaken.

Consultant of Data Processing

The candidate should have a degree in Engineering or an Environmental Science from a recognised University. Preference would be given to candidates who also have a postgraduate qualification in Hydrology. The candidate should have at least 10 years of experience in the use of computers for the processing of hydrological data. The candidate should also possess experience of work in Tropical countries. In particular the candidate must posses a good knowledge of and experience in the use of one or more hydrometric data processing packages. A good knowledge of English language is required.

In conjunction with counterpart staff the consultant would, during his initial assignment, decide what equipment would need to be procured. During subsequent missions he would help the Hydrological Unit to set up a data processing service, to computerise past data, to establish procedures to enter current data on a regular basis and to train staff. The first mission would be of six months duration. In first year two further missions of 1 month each would be carried out. In each of the two following years four missions of 1 month duration would also be undertaken.

Appendix B Training

Item	Amount (US$)
Postgraduate training	30 000
Fellowship in network management	12 500
Fellowship in data processing	12 500
Short course in observational techniques	10 000
Short course in hydrometric package	10 000
Support for other training activities (on-the-job training, data entry etc)	10 000
TOTAL	85 000

Appendix C Equipment

The current network of level stations consists of staff gauges only. It will necessary to procure gauge boards for a small number of new stations, possibly just two on rivers forming the boundaries with Liberia and Guinea, and automatic level recorders on six stations. Given their ease of installation and low maintenance costs consideration should be given to the pressure transducer type of equipment. Current metering equipment would also be procured.

It will be also be necessary to procure computer equipment. In choosing new equipment consideration should be given to the purchase of portable computers with built-in battery back-up, given the difficulties the country experiences with electricity supplies. It will also be necessary to purchase peripherals including digitisers and plotters.

The cost of the computers would be:

Item	Nr	Rate (US$)	Amount (US$)
PC compatible 386 based computers with VGA	3	6 000	18 000
24-pin dot matrix printers	2	750	1 500
Ink-jet laser compatible printer			2 000
A3 size digitising tablet	2	750	1 500
A3 size graph plotter	2	1 250	2 500
UPS system 500VA	3	1 500	4 500
TOTAL			30 000

Country:	Sierra Leone
Date:	February 1991
Project Nr:	SIL-3
Proposed Title:	Establishment of Water Quality Baseline
Government Implementing Agency:	Water Supply Department and University of Sierra Leone (Njala Agricultural College)
Estimated Duration:	5 years
Tentative International Contribution:	US$ 727 000
Estimated Counterpart Costs:	To be calculated
Source of Funds:	To be decided

I Development Objective and its Relation to the Country Programme

1 Country Programme

At present Sierra Leone has one of the highest rates of infant mortality and one of the shortest life expectancies in the world. This is due in no small measure to waterborne diseases. The country is striving to eradicate, or at least reduce the severity of, many of these diseases.

2 Project Objectives

At present there are only limited data available on water quality and there is no central repository of such data. Most of the data on quality have been collected as a component of other projects. The aim of the project would be to set up a number of sampling sites throughout the country covering the main sources of water supply: bored wells, dug wells, streams, rivers and marshes. The quality, both bacteriological and chemical, would be measured at these sites during the initial year of the project and with the assistance of an international expert. Equipment and training would be provided to enable the country to continue monitoring the same sites and parameters on a long term basis.

The project would also look at suspended sediment loads in the river system.

3 Special Considerations

For several years the economy of the country has been undergoing a structural adjustment programme which has resulted in significant improvements in its balance of payments. The country has also more recently been trying to improve its economic management, particularly in relation to externally financed projects. There are signs that these efforts are beginning to bear fruit and if that is the case then donors, who have been limiting their funding for activities in the country, may once again become more active.

II Major Elements

The first aim of the project would be to establish a network of water quality sampling points, chosen to be representative of the country. This would include a number of bored wells of different depths in different strata, dug wells, rivers used for urban water supply, streams used for controlled gravity supplies to village and streams and marshes used for uncontrolled water supplies to villages. The choice of sites would be such that there was a reasonable geographic distribution. Analysis would be carried out at all sites at least four times during the first year and at certain selected sites more frequently. The analysis would cover bacteriological quality (human or animal faecal contamination, other organic matter, etc) and chemical quality. The initial survey would be more intense than that planned for subsequent years as it would be necessary to determine which parameters were most critical and which required the most frequent analysis. A report of the findings would be published.

The next stage of the project would be to continue the survey for a number of years with occasional visits for advice and training. Annual reports on the water quality would be published.

III Project Strategy

1 Who are the people and/or institutions who would benefit in the first instance from the project's outputs and activities?

The initial beneficiary would be the Water Supply Department, who would have a better idea of what were the critical water quality related problems in the country and who would therefore be able to put their own resources and those of donors in this sector to the best use. The laboratory at the Njala Agricultural College would have new equipment and training.

2 Target beneficiaries

At present there are many deaths each year from infantile diarrhoea and other waterborne diseases. These contribute to the high infantile mortality rate and the low life expectancy. If not only the main problems, but also the most effective solutions of those tried in the past, could be more clearly identified then it would be easier to target future rural and urban water supply projects to give the maximum benefit.

3 Implementation arrangements for the project

The project would be based partly in the offices of the Water Supply Department in Freetown but would also work closely with the laboratory at the Njala Agricultural College. During the first two months the project's Chief Technical Adviser would work closely with counterpart staff to identify sites for sampling, to establish a programme of field and laboratory activities and to procure equipment. Then, with the assistance of a volunteer, a series of regular analyses would be performed over a twelve-month period. During a two-month period these results would be assembled, processed by computer and published. In the succeeding years of the project sampling at selected sites and at selected frequencies would be continued by national staff with occasional visits from the CTA to give specialist advice and training.

4 Alternative implementation strategies

One option considered was to have a shorter project with the aim of establishing the baseline water quality analyses at a limited number of sites over a one-year period only. It was considered that the extra cost of providing the equipment and materials for a permanent laboratory and training national staff in their use was relatively small and brings much more long-term benefit to the country.

IV Host Country Commitment

1 Counterpart support

The Water Supply Department would be expected to provide two graduate chemists to work as counterparts during the first year and to continue with the survey on a regular basis in subsequent years. Two Senior Technicians, capable of taking samples and performing basic analyses would also be needed. A further graduate in Chemistry and two laboratory technicians would be required for the Water Quality laboratory at Njala Agricultural University. The University is already involved in water quality analysis and so this would represent an extension of its work.

2 Legal arrangements and future staffing

There was not reported to be any major loss of government staff to the private sector. That this was so was due in part to the fact that some staff were able to supplement their government incomes with outside consultancy work while remaining nominally in government service. There is not felt to be a need to introduce legal arrangements to ensure that staff stay in government employ.

V Risks

No special risks have been identified.

VI Inputs

1 Outline of Inputs

The counterpart organisations would provide graduate chemists and technicians for both laboratory and field work. They would also make available the existing laboratory.

During the first two months the project's Chief Technical Adviser would procure equipment and establish a programme. Over the first year of monitoring he would be closely involved in the sampling and analysis activities making two visits. In the three months following the first sampling year the main activity would be the publication of a report on the activities. Over the remaining life of the project he would visit the project at intervals.

During the first twelve-month sampling period a volunteer would be involved to give on-the-job training during the course of sample collection and analysis. A data processing consultant would be used to establish the computer procedures to be used for setting up a database.

A small budget has been included for overseas training to be given in both laboratory and field sampling techniques but the consultants would be expected to give most of the training themselves in the country. This would take the form both of short courses and on-the-job training. Areas which would be covered would include sampling procedures, laboratory analysis and data processing.

The project would also provide field sampling equipment and laboratory equipment. The field equipment would include equipment for suspended solid sampling and for field analysis of parameters which change rapidly with time. The laboratory component would consist both of equipment, including balances and an oven, and the reagents necessary to perform the tests.

2 Skeleton Budget

Personnel

Item	Duration (months)	Rate (US$/month)	Amount (US$)
Chief Technical Adviser	16	20 000	320 000
Data Processing Consultant	2	16 000	32 000
Volunteer	12	5 000	60 000
Travel			40 000
Subsistence			60 000
Sub-total			512 000

Training

Item	Amount (US$)
Short courses overseas	25 000
Support to short courses in-country	30 000
Sub-total	55 000

Equipment

Item	Nr	Rate	Amount (US$)
Sampling equipment	2	25 000	20 000
Laboratory equipment - chemical analysis			20 000
Laboratory equipment - biological analysis			25 000
Computer equipment			15 000
Printing of reports			10 000
Initial stock of computer reagents			10 000
Four WD vehicles			50 000
Miscellaneous			10 000
Sub-total			160 000

TOTAL	727 000

3 Policy Issues

The project is not thought to raise any policy issues.

Appendix A International Personnel

Chief Technical Adviser in Water Quality Analysis

The candidate should have a degree in Chemistry or Biochemistry from a recognised university. Preference would be given to candidates who also have an appropriate postgraduate qualification. The candidate should have at least fifteen years of experience in the use and organisation of water quality networks of which at least five must have been in a position of responsibility. The candidate should also possess experience of work in tropical countries. A good knowledge of the English language is required.

In conjunction with counterpart staff the consultant would, during his first two months, procure the equipment, select the sites for sampling and establish a programme of field and laboratory work. With an overall eight month input during the next twelve months, and with the assistance of a volunteer, he would supervise and participate in an extensive programme of sampling and analysis. In a further two-month period the results of the survey would be assembled and published. During the remaining life of the project he would return for two one-month visits each year to give additional advice and training.

Volunteer with Water Quality Expertise

The candidate should have a degree in Chemistry or Biochemistry from a recognised university. Preference would be given to candidates who also have an appropriate postgraduate qualification. The candidate should also possess experience of work in tropical countries. A good knowledge of English language is required.

The main role of the volunteer would be to participate in the first year baseline survey of water quality and, with the assistance of the CTA, to give on-the-job training to counterpart staff.

Consultant in Data Processing

The candidate should have a degree in Chemistry, Computer Science or equivalent qualification from a recognised university. The candidate should have at least ten years of experience in the use of computers for the analysis, quality control and processing of water quality data. The candidate should also possess experience of work in tropical countries. A good knowledge of English language is required.

The consultant would visit for one month early in the project to procure the computer equipment and start assembling the data for processing. When the equipment had arrived he would return and the data would be processed by computer and output for printing in the water quality report.

Appendix B Training

Item	Nr	Rate (US$)	Amount (US$)
Fellowship in water quality analysis	2	12 500	25 000
Short course in sampling techniques			10 000
Short course in laboratory techniques			10 000
Short course in interpretation of water quality data			10 000
TOTAL			55 000

Appendix C Equipment

The equipment would consist of laboratory and field equipment for both chemical and bacteriological analysis. For the chemical analysis two 'Hach' kits would be purchased. Equipment would also be purchased for the analysis of sediment including a balance and an oven.

Two vehicles for field sampling would be procured.

The computer equipment would include a laser quality ink-jet printer and graph plotter for report publication.

