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GROUNDWATER MANAGEMENT IN DROUGHT PRONE AREAS OF AFRICA NORTHERN GHANA - INCEPTION REPORT

A M MacDonald[1], R C Calow[1], A J Andrews[2] and S Appiah[3]

1 British Geological Survey 2 Institute of Hydrology 3 Ghana Water and Sewerage Corporation

Natural
Environment
Research
Council

International Division
British Geological Survey
Keyworth
Nottingham
United Kingdom NG12 5GG

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[1]A M MacDonald and R C Calow, British Geological Survey

[2]A J Andrews, Institute of Hydrology

[3]S Appiah, Ghana Water and Sewerage Corporation

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Collecting water from a traditional well in Upper East, Ghana

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PREFACE

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

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

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

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

This report forms an inception report for Ghana. The data and information has been gathered by BGS, GWSC and IH staff over the period April 95 to March 96.

ACKNOWLEDGEMENTS

This project represents a partnership between different institutions, from different countries, north and south. It is supported by the British Overseas Aministration's Technology, Development and Research Programme (R6233). The cooperation and enthusiasm of everyone involved has been instrumental in getting the project up and running and, it is hoped, will contribute to greater awareness of the impact of drought on groundwater resources and the methods by which impacts can be prevented or mitigated.

Thanks are due to all staff at the GWSC and WRRI, who assisted in the compilation of this report in September/October 1995. Specifically Alfred Osafo-Yeboah, Bob Bannerman, Mr Kortatsi and Peter Akari are thanked for their help. The cooperation of staff from Wateraid, Rural Aid and CIDA is appreciated. The authors would also like to thank all those who took the time to relate the experience of drought in Northern Ghana with great patience and good humour.

1. INTRODUCTION

On the face of it, Ghana is an unusual choice in a study about managing groundwater in drought prone areas. Rainfall is much higher than in the other study areas of Malawi and South Africa. Ghana, provides an interesting contrast. As rainfall is relatively high, there is a degree of reliance upon surface water. Agriculture is largely rainfed and many of the larger towns and cities rely on perennial rivers or reservoirs to provide water for a piped system. Smaller communities do not generally have piped supply and rely upon both groundwater and surface water. Small dug-outs and dams are used to impound surface water and are utilised for much of the year round usually to water livestock. Groundwater is exploited via boreholes or hand-dug wells.

The principal objectives of this first (inception) report is to provide a resource of background data (both hydrological, hydrogeological and socio-economic) to draw on for the remainder of the project and beyond. Data on Ghana as a whole is given as well as more detailed information on the Northern and Upper Regions. The information was gathered during a visit to Ghana of BGS staff during Autumn 1995 (26 September - 4 October). This report should be regarded as a working document rather than a final report, with questions (rather than answers) identified, and future needs and tasks outlined.

2. COUNTRY BACKGROUND

2.1 Overview

The Republic of Ghana is located in West Africa, occupying a modest land area of about 240 000 km^2 between Cote d'Ivoire to the west, Burkina Faso to the north, and Togo to the east (Figure 1). The capital city of Accra, located on the southern Atlantic coast, contains some 7% of the total population of about 16 million, and other towns and cities are expanding rapidly. Nevertheless, most (approx 10 million) of the population live in rural communities (<5000 people), with over half of the population living in communities of less that 1500 people. Two thirds of the poorest Ghanaians live in these small communities, with most concentrated in the Northern and Upper Regions. Administratively, Ghana is divided into 10 regions; there are 110 districts in the country

The elevation of much of country is below 300 m although few areas, most notably the remnants of the Kwahu Plateau stretching from the Accra Plains to the Côte d'Ivoire border and the ranges of Adensi, Atewa - Atwiredu, Akwapim and Togo, rise above 600 m. The surface drainage network is dense and dendritic with the Kwahu Plateau dividing the country into two basins; the catchments in the south-west of Ghana and the catchments of the Volta basin. The principal hydrological feature is the Volta Lake which was created in 1966 after the completion of the dam on the Volta River at Akosombo. The Volta Lake covers an area of approximately 8500 km^2.

Four broad vegetation zones have been distinguished in Ghana although the boundaries between them are seldom well defined. High forest occurs mainly south-west of the Kwahu Plateau and savannah woodland is most extensive in the north of the region. Coastal scrub and grassland runs in a belt 15 km to 30 km wide between Sekondi - Takoradi and the Volta Estuary.

Ghana is one of the rich countries of the continent. It is endowed with a wide range of natural resources, including arable land, forests, sizeable deposits of gold, bauxite, diamonds and manganese, and considerable potential for hydroelectric power from the north-south flowing Volta river. Despite enjoying this comparative advantage in natural capital, Ghana is a poor country. Per capita GNP is among the lowest in Africa at 430 US$ (1993), the country is severely indebted to the industrial

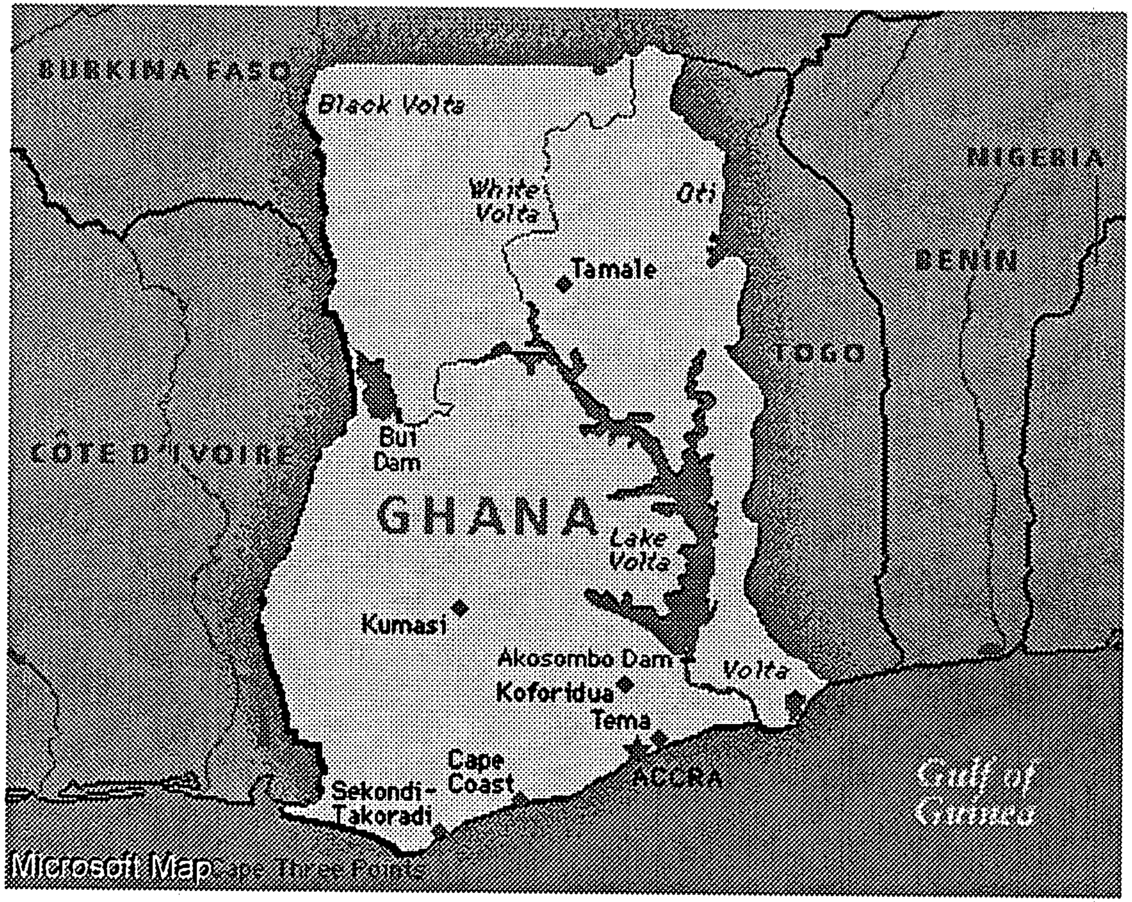

Figure 1 Map of Ghana (Microsoft Encarta 95)

nations, and traditional dependence on primary production and export of unprocessed primary products remains (World Bank 1995b). Throughout the 1970s and 1980s, income levels, production and exports all fell in real terms as unrealistic and misguided economic policies took their toll and external terms of trade declined. The situation was exacerbated in the early 1980s by the return of over 1 million Ghanaians from Nigeria, coming on top of severe drought in 1982/83.

Against a background of increasing poverty and macroeconomic crisis, Ghana introduced an Economic Recovery Programme (ERP) in 1983 to restore and sustain macroeconomic stability and promote economic growth. The programme was "supported" by financial and technical assistance from the World Bank, the IMF, and other multi-lateral and bi-lateral donors. Results have been impressive relative to other countries in the region, with Ghana often held up as an example of how structural adjustment can succeed. More recent reforms have focused on establishing an enabling environment for private sector development, capacity building in the public sector, investment in basic infrastructure and the promotion of environmentally sustainable growth.

In terms of rural development, perhaps the most important reform has been the decentralisation programme mandated by the 1992 Constitution and the Local Government Act of 1993. The decentralisation policy requires Ghana's 110 District Assemblies to take responsibility for the provision of basic services and local infrastructure. However, in terms of rural water supply and sanitation (RWSS) the emphasis is very much on promotion rather than provision. Experience in Ghana (and elsewhere) with a centralised, public service approach to RWSS has proved technically and financially unsustainable, and community participation has been lacking or non-existent.

Table 1 **Basic social and economic indicators. Source: World Bank 1995b, 1995c**

Demographic indicators	
Population	16.4 million (mid 1993 estimate)
Annual growth rate	3.0%
Urban/rural	66% rural (<5000 people)
Water coverage and spending	
Access to safe drinking water (total)	35% in 1970; 56% in 1985
Urban	86% in 1970; 93% in 1985
Rural	14% in 1970; 39% in 1985
Economic status	
GNP/capita	
Poorest regions	US$ 430 (1993)
Characteristics of poor	Northern and Upper
	Smaller rural communities; small holder-type agriculture; areas where dry season wage labour opportunities lowest
Environment	
Land area	240 000 km
Protected area (% total)	5%
Forest area (1980)	87 000 km open; 17 000 km closed
Annual deforestation (1981-85)	0.72% open; 0.22% closed

2.2 Physical environment

2.2.1 *Physical geography*

The Republic of Ghana is located north of the equator between latitude 4° 44' and 11° 11', and astride the Greenwich Meridian from 3° 15' west to 1° 12' east (Figure 1). It is roughly rectangular in shape with an area of 239 460 km^2. Ghana is not a mountainous country with the majority of the land below 300 m above sea level. The following six physiographic regions have been identified (Kesse 1985):

(1) The *low-lying coastal plain* extends inland for 24 to 100 km with an elevation of 0 - 32 m asl.

(2) The *interior expansive Voltaian Basin* occupies over 40 % of Ghana's land area. This fairly flat area varies in height from 100 - 200 m asl and is surrounded by highlands with outward facing scarps

(3) The *Mampong - Mpraeso - Koforidua ridge* also known as the Voltaian Highlands stretches northwestwards for about 260 km at an average elevation of 780 m.

(4) The *Akwapim-Togo Range* lies a in the southeastern corner of the country and extends from Accra northeastward into Togo. Within Ghana the range has a maximum elevation of 885 m.

(5) The *Plateau of the north and northwest* ranges in height from 150 to 300 m

(6) The *plateau of the southwest* again varies in height from 150 - 300 m but is broken by a number of isolated hills ranging up to 700 m.

Four broad vegetation zones are distinguished in Ghana: (1) high forest; (2) savannah woodland; (3) coastal scrub and grassland; and (4) strand and mangrove. The high forest occurs in the southwest plateau, while the coastal scrub and grassland and strand and mangrove zones occur in a strip less than 30 km thick along the coast. The vast majority of the country is covered by vegetation characteristic of savannah woodland.

2.2.2 *Climate*

Like the rest of tropical West Africa, the climate of Ghana is dominated by the movement of the Inter Tropical Convergence Zone (ITCZ). The ITCZ is characterized by vigorous activity on a front where hot, dry and dusty air mass from the Sahara meets the cool, moist monsoon air from the South Atlantic. The activity and movement of this front controls the intensity and duration of rainfall. Between December to February the front lies across the Gulf of Guinea and dry air prevails over the whole of the country. During the rest of the year the ITCZ moves across Ghana crossing some areas twice, bringing with it two rainfall seasons in the south during June/July and September/October and maximum rainfall in the northern regions during September.

Figure 2 illustrates the bimodal rainfall pattern in the south which is represented by Accra and the single peak in the north represented by Tamale. The mean annual rainfall ranges from over 2000 mm in the extreme south-west of Ghana, reducing eastward and northwards to approximately 730 mm in Accra and 1050 mm in Tamale (see Figure 3).

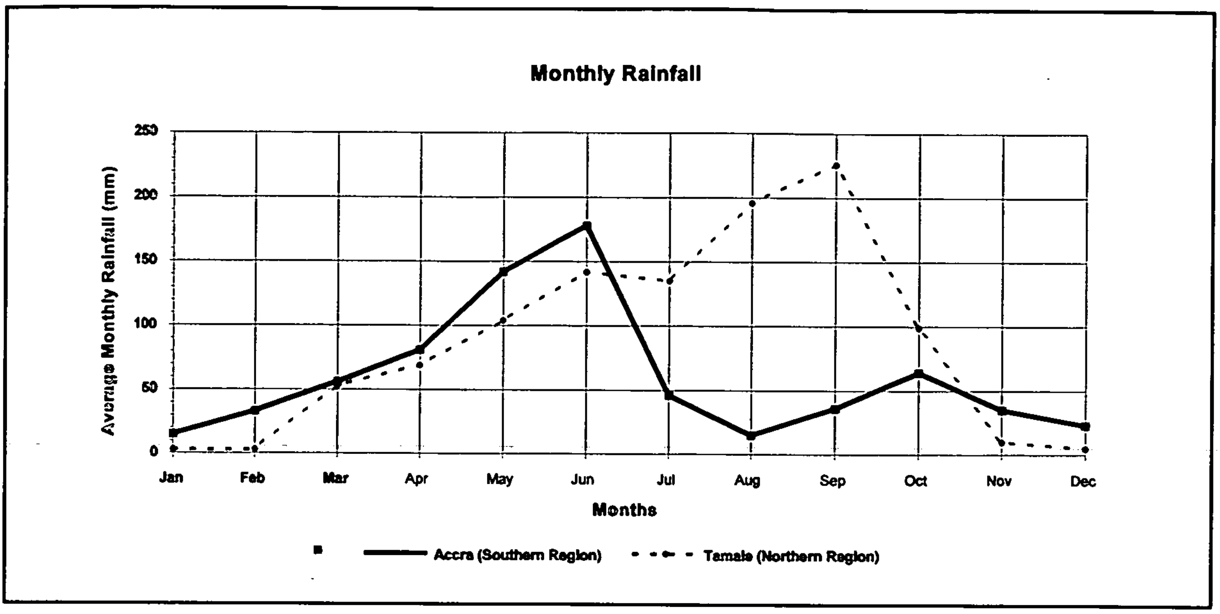

Figure 2 Rainfall for Accra and Tamale. Source: Pearce and Smith 1993.

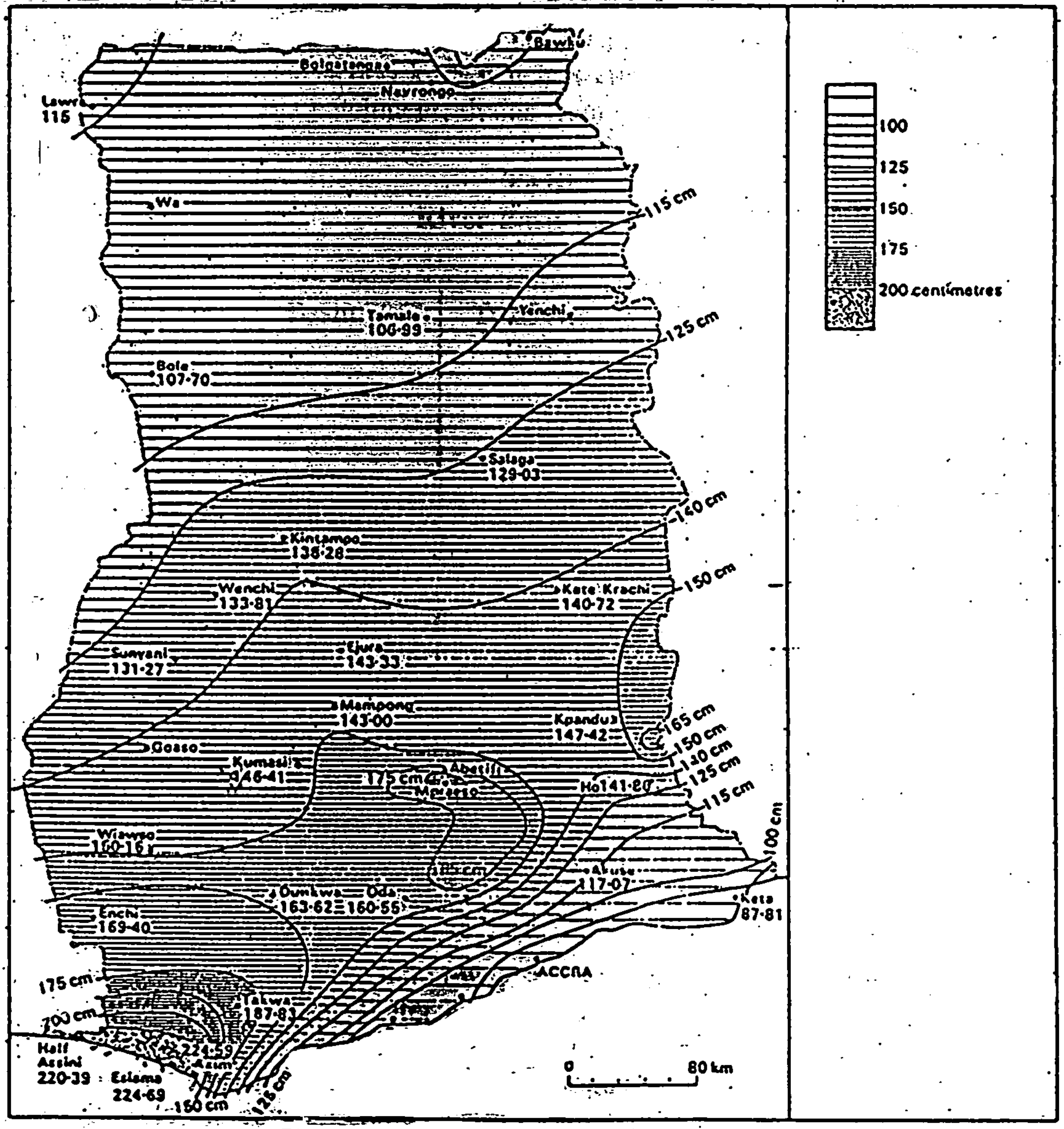

Figure 3 Rainfall distribution for the country (after Gill 1969).

The mean minimum monthly temperature is 23°C at Accra and Tamale and the mean maximum monthly temperatures are 30°C and 33°C, respectively (Figure 4). The mean annual temperatures approach 30°C and humidity is high at the coast (90%) and low (20%) in the north during the dry season. Mean annual evaporation generally increases to the north. Penman estimates of potential evaporation at Navrongo, Tamale and Wenchi are 1828 mm, 1768 mm and 1460 mm respectively. Estimates of actual evaporation from water balance studies have been quoted at around 900 mm reaching 1000 - 1300 mm in wet years and less than 650 mm in dry years.

2.2.3 *Surface water resources*

All rivers in Ghana drain southwards into the Gulf of Guinea. The River Volta, with a catchment area of 165 700 km^2 has the largest catchment area in Ghana and drains the entire north, centre and east of the country. The remaining rivers in the south and south-west drain approximately one third of the country. These rivers account for more than 50% of Ghana's internal runoff because of the higher rainfall regime.

The Hydrology Division of the Architectural and Engineering Services Corporation (AESC) of the Ministry of Works and housing is responsible for the national hydrological network and river flow databases. The AESC divided Ghana into 12 hydrological basins (see Figure 5 and Table 2) and 47 sub-basins (World Bank/UNDP, 1990). The total area draining from neighbouring countries, principally Burkina Faso is approximately 234 000 km^2.

The northern region of Ghana is drained by three main rivers:

- Black Volta with a drainage area of 87 757 km$_2$ (20 573 km^2 in Ghana) originates from the Upper Volta and Ivory Coast and enters Ghana in the Lawra District. The river drains a narrow strip, 32 to 48 km wide on the western side. The main tributary is the Sorri River.

- White Volta with a drainage area of 65 940 km^2 (30 410 km^2 in Ghana) has ten main tributaries: Red Volta, Morago, Tamne, Sissili, Kulpawn, Nasia, Nabogo, Mole, Kilurakun and Daka.

