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African Development Bank
French Fund for Aid and Cooperation

Sub-Saharan Africa Hydrological Assessment West African Countries

Regional Report

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PREFACE

This report is based on information obtained and documents collected during missions to countries in West Africa over the period November 1990 to November 1991. The missions were undertaken by staff from the Consultants (Mott MacDonald International, BCEOM, and SOGREAH, assisted by a number of local experts), in conjunction with staff from ORSTOM.

We wish to place on record our appreciation of the very considerable help that we received during our visits; unfortunately it is not possible to name here all those who assisted us.

The report was issued in draft in June 1992. The World Bank invited the UNDTCD, the WMO, CIEH, and representatives of the countries of the region, to review the draft report and particularly to comment on the project proposals. The country representatives discussed and agreed their recommendations at two workshops, held in Abidjan 8-10 September and in Accra 14-16 September 1992.

Whilst every effort has been made to take account of the views expressed, a number of important issues were raised which could not be properly addressed at this late stage in the project. These issues have been only briefly introduced in the final report, but they are subjects which should be examined in greater detail in the future as part of the on-going debate on water resources development in Africa.

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ABBREVIATIONS

International

ACMAD	African Centre of Meteorological Applications for Development
ASECNA	Association de Securité de Navigation Aerienne, Dakar, Senegal
CIEH	Comité Inter-africaine d'études Hydrauliques, Ouagadougou, Burkina Faso
CILSS	Comité Inter-états de Lutte contre la Sécheresse dans le Sahel, Ouagadougou, Burkina Faso
EDF	European Development Fund
EEC	European Economic Community
EIER	Ecole pour les Ingénieurs de l'Equipement Rural, Ouagadougou, Burkina Faso
ETSHER	Ecole pour les Techniciens Supérieurs de l'Hydraulique et de l'Equipment Rural, Ouagadougou, Burkina Faso
FAC	Fond d'Aide et de Co-opération, French aid
FAO	Food and Agriculture Organisation
GIEWS	Global Information and Early Warning System, an FAO programme
HDP	Hydrometry Development Programme for West Africa, proposed by this study
IGADD	Inter-governmental Authority for Drought and Development
LCBC	Lake Chad Basin Commission, N'Djamena, Chad
NBA	Niger Basin Authority, Niamey, Niger
OCP	Onchocerciasis Control Programme, a WHO programme
ODA	Overseas Development Administration, British aid
OMVG	Organisation de Mise en Valeur du Fleuve Gambie, Dakar, Senegal
OMVS	Organisation de Mise en Valeur du Fleuve Senegal, Dakar, Senegal
OPEC	Organisation of Petroleum Exporting Countries
ORSTOM	Institut Français de Recherche Scientifique pour le Developpement en Coopération
SADCC	Southern African Development Co-ordination Conference, Maseru, Lesotho
UNDP	United Nations Development Programme
UNDTCD	United Nations Department for Technical Cooperation and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNSO	United Nations Sudano-Sahelian Office
USAID	American aid
WHO	World Health Organisation
WMO	World Meteorological Organisation

ABBREVIATIONS (Cont.)

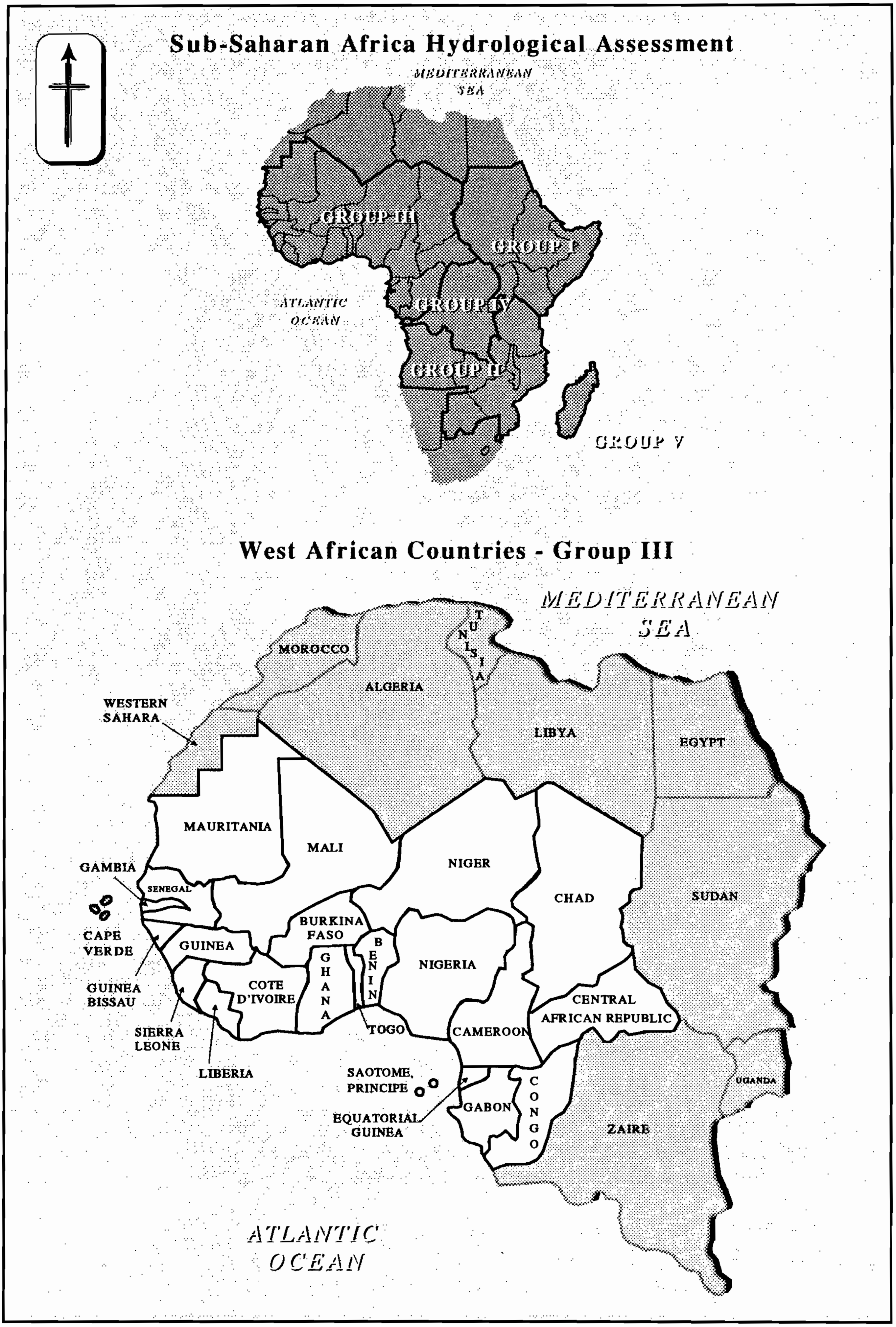
National

AWRC	Australian Water Resources Council
NEPA	National Electric Power Authority, Nigeria
NIWR	National Institute for Water Resources, Kaduna, Nigeria
SCIP	South Chad Irrigation Project, Nigeria
SEMRY	Societé d'Expansion et de Modernisation de Riziculture de Yagoua, Cameroon
VRA	Volta River Authority, Akosombo, Ghana
WRRI	Water Resources Research Institute, Accra, Ghana

Technical

CFCs	Chlorofluorocarbons
DCP	Data collection platform
EPROM	Extended programmable read only memory
GCMs	General circulation models
GHGs	Greenhouse gases
HEP	Hydroelectric power
ITCZ	Inter tropical Convergence zone
SST	Sea surface temperature
SWOT	Strength, weakness, opportunity, threat
TA	Technical assistance

Figure S.1
The Study Area



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SUMMARY

1 Introduction

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

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

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

2 Water Resources

Regional water resources monitoring was to be assessed against the criterion of availability of reliable data to meet the needs of those planning the development of water resources in the medium to long term future. A brief description is given of the major surface water and groundwater resources and the present level of their development. Future development potential has been taken from available government plans and consultants' reports. No attempt has been made to prepare new water demand estimates for this project.

The climate of the region, and in particular the recent period of severe and sustained drought in the Sahel, is described. The latest thinking on the possible effects of man on the global and regional climate is also considered. There is a considerable body of scientific opinion which forsees global changes which may well adversely affect the region, this is discussed further in an appendix.

Competition for scarce water resources over much of the region will become more intense in the future driven by the twin factors of rapid population increase and raised expectations with regard to standards of living. In the northern countries the need to manage their limited resources is well recognised but even in the wetter equatorial countries of the region water may be of poor quality or may be insufficient at certain times of the year. The availability of good quality hygenic water is a problem in both the wet and the dry parts of the region.

3 Regional Organisations, Programmes and Projects

The international nature of water resource problems in West Africa has been long recognised but the onset of the drought which has devastated the Sahel since the early 1970s brought the need for international and regional co-operation into sharp focus. As a result today there are several bodies, regional programmes, and support projects which are active in the fields of water resources data collection, data management, and resource planning. In many of the countries of the region the hydrological assessment would be incomplete without reference to the activities of these international organisations and their regional projects.

Brief descriptions are given of eight organisations and five programmes/projects; their performance is discussed subsequently, in Chapter 7. Of the organisations five are based on surface water basins as is one project, HYDRONIGER. The organisation CILSS and its associated programme AGRHYMET is based on those countries in the Sahel zone who constantly face the scourge of drought. CIEH is an intergovernmental organisation of largely francophone countries. The three remaining projects, the OCP, CLICOM, and DARE, are all internationally sponsored and each covers a large part of West Africa.

4 Methods of Assessment of Data Collection Systems

An objective measure of hydrological data systems is provided by guidelines published by UNESCO/WMO ('Water Resource Assessment Activities: Handbook for National Evaluation') which establish 'world' norms against which hydrological services and their activities can be compared. The application of such a standard set of criteria is however a crude measure as the systems should be evaluated relative to likely future data needs and the country's ability to support the financial and manpower burden. A further weakness is that the analysis stresses quantitative aspects rather than the quality of the data collected. A preferred alternative method of assessing the adequacy of a national hydrometric service, when sufficient time is available, is to undertake a benefit-cost analysis relating the cost of services to the benefits of future water development.

In the present study we have made some use of the UNESCO/WMO approach but have also undertaken a more subjective and detailed evaluation for each country with particular reference to identified water development projects. The more detailed analyses were all geared towards identifying a reasonable development plan for the hydrological services over the next five to ten years.

The work of the hydrological agencies was assessed by identifying: 1) the spatial and temporal gaps in the data collected, 2) the present constraints within the data collection and processing systems, 3) the quality and accessibility of the data, 4) the likely future data requirements, 5) the development priorities within the data collection agencies, and 6) the likely scale of funding available from internal and external sources. The preliminary assessment of constraints and future directions was discussed with senior officials. Where external funding is likely to be needed we have identified projects containing the required elements within a format designed to assist potential donor agencies in their evaluation of any request for help.

In those areas such as development of data processing techniques, equipment repair/maintenance facilities, and training, where regional co-operation would allow costs to be shared, regional projects were investigated.

5 Regional Data Collection Situation

The results of our assessment are presented under three headings: data collection, data handling, and institutional aspects. These topics are however closely interlinked, most obviously by financial considerations, but also at a technical level since the choice between, for example, mechanical field instruments or electronic devices has implications for data management and staff training. These linkages must be borne in mind when examining the results of the assessment on a topic basis.

Within the region hydrometric agencies display a wide variation in the level of development of their organisations and the range of activities routinely undertaken. Generally it is more often organisational and administrative problems that constrain their performance than technical difficulties. A very common constraint placed upon the data collection agencies is inadequate funding associated with poor national economic performance. A sustained shortage of funds has led to reduced staffing levels and shortages of equipment and transport that lead to an inability to adequately service station networks established in times of less restricted budgets. Funding at present has been squeezed to such an extent that many agencies are barely able to function, and very few function efficiently. Regional support programmes such as AGRHYMET and the OCP are very important, in many countries virtually supporting whole areas of hydrometric activity utilising outside funding. If this support were withdrawn all surface water monitoring might cease in several countries.

The process of evaluating and modifying the design of their monitoring networks is an on-going activity for all the region's agencies, but two factors have recently focused greater attention on this vital task: restricted budgets, and the advent of new technologies for data collection. The advent of electronic monitoring equipment allows the entire process of data collection and handling to be effected directly, data is stored in the field on electronic devices and transferred directly to computer. Regional projects have led the way starting some 10 years ago with the HYDRONIGER network of 65 stations linked by satellite telemetry to a flood forecasting centre in Niamey but some national agencies monitoring surface water are starting to incorporate such technology into their networks. The new technology offers potential savings in field staff and a reduced requirement for transport.

Reliable data are the culmination of good field hydrometric data collection and good data processing. In some of the countries field inspection, gauging and sampling activity has now declined to such an extent that concern has been expressed that such data as is being collected from the operational networks cannot be processed to yield reliable information. There has been no evidence seen for example of any attempt to plan annual gauging programmes on the basis of an assessment of where the gauging is most needed to maintain the quality of the processed flows.

It is essential that the region's agencies take a long term view of data collection and prioritise their activities so that it is clear which tasks may be curtailed or temporarily suspended if the financial situation demands. This perhaps best described in terms of 'primary' and 'secondary' activities. Having identified the long term primary network of, for example, water level monitoring points and all field activities required to maintain it (gauging programme, maintenance visits, equipment replacement, etc) the agency will be in a position to determine the extent of its secondary programmes. The selected primary monitoring activities should be the best compromise between the conflicting demands of remaining within budget and of providing high quality data of the type most likely to be required in the future by those planning water resources development.

Few countries attempt any systematic monitoring of sediment. When consideration is given to the uses of sediment data in development planning (estimating siltation at potential reservoir sites, the effect of land use practices on erosion, etc), and the difficulties inherent in actually measuring sediment load in rivers (both field and laboratory), it appears that such monitoring would be better handled on a project basis, perhaps with the national agency undertaking programmes of measurement under contract. Water quality monitoring poses similar problems and again is not easily managed on the basis of a national monitoring network. The need to check the quality of potable sources before commissioning is well recognised but not always achieved especially by rural drilling programmes, regular monitoring is only undertaken at a few major urban sources. Background environmental monitoring could appropriately be introduced in the form of intensive national dry season surveys of surface sources carried out perhaps every five or ten years and organised on a project basis.

6 Data Handling

The data collection agencies of the region are mostly in a transition period with respect to data handling techniques: in the process of moving from the older, manual systems towards the adoption of computer based systems. Data handling systems encompass activities from the noting of readings by observers, through the handling procedures to the central data processing facility, data storage, filing, retrieval and publication. Occasionally, the entire system can be computer-run, especially where data telemetry systems are used

The financial constraints on national services have had an adverse effect on the recent performance of their data handling systems. Problems with data handling are legion, and often stem from a number of fundamental causes, such as:

- poor administrative procedures;
- piecemeal development of systems which may introduce areas of incompatibility and duplication;
- inadequate manpower skills and resources;
- inadequately thought out and inefficient data storage systems;
- poor facilities;
- inadequate supervision of work;
- lack of support and maintenance of computers and software.

A necessary pre-condition of a successful data handling system, whether manual or computerised, is good management and a sufficient number of well trained staff. In a situation where the existing manual systems are overstretched or poorly supervised the introduction of computers cannot provided the whole solution. A major development in data handling techniques within the region has been the widespread introduction of specialised software for meteorology and surface water: the WMO 'CLICOM' and the HYDROM processing systems. In the field of groundwater, databases written using well known commercial packages such as dBase are now widely available. The introduction of similar packages provides an opportunity to create regional standards for efficient data processing, improved data storage and retrieval systems, and an opportunity for more effective data publication.

A number of observations can be made on the current status of computerised data handling in the region:

- Hardware support is minimal and a very real problem despite the robustness of the latest generation of microcomputers.
- Quality control is variable and there are instances of databases on which no checking has been undertaken; this is potentially serious deficiency because of the tendency to regard data printed out by the computer as correct.
- Where technical assistance has been provided long term, or the database has been maintained as part of a specific project, the systems have operated relatively successfully, but where, as with many of the CLICOM installations, insufficient support has been provided the system has not fulfilled its potential.
- It is not clear that the long term storage of computerised data is being properly addressed.

Computer data handling systems require good management and they are more demanding of management than the manual systems they replace - a failure to ensure adequate staff training, to maintain the equipment, and to maintain the most rigorous of data storage procedures may endanger the long term security of the data. The advent of cheaper computers does however offer the opportunity to decentralise the basic data processing (entry and primary quality control) and thus to involve the hydrometrists responsible for the data collection whose knowledge of the monitoring sites can make quality control more effective.

7 Institutional Development

Recent experience has shown that hydrometric data collection agencies are a common target for emergency budget trimming exercises. In order to lobby more strongly for larger budgets, the economic benefits that arise from good quality data need to be known in order that decision makers can be made aware of the hazards of designing projects with inadequate hydrological data.

Transport availability is a serious problem for many of the agencies having a significant impact on their operations.

Manpower shortages are a major concern in many of the agencies. This is both a reflection of a skill shortage nationally and of the generally low profile of hydrometric services and the often poor career structure, pay, and working conditions within them.

Many of the agencies in the region are in urgent need of funds in order to maintain even the most basic of day to day services.

Regional co-operation is becoming ever more urgent given the rapid population increase, the desire to raise levels of provision, and uncertainty over the stability of climate and the possiblity that the recent drought might either persist or recur with greater frequency. There are a number of alternative means of achieving such co-operation ranging from large permanent organisations such as the Niger Basin Authority to small inter-governmental committees. Our assessment of these alternatives indicates that small establishments with a relatively narrow focus are more likely to be successful. The AGRHYMET programme shows many attributes which we feel should be incorporated into future projects.

8 Recommendations

We believe that the best prospects for more effective monitoring and management of water resources lie in a long-term regional and national support programme covering all aspects of the hydrometric services. The emphasis should be on a sustained period of assistance; many of the region's hydrometric problems have a long history which past experience has shown cannot be solved by two or three years of assistance.

The 'Hydrometry Development Programme for West Africa' has been formulated from this perspective and all the recommendations are aimed at equipping water resources monitoring agencies to fulfil their functions effectively on a planned and sustainable basis. A period of 10 to 15 years of direct assistance is needed with large and systematic infusions of capital goods, expertise, and training, designed to meet the needs of each country.

Our recommendations cover all aspects of water resources monitoring from basic field procedures, data management, data processing, data presentation, and applications of the data. Throughout we have been mindful of the financial and administrative implications for each country.

The programme consists of a series of country projects which have been carefully designed to raise standards of operation. In addition to the country projects, a number of regional projects have been designed to foster regional co-operation and to promote, support and monitor hydrometric services.

The Hydrometry Development Programme is based on a number of elements found to be successful in the long running AGRHYMET programme, particularly in the co-ordination of regional and national components of the programme. Careful attention has been paid to the institutional structure of the programme, drawing on the results of a detailed evaluation of a number of regional organisations and projects, and the different perspectives of the national agencies and the bilateral or multilateral donors on many issues such as the balance between country and regional projects or the extent of international inputs vis a vis inputs of capital goods.

Five regional projects and 153 country projects have been identified at a total cost of around US$ 150 million. The project proposals have been drawn up using the UNDP publication 'Guidelines for Project Evaluation and Project Document Formulation' and as such are in a suitable format for preliminary donor evaluation. The regional projects are described in this report, and the country projects are contained in the relevant country reports.

The five regional projects are as follows:

REG-1	Umbrella Project;
REG-2	Training Programmes for Technicians and Professionals;
REG-3	Advanced Hydrological and Environmental Monitoring Programme;
REG-4	Data Rescue Programme;
REG-5	Assess Economic/Social Benefits of Water Resources Data Collection in West Africa.

The 'Umbrella Project' is designed to establish a small co-ordination team for the Hydrometry Development Programme with the purpose of providing a continuing presence of technical expertise within the region for a period of 10-15 years. The Umbrella unit is designed to provide a demonstrably efficient, cost effective link between all the components of the Hydrometry Development Programme rather than an expensive prestige project. The relationship of the Umbrella Project to the larger Hydrometry Development Programme and to all the other identified projects is shown in Figure S.2.

The main activites of the Umbrella Project can be categorised as follows:

- Co-ordination of the Hydrometry Development Programme components;
- Promotion;
- Training (in support of project REG-2 and training components of country projects);
- Standardisation - of practices and equipment to encourage regional harmonisation;
- Maintenance;
- Computer hardware and software - support to other projects;
- Assistance to ensure the regular supply of a minimum of reliable data (in support of project REG-3 and a number of the country projects).

9 Summary of Comments on the Draft Regional Report

The World Bank invited the UNDTCD, the WMO, CIEH, and representatives of the countries of the region, to review the draft regional report and particularly to comment on the project proposals.

A number of common themes were identified among the comments received and every effort was made to take these into account in finalising the report:

- Projects should emphasise 'sustainability' with maximum use of African experts.
- An existing regional organisation should be identified within which to base the Umbrella project REG-1.
- The general concept of the continent-wide environmental monitoring project, and REG-3 its regional offshoot, was accepted.
- Problems were anticipated in regional projects involving sharing water resources data which is often not considered to be in the "public domain".
- The recognition that high technology equipment may have an important role to play, but tempered by experience of costs (training needs especially in maintenance, short life of some equipment with consequent need to upgrade regularly).
- As presented the project REG-5 was generally perceived by country representatives as an implied criticism of service directors and of little or no value.

However certain opinions were only expressed by a single source and, at this stage in the project, it was not possible either to reconcile divergent views with those of the other contributors, or where new concepts were raised for these to be given a proper examination. For example:

- The participants in Abidjan suggested that a regional programme was required for water resources, and that the Hydrometry Development Programme represented an essential first stage to such a programme.
- The Accra workshop participants rejected the need for the Umbrella Project, REG-1.
- The Accra particpants also wanted to emphasise the importance of the country projects which should be given priority over regional projects.
- UNDTCD comments on REG-3 suggested that other lower technology avenues should be explored.
- Contributors to the Abidjan workshop prefered the alternative strategy suggested for REG-3 which minimises responsibilities of the REG-3 project team in favour of maximising the involvement of national agencies, suggesting that REG-3 be combined with REG-1.
- The idea of bringing all aspects of water resources into one organisation, and, where the political climate favoured it, setting this up as a semi-autonomous agency, part government funded and part funded by commercial activities, with aim of increasing overall funding and improving the general employment package was approved of by the Abidjan participants.

These points are all valuable contributions to the on-going debate on the right approach to international assistance in the field of water resources development in the region, and in particular ways to strengthen national hydrometric services.

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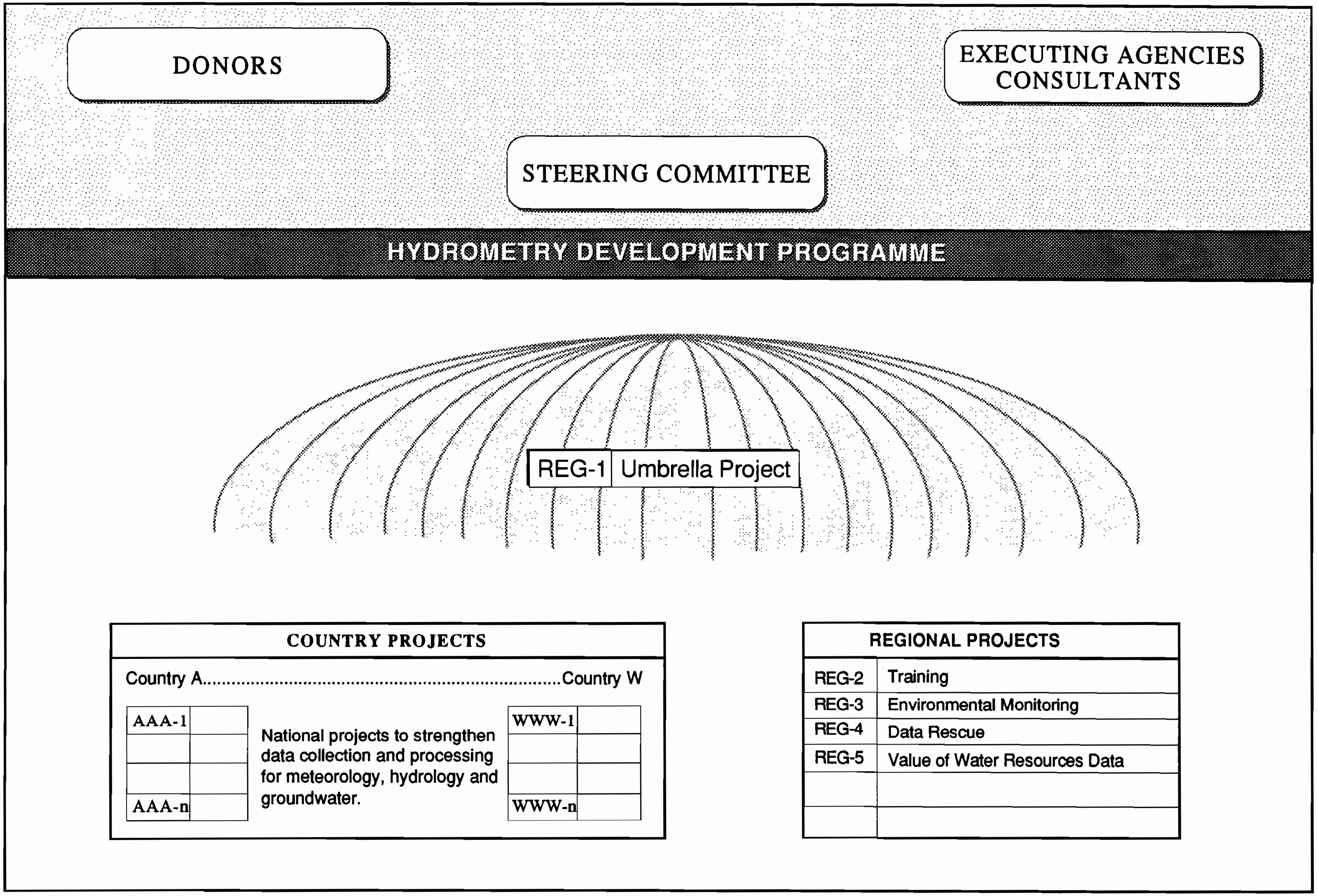


Figure S.2 Organisation of the Hydrometry Development Programme

CHAPTER 1

INTRODUCTION

1.1 Background to Study

The assignment to assess the hydrological data collection systems of twenty-three countries in West Africa forms part of a larger study of all the sub-Saharan countries in Africa as shown in Figure 1.1. The present work is being jointly financed by the United Nations Development Programme (Project number RAF/87/030), the African Development Bank and French aid (FAC), and is administered by the World Bank. The West African assignment is the third part of the overall study to be let: work on the assessment in IGADD member countries (Group I) was completed in 1989, and for SADCC member countries (Group II) was completed in 1990.

The purpose of the project is to evaluate the status of all existing hydrological data, networks and collection systems and make recommendations for the filling of important gaps, upgrading of quality of data collection and for the general enhancement of the capability to measure, retrieve, process and publish hydrological data and information in sub-Saharan countries. The ultimate aim is to assist countries in the creation or improvement of a sound hydrometric base for the purposes of planning and evaluating water resource development programmes and projects. The studies apply to hydrometeorological data, surface water resources, and groundwater.

Throughout the West African study the Comité Interafricain d'Etudes Hydrauliques (CIEH) has provided co-ordination between its 14 member countries, the Consultants, and the World Bank. The CIEH assistance was of particular value at the start of the assessment visits to their member countries. In the period after submission of the draft reports they provided the Bank with their own detailed comments and also gathered together the comments of their members.

1.2 The Value of Hydrological Data

A fundamental prerequisite to the assessment of any data collection system is a determination of the value of the information to be collected, that is to say both its importance and utility, and the cost of its collection.

It is very difficult to put a financial value on hydrological data, especially the general background information such as accurate identification of rainfall patterns. Studies can be made for major projects, such as the construction of a dam, and the cost implications of uncertainty in the streamflow data can be assessed, although this is rarely done.

In West Africa, however, the greatest use for hydrological data is for small scale development: for the evaluation of water rights applications, for the design of small water abstraction systems for rural water supply schemes, or for the design of minor irrigation systems. In most cases, direct measurement of the water source will not have been attempted, and full reliance will have to be placed upon a regionalisation of measured information, to produce estimates of minimum reliable runoff rates or groundwater potential. Accuracy in such regionalisation would have immense benefits, but at present it is very difficult to determine just how inaccurate the currently used interpolation techniques are.

Broader assessments of the value of hydrological data can also be made, comparing, for example, the cost and effort put into the design, construction, operation and maintenance of water development projects with the resources put into collecting hydrological data. Preliminary comparisons of this type are made later in the report when considering the development of the hydrological data collection agencies.

A significant factor to bear in mind during any evaluation of the benefits derived from hydrological data collection is the need to establish a clear picture of the long-term variability of any hydrologic parameter, in order to plan the optimum exploitation of that resource. This means that for projects that may be developed over the next say 50 years, data collected this year could be of particular value. This is particularly true with current concern over the effect man is having on the long-term behaviour of the weather systems, the 'greenhouse' effect and consequent global warming, desertification, increasing soil erosion and other trends. The only means of monitoring such slow environmental changes is to maintain an accurate, reliable network of measurement points.