Country:	Sierra Léone
Date:	February, 1991
Project Nr:	SIL-4
Proposed Title:	Groundwater Resource Evaluation and Development Guidelines
Government Implementing Agency:	Water Supply Department, Ministry of Energy and Power
Estimated Duration:	30 months
Tentative International Contribution:	US$ 2 278 013
Estimated Counterpart Costs:	To be calculated
Source of Funds:	To be decided

I Development Objective and its Relation to the Country Programme

1 Country Programme

In the past, the great majority of Sierra Leone's population relied on untreated surface water for their potable supplies, in an environment where waterborne viral, bacterial and parasitic diseases are rife. Groundwater development offers relatively cheap and technically feasible opportunities for providing safe supplies to the rural population by means of dug and drilled wells with handpumps, and for some towns by means of boreholes with mechanically or electrically driven pumps. During the United Nations Water Supply and Sanitation Decade (1981 to 1990) some 1 800 wells with handpumps have been installed by a series of foreign aid financed rural water supply projects; these have identified a number of hydrogeological, hydrochemical, engineering and social problems, the solution of which would make future development much more efficient. So far only some 20% of the rural population has access to well water. In addition many towns' water supply systems are in need of rehabilitation or replacement and, in some cases, groundwater may provide the optimum alternative.

2 Project Objectives

The primary objective is to produce an overview of the groundwater resource of Sierra Leone and to establish some standardised guidelines for its development, particularly for the currently prevalent use of rural water supply. The present institutional framework of three separate ministries with interest in groundwater but poorly defined responsibilities, will have to be rationalised and the agency most active in the field, namely the Water Supply Department of the Ministry of Energy and Power, should be reorganised to take full control of groundwater related studies, research and development.

The project, successfully completed, should promote increased investment in the water supply sector, particularly from international and bilateral donor agencies.

II Major Elements

- Review all previous work relevant to the hydrogeology and groundwater development in Sierra Leone.

- Collect, compile and collate all relevant data gathered by the rural water supply projects.

- Organise the procurement of the equipment and materials required to attain the project's aim.

- Undertake a partial inventory of wells and springs, and evaluate their usage.

- Carry out hydrochemical survey of water points, particularly in relation to radicles undesirable in drinking water and harmful to health.

- Undertake geophysical surveys for aquifer occurrence particularly in Basement rocks.

- Carry out pumping tests on some of the dug wells installed under the recent rural water supply programmes.

- Establish a computerised database for all well and borehole records.

- Undertake groundwater recharge estimate using the water balance, groundwater discharge to rivers and any other appropriate methods.

- Formulate standard procedures for well site selection in hard rock terrain.

- Compare the suitability and economics of dug and drilled wells for various aquifer conditions.

- Review the performance of different handpumps and recommend optimum types for the future.

- Identify any social constraints to the use of groundwater and wells for potable supplies.

- Organise on-the-job and academic training programmes for counterpart staff.

- Compile all available groundwater data in the form of databases and resource maps.

- Prepare general guidelines for future groundwater development, particularly with respect to rural water supply.

III Project Strategy

1 Who are the people and/or institutions who would benefit in the first instance from the project's outputs and activities?

The initial beneficiary would be the Water Supply Department of the Ministry of Energy and Power. It would attain a higher level of expertise and knowledge of the groundwater resource and development potential, and its planning and search for financing for rural water supply projects would be made considerably easier. In urban water supply for provincial towns, many of which are in urgent need of rehabilitation of the existing water works, the project may suggest alternative sources, the water from which needs only rudimentary treatment for potability.

2 Target Beneficiaries

Water-borne diseases are endemic in Sierra Leone, particularly amongst the rural population. In the past decade the rural water supply situation has been much improved by installation of some 1 800 wells with handpumps, but in some cases the chemical quality of well water may be hazardous to health. Some of the towns are suffering from water shortages because of long neglect of their supply systems, which are in urgent need of rehabilitation or replacement.

The project would start laying the necessary planning foundation for the improvement of this situation, nation-wide. It is probable that safe groundwater based rural supplies can be provided in most areas, but some of the current water supply projects may have identified some hazardous quality groundwater areas, where alternative supplies may have to be provided.

Ultimately the project would improve the quality of life of much of the rural, and some of the urban, population of Sierra Leone.

3 Implementation Arrangements for the Project

The project headquarters would be at the offices of the WSD in Freetown, but many of its operations would be in the field through WSD provincial centres, established for the well installation projects implemented during the last decade.

In terms of equipment procurement (which may be the major cost component), it is planned to take advantage of the machinery and various apparatus to be left behind by the current rural water supply projects, some of which are due for completion in 1991. However, some of the equipment would have to be reconditioned and refurbished and would require spare parts and consumable materials.

The project would be implemented in close co-operation with counterpart staff, possibly members of the proposed Hydrogeology Unit of the WSD, if that proposal is accepted.

4 Alternative Implementation Strategies

The option of procuring the full complement of new equipment and executing the drilling and well testing component of the project by subcontract, rather than taking over the Bombali/Kambia project equipment, were considered and rejected on the grounds of cost. However, these options may have to be considered again, if the ex-JICA equipment does not become available because of an extension of that project or for some other reason.

IV Host Country Commitment

1 Counterpart Support

The Sierra Leone authorities would be expected to set up the recommended Hydrogeology Unit of the WSD, with at least three of the senior staff in post by the third month of the project, or if the reorganisation recommendation is not accepted, to provide at least three graduates in suitable disciplines. In addition two matriculate assistants, two drillers, five drivers and a full complement of unskilled support staff would be required.

If full staffing of the Hydrogeology Unit was available at the beginning of the project, two of the graduates would be sent overseas on post-graduate courses for masters degrees in appropriate subjects.

2 Legal Arrangements and Future Staffing

The legal arrangements between the Sierra Leone authorities, the funding agency and the selected consulting organisation, cannot be specified at present as the funding agency, which is not known at this stage, is likely to have its own rules on this subject.

If the institutional recommendations are implemented, the level of local staffing would be sufficient to undertake the implementation of the project's conclusions. No major losses of government technical staff to the private sector were reported but apparently there is a considerable disparity in pay between civil service and private industry salary. Therefore qualified staff loss from government agencies may be expected if suitable employment opportunities come up in the private sector.

V Risks

1 Factors which may cause delay at the outset of the project

The project is one of a group of national and regional projects proposed as a result of the Hydrological Assessment of West African countries. The planning of all the projects will have to be carefully co-ordinated to ensure that delays in starting one project do not lead to delays in starting other complementary projects.

There is a risk that the Sierra Leone authorities might be reluctant to start a groundwater study in case this might discourage donor investment in rural water supply developments, until the study is completed. This problem should not arise, as there is certainly enough existing information to continue such developments; this study, through an early compilation of past records, would merely aim to make the projects more successful, and would impose a certain discipline regarding data collection procedures and data processing and compilation, to ensure that the chances of attaining the maximum possible success, improve with each completed well.

2 Factors which could over time cause delays or prevent achievement of the project outputs and objectives

As stated above, this project is one of a number of complementary regional and national projects. Meticulously co-ordinated management of the execution of the projects is essential to ensure that the late delivery of outputs from one project does not delay the execution of other projects.

VI Inputs

1 Skeleton Budget

Personnel - International

Designation	Duration of input (months)	Charge rate (US$)	Total (US$)
Project Manager/Hydrogeologist or Groundwater Engineer	30	20 000	600 000
Groundwater Engineer	6	16 000	96 000
Geophysicist	6	20 000	120 000
Database Specialist	6	16 000	96 000
Hydrochemist	3	20 000	60 000
Supervising Hydrogeologist or Groundwater Engineer	2	20 000	40 000
Travel			60 000
Subsistence			122 780
Sub-Total			1 290 780

Personnel - National

Designation	Duration of input (months)
Counterpart Project Manager/Hydrogeologist	30
Geologist/Geophysicist	30
Computer Specialist	30
Hydrogeology Technician 1	28
Hydrogeology Technician 2	28
Geophysics Technician	28

Training

Type of training	Duration (months)	Total cost (US$)
Overseas fellowship MSc in Hydrogeology	12	20 000
Overseas fellowship MSc in Geophysics	12	20 000
Short courses overseas	6	10 000
Support to short courses in Sierra Leone	12	8 000
Sub-total		58 000

Equipment

Item	Amount (US$)
Hydrogeological equipment	665 321
Office equipment	23 000
Miscellaneous	240 912
Sub-total	929 233

TOTAL	2 278 013

2. Policy Issues

The project is not considered to give rise to any major policy issues.

Appendix A International Personnel

Project Manager

The candidate for this post should have a degree in engineering or science from a recognised university and preferably a post-graduate qualification in hydrogeology, groundwater engineering, water resources technology or a related subject. He should also have at least 15 years experience of groundwater work, much of it on groundwater studies in the developing countries, some of them in Africa. Experience in equatorial West Africa would be an advantage and some experience of management of multi-disciplinary projects should be a requirement. In addition, he must have a good command of the English language.

The main duties of the Project Manager would be the direction and quality control of the technical work, co-ordination of the activities in different disciplines, organisation of the required logistic support, ensuring timely submission of all reports, and liaison with the relevant Sierra Leone authorities and the funding agency. In addition he would be expected to organise the various components of the training programme and to take a leading part in the formulation of the master plan for future groundwater development. Lastly, he would also be in overall charge of administrative support to ensure smooth progress of the technical work.

Groundwater Engineer

This post requires a person with a degree in engineering from a recognised university and a post graduate qualification in a groundwater-related subject. He should have at least 5 years relevant experience in the developing countries, preferably in Africa. Familiarity with rural water supply projects, based on wells with handpumps in low permeability aquifers, would be a definite advantage.

Amongst his duties would be the compilation of detailed lists of equipment, spares and material requirements, preparation of documentation for competitive bidding by suppliers, review of well designs used in the past, rationalisation of designs for the future, and review and ranking of suitable handpumps. In addition he would play a major part in the master planning component of the project with regard to recommendations for well design, pump selection and cost estimates of the proposed developments.

Geophysicist

The candidate for this post should have either a geophysics degree, or a geology degree with a post-graduate qualification in geophysics and at least 10 years experience of geophysical surveys, including the application of the resistivity, EM and VLF techniques to groundwater problems. Extensive experience in the developing countries would be essential and familiarity with the Basement aquifers in Africa would be very advantageous.

The Geophysicist's duties would be concerned mainly with two topics:

- the distribution of fresh and saline groundwater in the Coastal Bullom Series;
- the application of geophysical methods for siting of rural water supply wells.

Conventional resistivity surveys are normally applied to problems of the first kind. For those of the second kind, the standard geophysical package is EM traversing, sometimes assisted by VLF, followed by vertical resistivity soundings on promising anomalies.

Database Specialist

The candidate for this post should have a science, mathematics or engineering degree from a recognised university and at least 5 years experience of computer work on databases (including digital mapping and graphic output) and hydrogeological or hydrological modelling. Experience in the developing countries, particularly in Africa, would be an advantage.

His initial task would be to help with the procurement of hardware and software for the setting up a computerised data bank for borehole and well records. Later he would be expected to adopt commercial software to develop a user-friendly database with a digitised mapping option and good output graphics. He would then undertake (with the help of the support staff) the storage of all available well and borehole records some data processing options should be linked with the database, with the master planning of groundwater resources development in view.