- Oti with a drainage area of 46 400 km^2 (10 380 km^2 in Ghana) rises in Dahomey and Togo and drains a narrow eastern strip 64 km wide in the north, 8 km wide in the south. The main tributaries are the Konkombu and Kulaw.

The average annual runoff in Ghana is approximately 55 000 million m^3. Virtually all the external inflow to the country is via the Volta Basin. The Nathan Report quoted river discharges and long-term average basin flows up to the 1960s. These are presented in Table 3. This shows that the River Volta, with an average annual runoff of 37 000 million m^3 accounts for more than two thirds of the national average annual runoff.

The main Volta river was first regulated by the Volta Dam constructed in 1961 at Akosombo. The Volta reservoir is by far the most important water resources development in Ghana. The 100 m high Akosombo Dam stores 148 000 million m^3 and at the highest water level covers 8 500 km^2 or 4% of the surface area of the country. The reservoir has a storage equivalent of about five years of the average inflow. The scheme was developed principally for hydropower generation and the impetus came from the development of the aluminium capacity to add value to Ghana's export of bauxite. In 1981 the Kpong Dam was constructed in the form of a tail dam downstream of Akosombo. The combined annual power output is 5000 GWh which supplies almost the entire energy requirements of the country. The operation of the schemes at Asokombo and Kpong are carried out under the auspices of the Volta River Authority established in 1961 as a completely Ghanaian organisation.

Table 2 **Major river basins of Ghana. Source: World Bank/UNDP, 1990**

No.	Basin	Total Area (km²)	Ghana Area (km²)	Ghana Area (%)	External Area (km²)
I	Volta	398 374	165 714	42	232 660
II	Bia	6 475	6 475	100	0
III	Tano	16 074	14 872	93	1 202
IV	Ankobra	8 462	8 462	100	0
V	Pra	23 188	23 188	100	0
VI	Ochi-Amissa	1 368	1 368	100	0
VII	Ochi-Nakwa	1 502	1 502	100	0
VIII	Ayensu	1 709	1 709	100	0
IX	Densu	2 551	2 551	100	0
X	Todzie	2 227	1 865	84	363
XI	Miscellaneous	8 446	8 446	100	0
XII	Aka/Keta	1 826	1 722	94	104
	Total Area (km²)	472 202	237 874	51	234 328

Table 3 **Basin runoff in Ghana. Source: World Bank/UNDP 1990**

No.	Basin	Total Basin (m³ x 10⁶)	Ghana portion (m³ x 10⁶)	Ghana portion (mm)	Percentage of rainfall (%)
I	*VOLTA*				
	White Volta	8 634	4 564	100	10.0
	Black Volta	7 648	2 097	60	5.1
	Oti	15 789	4 687	289	19.7
	Lower Volta	4 934	4 687	68	4.5
	Sub-total	37 004	16 035		
	OTHERS				
II	Bia	1 357	1 357	210	14.6
III	Tano	2 344	2 344	158	9.1
IV	Ankobra	3 824	3 824	452	25.4
V	Pra	7 524	7 524	324	18.6
VI	Ochi-Amissa	-	-	-	-
VII	Ochi-Nakwa	-	-	-	-
VIII	Ayensu	1 974	1 974	127	@10.0*
IX	Densu	-	-	-	-
X/	Todzie/Ada & Keta	-	-	-	-
XI	Miscellaneous	-	-	-	-
	Lagoon	493	493	138	9.8
	Sub-total	17 515	17 515		
	TOTAL	54 520	33 551		

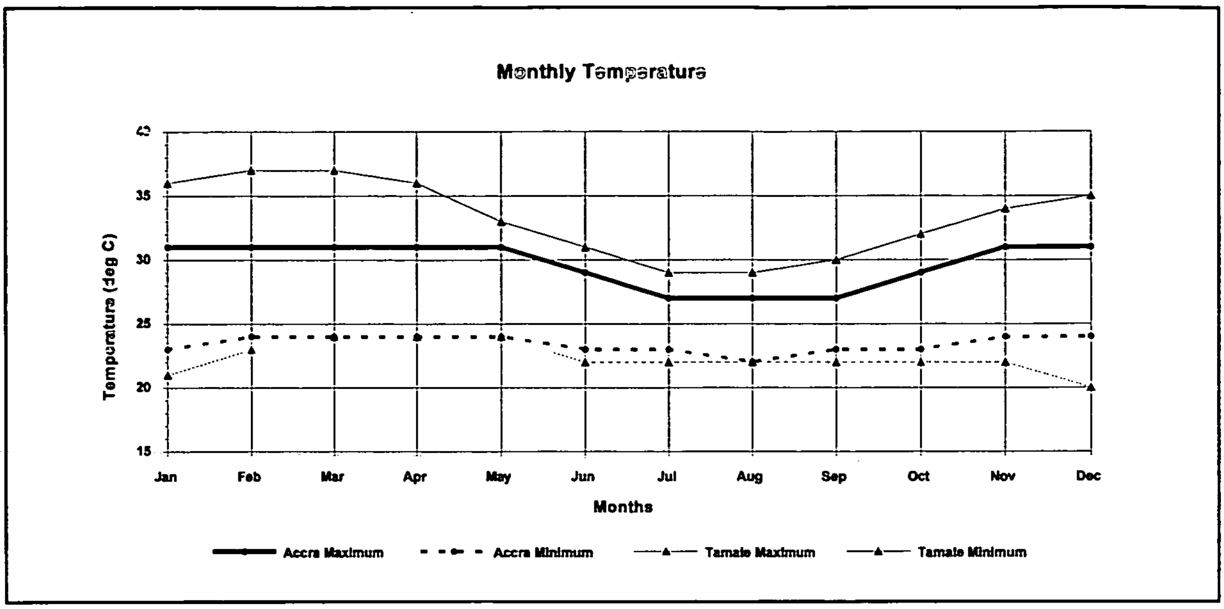

Figure 4 Temperature for Accra and Tamale. Source: Pearce and Smith 1993.

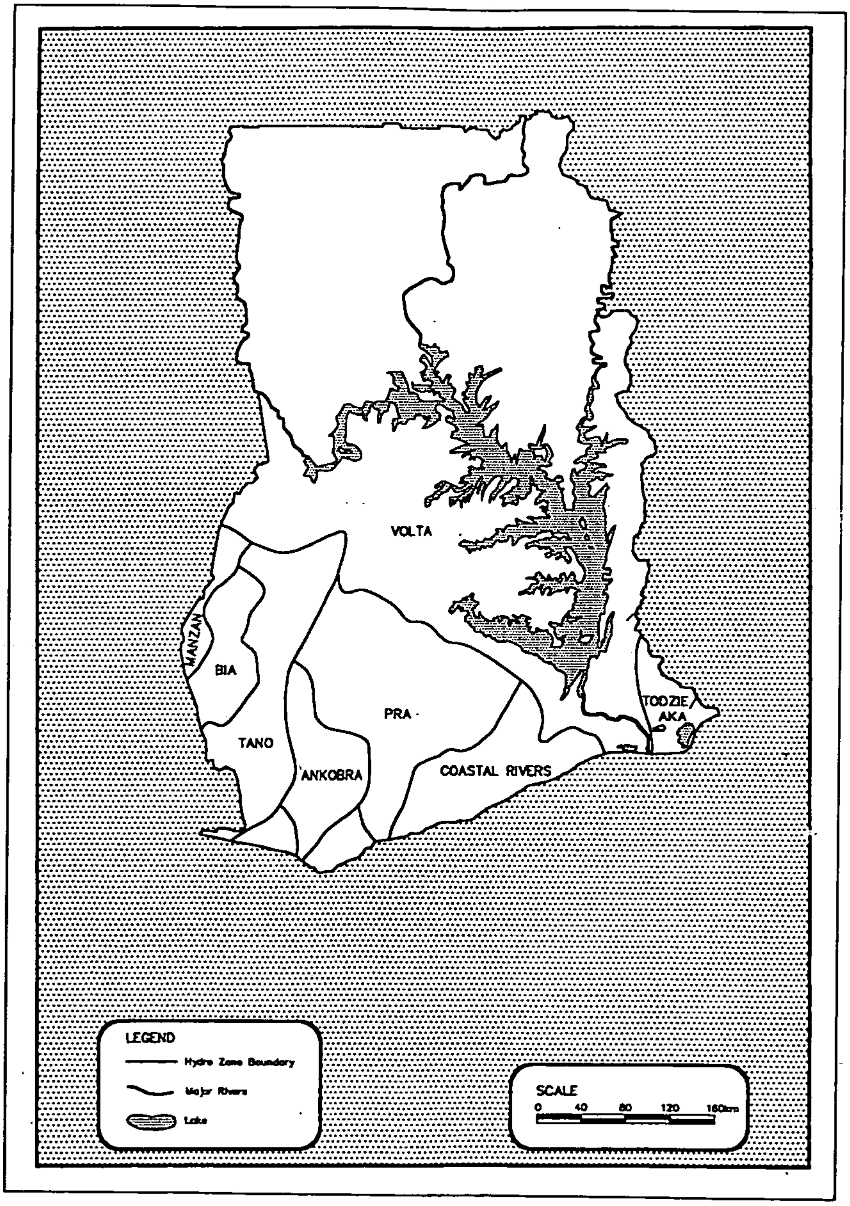

Figure 5 River Network and hydrological boundaries (after World Bank/UNDP 1990).

2.2.4 *Geology*

Kesse (1985) divided Ghana into five geological domains on the basis of age, tectonics and lithology (Figure 6). The five domains are: (1) the western unit which lies on the eastern margin of the Precambrian West African Shield; (2) The southeastern unit which belongs to the Precambrian Mobile Belt; (3) The flat lying central unit comprising sediments from the Voltaian System; (4) the coastal basins; and (5) Cenozoic deposits.

The Western Unit

The Ghanaian Shield area underlies about 45 % of the country. Two main rock systems are evident: Lower Proterozoic volcanics and metasediments of the Birimian system, with associated granitoid intrusions; and within northeasterly trending elongate basins, Middle Proterozoic sediments of the Tarkwaian system. The rocks within the Birimian System are the most important in Ghana for mineral exploration - gold. diamond, bauxite, manganese, and iron have all been found and exploited.

The Mobile Belt

The rocks that make up the Mobile Belt consist of the Dahomeyan System, Togo Series and the Buem Formation. The Dahomeyan System comprises four alternate belts of acid and basic gneiss, and forms a low lying plain broken by inselbergs of ultrabasic rocks or outliers from the Togo series. The Togo series is younger and comprise quartzite and quartz-mica schist, phyllite and silicified limestone. The Buem formation crops out at the northern edge of the Togo Series and consists of a series of argillaceous sediments and volcanic rocks.

The Voltaian System

Almost a third of the land area of Ghana is underlain by rocks of the Voltaian System, which, because of the dearth of exploitable mineral resources, have been poorly studied. The Voltaian comprises horizontally bedded sandstones, shales, mudstones and conglomerates of late Proterozoic, early Palaeozoic age. The System rests unconformably on the Birimian and is thought to be 3000 - 4000 m thick and undeformed.

The Coastal Sedimentary Basins

There are five sedimentary basins located along the coast of Ghana. The basins contain sediments of various ages, from Devonian to Recent, and comprise interbedded sands, gravels shales, clays, limestones and sandstones. There has been some exploration for hydrocarbons within these basins.

Cenozoic Deposits

These deposits consist of river, lacustrine and marine sediments with laterite, bauxite and surface ironstone. The gravels are worked for gold and diamonds.

2.2.5 *The hydrogeology of Ghana*

Ghana can be divided into two main, and one minor, hydrogeological provinces (Gill 1969, Kortatsi 1994). The main units are the Basement Complex, comprising the western unit and mobile belt discussed above; and the Voltaian Province comprising sediments from the Voltaian system. The coastal basins and recent deposits make up the remaining minor province.

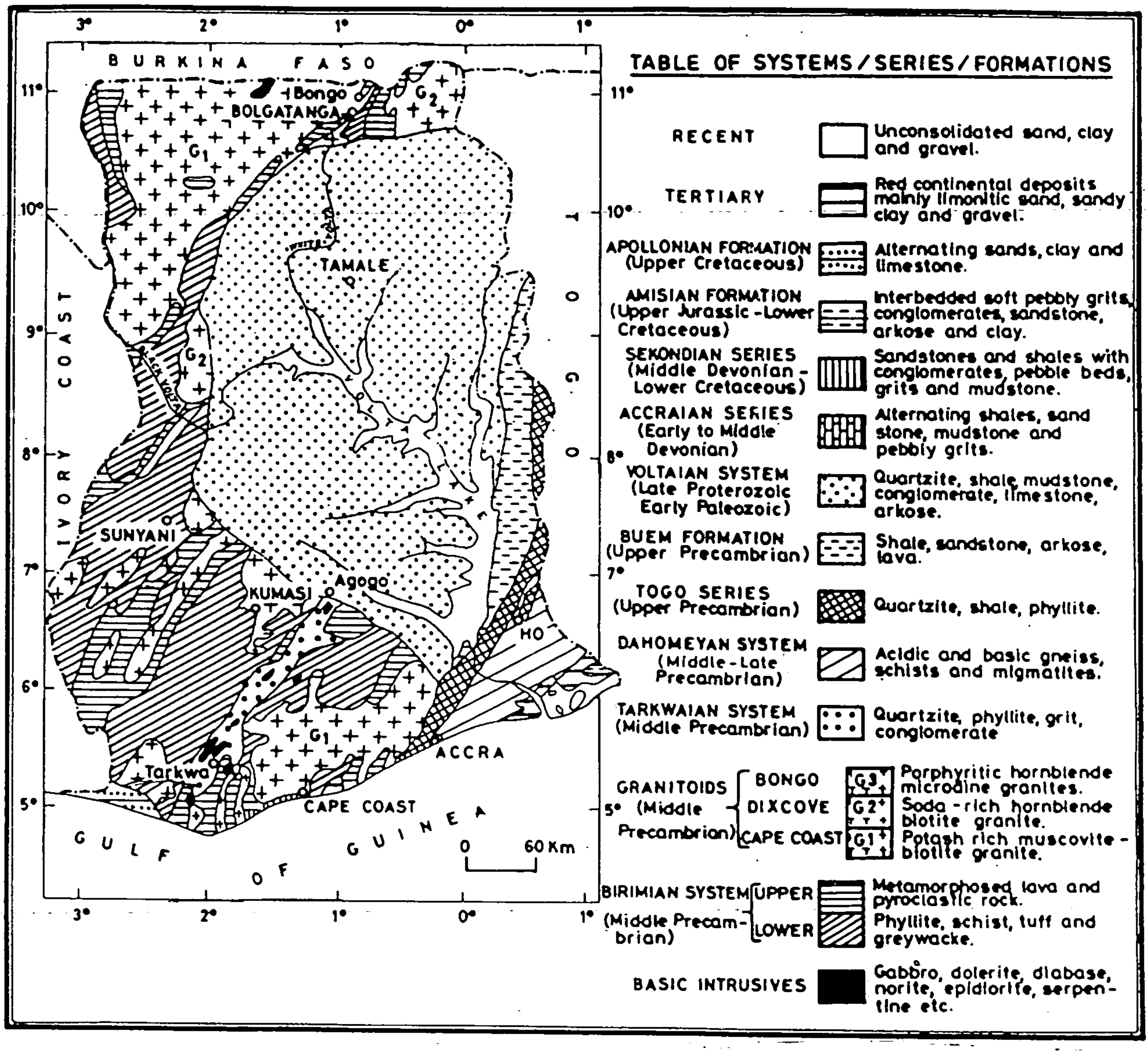

Figure 6 **Geology of Ghana (after Kesse 1985).**

The rocks of the basement complex have little or no primary porosity. There are two ways in which aquifers can be developed: (1) within the sands and gravels of the weathered zone; and (2) within fractures. The weathered layer can range from 0 m at outcrop to over 100 m. It tends to be most well developed in wetter south-western corner of Ghana where the weathered zone averages about 60 m. In the more arid north, however, the weathered zone is less developed and is on average 10 m thick. The fractured aquifer occurs beneath the weathered zone and is less predictable, relying on tectonic disturbance to create the fractures. Both aquifers are thin and limited in extent.

The rocks of the Voltaian System have little or no primary porosity and therefore also rely upon weathering or fracturing to provide secondary aquifer properties. However, the shale that underlies much of the area weathers to low permeability clay, and any fractures that may develop quickly close up. Only the sandstones or conglomerates within the Voltaian System weather to give acceptable aquifer properties. As a consequence much of the area underlain by Voltaian rocks has poor potential for groundwater development, and only where sandstone or conglomerate is present can sustainable water supplies be found easily.

The third hydrogeological province occurs along the coast of Ghana. Three aquifers occur within the Cenozoic and Mesozoic sediments. The first occurs within recent sand very close to the coast is generally thin (2 - 4 m) and contains fresh water. The second occurs within sandy clays of the Red Continental deposits and usually contains saline water. The third aquifer is found within the Cretaceous limestones at a depth of over 100 m. The groundwater is usually fresh and under artesian conditions (Kortatsi 1994).

The longest continuous hydrograph in the country is from a borehole in the WRRI compound in Accra. Figure 7 shows water levels and rainfall over the recorded period (1976 - 1987). The borehole is situated in a semi-confined aquifer which sometimes becomes artesian. However despite the complexity the water levels show a high degree of correlation with the rainfall events. Lowest water levels correspond to late 1977 when rainfall was very low. However, some recharge does appear to occur in drought years following any months with significant rainfall (e.g. during 1983).

Other minor aquifers will be found in alluvial deposits throughout the country. Sand rivers are important forms of water supply for livestock in the north of the country, but throughout the majority of Ghana alluvial aquifers have not been extensively developed.

2.3 Non-rural water usage within Ghana

2.3.1 *Hydropower*

The greatest user of water in Ghana is the hydropower industry. The Volta Reservoir is by far the most important water resources development in Ghana. The 100 m high Akosombo Dam stores 148 000 million m^3 and at the highest water level covers 8500 km^2 or 4% of the surface area of the country. The reservoir has a storage equivalent of about five years of average inflow. The Kpong Dam has been developed in the form of a tail dam for the Akosombo and together the 10 generators have an installed capacity of 1028 Mw. The annual output from the generators is 5000 GWh and supplies almost the entire energy requirements of the country. A further 19 dam sites have been identified for hydro-power potential although less emphasis has been placed on mini-hydropower potential which exist in the more remote regions of the country.

On average 900 m^3/s passes through the Akosombo and Kpong facilities and evaporation from the Lake surface probably exceeds the entire water use in Ghana's arable cropping of over 2 million hectares which is entirely rainfed. The increasing trend in water consumption is expected to continue especially considering the development of major hydropower schemes in neighbouring countries upstream of Lake Volta. The Bakri Dam in Burkina Faso is a case in point.

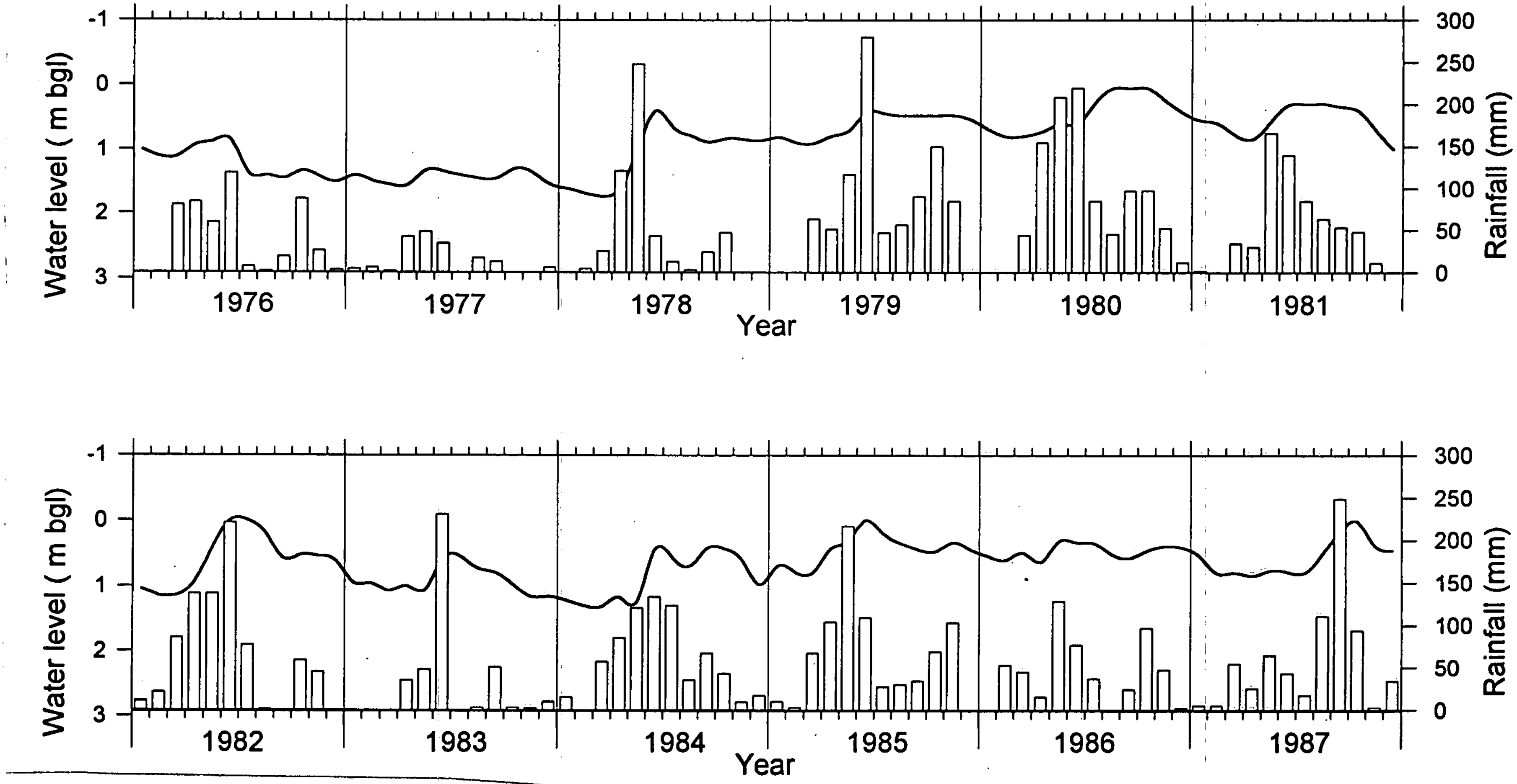

Figure 7 Monthly groundwater levels and rainfall in Accra. Data from WRRI and Pearce and Smith 1993.