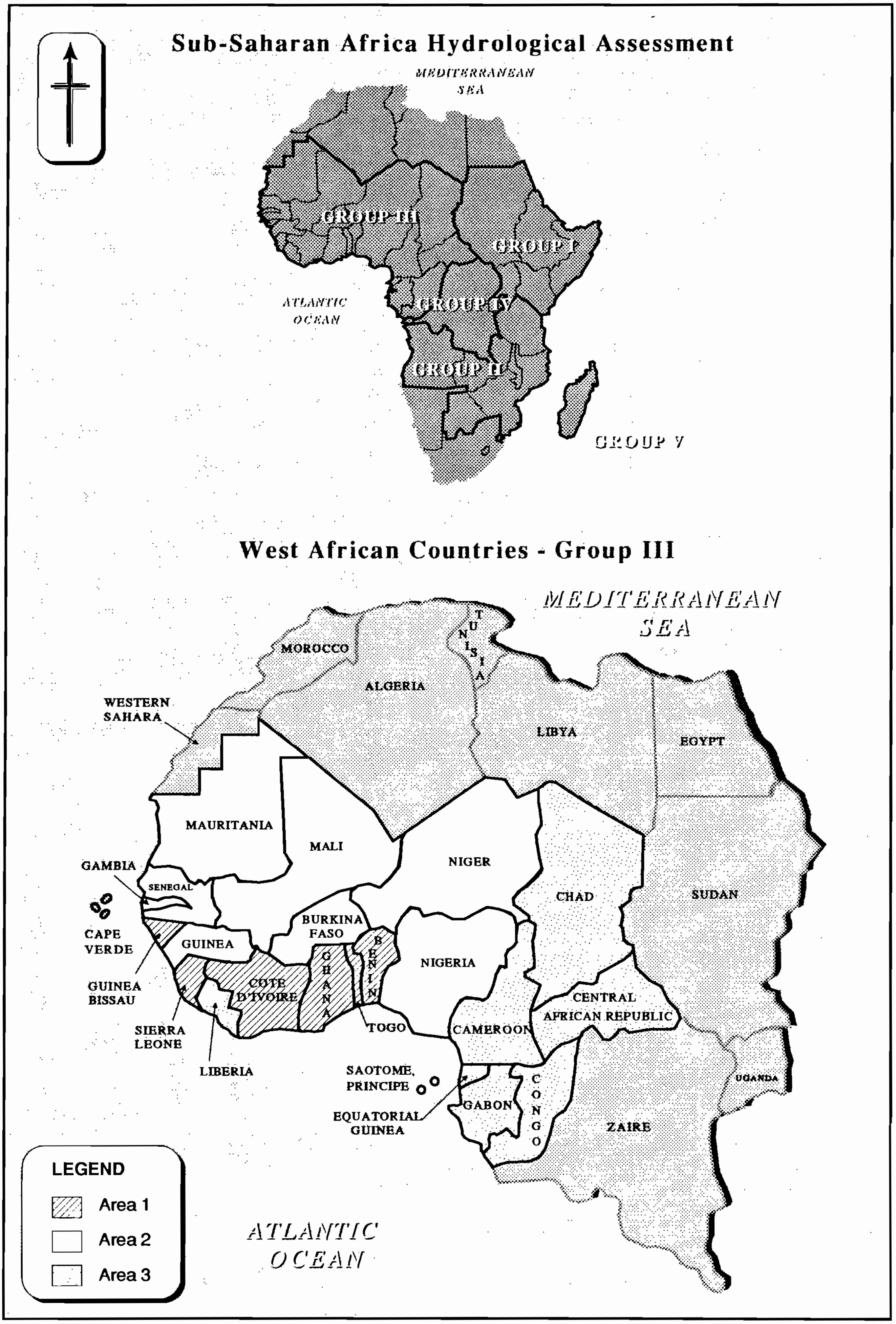
Long records are essential to the reliable estimation of the frequency of severe events for the design of schemes. The length of record required cannot easily be defined, extreme events, such as major storms and floods, can occur at any time and even where long records have been kept at the site may invalidate the results of previous frequency analyses based on the historic records.

There is however undoubtedly also a degree of 'diminishing return' in the taking of hydrological measurements. The first year of data collection for a variable at a site will be of more benefit than the tenth year, which in turn will have greater value than the fiftieth year of data. The concept of a two-tier gauging network has developed from this feature. The top tier of 'primary' gauges are used to provide information on the temporal variability of the resource, and are maintained to be as constant and as consistent as possible; the lower tier of gauges provide the spatial detail to allow interpolation of resource values between the primary gauges, and consequently can be closed as soon as the patterns of spatial variation are accurately defined. Unfortunately, none of the countries in West Africa are currently in the position whereby the spatial variation of the principal hydrological parameters can be considered to be accurately defined. Thus it is not possible to recommend major reductions in monitoring networks on these grounds at the present time. In fact in many countries significant reductions in monitoring activities have occurred recently due to financial constraints and it is apparent that even 'primary' sites have been affected.

In the past hydrological data have been grossly undervalued in West Africa with all countries having data collection agencies struggling with unrealistic budgets and totally inadequate resources. The drought which afflicted the Sahelian countries has led to a number of important international iniatives

Figure 1.1

The Study Area



to ensure that certain types of hydrological information are readily available. The drought has therefore played a major part in focusing attention on the importance of hydrological data in an environment so sensitive to change.

1.3 Approach to the Study

The study was carried out in three phases: a short preliminary inception phase, the assessment and draft report preparation phase, and lastly the finalisation phase, see Figure 1.2. The twenty-three countries were grouped for convenience into three areas (see Figure 1.1), this was to assist in co-ordination and management and it also allowed individual members of the study team to carry out assessments in several countries.

The assessment for individual countries began with the attendance of the country representatives at a Pre-implementation Meeting at which the objectives of the study were introduced and a formal request made for preliminary data collection prior to the Consultants' visit. Two such meetings were held: in October 1990 for the first two areas, and in May 1991 for the third area.

During the inception phase guidelines were prepared and distributed to all team members to ensure consistency of approach to the assessment, to report preparation, and most importantly to the formulation of project proposals.

The programme of country visits undertaken during the assessment phase is given in Table 1.1. The table indicates the division of responsibilities between the Consultants and ORSTOM; local consultants were involved in the assessments for Cameroon, Chad, Ghana, Nigeria, and Senegal. The table highlights the fact that the assessment visits were extremely short requiring the team members to adopt a highly focused approach and to prioritise their activities; the total time allocated to an individual country averaged only six weeks including time in the Consultants' home offices. A consequence of this restricted input was that investigating management and data handling procedures were accorded a higher priority than the compilation of inventories.

Superimposed upon the fundamental objectives of the assignment - the evaluation of existing hydrological data, networks, collection and processing systems, and the preparation of hydrometeorological maps - are a number of more detailed, country-specific requirements contained within the Particular Terms of Reference. High priority was given to meeting these requirements as fully as possible, and these issues were all discussed in detail with representatives of the departments concerned, and conclusions drawn reported in detail within the appropriate section of the relevant country report.

At the start of the finalisation phase the country representatives attended meetings in Ougadougou and Accra in May 1992 at which the Consultants presented their findings on the situation in each country. Subsequently two further workshops were held in the region in September 1992 at which the country representatives discussed and agreed comments on the draft of the Regional Report and the project proposals contained therein.

TABLE 1.1

Programme of Country Visits

Country	Start Date	Duration	Meteorology and Surface Water	Groundwater
Mauritania	May 1991	3 weeks	ORSTOM	BCEOM
Mali	May 1991	3 weeks	ORSTOM	BCEOM
Niger	March 1991	3 weeks	ORSTOM	BCEOM
Chad	June 1991	3 weeks	ORSTOM	SOGREAH
Senegal	March 1991	3 weeks	ORSTOM	SOGREAH
The Gambia	June 1991	2 weeks	Mott MacDonald	Mott MacDonald
Guinea Bissau	January 1991	2 weeks	ORSTOM	BCEOM
Guinea	February 1991	3 weeks	ORSTOM	BCEOM
Sierra Leone	January 1991	3 weeks	Mott MacDonald	Mott MacDonald
Liberia		3 weeks	Mott MacDonald	Mott MacDonald
Côte d'Ivoire	January 1991	3 weeks	ORSTOM	SOGREAH
Burkina Faso	April 1991	3 weeks	ORSTOM	SOGREAH
Ghana	February 1991	3 weeks	Mott MacDonald	Mott MacDonald
Togo	February 1991	3 weeks	ORSTOM	SOGREAH
Benin	November 1990	3 weeks	ORSTOM	SOGREAH
Nigeria	July 1991	5 weeks	Mott MacDonald	Mott MacDonald
Cameroon	June 1991	3 weeks	ORSTOM	SOGREAH
Central Afr Rep	October 1991	3 weeks	ORSTOM	BCEOM
Equatorial Guinea	August 1991	2 weeks	Mott MacDonald	Mott MacDonald
Gabon	July 1991	3 weeks	ORSTOM	BCEOM
Congo	July 1991	2 weeks	ORSTOM	SOGREAH
Cape Verde	November 1990	2 weeks	ORSTOM	BCEOM
São Tomé & Príncipe	August 1991	3 weeks	Mott MacDonald	Mott MacDonald

As data from an individual country may not be relevant outside that country, it has been decided to subdivide the final report, and distribute only the relevant parts of it to each country. Consequently the final report is in 24 volumes; one regional report and 23 country reports. The regional report has been prepared in both English and French. The reports on the three Lusophone countries and Equatorial Guinea have been prepared in both the appropriate local language and either English or French. It is intended that each country will receive its own country report together with either the English or French version of the regional report as appropriate.

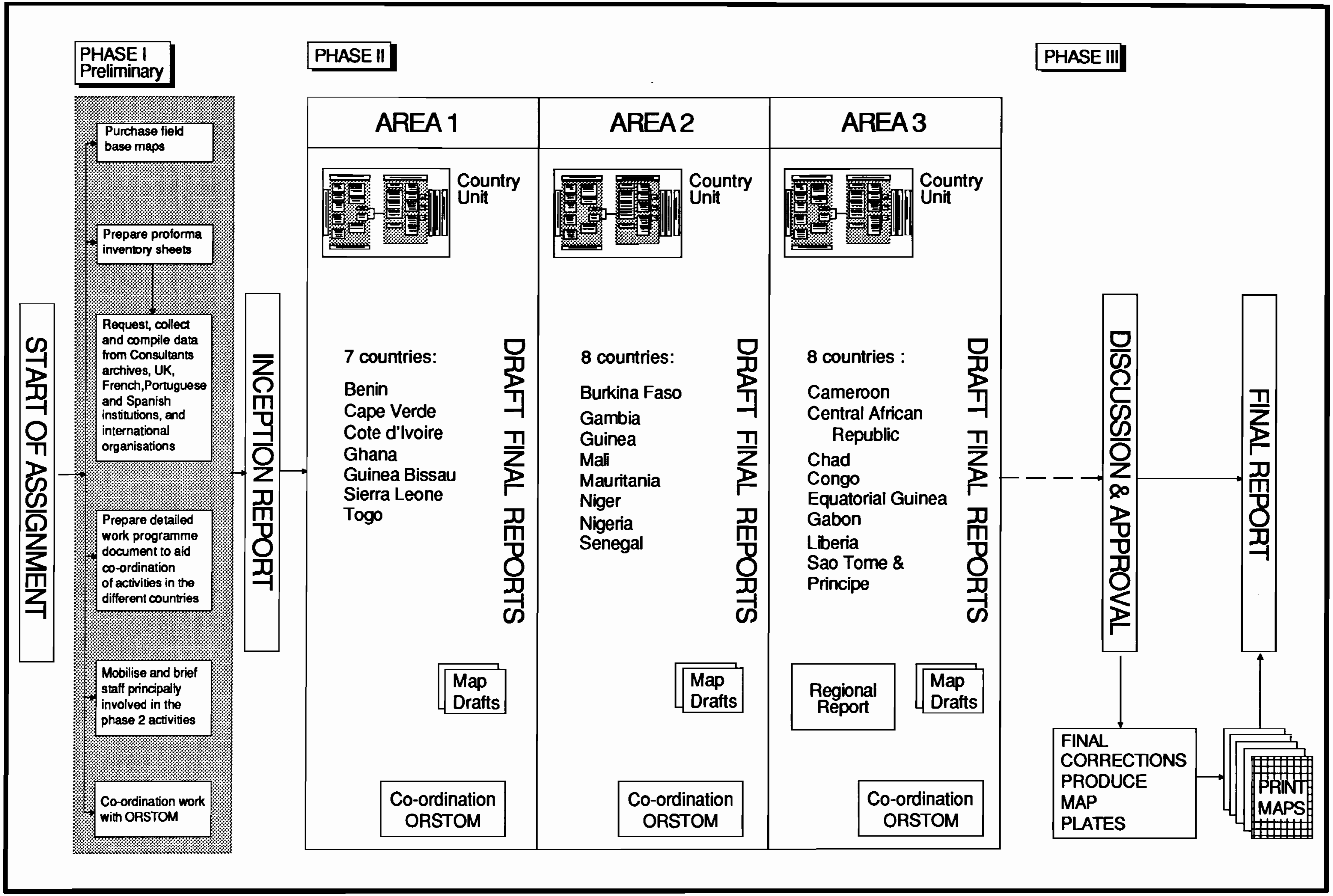


Figure 1.2
Work Flow Chart

CHAPTER 2

REGIONAL WATER RESOURCES

2.1 Introduction

The prime objective of the Sub-Saharan Africa Hydrological Assessment project is to evaluate the status of the existing hydrological data collection networks in West African countries and make recommendations for modification and enhancement to meet the requirements for future water resource development programmes. It was not the purpose of the project to assess the water resources and future demands within individual countries, the time available was anyway quite inadequate for such an undertaking. We have however made every effort to obtain the latest government figures for each country and this information is presented in the country reports. Where the data is related to resources shared between states it is summarised in this chapter.

2.2 Climate in West Africa

2.2.1 Introduction

In the past water resources have been assessed on the basis of unchanging climatic conditions. The design of schemes in arid areas took account of greater inter-annual variation than allowed for in humid zones, but local climate was thought of as constant for the expected life of the project. The drastic consequences of the prolonged drought in the Sahel which exposed the dangers of project design with relatively short records, and the increasing body of international opinion supporting the concept of global warming have brought climate into focus as a major factor in assessing water development needs and potential.

This section briefly reviews the regional climate and the possible consequences of global warming. A more detailed discussion is contained in Appendix B.

2.2.2 Recent Climatic Change

In contrast to the other continents and other regions within Africa, West Africa has no major mountain barriers, either longitudinally or latitudinally oriented, to disrupt the dominant monsoon circulation. Consequently, its climate is governed to a large extent by the seasonal movements of the Inter-tropical Convergence Zone (ITCZ). Rainfall over West Africa is therefore strongly seasonal with the wet season occurring between July and September over the more northerly latitudes (12-16°N), lengthening to April to November further south. Along the Gulf of Guinea coast (5-8°N) there is a weak bimodality in the rainfall regime with peak rainfall occurring in May and October separated by a short dry season in July and August.

African rainfall is highly variable both from year to year and from decade to decade, especially in the tropical semi-arid and sub-humid margins of the continent (Hulme, 1992). This variability is an inherent feature of African climate and has been shown to have prevailed historically for at least several centuries (Nicholson, 1978).

Figure 2.1 shows the rainfall anomalies within Africa for the generally wet decade, 1951 to 1960 and the dry decade 1981 to 1990. Maps (a) and (b) in Figure 2.1 demonstrate the coherence of these decadal rainfall anomalies throughout the whole of West Africa. Also noted is a tendency for equatorial Africa to possess opposite rainfall anomalies to the rest of the continent. This contrasting rainfall behaviour has been clearly demonstrated by the levels recorded in Lake Victoria, Lake Tanganyika and Lake Malawi. Perhaps the clearest example of this feature, however, is the persistence of higher White Nile flows since 1961 (source is in equatorial Africa), whilst over the last two decades the Blue Nile (source in tropical north Africa) has suffered the most serious reductions in discharge recorded this century.

Individual years as well as decades show considerable spatial coherence in rainfall anomalies over Africa. This is illustrated for 1950 (wet) and 1984 (dry) (see maps (c) and (d) of Figure 2.1). It seems that for individual extreme wet and dry years nearly the whole continent can be affected (eg 1984). Nicholson (1986) has isolated four different preferential rainfall anomaly patterns over the African continent. These modes are:

- northern and southern tropical margins dry; equatorial regions wet;
- northern and southern tropical margins wet; equatorial regions dry;
- whole continent dry;
- whole continent wet.

A more subtle mode of rainfall variation of importance for West Africa is the contrast in rainfall anomalies between the Guinea coast and the interior Sahel. This contrast is seen in the generally wet year of 1950 (Figure 2.1, map (c)) and is also illustrated in Figure 2.2 which shows the change in June to August rainfall from 1931-60 to 1961-90. Whilst rainfall in the Sahel has declined by up to 1mm day^{-1}, rainfall along the the Guinea coast has increased by a similar amount.

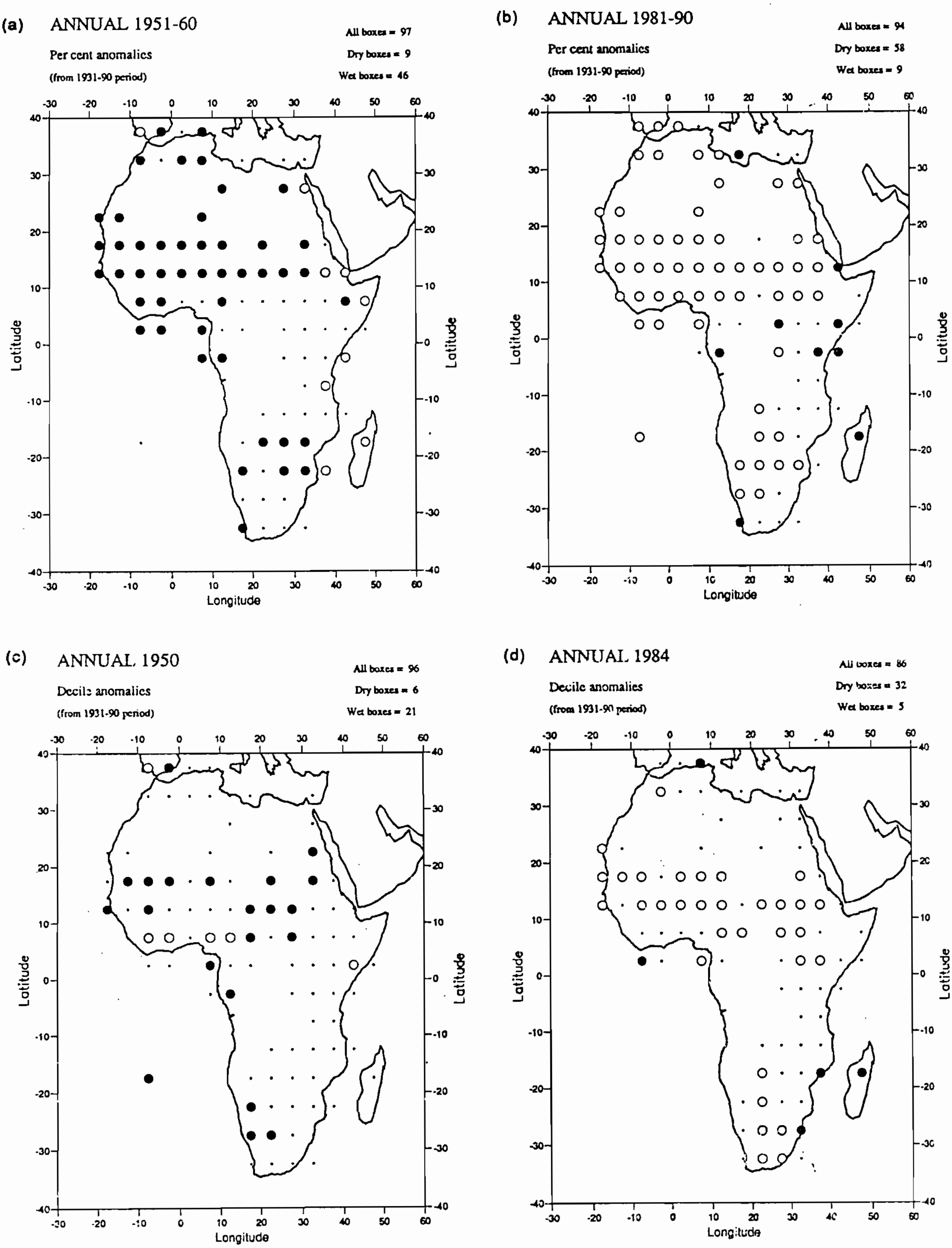
Hydrologists usually rely on statistical evidence for their estimation of the reliability of river flows, whether this evidence is stochastically generated or based on historic records. Both trends and persistence are generally ignored unless physical explanations can be presented to justify their inclusion. In this respect, three factors are of importance when considering climatic change over West Africa:

- as the Sahelian drought persists (Figure 2.3) the statistical evidence is growing that river yield estimates will be affected;

- extensive meteorological research is producing results that purport to explain the drought in physical terms;

Figure 2.1

Percent Anomaly Maps for the Decades 1951-60 and 1981-90
Decile Rainfall Anomaly Maps for 1950 and 1984



Filled circles in maps (a) and (b) indicate mean annual rainfall for the decade was more than 5% above the 1931 to 1990 average and open circles more than 5% below, dots indicate rainfall within 5% of the 1931 to 1990 average. In maps (c) and (d) filled circles indicate that the selected year falls within the wettest 10% of years between 1931 and 1990, open circles the driest 10%, and dots all remaining values.

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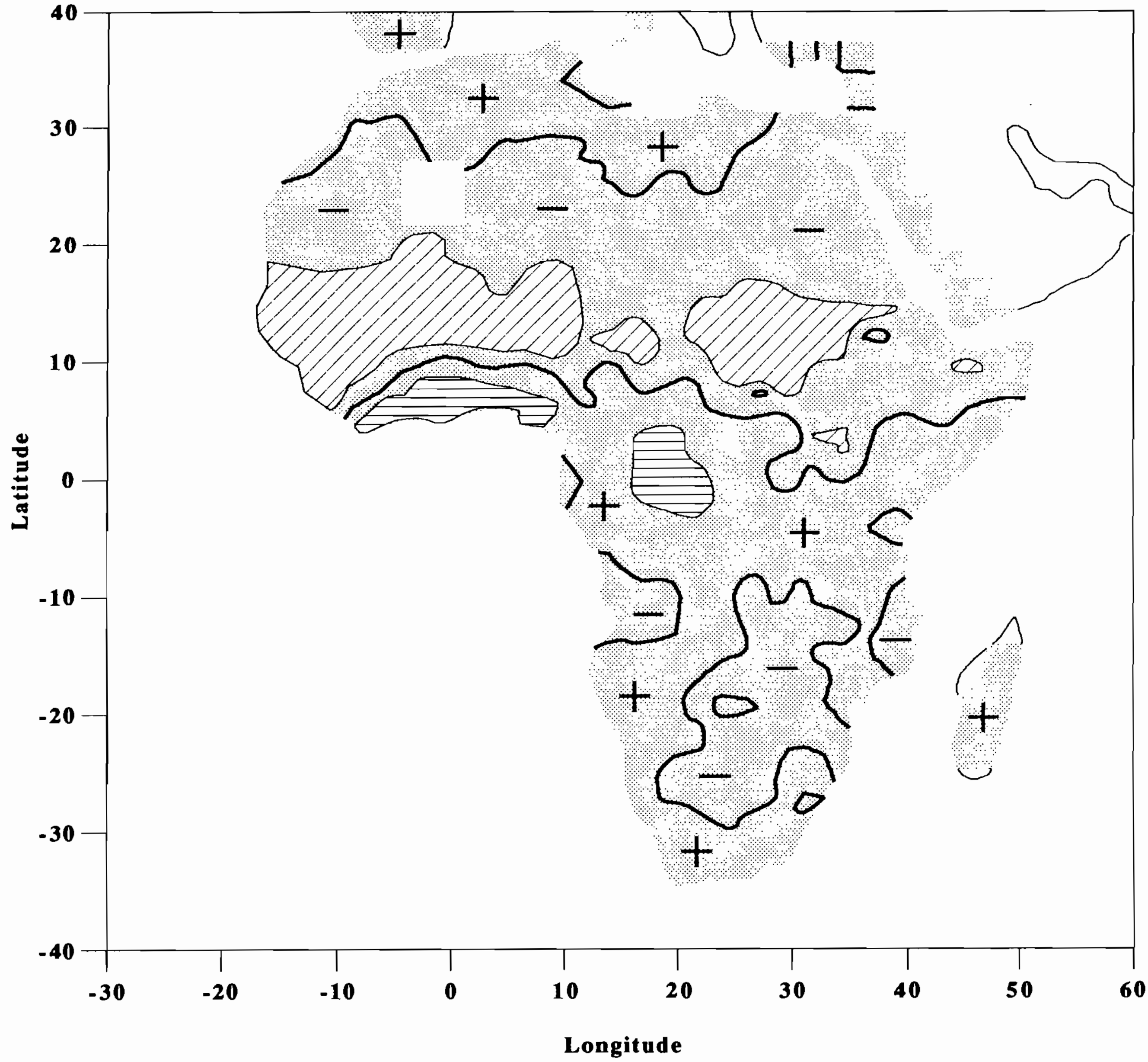
Figure 2.2

Mean Summer (JJA) Rainfall Change Between 1931-60 and 1961-90



Key :-

Rainfall increase > 0.5 mm / day

No change

Rainfall change $\pm$ 0.5 mm / day

Rainfall decrease > 0.5 mm / day

JJA June, July, August

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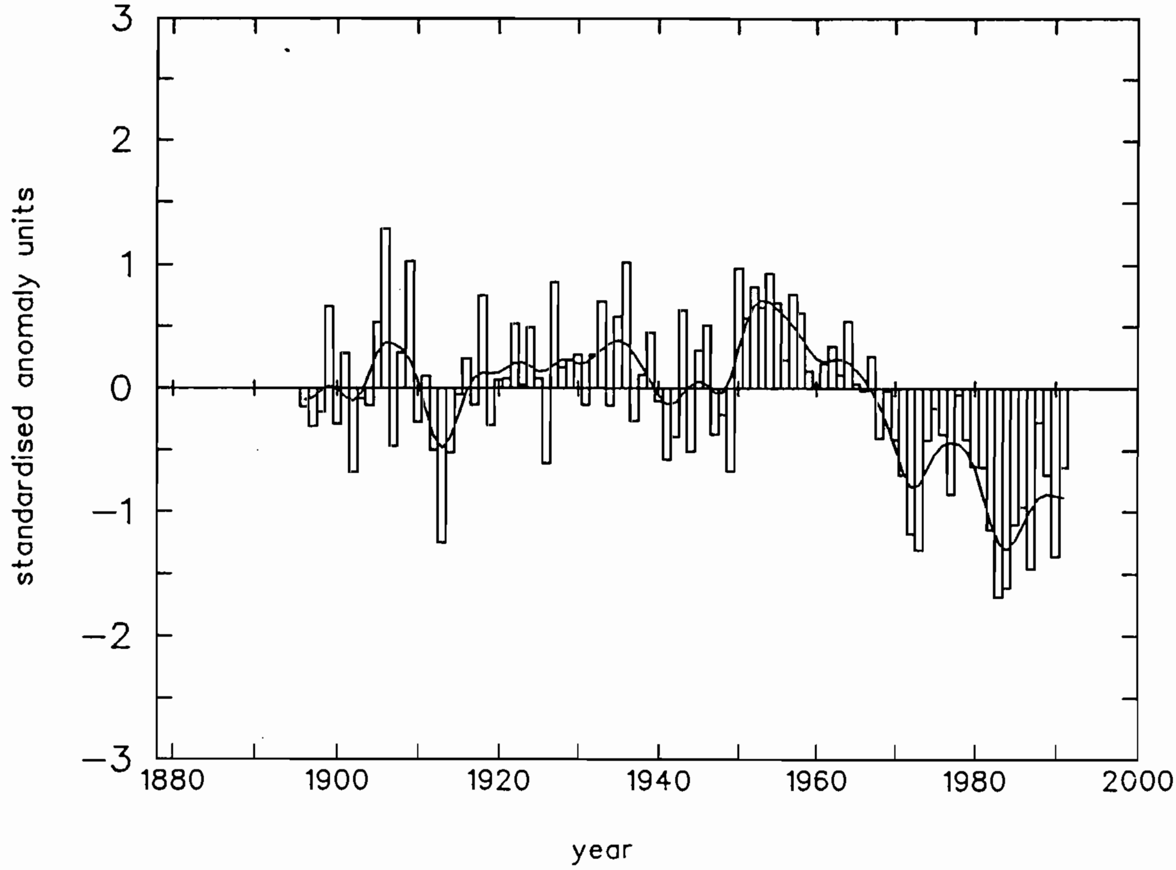
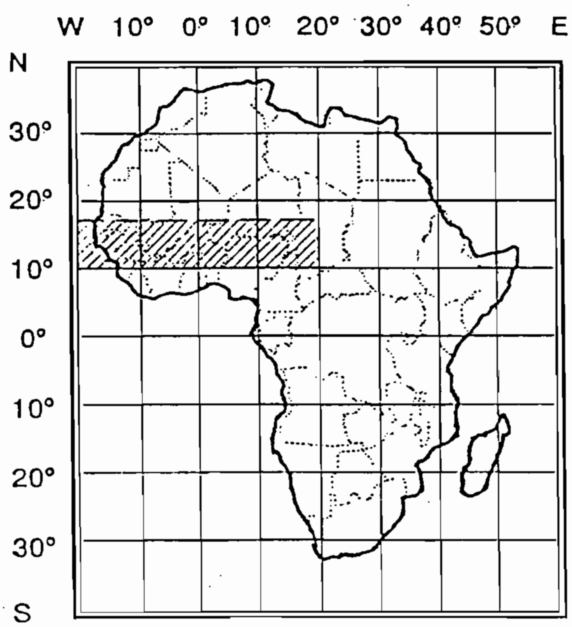
Figure 2.3

Annual Rainfall Anomaly Index for the West African Sahel from 1888 to 1991



Latitude 10°N to 17°N

Longitude 20°W to 22°E



Anomalies are expressed relative to the 1951 to 1980 average.

The region represented by this index is shown on the map.

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- if the recent decline in rainfall is related to physical changes in the climate system introduced by Man then its persistence and consequences may be more pronounced and potentially serious than those recorded in the past.

The search for a causal explanation of the African drought has been led by the research undertaken in the UK Meteorological Office (Folland et al, 1991). This work has demonstrated a strong correlation between global sea surface temperature (SST) anomalies and wet and dry periods in Africa.

Beginning in the mid-1960s, a marked warming was observed of the southern hemisphere's oceans relative to the northern hemisphere's oceans. The Indian Ocean tended to warm in phase with the southern hemisphere rather than with the north Pacific and north Atlantic. A time series plot of the SST anomaly difference between the oceans of the southern hemisphere (plus the Indian Ocean) and those of the northern hemisphere against rainfall anomalies for the West African Sahel, shows a strong negative correlation (Figure 2.4). The correlation between the July to September SST pattern and Sahel rainfall for the period 1901-88 was -0.62, significant at the 99% probability level.

Experiments using numerical climate models have also been undertaken by the UK Meteorological Office which have simulated the rainfall anomalies in the Sahel for seven recent years: 1950, 1958, 1976, 1983, 1984, 1988 and 1990 (Rowell et al., 1991). These simulation experiments initalised the model with the observed global SST patterns for each respective year whilst keeping all other parameters the same. The good simulation of Sahel rainfall achieved in these experiments using June SST anomalies reinforces the idea that large-scale SST anomalies can significantly alter rainfall in the Sahel.

Although the observed warming of the southern oceans at a faster rate than the northern oceans is thought to be due to a reduction in the heat transfer from south to north, the actual mechanisms are not fully understood.

2.2.3 Future Climatic Change

Over the last decade a number of major climate modelling experiments have been undertaken to assess the effect of increased atmospheric concentrations of CO_2 and other greenhouse gases (GHGs) on future precipitation and temperatures. These investigations have relied mostly on Atmospheric General Circulation Models (AGCMs), although some recent experiments have been completed with Coupled ocean-atmosphere GCMs (CGCMs). The consensus outcome of these experiments is that the mean equilibrium temperature of the Earth would increse by between 1.5° and 4.5°C for a doubling of GHG concentrations. The best guess equilibrium global warming would be 2.5°C (Houghton et al., 1990). The date by which such warming might occur is uncertain due to a number of factors. All these conclusions should be regarded as research hypotheses which await validation. In Appendix B an expert in the field, Dr M Hulme, presents the latest research findings in more detail.