Hydrochemist

This expert should have a chemistry degree from a recognised university and at least 15 years relevant experience. A postgraduate qualification in a water related subject would be an advantage. Some of his experience should be in the developing world. Familiarity with the hydrochemistry of low permeability aquifers in the wet tropics would be a great advantage.

During his first visit to Sierra Leone, the Hydrochemist would be expected to review the analytical facilities available in Sierra Leone, particularly the laboratory at the Njala Agricultural University and evaluate any additional requirements to undertake the project's water analyses. He would also assess the results of past analyses with regard to consistency and completeness from the point of view of potability. During later visits he would evaluate the project's work and prepare reviews of groundwater quality, to be incorporated in project reports. Groundwater quality may be one of the main constraint to development and he would assess its importance for the master plan.

Supervising and Specialist Supporting Staff

The candidate for the Supervising Hydrogeologist/Groundwater Engineer should be a graduate with more than 15 years' relevant experience, including experience of rural water supply projects in Africa. Familiarity with the particular problems of equatorial West Africa would be an advantage.

Their inputs would be in the form of short visits and their function would the direction, supervision and support of the resident team.

Appendix B Training

There is a great need to expand the level of available expertise in groundwater-related disciplines in Sierra Leone and the project's training programme would concentrate on this objective. The programme would include postgraduate academic training and short courses abroad, and training seminars in Sierra Leone.

Two of the graduate counterparts would be sent abroad to a recognised institution to do masters degrees in hydrogeology and groundwater engineering or geophysics or another related subject. All such MSc courses are normally of 12 months duration.

Three others of the local professional staff would go abroad to attend short courses on subjects such as water chemistry, rural water supply and sanitation, and computerised data storage, processing and retrieval. In addition, on-the-job training would be undertaken by the project in Sierra Leone, supported by talks, lectures and demonstrations by the international staff.

Appendix C Equipment

An extensive list of equipment to be procured for this project is given below. It is hoped that much of this equipment would be inherited from the currently on-going rural water supply projects, which are due for completion in 1991 and early 1992. If this were not possible, then many of the required items would have to be procured by international competitive bidding (ICB), for which specification and contract documents would have to be prepared, bids obtained and evaluated, best offers accepted and delivery periods (in some cases at least 6 months) allowed for. Consequently it is crucial to establish if the preferred scheme of obtaining the required equipment is feasible as soon as possible; if it is then accessories, spares and consumable could be obtained quickly by prudent shopping (PS).

It is proposed that the required computing equipment should also be procured by PS, keeping in mind its compatibility with the hardware and software already used by the WSD and that to be procured by other projects in Sierra Leone, arising from this Hydrological Assessment. This project's requirement is for both hardware and software, including processors, plotters, printers and digitisers as well as commercially available programs such as database, spreadsheet, word processing, hydrochemistry, test well interpretation and other packages.

Equipment item	Quantity	Unit cost (US$)	Total (US$)
Drilling rig, rotary/DTH with accessories*	1	200 000	200 000
Compressor 250 psi 820 cfm*	1	83 600	83 600
Compressor 170 psi 360 cfm*	1	28 160	28 160
Heavy duty truck*	1	61 000	61 000
Flat-top water truck*	1	61 000	61 000
FWD pick-up*	5	18 128	90 640
Electric submersible pump max discharge 20 l/s, head 20m	1	2 500	2 500
Electric submersible pump* max discharge 5 l/s, head 30m	1	1 530	1 530
Generator 5 kW	1	2 400	2 400
Generator 15 kW*	1	6 100	6 100
Geophysical borehole logger*	1	52 800	52 800
Resistivity equipment*	1	21 120	21 120
EM-equipment*	1	19 300	19 300
Portable chemical water laboratory (Hach DREL 2 000)*	2	4 330	8 660
pH meter	5	405	2 025
EC meter	5	510	2 550
Water level indicators* 100 m	4	440	1 760
Computing equipment: includes 1 laptop, 1 desktop, printer, power supply, software	1	23 000	23 000
150 mm dia UPVC casing, flush jointed 5.8 m lengths	52 x 5.8 m	167	8 684
150 mm dia UPVC slotted screen, flush jointed 5.8 m lengths	52 x 5.8 m	221	11 492
Sub-total			688 321
Spare parts, etc 20% of total			137 664
Contingencies, 15% of total			103 248
Sub-total			929 233

Note: * It is hoped that these can be obtained from the current rural water supply projects.

Country:	Sierra Lėone
Date:	February 1991
Project Nr:	SIL-5
Proposed Title:	Development of a Groundwater Monitoring Network
Government Implementing Agency:	Water Supply Department, Ministry of Energy and Power
Estimated Duration:	5 years
Tentative International Contribution:	US$ 372 560
Estimated Counterpart Costs:	To be calculated
Source of Funds:	To be decided

I Development Objective and its Relation to the Country Programme

1 Country Programme

In pursuance of the aim of the UN Water Supply and Sanitation Decade to provide everybody with access to safe water the Government of Sierra Leone, with the aid of external donors, has undertaken large scale construction of dug and drilled wells in rural areas. During the Decade some 1 800 wells with handpumps have been installed and some old wells rehabilitated, providing supplies to about 20% of the rural population; the rest still use surface water mainly from streams, creeks and ponds, resulting in a high incidence of serious waterborne diseases.

Groundwater from wells is the cheapest and quickest way of providing alternative supplies to villages; such water is bacteriologically safe, though in some areas the chemical quality may be a problem. Nevertheless, groundwater-based rural supply development is sure to continue; in addition some of the urban supplies, which are in urgent need of rehabilitation, may also be most conveniently obtained from wellfields.

2 Project Objectives

The primary objective is to establish a groundwater monitoring network in Sierra Leone which will make further groundwater development easier and will identify any negative physical consequences arising from the completed programmes. Regular country-wide measurements of groundwater levels will allow better design of future wells and should help to identify any local or regional depletion of the resource; the latter would be particularly important if significant abstraction from the Bullom Series aquifer are implemented for urban supplies. In addition the monitoring of water quality from pumped wells, will determine if chemical changes are common and need attention, as well as the frequency of biological contamination and of requirements for treatment by disinfection.

Such monitoring data is most important from the point of view of the optimum formulation of the design, operation and maintenance of groundwater abstraction facilities. Consequently, a properly set up and observed monitoring network should allow better and cheaper well design and should promote donor interest in groundwater development.

II Major Elements

- Review all previous work relevant to the hydrogeology of, and groundwater development in Sierra Leone.

- Discussions with the rural water supply projects regarding suitable monitoring points in their areas.

- Selection of existing disused wells for water level monitoring.

- Selection of existing pumped wells for water quality monitoring.

- Construction of observation wells for water level monitoring, where there are not suitable existing wells.

- Formulation of a detailed monitoring plan regarding which measurements are to be made, at what frequency, and who is to make them.

- Implementation of the monitoring plan for five years.

- Compilation, processing and convenient storage of the monitoring data.

III Project Strategy

1 Who are the people and/or institutions who would benefit in first instance from the project outputs and activities?

The initial beneficiary would be the Water Supply Department of the Ministry of Energy and Power. It would build up a better understanding of the groundwater resource and obtain important data for the design, operation and maintenance of abstraction facilities.

2 Target Beneficiaries

Since the aim of the monitoring is better design, operation and maintenance of water supply systems, clearly the ultimate target beneficiaries are the people of Sierra Leone. Groundwater based supplies are certain to play a larger role in rural areas than in towns and cities. Consequently the main beneficiary will be the rural population of the Republic.

3 Implementation Arrangements for the Project

Monitoring of water levels and quality is the most neglected part of groundwater studies virtually all over the world. The difficulty is in getting local, often casual, staff who do not understand the importance of the measurements they are asked to make, to meticulously measure and record water levels in wells at fortnightly or monthly intervals. The payment for these activities is always small and observers often forget that a measurement is due on a particular date; in such cases there is a great temptation to invent a reading, usually similar to the previous one.

In the case of groundwater quality monitoring some relatively complex measurements have to be made on site and trained personnel are essential. Trying to run a monitoring system from a head office in Freetown, such staff would have to spend most of their time travelling all over the country; in Sierra Leone with poor roads and shortages of petrol a monitoring system relying on such a centralised observer service is probably impracticable.

Because of these difficulties, it is proposed to make the maximum use of the regional outposts of all water related agencies, but particularly of the rural water supply projects, all of which are nominally under the jurisdiction of the Water Supply Department, the implementing agency for this project. It is recommended that at the planning stage, the availability of observers is kept firmly in mind. Thus, as far as possible, monitoring points are chosen near to an on-going project base and in areas which are routinely visited by their staff. There may also be groundwater monitoring points near meteorological or river gauging stations, regularly visited by staff (in the former case staff from another ministry), who can be trusted to make routine measurements properly.

The main problem with this approach is that at least some of the rural water supply projects may not have long to run, but it is strongly recommended that any project with one year or more until scheduled completion be used for monitoring purposes; even one year of monitoring data for a particular point would be useful and there may be project extension, or a viable alternative may emerge for undertaking the necessary measurements. It is considered that these suggested arrangements give the monitoring project the best possible chances of success.

4 Alternative Implementation Strategies

An alternative strategy for the implementation of the project to that outlined above, would be to construct the required number of special observation wells and set up a full monitoring service which would make the necessary measurements at appropriate time intervals. This options would be much more expensive and would have less chance of being fully successful. Therefore it is not recommended for the immediate future.

However, it is possible that once the proposed monitoring project develops sufficient momentum, such a full monitoring service will become more viable and may be implemented.

IV Host Country Commitment

1 Counterpart Support

This project would be implemented largely by the newly set up Hydrogeology Unit of the Water Supply Department (if the recommended reorganisation is implemented by the WSD). It is proposed that maximum possible use should be made of existing staff resources of water related agencies (public or private) to make the actual measurements, but the full time commitment of one hydrogeologist and part-time participation of the data processing and storage section would be required. In addition the facilities of the water laboratory should be made available to the project to undertake analyses of about 30 water samples per month.

Supporting staff would include one or two matriculate assistants and one driver; it is anticipated that only casual participation of unskilled staff would be required.

2 Legal Arrangement and Future Staffing

The legal arrangements between the Sierra Leone authorities, the funding agency and the selected consulting organisation, cannot be defined at present as it will depend on the source of funding and other factors not yet known.

Though there is a considerable disparity in pay between the civil service and the private sector, there are limited opportunities for trained staff in groundwater-related disciplines; consequently no staff loss from the proposed monitoring service is anticipated.

V Risks

1 Factors Which May Cause Delay at the Outset of the Project

The project is one of a group of national and regional projects proposed as a result of the Hydrogeological Assessment of West African countries. The planning of all projects will have to be carefully co-ordinated to ensure that delays in starting one project do not lead to delays in starting other complementary projects.

In this particular case, it is important that this project is closely co-ordinated with the proposed groundwater study, as the latter is expected to undertake the construction (drilling) of some of the required monitoring points, particularly some of those located on the Bullom Series aquifer.

2 Factors which could over time cause delays or prevent achievement of the project outputs and objectives

As stated above this project is one of a number of complementary regional and national projects. Meticulously co-ordinated management of the execution of all the projects is essential to ensure that the late delivery of outputs from one project does not delay the execution of other projects.