2.3.2 *Municipal and industrial*

Approximately 60% of the population in Ghana have piped and treated domestic supplies either from surface water or groundwater sources. Provision for this supply is the responsibility of the Ghana Water and Sewerage Corporation (GWSC). Supplies to urban areas are principally from dams and diversion weirs and rural areas are entirely reliant on groundwater supplies. A large proportion of the 130 million m^3 of piped water is supplied to the three main urban centres in Ghana: Accra-Tema, Kumasi and Sekondi-Takoradi. This figure is expected to rise to 200 million m^3 after the completion of a rehabilitation and development programme.

Industrial water demand was estimated in 1987 at 10 million m^3 the bulk of which was in gold mining operations, with food processing, textiles, breweries, cooling water and rubber processing being other important users.

2.3.3 *Agriculture*

The development of irrigation schemes in Ghana has been slow and farming has been traditionally rainfed. In the Central Regions and coastal plains in Greater Accra, the periods when rainfall exceeds the potential evaporation is so short that even single cropping is difficult without the irrigation. Irrigation in Ghana amounts to approximately 10 000 ha with twice this area being developed in the form of pilot or small schemes aimed at rice cultivation. The potential area for irrigation based on land suitability and availability of water supplies in 1970 was estimated at more than 1 million.

2.4 Rural water supplies: the importance of groundwater

2.4.1 *Development of rural water supply*

Groundwater is available in most parts of the country, and has always provided the basis for rural water supplies. It is considered to offer the best opportunities for providing safe, low cost water systems to large numbers of scattered rural communities.

Ghana's RWS relies on a mixture of dug wells, boreholes and piped systems. Shallow wells have traditionally formed the backbone of rural water supply in Ghana. Before government and donor involvement in the sector, communities relied on simple unlined wells dug at the initiative of individuals and communities. Community participation in the development, protection and maintenance of wells has strong traditions. In the Ghanaian village setting, the term "noboa" in the Akan language is used to describe self-help among farmers, embracing many things including provision of water supplies (Sackey, 1995).

The history of hand dug well construction can be traced back to the previous century. In the period between 1920 and 1945, the Colonial Administration undertook a nationwide hand dug well programme under the auspices of the Rural Water Division, an offshoot of the Gold Coast Geological Survey Department. Most hand dug wells have been constructed in recent times, however, with perhaps 55% of the estimated 60 000[1] hand dug wells scattered throughout the country constructed since 1980 (Bannerman and Allison, 1993).

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[1] Estimates of the number of shallow wells are difficult to make. However, an inventory carried out recently in 11 Districts in the Volta Region by the WRRI on behalf of DANIDA indicated that there were approximately 4500 dug wells in the region. Assuming that each of the 10 Regions contains roughly the same number of shallow wells, a figure of 60 000 is arrived at.

Borehole drilling began in about 1946 in the Northern Territories to provide water for larger rural communities. Since then, large numbers of both deep and shallow boreholes have been drilled by national and international organisations. Since 1974, a number of externally aided drilling programmes been executed throughout Ghana (see sections below), and some 10 000 boreholes and handpumps installed (Bannerman and Allison, 1993).

2.4.2 *Approach*

Since Ghana's independence in 1957, provision of water supply has been the exclusive responsibility of the government, represented by the Ghana Water and Sewerage Corporation (GWSC), a government parastatal. The underlying philosophy has been one of 'public service', with communities playing the role of spectators in their own development (Laryea, 1994). Planning and implementation has been prescribed, technology options and choice severely restricted, and community participation negligible or symbolic.

Over the past 20 years or so, this approach has become increasingly untenable. Demands from both rural and urban residents for new schemes and maintenance and rehabilitation of existing ones meant that GWSC was severely overstretched. At the same time, the increases in coverage achieved in rural areas over the past 20 years or so has only proved technically and financially viable with large donor assistance. Many of these have themselves been problematic: major donor supported projects begun as drilling programmes, and have subsequently become maintenance and rehabilitation programmes.

Against this background Ghana, like many other developing countries, is now moving towards a system of decentralised public sector promotion, private sector provision, and community financing and management of O&M, with the aim of transferring management of water supplies in rural communities and small towns to the beneficiaries, releasing government from its liability for the recurrent costs and maintenance of RWS. Part of this new approach involves the separation of GWSC into urban (commercial) and Community Water and Sanitation Divisions (CWSD). See Box 1.

Box 1 Ghana's Community Water and Sanitation Programme

Ghana's CWSP is the outcome of a dialogue between sector specialists and representatives of national and international agencies involved in rural water supply in Ghana, aimed at increasing the effectiveness of water supply and sanitation investments. Basic principles agreed include community management, district support for communities, and a Community Water and Sanitation Division within GWSC.

The CWSP aims to establish a framework within which community demand for services can be met, and through which financial and technical assistance can be channelled. The 3 major objectives of the programme are as follows (GWSC, 1994):

1. Provide basic water and sanitation services to communities on the basis of community contributions to capital and Operation and Maintenance costs.
2. Ensure sustainability of these facilities through community ownership and management, community decision-making in their design, active involvement of women in all stages, private provision of goods and services, and public sector promotion and support.
3. Maximise health benefits by integrating RWS with sanitation and health components.

A Sector Investment Plan (SIP) attempts to put the CWSP into some form of future context by setting goals for RWSS development in the different Regions, with the ultimate aim of achieving 80% coverage by 2009. The SIP envisages a total investment of about US$200 million over the next 15 years.

A full scale demonstration of the CWSP is currently underway in Ghana, funded principally by IDA (US$21.96 million out of a total of US$27 million), with IDA credit helping to finance training and technical assistance for rural communities in Ashanti, Brongahafo, Northern and Western Regions, and for small towns in these and the Upper East and Upper West Regions. Key elements of the project, intended to serve as a role model for the future, include:

1. *Financing:* the government of Ghana will fund the capital cost of systems based on demand (subject to availability of funds), with local beneficiaries required to contribute 5-10% of capital costs. Communities are responsible for all recurrent (O&M) costs.

2. *Technology:* Communities are presented with a menu of different technology, ranging from simple hand dug wells to piped systems. These are discussed with community WATSAN committees, who chose a system they would (i) like, (ii) can afford, and (iii), that they can manage and maintain.

3. *Operation and Maintenance:* this is the responsibility of communities through their WATSAN committees. Training in day to day maintenance and repairs to VLOM handpumps is provided; major repairs would be carried out by private sector technicians, with spare parts also provided by the private sector.

4. *Implementation:* at the community level the project is promoted by District Water and Sanitation Teams (DWSTs, coming under the umbrella of the new District Assemblies, and consisting of a community mobiliser, water supply technician and health officer) and NGOs/companies that have been pre-qualified as 'partner organisations' to provide planning assistance to communities.

Acquisition of a new or improved water supply begins when a community submits a "Construction Grant Application" to its District Assembly, through the local DWST (a 2 or 3 person group of community development, water and sanitation specialists under the authority of the DA). After reviewing the application, the District passes acceptable ones onto the GWSC Regional Water and Sanitation Team (RWST), whose job it is to inform the community that it may chose a PO to help plan its system. The PO would first go through a mobilisation phase to ensure 'adequate representation' of women in the planning process, and then work with the community on a Facilities and Management Plan, with choice, management and design of system, including details on how the system would be maintained, repaired etc. The Plan is then vetted by the DWST, passed on to GWSCs RWST for checking, and returned to the DA for approval. Hand dug wells are constructed by local contractors and boreholes by drilling companies; hand pumps are installed by private distributors who also establish a spare parts supply system.

Critical assumptions of include:

- Communities are willing and able to pay for capital and O&M costs as stipulated
- Public and, crucially private sector capacity exists to support the programme
- Donor support continues (entirely dependent, technically and financially)
- VLOM handpumps and their spare parts are available

2.4.3 *Coverage*

Two thirds of Ghana's 16 million inhabitants live in rural communities (see Box 2 for information on population). Over the last 20 years or so, water supply schemes with a potential to serve about 4 million rural inhabitants (40%) have been installed. The goal of the SIP is to achieve 80% rural coverage by 2009.

Urban water supply has generally received preference over rural water supply. In 1960, about 34% of the urban population was covered while only 11% of the rural population had access to potable water (Yanore, 1994). Following the incorporation of the rural water supply division of Public Works Department into GWSC, the imbalance grew although absolute coverage increased. The first major attempts at redressing the rural-urban imbalance began in the 1970s with the implementation of 2 major rural water supply projects - the Upper Regions Water Supply Project supported by CIDA, and the 3000 wells project in southern Ghana supported by Germany (see below). Since then, the majority of rural water and sanitation investments have been made by external donors, with GWSC concentrating on the urban sector.

In reality, population served is likely to be much lower than the figures suggest. Maintenance of a rapidly expanding infrastructure has proved problematic with service subject to frequent and long outages. In the Upper East region, for example, about 42% of hand pumps are not functioning for various reasons, including, lack of spare parts, poor yields and non-payment of tariffs (Yanore, 1994). Other reports highlight similar problems. A recent review of Rural Aid's and BACH's hand dug well programme in the Upper East Region carried out by COWAP indicated that, shortly after the rainy season, over 40% of wells were dry most of the time (COWAP, 1995). Taken together, these reports suggest coverage estimates may seriously over-estimate actual coverage. If we assume that 25% of boreholes and wells are out of operation, malfunctioning and/or dry at any one time (a conservative assumption) then only about 30% of the rural population have access to a safe supply of water on the basis of government standards for consumption[2]. This represents almost 5 million rural residents at health risk and socially and economically constrained because of inadequate supply.

Regional variations in coverage are pronounced (Table 4). Upper East and Upper West are relatively well served with 60% and 88% coverage respectively. In contrast, Greater Accra, Central, Eastern and Ashanti Regions are comparatively poorly served, with between 4 and 21% coverage. It should be noted that the total coverage figures in this table differ from those presented earlier. This illustrates a problem which often arises with such figures. "Coverage" can be defined in different ways, as can the term "rural". In addition, it is not clear whether the figures only include "government" facilities, ignoring the many "private" facilities (e.g. traditional shallow wells). For these reasons. the coverage figures are only loosely indicative and need to be treated with a great deal of caution.

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[2] Ghana's CWSP document (1994) defines 'basic service' as protected, year round supply of at least 20 l/capita/day, preferably within 250-300m of all households, with water points serving no more than 300 people each.

Box 2 Population

The results of the last population census carried out in 1984 are out of date due to rapid growth and urbanisation. The annual growth of population in recent years has been put at 3.5%. In 1991 the population of Ghana was estimated at 16.7 million (FAO, 1991) and 16.4 million by World Bank UNDP in mid 1993 (1995). Approximately 40 to 45% of the population living in communities larger than 5 000 persons.

The overall population density in 1984 was 52 persons per km^2, which varied from 17 persons per km^2 in the Upper West Region to 441 persons per km^2 in Accra. These figures are increasing and the overall population density was estimated at 63 persons per km^2 in 1991. In 1985 the rural area comprised 75% coverage of communities between 500 and 5 000 persons and only 15% of communities with less than 500 persons. Many communities in the rural areas are still without access to safe water.

In 1969 Ghana became the first country in Sub-Saharan region to adopt a population policy. The objective was to reduce the population growth rate to 2% per annum by the year 2000. The Ministry of Health instituted the Ghana National Family Planning Programme but the fertility rate remains high.

Table 4 Regional variation in coverage. Source: Bannerman and Allison 1993

				Rural Population by Community Size				
Region	Number of Rural Dist	Rural Population 1990 (000s)	Population Served 1990	Disbursed <75 (000s)	Small 75-200 (000s)	Medium 200-1500 (000s)	Large 1500-5000 (000s)	Total 2009 (000s)
Ashanti	17	1,568	21%	114	457	799	914	2,284
Brong Ahafo	12	920	23%	107	295	536	402	1,340
Central	10	949	17%	111	304	553	415	1,383
Eastern	14	1,405	18%	164	450	819	614	2,047
Greater Accra	3	282	4%	21	82	144	164	411
Northern	12	987	22%	144	288	647	359	1,438
Upper East	5	785	60%	114	229	515	286	1,144
Upper West	4	456	88%	66	133	299	166	664
Volta	11	1,124	23%	131	360	655	491	1,637
Western	10	896	29%	104	287	522	392	1,305
Total	98	9,372	28%	1,076	2,885	5,489	4,203	13,653

Table 5 Organisations in the water sector. Source: World Bank/UNDP 1990

ORGANIZATIONS INVOLVED	
FOREIGN	**LOCAL**
CIDA - Canada	Government of Ghana (GOG)
DANIDA - Denmark	Action Aid
Caisse Centrale - France	Adventist Development & Relief Agency (ADRA)
CEBEMO - Holland	Ashanti Goldfields Corporation (AGC), Obuasi
GTZ - Germany	Baptist Mission
KfW/GTZ - Germany	Catholic Arch-Diocese of Tamale
MISEREOR	Catholic Arch-Diocese of Cape Coast
Conrad Hilton Foundation	Catholic Diocese of Wa
Global 2000	Catholic Diocese of Navrongo/Bolgatanga
TROCAIRE - Ireland	Catholic Diocese of Kumasi
UNICEF	Catholic Diocese of Keta/Ho
UNDP	Catholic Diocese of Accra
Africa 2000 Network - UNDP	Catholic Diocese of Sunyani
USAID	Catholic Diocese of Sekondi/Takoradi
WORLD BANK	CEDEP, Ashanti
JICA - Japan	Danish Community Project
	Church of Christ Mission
	Evangelical Presbyterian Church, Ho
	Global 2000 - Guinea Worm Eradication Project
	International Social Development Centre
	Methodist Church
	Oxfam, Tamale/Kumasi
	Peace Corp, Ghana
	Presbyterian Church of Ghana
	Volta Regional Development Programme (VORADEP)
	World Vision International
	WaterAid, Ghana

2.4.4 *Donor support*

Donor support has always been critical to the development and maintenance of the sector. Table 5 lists organisations active in the water sector. At the time of writing, no comprehensive overview of financial support provided by different agencies was available. However, US$ 27 million is committed to the CWSP demonstration project (see above) out of a total of some US$50 million committed by donors to the CWSP so far (CWSP, 1994). The SIP envisages a total outlay of some $200 million by 2010.

Major programmes that have taken place in recent years include:

- The Canadian (CIDA) sponsored rural water supply project in the Upper Regions, now in its third phase. Two thousand eight hundred boreholes were sunk in the 1970s during the first phase, and were subsequently rehabilitated in the second (1980s) phase. This is a classic illustration of how water supply projects turn into maintenance projects when sustainable systems are not put in place.

- Three thousand boreholes project in Central and Southern Ghana, sponsored by Kreditanstalt fur Wiederaufabau (KFW).

- Japanese sponsored drilling projects (JICA) in Nanumba District, Jaman/Berekum District and Juabeso/Bia and Sefwi-Wiawso Districts.

- French Government (Caisse Centrale de Cooperation Ecomomique) rural water supply project in the Central Region (450 boreholes-first phase).

- World Vision International (WVI) in several Regions, and currently in the Greater Afram Plains of Central Ghana (500 boreholes).

- World Bank sponsored development, forming part of the Voradep rural/agricultural development project in the Volta Region (250 boreholes).

- Catholic Church sponsored projects in 8 Dioiceses (900 boreholes).

- Other NGOs, particularly those sponsored by Water Aid UK, e.g. Rural Aid in the Upper East Region (over 400 hand dug wells).

It is interesting to note that none of these programmes could be termed "emergency assistance", in the way that emergency drilling programmes in response to drought in Malawi were. However, no information is available on donor (or government) response to the severe drought of 1983 and 1984. Water Aid received a request from the British Embassy to provide "emergency assistance" during the troubles in Northern Region in 1994. This was turned down, on the basis that Water Aid is not a relief agency.

Annual meetings (MOLE conferences) of all those involved in the water sector (government, local NGOs, donors etc) are held to discuss approaches, share experiences and coordinate activities. The theme of the last meeting, was the role of partner organisations.

3. THE NATURE OF WATER SHORTAGE IN NORTHERN AND UPPER REGION

3.1 The study area

3.1.1 *Preamble*

The study area includes the Northern and Upper Regions of Ghana. Several factors were taken into consideration when choosing Northern Ghana: (1) because of its single wet season (and therefore longer dry season) the north is more susceptible to drought; (2) the two main hydrogeological units are represented within the area, therefore the response of both to drought could be monitored; (3) as a consequence of a drilling programme by CIDA in the Upper Regions some hydrogeological data exists for the Upper Region; and (4) Wateraid (via Rural Aid) have a large hand-dug well programme in Upper East, therefore the difference in behaviour of the two abstraction methods could be monitored.

The chief difficulty in studying the effect of drought on groundwater is the lack of data available during drought periods. As a consequence, it is difficult to describe quantitatively the response of both the groundwater resource and individual sources under different conditions. Anecdotal information exits, although this is less reliable, especially when trying to unravel events that occurred 10 - 20 years ago. A list of available data is given in Annex 1. In general more time series data exists for the Upper Regions, where CIDA have had a long term commitment (Wardrop 1980). Various projects have been undertaken in the Northern Region, however, long term monitoring or detailed data collection have not played a prominent part.

The purpose of this inception report is not to undertake detailed analysis of the groundwater, hydrology or drought within the Northern and Upper Regions, rather, to describe some of the key issues pertaining to the subject that require further analysis in course of the study.

3.1.2 *Surface water, runoff distribution and drought*

Preliminary analysis of monthly streamflow characteristics of the rivers in Ghana has been carried out by researchers at WRRI. Figure 8 and Table 6 illustrate the seasonality of flows for selected rivers in the north and south of the country.

The flow regime of the northern rivers is similar with almost no runoff for six months of the year followed by increasing flow from April, reaching a maximum in September. Many of the rivers in the northern region are ephemeral because of the long dry season and limited baseflow. Even in the wet season rivers may only flow after intense rainfall and water is obtained through shallow dug outs (Figure 9). The White Volta experiences zero flow during January to April but the Black Volta and Oti have higher low flows during this period. The main Volta river and the southern rivers have a more evenly distrusted flow pattern and are perennial.

Ghana can be divided into the northern and southern region using the magnitude and characteristics of specific yield (volume of runoff per unit area per unit time). This boundary approximates to the topographic divide separating the Volta from the coastal river systems. The northern zone has typically low specific yield, with the minimum found at Lawra and Black Volta. The specific yield increases eastwards across the White Volta with the river Oti recording the highest value at Kpetchu.