One of the problems of relying on these model experiments to determine possible regional changes in climate is that the model results often disagree with each other. This is more so for precipitation than for temperature. Recent work by the Climatic Research Unit, UK (Wigley et al., 1992) has combined the results of five such equilibrium experiments thereby enabling an assessment to be made of uncertainty in the regional climate change scenarios. According to this composite model scenario some reduction in June to August rainfall is anticipated along the west coast of Africa between Côte d'Ivoire and Cameroon (Figure 2.5). Further north and east, increases in summer rainfall are projected and this area of increase could extend northwards as far as Lake Chad. Increases may be up to 0.5 mm day^{-1} for a doubling of CO_2. However, probably little change in rainfall would be experienced over the upper Chari and Logone catchments. Winter rainfall (December to February) is suggested as increasing by up to 1 mm day^{-1} over west equatorial Africa.

The composite scenario generates mean annual temperature increases of between 3° and 4°C over much of West Africa and the Lake Chad Basin. The confidence placed in the temperature projections of these models is considerably greater than in those for rainfall. This temperature increase, with its effect on lake evaporation and catchment evapotranspiration, could present a more serious problem for the water resources in the region than the change in rainfall supply. Increased water losses through evaporation and transpiration would likely cancel out the benefits of any increases in rainfall, or substantially exacerbate problems caused by any decreases in rainfall.

These projections of possible effects of global warming are based on a doubling of the atmospheric CO_2 under steady state conditions. It is more difficult to simulate the changing global climate under scenarios of realistically increasing GHG concentrations (see Appendix B). A realistic model of the circulation of the oceans and the solution of CO_2 in the oceans is required for such transient experiments.

In summarising our present understanding of the Sahel drought and future possible climate changes in West Africa we can identify the following factors which are likely to be related to the current drought and suggest that it may well continue for a number of years to come:

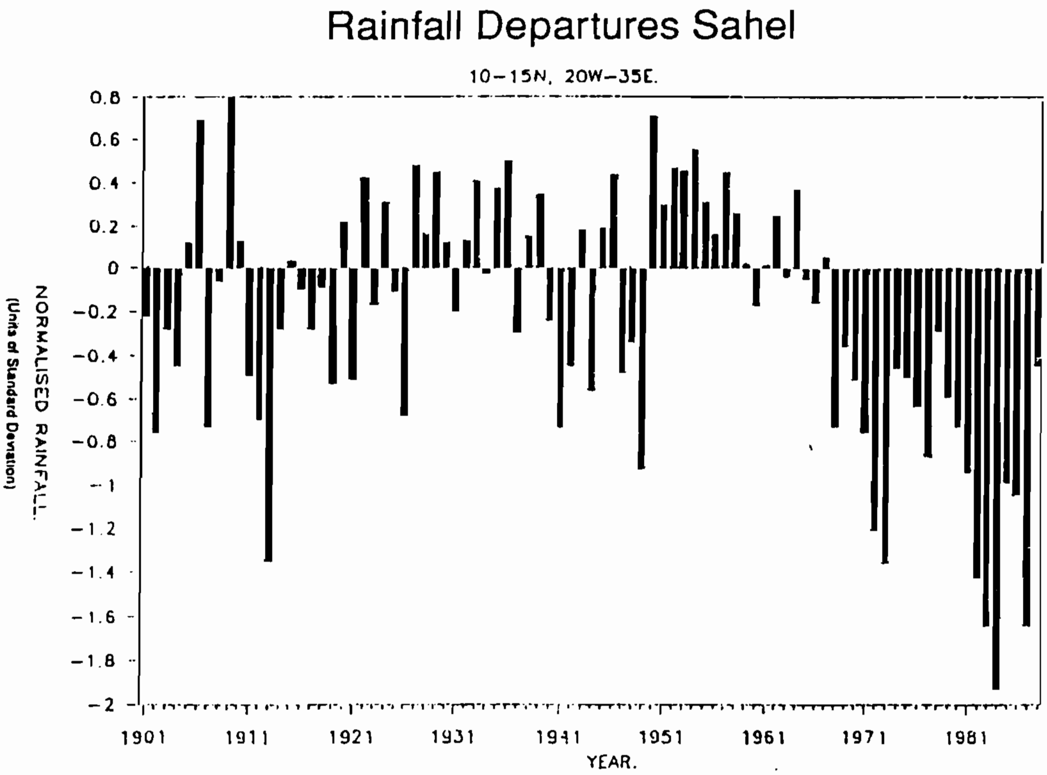
- differential warming of the oceans, particularly in the southern hemisphere and Indian Ocean, establishing SST anomaly patterns which can effectively reduce rainfall particularly in the tropical zone in north Africa. The reason for the differential warming between hemispheres is not properly understood; it may be related to changes in the thermo-haline circulation in the Atlantic or to Man-induced global warming.

- biogeophysical feedback mechanisms such as increased albedo and decreased soil moisture within the Sahel which aid the presistence of drought and tend to inhibit a return to the previous rainfall regime.

- increases in atmospheric CO_2 concentrations resulting in a general warming of the near-surface atmosphere. Even if CO_2 and other GHG concentrations could be stabilised at current levels, it is likely that significant changes will result to the present temperature and

Figure 2.4

Sahel Rainfall Departures and Sea Surface Temperature Differences between the Hemispheres



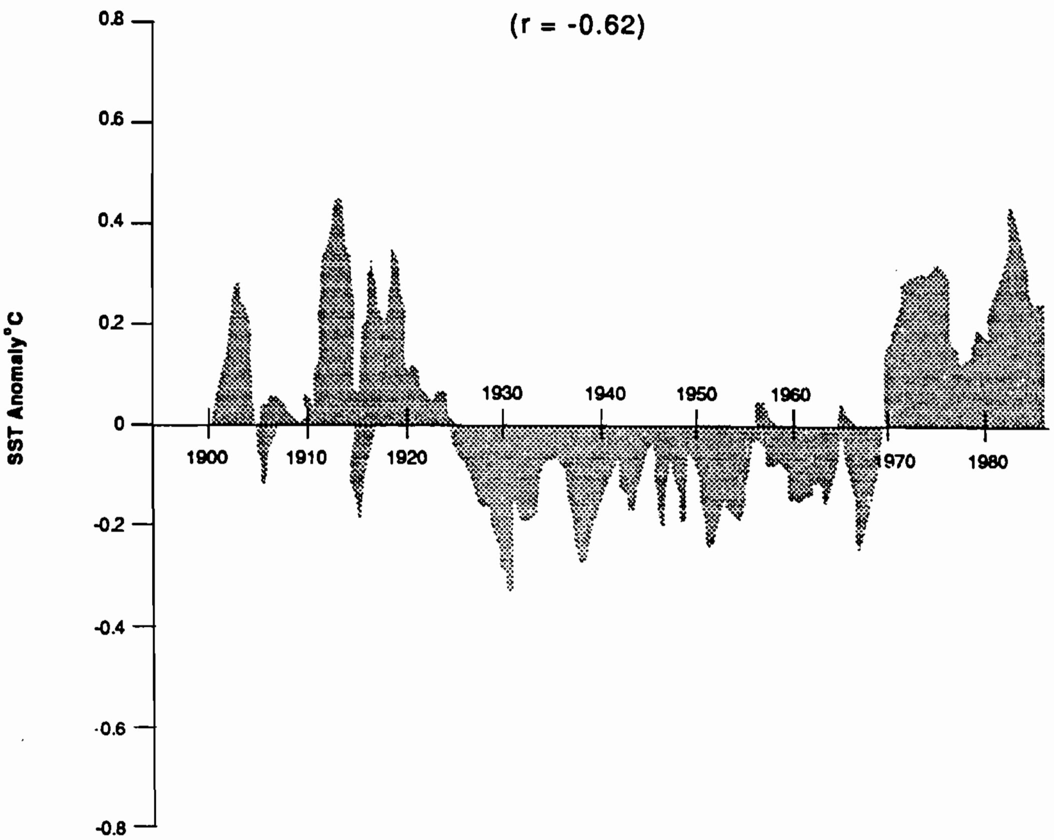


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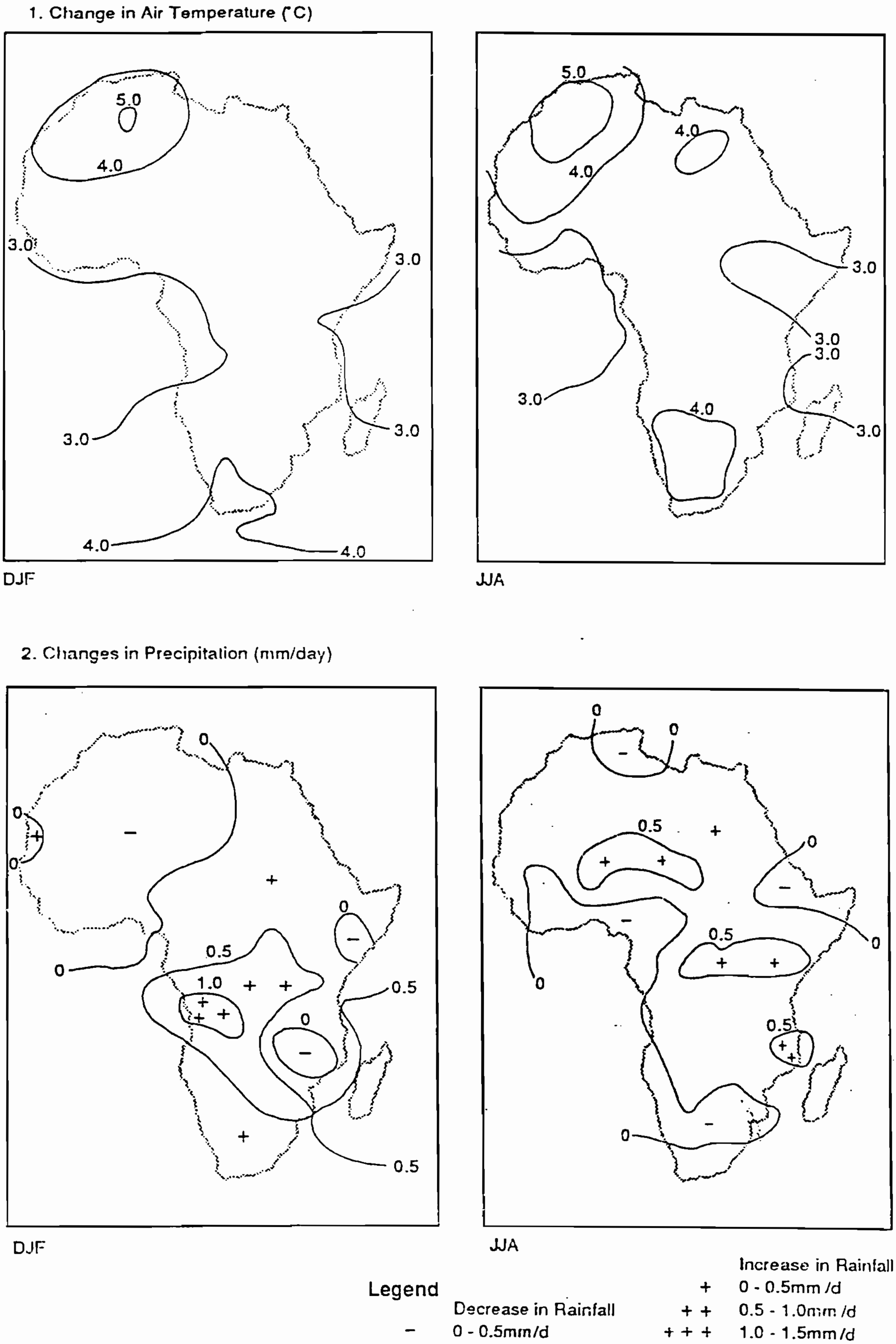
Figure 2.5

Model Average Results for Doubling of Atmospheric CO_2



(After Wigley et al, 1992)

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precipitation regimes of the West African countries. Assessments of future water resource supply and demand in the region need careful consideration of this possibility.

2.3 Major Surface Water Resources Basins

2.3.1 Introduction

The basins of the major rivers of the region are shown in Figure 2.6, a list countries sharing the resources of these rivers is given in Table 2.1. The basins are ancient and have been affected by tectonic movements and climate change. The effect of tectonic movement is seen in the abrupt changes in slope on many of the rivers, and the effects of older climatic regimes can be seen in the successive shorelines of Lake Chad. River capture at various times has resulted in the strange courses of some of these rivers, for example the main stem of the Niger. The process continues today, for example the Benue is at present actively cutting headwards and may eventually capture the Logone via the Mayo Kebi.

TABLE 2.1

International River Basins

Basin Area (km^2)	Niger 2 000 000	Senegal 340 000	Gambia 80 000	Volta 390 000	L Chad 2 500 000	Zaire 4 100 000
Benin	*			*		
Burkina Faso	*			*		
Cameroon	*				*	*
Central African Rep					*	*
Chad	*				*	
Congo						*
Côte d'Ivoire	*			*		
Guinea	*	*	*			
Gambia			*			
Ghana				*		
Mali	*	*		*		
Mauritania		*				
Niger	*				*	
Nigeria	*				*	
Senegal		*	*			
Togo				*		

Note: The Zaire or Congo basin is also shared with countries in Groups II and IV of the Sub-Saharan Africa Hydrological Assessment.

2.3.2 The Niger River

The Niger and its principal tributary the Benue flow through the territory of nine countries, its development therefore raises many international issues. All the riparian states are members of the Niger Basin Authority, see Section 3.2.1.

The Niger is some 4 200 km long and drains an area of about 1 870 000 km^2, however, because of the variable climatic and physiographic regions through which it passes only a relatively small proportion of this vast area contributes significantly to its flow. As a result of the large distances involved significant time delays arise, for example, these is almost a six month phase difference between the 'black flood' generated in the upland catchment of Guinea, Mali and Côte d'Ivoire and the 'white flood', so called because of its high silt load, which is generated within Nigeria.

The headwaters of the Niger are largely in Guinea. The many tributary streams form a dense network draining a vast plateau, oriented towards the north-east they descend progressively from the rugged topography of the Guinean mountains towards the basin of the inner delta.

The Niger itself rises at about 800 m on the Guinea/Sierra Leone border. For the first 40 km the slope is very steep (7.5 m/km), as far as Faranah it remains above 0.3 m/km despite meandering over a vast flood plain. Here the mean annual discharge is around 73 m^3/s for rainfall around 1 900 mm. Below Faranah the slope is maintained with inflows from the left bank of small but very steep tributaries issuing from the Futa Jalon (Balé, Koba, Niantan). Immediately after the Mafou confluence the Niger falls tens of metres by a series of imposing rapids. As far as Bamako the character of the river remains the same: banks 5 to 6 m in height, extensive flood plain, large radius bends, many islands, and a slope around 0.12 m/km. At Kouroussa the annual discharge is 240 m^3/s for an annual rainfall of 1 500 mm. On leaving Guinea the annual discharge is around 1 130 m^3/s for a rainfall of around 1 450 mm. The well known 1967 flood peak, which arrived at the end of September, was greater than 5 300 m^3/s at Tiguibéry and 7 200 m^3/s at Dialakoro (ORSTOM, 1986).

At Kouliokoro (Figure 2.7) the mean annual discharge is 1 450 m^3/s and the peak flood occurs in September. The average volume is 47 km^3, but as illustrated by Figure 2.7 there is evidence of a declining trend in recent decades. Below Koulikoro the river soon spreads out to form the 'internal delta' which extends some 17 000 km, almost to Timbuktu. In this reach the principal tributary is the Bani which rises in Côte d'Ivoire. The water courses have changed position frequently in the past and there are several channels which diverge and reunite as the river crosses the plain. There are a large number of small lakes that are connected with the many branches of the river, some of these are permanent but most are ephemeral. Losses in the internal delta to infiltration and evaporation are very considerable (see Figure 2.8) amounting to 50% of incoming runoff and all the local rainfall contribution.

Downstream of the internal delta the Niger flows through very arid country and at the border of the Republic of Niger the mean annual discharge is of the order of 1 000 m^3/s (1952-78). At Niamey the flood peaks in January/February and the lowest flows occur in June/July. On the right bank the Niger is joined by several tributaries originating in Burkina Faso (Gorouol, Dargol, Sirba, Goroubi

Figure 2.6

Major River Basins in West and Central Africa

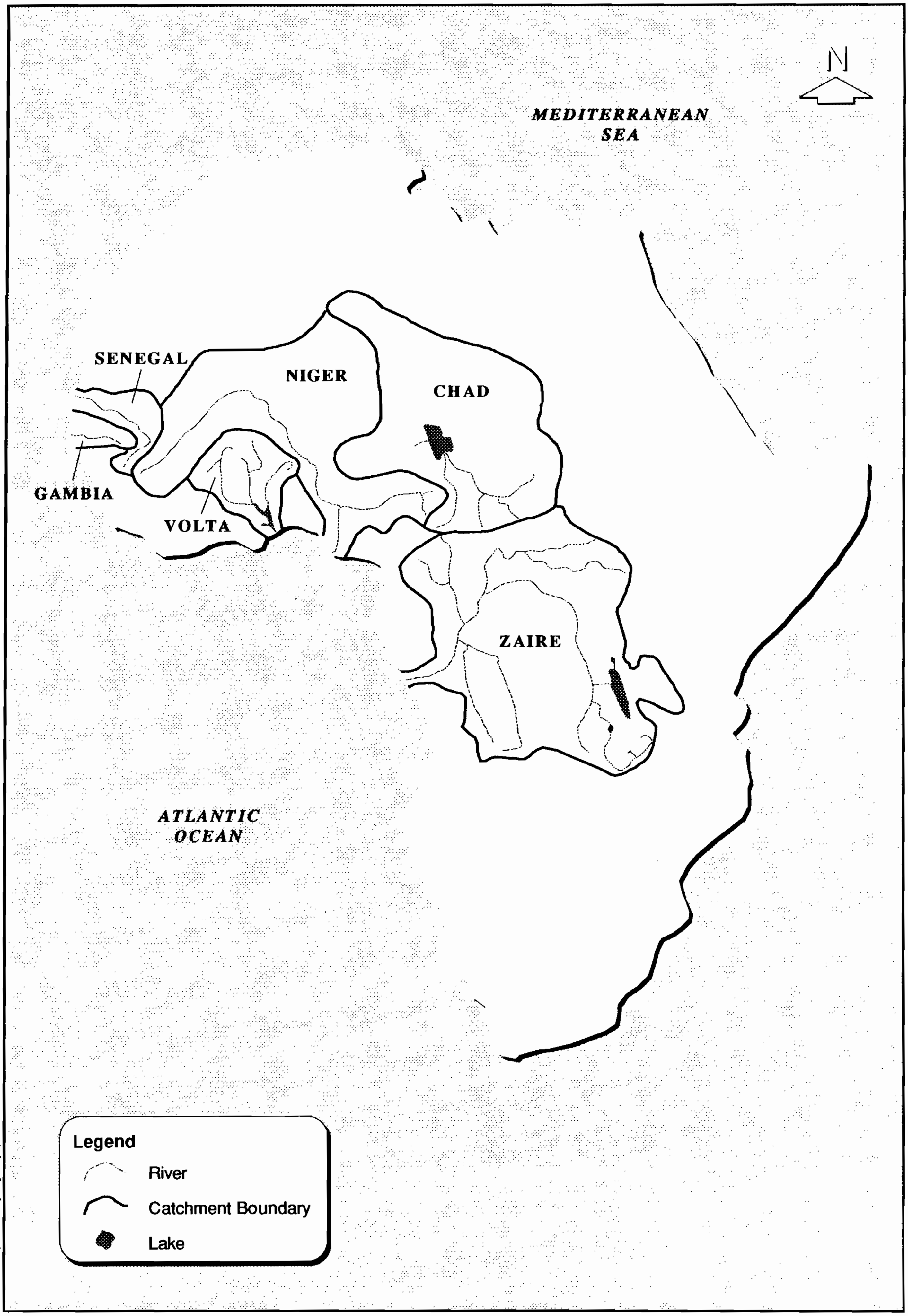

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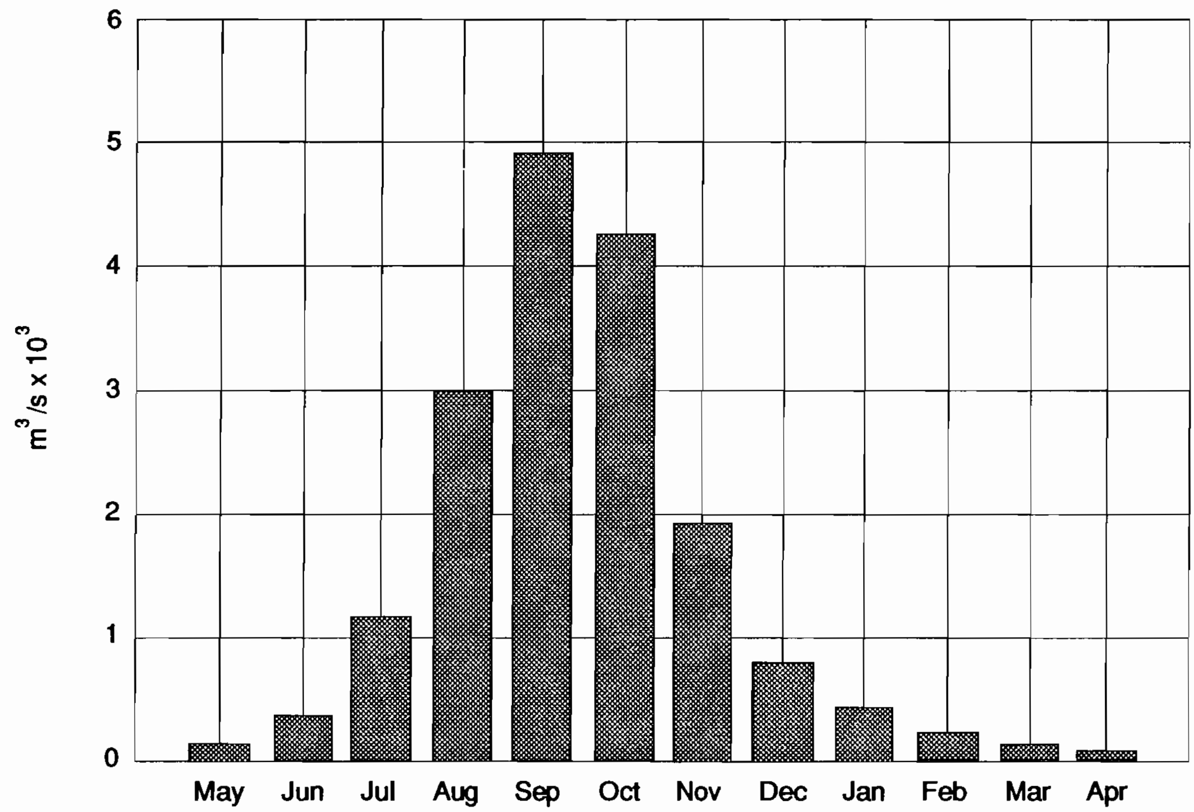
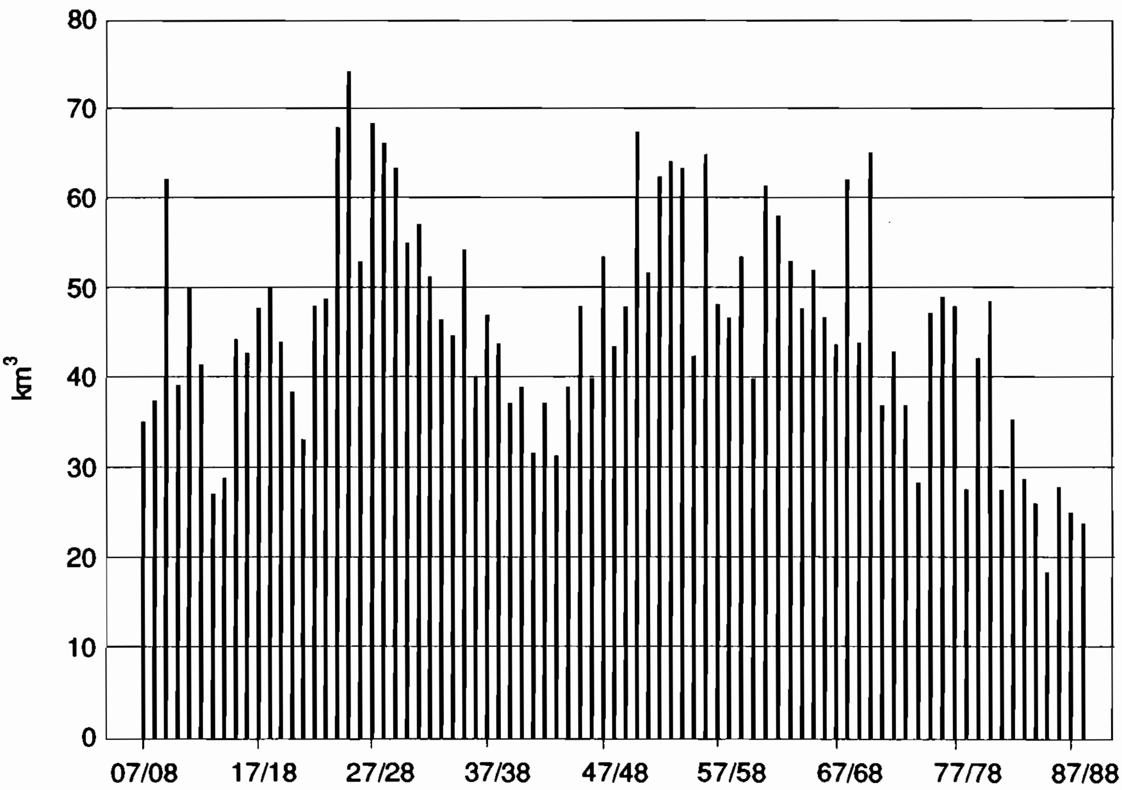
Figure 2.7

Niger at Kouliokoro - Flow Characteristics





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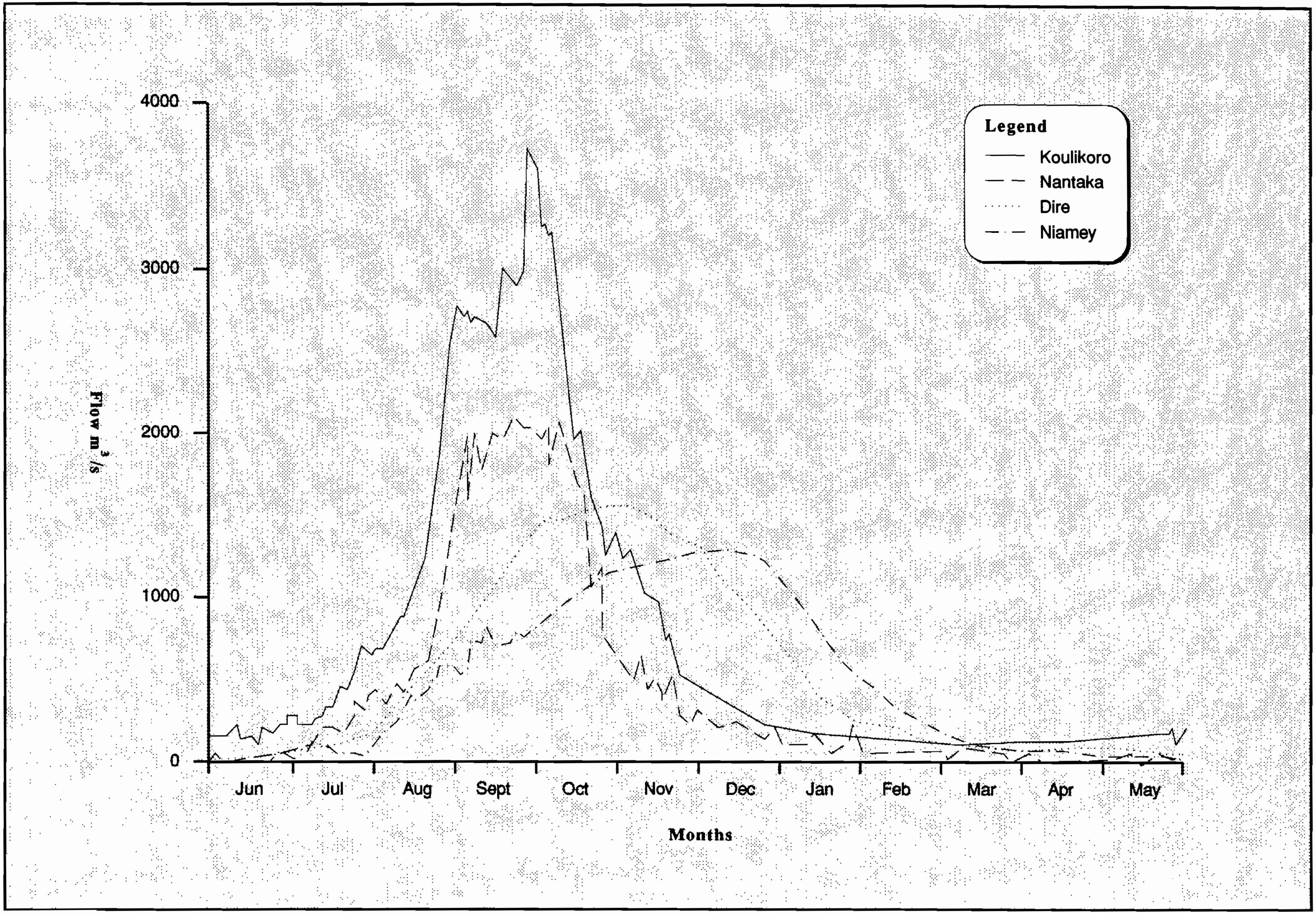


River Niger: Inflow and Outlow, Inner Delta - 1986 / 87

Figure 2.8

Diamangou, Tapoa) and Benin (Mekrou) which between them contribute on average 29 m^3/s with large inter-annual variation (10 year dry 12 m^3/s to 10 year wet 53 m^3/s).

The river receives no further significant tributaries until the confluence with the Sokoto which rises in the highlands of north-western Nigeria and is ephemeral in its upper reaches. Below the Sokoto confluence at Jebba the mean discharge rises to 1 600 m^3/s and the 'white flood' predominates. The Kaduna River rising on the Jos Plateau also makes an important contribution, the mean annual discharge in the Niger below their confluence rising to 2 500 m^3/s.

The Benue River joins the Niger at Lokoja more than doubling the mean discharge with its contribution of 3 400 m^3/s. The peak flood flows in the Benue occur during August/September in the headwaters in Cameroon, and at its confluence with the Niger in mid-October.