VI Inputs

1 Skeleton Budget

Personnel - International

Designation	Duration of input (months)	Charge rate (US$)	Total (US$)
Chief Adviser	6	20 000	120 000
Data Processing and Storage Specialist	5	16 000	80 000
Travel			35 000
Subsistence			41 580
Sub-total			276 580

Personnel - National

Designation	Duration of input (months)	Charge rate (US$)	Total (US$)
Hydrogeologist	60		
Computer Specialist	15		
Monitoring Assistant 1	60		
Monitoring Assistant 2	54		

Training

Support to short course in Sierra Leone US$ 40 000

Equipment

Hydrogeological equipment US$ 55 977

TOTAL	372 560

2 Policy Issues

The project is not considered to give rise to any policy issues.

Appendix A International Personnel

Chief Adviser

The candidate for this post should have a science or engineering degree from a recognised university and at least 15 years of relevant experience, mainly in developing countries. Some experience of the hydrogeology of the Basement aquifers in Africa would be essential and familiarity with groundwater in equatorial Africa would be a definite advantage. The Adviser should have a good knowledge of the English Language.

During his first visit he would be expected to select the monitoring network together with the local hydrogeologist in charge of the project. On his subsequent visits he would review the monitoring records each year and the processing of these records, and prepare a short annual report incorporating most of data collected.

Data Processing and Storage Specialist

This post would require a graduate from a recognised university with at least five years experience of the application of computing techniques to data processing and storage. Some experience in the developing countries, particularly in Africa, would be very advantageous.

His main task during his first visit would be to establish the procedures for the monitoring data processing and storage, and the format of output to be incorporated in the annual reports. On later visits he would assess the success of the procedures, implement modifications if necessary, and assist with the preparation of the annual reports.

Appendix B Training

The training programme associated with this project would involve both the observers and the data processors and interpreters. Though as mentioned before, in the first category it is proposed to make sure of personnel of the various water related projects to implement the necessary measurements, some explanations of the purpose of monitoring are thought to be necessary. It is therefore proposed to organise seminars for that purpose.

Training for senior local staff would concentrate on the use of the computerised database, presentation of data and interpretation of results. This would be in the form of short courses, if possible associated with the training programmes of other projects arising from this hydrological assessment.

Appendix C Equipment

The list of equipment required to implement the necessary measurements of the monitoring network is given below. It should be noted no computer hardware or software has been included; it is assumed that one of the other projects recommended by this report would have sufficient spare capacity to provide computer facilities to this project.

Equipment item	Quantity	Unit cost (US$)	Total (US$)
Water level indicators	20	440	8 800
Autographic water level recorders	4	2 464	9 856
Portable chemical laboratories (Hach OREL 2000)	2	4 330	8 660
Kits for detection of bacteria	2	2 970	5 940
50 mm dia UPVC casing, flush jointed, 2.85 m lengths	106 x 2.85 m	53	5 618
50 mm dia UPVC slotted screen, flush jointed, 2.85 m lengths	35 x 2.85 m	74	2 590
Sub-total			41 464
Spare parts etc 20% of total			8 293
Contingencies 15% of total			6 220
Sub-total			55 977

APPENDIX C

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APPENDIX C

BIBLIOGRAPHY

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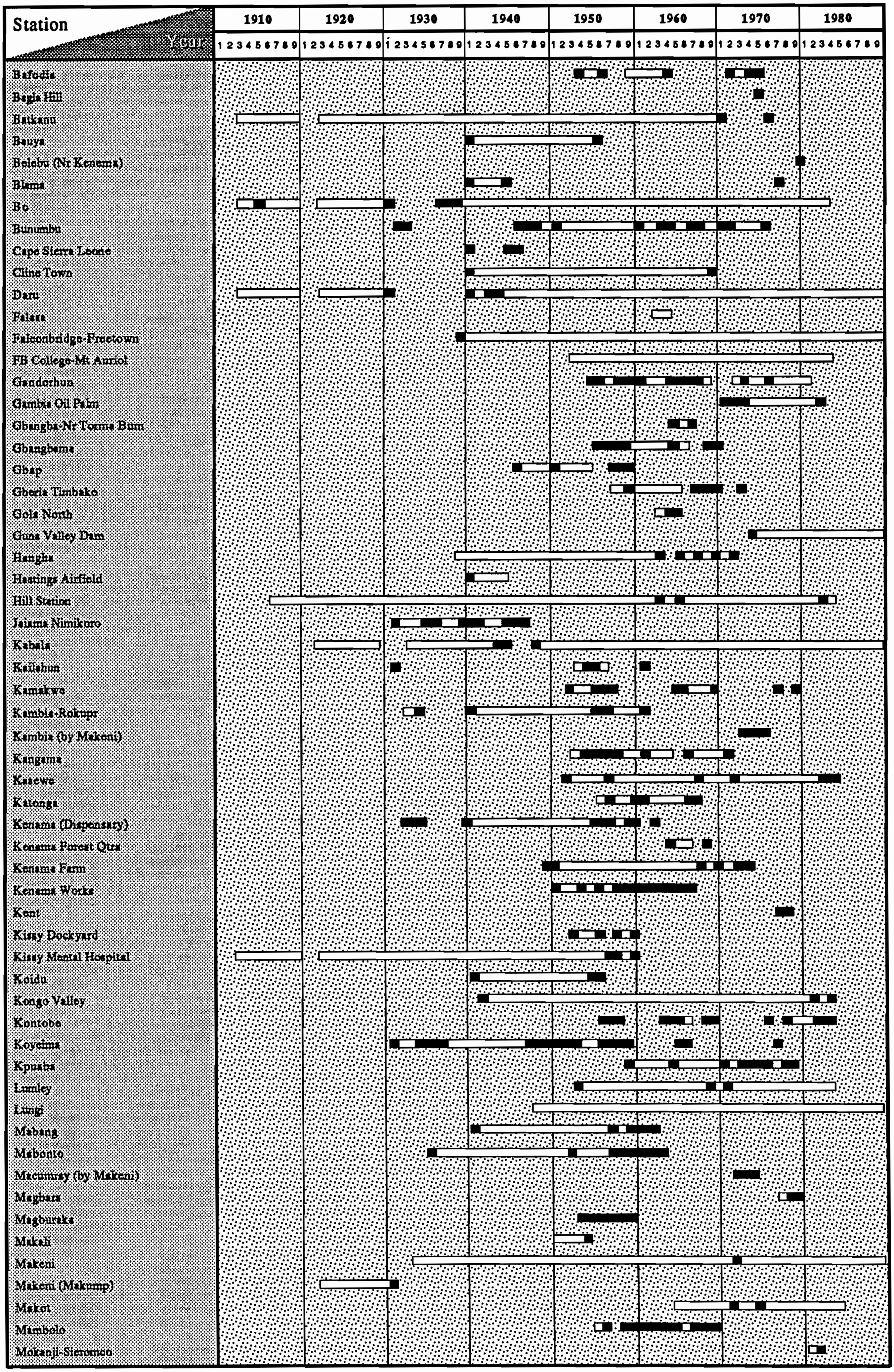
APPENDIX D

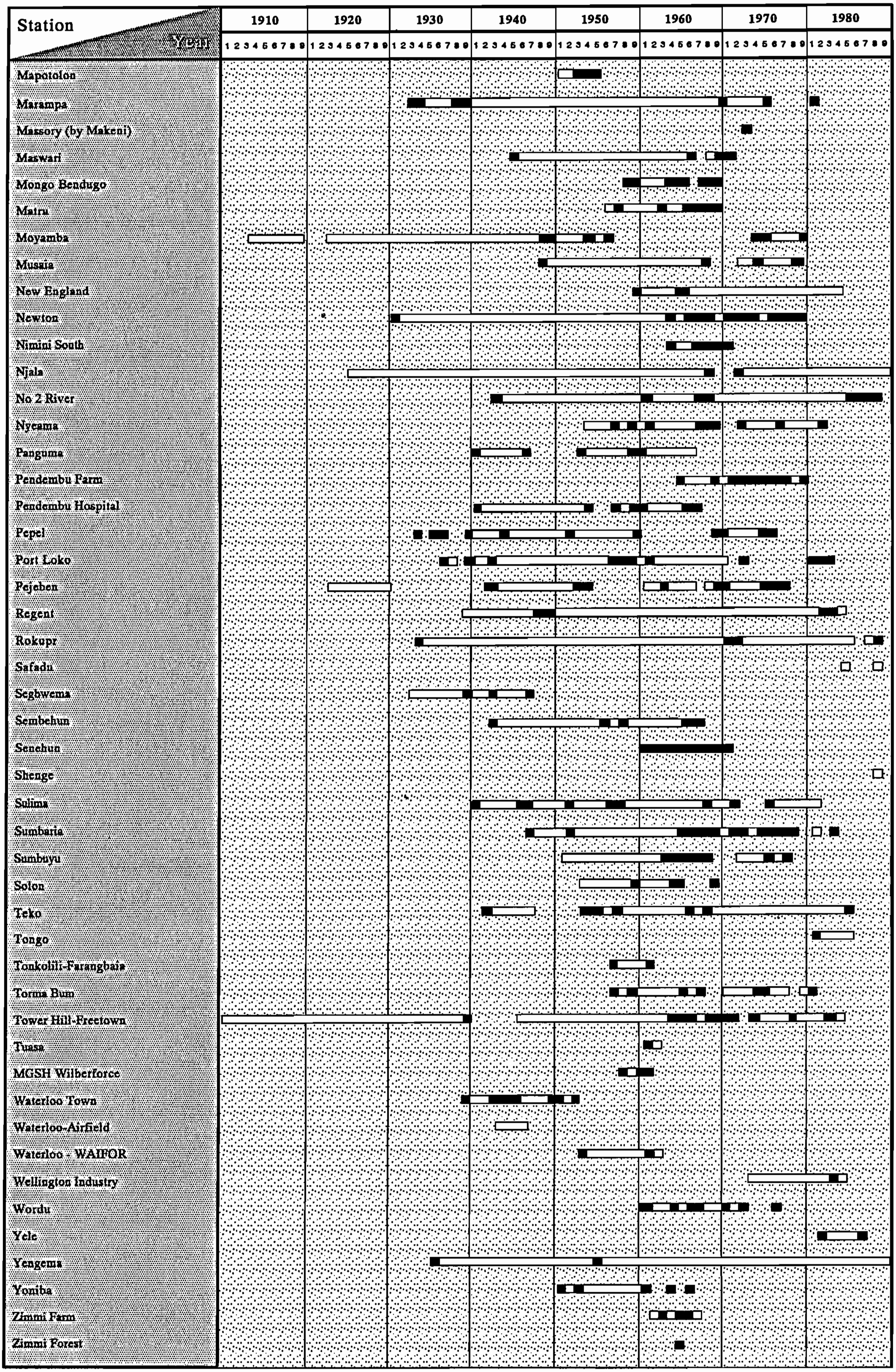
RAINFALL STATIONS AND THEIR PERIODS OF OPERATION

Notes

This appendix shows all the rainfall gauges which have operated in Sierra Leone, including those sited at climate stations. All of the gauges are read daily. In the following bar charts a white bar indicates that the record is complete for the year at the station, a black bar indicates that there are gaps in the data record for the year.