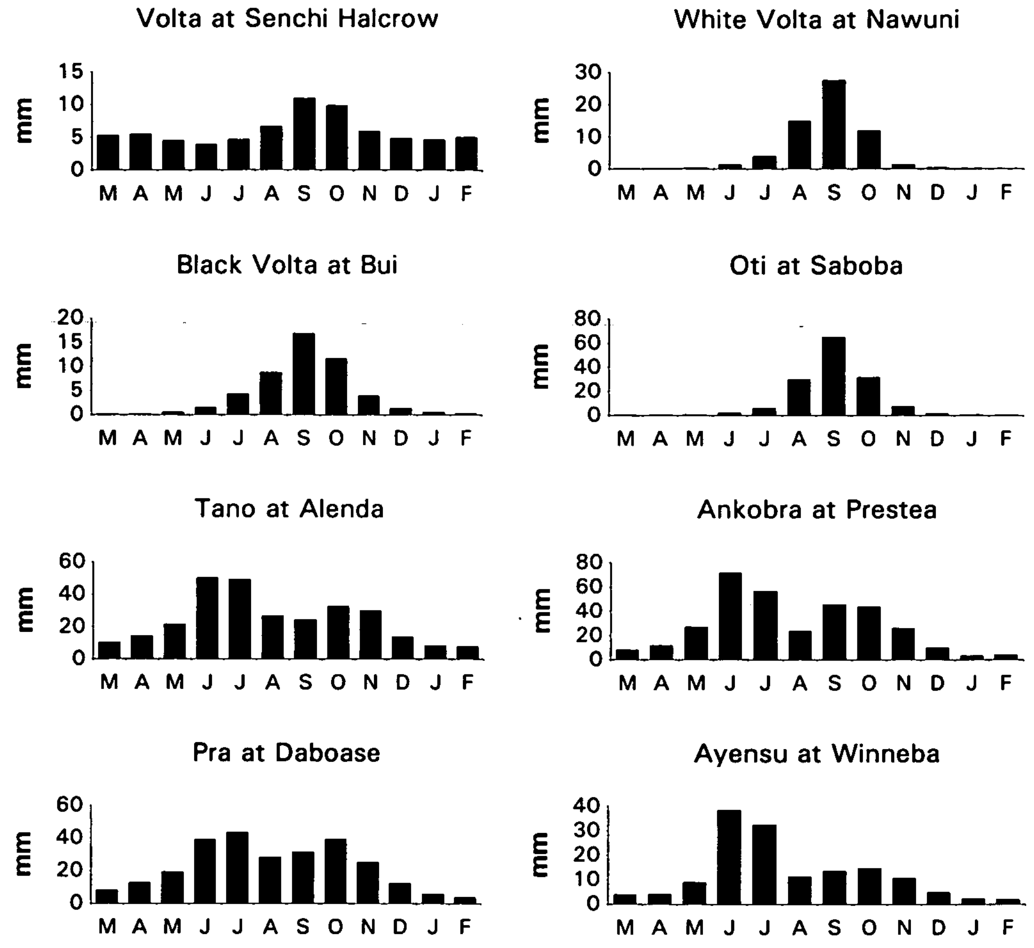

Figure 8 Seasonality of river flows. Data from WRRI, Accra.

Table 6 Average recorded average monthly yield (mm) for selected gauging stations. Data from WRRI, Accra.

River and Station	Area	Period	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Year
Volta at Senchi Halcrow	390 758	1965-81	5.3	5.5	4.6	4	4.7	6.7	11	9.9	6	4.9	4.7	5.1	72.4
White Volta at Nawuni	96 957	1965-84	0.1	0.1	0.5	1.5	4.1	15	27.7	12	1.4	0.4	0.2	0.2	63.2
Black Volta at Bui	121 026	1965-82	0.2	0.2	0.6	1.6	4.3	8.8	16.9	11.7	4	1.4	0.6	0.3	50.6
Oti at Saboba	54 890	1965-84	0.2	0.3	0.8	2.2	6.1	29.8	64.9	31.8	7.5	1.7	0.6	0.2	146.1
Tano at Alenda	15 975	1965-78	10.3	14.4	21.6	50.3	49.2	26.7	24.4	32.8	30	13.9	8.4	8	290
Ankobra at Prestea	4 268	1965-81	8.3	11.9	27.2	71.8	56.8	23.7	45.8	43.9	26.1	10.1	3.6	4.3	333.5
Pra at Daboase	22 820	1965-84	8.1	12.9	19.5	39.3	43.6	28.5	31.6	39.5	25.5	12.7	6	3.9	271.1
Ayensu at Winneba	1 658	1965-84	4	4.2	9.1	38.5	32.5	11.4	13.6	14.7	10.7	4.9	2.3	2	147.9

Figure 9 River bed during the wet season in Northern Ghana.

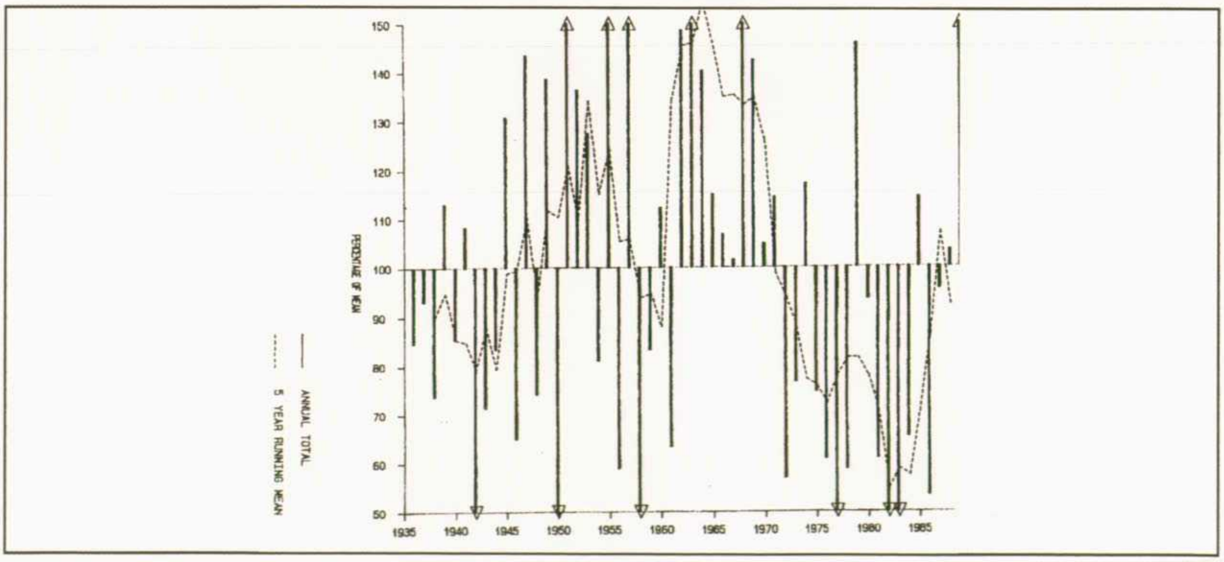

Figure 10 Departures from mean annual flow in Lake Volta (after World Bank/UNDP 1990).

The pattern and distribution of specific yield and mean annual rainfall in Ghana are similar. Exceptions to this rule are the coastal regions. Higher specific yields compared to mean annual rainfall are found because the coastal stations are downstream and receive water draining from the higher rainfall regions further upstream.

Areas of high population density are found in high specific yield areas. The Pra basin has a high population density of 88 persons/km^2 and has between 150 000 m^3/km^2 to 400 000 m^3/km^2 specific yield compared to the lowest population density of 23 persons/km^2 found in the Black Volta basin, which has the lowest specific yield of 36 000 m^3/km^2 to 70 000 m^3/km^2. This equates to approximately 4.7 m^3 to 12.5 m^3 of water per person per day in the Pra basin compared to 4.3 m^3 to 8.3 m^3 per person per day in the Black Volta. According to AEW, the domestic water demand per person per day in 1984 was 0.114 m^3. This is projected to increase to 0.136 m^3 by the year 2000. It could therefore be argued that there is adequate amount of water to meet the domestic needs of the population in urban centres.

It has been estimated (Sam and Ayibotele, 1987) that less than 1% of the nations average annual water resources of 55 000 million m^3 is being consumed. This figure is misleading because it does not take into account the serious shortages resulting from seasonal and spatial distribution effects. The northern region can have overall high annual rainfall but is very seasonal. During the pronounced dry season untreated surface water can become very scarce and can be a serious risk to health. These factors combined make the secondary permeability aquifers a very important source of water in the region.

Best evidence of low flow years and drought periods can be seen in the reduction of inflows into Lake Volta. Departures from the mean annual inflow into Lake Volta are illustrated in Figure 10 with the low flow sequence starting in 1972 (World Bank/UNDP, 1990). During the period 1970-1990 the mean runoff from the Volta catchment was only 80% of the long term mean used to design the Akosombo scheme. During the 1980s, the Lake level was below the lower rule curve in seven out of the ten years and failure of the rains in 1983/84 led to a crisis in power generation, with rationing and reductions imposed.

The recent Sahelian drought has caused concern in Ghana that the firm power from the Volta scheme is less than was originally designed. Although recovery from dangerously low lake levels occurred after the high flow events in 1989, the 1990 season gave a further indication that the Sahelian drought had not ended, with only 14 000 million m^3 of runoff, equivalent to 38% of the long term mean.

3.1.3 *Hydrogeology, well types and yields*

Northern Region

The majority of the Northern Region is underlain by shale and sandstone from the Voltaian System. Permeability is generally quite low and many boreholes and wells are dry. The region is infamous for the difficulty in finding sustainable sources of groundwater. Areas underlain by sandstone or conglomerate are generally more favourable than others. Usable groundwater resources are found in areas where the sandstone, siltstone or conglomerate are fractured or weathered. Unfortunately, since the geology has not been mapped in great detail, identifying such areas is difficult, and therefore borehole/well siting difficult. Resistivity has been used to try to increase the success rate of borehole/well siting, but generally it has not be of much use. Clay and shale have low resistivity and can mask the presence of the high resistivity sands and conglomerates. The most detailed geological map available for the Northern Region is shown in Figure 11.

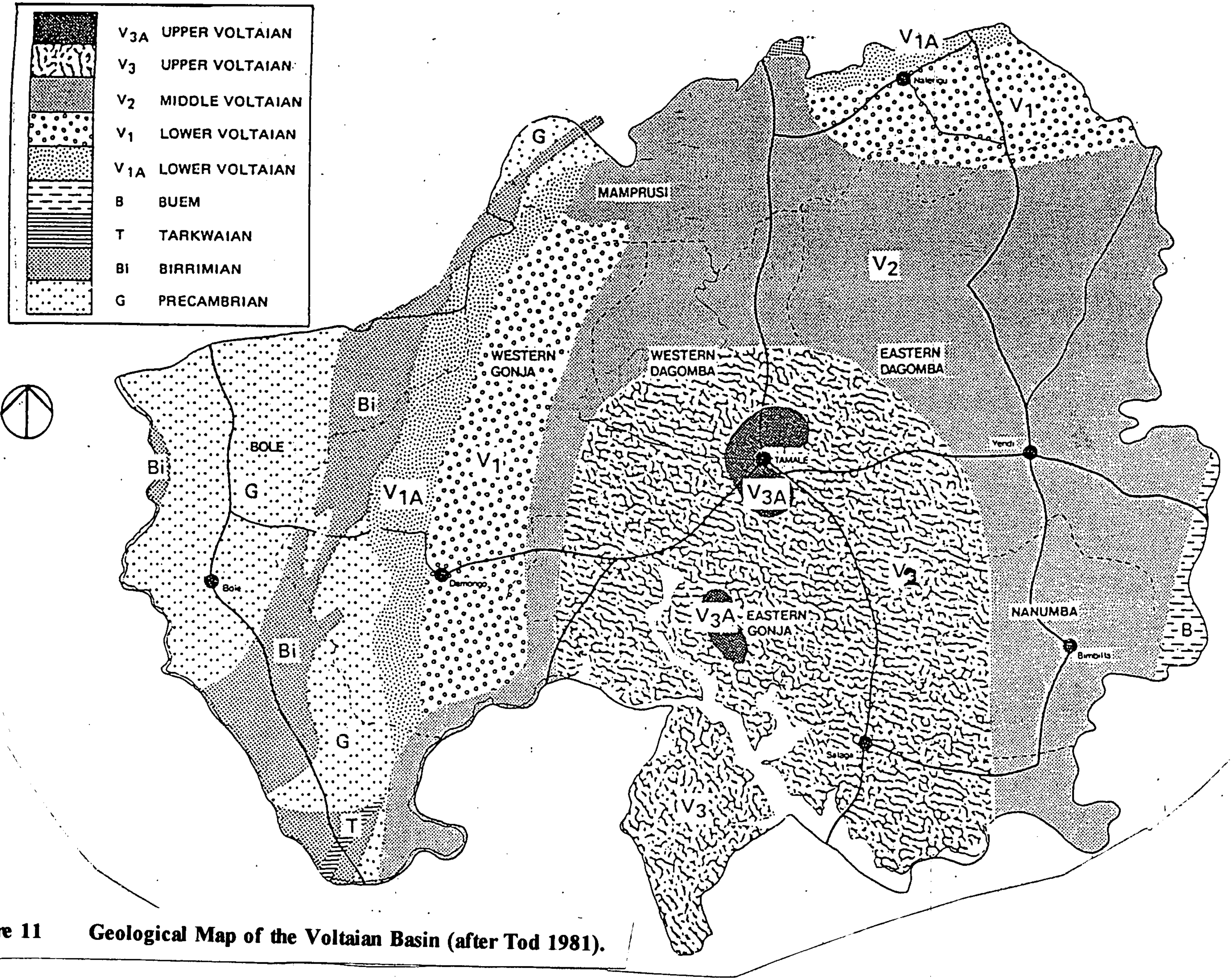

Figure 11 Geological Map of the Voltaian Basin (after Tod 1981).

In the Northern Region yields are unpredictable. Figure 12 shows a sketch map of Ghana illustrating the probability of drilling a successful well. The map is based on little data and is very approximate, but illustrates the low probability of drilling a successful borehole in the northern region. A summary of 571 boreholes drilled in the Voltaian Basin between 1984 and 1988 has been given by Bannerman (1995). The boreholes are mainly sited in the higher yielding sandstone areas of the basin and are generally less than 100 m deep. Recorded yields ranged from 0.1 to 12 l/s, but more commonly were between 2 and 3 l/s. Since only successful wells were tested the data is biased towards higher values. Other studies (e.g. Tod 1981) illustrate much lower yields in the Northern region and a high probability of drilling a dry hole (see Table 7).

Hand dug wells are widespread throughout the Northern Region. A recent report by Bannerman (1990) suggested that boreholes were technically superior to wells in the Voltaian Basin; boreholes are likely to be more effective where deep fractures are important for supply. In low permeability areas, however, a large diameter well is required to provide sufficient storage to meet water needs. GWSC have often found that in some areas within the Northern Region where boreholes have been unsuccessful, large diameter wells have provided sustainable supplies. From 1920 to 1945, the Colonial Administration initiated a large well digging programme, many of which are still observed today. After 1946 boreholes were favoured. Recently, hand dug wells have come back to the fore for rural water supply. Little information exists on the quantity or behaviour of hand dug wells in the region.

Another traditional system for water supply was prevalent early in the 20th century in the Northern Region, although its practice appears now to have died out. The method involved digging flask like structures called *Biligas* in low permeability clay (Geological Survey 1936, Junner and Hirst 1946). The Biliga was essentially a rainwater harvesting system which collected water during the wet season and stored it for use during the dry season. The success of the Biliga is testimony to how impermeable the geology is within the Northern Region. The Geological Survey (1936) concluded that the Biligas was the only viable option for water supply in the region; the absence of such structures today is a mystery, but may be due to unsustainability towards the end of the dry season.

Table 7 **The yield of the various Geological units in the Voltaian Basin. Source: Tod 1981**

Geological unit	Variation in yield	Probability of successful borehole (>0.17 l/s)
Lower Voltaian	dry - 2 l/s	50%
Middle Voltaian	dry - 4 l/s	63%
Upper Voltaian	dry - 3 l/s	28%

Mean annual rainfall is 1050 mm in Tamale. Significant rainfall usually occurs between March/April and October with a severe dry season for the remaining 4/5 months. Rainfall events can be intense and rapid with a high degree of runoff. Penman evaporation is high, approximately 1850 mm. The vegetation of the area is wooded savannah with approximately 25% of the land area cultivated.

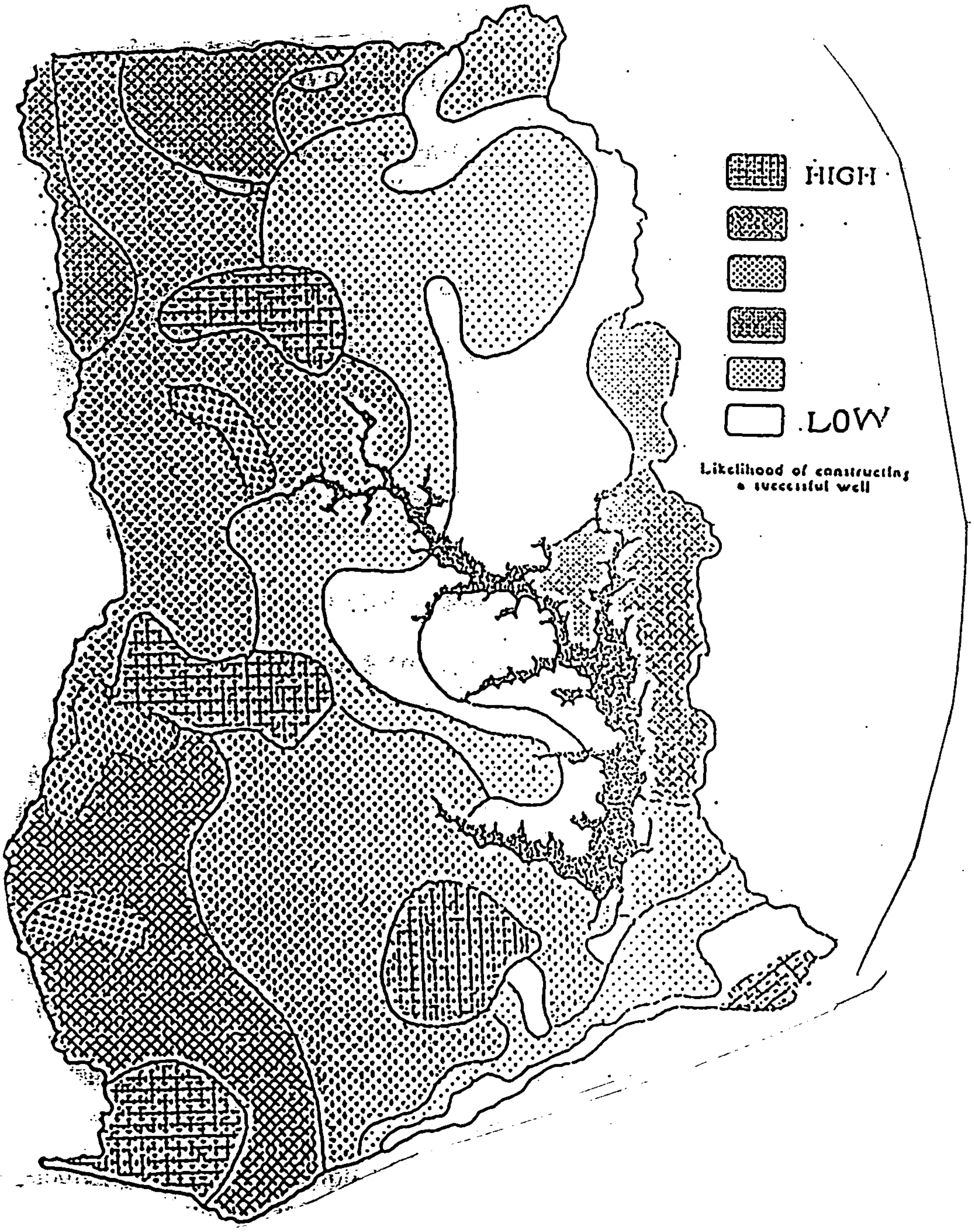

Figure 12 Well yield map of Ghana (after Bannerman and Allison 1993)

During the wet season many people rely on surface water from ephemeral rivers and small dams. The dams are used both for domestic supply and watering animals. As the dry season develops, the surface water sources progressively disappear and communities become more reliant on groundwater. The quality of the water from the small dams is poor. Often they are infested with guinea worm.

Upper Regions

The geology of Upper East and Upper West is favourable for providing groundwater. The rocks are PreCambrian consisting of granite and some metamorphic rocks known as the Birimian (see above). These rocks provide a hydrogeological environment that has been much studied throughout Africa (e.g. Wright and Burgess, 1992). The fracturing of the bedrock and the depth of weathering all affect the occurrence of groundwater resources. In Upper region, deep weathering was found in areas with a high degree of fracturing or quartz veins (Wardrop 1980).

Aquifer properties vary greatly, depending on the degree of weathering, boreholes drilled only a few metres apart can have radically different yields. In Upper Region transmissivity values of 7-30 m^2/d are common for successful boreholes and values of storage coefficient from 3×10^{-4} to 0.008. Wardrop (1980) quote 0.01 as a long term estimate of specific yield. Since the basement aquifer occurs in pockets, depending on deep weathering, there is little regional groundwater flow. Problems with reliable perennial supplies are found only in areas with limited weathering.