The Benue rises on the Adamawa Plateau in Cameroon at about 1 300 m amsl, the headwaters are steep but over the lower 110 km to the Niger confluence the gradient is very shallow. The valley is characterised by wide fertile flood plains and the river is braided for much of its course. The seasonal variation of runoff is very marked with the river reduced to about 100 m^3/s in the dry season. The extensive flooding has restricted development of the flood plains. The duration of flooding in an average year varies from some 7 weeks near Yola to 20 to 30 weeks below Makurdi.

The Niger delta covers an area of 30 000 km^2, the mean annual discharge at the coast totalling approximately 7 000 m^3/s.

The development of the resources of the Niger and its tributaries is indicated in Table 2.2 which shows existing projects, those currently under construction, and details of further developments which have been the subject of preliminary evaluation. The table shows that the projects cover the whole spectrum of uses including flood control, hydropower generation, irrigation, and navigation. Other important uses of the Inner Delta and the extensive flood plains are fishing and grazing.

The economic importance of the internal delta is threefold:

- for growing crops, especially rice, a dam was constructed at Markala in 1946 to control irrigation;
- dry season cattle grazing, the delta floods provide good grazing ('le bourgou') when the surrounding region is too dry for cattle;
- fisheries - largely during the flood period.

The fadamas of the Sokoto below the Rima confluence are also important for the same reasons, although the principal fishing period is as the pools on the floodplain dry out trapping the fish. There is considerable interest in Nigeria in new techniques to exploit seasonal groundwater on the fadamas for more extensive irrigation.

TABLE 2.2

Major Schemes in the Niger Basin

Scheme	River	Country	Type	Comments
Existing:				
Selingue Dam	Sankarani	Mali	Multi-purpose	2 000 ha irrigation/44 MW hydropower
Markala			Irrigation	60 000 ha
Lagdo Dam	Benue	Cameroon		
Goronyo	Sokoto	Nigeria	Irrigation	33 000 ha
Bakolori Dam	Sokoto	Nigeria	Irrigation	450 million m^3 reservoir
Kanji	Niger	Nigeria	Hydropower	760 MW
Jebba	Niger	Nigeria	Hydropower	500 MW
Shiroro	Chanchanga	Nigeria	Hydropower	300 MW
Kiri	Gongola	Nigeria	Irrigation	325 million m^3 reservoir
Dadin Kowa	Gongola	Nigeria	Irrigation	2 765 million m^3 reservoir
Tungan Kawo	Niger	Nigeria	Irrigation	22 million m^3 reservoir, 800 ha irrigation
Under Construction:				
Omi	Kampe	Nigeria	Irrigation	6 000 ha
Under Investigation:				
Fomi	Niandan	Guinea	Multi-purpose	Hydropower/
Tossaye	Niger	Niger/Mali Burkina Faso	Multi-purpose	83 000 ha irrigation, in excess of 2.5 km^3 reservoir, 30-40 MW
Kandaji	Niger	Niger	Multi-purpose	Irrigation and hydropower
Zunguru	Kaduna	Nigeria	Hydropower	950 MW
Dasin Hausa	Benue	Nigeria		
Makurdi	Benue	Nigeria	Hydropower	600 MW
Lokoja	Niger	Nigeria	Hydropower	1 950 MW
Onitsha	Niger	Nigeria	Hydropower	750 MW

Irrigation development on the flood plains of the Benue has been limited by the extent of the annual flooding and low dry season flows, development is therefore dependent on the construction of dams to regulate the flow.

Hydropower generation is important on the lower Niger in Nigeria since the construction of Kainji dam in 1968 and the recent completion of a dam further downstream at Jebba. As shown by Table 2.2 Nigeria has several further hydropower developments under consideration.

The lower Niger and the Benue are navigable. It is possible for certain craft to travel the Niger from Niamey to the sea, the season has been extended by the regulation at Kainji and Jebba. At Jebba navigation is possible from July to December, downstream at Lokoja it is possible from July to April. The Benue is navigable as far upstream as Garua 1 000 km from the Niger confluence. However for commercial fleets navigation on the Benue is restricted by the very low dry season flows and conditions are difficult at the beginning and end of the wet season. Coasters with a draft of 3 m can operate as far as Makurdi during a season from mid-June to the end of September, at Garua the season runs from the end of July to late September and the usual draft is less than 2 m. Dredging is required to keep the major waterways of the delta open to navigation all year. Transport by river has however been largely overtaken by road haulage despite its natural advantages for bulk cargoes; in Nigeria cheap locally produced fuel led to a rapid expansion in road use and to an emphasis on the development of the road network whilst the port infrastructure deteriorated.

2.3.3 Senegal River

The Bafing and its major tributaries, the Bakoye and the Baoulé on the right bank and the Falémé on the left bank, form the upper course of the Senegal River. Flows in the river are largely regulated by the Manantali Dam on the Bafing. Since the wet season of 1992 this structure has allowed the interannual regulation of flows in the river at Kayes and further downstream in the Senegalo-Mauritanian valley.

Table 2.3 shows certain physical characteristics of the sub-basins corresponding to the principal hydrometric stations in the upper and middle catchment.

At Kayes the runoff characteristics over the period 1905 to 1989 are as follows:

Mean annual	545 m^3/s
1 in 10 year dry	284 m^3/s
1 in 10 year wet	829 m^3/s
Coefficient of variation	2.92
Maximum recorded	966 m^3/s (1924)
Minimum recorded	162 m^3/s (1987)
Maximum daily flow	5 960 m^3/s (1958/59)
Minimum flow	dry on several occasions (1980-90)

TABLE 2.3

Upper Senegal Physiographic Characteristics

River	Gauging Station	Catchment Area (km^2)	Slope (m/km)
Bafing	Dakka Saidou	15 700	1.59
	Mahina	38 400	1.01
Falémé	Kidira	28 900	1.50
Bakoye	Oualia	84 700	0.38
	Toukoto	16 500	1.03
Baoulé	Siramakana	59 500	0.52
Senegal	Bafoulabé	124 700	0.48
	Kayes	157 400	0.49

For the recent period from 1968 to 1989 the annual runoff volume at Kayes was never more than 10.5 km^3 compared to 17.2 km^3 for the period 1905 to 1989 (Figure 2.9).

Manantali Dam is the principal structure on the upper Senegal. It is situated on the Bafing downstream of its confluence with the Bakoye. The catchment above the dam is around 28 000 km^2.

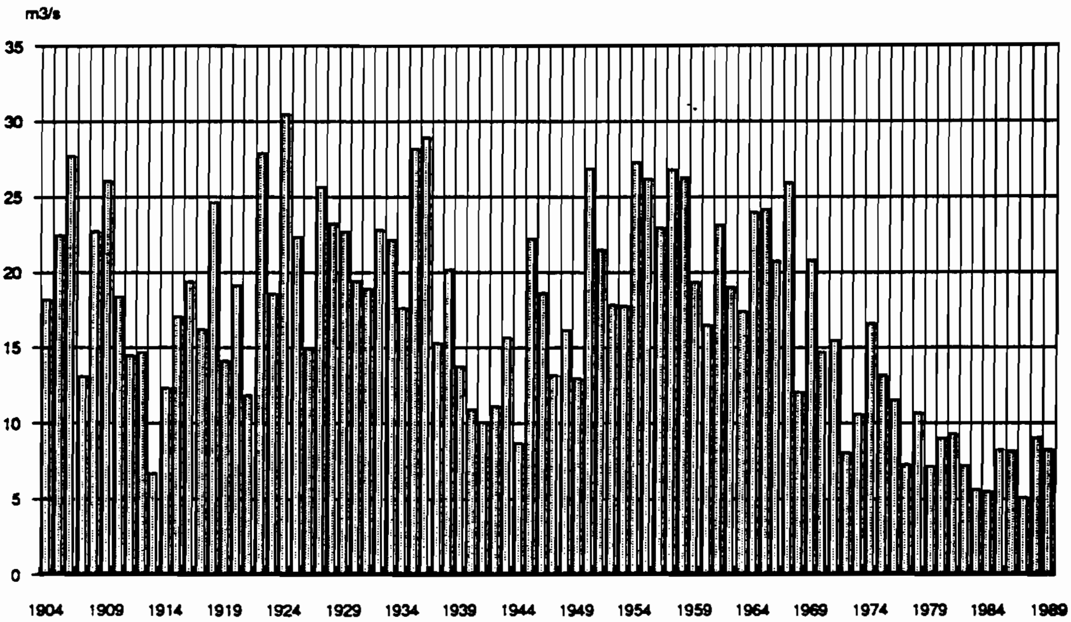
The total volume of the reservoir is approximately 12 km^3 with a live storage of 7.85 km^3. The structure is multipurpose with the following objectives:

- hydropower (200 MW potential);
- flood regulation to protect downstream irrigation;
- to support flows in the dry season to permit navigation between the estuary and Kayes;
- to guarantee a minimum flow in the river at Bakel to supply all the irrigated areas in the valley (long term potential 300 000 ha);
- to support the flood in the Senegal in amount and duration to satisfy traditional cultivation of flood crops (it is envisaged that this method of cultivation will eventually be abandoned once the area under irrigation is sufficient).

The dam was completed in 1987 and the reservoir attained full supply level in September 1991. The hydroelectric station has yet to be installed. The dam is currently used to generate an artificial flood allowing 50 000 ha to be cultivated by traditional means. The resources of the Senegal basin are managed by the OMVS an international body whose members are Mali, Mauritania and Senegal (see Section 3.2.3). A telemetry system has been installed on the Senegal for the OMVS and a model of water utilisation developed to make use of the real time water level data transmitted by the telemetry network. Releases from Manantali can be thus be made in response to water level changes at Bakel. Different operating rules have been tested using a databank of all historic daily flows for the Senegal and its tributaries.

Figure 2.9

Senegal at Kayes - Flow Characteristics



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The available resources of the lower valley are well characterised by data at Bakel, since inflows below this station are practically negligible. Figure 2.10 presents the annual series of runoff at Bakel from 1904. This shows a trend of declining runoff since the end of the 1960s which is more pronounced than two earlier dry periods centred on 1913 and 1942. For the period 1904 to 1987 mean annual runoff was 684 m^3/s, however since 1987 the regime has been modified by the presence of Manantali dam.

At Richard-Toll on the lower Senegal the Tahouey Canal functions as a distributary feeding Lake Guiers, a vast natural depression which has a capacity of some 600 million m^3 (equivalent to an annual runoff of 19 m^3/s). The annual filling of Lake Guiers, which provides water to the lower Ferlo valley, is potentially guaranteed by the presence of the Diama Barrage which permits the river at Richard-Toll to be artificially maintained at a level sufficient to feed the canal.

The Diama barrage is situated on the Senegal Delta around 15 km upstream of Saint Louis. It is managed by the OMVS and is operated in conjunction with Manantali to control the resources of the river. It has two functions:

- prevent saline intrusion into the delta;
- to maintain a water level sufficient to supply the numerous irrigation schemes in the delta at low energy cost, and by maintaining supply to Lake Guiers provide part of the potable supply to Dakar.

During the flood the gates are raised and high flows can be passed. The gates are then lowered in order to maintain a level of 1.5 m NG. This level can be maintained because of the presence of embankments on both banks as far as Rosso. At the optimum operational level (1.5-1.8 m NG) the barrage has a zone of influence stretching more than 350 km. The barrage has been functioning since 1986.

2.3.4 The Gambia River

The location of the catchment of the Gambia River is shown in Figure 2.6, the drainage area is about 77 000 km^2. The catchment is divided between four countries: Guinea where it rises at 1 125 m near Labé (11 866 km^2), Senegal where it drains almost the whole of the Senegal Oriental region, part of Haute Casamance and Siné Saloun (54 631 km^2), The Gambia (10 556 km^2), and finally a tiny part of Guinea Bissau (16 km^2). The total length of the river is 1 150 km of which 205, 485, and 460 km are in Guinea, Senegal and The Gambia respectively.

In Guinea the river flows through ancient crystalline and metamorphic formations and in Senegal and The Gambia through a flat homogeneous sedimentary basin. In many studies a different division is used: the 'continental basin' upstream of the tidal limit in Senegal, and the 'maritime basin' from this point to the mouth of the river. The maritime basin is very flat, the zero of the gauging scale at Gouloumbo near the tidal limit and 500 km from the mouth is below sea level, and the river is also saline for some 250 km.

The maximum flow in the Gambia River measured at Gouloumbo was 2 100 m^3/s recorded on 15 September 1961. At this site there is sufficient tidal influence to render the rating curve unusable for low flows. The lowest flow gauged was 4.58 m^3/s on 26 January 1984. However this is some 5 months before the lowest flows at the end of the dry season would occur so it can be assumed that the flow is almost zero at the end of the dry season. The gauging station at Gouloumbo measures the flows from a basin of 42,000 km^2 whereas the total basin is 77,000 km^2. Apart from measurements over short periods of time by consultants no gaugings have been attempted on the lower river.

Flows are known more precisely at Wassadou-aval (Figure 2.11) but the catchment is much smaller (33 500 km^2) and complete data is only available from 1974. The mean annual discharge is 113 m^3/s (1974-84).

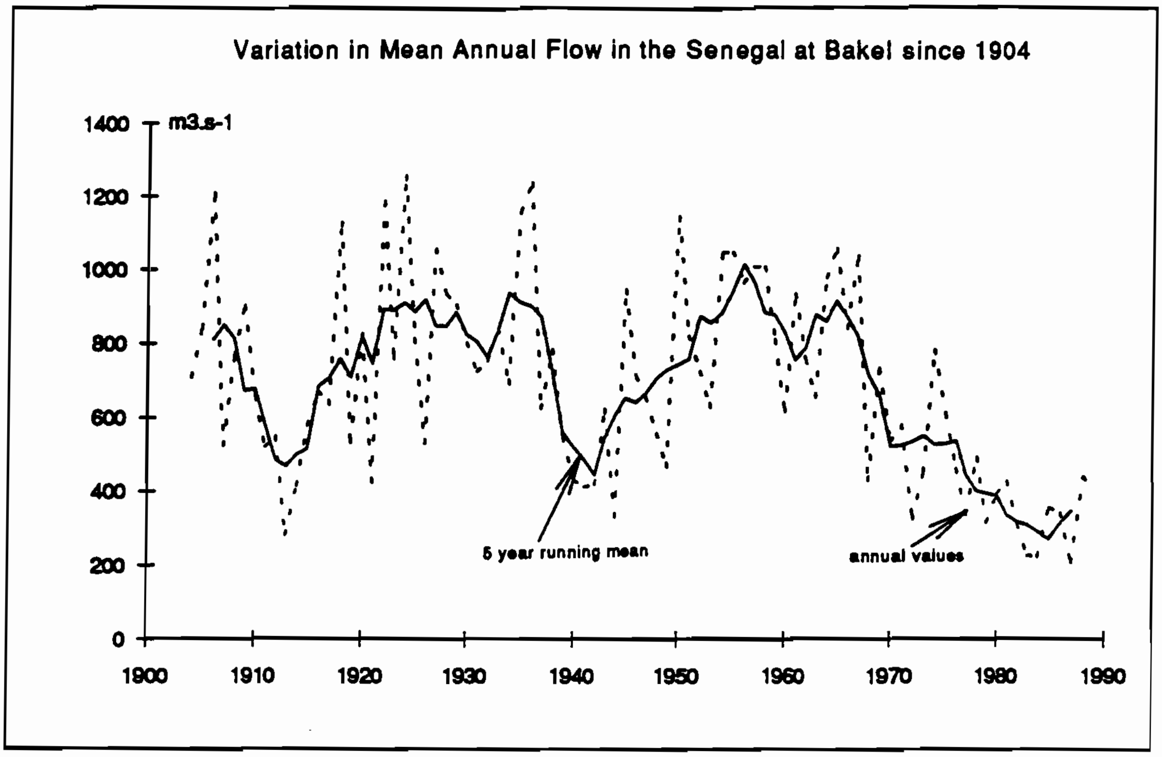
Over the period 1971 to 1986 the mean annual discharge at Kédougou was 70 m^3/s, this site is far upstream on the border between Senegal and Guinea. As shown by Figure 2.11 the years 1983 and 1984 were dry but overall this short period of record does not exhibit any trend. The pattern of runoff shows marked seasonal variation with a typical flood of 649 m^3/s and zero flow at the end of the dry season.

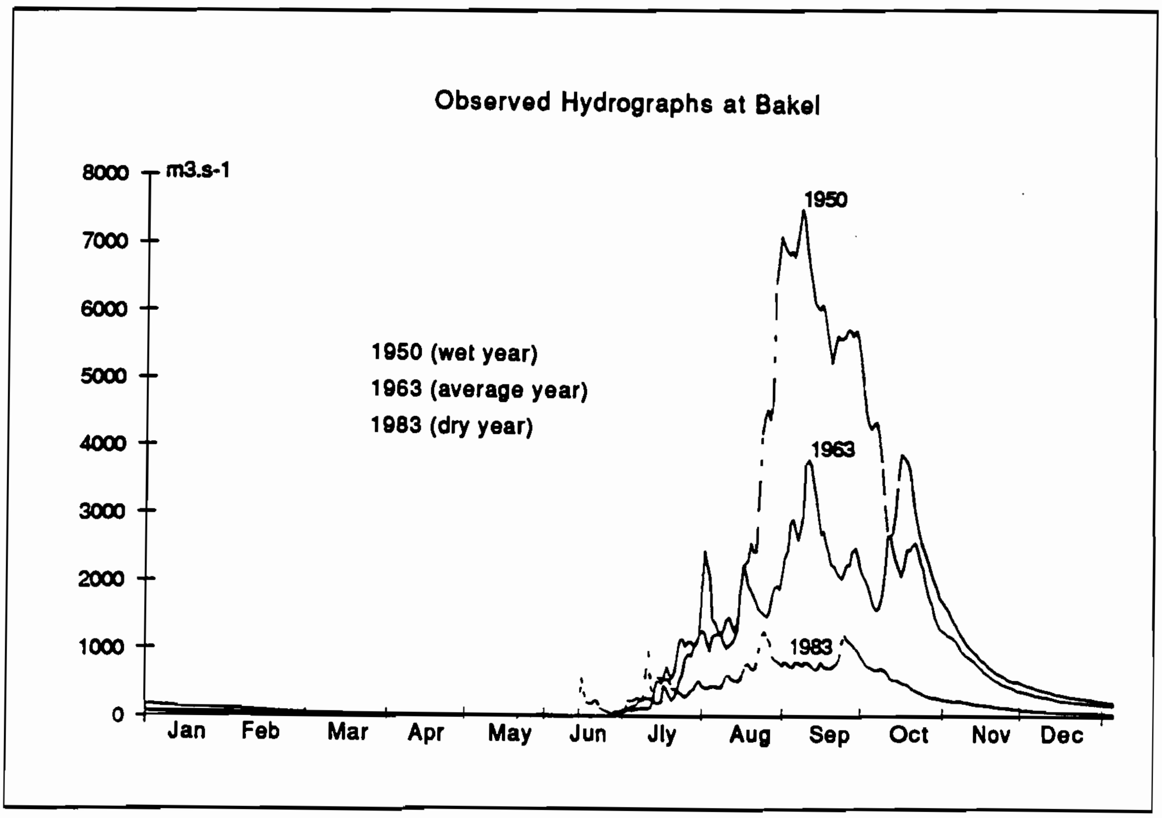
One unusual feature of the Gambia River is the long distance which is saline. The saline/fresh-water interface varies with the flow in the river. In very dry periods, when flow is only 1-2 m^3/s, it is 250 km from the sea, but for a flow of 150 m^3/s it is 115 km from the sea. At the height of the rainy season it may move to within 80 km of the mouth of the river. Associated with this feature is the length of tidal influence. At the mouth of the estuary at Banjul the tidal range is two metres, at Balingho some 150 km upstream it is 1.5 m, at the Jahally canal 270 km from the mouth the range is still more than 1 m. At Fatoto, the gauging station furthest upstream in The Gambia and 477 km^2 from the sea the range is 0.4m, and even at Gouloumbo more than 500 km from the mouth the range is still around 0.1 m.

In 1978 the OMVG was set up to co-ordinate water resources planning in the basin (see Section 3.2.4). Under the auspices of the OMVG there have been several studies of the river. A dam within Senegal at Kekreti has been proposed and also a barrage on the lower river within The Gambia. A particular concern is the sensitivity of the saline/freshwater interface to any change in the pattern of flows in the river. There is a danger that upstream regulation might lead to a deeper penetration inland of the saline front restricting the existing tidal irrigation systems within The Gambia which rely on being able to obtain freshwater at the top of the tide during the wet season. The barrage would also be the first permanent crossing of the lower river replacing the ferry service on the Trans-Gambia Highway. The latest studies have shown the two schemes to be uneconomic, in part because Senegal has the opportunity to obtain hydro-power by installing turbines at the Manantali Dam on the Senegal River.

Figure 2.10

Senegal at Bakel - Flow Characteristics





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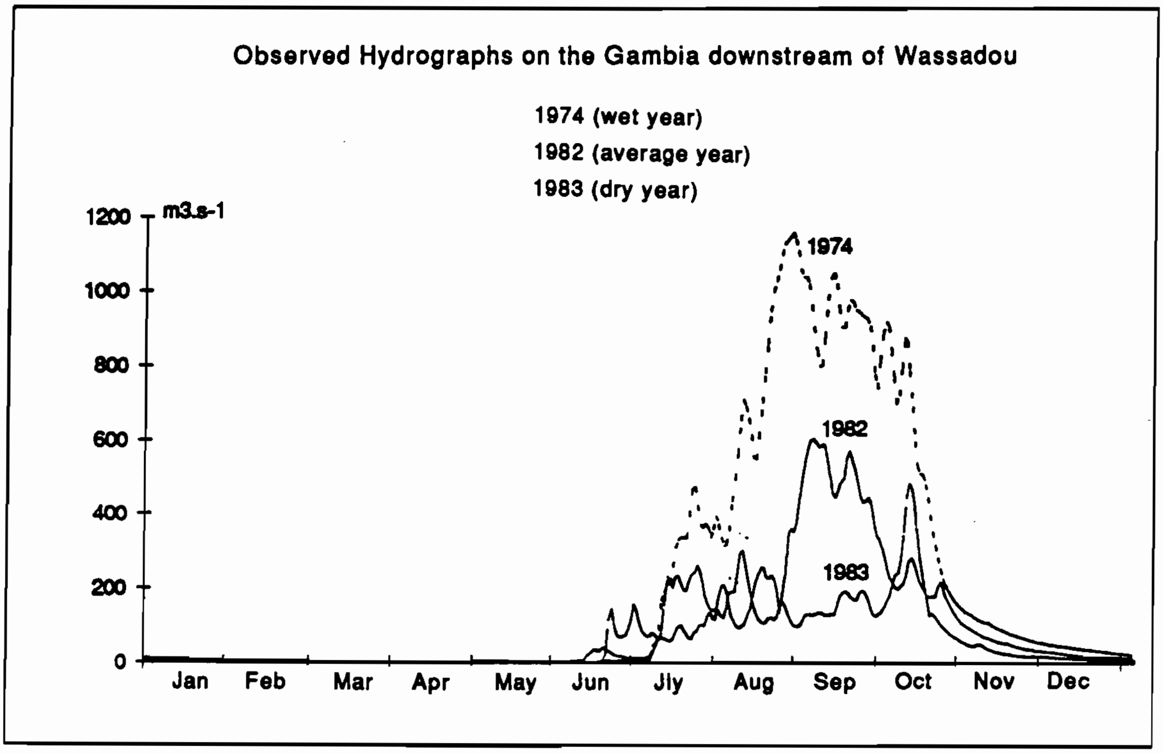
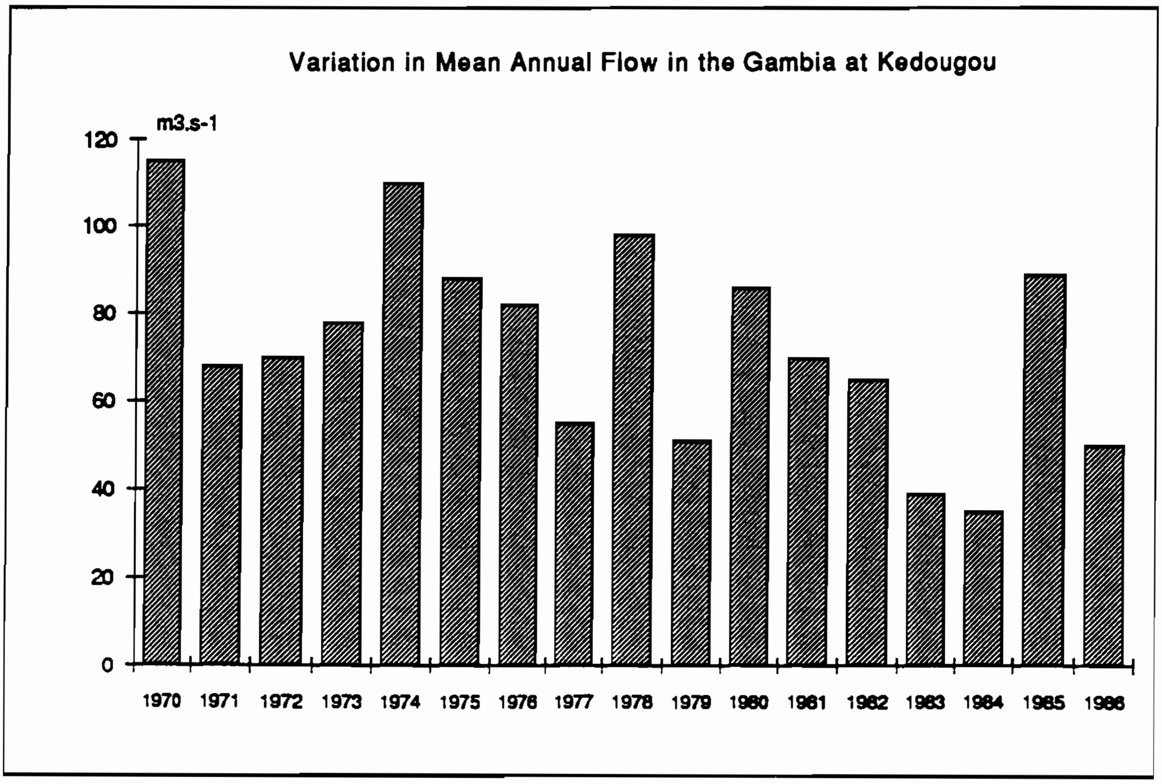
Gambia River Flow Characteristics





2.3.5 The Volta River

The Volta River drains a catchment area of 398 700 km^2 including parts of Mali, Burkina Faso, Côte d'Ivoire, Togo, Benin, finally draining to the Gulf of Guinea through Ghana. Most of this catchment is contained within Burkina Faso (43%) and Ghana (42%). The mean annual runoff from this catchment is 37 000 million m^3, although during the last two decades of drought in the region flows have been well below the long term average, see Figure 2.12. Flows in the tributary rivers, particularly in the drier north, are highly seasonal with almost no runoff for six months of the year and a marked peak in August/September; flows in the main river and the southern tributaries are more evenly distributed.

The main river was first regulated by the Volta Dam at Akosombo which was completed in 1965. The Volta Lake retained by the dam is the largest man-made body of water in the region with a capacity of 148 000 million m^3 and a surface area of 8 500 km^2 at full supply level. The main purpose of the dam is the generation of hydropower and the impetus for the development of the scheme came from the desire to develop an aluminium smelting capacity to add value to Ghana's exports of bauxite. In 1981 Kpong Dam was completed immediately downstream of Akosombo to generate further hydropower. The tailwater level at Kpong is 3.0 m and the dam is only 97 km from the sea. These developments were carried out under the auspices of the Volta River Authority (VRA), a wholly Ghanaian organisation, which was established in 1961.

The VRA is actively seeking to increase the generation of hydropower from the Volta and has sponsored studies of the potential of this resource. A total of ten potential new sites on the Volta have been identified, see Table 2.4; the site at Bui on the Black Volta where there is potential of 300 MW has been taken to the design stage and three sites on the White Volta are currently the subject of pre-feasibility studies.

The VRA has arranged for the export of power to neighbouring Togo and Benin and there is scope for further export, possibly to Burkina Faso.

The recent Sahelian drought has led to considerable concern in Ghana that the firm power available from the Volta schemes is less than was anticipated at the time of their design. In fact from 1970 to 1990 the mean runoff from the Volta catchment was only 80% of the long term mean flow used to design the Akosombo scheme. The behaviour of the lake since 1965 is illustrated in Figure 2.12. During the 1980s levels were below the lower rule curve in seven out of ten years. The failure of the rains in 1983/84 led to a crisis with power generation reductions imposed. Details of energy generated between 1984 and 1989 are provided in Table 2.5; for comparison the expected average annual quantity of firm power is some 5 000 GW.h, with total power output around 7 000 GW.h. As can be seen from Figure 2.12 good rains in 1989 restored the lake storage and allowed almost full power generation, however, 1990 gave a warning that the Sahelian drought has not ended with an estimated river flow of 14 000 million m^3, only 38% of the long term mean.