Appendix D - Part A

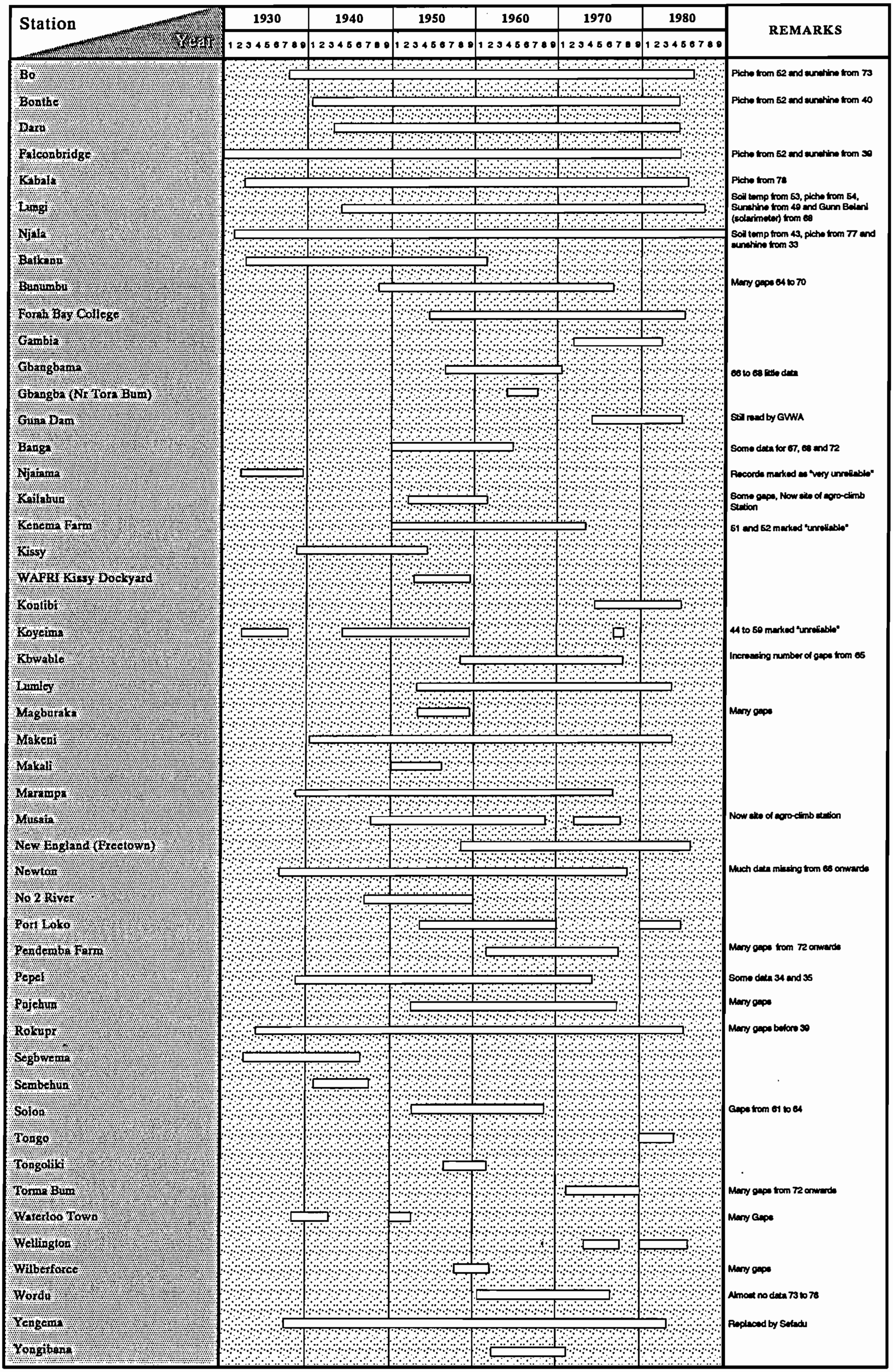



Station
Year
1910
1920
1930
1940
1950
1960
1970
1980
Mapotolon
Marampa
Massory (by Makeni)
Maswari
Mongo Bendugo
Mairu
Moyamba
Musaia
New England
Newton
Nimini South
Njala
No 2 River
Nyeama
Panguma
Pendembu Farm
Pendembu Hospital
Pepel
Port Loko
Pejeben
Regent
Rokupr
Safadu
Segbwema
Sembehun
Senehun
Shenge
Sulima
Sumbaria
Sumbuyu
Solon
Teko
Tongo
Tonkolili-Farangbaia
Torma Bum
Tower Hill-Freetown
Tuasa
MGSH Wilberforce
Waterloo Town
Waterloo-Airfield
Waterloo - WAIFOR
Wellington Industry
Wordu
Yele
Yengema
Yoniba
Zimmi Farm
Zimmi Forest

APPENDIX E

CLIMATE STATION INVENTORY

Appendix E


Station
Year
1930
1940
1950
1960
1970
1980
REMARKS
Bo
Piche from 52 and sunshine from 73
Bonthe
Piche from 52 and sunshine from 40
Daru
Falconbridge
Piche from 52 and sunshine from 39
Kabala
Piche from 78
Lungi
Soil temp from 53, piche from 54, Sunshine from 49 and Gunn Belani (solarimeter) from 68
Njala
Soil temp from 43, piche from 77 and sunshine from 33
Baikanu
Bunumbu
Many gaps 64 to 70
Forah Bay College
Gambia
Gbangbama
66 to 68 little data
Gbangba (Nr Tora Bum)
Guma Dam
Still read by GVWA
Bauga
Some data for 67, 68 and 72
Njaiama
Records marked as "very unreliable"
Kailahun
Some gaps, Now site of agro-climb Station
Kenema Farm
51 and 52 marked "unreliable"
Kissy
WAFRI Kissy Dockyard
Kontibi
Koyeima
44 to 59 marked "unreliable"
Kbwable
Increasing number of gaps from 65
Lumley
Magburaka
Many gaps
Makeni
Makali
Marampa
Musaia
Now site of agro-climb station
New England (Freetown)
Newton
Much data missing from 68 onwards
No 2 River
Port Loko
Pendemba Farm
Many gaps from 72 onwards
Pepel
Some data 34 and 35
Pujehun
Many gaps
Rokupr
Many gaps before 39
Segbwema
Sembehun
Solon
Gaps from 61 to 64
Tongo
Tongoliki
Torma Bum
Many gaps from 72 onwards
Waterloo Town
Many Gaps
Wellington
Wilberforce
Many gaps
Wordu
Almost no data 73 to 76
Yengema
Replaced by Sefadu
Yongibana

APPENDIX F

HYDROMETRIC STATION INVENTORY

Detailed Specification of Fields in the Hydrometric Station Inventory

Type (Field Nr 7)

S	Structure eg, weir, flume
C	Open channel
D	Dam (reservoir water balance to establish inflows)

Equipment (Field Nr 8)

1	Staff gauge only
2	Automatic water level recorder only
3	Staff gauge plus automatic water level recorder

Observer (Field Nr 9)

Y/N	observer present

Gaps (Field Nr 12)

Where details of the data record are available the periods with observations are shown as paired open and close dates (yymmyymm) so that the record for station 4 the Mabole at Kunshu there are gaps between April 1976 until March 1988.

Discharge (Field Nr 13)

1	Low flows only
2	Full range of flows

Rating (Field Nr 14)

1	Stable
2	Unstable
3	Affected by backwater
4	Combine 2 and 3

Sediment Measurement (Field Nr 15)

Y/N	Any sediment data, either suspended, bed or total load

Water Qualtiy (Field Nr 16)

Y/N	Any water quality sampling

NUMBER	BASIN	RIVER	STN_NAME	LATITUDE	LONGITUDE	TYPE	EQUIP -MENT	OBS.	YEAR OPENED	YEAR CLOSED	GAPS	DISCHARGE	RATING	SEDIMENT	WATER QUAL.
1	Little Scarcies or Kaba	Kaba	Outamba	9x35'N	12x10'W	C	1	N	1988	-		2	1	0	N
2	Little Scarcies or Kaba	Kaba	Kaba Ferry	9x35'N	12x13'W	C	1	N	1988	-		2	1	0	N
R2	Little Scarcies or Kaba	Kaba	Mange	8x55'N	12x49'W	C	1	-	1972	1976		0	0	0	N
3	Little Scarcies or Kaba	Mongo	Musaia	9x46'N	11x36'W	C	1	N	1975	-		2	1	0	N
4	Little Scarcies or Kaba	Mabole	Kunshu(Mabole)	8x58'N	12x06'W	C	1	N	1975	-	7508760388049101	2	1	N	N
5	Little Scarcies or Mabole	Mabole	Mabanta	9x01'N	12x37'W	C	1	N	1988	-		2	1	N	N
R6/6	Rokel	Seli	Arfania(Badala)	9x19'N	11x32'W	C	1	N	1970	-	7006760388029101	2	1	N	N
7	Rokel	Seli	Bumbuna	9x02'N	11x45'W	C	1	N	1970	-	7005760388049101	2	1	N	N
8	Rokel	Seli	Magburaka	8x44'N	11x57'W	C	1	N	1988	-		2	1	N	N
9	Rokel	Seli	Marampa	8x40'N	12x27'W	C	1	N	1988	-		2	1	N	N
R6-1	Rokel	Seli	Mador	9x03'N	11x43'W	C	1	N	1975	1976		0	1	N	N
11	Sewa	Bagbe	Yifin	9x07'N	11x15'W	C	1	N	1988	-		2	1	N	N
12	Sewa	Bafi	Yima Ferry	8x41'N	11x09'W	C	1	N	1988	-		2	1	N	N
R13/13	Sewa	Sewa	Njaiama-Sewafe(Sewa)	8x34'N	11x16'W	C	1	N	1971	-	7107760389049101	@	1	N	N
R16	Sewa	Moboa	Doda	8x09'N	11x09'W	C	1	N	1972	1976		2	1	N	N
R15	Sewa	Bundoye	Palima	8x06'N	11x19'W	C	1	N	1972	1976		2	1	N	N
19	Sewa	Sewa	Lembema	7x50'N	11x45'W	C	1	N	1990	-		2	1	N	N
18	Sewa	Tabe	Bumbe	7x52'N	11x53'W	C	1	N	1990	-		2	1	N	N
R9/10	Pampana or Jong	Pampana	Matotoka(Pampana)	8x40'N	11x52'W	C	1	N	1971	-	7109760388059101	2	1	N	N
14	Pampona or Jong	Teye	Yele	8x24'N	11x51'W	C	1	N	1988	-		2	1	N	N
17	Pampana or Jong	Jong	Mokele	7x43'N	12x10'W	C	1	N	1990	-		2	1	N	N
15	Pampana or Jong	Jong/Taia	Taiama	8x12'N	12x04'W	C	1	N	1990	-		2	1	N	N
R17/22	Moa	Moa	Gofor(Moa)	7x49'N	11x10'W	C	1	N	1971	-	7101750890059101	2	1	N	N
23	Moa	Male	Masahun	8x03'N	10x58'W	C	1	N	1990	-		2	1	N	N
24	Moa	Moa	Batiwa	8x09'N	10x44'W	C	1	N	1990	-		2	1	N	N
21	Moa	Moa	Bandasuma	7x23'N	11x25'W	C	1	N	1990	-		2	1	N	N
16	Gbangbaia	Gbangbaia	Mokasi	8x00'N	12x25'W	C	1	N	1990	-		2	1	N	N
20	Waanje	Waanje	Bandajuma	7x34'N	11x38'W	C	1	N	1990	-		2	1	N	N