As a consequence of the good aquifer properties of weathered basement groundwater has been extensively developed in the Upper Region, with several phases of borehole drilling and hand dug well construction. Large scale projects are being undertaken by CIDA and Wateraid. The combination of moderate permeability and little storage has made the aquifer slightly susceptible to over-exploitation. Concern by some of the donors lead to a study (McIvor 1993) which concluded that over exploitation was not actually occurring throughout the aquifer. Rather, some localised problems are caused by high pumping for urban areas; rural water supply has a negligible effect on the overall groundwater resources.

Rainfall in the Upper Regions is similar to that in the Northern Region. At Wa in Upper West, average rainfall 1917-91 was 1070 mm, again with a 4/5 month dry season and intense short storms during the wet season.

3.1.4 *Water supply programmes in the study areas*

Both Northern and Upper Regions have received donor support, in terms of technical and financial assistance, for several decades. It seems that both regions were initially selected for assistance because of the poor water supply situation prevailing in these poorer areas. No historic coverage records are available, but it would seem that coverage in these areas was initially very low. After much assistance, coverage is now among the highest in Ghana.

The Upper Regions have received support from the Canadian Government, through CIDA, for over 2 decades. The CIDA programme is an interesting example of how support tends to proceed from supply development (borehole drilling in this case) to maintenance and rehabilitation as initial investment proves unsustainable. The phases followed are as follows:

Phase 1:	Water Supply project
Phase 2:	Water Utilization/Maintenance project

Phase 3: Community water supply project (COWAP).

The CIDA programme, like most others, is now focused much more on ensuring the sustainability of investments through community based management (CBM).

Wateraid also have a large water supply programme in Upper East. Working through Rural Aid and Bach. The activities of these organisations started in 1987 and by 1993 over 400 wells had been sunk. By 1995 over 750 wells had been sunk. Table 8 shows recent groundwater based rural water supply projects in the Upper and Northern Regions.

Table 8 **Distribution of recent groundwater based rural water supply projects. Source: World Bank/UNDP 1990**

Project	Schedule	Agency	Planned WS facilities
Northern Region			
NORRIP	1988-90	GWSC/CIDA	350
RWS Project Phase I	1987-88	GWSC/JICA	151
RWS Project	1986-90	Baptist Church	300
BH RWS Project	1985-88	Catholic Church	141
Tamale drilling Project	1985-86	Catholic Church	175
HDW Project	1986-90	Church World	?
HDW Project	1986-89	Lutheran Church	?
Upper Regions			
Water Utilisation	1974-80	GWSC/CIDA	2600
CWS, HP testing	1988-90	UNDP/WB	50
CWS/S Project	1987-91	DCD/UNICEF	560 spread throughout 5 regions
Wa Dug Well project	1986-	Catholic Church	?
Wa drilling	1985-90	Catholic Church	220
Dug well project	1985-90	Peace Corp	100
Rural Aid	1987-95	WaterAid	790
BACH	1989-95	Water Aid	113

3.2 Water demands: long term and short term patterns

3.2.1 *Seasonal variations in groundwater demand*

An important hypothesis emerging from the nature of "groundwater drought" (see MacDonald and Calow 1996) was that short term, seasonal changes in demand may be an important factor influencing source behaviour. Here, short term changes are examined in the context of (i) the household/village, and (ii) the wider community.

During the short time of the study visit, it was not possible to collect detailed information on household water use. The only information available (other than through observation and oral reports) comes from a survey into village/household level water and sanitation conducted in 1970 for CIDA (see Box 3). The results of the (introductory) survey would seem to lend support to the argument that most water is used to meet basic needs.

Some estimates of the variation in water pumped from a local community well serving 1000 people has been given by McIvor (1993). During the wet season roughly 6 m^3 was pumped from the well per day. Towards the end of the dry season the supply of groundwater increased to 15 m^3 per day. Although these figures should be treated with caution, the small study does illustrate the marked seasonal fluctuation in demand for groundwater.

A recent report into poverty in Ghana (World Bank, 1995a) indicated that, in the rural north, households rank access to food, health care, education and water (for both productive and domestic use) as most important. Survey results indicated that for extremely resource-poor communities in the Upper Regions (especially very densely populated areas such as Bongo and Bawku), access to dry season water was a particular problem. The importance of water for vegetable gardens was stressed, as these could be a vital source of income in the 'hungry season' prior to the main harvest in the rainy season. In addition, the importance of water for animals was emphasised: water is used to allow animals to be pastured near the village, so that manure resources (vital to maintain overstressed farming land) can be utilised.

Box 3 Water use at village level

A study conducted for GWSC and CIDA into factors affecting water use (Wardrop and Associates Ltd, 1977) sheds some light on water use patterns, despite being rather dated. Principal conclusions of this brief study included:

- Water is taken from a variety of different sources according to seasonal availability, preferences, access, etc. Water pumped from boreholes increases in the dry season and decreases in the wet season, when other sources are available (rivers, dams etc)
- Total water use increases in the dry season: more water is drunk, people bath more often and non-essential use (e.g. making mud blocks for walls and houses, irrigating dry season gardens, etc) increases. No information was collected on relative quantities used for different essential versus non-essential purposes, but reports from GWSC staff indicate that quantities are relatively small. No mention was made of water used for livestock.
- Increases in water supply coverage, for instance through drilling of an extra borehole, is not thought to increase water use in most situations, as carrying water from well to home is hard work and so minimum amounts are generally used.
- Precise determination of per capita water use is difficult. Figures of between 15-35 l/capita/day have been suggested. GWSC uses a figure of approx 23 l/capita day as a design figure in rural areas.

Short term migration patterns have also been noted. Laryea (1994) reports that migrant farming is common place, with farmers belonging to small ethnic groups moving far and wide for short (not specified) periods of time.

3.2.2 *Long term processes affecting groundwater demand*

A preliminary conclusion, based on anecdotal evidence and some reports (see below), is that demographic change (rather than, say, economic change) has been the main driver of long term changes in groundwater demand. This conclusion is based on the evidence that most water, certainly in the rainy season, is used to meet basic needs such as drinking and washing (see below), and the fact that the structure of the rural economy in these areas is based heavily on subsistence, rainfed, agriculture.

The following would seem to support this conclusion:

- The low stage of development of many rural communities (Northern and Upper Regions are the poorest in Ghana), which would indicate, a priori, that the range and water intensity of different water using activities is low. The GOG suggest a figure of 20 l/capita/day as sufficient to meet basic needs.
- Reports suggest that some households keep dry season vegetable gardens to supplement food and income needs during the dry season, and that other water uses (e.g. making mud bricks and watering livestock) may also be important in the dry season. However, it seems unlikely that these activities place heavy demands on water sources, as water needs for such small scale activities are probably low.
- The poor yield of many water sources probably precludes heavy abstraction in the first place.
- The technologies employed to collect and transport water (typically buckets and hand pumps; water carried back to the household in small buckets) dictate that only small amounts of water are used.

An interesting hypothesis is that increasing coverage following RWS projects may increase water use over the long term, as latent demand for water is satisfied. A preliminary conclusion is that this is unlikely, at least to any significant extent, because water collection and transport is still a very labour intensive and time consuming chore, even at relatively high water point densities. Sanitation and health education, an important component of the CWSP, may increase water use over the longer term although, again, perhaps not to any significant extent.

If demographic change is the main driver of changing water demand, what has been the nature of demographic change in the area, and can projections and predictions be made? Tables 9 and 10 below present population data drawn from a review of water supply status in the Upper Regions carried out by Bannerman (1990) for CIDA. No demographic data, other than the total rural population (see Table 4 above), was available for the Northern Region. The data indicate that population growth can be expected to almost double the number of rural dwellers in the Upper East Region over the next 25 years.

Migration may also be a significant factor in affecting local and regional demands. Bannerman (1990) and others report a movement of people from countryside to town and city in many areas, although not significant enough to compensate for rural growth rates. As the events in the Northern Region in 1994 demonstrated, political and ethnic disturbances can also precipitate short term, and perhaps permanent, migration. Additional seasonal migrations of farmers have also been reported (see below), and this may be widespread.

Table 9 **Population projections for the Upper Region. Source: Bannerman (1990)**

Region	1984	1990	1995	2000
Upper East	771 584(88%)	926 692(86%)	1 079 515(85%)	1 257 540(83%)
Upper West	439 161(89%)	521 637(86%)	602 083(85%)	692 935(83%)

Note: last census carried out in 1984. Projections based on questionnaire results? Figures in parentheses denote % rural.

Table 10 **Rural population (1990 estimate) served by boreholes in the Upper Region. Source: Bannerman (1990)**

Region/District	Total pop (rural)	Population served	% population served
<u>Upper East</u>			
Bawku East	255 135	141 600	56%
Bawku West	77 195	33 000	43%
Bolgatanga	158 145	82 800	52%
Bongo	82 419	49 500	60%
Kassena-Nankana	143 693	73 800	51%
Builsa	81 509	30 300	37%
Total	798 096 (86%)	411 000	51%
<u>Upper West</u>			
Wa and Nadowli	215 216	143 700	67%
Jirapa-Lambussie	79 983	58 800	74%
Lawra	97 311	60 300	62%
Sissala	62 598	57 300	92%
Total	455 108 (87%)	320 098	70%

3.3 General Picture of drought in Northern Ghana

The rainfall records show the mid 80s and in particular 1983 as a time of drought within both the Upper and Northern regions of Ghana. Many Ghanaians, when asked about drought referred to 1983 as being most severe, possibly because of the large bush fires that raged that year, causing much damage. In the Northern region 1993/94 was also mentioned as a time of stress on water sources. This was a time of tribal disturbance, resulting in the destruction of property (including pumps and boreholes) and also significant migration.

In addition to these two water supply "crisis", there are many problems with general groundwater supply in normal, non-drought years, particularly during the dry season. Problems are most severe within the Northern Region, due to the low yielding boreholes and wells.

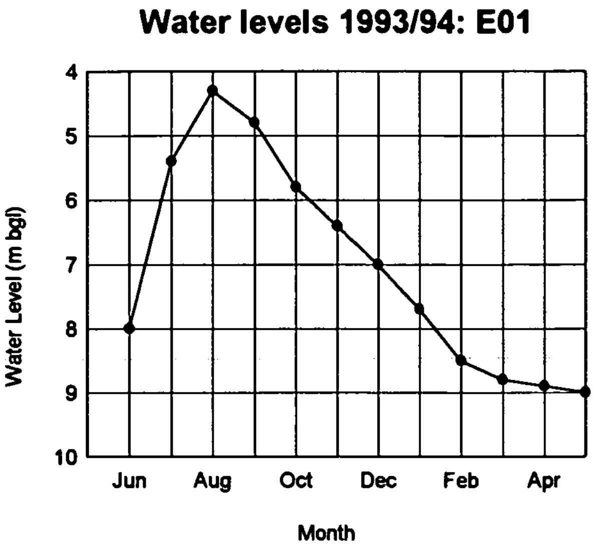

Figure 13 Typical hydrograph for the Upper Region. Data from GWSC, Bolgatanga.

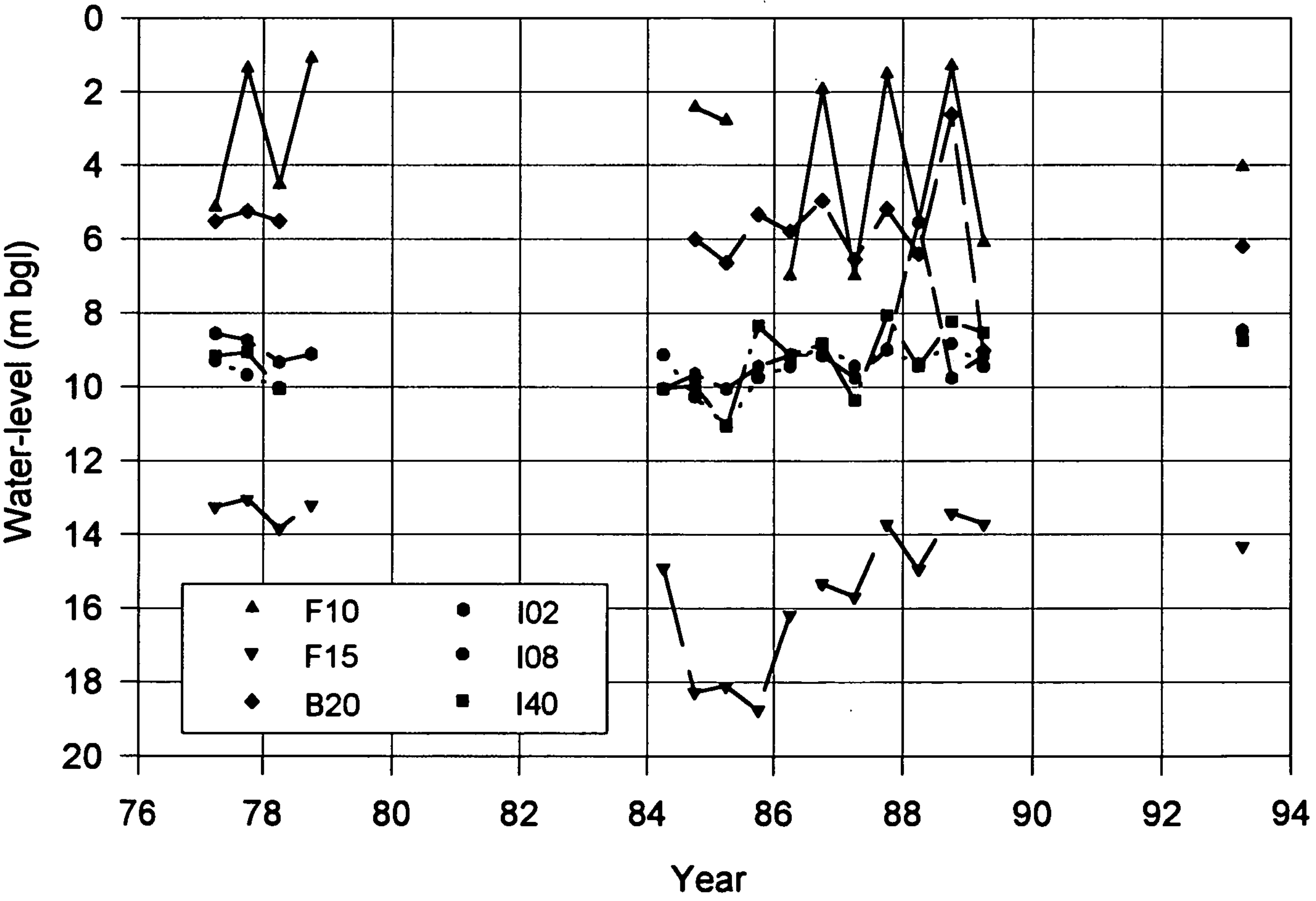

Figure 14 Long term hydrograph for the Upper Region. Data from GWSC, Bolgatanga.

Groundwater hydrographs are available only for the Upper Region (see Annex 2). Monthly water levels are only available for one cycle, 1993/94. Water levels were measured in pumping boreholes after one hours rest; only high permeability sites were monitored to minimise the problems of incomplete recovery. Highest groundwater levels were generally recorded in September and lowest levels in March. Figure 13 illustrates a typical hydrograph. Fluctuations in groundwater level varied from less than 1 m to over 7 m; generally fluctuations were between 2 and 4 m.

Box 4 Yawn boreholes

The village of Yawn lies very close to the Burkina Faso border. A borehole was drilled in the early 1970s during the CIDA programme to a depth of 17 m (455 A28) but had radically reduced yields sometime after, eventually 'drying up'. It was assumed that the water levels had declined in the borehole. People would come at 3 am to queue for water. When the problem was reported to CIDA the pump was removed. Traditional wells also dried up in this period - the community thought this was linked to the borehole (possibly the wells were not maintained after borehole drilled, falling quickly into disrepair and low yield).

During the drought years of the early 1980s people travelled to Burkina Faso (1 mile) to fetch/buy water. The Catholic Mission replaced their borehole in 1993 with one drilled to 33 m. Currently it yields very well.

Long term hydrographs are available at a number of sites in the Upper Region, but unfortunately none of the records are complete (see Annex 3 and Figure 14). In particular, records from 1979 to 1984 are missing. Sufficient information is available in the hydrographs to show some general points about the response of the aquifer over the past 20 years:

1) There appears to be little long term decline of water levels. Measurement in 1993 are roughly similar to measurements in 1976.

2) Seasonal fluctuations appear greater in boreholes with shallower water tables.

3) Water levels in the deeper aquifers were still declining at the end of the meteorological drought in 1984. The lowest water-levels were recorded in late 1986.

4) The shallow aquifers had already started recovering by 1984.

Maintenance records are available for boreholes in the Upper Region over the drought period (see Figure 15). These show a high degree of correlation with the seasons. Box 4 illustrates an example. More boreholes were out of commission during the dry season than the wet season. In particular, many boreholes were not working during March 1983 and March 1985 (Wardrop 1987a). Several reasons were identified (Wardrop 1987b):

- the borehole originally had a low yield
- the water levels had fallen below the pump intake
- the borehole had become infilled with silt.

As yet, the many hand dug wells completed in the Upper Region have not yet experience a severe drought, therefore their performance cannot be assessed. It is standard practice for the wells to be completed 3 m below the dry season minimum to proof against drought. Extra lining rings are cast and left around the well head to facilitate the deepening of wells during particularly difficult years.

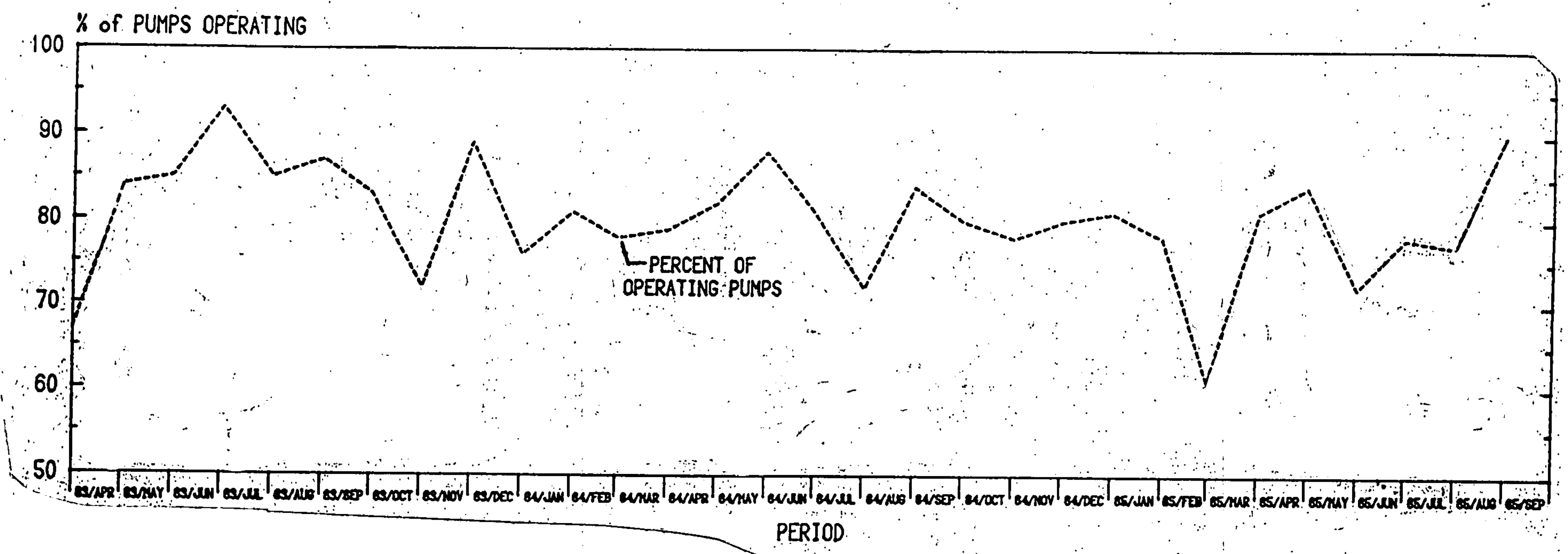

Figure 15 Maintenance records for the Upper Region (after Wardrop 1987b)

The sustainability of 400 dug wells was assessed during the 1993/94 dry season (COWAP, 1994). This survey indicated that nearly 50% of the hand dug wells were not in operation just after the end of the wet season: the situation is likely to be much worse towards the end of the dry season. Three districts were particularly affected: Bawku-East, Bawku-West and Builsa. The reasons for the poor performance were not assessed during the survey, but deep water levels and shallow wells were suggested as the major contributor.

Unfortunately no information exists about the performance of boreholes and wells in the Northern Region during the 1983 drought and the troubles of 1993/94. Anecdotal accounts suggest that many problems were encountered.

It appears that the high reliance upon surface water in the two areas exacerbated the effect of the drought. When the rains failed, the surface sources dried up quickly leading to a high demand on the groundwater. The capacity to meet this high demand was not there, particularly in the Northern Region, where the existing sources were put under severe stress.