TABLE 2.4

Potential Hydropower Sites on the Volta within Ghana

River and Site	Area (km^2)	Mean Annual Flow (m^3/s)	Possible Installed Capacity (MW)
Black Volta (Mou Houn)			
Koulbi	107 000	191	68
Nterso	121 000	209	64
Lanka	124 300	217	95
Bui	125 100	217	300
Jambito	139 100	241	55
White Volta (Nakanbé)			
Pwalugu	57 450	150	50
Kulpawn	94 760	234	70
Daboya	98 060	245	80
Oti			
Juale 1	64 750	390	100
Juale 2	64 750	390	50

TABLE 2.5

Electricity Generation at Akosombo/Kpong

Year	Akosombo (GW.h)	Kpong (GW.h)	Total (GW.h)
1984	1 468.50	330.18	1 814
1985	2 461.37	534.82	2 996
1986	3 677.79	727.25	4 405
1987	3 880.56	795.74	4 676
1988	3 996.49	811.36	4 808
1989	4 383.24	847.27	5 231

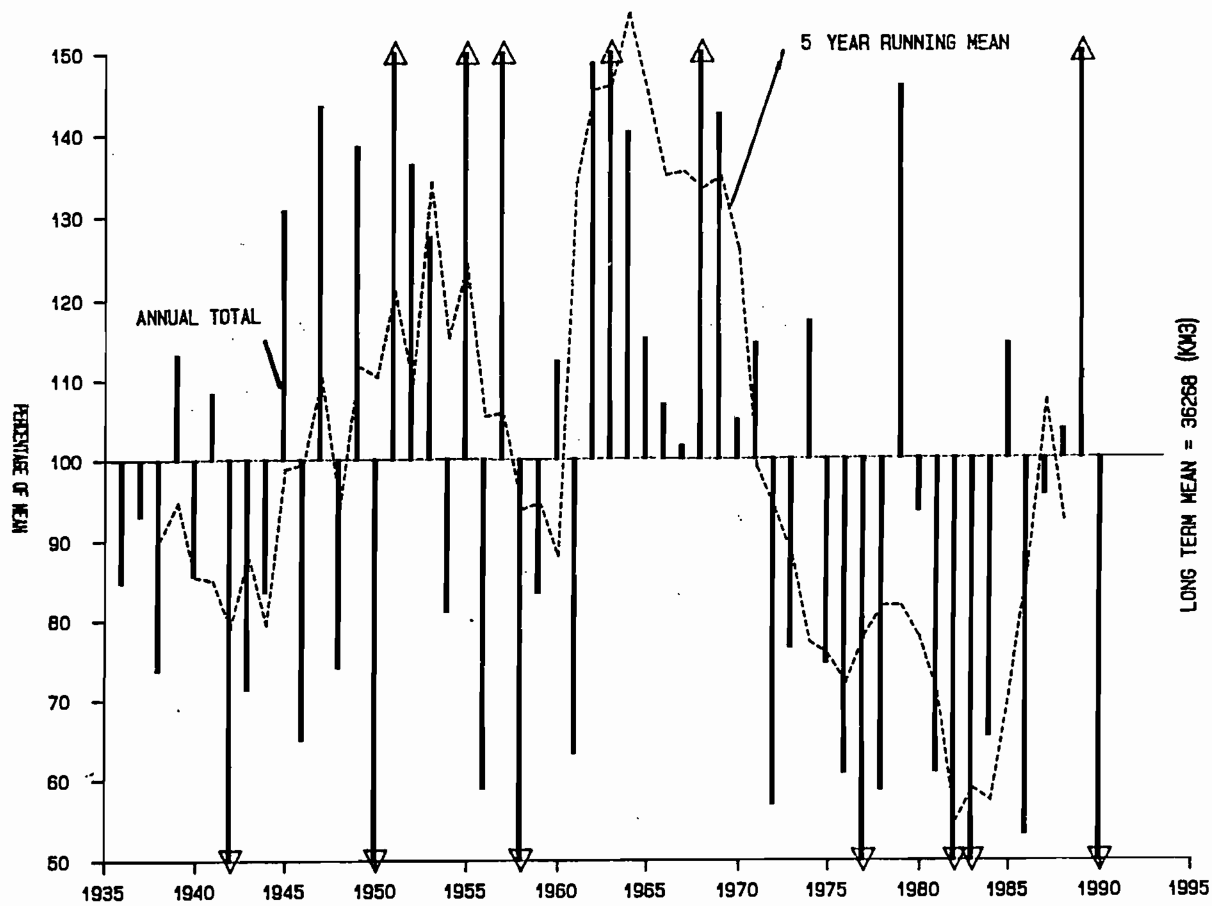
Source: Quarterly Digest of Statistics, Ghana, June 1990.

Upstream development in Burkina Faso has been largely intended for irrigation and drinking water supply. With its long dry season storage is essential to the further development of surface water resources and many small dams have been constructed. Major developments existing and planned are given in Table 2.6.

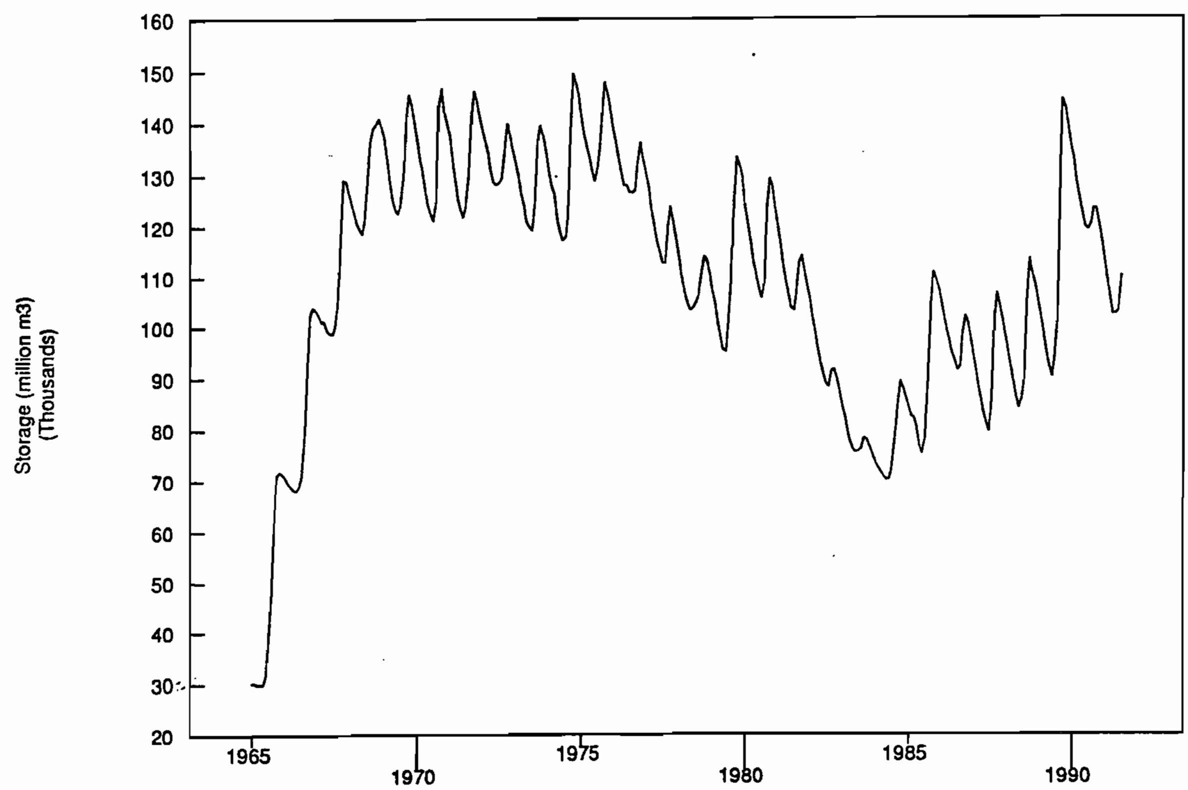
Figure 2.12

Lake Volta

Departures from Mean Annual Inflow to Lake Volta



Lake Volta Storage



Development of the resources of the river have proceeded independently and there is no supra-national body co-ordinating development. Ghana, which has most actively developed the rivers resources has largely done so for hydropower. Major development upstream would of course have a significant impact on the existing Ghanaian schemes, particularly if the recent drought conditions were to continue.

TABLE 2.6

Existing and Projected Developments on the Volta in Burkina Faso

River and Site	Purpose	Date	Capacity (million m^3)
Mou Houn (Black Volta)			
Plaine de Banzo	Irrigation	1977	Canal 1.85 m^3/s
Kou Valley	Irrigation	1973	Canal 3.5 m^3/s
Samandeni	Irrigation/HEP	Projected	610
Sourou	Irrigation	1976-84	370
Tenado/Koudougou	Potable water	1978	
Poura Mine	Water supply		
Noumbiel	Hydropower	Projected	11 300 (60 MW)
Nakanbé (White Volta)			
Ouaga Barrages	Potable water	1955	6
Loumbila	Potable water	1970	35
Ziga	Potable water	Projected	194
Bagré	Irrigation/HEP	Projected	1 700 (16 MW)
Kompienga	Hydropower	1988	2 000 (14 MW)

2.3.6 Lake Chad

Lake Chad is situated at an altitude of about 280 m above sea level on the border of the Sahara between latitudes 12°N and 14°30'N and longitudes 13°E and 15°30'E. The lake has no outlet to the sea and is the main focus of an internal drainage basin of 2 500 000 km^2 that collects water from Algeria, Chad, Niger, Nigeria, Cameroon, Sudan and the Central African Republic. Over 90 % of the total lake inflow comes from the Chari-Logone system which rises on the southern margin of the basin.

The hydrology of the Chari catchment is complicated by the presence of vast areas, the 'yaeres', which are subject to seasonal inundation. These areas lie below Miltou on the Chari and Lai on the Logone. The area inundated is related to the size of the main river flood and as a consequence losses to evaporation and infiltration are greater in wet years. The need for a good understanding of this complex phenomenon has long been recognised. The urgency stems from the development needs of the whole area and particularly the desirability of preserving traditional flood areas which are ecologically and economically important whilst at the same time developing artificial flood control in the upper catchment and abstracting irrigation water in the middle and lower reaches.

Lake Chad is shallow, average depths vary between 1.5 and 5 m, with the result that its surface area is very sensitive to changes in volume due to fluctuations in inflows and losses. At elevations below 279 m a ridge, the 'grande barriere', becomes exposed between Baga Kawa and Baga Kiskra dividing the lake into northern and southern pools. After exposure the ridge rapidly develops a dense cover of vegetation which restricts flow between the two pools. After separation the two pools exhibit different behaviour reflecting the unequal distribution of inflow. The southern pool receives all the flow of the Chari, whilst the northern pool only receives inflows from the Komadougou-Yobe catchment, other ephemeral systems, plus any spill from the southern pool over the ridge.

The sudden onset of the Sahelian drought in the 1970's (Figure 2.13) resulted in severe contraction in the size and volume of the lake, which changed the character of Lake Chad from a lake to a swampy delta of the River Chari, with disastrous consequences for lake-side communities and other schemes dependent on the resources of the lake. There has subseqently been much research into the historic behaviour of the lake. In the last few years numerous engineering schemes have been floated, of which transfers from the Zaire basin are not the least. However, few have been studied in sufficient depth to establish their feasibility.

Table 2.7 gives a recent compilation of irrigation development projects in the Lake Chad conventional basin by country showing the source of supply. The areas for some schemes are not included and therefore the totals are underestimated. The table shows that only a small proportion of the area in large schemes either completed or scheduled for construction is actually functioning (about 23%), this reflects the serious effects of the drought particularly on schemes designed to abstract from the lake itself. Figure 2.14 shows the location of these developments.

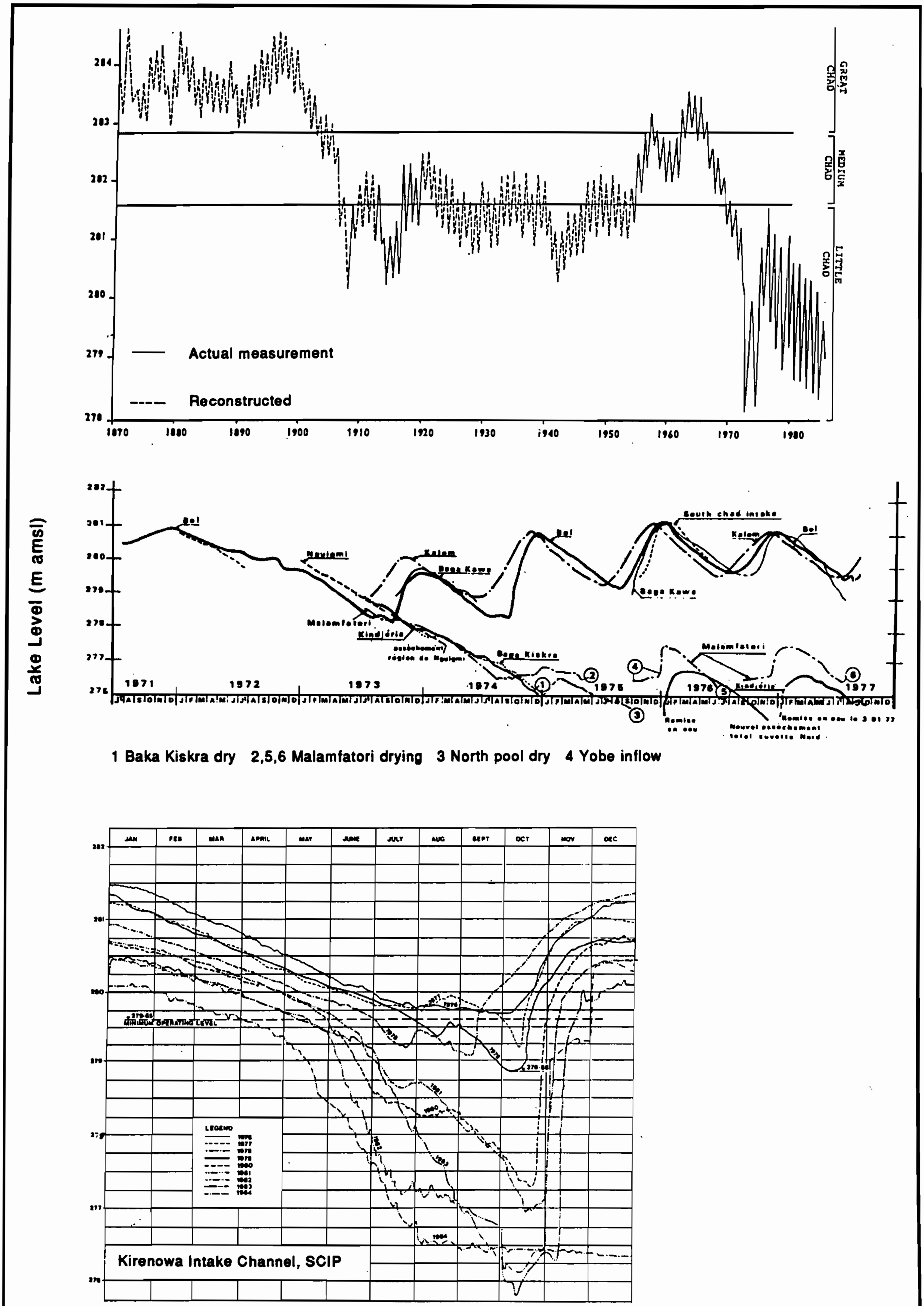
Development Based on the Lake

The largest and most important water development scheme constructed in the region is the South Chad Irrigation Project (SCIP) in Nigeria. SCIP was designed for 3-stage implementation. Two stages have been built: Stage I in 1979, and Stage II in 1983. Stage III was not constructed due to the falling water levels of Lake Chad. A pump station with a total capacity of 103 m^3/s (current capacity 75 m^3/s) has been constructed to pump water from the lake via a canal. The scheme has a gross area of 66 000 ha and stages I and II a net area of 40 000 ha.

However, the design area under cultivation has not been achieved, in the best year to date, 1989, 7 400 ha of irrigated wheat was possible but in the following year the lake levels fell again and no irrigation was possible. Levels at the Kirenowa pump station are shown in Figure 2.13. The small amount of irrigation possible due to low lake levels confirms that to date SCIP has not influenced Lake Chad levels. However, it will be necessary to investigate the influence of SCIP abstractions in combination with other development options and flood protection measures.

Figure 2.13

Historical Behaviour of Lake Chad



Source: ORSTOM and SCIP

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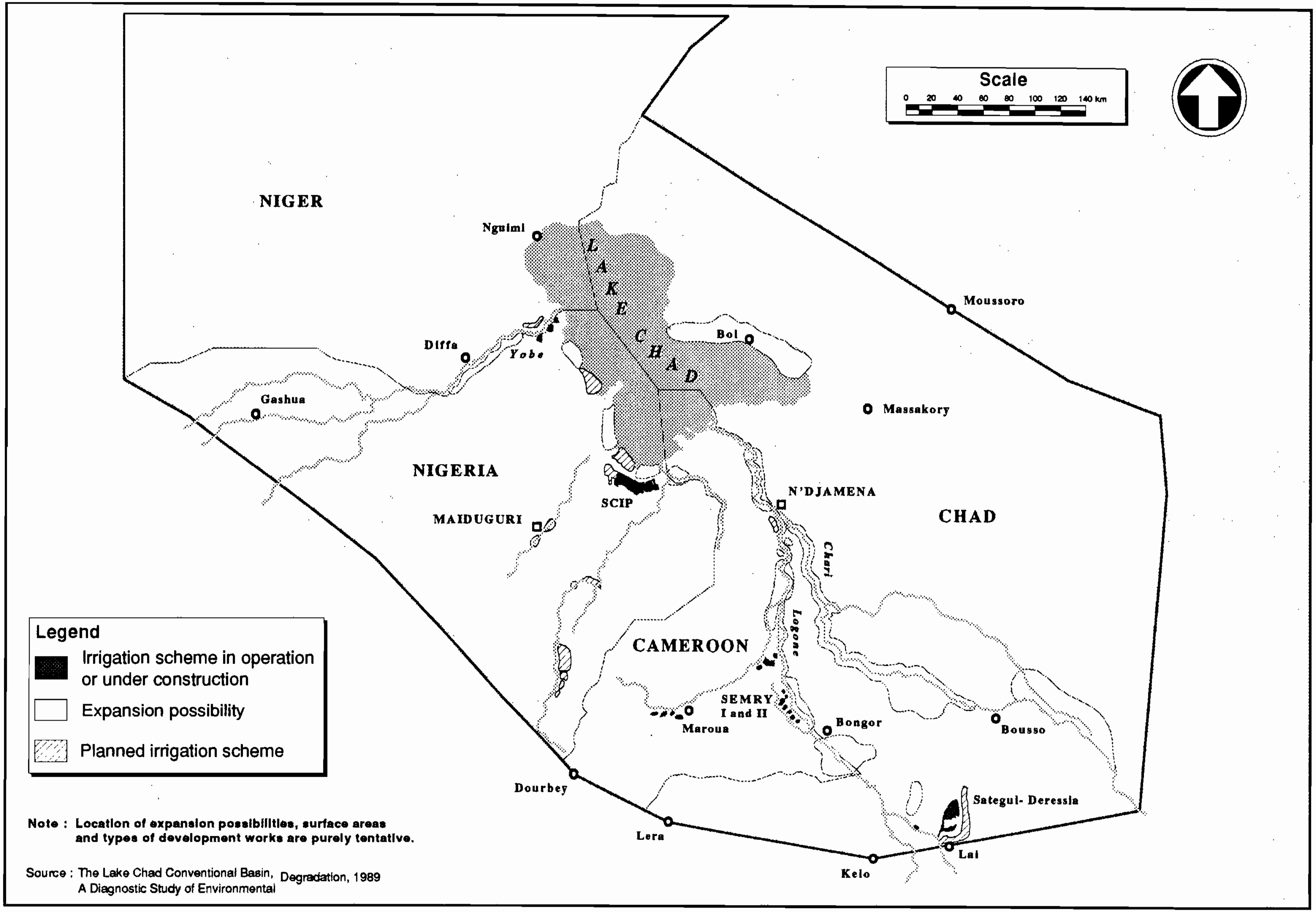


Lake Chad Basin - Irrigation Development

Figure 2.14

TABLE 2.7

Irrigation Development Projects in the Lake Chad Basin
(Area in ha)

Source of Water	Chad	Niger	Cameroon	Nigeria	Total
Existing or Under Construction:					
Lake Chad	3650			84000	87650
Chari	5000		450	-	5450
Logone	5000		10000	-	15000
Yobe	-	> 185	-	?	200
Possible extensions:					
Lake Chad				110	1100
Chari			2000	-	2000
Logone			?	-	
Yobe		2000		100000	102000
Functioning:					
a) Large Schemes					
Lake Chad	1200			3500	4700
Chari	5000		450	-	5450
Logone	5000		9550	-	14550
Yobe	-	185			
b) Small Schemes					
Chari	269				269
Logone			234		234
Yobe		800	-	405	1205
Yedseram			-	100	100
Small lakes/ponds			265		265
Mayo Tsanaga			(7000)		7000

Note: ? Data not collected during survey.
Source: Project RAF/88/029, N'Djamena, 1991.

Studies are currently in progress to develop additional polders in the Bol region of Lake Chad. Three polders are proposed, of which two are partially constructed: Guini and Berim with a combined irrigable area of 1 200 ha are 90% and 20% built respectively. The third polder is Mamdi (1 800 ha) for which a 36 km canal is under design.

Development Based on the Chari/Logone System

Most of the proposed developments are located in the Logone catchment. The largest irrigation scheme is named after the Sategui-Deressia River, a right bank tributary of the Logone in Chad. Construction of this 10 000 ha scheme for rice cultivation commenced in 1975, was interrupted by civil strife, and is now being reactivated.

The Maga dam polder diverts Logone water and partially blocks runoff to the yaeres. It is used to supplement supplies to the SEMRY II project (Societé d'Expansion et de Modernisation de Riziculture de Yagoua) in the Cameroon. The three SEMRY projects irrigate areas of:

SEMRY I	5 300 ha (Logone abstractions)
SEMRY II	6 000 ha (Maga dam/abstractions)
SEMRY III	1 500 ha pumped abstractions.

Originally a Chad-Cameroon agreement allowed abstractions of 5 m^3/s (January-April) and 10 m^3/s (May-December), however SEMRY I alone requires 5 m^3/s so a revised agreement allows each country to withdraw one half of flows exceeding 40 m^3/s.

The construction of two flood regulation reservoirs on the Vina Nord at Koumban (5.0 km^3) and the Pende at Gore (2.8 km^3) has been proposed. These reservoirs, of which Koumban was given a higher priority, were intended to provide a regulation of the Logone and also to reduce overspill below Lai, thereby reducing the losses from the yaeres and increasing the volume of water in the lake. A hydroelectric station at Pandzangwe using regularised flows below Koumban was also proposed.

The construction of dikes along sections of the Logone to protect irrigation schemes, such as the Semab embankment from Katoa to Bongor, has resulted in an increased flood risk downstream and, in particular, the loss of return flow from the overspill zones during the recession has reduced the discharge in the Logone in the dry season. Further flood embankments along the Logone River have been proposed.

Little is known of engineering works in the Central African Republic although storage schemes at the source of the Chari River may have an important impact on flow entering Chad.

Other Development

Within Nigeria there are several schemes for increasing flows within the Chad basin by inter-basin transfer:

- River Hawal transfer from the Gongola (Niger) basin into the Ngadda and Yedserem rivers (storage 822 million m^3 and yield 20 m^3/s);
- Dindima dam, transfer to the Komadougou-Yobe.

The contribution to inflow to Lake Chad of both is almost negligible in volume terms, but the Komadougou-Yobe flow is ecologically important as it is the only source of inflow to the northern pool when the lake is divided. Some concern has been expressed as to the effect of river control and irrigation projects in the Komodougu-Yobe basin, for the ultimate development scenario of 102 000 ha flow reductions ranging from 32 to 100 percent have been suggested.

2.3.7 Zaire or Congo River

The Zaire River basin covers an area of over 4 000 000 km^2 across the equator from about 7°N to 12°S (see Figure 2.15). One third of the catchment lies in the northern hemisphere. The relatively flat central region lies in one of the ancient continental basins which was more than once invaded by the sea during the Mesozoic. The subsequent uplifting of the peripheral land accentuated the basin and obstructed its drainage to the coast and a large lake formed during the Pliocene. By the Pleistocene the central area was again draining to the Atlantic coast the point of capture probably lay just below Stanley Pool and the shallow lakes and swamps in the western portion of the central basin can be regarded as remnants of this lake. Many of the tributary rivers have falls and rapids in their upper reaches a legacy from previous tectonic activity. The Zaire is the fifth longest river in the world at 4 373 km, but second in terms of mean annual runoff (41 000 m^3/s) and catchment size. The regularity of its discharge is explained by its position straddling the equator: on an annual basis the maximum and minimum daily discharges vary by a factor of only 2, and even when the lowest and highest values on record (22 000 m^3/s and 76 500 m^3/s respectively) are compared the factor is only 3.5.

The Upper Zaire or Lualaba

From its source, on the Shaba Plateau at 1 400 m elevation, as far as Kisangani the river is called the Lualaba. In the headwaters the river is a torrent which calms on entering the Ubemba depression, it flows from south to north alternating flat reaches and rapids (Portes d'Enfer downstream of Kongolo, Tshungu Falls at Kisangani). The tributaries which drain the mountainous region (Lomani, Lindi, Lowa) have high runoff coefficients (>40%) which explain the dramatic increase in runoff in the main river which increases from 2 000 m^3/s at Kindu to 5 740 m^3/s at Lowa.

The Middle Course

At Kisangani the river changes direction first towards the north-west, then to the west, and then to the south-west; the river enlarges as a result of inflows from major tributaries draining large catchments (Luelle, Aruwini and the most significant the Oubangui). More than 10 km in width the bed of the Congo is full of sandbanks and islands, then below its confluence with the Kwa (union of the mighty Kasai and the Fimi) its course narrows and forms a corridor flowing SSW crossing the Batéké Plateau. Above Brazzaville and Kinshasa the river spreads out in a vast depression called Malebo Pool or Stanley Pool leaving towards the west across a sandstone bar in a gorge 1 700 m in width forming the rapids 'du Djoué'.

The Oubangui

This river which forms the border between the Republic of Zaire and the Central African Republic is situated at the heart of the continent. Its hydrograph at Bangui is a typical example of the tropical humid regime with a maximum in September-October and a minimum in March/April. The river falls from 1 382 m (the source of the Uélé) to 350 m at Bangui where the catchment area is 480 000 km^2. The course in the upper reaches is oriented east-west to the bend at Bangui, after which the course follows a southerly direction as far as the confluence with the Congo forming the border between the republics of Zaire and the Congo for 400 km. The contribution of the intermediate catchment below Bangui is modest and the mean annual runoff at Bangui of 4 080 m^3/s is hardly changed at the confluence with the Congo. After passing the Zinga Rapids the course of the lower Oubangui is characterised by a succession of level reaches littered with islands which migrate slowly downstream and sand banks which are a constant obstacle to navigation at low flows. The river is hemmed in on both sides by steep banks covered by a thick forest which is inundated for much of the year. Connections, either natural or partially assisted by man, exist with neighbouring rivers, the Likoula-aux-Herbes and the Sangha.

Rapids and Coastal Reaches

The most dramatic falls are in the reach between Kinshasa and Matadi where the river plunges 265 m over 300 km in a series of 32 rapids the most famous of which are the Inga Falls. Passing through Mayombe the course is characterised by sharp changes of direction imposed by the parallel ridges of the coastal range. Below Matadi the river again spreads widely, to around 5 km in width at Boma and 10 km at the estuary. The current is still perceptible 50 km offshore from Banama.

The Regime of the Congo at Brazzaville

The river is not only equatorial in its abundance but also in the relative regularity of its regime which at Brazzaville shows two maxima in the year, the principal peak in December and a secondary peak in May, the main dry season is in August and there is a lesser one in March (Figure 2.16). The hydrograph appears to conform to the equatorial type, but this form is the result of the particular geometry of the catchment and the long travel times of the floods of tropical type, generated in the summer in headwaters either side of the equator, which combine upstream of Brazzaville. The complementarity of the regimes of the Kasai, Oubangui, and the Congo at Kisangani routed to Brazzaville where they combine with the inflows from the truely equatorial tributaries of the central portion of the catchment give the river its regular regime and its constant flows (Figure 2.16). Statistics for the period 1947-90 are:

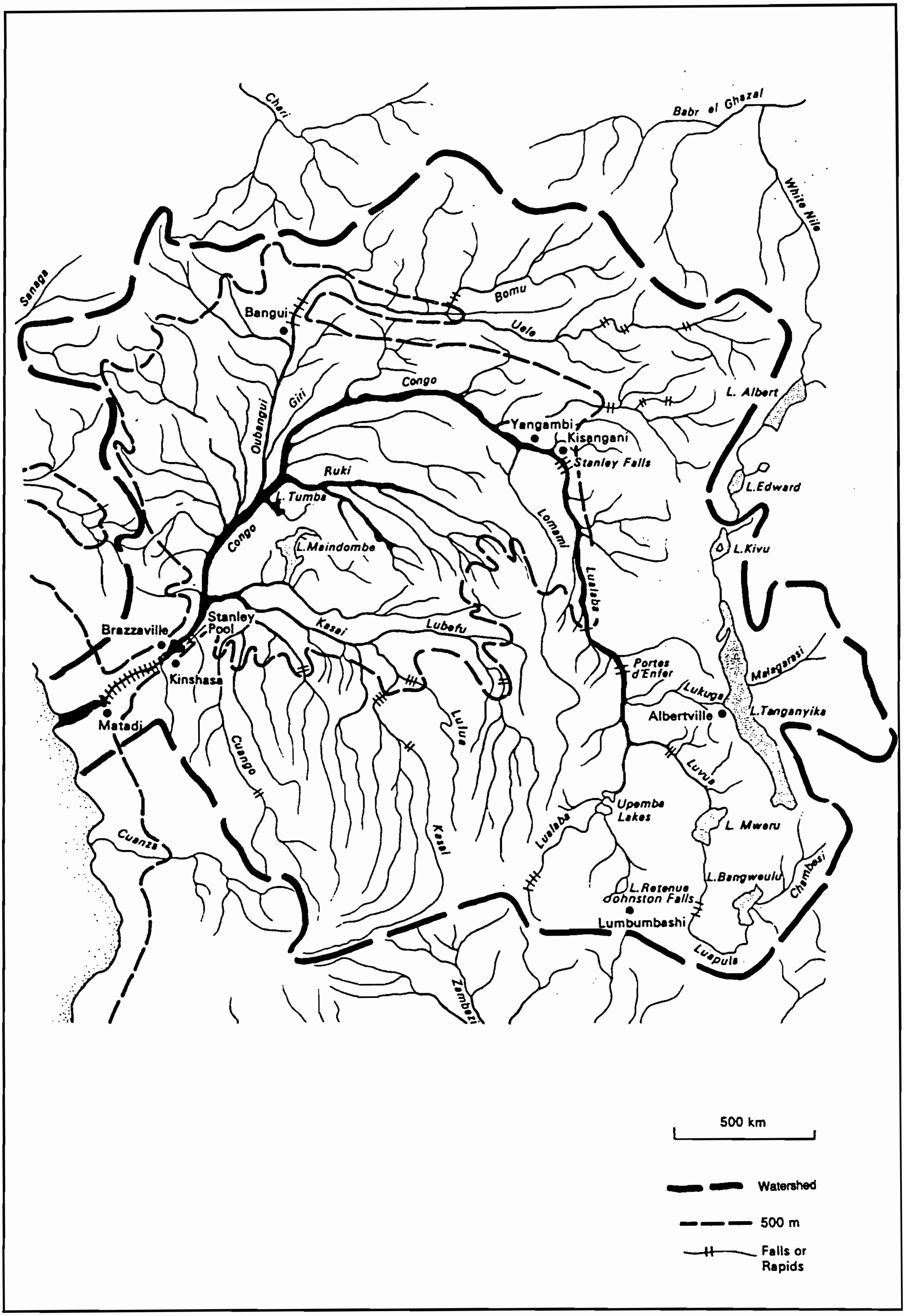
Interannual mean	1947-90	42 000 m^3/s
Maximum	1962	55 200 m^3/s
Minimum	1984	33 300 m^3/s
Lowest recorded flow	1990	22 800 m^3/s
Highest annual minima	1969	41 300 m^3/s
Highest recorded flow	1961	77 000 m^3/s
Lowest annual maxima	1984	47 500 m^3/s

The volume of annual runoff at Brazzaville over the period 1947 to 1990 varied between 1 050 km^3 and 1 740 km^3.

Recently several proposals have been made to divert water from the Zaire to the Lake Chad Basin. The possibilities of such a scheme are discussed in Section 2.6 below.