NUMBER	STN_NAME	REMARKS
1	Outamba	OCP station. Rating curve in course of preparation
2	Kaba Ferry	OCP station. Rating curve in course of preparation
R2	Mange	No rating curve was established due to tidal effects
3	Musaia	OCP Station. Rating curve in course of preparation
4	Kunshu(Mabole)	In 1975 there was an automatic recorder. No rating established. Now OCP station.
5	Mabanta	OCP station.
R6/6	Arfania(Badala)	In 1970/6 there was an automatic recorder and provisional rating curve. OCP station.
7	Bumbuna	OCP station.
8	Magburaka	A few levels were recorded at a staff gauge in 1975/6. OCP station.
9	Marampa	There was a station with a staff gauge at Marampa from 1972 but data not reliable and never published. OCP station.
R6-1	Mador	This station operated for 1 year only.
11	Yifin	OCP station.
12	Yima Ferry	OCP station.
R13/13	Njaiama-Sewafe(Sewa)	In 1970/76 there was an automatic recorder and provisional rating curve. OCP station.
R16	Doda	Mini-hydro scheme was built between Doda and Palima stations.
R15	Palima	Mini-hydro scheme was built between Doda and Palima stations.
19	Lembena	OCP station.
18	Bumbe	OCP station.
R9/10	Matotoka(Pampana)	The 1970/76 data are based on a staff gauge. OCP station.
14	Yele	OCP station.
17	Mokele	OCP station.
15	Taiama	OCP station.
R17/22	Gofor(Moa)	In 1971/76 there was an automatic station with a good rating curve. OCP station.
23	Masahun	OCP station.
24	Batiwa	OCP station.
21	Bandasuma	OCP station.
16	Mokasi	OCP station.
20	Bandajuma	OCP station

APPENDIX G

GROUNDWATER RESOURCES

APPENDIX G

GROUNDWATER RESOURCES

G.1 Sources of Information

Most of the groundwater information contained in this report has been obtained from the following sources:

- Water Supply Department (WSD), Ministry of Energy and Power, Freetown;
- Land and Water Development Division (LWDD), Ministry of Agriculture and Natural Resources, Freetown;
- Geological Department, Ministry of Mines, Freetown;
- United Nations Agencies, Freetown;
- World Health Organisation, Freetown;
- Agricultural University, Njala;
- Prakla Seismos Geomechanik GmbH, Drilling Contractor, Bo;
- GKW Consult, Consulting Engineers, Bo;
- Water Aid, Ministry of Energy and Power, Freetown;
- Ministry of Lands and Country Planning, Freetown;
- British Geological Survey, Hydrogeology Unit, Wallingford, UK.

G.2 Background

Historical Perspective

The groundwater resources of Sierra Leone have not been fully studied. It is only during the UN Water Supply and Sanitation Decade (1981 - 1990) that major systematic work on the hydrogeology of some regions of the country has been undertaken, as a part of the various rural water supply programmes, co-ordinated by the Water Supply Division (WSD) of the Ministry of Energy and Power.

The geology of Sierra Leone is reasonably well documented; some work in this field was done at the end of the last century, but major advances were made by Dixey in the 1920s, culminating with the publication of his paper 'The Geology of Sierra Leone' in 1925. With increasing attention given to Sierra Leone by various mining interests, much geological work followed, described in later publications of the Geological Survey.

In 1945 the Survey was expanded and started systematic mapping of the country, mainly at a reconnaissance level, except for areas of mining potential where more detailed work was done. This state of affairs continued for several years, greatly increasing the understanding of the stratigraphy and structure and identifying commercial mineral occurrences. In 1964, Allum of the UK Institute of Geological Sciences, mapped the whole of Sierra Leone west of 12°W longitude at the scale of 1 : 50 000, using the photogeology technique. Other workers, such as MacFarlane et al (1980) mapped overlapping and additional areas, until the whole country was covered by reasonable geological mapping, albeit at different scales.

The interpretation of Sierra Leone stratigraphy shown in Table G.1 is that of Macfarlane et al (1980) and differs somewhat from the mapping units shown on the geological map given in Figure 2.1; nevertheless the correlation between the two interpretation can be readily deduced.

In 1964/65, the United States Mission to Sierra Leone supplied a cable-tool drilling rig and a master driller to the Ministry of Works, to undertake a programme of well construction and training of local staff. Exploratory holes were drilled at Kabala and Kamawakwie, but were considered unsuitable for potable supplies. Later, in 1968 two boreholes were drilled at Lungi, at 150 mm diameter and of 22.5 m depth, to supply water for the airport. In 1970 another borehole was sunk at Milestone 91 from Freetown. After that, because of lack of spare parts, the cable-tool rig was broken up for scrap. Since then there has been no drilling for groundwater in Sierra Leone until 1987, when the German and Japanese assisted rural water supply projects started.

The first compilation of groundwater data was issued in 1966 by the consultants McCreary Koretsky Engineers (MKE) as a part of their water resources inventory. Their proposal that groundwater should form the basis of rural water supply in most of the country was not immediately taken up. It was not until 1976 that the first major well installation project (Northern Integrated Agricultural Development Project (IADP) financed by the International Development Agency) was started; by 1984 some 400 dug wells, equipped with handpumps had been completed under this and another IADP.

The IDA Programme overlapped with several other rural water supply projects, undertaken since 1981, under the impetus of the UN Water Supply and Sanitation Decade. These have included dug wells, spring boxes, gravity systems, and since 1987, boreholes, in addition to latrine construction to improve sanitation. Financial assistance for the water supply sector was obtained from International Agencies (the World Bank and various UN agencies) as well as from bilateral aid from several countries and from non-governmental organisations (NGOs) United Nations Development Programme (UNDP) provided financial and technical assistance for the co-ordination of this rapidly accelerating development.

TABLE G.1

Stratigraphic Sequence

ERA/System	Formation	Lithology
Cainozoic		
Quaternary	Superficial deposits	Alluvial sands and clays, colluvium and residual deposits
Tertiary	Bullom Series	Clays and ferruginous sandstones with lignites
Palaeozoic	Rokel River Group	
Late Precambrian to Early Palaeozoic	Mabole	Mainly mudstones and shales, schistose in the west, with minor arenites
	Kasawe Hill	Andesite pillow lavas and dacitic tuffs
	Teye	Shales and sandstones
	Tabe-Makeni	Sandstones, arkoses, siltstones, shales, grey wackers and conglomerates (including the Saionya Scarp Congolmerate)
Precambrian		
Upper - Kambui Supergroup	Sula Group	
	Sonfon	Amphibolites with pillow lavas and ultramafic bands
	Tonkolili	Schists, gneisses and greenstones
	Kasila - Maramba Group	
	Rotokolon	Pelitic and psamitic schists and granulites
	Matoto	Schistose grey-green, fine grained volcanics and amphibolites
Middle	Loko Group	Amphibolites, quartzites and banded ironstones
Lower	Liberian and Leonidean Granitoids	Granites, gneisses and migmatites
Intrusives		
Mesozoic		Dolerite dykes and sills, and larger gabbro and norite intrusions; some kimberlite pipes
Precambrian		Amphibolites, serpentines, talc schists and lamprophyres

Source: Macfarlane et al (1980)

Many technical reports and papers have been issued by the local Water Supply Division and UN personnel as well as by consultants involved in the projects; some of these are of general nature, giving useful summaries of achievements of up to particular dates (Harleston and Owusu 1986, Najir and Sharma 1988, Bicego 1990), whilst some, particularly the KfW and JICA assisted projects give individual well completion reports with details of geology, groundwater occurrence, well design and hydrochemistry (GKW 1988, C-Itoh & Co Ltd 1989). Much of the effort of the various organisations has apparently been focused on motivating the rural population to use and maintain the provided water supply facilities properly (IWACO & ENGCON 1988, Bellin 1989).

At the end of the Water Supply and Sanitation Decade there appears to be a lull in the groundwater study and development activities. This should prove to be temporary, though a recent UN review takes a pessimistic view, observing that many of the water supply projects 'are drawing to a close and there are no firm signs of successors to follow' (Farrant,1990). Nevertheless the German and Japanese assisted projects concerned with drilled wells are scheduled to continue as are at least some of the NGO programmes.

Geology

The Basement outcrops are affected by fracture systems, evident as lineations on aerial photographs. Other significant features which may be mapped are zones of mylonite and the trend of minor intrusions (dyke swarms). The main directions of the latter are north-south/west-north-west-/east-south-east.

Sub-Saharan African geomorphology is dominated by erosion surfaces of various ages, some of them very ancient, the remnants of which may form mountain and hill ranges. Six such surfaces have been mapped in Sierra Leone:

Bullom surface	Pleistocene, probably partly depositional, elevation 0 to 40 m
Coastal plain surface	Upper Tertiary, tilted towards the sea with a gradient of about 2 m per km; elevation mainly from 40 to 60 m
Main plateau surface	Upper Cretaceous to Eocene; usually lateritised; tilted towards the coast with a gradient of 1.5 m per km; elevation mainly between 300 and 500 m
Sula surface	Lower to Mid-Cretaceous; thickly duricrusted; elevation normally 500 to 600 m
Nimini surface	Lower Mesozoic; capped by well developed duricrust; elevation about 650 m

Loma surface	Lower Páläeozoic; elevations between 800 and 1 800 m, the disparity being due to post-erosion block faulting.

Most of Sierra Leone is comprised of the three youngest surfaces. The older erosion levels are evident as hilly remnants, dissected by later denudation, sometimes to the form of isolated inselbergs. Thus the Loma surface is evident in the alignment of the peaks of the Loma, Tingi and Sula ranges. The Nimini surface has also been mapped as benches in the hills and mountains, particularly in the Nimini Hills, and as inselbergs forming the Kabala Hills. Finally, the Sula surface survives as wide benches as well as many small ridges and knolls in the north-east of the country.

G.3 Groundwater Occurrence

The Basement rocks, which cover much of Sierra Leone, have no primary porosity or permeability in the unaltered state; groundwater in small but exploitable quantities are found mainly in the near surface secondary features such as joints, fractures and the zone of weathering. The variation in yield of basement wells testifies to the non-homogeneity or even discontinuity of this near-surface aquifer.

There is abundant evidence that the near-surface weathered/fractured zone aquifer in the Basement terrain of Sierra Leone is well developed. It is at present uncertain whether the eastern part of the country (older erosion surfaces) has better developed aquifers than the western part, or if higher permeabilities are developed at the margins of dykes and other intrusions. However, both the weathered zone and the underlying fracture zone can be productive as witnessed by the high success ratio of both dug and drilled wells tapping the two layers respectively.

The sedimentary strata of the Rokel River Group, are also almost certainly water bearing only where affected by weathering and fracturing. This is supported by the strongly consolidated nature of the rocks and by the fact that wells in the normally impermeable lithologies such as shales and mudstones, are apparently as productive as those in sandstones and conglomerates.