There were troubles in the Northern Region during 1993/94, which led to significant migration. Water supply in the region was affected: (1) some infrastructure was destroyed, reducing the number of sources; and (2) the migration led to increased demand in certain areas. Not much specific information is available for the period, but it does appear that a temporary drought was induced by the high demand.

3.4 Summary of Groundwater and Drought in Northern Ghana

1) Two different hydrogeological regions are present in Northern Ghana: (a) the Upper Regions have moderately yielding weathered basement; and (b) the Northern Region has very poor yielding shales with moderately yielding sandstones.

2) Mean annual rainfall is approximately 1000 mm with a 4/5 month dry season. Rainfall events tend to be short and intense.

3) Most of the rivers in the area are ephemeral.

4) Rural water supply relies upon both groundwater and small surface water impoundments during the dry season. Dugouts and dams tend to be of poor quality and generally fail before the end of the dry season. Boreholes and hand dug wells tend to be more sustainable.

5) A severe lack of rainfall in the early 1980s led to drought, which was particularly bad in 1983.

6) Hydrographs in the Upper region indicate that deep aquifers were not immediately affected, lowest water levels were recorded in 1986. Shallow aquifers appear to have been affected and recovered quicker.

7) Maintenance records in the Upper Region illustrate about 30% of boreholes are out of commission in the dry season and possibly more than 50% of hand dug wells.

8) There are no data in the Northern Region to assess how boreholes or wells fared during the drought.

9) During 1994, troubles in the Northern Region led to increased demand on a limited number of sources, causing water supply problems.

4. FUTURE WORK

There are several issues that have arisen from this first visit to Ghana that would merit further investigation. The issues are discussed below in no particular order giving a list of possible further work given.

(1) Investigate the role of monitoring in water supply programmes and the nature of donor support.

(2) Digitise geology map and information on boreholes from GWSC. This would indicates which areas (and geology) have low yields. The hydrograph information could then be digitised illustrating different response in different areas.

(3) Estimate recharge. Different methods could be used to try and estimate the normal recharge in the region and years when recharge was particularly low. This would help ascertain the vulnerability of areas to changes in rainfall.

(4) Try to dig up more information on the response of the areas (in particular the northern region) to drought. The Tamne Basin drought report would be most useful. Uncover more information on the impacts of drought and demand changes from dry to wet season (WaterAid). Estimate the impact of cattle an water demand. Try to find water level data from Catholic Mission in Northern Upper Region.

(5) Use the aquifer properties data available for the two regions to build various models of the behaviour of different types of sources under different rainfall and demand scenarios.

(6) Use the geology and yield maps, recharge and demographic/coverage data to build vulnerability maps. Some data is available on the Internet.

(7) Pseudo water level data could be generated using information when a borehole was drilled. Water levels could be measured in 1995/96 in boreholes/wells that were sunk at the same time of year in the past. Then a rough idea of whether water levels have risen or fallen could be given.

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Annex 1 Main Data identified during the October 95 mission.

General

Maps and Data

Geological Map of Ghana (1:1 000 000). Source: Ghana Geological Survey
Soil Map of Ghana (1:1 500 000). Source: Ghana Soil Survey
DTM on 1 km^2 grid, taken from topographic Map (1:1 000 000). Source: Internet
Geohydrologic Province Map (1: 2 000 000). Source: Gill 1969 (USGS)
Hydrogeological Map of Ghana (1: 1000 000). Source: Ghana Geological Survey
Vegetation Zone Map (1: 2 000 000). Source: Gill 1969 (USGS)
Rainfall Map (1: 2 000 000). Source: Gill 1969 (USGS)
Monthly rainfall data for Accra 1977 - 1987. Source: WRRI
Monthly groundwater-level data for Accra 1977 - 1987. Source WRRI
HYDATA: Source WRRI (Joanna Owusu-Ofoi) about 8 monitoring sites in Northern Ghana
Monthly rainfall data for several sites in Northern Ghana
GRIPS (in disrepair): WRRI (William Agyekum)
AVHIR ? On 1 km grid vegetation index. Source: Internet

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Northern Region

Maps and Data

Database (Dbase 4) containing borehole particulars of about 1000 boreholes (no coordinates). Source: Sam Appiah GWSC Tamale.
Geological map of the Voltaian Basin (1:1000 000). Source: Annan-Yorke 1971
Topographic Maps (1:250 000). Source: Survey Department (to be sent to the UK)
Basic water chemistry data for 15 boreholes. Source: Sanyu 1989. (JICA)
Basic water chemistry data for 120 boreholes in West Gonja and Nanumba Districts. Source: Bannerman 1989 (NORRIP)
Resistivity, Short Pumping test data, Well Log and Chemistry for about 10 boreholes. Source: SRDP Water Development Project.
Resistivity, Short Pumping test data, Well Log and Chemistry for about 5 boreholes. Source: NORRIP Final Report

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Upper Regions (mainly Upper East)

Maps and data

Water level data for about 30 boreholes measured twice a year for 1977-79 and 1985-88. The Location of the boreholes has been plotted on various maps and can therefore be easily digitised. Source: Alfred Osafo-Yeboah GWSC Bolgatanga.

Monthly rainfall data from 1970-91 for Navongo. Source: Ghana Meteorological Office.

Database containing details of about 1000 boreholes (no coordinates) from the CIDA project. Source: Alfred Osafo-Yeboah GWSC Bolgatanga.

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Surface Water data availability

The Hydrology Division of the Architectural and Engineering Services Corporation has been responsible for Ghana's surface water monitoring network since 1969. There are four Regional Offices to look after the hydrometric fieldwork: Ashanti Region Office at Kumasi serves Ashanti and Brong-Ahafo regions; the Eastern Regional/South Office at Accra serves the Eastern, Greater Accra, Volta and part of the Central region; the Northern Regional Office at Tamale serves the Upper East, Upper West and Northern Region; and the Western Regional Office at Takoradi serves Western and part of the Central Regions.

A total of 230 gauging stations (principally natural sections) is known to have been installed in Ghana for observing and monitoring river levels and flows. Financial constraints, limited resources, disuse, and submersion by Lake Volta has resulted in the loss of 76 stations. The network at present comprises approximately 108 river gauging stations although it is hoped that this number will increase under the Station Rehabilitation Project.

River levels and discharge data prior to 1969 were published in the 'Water Year Books, River basins of Ghana' produced by the Ministry of Works and Housing. Since then a commercial company West Africa Data Services Bureau have produced the hydrological yearbooks. In order to do this, the hydrological data has been digitized and the provision of this data is currently under negotiation between AESC and West African Data Services.

There exists four sources of daily river flow data in Ghana. These are: hardcopies of the original recorder sheets; the Hydrological Yearbooks which can be found in the AESC library; spreadsheets of selected stations; and the data in computer format which can be purchased from West African Data Services through an arrangement with AESC. The availability of these data sources is presented in Table A1. Note that for some station years there are a number of sources available and no data exists for some station years.

Eleven gauging stations located in the Northern Region of Ghana were selected by the Water Resources Research Institute based on data availability and data quality. The details of the catchments are presented in Table A2 and the location of the gauging stations illustrated in Figure A1.

The only source of daily data in computer format is from the West African Data Services Bureau. The availability of this data is shown in Table A2 and has been ordered. Copies of the relevant pages from the hydrological yearbooks and recorder sheets are stored at the Institute of Hydrology. Therefore, at present no daily river flow data exists in computer format. The monthly totals have been inputted onto spreadsheets and are available at the Institute of Hydrology.

Year	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
Tainso	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	H	H	N	H	N	N	N	H	HY	HY	HY	HY	HY	HY	HY	HY	HY	HY	HY	N	N	N	N	N	N	N	N	Y	H	N	N	N	N
Yarugu	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	H	H	H	H	H	H	H	H	HY	HY	HY	HY	HY	HY	HY	HY	H	N	?	N	N	N	N	N	N	N	N	Y	H	N	N	N	N
Yendi	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	H	H	H	H	H	H	H	H	H	H	H	H	HY	HY	HY	HY	HY	HY	Y	HY	HY	HY	HY	N	HY	N	N	HY	N	HY	N	N	H	N	N	N	N
Lawra	n/o	H	H	H	H	H	H	H	H	H	H	H	H	H	N	H	H	H	H	H	HY	HY	HY	HY	HY	HY	Y	Y	Y	Y	Y	N	N	N	N	Y	N	N	N	Y	H	N	N	N	N
Bui	n/o	n/o	n/o	n/o	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	HY	HY	HY	HY	HY	HY	Y	HY	HY	HY	HY	HY	HY	N	N	N	N	N	N	HY	H	N	N	N	N
Pwalug	n/o	N	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	HY	HY	HY	HY	HY	HY	HY	HY	Y	N	HY	N	N	N	N	N	N	Y	Y	Y	H	N	N	N	N
Garu	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	n/o	S	S	S	S	SY	SY	SY	SY	SY	SY	SY	S	N	N	?	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Bamboi	N	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DY	DY	DY	DY	DY	DY	DY	DY	N	N	D	N	DY	N	DY	N	N	N	N	Y	D	N	N	D	N
Yagaba	n/o	n/o	n/o	n/o	n/o	n/o	n/o	N	D	D	D	D	D	D	D	D	D	D	D	D	DY	Y	Y	Y	Y	Y	Y	DY	Y	DY	?	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Nawuni	n/o	n/o	n/o	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	DY	DY	DY	DY	DY	DY	DY	DY	DY	DY	D	Y	DY	Y	D	DY	Y	DY	DY	DY	N	N	N	N	N
Saboba	n/o	n/o	n/o	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	?	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N

n/o=Station not open
H=Recorder sheets
Y=Yearbook (note that the digital data may be available from West African Data Services Bureau)
D=Data already on HYDATA so no more work needed
S=Data available in Quattro 4
N=Data not available from any of the sources

Table A1 Availability of daily discharge data for eleven stations in the Northern Region

Station Name	River Name	Area (km2)	Latitude	Longitude	Date Opened
Bamboi	Black Volta	128 864	08° 09' N	02° 02' W	08/03/1950
Bui	Black Volta	121 124	08° 17' N	02° 02' W	17/02/1965
Garu	Tamne	438	10° 55' N	00° 11' W	01/09/1966
Lawra	Volta	90 731	10° 38' N	02° 55' W	01/05/1951
Nawuni	White Volta	96 377	09° 42' N	01° 05' W	08/05/1953
Pwalugu	White Volta	57 620	10° 35' N	00° 51' W	01/05/1951
Saboba	Oti	54 934	09° 36' N	00° 19' W	20/03/1953
Tainso u/s	Tain	3 492	07° 47' N	02° 12' W	05/05/1962
Yagaba	Kulpawn	10 133	10° 14' N	01° 17' W	20/02/1958
Yarugu	White Volta	41 756	10° 59' N	00° 24' W	12/07/1962
Yendi	Daka	1 002	09° 26' N	00° 04' W	01/10/1955

TABLE A2 Details of selected gauging stations in Ghana

Rainfall Data

In 1971 there existed 14 full synotic stations, 450 rainfall stations, 75 climatological stations, 25 agrometeorological stations and 4 experimental stations in Ghana. The whole network shrank during the 1970's and 1980's due to economic difficulties to a present level estimated at 22 synoptic stations, 222 rainfall stations, 36 agrometeorological stations, 52 climatological stations and 4 experimental stations. Figure A2 illustrates that (scanned image of SSHAP report) all regions of the country are represented with regard to the primary synoptic stations. The network is denser in the northern, central and south western regions of Ghana.

Monthly rainfall totals for five of the synoptic stations will be made available in spreadsheet format although no details are available at the moment.

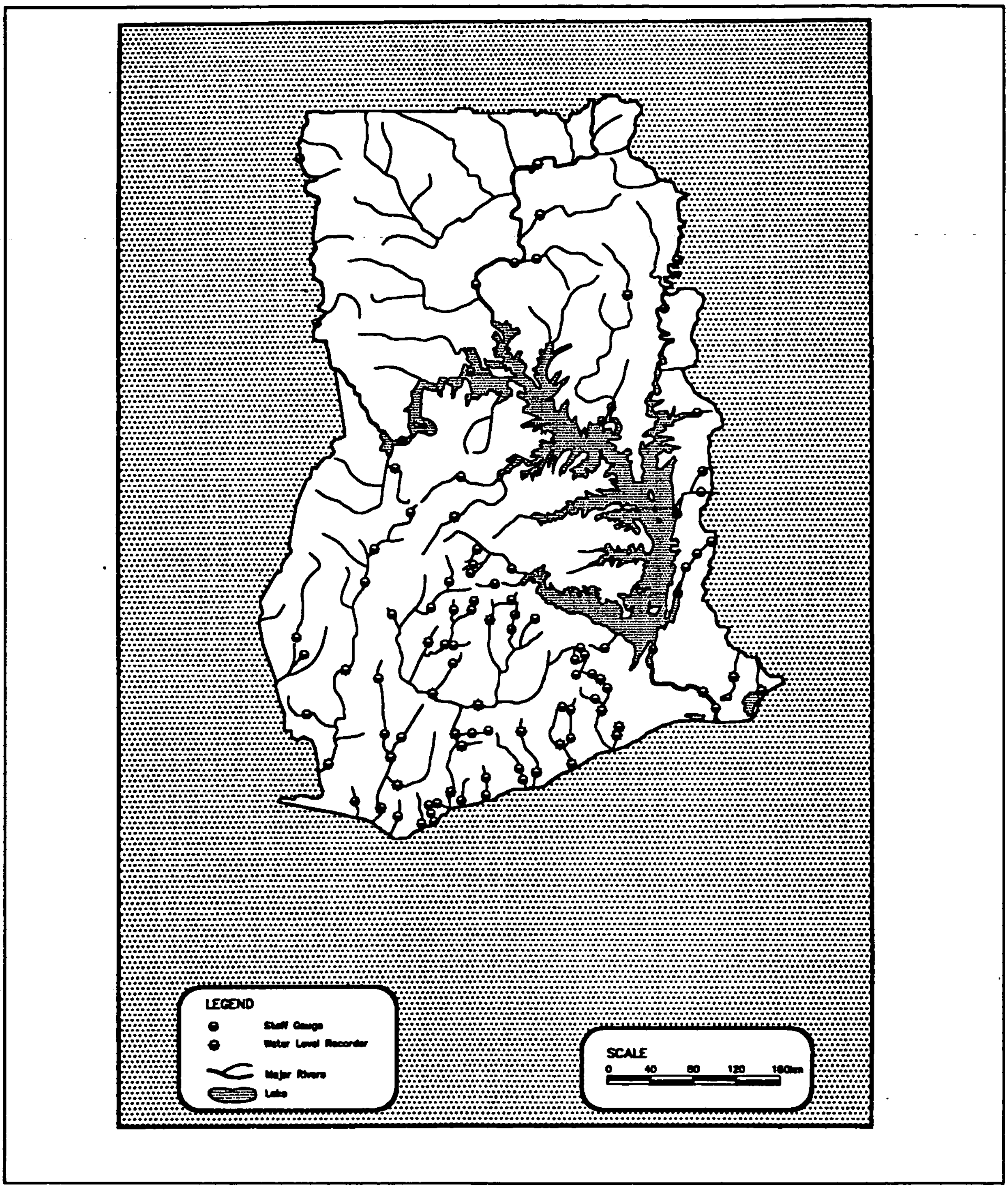
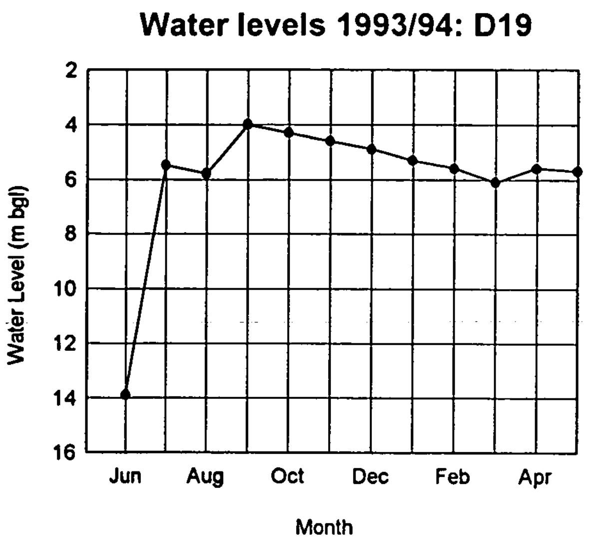
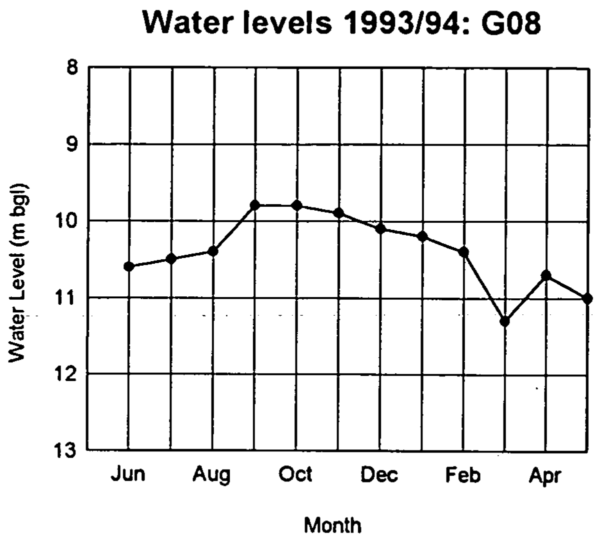


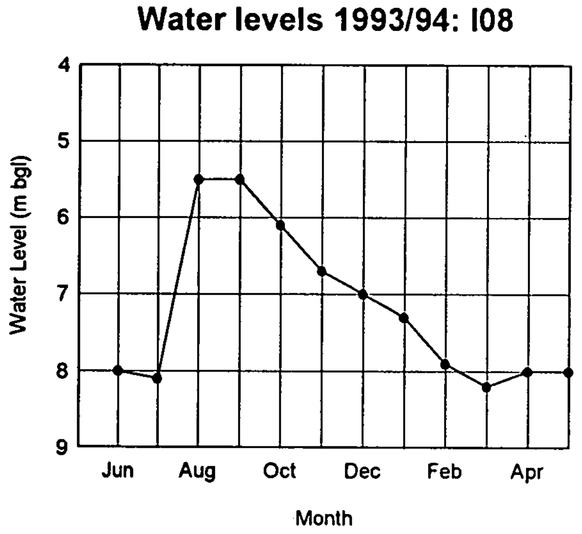
FIGURE A1 *Location of gauging stations in the Northern Region to be used in this study (World Bank/UNDP, 1990a)*

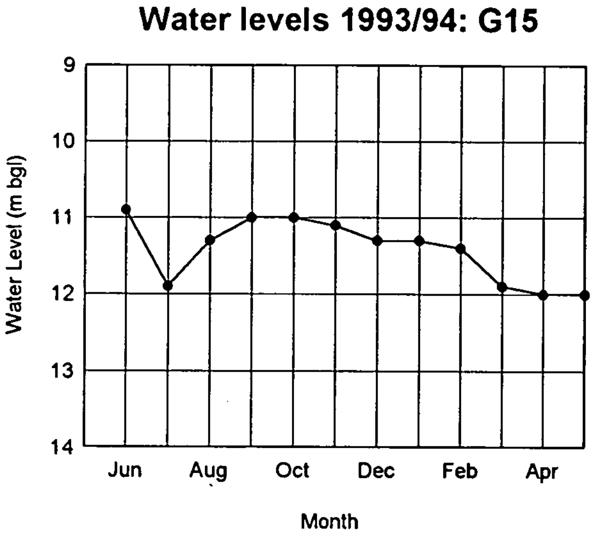
Annex 2: Monthly water levels

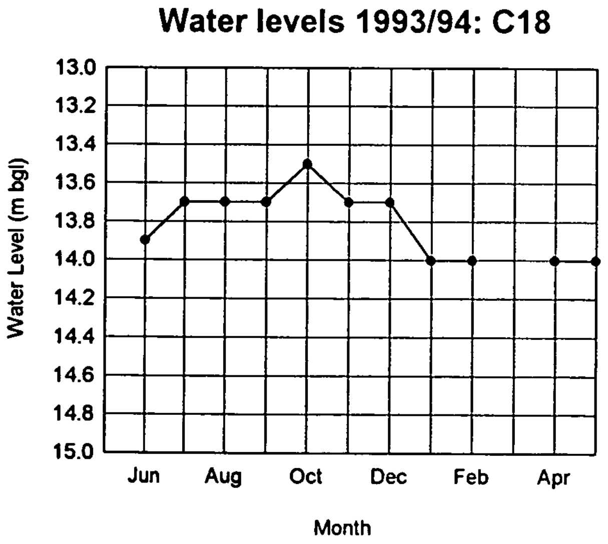
Monthly water levels for various boreholes in the Upper Regions during 1993/94 (From GWSC Bolgatanga)