Figure 2.15

Zaire Catchment



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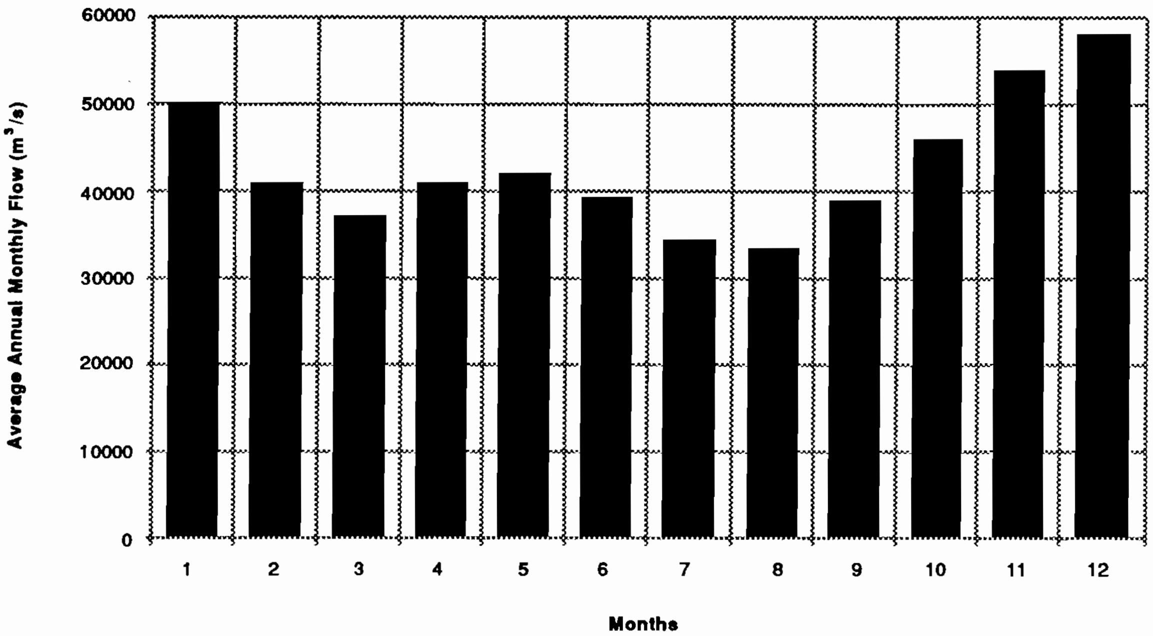
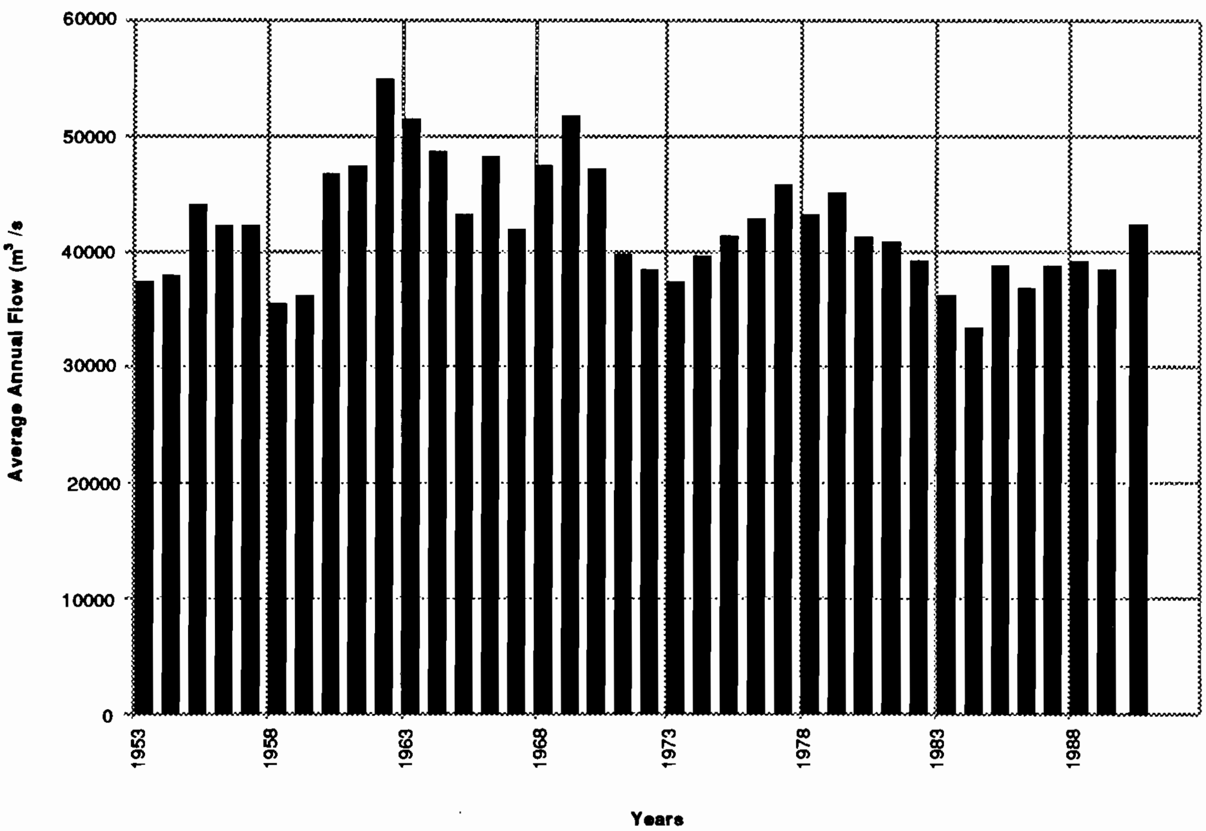
Congo at Brazzaville - Flow Characteristics





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2.4 Groundwater Resources

2.4.1 Introduction

Groundwater in West Africa is found in two types of aquifer formations: (1) large sedimentary basins, composed of sandy clays and clayey, sandy and calcareous sands; (2) fractured and weathered zones of the ancient basement including crystalline igneous, metamorphic and volcanic rocks. In the sedimentary formations, groundwater is contained within the interstitial primary porosity, whereas in the otherwise impermeable basement water reserves are held in secondarily developed rock fractures and weathered zones.

A further subdivision of the aquifers in the region can be made between the continuous and discontinuous aquifers (UNESCO, 1988). Most sedimentary formations can be classified as continuous aquifers with the basement aquifers falling in the discontinuous or 'local' category.

The regional sedimentary aquifers are of several types:

(a) Coastal basins including:

- the Ivory Coast coastal sedimentary basin including the southern part of Côte d'Ivoire and a part of southern Ghana
- the coastal sedimentary basin of the Benin gulf including a small area in the south of Ghana, southern Togo, southern Benin and southern Nigeria.

The coastal sedimentary formations occupy a relatively small area in each of the countries, but have considerable importance because boreholes can yield substantial discharges and they are located close to areas of high water demand, for example capital cities or large communities.

(b) Sedimentary basins including:

- the Senegalo-Mauritanian basin underlying Mauritania, Senegal and Guinea-Bissau
- the Taoudenit sedimentary basin underlying Mauritania and Mali
- the Iullemmeden-Lake Chad basin underlying Cameroon, Chad, Niger and Nigeria.

These basins hold the major groundwater resource of the West African region. They are of vast size stretching from Mauritania in the west, through central Mali and Niger to Chad, a distance of almost 4 000 kms. The degree of interconnectedness between the basins remains to be established.

The basins can be subdivided into two halves at the narrow (120 km) Detroit Soudanais neck in eastern Mali. The western half is dominated by the Taoudenit (El Djouf) and Azouad basins and the eastern by the Iullemmeden and Lake Chad basins. The Niger river drains the southern sector of the Taoudenit basin and the Iullemmeden basin. The Chad basin is internally draining accepting several major rivers including the Chari. The basins are extensively covered in sand dunes and associated aeolian deposits making accessibility difficult.

The discontinuous aquifers constitute a small resource compared to those of the sedimentary formations but are an important source of water for potable supplies to small communities because of their widespread occurrence.

In the following sections we describe firstly the resources of the sedimentary or continuous aquifers and then the discontinuous aquifers. The locations of these aquifers is shown in Figure 2.17.

2.4.2 Aquifers of the Coastal Basins

(a) Geology and Structure

The major geological divisions include:

- Quaternary formations including sandy beach deposits and sandy-clayey river alluvia.
- Formations of Paleocene, Eocene and Oligo-Miocene age, including the Continental Terminal.
- Cretaceous age formations including continental Cretaceous and marine Cretaceous (Maestrichtian).

The lithologies of these formations are as follows:

Formation	Lithologies
Quaternary	Beach sands. Sandy-clayey alluvial formations, with Quaternary gravels corresponding to the collapsed zones and to the position of the large valleys which cross these sedimentary basins.
Continental Terminal	Sandy-clayey formations, generally constituting the easiest aquifer to exploit and thus is well developed.
Eo-Palaeocene	Poorly defined limestones in Benin; phosphatic and marly Eocene limestones of Togo; fossiliferous white limestones associated with the Palaeocene sands in Togo. Facies variations are important with clayey formations predominant in the north of the basins.
Upper Cretaceous	Continental facies: red clayey-sandy-gritty weathered zones.
Maestrichtian	Marine Cretaceous composed of clayey, marly and calcareous sands, brown and beige-green clays, fine to coarse sands.

These coastal sedimentary basins are caused by tectonic subsidence along a series of stepped faults oriented between N50° and N70°, approximately parallel to the present coast line.

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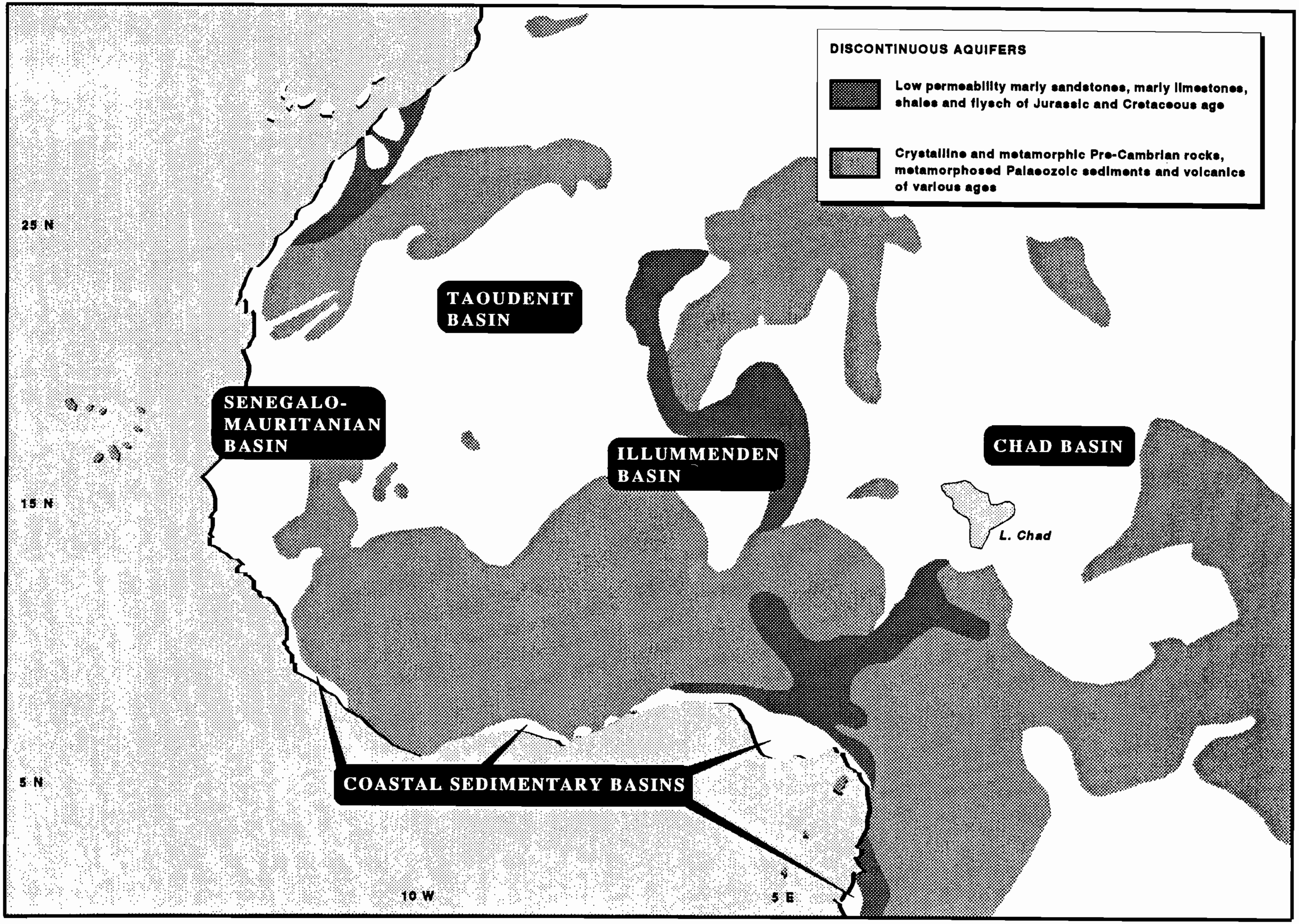


Figure 2.17
Regional Aquifers

The faulting has produced the following downthrows:

- 3 000 m over a distance of 50 km in Togo (average gradient 6%)
- 2 500 m over a distance of 100 km in Benin (average gradient 2.5%)
- over 3 500 m in Côte d'Ivoire where a major fault passes to the north of the coastal lagoons.

A series of faults trending N20° and N30° form the boundary between the coastal basins and the inland zone of alluvial valleys and marshes.

The coastal sedimentary formations occupy a relatively small area, see Figure 2.17, their importance stems from their proximity to large centres of population and their potential yield. Boreholes can provide substantial discharges of between 100 and 200 m^3 per hour.

The main characteristics of the major aquifers are described below:

Beach Sands:

These sands extend all along the coastline, they vary between 1 to 2 km in width and 10 and 35 m in thickness. Fresh water occurs floating on saline water restricting exploitation to shallow, low yielding wells to avoid saline intrusion. Borehole yields are commonly in the range 1 to 15 m^3/h. As the sands have a high permeability, pollution risks are high.

Quaternary sandy-clayey alluvium:

The thickness may vary from 10 to 50 m, sometimes up to 90 m (eg in Benin); wells or boreholes 60 to 90 m deep. Flows obtained may occasionally reach 50 to 100 m^3/h. The water is generally slightly mineralised, pH varies between 6 and 7. The water quality has a calcium to sodium bicarbonate character when in contact with saline waters of the coastal zone. The total salinity can reach 15 600 mg/l at 33 m depth along the coast. Transmissivity may range between 10^{-3} to 3.10^{-2} m^2/s. Pollution risks are high.

Continental Terminal:

Near to Lomé, in Togo, this formation has a thickness of 30 to 70 m. In Benin, its depth is between 100 m and 150 m. This aquifer is heavily exploited by wells and boreholes providing water supplies to the capitals Abidjan, Lomé, and Cotonou. Borehole discharges may be up to 150 to 250 m^3/h. Specific capacities (discharge per metre of drawdown) are very variable (between 0.7 and 33 $m^3/h/m$) depending on aquifer thickness and percentage of clays or clayey sands. This aquifer is very vulnerable to saline invasion. Transmissivity and storage coefficients range from 2.10^{-4} to 3.10^{-1} m^2/s and 1.10^{-2} to 3.10^{-1} respectively in Côte d'Ivoire, where the aquifer is unconfined to semi-confined, and from 5.10^{-3} to 10^{-2} m^2/s and 5.10^{-2} respectively in Togo, where the aquifer is unconfined.

The waters are slightly aggressive with a pH of less than 7. The waters are classified as calcium to sodium bicarbonate where they are in contact with saline water. Contamination of the aquifer is common.

Calcareous Eo-Palaeocene:

This aquifer is poorly known and relatively poorly developed. The formation varies between 25 and 35 m in thickness. The formation's base is found between 140 to 240 m to the north of Lomé and between 225 to 250 m in southern Benin and to the south of Lomé (Togo). Discharge rates from boreholes are in the range 60 to 100 m^3/h and occasionally up to 150 m^3/h with a specific capacity of 8.8 m^3 per hour per m of drawdown. The transmissivity of this aquifer is extremely variable: 2.5 10^{-5} to 1.7 10^{-2} m^2/s. The available values of storage coefficient indicate a range of between 1.5 10^{-4} to 6.0 10^{-5}. These values are typical of a confined aquifer.

The waters have a calcium bicarbonate character, pH values are around 7 although slightly more alkaline in Togo. In certain areas, for example Benin, it may supply water with a fetid smell. Saline or bitter water is sometimes associated with Eocene clays.

Maestrichtian (Cretaceous):

This is the deepest aquifer and the least known. In the Lama depression in Benin, the aquifer is exploited by 200 to 700 m deep boreholes. Its exploitation is limited by its depth and the presence of clayey zones. In Togo the aquifer can be reached at 50 m depth in the north of the basin and at 400 m in the south. It is heterogeneous and broken up by numerous faults which are sometimes in hydraulic communication with the Continental Terminal. In Togo the thickness of sand beds may be between 5 and 25 m.

The development of this aquifer is limited as it can only be exploited by deep boreholes. Discharges may reach 100 m^3/h with specific capacities of between 1 and 8 m^3 per hour per m drawdown. The aquifer has been investigated in Togo where it has good potential to the east of Tabligbo. This aquifer possesses variable transmissivities between 2 10^{-2} and 6 10^{-3} and rarely 4 10^{-4} m^2/s. Storage coefficient values of 1 10^{-2} to 2 10^{-4} indicates unconfined to semi-confined aquifer. The waters are of calcium bicarbonate character, slightly mineralised, the pH is in the slightly acid range.

(b) Aquifer recharge and resources

Only a small proportion of rainfall infiltrates to the aquifers. The remainder of the rainfall is lost to high evapotranspiration requirements and to runoff caused by the presence of surface clay formations.

Recharge to the Continental Terminal is considered to occur over its entire surface. The underlying aquifers are recharged only over their outcrops. These areas are in the north of the basins in the vicinity of contacts with the basement.

The extensive clays which separate the various aquifers, contain, within their pores, large groundwater reserves. Where pumped abstractions have reversed hydraulic gradients, leakage is induced from the clays into the adjacent aquifers.

There is little difference between the piezometric heads of these various aquifers. Storage coefficients derived by pumping test, indicate that the aquifers are unconfined or confined to semi-confined, but never artesian. The Continental Terminal is an unconfined aquifer.

Various recharge estimations are summarised in the following table. It should be noted that they are very imprecise.

Country	Formation	Area (km^2)	Recharge (million m^3/annum)
Benin	Cretaceous	800	96 to 160
	Continental Terminal	6 000	642 to 834
Total			738 to 994
Côte d'Ivoire	Continental Terminal	6 000	2 100
	Quaternary	1 800	640
	Deep aquifers		not determined
Total			2 740
Togo	Maestrichtian		25
	Eo-Palaeocene		1 to 2
	Continental Terminal		35.5 to 36
Total			

The groundwater balance for the coastal sedimentary basin has been estimated and indicates that 2.6% of the average annual recharge is abstracted each year in Côte d'Ivoire, 2.4% in Benin, and 28% in Togo where exploitation of this resource is most developed.

2.4.3 Aquifers of the Sedimentary Basins

(a) Geology

The igneous and metamorphic rocks of the Basement Complex form the floor to the basins. The basins contain over 1 000 m of sediments. The process of basin-filling moved progressively from west to east. In the Taoudenit basin the exposed formations are generally Palaeozoic in age with Mesozoic and Tertiary formations dominating the Iullemmeden basin. The Chad basin sediments are mainly Quaternary in age.

The boundary between the Basement Complex and the overlying sediments is uneven and 'islands' of Basement Complex appear within the basins.

The major divisions of the sedimentary formations are as follows:

Age	Description
Quaternary and Neogene	Chad formation: alluvium, sands, clays
Upper Cretaceous to Paleogene	Continental Terminal: lacustrine and deltaic sediments
Upper Cretaceous	Marine shales and continental sandstones
Permian to Upper Paleozoic	Continental Intercalaire: sandstones and Cretaceous deltaic sediments; Cambrian/Ordovician and Devonian sandstones; Silurian and Carboniferous shales

The Paleozoic formations are generally consolidated and have been subjected to large-scale folding. The formations are covered by Cretaceous and later formations in the centre of the basins but outcrop around the margins.

There is some doubt and discussion over the age and relationships of the Cretaceous and later formations within the basins. In the Francophone countries, a division is made between:

- Continental Intercalaire: a series of poorly consolidated continental sands and clays deposited during the 'continental' period between the Carboniferous and Upper Cretaceous marine periods;

- Marine Upper Cretaceous or Continental Hamadien: marine conditions generally prevailed during the Upper Cretaceous period with shale deposits, continental sediments were deposited on margins;

- Continental Terminal which is a complex series of Late or post Cretaceous (commonly Neogene) age including sandstones, clays and argillaceous sands deposited during the 'continental' period which suceeded the Upper Cretaceous marine transgression.

It is generally difficult to determine the boundary between the Continental Intercalaire and Terminal except where the lagoonal marls and limestones of the Upper Cretaceous/Lower Eocene form a dividing formation as in western Mali and eastern Niger.

(b) Senegalo-Mauritanian Basin

Geological formations of the following ages occur within the basin:

- marine and continental deposits of the Quaternary;
- Eocene, Oligocene and Miocene;
- Turonian to Maestrichtian stages of Upper Cretaceous;
- upper Aptian to Cenomanian stages of Middle Cretaceous;

- Neocomian stage of Lower Cretaceous;
- Jurassic.

The following table indicates the lithologies of the major formations:

Formation	Lithologies
Quaternary	marine, lagoonal, lacustrine, aeolian and volcanic formations
Oligocene to Miocene	marly limestones, clays and sands
Eocene	marly limestones and sands
Palaeocene	limestones and marls
Upper Cretaceous	black shales in Turonian, sandy clays in Senonian, grits and sands in Maestrichtian passing into clayey facies in west
Middle Cretaceous	grits in west, calcareous clays, clays and silts in centre
Neocomian	grits and silty clays are found in the centre of the basin, calcareous in the west, clays and grits below Dakar
Jurassic	limestones and dolomites, found at depths of between 3000 and 4000 m

These formations fill the basin above the floor of Basement Complex and Palaeozoic formations which outcrop around the periphery of the basin: in the east of Guinea Bissau, the upper valleys of the Gambia and Senegal rivers and the Mauritanides mountain range.

Faulting within the basin has produced a series of horsts and troughs. The uplifted areas include the Kounkane and Ndiass horsts and the Dagana area. One of the troughs is followed by the Gambia River.

The sedimentary basin covers an area of 270 000 km^2, the majority of which is within Senegal with smaller areas in Guinea Bissau and Mauritania.

The main characteristics of the major aquifers are described below:

Maestrichtian aquifer:

This formation is the principal aquifer in Senegal and Guinea Bissau. The aquifer includes the Maestrichtian and the under-lying Cretaceous formations. Generally only the upper 200 m of the aquifer contains freshwater; the aquifer is saline in the area upstream of the River Senegal.

Eocene-Paleocene aquifer:

This formation is a good limestone aquifer in Ndiass horst block where it is around 100 m thick. The aquifer is also exploited along the coastal zone to the north of Dakar and in Guinea Bissau.

Continental Terminal aquifer:

The thickness of this aquifer ranges from several tens to several hundreds of metres. The formation contains marls in the Ferlo region as well as along the Senegal/Guinea Bissau border.

Quaternary aquifer:

This aquifer is locally important. Examples of its exploitation include: coastal sands north of Dakar, freshwater lenses on the Saloum islands and in Basse Casamance, the coastal aquifers in Guinea Bissau and, most importantly, the basalt/coastal sand aquifer exploited for Dakar water supply.

Aquifer			Unit Flow (m^3/hr)	Renewable Resource (million m^3/a)
Mauritania				
	Quaternary			
	Continental Terminal			
		Boulanouar	4	
		Benichab	3	
	Eocene			
		Maestrictian+Eocene	1.5	
	Palaeocene			
	Maestrichtian			
Senegal				
	Quaternary			
		Northern littoral	4-17	42
		Basalt aquifer	8	7
		Sands Cap Vert peninsula		17
		River valleys	<4	51
		Basse Casamance	2	
	Continental Terminal			
		Western Senegal	<0.8	
		Miocene		170
		Casamance	2	38
	Eocene			
	Palaeocene			
		Sébikotane	13	33
		Pout-Mbour	6	14
	Maestrichtian			
		Pout-Mbour	10	162
		Taiba	7	
Guinea Bissau				
	Quaternary			
		Rio Geba	0.25	several hundreds
	Continental Terminal			
		Miocene average	0.4	<5
		Oligocene	0.4	3-9
		Cachou	4	
	Eocene			probably limited
	Palaeocene		0.4	probably limited
	Maestrichtian		2-3	5-15

Estimates are not available for the renewable resource in each of the aquifers in Mauritania. The values are expected to be low due to the dry climate and abstraction is expected to be supported from groundwater storage.

Transmissivities are best known in Senegal where values range from very high to high in the Quaternary and Palaeocene aquifers to moderate values in the Maestrichtian and Continental Terminal aquifers. Eocene aquifers generally have low values.

Less data is available from Mauritania and Guinea Bissau although the Quaternary and Maestrichtian aquifers are known to posses moderate to high transmissivity values (in range $5\ 10^{-4}$ to $5\ 10^{-2}$ m^2/s).

The Senegalo-Mauritanian basin is open to the Atlantic Ocean. Shallow or isolated coastal formations are underlain by a saline wedge; examples include Quaternary alluvium, Continental Terminal in Mauritania and Casamance and the Neogene formations of Guinea Bissau. In some localities, for example, the Cap Vert peninsula, the freshwater reserve is protected by underlying low permeability formations.

Saline groundwater is generally found at depth in the Maestrichtian aquifer. The aquifer only contains brackish water in the area between Louga and Kaolack. To the north of Kaolack and in the region above the Senegal river, all aquifers contain saline water.

(c) Taoudenit Basin

The following geological formations occur within the Taoudenit basin:

- formations of Quaternary age;
- formations of lower Eocene age;
- Continental terminal formations of Cretaceous and Tertiary age;
- Continental intercalaire formations of Jurassic age.

The following table indicates the lithologies of the major formations:

Formation	Lithology
Continental Terminal and Quaternary	Clays, sandy clays, sands and dune formations
Upper Cretaceous and Lower Eocene	Limestones and marls
Continental Intercalaire and Terminal	Sands, sandy clays and clays
Continental Intercalaire	Sands and sandstones

The underlying Basement Complex and Palaeozoic formations outcrop around the periphery of the basin: the Chaine de Mauritanides in the west, infraCambrian sandstones at Ayoun, Cambro-

Ordovician pelites at Hodh, infraCambrian formations at Gourma, and PreCambrian basement in the Adrar des Iforas, Taoudenit and in the interior delta of the Niger.

The basin can be subdivided in the following manner:

- the North Azaouad basin which is limited to the south by the Azaouad ridge;
- the Nara trough and the South Azaouad basin;
- the interior delta of the Niger.

The sedimentary basin covers an area of 650 000 km^2 and includes 40% of the area of Mali and more than 15% of the area of Mauritania.

The following table summarises aquifer thicknesses and borehole yields in the major formations:

Aquifer	Basin	Aquifer thickness (m)	Average borehole yield (m^3/hr)
Continental Terminal/Quaternary	Interior delta	30 to 80 m in the south and west, 100 to 150 m in the centre	8
	South Azaouad	300 m	15 to 25
	Gourma NW	20 m	15 to 25
Upper Cretaceous/ Lower Eocene	Adrar des Iforas edges	100 to 400 m	7
Undifferentiated aquifer, Continental Intercalaire, Continental Terminal	North Azaouad	150 to 200 m, reduces to the north and increases to 500 m in west	10
	Nara trough	500 m along axis, reduces to 50 m at edges	

The recharge to the basin occurs from direct infiltration of rainfall and infiltration from surface water. Recharge is very irregular and is concentrated in the southern edge of the basin. The recharge occurs almost totally to the Continental Intercalaire and Quaternary formations. The following table summarises the water balance for the entire basin:

Item	Volume (million m^3/year)
Inflows:	
Direct infiltration	7 712
Infiltration of surfacewater	1 600
Inflows at boundaries	25
Total	9 337

Outflows:	
Drainage to rivers	16
Evapotranspiration	9 319
Losses at boundaries	3
Total	9 338

Aquifer transmissivities have been calculated from over 540 pumping tests. The tests have mainly been made in the Continental Intercalaire and Quaternary aquifers particularly in the Interior Delta area.

The transmissivities for the Continental Intercalaire and Quaternary aquifers range from 1.4 10^{-7} and 5.0 10^{-2} m^2 per second, averaging 1.2 10^{-3} m^2 per second. The transmissivity of the Upper Cretaceous and Lower Eocene aquifers are of the same order, averaging 1.9 10^{-3} m^2 per second. The values for the Continental Terminal and Continental Intercalaire aquifers in the Nara trough and at Azaouad North are slightly higher with an average of 7.4 10^{-3} m^2 per second.

The chemical quality of groundwater in the Taoudenit basin is generally good with total dissolved solids of less than 600 mg/litre. The chemical quality within the Interior Delta appears to improve from west to east. Salinities in the Gao trough and in Azaouad South basin are between 2 000 and 5 000 mg/litre.

(d) Iullemmeden basin:

The division between the Iullemmeden and Chad basins is generally taken along a line between the basement outcrops at Agades and Zinder. Most of the Iullemmeden basin lies within Niger although the western end (the Détroit Soudanais neck) is in Mali and the southern part is within Nigeria where it is known as the Sokoto basin. The basin has been subdivided into a series of subbasins.

The Palaeozoic formations are exposed along the northern edge of the basin in the Tin Seririne and Djado subbasins. These formations which include Cambrian and Devonian sandstone aquifers occur in synclinal forms. Marine conditions reinvaded the area in Cretaceous times allowing deposits from Continental Intercalaire to Continental Hamadien and Continental Terminal to rest directly on Basement Complex over the major part of the basin.

The Continental Intercalaire and the Continental Terminal contain sands and sandstones which are water bearing; some of the formations for example the Tagoma sandstone are regionally extensive. The Continental Hamadien is mainly argillaceous with little groundwater potential; it outcrops along an arc from the Adras des Iforas to Sokoto.

The main aquifers in the Iullemmeden basin are the:

- Cambrian-Ordovician sandstones;
- Upper Devonian sandstones;
- Carboniferous (including Tagora and Farazekat) sandstones;
- Triassic/Jurassic sandstones (the Agades group);
- Continental Intercalaire including the Tegama sandstones;
- Sands within the Continental Terminal in the Niger River basin;
- Continental Terminal including the Bilma and Termit sandstones in the east.