The secondary nature of the water bearing characteristics of all the Precambrian and Palaeozoic aquifers is further supported by the mode of spring occurrence. Apparently there are very many springs in Sierra Leone, but the great majority are small (discharge of the order 1 l/s) and most are tectonically controlled, including the larger ones which normally occur at faults. Moreover, the flows of many decline rapidly during the dry season, reflecting the low storage of their catchments, a characteristic typical of fissure flow.

Quantitative data on the quality of the aquifer is, at present, available only from the borehole projects, which have published some of their boreholes records. Apparently, the dug wells are being properly tested and fully documented but the records are kept in files at the regional centres. Collection, compilation and statistical treatment of such unpublished, dispersed records are totally beyond the staff resources of this project.

Unfortunately the two drilled well projects currently in progress in Sierra Leone use different definitions, methods and designs and therefore the results are difficult to compare; hence they have to be treated separately.

The Bo/Pujehun Project reported the following accomplishments by 30 April 1990:

TABLE G.2

Accomplishments of the Bo/Pujehun Project

	Nr	Average depth (m)	Average discharge (l/s)
Boreholes	452	39.3	-
Successful*	337	33.5	1.2
Unsuccessful	115	56.3	-
Dug wells	40	NR	-
Successful*	36	NR	NR
Unsuccessful	4	NR	-

NR - not recorded

* Success is defined as minimum sustainable discharge of 0.8 m^3/h (0.22 l/s).

More detailed records are available for 137 drilled wells, in a report published in 1988. Statistical treatment of these records is given in Table G.3.

TABLE G.3

Statistics of Borehole Records
(Bo/Pujehun Rural Water Supply and Sanitation Project)

	Sample population	Range	Mean	Standard deviation	Median	Lower quartile	Upper quartile
Drilled depth (m)	136	15 - 70	40.8	15.3	37.8	27.7	58.8
Depth to water level (m)	109	2 - 21	8.6	3.5	8.5	6.3	12.0
Well yield* (l/s)	105	0.2 - 2.5	1.1	0.7	1.0	0.6	1.6
Specific capacity* (m^3/h/per metre)	105	0.07 - 22.50	1.48	2.79	0.47	0.24	1.54

* Apply to successful wells only

Source: GKW 1988

The pumping (acceptance) tests were normally of 2 hours duration; the specific capacities apply to that time of pumping.

As can be seen, the success ratio on this project is about 75%; the selection of drilling sites has been done without the aid of geophysics except for VLF surveys. All the wells have been logged as penetrating decomposed rock overlying granite. The most productive layer is reported to be the fracture zone but sandy layers within the weathered zone are normally screened as well.

It is of interest to record that the experience of the Bo/Pujehun Project is very much in line with that of the Basement wells in other parts of sub-Saharan Africa. Most of the successful wells are in the range of depth from 20 to 40 m. The average well yield is about 1 l/s. The distribution of results for well depth, depth to watertable and well yield is approximately normal, whereas that for specific capacity (and usually that for transmissivity and permeability) is distinctly log-normal.

The Bombali/Kambia Rural Water Supply Project, the only other project concerned with drilled wells, has published the records of 55 successful wells. The success ratio is reported as 85% (siting is with the aid of geophysics), but success is defined as a sustainable discharge of at least 3 l/min that is 0.18 m^3/h or 0.05 l/s; this can only sustain intermittent pumping with a handpump.

The project area is underlain by the Rokel River Group as well as Basement and the productive zones have been logged as mudstone, shale, volcanics of various kinds and weathered and fractured granite, as well as some rarer rock types, such as mylonite and schist. Statistical treatment of the borehole characteristics are given in Table G.4.

TABLE G.4

Statistics of Borehole Records
(Bombali/Kambia Rural Water Supply Project)

	Sample population	Range	Mean	Standard deviation	Median	Lower quartile	Upper quartile
Drilled depth (m)	55	19.3 - 50.5	38.7	9.9	41.7	31.1	46.8
Depth to water level (m)	55	1 - 20	8.5	4.5	8.1	4.7	11.7
Well yield* (l/s)	55	0.05 - 2.50	1.1	0.8	0.8	0.4	1.6
Specific capacity* (m^3/h/per metre)	55	0.01 - 5.24	0.9	1.0	0.5	0.2	0.9

Source: C - Itoh & Co 1989

The most noticeable aspect of these data is how similar they are to the Bo/Pujehun records. In fact - if the same definition of a successful well were used, the similarity would be even closer.

Since the Bombali/Kambia wells have been installed in strata of different lithologies, it is of interest to examine whether there is any clear relation between the lithology and the quality of the near surface aquifers. Three types of rock apparently predominate in the area, namely mudstone/shale, intermediate volcanics (andesite/dacite) and granite/granite gneiss; only profiles completely of one of these lithologies were considered, with the following results:

TABLE G.5

Impact of Lithology on Well Performance

Lithology	Nr of wells	Specific range	Capacity ($m^3/h/m$) Average
Mudstone/shale	13	0.2 - 4.6	1.2
Volcanic	12	0.5 - 5.2	1.3
Granite/Granite Gneiss	16	0.01 - 1.1	0.3

It would seem that the granitic rocks are less productive than the other two lithologies considered. However, in view of the results from the Bo/Pujehun Project, which is located mainly on granitic terrain, the above results cannot be accepted as conclusive.

The Bullom Series, though consisting predominantly of clays and lignites, contain coarse, uncemented clastics, which possess primary porosity and permeability; these are generally considered as the most productive aquifers in the country. The maximum well depth recorded in these strata is 110 m and the maximum production rate from a drilled well in these deposits is reported as 15 l/s. The Bo/Pujehun Project has used dug wells in this aquifer, in an attempt to maximise diameter and limit depths in order to avoid salt water intrusion. No detailed records are as yet available.

Lastly, some of the superficial strata may form significant aquifers. Jalloh (1979) reports thicknesses of sandy alluvia of about 15 m at some inland river valleys. It is known some of the rutile mining enterprises get their water supplies from alluvial wells.

G.4 Groundwater Quality

The quality of groundwater in Sierra Leone is very poorly documented. Though some measurements of the various chemical and biological parameters of groundwater are routinely made during the installation of wells under the various rural water supply programmes, only the Bombali/Kambia Project has reported fully their findings in this field (Table G.6); these indicate that some chemical problems may exist in at least a few parts of the country.

As might be expected from the amount of rainfall, the physiography of the countryside, the dense vegetative cover of the surface and the rocks forming the aquifer, the groundwater has certain chemical characteristics, typical of that kind of environment. Thus overall mineralisation is very low, except where affected by recent marine history or sea water intrusion; most of the groundwater is acid (pH less than 7) and of negative redox potential; consequently it has the capacity to dissolve

TABLE G.6

Chemical Analyses of Water Samples
(Bombali/Kambia Rural Water Supply Project)

Well Nr	EC_x10^6 @ 25°	pH	Hardness as $CaCO_3$ (mg/l)	Cl (mg/l)	Cr (mg/l)	Fe (mg/l)	Zn (mg/l)	Mn (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	F (mg/l)	NO_3 (mg/l)
B-11-1	337	8.0	50	100	-	1.0	5.0	0.5	200	2.0	1
B-11-2	119	6.5	40	70	-	0.5	2.0	0.5	80	1.0	1
B-11-3	155	7.5	50	100	-	2.0	5.0	0.5	100	5.0	1
B-11-4	224	7.5	100	100	-	2.0	2.0	0.5	200	5.0	2
B-11-5	146	7.0	100	50	-	2.0	5.0	0.5	100	2.0	1
B-11-6	166	7.0	100	50	-	5.0	2.0	0.5	100	5.0	1
B-11-7	230	7.5	100	100	-	1.0	7.0	0.5	150	0.5	1
B-11-8	306	7.5	80	50	-	1.0	2.0	0.5	250	1.0	1
B-11-9	32	6.5	50	100	-	0.5	5.0	0.5	50	2.0	5
B-11-10	55	6.5	50	100	-	5.0	10.0	0.5	50	5.0	1
B-11-11	48	6.5	50	50	-	2.0	5.0	2.0	30	0.0	5
B-11-12	101	6.5	50	100	-	2.0	1.0	0.5	50	2.0	5
B-11-13	130	6.5	30	30	0.10	1.0	5.0	0.5	50	2.0	5
B-11-14	307	7.5	100	50	0.05	2.0	5.0	0.5	200	0.5	2
B-11-15	235	6.5	40	50	0.05	0.2	10.0	1.0	50	0.5	20
B-11-16	166	7.0	50	30	0.05	5.0	2.0	0.5	150	5.0	1
B-11-17	154	7.0	130	50	0.05	0.2	10.0	0.5	100	5.0	1
B-11-18	190	6.5	80	80	0.05	0.2	5.0	0.5	30	0.0	10
B-11-19	66	6.5	20	30	0.02	0.5	3.0	0.5	30	0.0	2
B-11-20	244	6.5	150	50	0.05	1.0	2.0	0.5	200	1.0	1
B-11-21	144	6.5	50	30	0.05	5.0	5.0	1.0	50	1.0	1
B-11-22	241	7.0	20	20	0.05	1.0	1.0	1.0	130	2.0	1
B-11-23	120	7.0	50	50	0.05	2.0	5.0	0.5	80	1.0	1
B-11-24	158	6.5	60	20	0.05	2.0	2.0	0.5	100	2.0	2
B-11-25	109	5.5	50	50	0.05	2.0	5.0	0.5	100	1.0	1
B-11-26	74	6.5	50	100	0.05	10.0	10.0	0.5	100	0.5	1
B-11-27	135	6.5	30	30	0.05	10.0	5.0	0.5	70	0.0	1
B-11-28	279	7.0	120	50	0.05	0.5	5.0	0.5	200	0.0	10
B-11-29	121	7.0	100	100	0.05	1.0	2.0	0.5	60	0.0	1
B-11-30	98	7.0	50	80	0.05	0.5	5.0	0.5	50	2.0	1
B-11-31	256	7.0	100	100	0.05	5.0	5.0	0.5	200	1.0	2
B-11-32	210	7.0	100	50	0.05	1.0	5.0	0.5	100	5.0	1
B-11-33	82	6.5	50	70	0.05	1.0	10.0	0.5	50	5.0	1
B-11-34	191	7.0	100	100	0.05	0.5	5.0	0.5	150	0.5	1
B-11-35	249	7.0	50	50	0.05	5.0	5.0	0.5	200	2.0	1
B-11-36	173	7.0	50	70	0.05	2.0	1.0	0.5	150	5.0	1
B-11-37	58	6.5	50	50	0.05	2.0	10.0	0.5	50	0.0	1
B-11-38	98	7.0	50	50	0.05	0.5	5.0	0.5	50	1.0	1
B-11-39	101	6.5	50	100	0.05	5.0	5.0	0.5	100	0.5	2
B-11-40	293	8.0	150	150	0.05	2.0	10.0	0.5	200	1.0	1
B-11-41	161	6.5	50	100	0.05	5.0	5.0	0.5	100	1.0	1
B-11-42	136	6.5	100	100	0.05	5.0	10.0	0.5	100	0.5	1
B-11-43	124	7.0	50	100	0.05	5.0	5.0	0.5	100	2.0	1
B-11-44	138	7.0	100	50	0.05	10.0	2.0	0.5	100	1.0	1
B-11-45	134	7.0	50	50	0.05	1.0	2.0	0.5	100	5.0	1
B-11-46	119	7.0	100	100	0.05	2.0	5.0	0.5	100	0.0	1
B-11-47	78	7.0	50	50	0.05	0.5	3.0	0.5	50	0.0	5
B-11-48	216	7.5	100	50	0.05	0.5	0.5	0.5	200	1.0	2
B-11-49	116	6.5	50	100	0.05	2.0	2.0	0.5	100	0.5	1
B-11-50	189	7.5	100	150	0.05	2.0	5.0	0.5	100	0.0	5
B-11-51	274	6.5	50	100	0.05	0.5	10.0	0.5	50	0.0	15
B-11-52	137	6.5	50	150	0.05	0.5	2.0	0.5	50	2.0	10
B-11-53	165	7.0	100	50	0.05	5.0	5.0	0.5	150	2.0	1
M-11-1	228	7.0	150	100	0.05	2.0	5.0	0.5	150	0.5	1
M-11-2	124	7.0	100	50	0.05	0.5	2.0	0.5	100	0.5	1

high quantities of heavy metals such as iron, manganese and zinc. The calcium hardness is very low in rocks such as granite; therefore high fluoride content can exist in solution in groundwater rather than precipitate as calcium fluoride. At the low lying coast, the Bullom Series aquifer can be expected to have the fresh groundwater underlain by salt water, more or less in line with the Ghyben-Herzberg principle. The understanding of these considerations indicates on which chemical parameters one should concentrate, when conducting analytical work to test groundwater for potability.