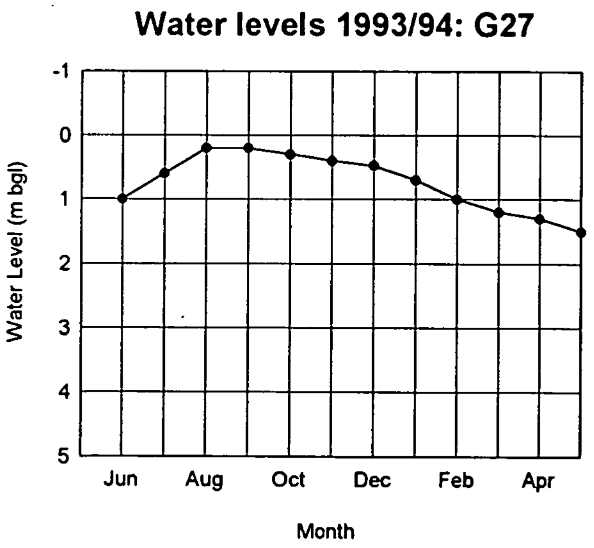

Water levels 1993/94: D19

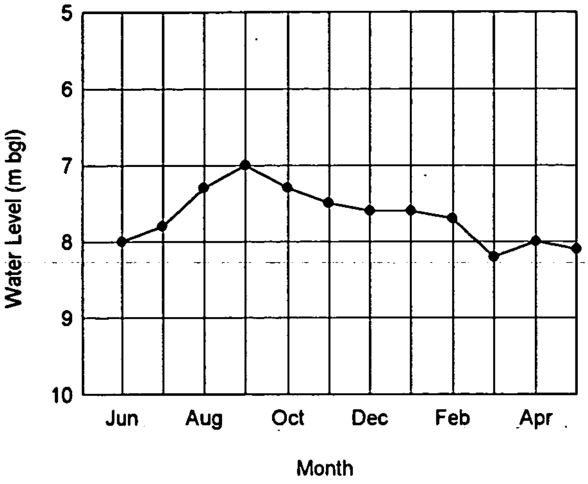

Water levels 1993/94: G08

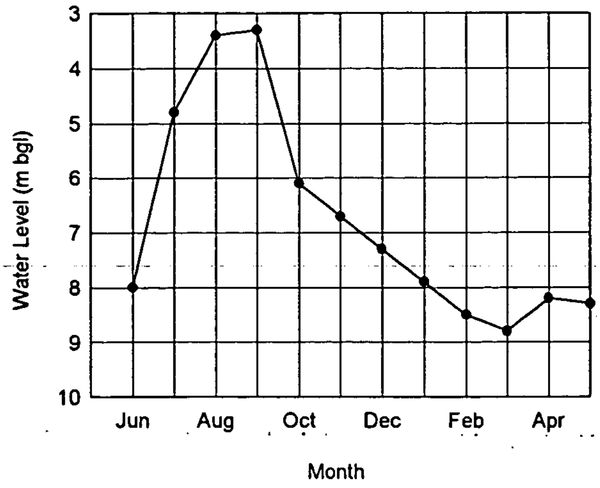

Water levels 1993/94: I08

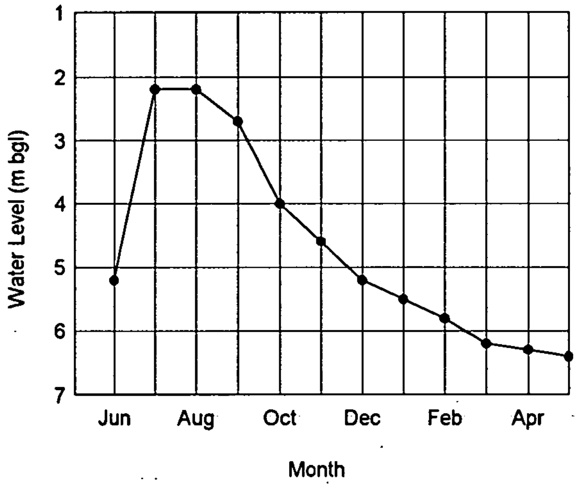

Water levels 1993/94: G15

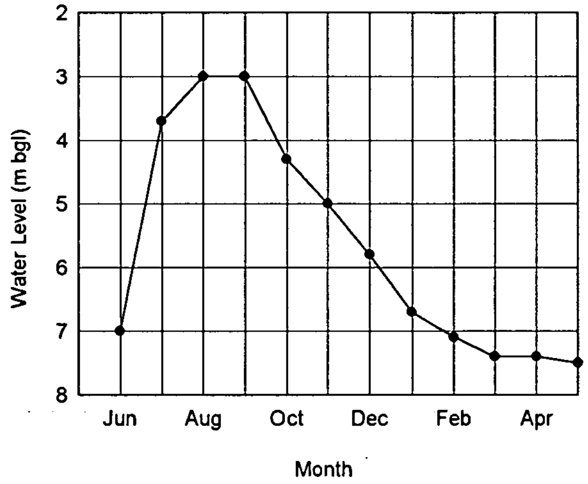

Water levels 1993/94: C18

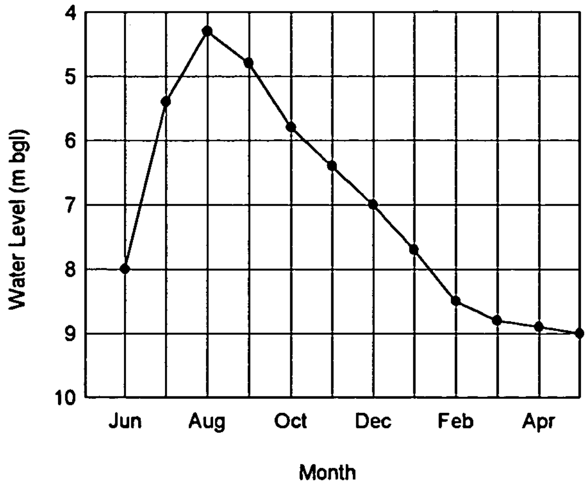

Water levels 1993/94: G27

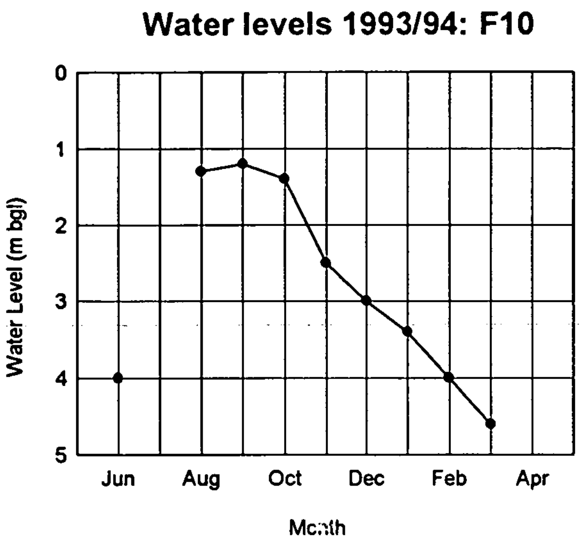

Water levels 1993/94: I42

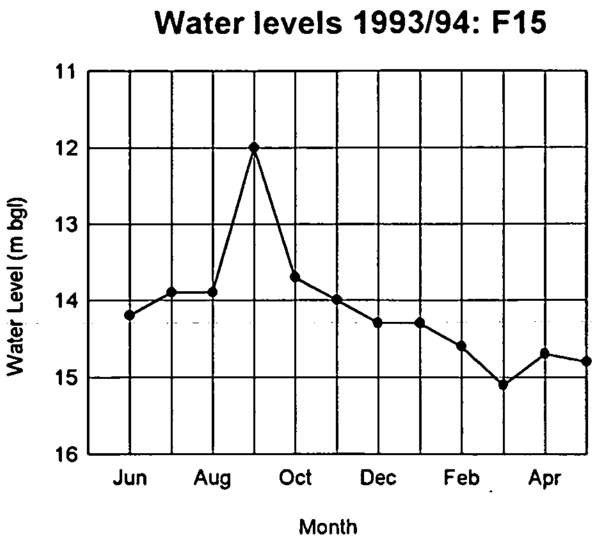

Water levels 1993/94:D08

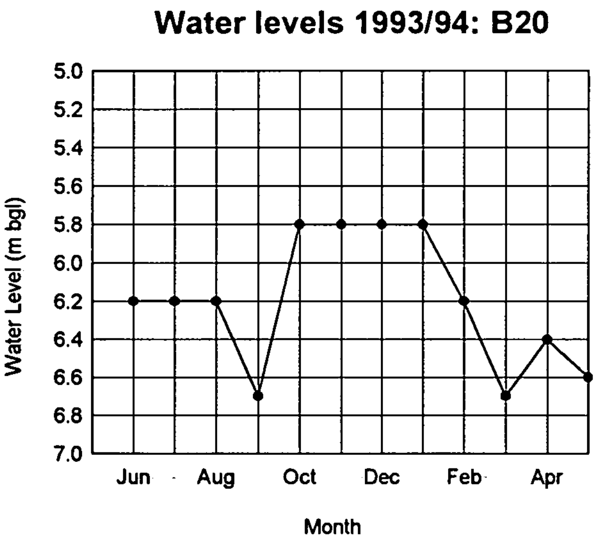

Water levels 1993/94: D01

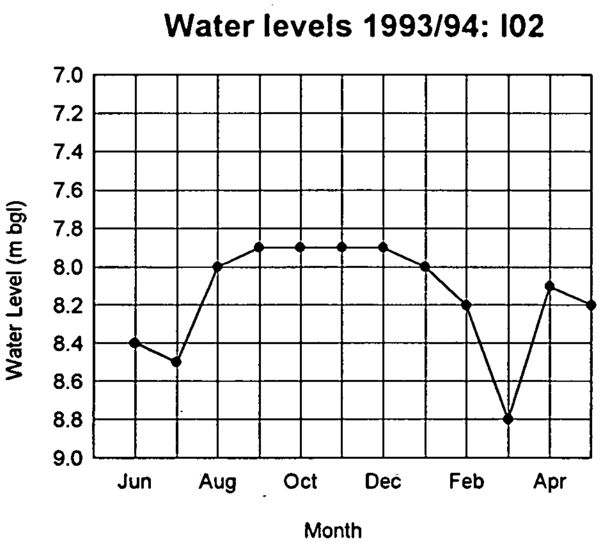

Water levels 1993/94: D11

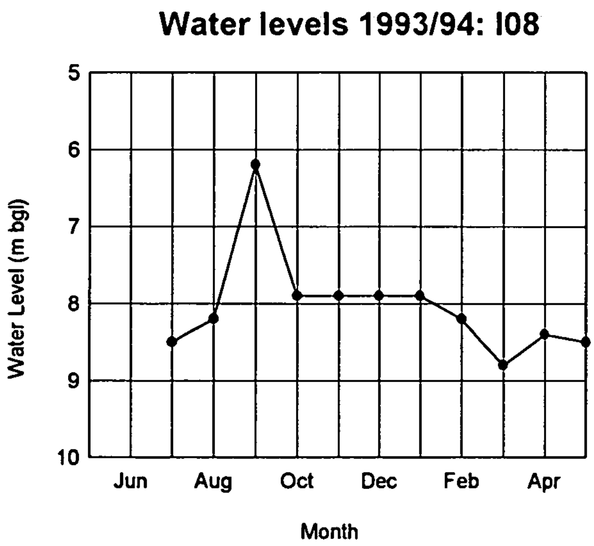

Water levels 1993/94: E01

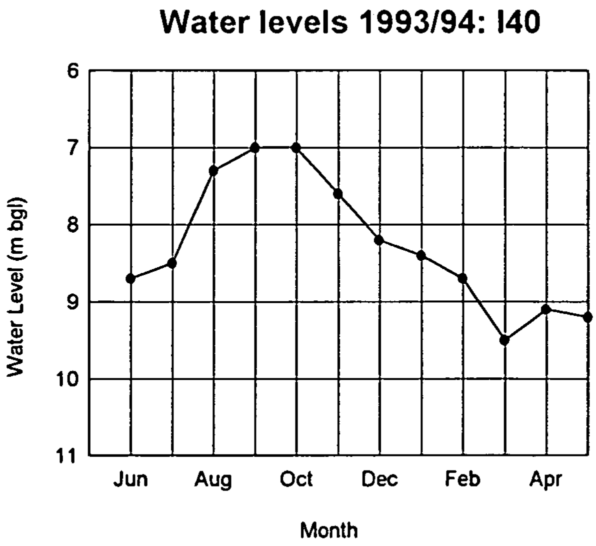

Water levels 1993/94: F10
Water Level (m bgl)
0
1
2
3
4
5
Jun
Aug
Oct
Dec
Feb
Apr
Month

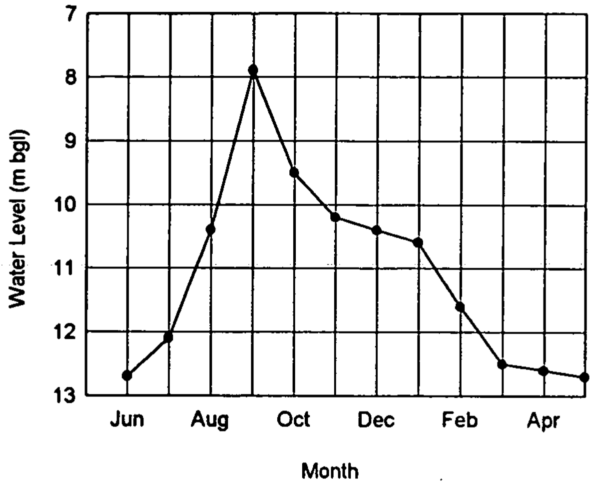

Water levels 1993/94: F15
Water Level (m bgl)
11
12
13
14
15
16
Jun
Aug
Oct
Dec
Feb
Apr
Month


Water levels 1993/94: B20
Water Level (m bgl)
5.0
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6
6.8
7.0
Jun
Aug
Oct
Dec
Feb
Apr
Month

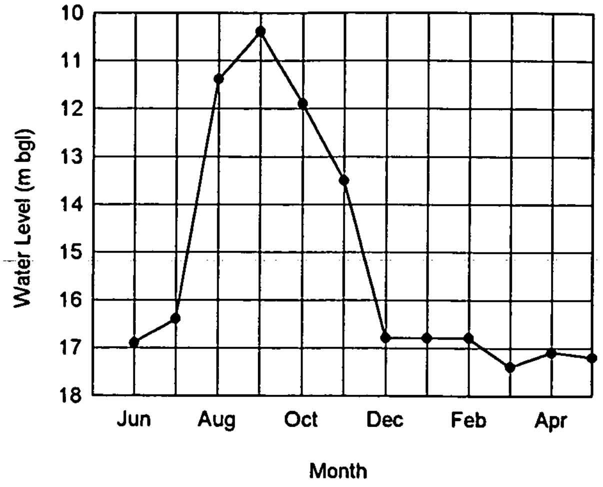

Water levels 1993/94: I02
Water Level (m bgl)
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
8.6
8.8
9.0
Jun
Aug
Oct
Dec
Feb
Apr
Month


Water levels 1993/94: I08
Water Level (m bgl)
5
6
7
8
9
10
Jun
Aug
Oct
Dec
Feb
Apr
Month

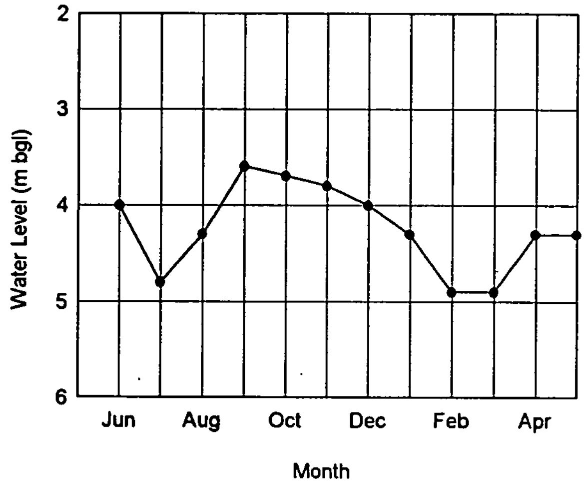

Water levels 1993/94: I40
Water Level (m bgl)
6
7
8
9
10
11
Jun
Aug
Oct
Dec
Feb
Apr
Month