Yields to boreholes are in the range 1 to 10 litres per second, with the majority of yields less than 5 litres per second. The higher yields are encountered in the Palaeozoic sandstones.

The sediments around the basins form a dry, unsaturated wedge; this wedge is up to several tens of kilometers wide.

Depths to waterlevel are generally between 5 and 50 m below groundlevel although where the aquifers are confined depths to the aquifer can be excessive. For example over half of the Ordovician aquifer lies at depths greater than 800 m and the Tegama sandstone (Continental Intercalaire) lies beneath a 500 to 600 m thick cover of clays.

Water quality is generally acceptable although areas of saline water exist within the Devonian and Carboniferous formations.

The groundwater flow pattern within the Iullemmeden basin is poorly known. Recharge is assumed to take place dominantly through the beds of intermittently flowing rivers although some groundwater level observations indicate that recharge is absent in the most arid areas.

Some discharge takes place as upward leakage producing saline evaporite deposits.

The total resources have been estimated for some of the major formations. The values in cubic kilometers are summarised as follows:

Formation	Outcrop area (km^2)	Exploitable resources	Annual recharge
Continental Terminal	100 000	40 to 100	1.20
Continental Intercalaire	200 000	100 to 20?	0.65
Agades sandstones	30 000	15 to 25	
Koramas basin	105 000		2.00

(e) **Chad basin:**

The Lake Chad Basin has been a structural depression since early Tertiary time, and has been a locus of subsidence and sedimentation rather than erosion.

There are two broad troughs in the basin: the Tibetsi-Cameroon trough trends NE/SW and the Air Chad trough trends NW/SE. The two trends cross at Lake Chad (Furon, 1960).

Although many boreholes have been drilled in the area for urban and rural water supplies and for feasibility studies, the data available are still not sufficient to resolve several controversies that have arisen over the hydrogeology of the basin.

The basin contains over 3 600 m of sediments. The crystalline basement is encountered in the eastern, south-eastern, south-western and northern rims of the basin. In addition, the basement rises to the surface at several localities including Bol, Logone Birni and Gudumbali. The configuration of the basement below the sediments around the lake is a series of horsts and graben, with thicker sediment accumulation in the latter.

The oldest formations within the basin are Cretaceous sediments of low permeability and probably containing hot, saline water. The succeeding sediments are collectively known as the Chad Formation. This formation contains three important aquifers: the Upper, Middle and Lower Aquifers Zones. The Upper Zone is phreatic or unconfined whereas the two lower zones are confined and artesian.

There is general agreement (Hanidu et al., 1989), that these Zones are geologically different and they should rather be considered to be of Quaternary, Lower Pliocene, and Continental Terminal respectively. In fact, the same names have already been used by the FAO (1973) survey.

The thickness of Quatenary deposits varies from 30 to 100 m but locally may reach 180 m. The surface area covers over 1 400 000 km^2. The phreatic aquifer is not continuous all over the basin area, and recharge conditions are poor. Maps of the watertable elevation (eg FAO, 1973) show that there is some seepage occurs from the Lake to the phreatic aquifer.

Natural recharge occurs not so much by infiltration of rainwater but rather through influent seepage from seasonal streams and perennial rivers that transverse the area. The watertable is generally close to groundlevel in areas with a dense network of streams. There is also a clear correlation between stream discharge with groundwater table fluctuations.

The lower Pliocene deposits are at least 200 m thick and contain one of the largest aquifers in the basin. The depth to the top of the aquifer varies between 150 and 400 m below ground level. Its total area is unknown, its extension to the northeast is undefined, and there are doubts as to the position of its southeastern edge. The surface area of the zone of artesian pressure can be estimated at 87 000 km^2, of which 25 000 km^2 is occupied by Lake Chad (FAO, 1973). Understanding of how it functions is very incomplete (BRGM, 1986). The fact that its recharge is questionable (no visible outcrop) was noticed in the early days of its exploitation (eg Miller et al 1968). But until the end of the 1960s, the rates of withdrawal were so low that no significant areal decline in artesian head has been observed.

The BRGM (1986) study illustrates the order of magnitude of groundwater resources of the Quaternary and Lower Pliocene deposits. For the Chadian part of the geographical basin only, mean annual recharge is estimated to be 3.6 km^3 per year, while volume of exploitable reserves is somewhere between 94 600 and 206 010 km^3. Compared to the volume of surface runoff (eg the average annual runoff of the River Chari is 36 km^3 at N'Djamena) it is clear that natural recharge of these aquifers is quite limited. The same source provides an estimate of the total mean annual recharge of all groundwater aquifers in Chad as 20.6 km^3 per year.

Recharge to the Quaternary and Lower Pliocene deposits in Niger has been estimated at 0.3 km^3 per year for the unconfined aquifer. The total exploitable storage for both the unconfined and middle aquifers is between 30 and 70 km^3.

The Continental Terminal deposits, usually encountered between 450 and 620 m from the surface, extend from Niger and Nigeria far into Cameroon and Chad. They contain a very extensive artesian aquifer, which is recharged in southern Cameroon and Chad. Limited aquifer testing shows that transmissivity ranges between 32.5 and 105 m^2 per day in Nigeria and between 0.3 and 129 m^2 per day in Chad and Niger. Yields to boreholes in Chad and Niger are unfortunately poor, contrary to Nigeria where the aquifer is heavily exploited and where serious declines in head have been noticed (up to 6 m per year). Knowledge of this aquifer is however limited (BRGM, 1986).

Vertical communication between all three aquifers appears to be very limited. Water quality is generally acceptable both for village and livestock use. The artesian aquifers contain warm, aggressive water with high values of iron and residual sodium carbonate making its use for irrigation purposes difficult.

The Continental Terminal deposits overlay five major Cretaceous formations (Kerri-Kerri, Combe Sandstones, Fika Shales, Congila and Bima Sandstones) exposed by recent oil explorations at depths of 2 700 to 4 500 m. These sedimentary successions are laid on the Basement Complex platform. Available data are not yet sufficient for the quantification of the aquifer characteristics (Hanidu et al 1989).

The Kerri-Kerri formation is about 200 m thick and outcrops near Potiskum in Nigeria. According to one hypothesis, the aquifer leaks vertically upwards into the Continental Terminal and Lower Pliocene aquifers. The Combe Sandstone has a maximum thickness of 350 m, which thins down towards Lake Chad. They form good aquifers in the outcrop areas.

Although the volume of water in storage within the aquifers of the Chad basin is very large, probably in excess of 300 000 km^3, annual recharge is poorly quantified but small. Recharge is also susceptible to variations in rainfall. The major groundwater development concerns include:

- maintenance of flow in rivers to allow phreatic water table recharge;
- determining the extent of 'fossil' water versus rechargeable water;
- reservation of groundwater for dry-years in order to prevent lowering of the groundwater table;
- increased pumping costs from lower groundwater, application of groundwater with high ion concentrations to irrigable farmland;
- pollution risks to major urban areas.

2.4.4 Discontinuous Aquifers

(a) Introduction

Outside the sedimentary basins, most of the region is underlain by strongly consolidated, often crystalline strata, of the Precambrian Basement Complex, metamorphosed Palaeozoic sediments and volcanics of various ages from Palaeozoic to Tertiary. A general characteristic of such rocks is the lack of primary porosity and permeability. Groundwater in mainly small, but often exploitable quantities, occurs erratically in near-surface secondary features, such as joints, fractures and the zone of weathering. The exception are metamorphosed carbonate strata, which when karstified, may be highly permeable and yield water in large quantities.

The other group of rocks excluded from the discussion of the sedimentary basins, are the outcrops of low permeability sediments of the Niger Basin in Nigeria and at the margins of the Chad and Mauritania - Sengal Basins in Mali and Niger. These sediments consists mainly of marly sandstones, marly limestones, shales and flysch of Jurassic and Cretaceous age.

The groundwater in the aquifers of both these groups, though scarce and sometimes difficult to find, is extremely important as a source of potable supplies to small communities. In some cases urban and industrial supplies are also obtained from boreholes in such aquifers. In recent years there have also been at least partially successful trials of using such groundwater for small scale irrigation, sometimes with innovative well and pump technology.

(b) Distribution

The distribution of the outcrops of the strongly consolidated strata (which will be referred to as Basement aquifers) and the Cretaceous/Jurassic sediments is shown in Figure 2.17. As can be seen the former underlie most of the region (as demonstrated by Table 2.8), including Cape Verde and São Tomé and Príncipe, which are essentially volcanic islands. The only significant carbonate outcrops occur in the Congo, Gabon and the Central African Republic; the major outcrops of the Cretaceous/Jurassic flysch etc occur in Nigeria, Mali and Niger, but minor outcrops are also found in Cameroon, Equatorial Guinea and Gabon.

TABLE 2.8

Occurrence of Discontinuous Aquifers in the Region

Country	Surface Area (km^2)	Percent of Area underlain by outcrops of:	
		Cretaceous /Jurassic	Basement Aquifers
Benin	112 600	0	c80
Burkina Faso	274 200	0	100
Cameroon	475 400	7	85
Cape Verde	4 000	0	c100
Central African Republic	623 000	25	63
Chad	1 284 000	9	48
Congo	341 800	6	49
Côte d'Ivoire	322 500	0	97
Equatorial Guinea	28 000	c15	c85
Gabon	267 700	15	80
Gambia	11 300	0	0
Ghana	238 000	0	99
Guinea	245 900	0	98
Guinea-Bissau	36 100	0	85
Liberia	111 400	0	96
Mali	1 240 000	11	49
Mauritania	1 240 000	4	48
Niger	1 267 000	43	36
Nigeria	923 800	30	43
São Tomé & Príncipe	1 000	0	c100
Senegal	196 200	48	31
Sierra Leone	71 700	15	c85
Togo	56 000	7	93

(c) Aquifer Properties

The main lithologies of the Basement group are Archean crystalline metamorphics such as gneisses, schists and migmatites, intruded by granites, gabbros and other plutons. Other significant units are ancient (mainly Precambrian and Palaeozoic) sedimentary rocks including sandstones (or quartzites), mudstones and shales as well as volcanics particularly basalt lavas, of various ages. Subsidiary occurrences of carbonate rocks (marbles, limestones and dolomites) have been mentioned already. All these tabular outcrops are locally intersected by swarms of mainly basic dykes.

The secondary porosity and permeability of these strata are predominantly near-surface characteristics, determined by a multiplicity of factors, which may include:

- original formation lithology;
- tectonic history, particularly the incidence of faulting;
- geomorphological history;
- occurrence of intrusions, particularly dykes and sills;
- climate.

Secondary permeability developed as a consequence of these factors in the form of joints, cracks, fissures and granular layers (in the weathered zone), is often highly variable but is concentrated in the top 30 to 60 m of the strata. There are some surface features which normally correspond to enhanced permeability in the subsurface. In carbonate terrain, surface karst development and occurrence of springs may help the definition of subsurface groundwater circulation patterns. In the more typical, less soluble lithologies, lineations, visible on aerial photographs, may correspond to faults and fractures, which may provide preferential paths for groundwater movement. Old erosion surfaces may be underlain by deeper weathered profiles, which normally include transmissive layers, than younger surfaces. Similarly, wet climates might be expected to assist deep weathering. Dykes and other intrusions may shatter the host rock and may themselves develop extensive fracture systems during cooling.

Quantitative determination of transmission and storage parameters of such secondary aquifers is difficult. Pumping tests on boreholes and wells are normally used for that purpose, but the calculations are based on assumptions of radial symmetry, totally Darcian flow, spatial and temporal homogeneity of hydraulic properties and large (theoretically infinite) radius of influence of the pumped well. These assumptions are not usually applicable to fracture flow systems. Consequently, it is sounder to use yield, particularly specific capacity as an index of aquifer quality; unfortunately drawdowns are often not measured, or at least not reported.

In absolute terms, yields of conventional wells and boreholes in non-carbonate Basement aquifers are mainly in the range of 0.2 to 2.0 m^3/h, but completely unproductive wells and yields of up to 10 m^3/h are not uncommon. In most countries of the region, local criteria have been developed relating probability of different yields to area and particular formation. In karst aquifers very high yields (greater than 200 m^3/h) can sometimes be obtained from properly sited and constructed wells.

The Cretaceous/Jurassic marly and shaly deposits normally include some productive sandy layers within the top 100 m of the profiles. The common range of borehole yields is 3 to 30 m^3/h.

(d) Groundwater Quality

It is difficult to generalise about groundwater quality in such a large area with climatic variation from extreme aridity (average annual rainfall less than 100 mm) to wet tropical conditions (annual rainfall greater than 2 000 mm). Nevertheless some general observations on this subject may be of value.

In terms of overall mineralisation, groundwater quality in the discontinuous aquifers of the region is generally good to reasonable though the region, including even the arid north. The main problem areas from the potability point of view are particular chemical constituents.

In high rainfall, thickly vegetated areas, infiltration through decaying vegetation (high carbonic acid) results in groundwater of low pH (sometimes as low as 4.5), giving it the capacity to maintain high concentrations of some metals in solution. Thus the groundwater may be particularly rich in iron and manganese as well as other heavy metals. Many of the Basement aquifer lithologies are particularly poor in calcium, consequently the groundwater may be of very low calcium hardness, which allows high concentrations of fluoride. For these reasons, the groundwater can be unpalatable and/or hazardous to health.

A recent quality problem has been groundwater pollution by residues of agricultural chemical, and domestic and industrial effluents. The most frequently measured index of agricultural pollution is nitrate; reported surveys indicate that such pollution may be widespread in aquifers underlying cultivated areas. Urban sewage is seldom treated in West African towns, but the main disposals are to the river and the sea, and do not greatly affect groundwater. The main sources of industrial pollution are mining enterprises, common on Basement outcrops, which sometimes dump extremely toxic chemicals, such as cyanide at gold mines.

Lastly, high bacterial contents have been identified in various countries in some groundwater sources. However, this is considered more a well protection problem than that of aquifer contamination.

In many of the countries of the region the subject of groundwater quality is not addressed adequately, largely because of the insufficiency of good laboratory facilities. This may result in the provision of a water supply to sections of the population, which may be hazardous to their health.

(e) Recharge

One important characteristic of the low permeability Basement aquifers, is that natural groundwater circulation is essentially vertical. The main recharge component is infiltration of rainfall and the main discharge mechanisms is evaporation and evapotranspiration, though discharge to river base flow and to small springs may also be significant.

In view of the huge variation in precipitation in the region from north to south, it is not possible to generalise about recharge quantities. However over much of the area accurate estimates are not of crucial importance. Because of very low productivity of the Basement aquifers only small amounts of groundwater can be abstracted by conventional wells in any one place and regional aquifer depletion is not a serious risk. The situation is similar in areas of the low permeability Cretaceous/Jurassic sediments though higher well yields are normally possible and consequently the risks of over exploitation are greater.

(f) Development Potential

Though most of the secondary permeability aquifers of the region are of low to very low permeability they are, nevertheless, of great importance. Though overall annual rainfall is high in some areas, much of the region experiences a pronounced dry season, when surface water becomes very scarce except for the vicinity of major rivers. Moreover, even when perennial surface water is available, its consumption in untreated state presents serious risks to human health. Groundwater sources are much easier to protect from pathogens and parasites responsible for some of the most damaging diseases in Africa.

Thus, dug wells and boreholes equipped with handpumps have become the mainstay of potable water supplies to rural populations throughout sub-Saharan Africa. Since much of the West African region is located on the Basement outcrops, these have become the most important aquifers in the area. Considerable technical effort has been directed at locating optimum sites of wells, improving methods of construction, refining designs and insuring proper operation and maintenance of such systems. Large scale installation of wells with handpumps started in the 1960s in many countries, but has been greatly accelerated by the UN Water Supply and Sanitation Decade between 1981 and 1990. Currently there are some hundreds of thousands of hand pumps installed in wells and boreholes in the region, most of them in Basement aquifers. A yield of about 1 m^3/h is required to sustain continuous use of a typical handpump but in difficult terrain yields as low as 0.3 m^3/h may acceptable for intermittent abstraction with handpumps. Much has been written about the so-called success ratio of various well and borehole installation programmes; this may be defined as the percentage of newly constructed wells or boreholes converted to permanent use, though the critical yield of groundwater varies from country to country and one installation programme to another. The reported success ratios vary from more than 90 to less than 50 percent but the overall figure for the region as a whole over the last 10 years is probably about 75 percent; that is three quarters of all wells and boreholes installed in the last decade have been successful.

Occasionally conventional Basement aquifer sources can produce much greater discharges, such as 20 or 30 m^3/h. However, as a rule, special technologies have to be used for a reasonable chance of obtaining such quantities of groundwater; trials with gallery wells in African Basement aquifers have been sufficiently encouraging to suggest that minor groundwater irrigation development in the region may be a viable option in the future. In view of the scarcity and high cost of energy in many of the West African countries, this may be particularly attractive if implemented with solar or wind powered pumps.

The development potential of the Basement and other low productivity aquifers in the region remain huge in much of the region. A considerable proportion of the population of many of the countries involved in this assessment has no access to safe water and wells or boreholes with handpumps continue to be fastest and most cost effective way of improving this situation. In addition innovative technology developments may make groundwater abstractions from such aquifers viable for small scale irrigation. Lastly, the accelerating industrial development in the region is also likely to rely increasingly on groundwater resources, as this gives the various enterprises complete control over their supplies.

2.5 Comparison Between Water Resources and Future Demands

2.5.1 Demand Estimates

Demand for water in the region will increase substantially in the future driven by population growth and a higher degree of economic development. With the economic difficulties experienced in most of the West African countries over the last decade industrial and agricultural demand for water has not grown as fast as perhaps expected. However the continuing high levels of population growth, typically 3% per year, will ensure that there is an ever increasing demand for water. Throughout the region governments are concerned to increase the level of provision of 'safe' water supplies to all their people, this in turn will raise demand for uncontaminated sources - usually groundwater. The last decades have seen rapid urbanisation which is likely to be a continuing trend. Urban dwellers are already more likely than the rural population to receive a water supply so that the rise in demand can be expected to be rapid. Statistical details are given in Table 2.9.

Where possible we have obtained the latest demand estimates and projections for each of the countries and these are given in the country reports. However, the overall picture is one of a continuing need for careful resource planning, particularly in the Sahel zone.

2.5.2 Water Sufficiency in West Africa

The importance of the collection of data on climate, surface and groundwater is inextricably linked to future water demands. The magnitude of the resource available to a country and the reliable yield in the long term are also key factors in determining the level of interest in hydrometry. The West African region encompasses the drought prone Sahel countries and the well watered equatorial zone, clearly these two extremes give rise to different water resource problems and potential. Those countries such as Congo and Gabon in the equatorial zone cannot be said to be short of water but even in these environments there may be a shortage of water at some times of the year, or a shortage of 'safe' water. The devastating affects of the recent drought which afflicted most of the northern countries of the region has served to highlight the need to determine reliable yields when planning developments especially in the Sahel zone.

TABLE 2.9

Population Statistics

Country	Area (km²)	Population 1991 (millions)	Fertility Rate	GNP US$ 1989	% Urban	Life Expectancy (years)
Mauritania	1 120 000	2.03	6.0	490	25	46
Mali	1 202 000	8.40	6.5	260	19	45
Niger	1 267 000	8.08	7.0	290	14	45
Chad	1 284 000	5.67	5.5	190	20	43
Senegal	196 000	7.50	6.6	650	34	46
The Gambia	11 000	0.86	6.5	230	30	36
Guinea Bissau	36 000	1.00	6.0	180	26	38
Guinea	246 000	7.04	6.0	430	26	37
Sierra Leone	72 000	4.25	6.5	200	23	38
Liberia	111 000	2.26	6.9	450	38	49
Côte d'Ivoire	322 000	12.60	6.6	790	44	52
Burkina Faso	274 000	9.24	6.5	310	11	44
Ghana	239 000	16.70	7.0	380	38	59
Togo	57 000	3.57	6.5	390	22	49
Benin	113 000	4.89	6.5	380	16	48
Nigeria	924 000	117.00	6.9	250	22	49
Cameroon	475 000	11.26	6.5	1 010	39	54
Central Afr Rep	623 000	2.98	5.5	390	44	48
Equatorial Guinea	28 000	0.45	5.0	430	57	44
Gabon	268 000	1.21	4.5	2 770	39	50
Congo	342 000	1.99	6.0	930	55	63
Cape Verde	4 000	0.39	5.8	760	27	64
São Tomé & Príncipe	960	0.12		360	32	65

Sources: World Bank 1986 Population Growth and Policies in Sub-Saharan Africa.
FAO, 1991 Food Supply Situation and Crop Prospects in Sub-Saharan Africa.

Hard numbers comparing water availability and future demand are limited and are only available as national estimates. However many in the region are aware that water should be treated, and valued in economic analyses, as a scarce resource which under certain adverse circumstances, such as the recent prolonged drought, might seriously disrupt development plans, economic performance, or even lead to disputes both within and between countries.

Some work has been done comparing the available resource with likely future demands to determine a national level of 'water sufficiency'. Whilst most of this work is based on a number of assumptions which are open to criticism it may provide a useful way for hydrologists to express their concerns in terms readily understood by politicians and technocrats in other disciplines.

Gustafsson (1977) suggested that from a hydrological perspective, a country would have the potential to be self-sufficient in food production at the subsistence level if there is 1 250 m^3/capita per year available to meet the needs of the population and subsistence crops. Gustafsson's subsistence level converts to 800 inhabitants per water unit of one million m^3/year, but it should be noted that no allowance is made for industrial and irrigation demands.

Falenmark (1989) made an attempt to introduce a variable level of agricultural development and to take account of the higher requirement for water in arid climates. He developed a 'water scarcity' matrix assuming that a level of demand of 500 inhabitants per million m^3/year was an appropriate measure of scarcity in Africa, and that 100 percent utilisation represented a 'water barrier'.

TABLE 2.10

Water Scarcity Matrix

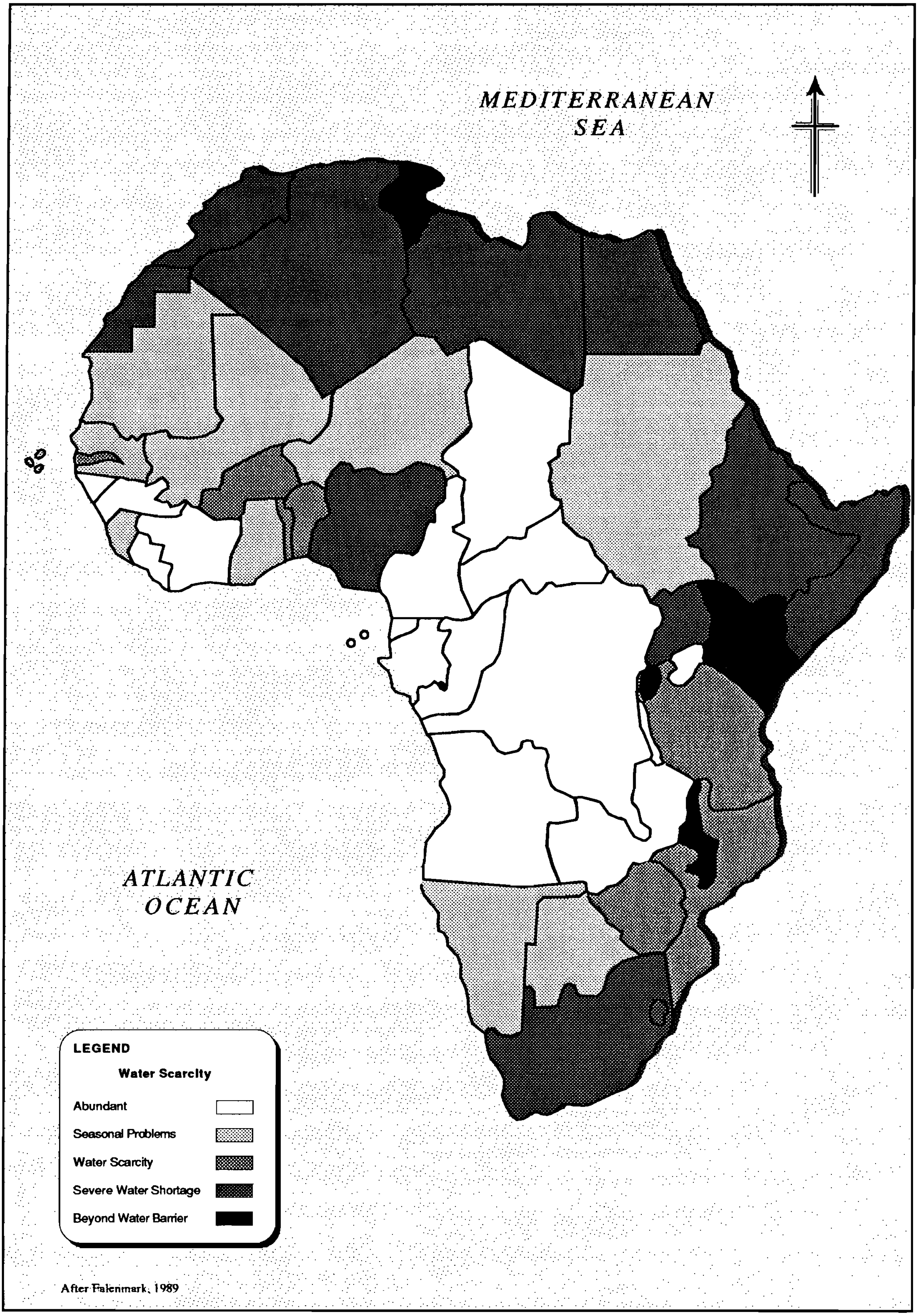
Level of Agricultural Technology for Self-sufficiency	Water Competition Level (people/million m^3 year)				
	<100	100-600	600-1000	1000-2000	>2000
Low	Abundant				
Intermediate	Seasonal Problems		Scarcity	Beyond the Water Barrier	
High			Severe Water Shortage		
Irrigation		Scarcity			

Source: Falenmark, 1989

Figure 2.18 is taken from this paper. Unsurprisingly the equatorial countries of the Zaire basin are classified as having abundant resources to meet their forseeable needs at the chosen year, 2025. That Chad and the Central African Republic should be in the same class is perhaps surprising considering

Figure 2.18

Water Scarcity in Africa (year 2025)



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the dramatic decline in flows in the Chari and the contraction in the size of Lake Chad. Nigeria with its huge population and its ambitious target for agricultural development is classed as likely to suffer from severe shortages by that date. Clearly this analysis is still very crude and cannot differentiate, for example, between the well watered south of Nigeria and the water short north. Despite these reservations the approach may be an aid to providing justification for the claim that water must be given due weight in development planning.

Such an approach may also highlight any opportunities for transfers of water between countries and/or river basins. Of the surface water basins discussed earlier only the Zaire has resources far in excess of forseeable demand in the riparian states.

2.6 Inter-basin Transfers from the Zaire River

2.6.1 Introduction

The devastating consequences of the Sahel drought on the Lake Chad basin have led to a number of ideas being put forward to alleviate the severe water shortages in the region. Some of these schemes involve the concept of inter-basin transfers from the water rich Zaire basin. Two of these ideas have been taken further and formulated as draft project proposals (Umolu and Oke, 1986).

Any such transfer between the basins would be a major undertaking and would need the most careful scrutiny from the earliest phase in order to ensure that all the advantages and disadvantages of the scheme were identified and costed. In particular the environmental consequences would require special attention. International water agreements would have to be negotiated since seven countries are potentially involved (Zaire, Congo, Central African Republic, Chad, Cameroon, Nigeria, and Niger), incorporating suitable incentives for those countries contributing water to the scheme.

2.6.2 The Bonifica Proposals

The first transfer scheme was put forward by an Italian firm Bonifica and involves a major economic development in which a water transfer is only a part of a larger infrastructural project.

The Bonifica proposals centre around a 2 400 km long navigable gravity canal that circuits the north-east rim of the Zaire basin, see Figure 2.19. This collects water from the tributaries that it crosses using dams or weirs. The basic philosophy is to use the canal as a transport axis for the transfer of goods east to west across the continent (the canal would link the Pan African Highway from Mombassa with navigation down the Benue/Niger to Port Harcourt), and by hydropower development encourage mining based industrialisation in Zaire and the Central African Republic, as well as providing water for irrigation and commercial agro-industrial development in Chad, north-east Nigeria, northern Cameroon, and Niger. Quantities given in the proposal include a tranfer rate of 3 200 m^3/s, the development of 7 million ha of irrigation, and the generation of up to 30-

35 GWh/annum of hydropower. There is also the development of transhipment facilities, freeports and industrial zones.

The tone of the report is fairly sensationalist with regard to the drought and environmental 'disaster' in the region and on the prospects for development offered by the scheme. This proposal epitomises the 'mega-project' approach to development which has been so disastrous in the past and against which there is understandable opposition.

A major project of this scope raises a large number of questions the first of which concerns the technical feasibility of the proposal. A figure of 10 km^3/year is quoted as the quantity of water which must be transfered in order to stabilise Lake Chad, the proposed capacity for the canal is 100 km^3/year. The topography along the canal alignment would seem to be very broken and the canal route crosses many dissected valleys and will have to make long snake backs or entail the construction of massive aqueducts. The earth moving quantities would be vast. Its starting location seems to be set by the need to join with the Pan African Highway and this has determined its route which cuts and captures many tributaries quite high up in their catchment.

Whilst it is quoted that overall only 5% of the total Zaire basin flow would be transfered the local sub-basin extraction rates are likely to be much higher than this. There are likely to be significant water shortage problems immediately downstream of the canal in many of these sub-catchments, especially bearing in mind the large quantities planned to be transfered. The philosophy of the Pan African Highway link rules out the option of a much shorter canal taking water from lower down the catchments.