As already mentioned, the fullest chemical analyses are recorded by the Bombali/Kambia Project. In the well completion reports, the Project routinely records temperature, electrical conductivity (EC), turbidity, colour, permanganate value, nitrate, nitrite, ammonia, hardness, chloride, hexavelant chromium, iron, copper, zinc, manganese, alkalinity, fluoride, presence of bacteria and presence of coliform organisms.

The analyses are not entirely internally consistent and the individual determinations are obviously approximate, suggesting that the measurement methods are fairly crude. The pH values greater than 7 are unusual in this kind of environment and should be checked, if the measurements are not done on site, immediately after sample collection, the pH would rise on exposure to air. The high heavy metal content is as might be expected in the case of iron and manganese, but the situation may have been aggravated by the reaction of aggressive water with the galvanised steel components of the wells; the relative abundance of zinc in the well water supports this contention.

High iron and maganese usually precipitate out of solution on exposure of the pumped groundwater to air, producing a residue and an unsightly scum at the surface. This makes the water unpleasant to drink and may stain clothes washed in it. Though not normally considered damaging to health, such water may be unacceptable to the consumers, who may return to their supplies from organically contaminated surface water.

Potentially, the most serious problem is fluoride. This cannot be identified by sight, taste or smell, but long-term intake of fluoride rich water can seriously damage health. Concentrations greater than about 2 mg/l may produce dental fluorosis or permanent staining of teeth in children, whereas higher concentrations may result in crippling skeletal fluorosis in old age (fusing of the bones at the joints which make the affected individual unable to bend down).

Lastly, coliform and other bacteria have been identified in many of the samples, but these may have been introduced into the wells during construction.

The Bo/Pujehun Project routinely reports temperature, EC and pH only. These parameters are generally in the expected range. More detailed analyses have been done in only a few cases; these comprised EC, pH, colour, turbidity, smell, chloride, nitrate, nitrite, ammonia, carbon dioxide, hydrogen sulphide, iron, manganese, sulphate and total hardness. The main parameter of interest amongst these is iron. In the case of 13 analyses inspected the iron content was as follows:

TABLE G.7

Bo/Pujehun Project: Iron Content of Water Samples

Iron Content (mg/l)	Nr of samples
0	7
0.01 - 1.00	5
1.01 - 5.00	0
> 5.00	1

In this project all the well and pump components are either of chemically inert (plastic) or corrosion resistant (stainless steel) materials; hence the results probably represent the composition of groundwater in situ. In the samples analysed, only one had unacceptably high iron. Fluoride has not been measured.

The project proposes to carry out chemical analyses of about 10% of the installed and commissioned wells at a later date.

Bacteriological determinations are reportedly done routinely as a part of well completion; in the case of presence of such organisms, the wells are disinfected with sodium hypochlorite.

No chemical analyses were obtained from all the other agencies involved in groundwater development for rural water supply. UNDP are reported to have imported two portable 'Hach' laboratories to Sierra Leone and UNICEF supports the chemical laboratory at the Njala University. However, no UN publications with chemical analyses were found. When questioned, the UN technical staff associated with the various rural water supply projects, identified iron as the main chemical problem; but produced no results. According to the Water Supply Division staff in Freetown, the UN co-ordinated programmes have concentrated on organic contamination and have done few chemical tests. In case of wells in which presence of bacteria is identified, disinfection with chlorine is carried out.

G.5 Recharge

The subject of recharge is discussed by Jalloh (1979) in his Hydrogeology MSc submission. In dealing with north Sierra Leone, he analyses a series of river hydrographs to obtain groundwater discharge to the rivers. The accuracy of this method can be questioned and apparently only a few full annual river hydrographs were available for such treatment: the results are summarised in Table G.8.

TABLE G.8

Groundwater Discharge to Rivers

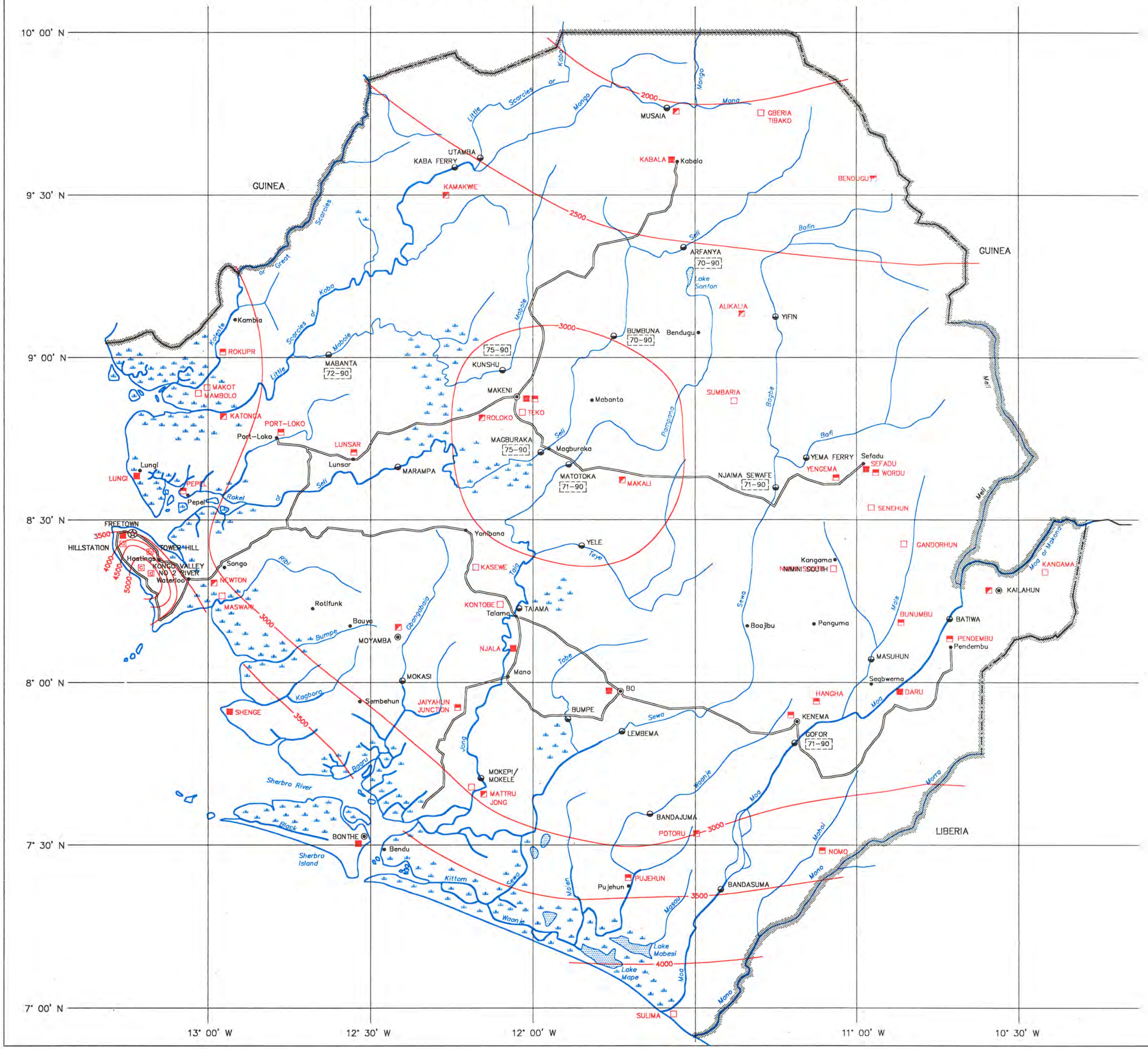
Hydrological station	Water year	Total river flow (Mm^3/year)	Groundwater component (Mm^3/year)	Groundwater component per unit catchment area (mm)
Sewa	1972 - 1973	5 644	4 516	657
Pampana	1972 - 1973	3 524	2 889	1 200
Badala	1971 - 1972 1972 - 1973	1 482 2 141	1 067 1 670	423 661
Bambuna	1971 - 1972 1972 - 1973	3 098 4 347	2 323 3 261	582 817

Source: Jalloh 1979

The figures in the last column are in effect estimates of recharge, but these have low credibility and seem much too high. Jalloh seems to recognise this himself as he obtains a much lower figure by an overall water balance for the northern half of Sierra Leone, as follows:

Average annual precipitation	2 550 mm
Average actual annual evapotranspiration	1 500 mm
Average annual surface run-off	908 mm
Average annual groundwater recharge	142 mm

HYDROMETEOROLOGICAL MAP OF SIERRA LEONE



SUB-SAHARAN AFRICA HYDROLOGICAL ASSESSMENT
(WEST AFRICAN COUNTRIES)
THE WORLD BANK
THE UNITED NATIONS DEVELOPMENT PROGRAMME
AFRICAN DEVELOPMENT BANK

prepared by
Mott MacDonald International
Cambridge, U.K.
in association with
BCEOM
Montferrier–sur–Lez, France
and
SOGREAH
Grenoble, France

Precipitation

— 3000 — Isohyets of mean annual precipitation (mm)

Meteorology

- Synoptic station
- Agro–meteorological station
- Climatological station
- Rain gauge
  - HILLSTATION
  - TOWER HILL
  - KONGO VALLEY
  - No 2 RIVER
- BO — Station name

River Gauging Stations

- Staff gauge and discharge measurements
- 70–90 — Period of record – discontinuous
- BASHUN — Station name

Surface Water

- River
- Lake
- Swamp

Topographic Features

- Paved road
- Town, village with airstrip
- City

Scale 1:1 000 000

0 10 20 30 40 50 km