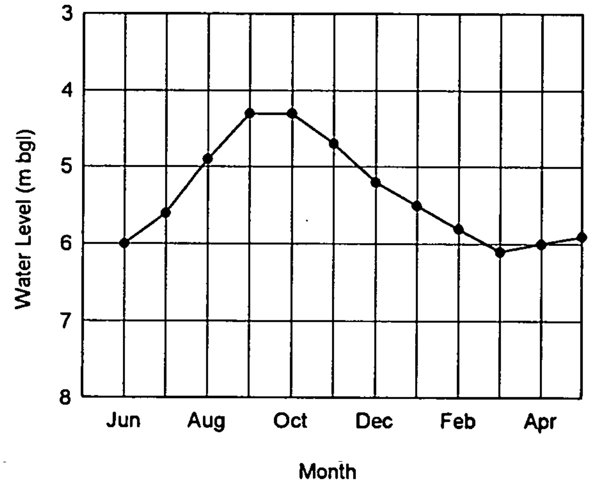
Water levels 1993/94: F01



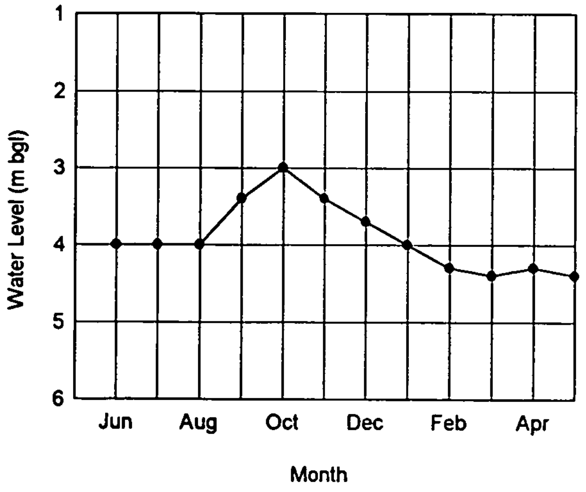
Water levels 1993/94: D01



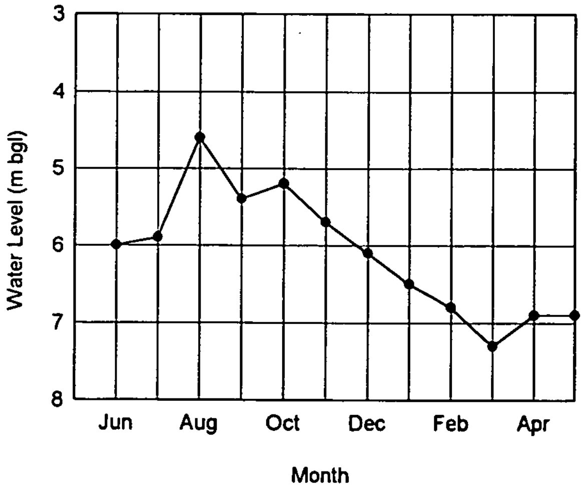
Water levels 1993/94: A07



Water levels 1993/94: B11

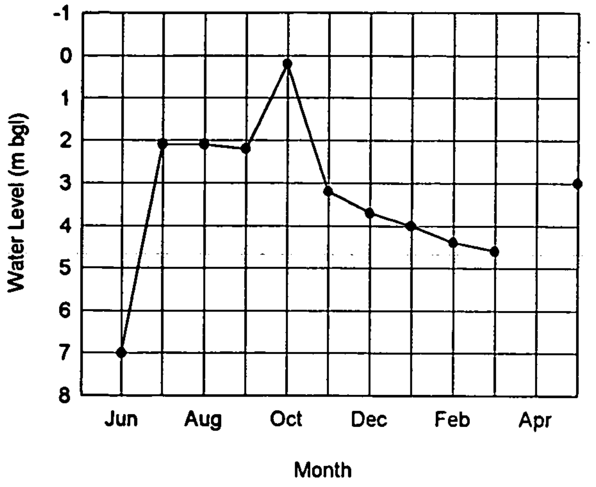


Water levels 1993/94: A04

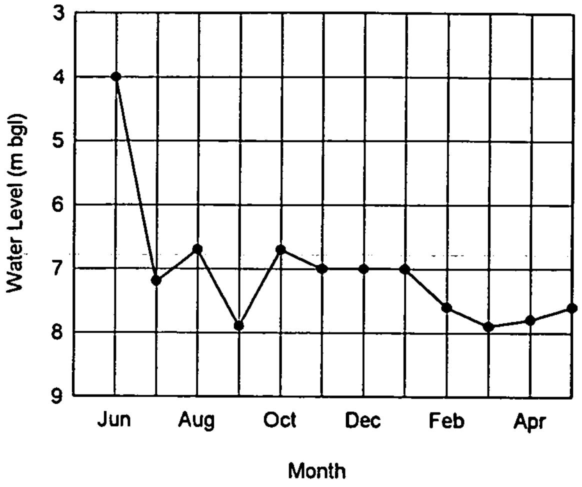


Water levels 1993/94: A05

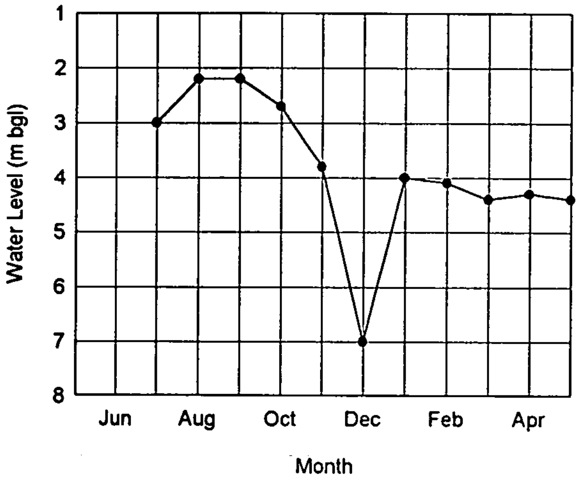
Water levels 1993/94: H08



Water levels 1993/94: H12

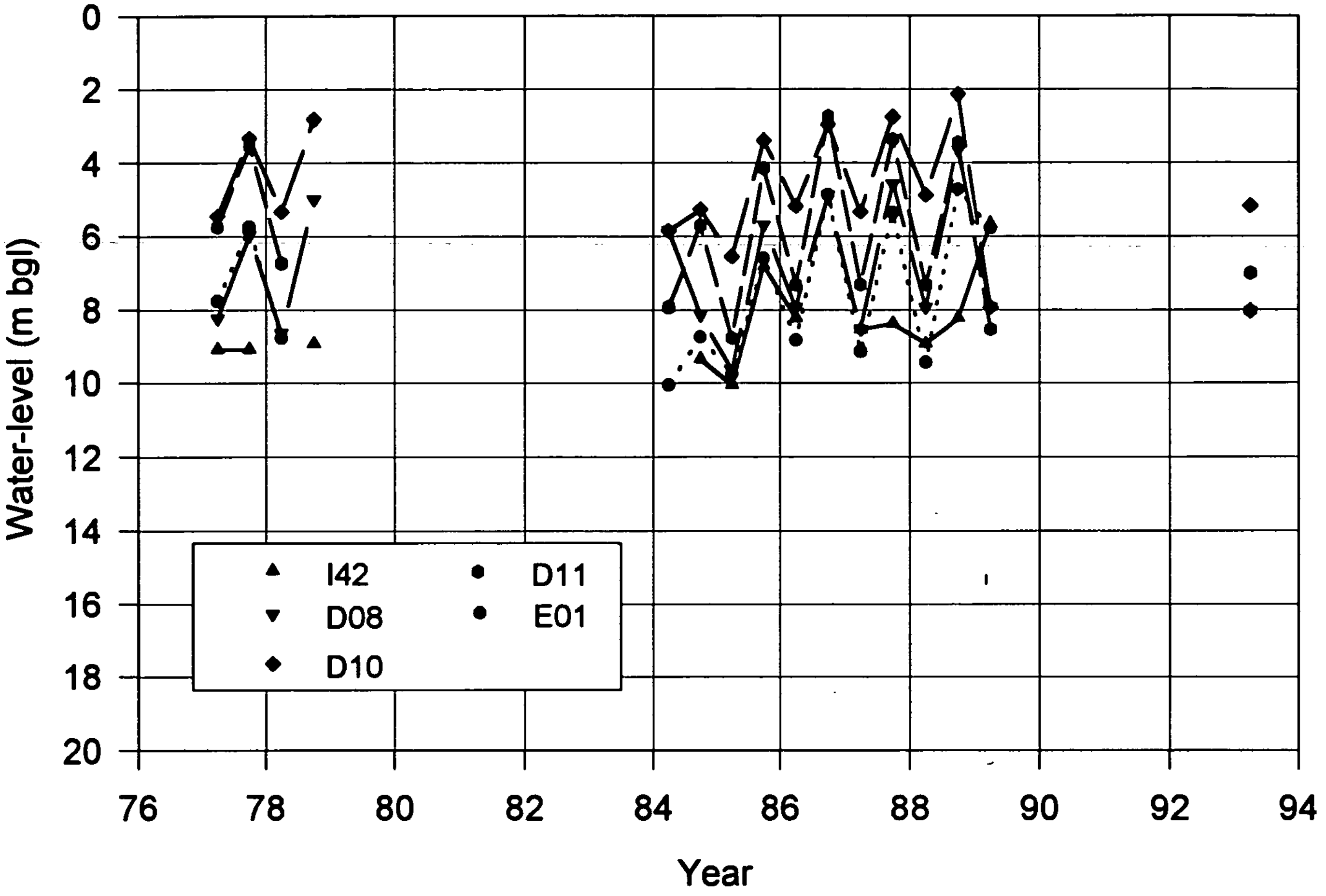


Water levels 1993/94: I03

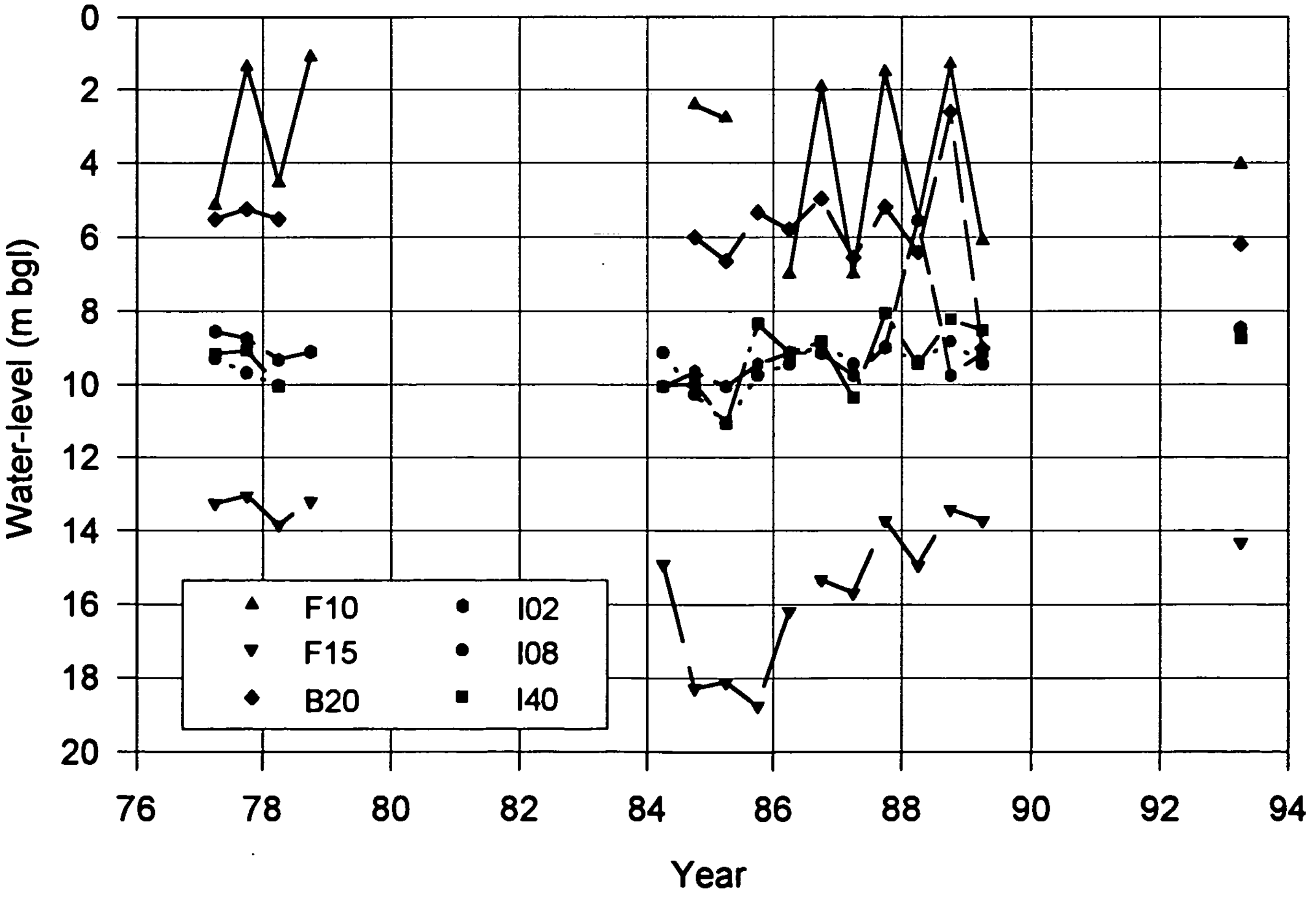


Annex 3: Annual water levels

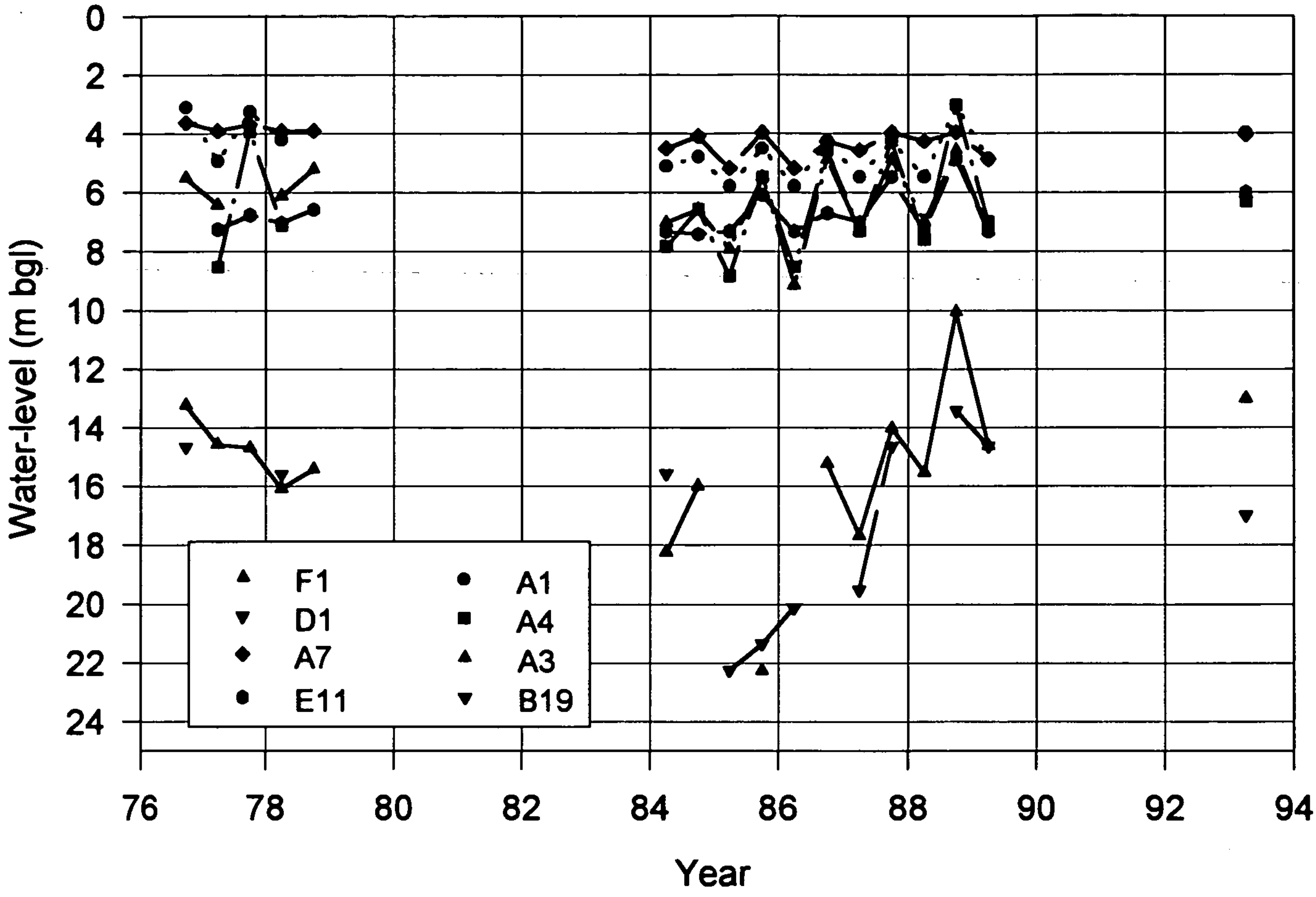
Biannual water levels for various boreholes in the Upper Regions from 1973-94 (From GWSC Bolgatanga).

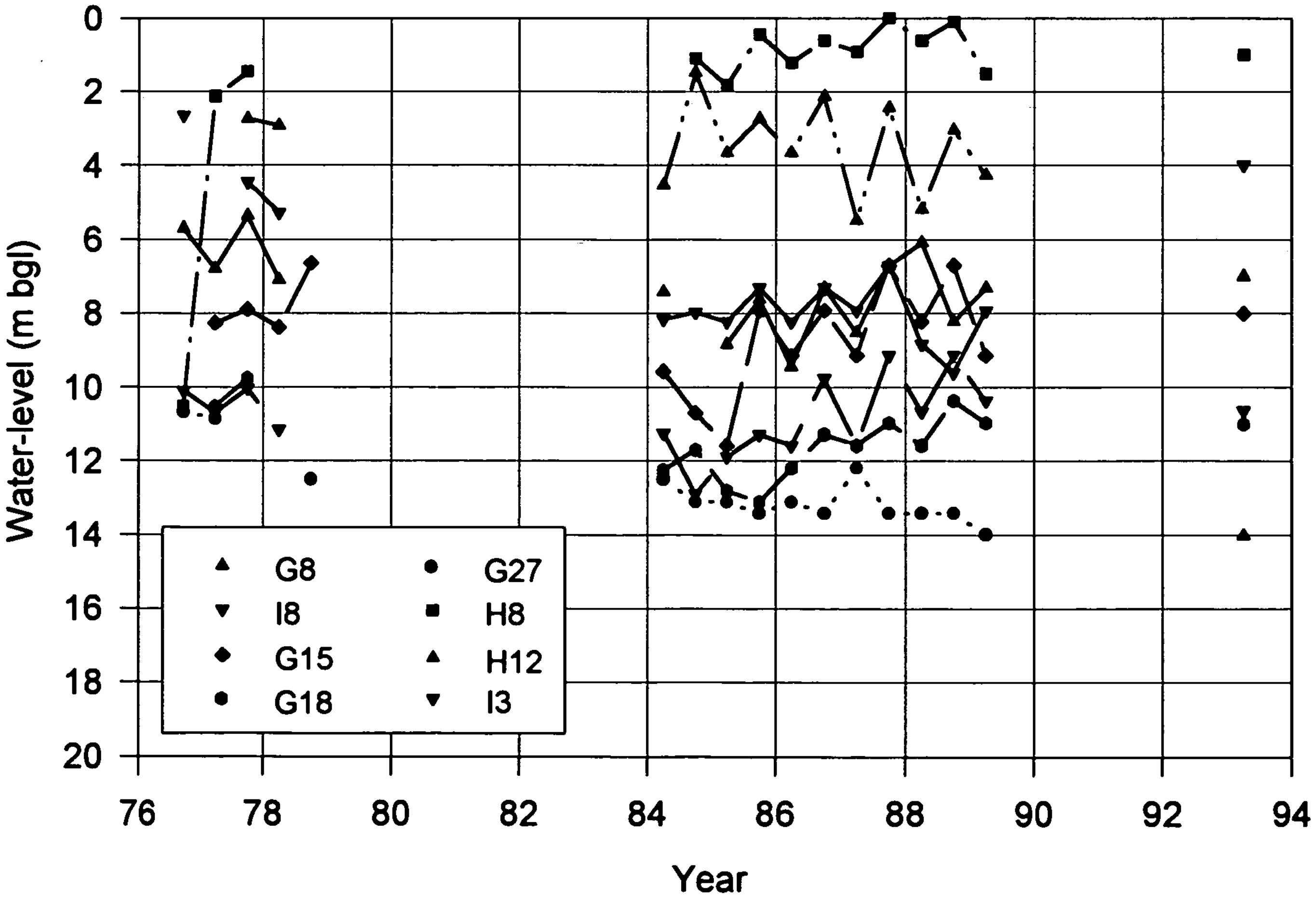


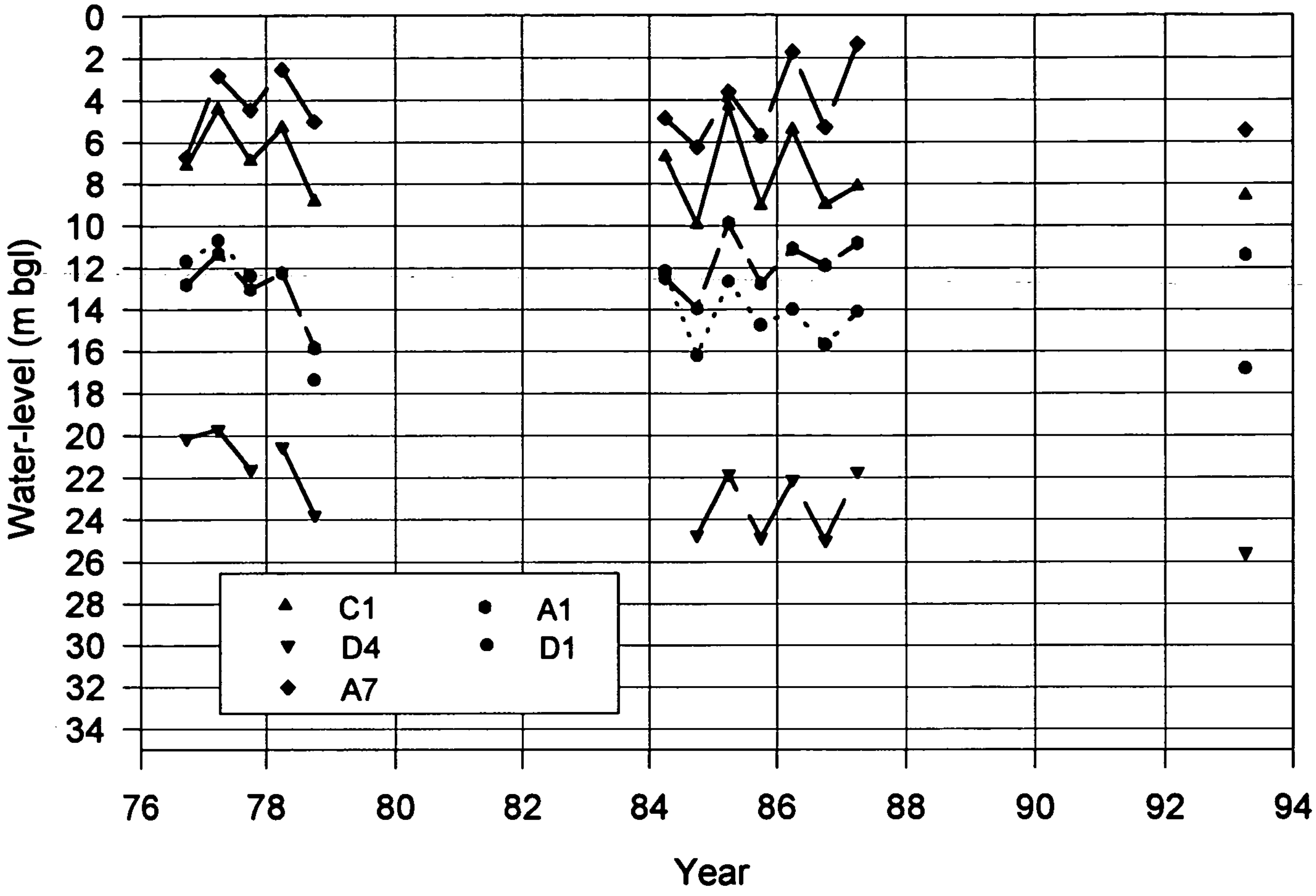
Water-level (m bgl)
0
2
4
6
8
10
12
14
16
18
20
76
78
80
82
84
86
88
90
92
94
Year
I42
D08
D10
D11
E01



Water-level (m bgl)
0
2
4
6
8
10
12
14
16
18
20
76
78
80
82
84
86
88
90
92
94
Year
F10
F15
B20
I02
I08
I40


Water-level (m bgl)
0
2
4
6
8
10
12
14
16
18
20
22
24
Year
76
78
80
82
84
86
88
90
92
94
F1
D1
A7
E11
A1
A4
A3
B19


Water-level (m bgl)
0
2
4
6
8
10
12
14
16
18
20
Year
76
78
80
82
84
86
88
90
92
94
G8
I8
G15
G18
G27
H8
H12
I3


Water-level (m bgl)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
76
78
80
82
84
86
88
90
92
94
Year
▲ C1
● A1
▼ D4
● D1
◆ A7