2.6.2 The Nigerian NEPA Proposals

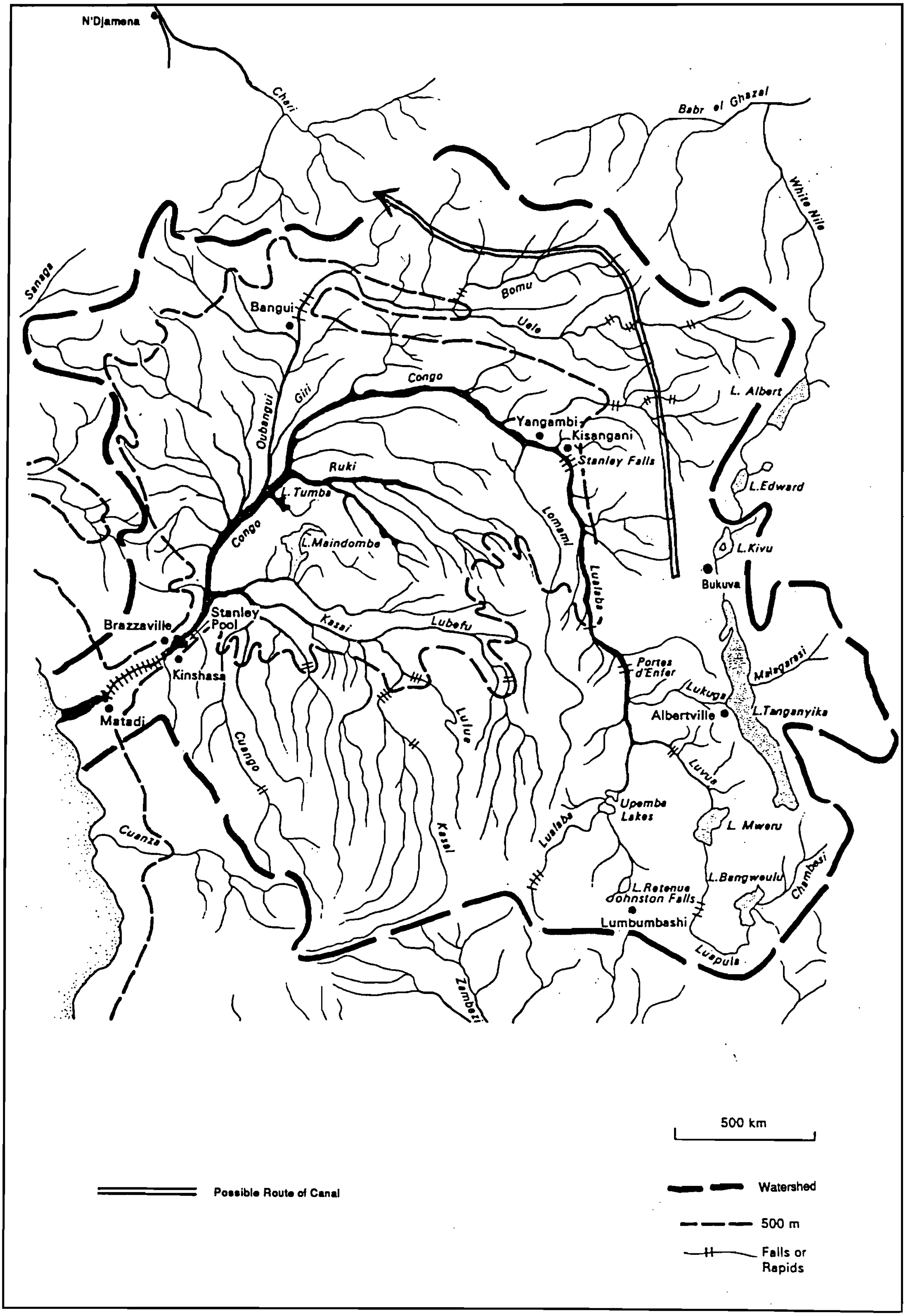
A second scheme has been put forward by the Nigerian Electric Power Authority (NEPA). The basic philosophy is very simple and shown on Figure 2.20. The aim is to address the decline in inflow to Lake Chad by pumping water up some 250 m over a distance of 100 km from the Oubangui River just upstream of Bangui and then discharging it into the River Fafa where it flows by gravity into the Chari system and then to Lake Chad. There is also provision for a dam just upstream of Bangui (this could be an option or intrinsic to the proposal depending upon volumes of water to be transfered plus pumping and power requirements) to provide sufficient storage to even out seasonal fluctuations in flows in the Oubangui and generate hydropower for the pumping.

Other options for further increasing the amount of water transfered include supplementing available water in the Oubangui (and hence addressing any problems of its downstream depletion) by a link from the main Zaire channel, a distance of 170 km. Additionally there is the possibility of transfer into the Benue and Niger river system by link canal from the Chari to the Logone and into the Mayo Kebbi and Lake Lere.

No details at all seem to be given as to likely quantities of water to be transfered.

Figure 2.19

Zaire Transfer Options - Bonifica Proposals



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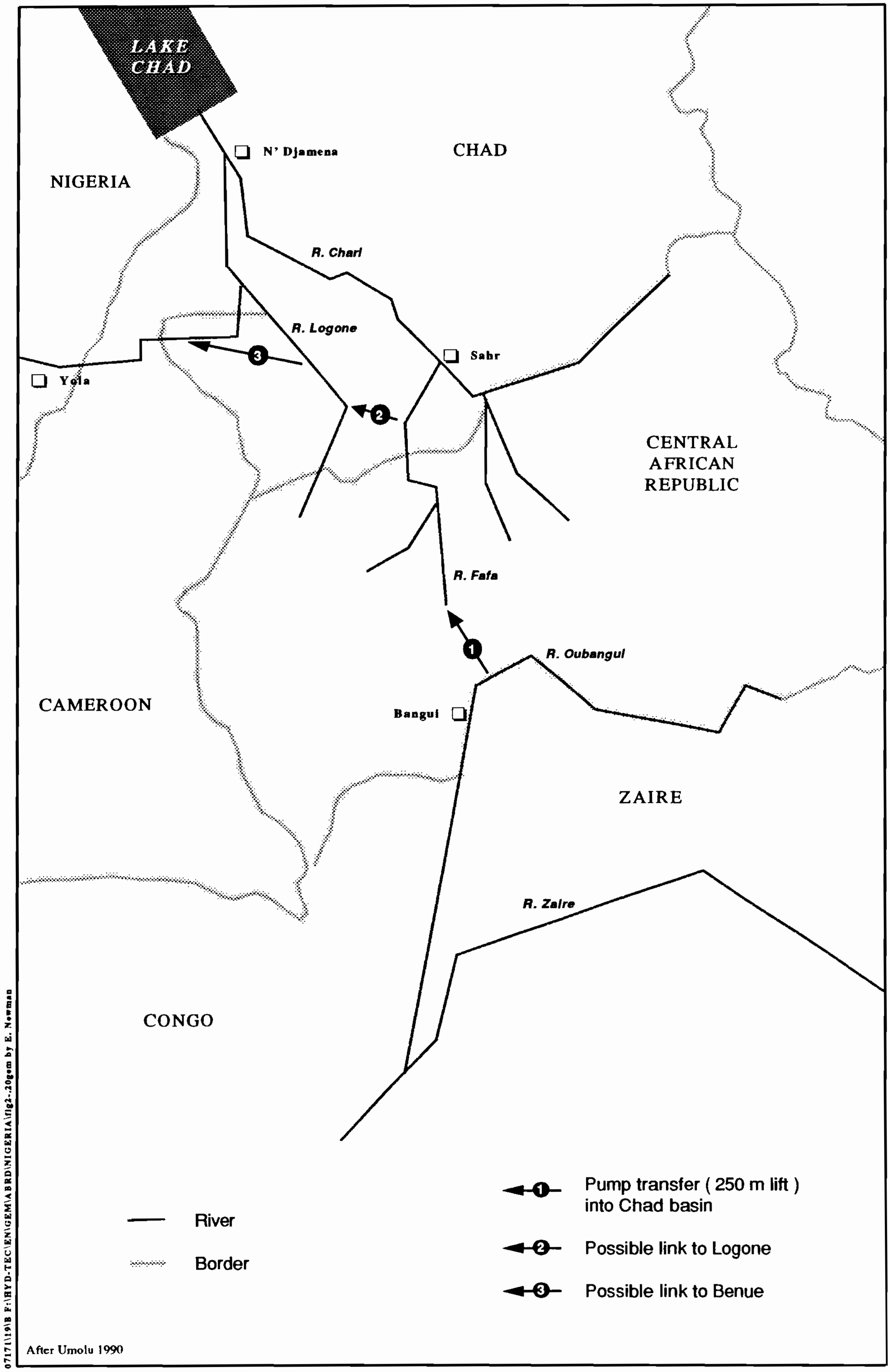
Zaire Transfer Options - Nigerian NEPA Proposals



The NEPA scheme is more modest in its ambitions and has potential for staged development. It also has the advantage of taking a smaller overall quantity from one downstream point on a large river. Should there be further interest in the possibility of such transfers it is the more likely of the two to be suitable for further investigation.

CHAPTER 3

REGIONAL ORGANISATIONS AND PROGRAMMES

3.1 Introduction

The international nature of water resource problems in West Africa has been long recognised but the onset of the drought which has devastated the Sahel since the early 1970s brought the need for international and regional co-operation into sharp focus. As a result today there are several bodies, regional programmes, and support projects which are active in the fields of water resources data collection, data management, and resource planning (see Figure 3.1). In many of the countries of the region the hydrological assessment would be incomplete without reference to the activities of these international organisations and their regional projects.

In developing our recommendations for each country's meteorological, hydrological and groundwater services we have kept in mind the on-going and planned activities of the international organisations. In certain areas projects have been identified which are of relevance to several countries and in these cases we have looked to the existing international organisations as possible executing agencies.

3.2 Regional Organisations in the Field of Water Resources

3.2.1 The Niger Basin Authority

The Niger Basin Commission was founded in 1964 with its head-quarters in Niamey, Niger. In 1980 its powers were extended and it was renamed as the Niger Basin Authority (NBA). It is governed by a quadrennial summit of the heads of state of its member countries and an annual meeting of responsible ministers from the member states. The member countries are Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger and Nigeria. The NBA has received help from a number of donor organisations including UNDP, EEC, USAID and the OPEC special fund. Activities have included the establishment of a documentation centre, hydrometric activities, and the HYDRONIGER Project. The latter, the most important activity undertaken under the auspices of the NBA, is described in Section 3.3.2.

In 1988 at the fifth summit of the heads of state, in an attempt to achieve a better balance of expenditure and income, a restructuring of the personnel of the authority was undertaken. In this restructuring the number of directorates and the total number of staff were reduced. The three departments retained were Planning, Documentation and Information, and Administration. In addition, in order to meet its counterpart obligations for the HYDRONIGER project, a system was instituted whereby funds due from member countries as part of their contribution to this project were paid into a fund administered by the UNDP. It remains to be seen whether this restructuring has helped significantly to ensuring the long term effectiveness of the authority.

3.2.2 Lake Chad Basin Commission

The Lake Chad Basin Commission (LCBC) was founded in 1964 and is based in N'Djamena, Chad; member states are Cameroon, Chad, Niger and Nigeria. The organisation's function is to co-ordinate activities for the social and economic development of the 'Conventional Basin' around the lake, see Figure 3.2. This area represents only 19% of the geographical basin and, more importantly, only includes 10% of the Chari and 25% of the Logone catchments which are the principal source of supply to the lake (Section 2.2.7). At the Heads of State meeting in 1985, where drought was a dominant theme, it was agreed that the focus of the LCBCs activities should be management of the environment and water resources by river basin. It was also recommended that to allow proper management of the Chari/Logone basin the Central African Republic should become a member.

A number of internationally funded projects have been executed under the auspices of the LCBC; there have been two phases of activity: up to 1979/80 when there were major regional water resources studies funded by UNDP, and since 1985/86. Since the mid 1980s there has been a long term technical assistance project and three major studies:

- Planning and Management of Water Resources of the Lake Chad Basin, RAF/88/029; 4 year programme funded by UNDP started in 1988.
- Lake Chad Conventional Basin - a Diagnostic Study of Environmental Degradation; for UNEP and UNSO, 1989.
- Master Plan for the Development and Environmentally Sound Management of the Natural Resources of the Lake Chad Conventional Basin; LCBC with the assistance of UNEP and UNSO, 1991.
- Action Plan for the Management of Water Resources of the Conventional Basin for Sustainable Agricultural Development; FAO TCP/RAF/9162, 1991.

The above studies recommend that the role of the LCBC should be to coordinate internationally funded basin-wide planning leaving bilateral aid project implementation to national agencies. For the LCBC to fulfil a role in resolving disputes over water between members it will have to be invested with greater powers.

3.2.3 Organisation de Mise en Valeur du Fleuve Senegal (OMVS) (Senegal River Development Organisation)

The OMVS, whose members are Mali, Mauritania and Senegal, was founded in 1972 following two earlier tentative attempts to form an association for the communal development and management of the water resources of the basin (an inter-state committee set up in 1963 and the Organisation des Etats Riverains du Sénégal in 1968). Guinea is an observer to the OMVS.

In order to satisfy the requirements of the OMVS programme for development in the basin (agriculture, hydropower, and navigation) it was estimated that it was necessary to maintain a minimum flow of 300 m^3/s at Bakel. To achieve this two structures have been built in the basin,

Figure 3.1

Regional Organisations

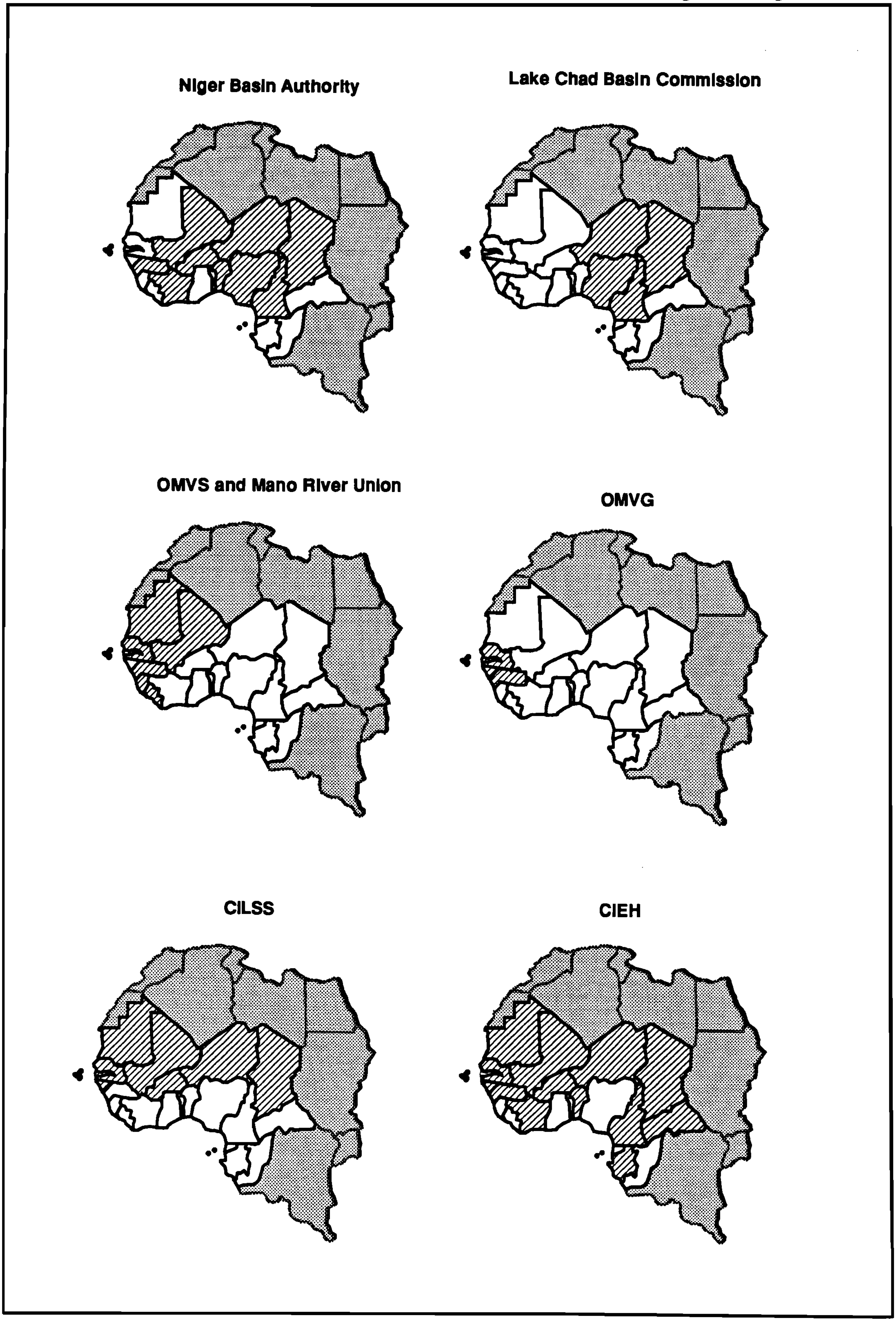


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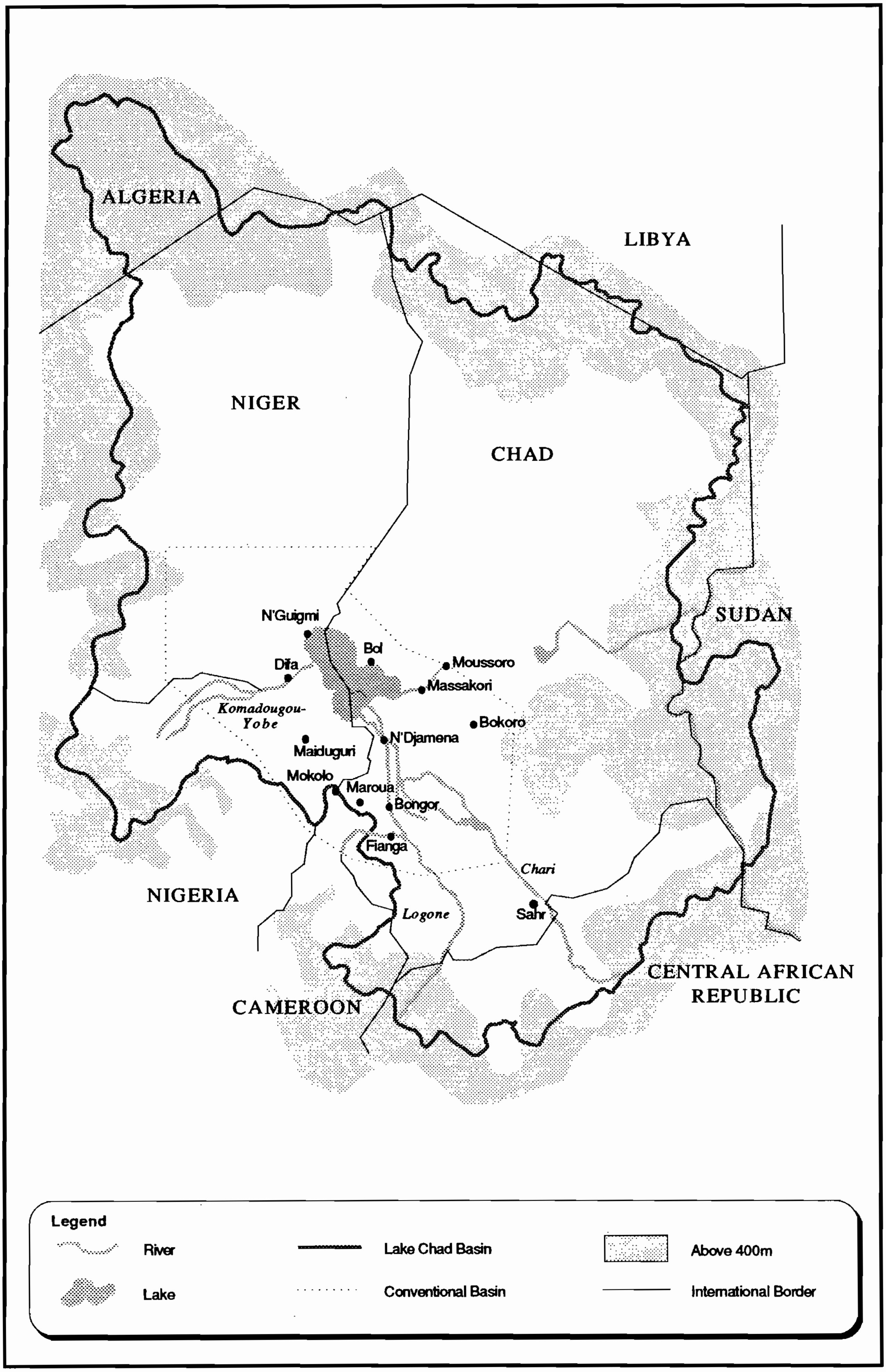
Figure 3.2

Lake Chad Conventional Basin



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Manantali Dam on the Bafing in Mali and the Diama Barrage in the estuary, see Section 2.3.5. The funding arranged by the OMVS for these two projects amounted to some US$ 62 million, of which US$ 51 million was for Manantali (1989 prices).

The executive of the organisation is constituted by the High Commission assisted by a General Secretariat. There are three departments: Regional Infrastructure, Development and Coordination, and Investment and Debt. Operational activities are presently organised by a provisional Management Unit which is directly under the High Commission. It is planned that this structure will evolve into a management agency which will be a semi-public organisation. The principal tasks of this agency will be:

- management of water resources;
- operation of the communal control structures (the dams);
- supervision of water users.

The OMVS has a documentation centre in St Louis which since 1970 has collected all information concerning the river.

The future of the OMVS is dependent on the political relationships between members. In recent months relations between Mauritania and Senegal have been strained and the short term prospects are not encouraging in this regard.

3.2.4 Organisation de Mise en Valeur du Fleuve Gambie (OMVG) (Gambia River Development Organisation)

The OMVG was originally set up by Senegal and The Gambia in 1978 in Dakar. Subsequently Guinea joined in 1980 and Guinea Bissau in 1983. Guinea Bissau contains only 0.02% of the Gambia catchment. The OMVG does not confine its concerns solely to development within the Gambia River basin and will sponsor studies on other basins within the member states.

The organisation is presently (early 1992) undergoing restructuring. The posts of High Commissioner and Executive Secretary have been merged and the number of departments reduced to three: Infrastructure, Studies and Planning; Agriculture; and Administration and Finances.

Developments on the Gambia River and studies planned under the auspices of the OMVG include:

- A barrage at Kekreti on the Gambia River which would allow the irrigation of 70 000 ha (55 000 ha in The Gambia and 15 000 ha in Senegal) and the generation of 157 G.Wh of hydropower per annum. This study will be included in a master planning exercise for the river for which UNDP funding is expected.

- A road bridge over the Gambia on the Nouadhibou-Legos coastal route.

- A study of the market for energy in member countries in order to schedule studies and the realisation of schemes at Kekreti, Kouya and Saltinho (on the Corubal in Guinea Bissau).

- Strengthening of baseline studies on the resource and the problems of the environment for the definition of master plans for the Kayanga Geba and the Koliba-Corubal. The African Development Bank will fund these projects up to US$ 2.4 million.

- The barrage/road crossing at Balhingo on the Gambia does not have a high priority because of the ecological consequences and the negative effect on the traditional method of cultivation which makes use of the fresh water above the saline tidal flow.

3.2.5 Mano River Union

The Mano River Union was founded in 1973 by Liberia and Sierra Leone; Guinea joined in 1980. Its headquarters are in Freetown. At present the organisation is under severe financial pressure as, in addition to arrears from some of its members, the difficulties in Liberia have resulted in no payments being received from that country.

In the field of river basin management its main achievements are the Mano River Basin Development Project, whose reports were published in 1981, and the evaluation of small hydropower sites in each of the three countries in 1987. An inter-state committee was set up to co-ordinate development activities including that of a proposed hydropower development on the Mano River.

3.2.6 Comité Inter-états de Lutte contre la Sécheresse dans le Sahel (CILSS) (Inter-state Committee to Combat Drought in the Sahel).

Following the semi-permanent drought condition which afflicted the Sahel region of West Africa from 1969 on, and which was particularly severe during the poor rainy seasons of 1972 and 1973, six countries decided to create a permanent committee to combat the drought in the region. These countries were Burkina Faso, Chad, Mali, Mauritania, Niger and Senegal. Other countries have joined subsequently: The Gambia (1974), Cape Verde Islands (1975), and Guinea Bissau (1986). The headquarters of the organisation are in Ouagadougou, Burkina Faso.

The organisation's supreme governing body is its Conference of Heads of State. Under this body comes the Council of Ministers which works in co-operation with the Club du Sahel. Beneath this come other specific organs which include the Consultative Co-ordinating Committee, the Executing Agencies, the Secretariat, the Executive Committee and the Counsel for Training and Science.

The operational funds come mainly from the member countries, with studies and special activities being financed by a wide range of donors. Donors include UNDP, and the governments of Belgium, France, the Netherlands, Switzerland and the USA. The activities of the donors have been co-ordinated with the assistance of the WMO.

An early aim of CILSS was to initiate studies concerning hydrometeorology, agroclimatology and meteorology. It also proposed the creation of a regional centre for training, undertaking studies in agroclimatology to reduce crop failure and experiments in rainfall augmentation. This led to the creation of the AGRHYMET programme and centre described in Section 3.3.1. The word AGRHYMET is formed of the three words AGRiculture, HYdrology and METeorology. In addition to activities carried out at the regional centre in Niamey other projects are carried out in individual countries under the auspices of AGRHYMET.

3.2.7 Comité Inter-africaine d'études Hydrauliques (CIEH) Inter African Committee for Hydraulic Studies

This organisation was founded in March 1960 in Niamey, Niger. It now has 14 member countries: Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, Gabon, Guinea, Guinea Bissau, Mali, Mauritania, Niger, Senegal and Togo. The headquarters are in Ouagadougou, Burkina Faso. Its objective is to promote regional co-operation in water resources by undertaking studies and making their results widely available. To achieve its aim of improving research into, and management of, water resources its programme of activities includes:

- studies of general interest or into special methods;
- technical support to member states if requested;
- making available knowledge and experience;
- training and distribution of information.

The CIEH is governed by its Ministerial Council which meets every two years in each of the member states by rotation. It reviews activities during the preceding two years and agrees the programme and budget for the coming two years. The operational budget comes from contributions of the member countries. The capital budget comes in part from member states but also from international aid.

The main areas of competence of the CIEH are in the fields of hydrology, hydrogeology, agroclimatology, urban and rural water supply, irrigation, water treatment, renewable energy, water law and regulation, and computing. It has a documentation centre, has undertaken more than 200 studies, and publishes a quarterly bulletin of which 1 000 copies are distributed.

The organisation has received the support of a several bilateral and multilateral donors and has worked with a number of regional and international organisations with an interest in its fields of study.

3.2.8 ORSTOM

The role of ORSTOM (a French institute for scientific research related to development) in the development of hydrometry in the francophone countries of the region must be mentioned when regional collaboration is under discussion. Hydrometric agencies in these countries share a degree of standardisation in organisational structures and methods of data management which are the common legacy of technical assistance by ORSTOM. This homogeneity has facilitated international collaboration on water resources within the francophone grouping.

From 1946 ORSTOM was directly responsible for the operation of hydrometric networks in all the francophone countries. Today each country is responsible for its own networks, but as shown in Table 3.1 many still receive significant assistance from ORSTOM. The direct management role of ORSTOM ended at different times in different countries, the most recent hand over being in Togo and Benin during the course of this assessment project.

TABLE 3.1

ORSTOM Presence in the Region - March 1992

Country	Engineers	Hydrometrists
Mali	2	1
Niger	9	4
Senegal	5	4
Guinea	1	
Côte d'Ivoire	2	1
Burkina Faso	1	1
Cameroon	1	
Central African Rep.	2	1
Congo	1	2
Total	24	14

ORSTOM introduced computerised processing in the francophone countries in the mid 1980s with their own PC compatible package - HYDROM. This package performs all the basic data entry and handling necessary for hydrometric data: entry of digitised graphical records, entry of flow gaugings, manual entry and checking of water levels at variable time intervals, calculation of discharges, annual summaries, inventory of available data. Hydrological data for all the francophone countries has been computerised by ORSTOM (see Section 6.1) using this system for the period from a station's inception until the start of the 1980s, and in a number of countries the data in this format is right up to date (eg Senegal, Congo).

The package is under continuing development by ORSTOM to adapt to new data collection technologies. The package is able to interface directly with telemetry systems based on the ARGOS and METEOSAT satellites a feature which is exploited in the national agencies in Benin and Guinea. The package has been introduced in other parts of the world and is available in languages other than French.

ORSTOM's introduction of this computerised data management system in the region has been part of a long term technical support programme to the national agencies in the francophone countries. In addition to regular short training courses in the use of the package held in France sustained on-the-job training was also given by ORSTOM staff in country. Support to users has therefore been far stronger than in the WMO CLICOM programme discussed below.

3.3 Regional Programmes and Support Projects

3.3.1 AGRHYMET

The AGRHYMET programme and centre were established as a means to achieve many of the central aims of CILSS. That is, to develop techniques whereby a study of the interaction of meteorology, hydrology and agriculture could lead to improved crop yields in the climatic conditions experienced in the Sahelian countries.

A joint mission conducted by the UNDP, WMO, and FAO in 1974 defined in detail the needs of the seven members and a programme of reinforcement of their agroclimatologic and hydrologic services was prepared. This led to the creation of the AGRHYMET centre in Niamey.

A building was constructed for the AGRHYMET programme on its own plot in Niamey. The buildings include a computer centre, library, classrooms, student accommodation and offices. At this centre courses are presented leading to the award of recognised qualifications. The centre also has its own experimental farm.

The programme has passed through a number of phases and its third phase is coming to an end in 1991. The main objectives of the third phase were to:

- Develop and put into practice observational and data collection techniques for agrometeorology and hydrology necessary for the monitoring of the weather, surface water, crops and livestock; including analysis and storage of these data at the centre and in each country and make the data available to users on demand;

- Contribute to the operation of an early warning system at a national, regional and global level (the GIEWS of the FAO, see Figure 3.3) by supplying information and meteorological, agrometeorological and hydrological forecasts;

- Contribute to the national and regional efforts to increase agricultural production by the development, evaluation and improvement of methods which integrate information on agrometeorology and hydrology with the existing agricultural production system;

- Follow up the strengthening of the national centres concerned with AGRHYMET in order to allow a progressive increase of responsibility by Sahelian staff over an outline 10 year programme.

The programme comes under the general management of the Counsel of Ministers of CILSS. There are two main committees (an executive committee and a consultative committee for co-ordination) which oversee more closely the activities of the programme, in particular to ensure effective co-operation between different funding agencies.

The executive committee is formed of three representatives from each member country (usually the heads of the meteorological, agricultural and hydrological services) and representatives of international organisations closely involved in the programme. The committee meets at least once a year. Its main functions are to:

(i) define the participation of the member countries in the execution of the programme;
(ii) provide overall co-ordination;
(iii) study scientific and technical proposals and recommend the objectives, orientation and future extension of the programme;
(iv) ensure that financial and counterpart contributions are available as required, and that buildings and equipment provided to meet the needs;
(v) examine the additional resources required by the programme and put forward proposals to the consultative co-ordinating committee.

Other duties include examining reports on project activities, examining the budget, proposing modifications to the budget and giving other relevant advice.

The consultative co-ordinating committee has representatives from the UNDP, UN specialised agencies involved in the execution of the programme, and of other donor countries. The committee meets once a year. The functions of this committee are:

(i) act as co-ordinator for all international contributions to the programme,
(ii) advise on the financial procedures for the management of the funds,
(iii) examine reports submitted on the activities of the programme,
(iv) examine reports submitted on the financial situation,
(v) examine reports from the WMO on the execution of the programme,
(vi) examine the action plan and budgets prepared by the WMO,
(vii) consider all other matters relevant to the execution and funding of the programme,
(viii) examine proposals for additional financing.

The main contributors to the programme during its third phase have been the members of CILSS and UNDP and Belgium, France, Italy, the Netherlands, Switzerland, and the USA.

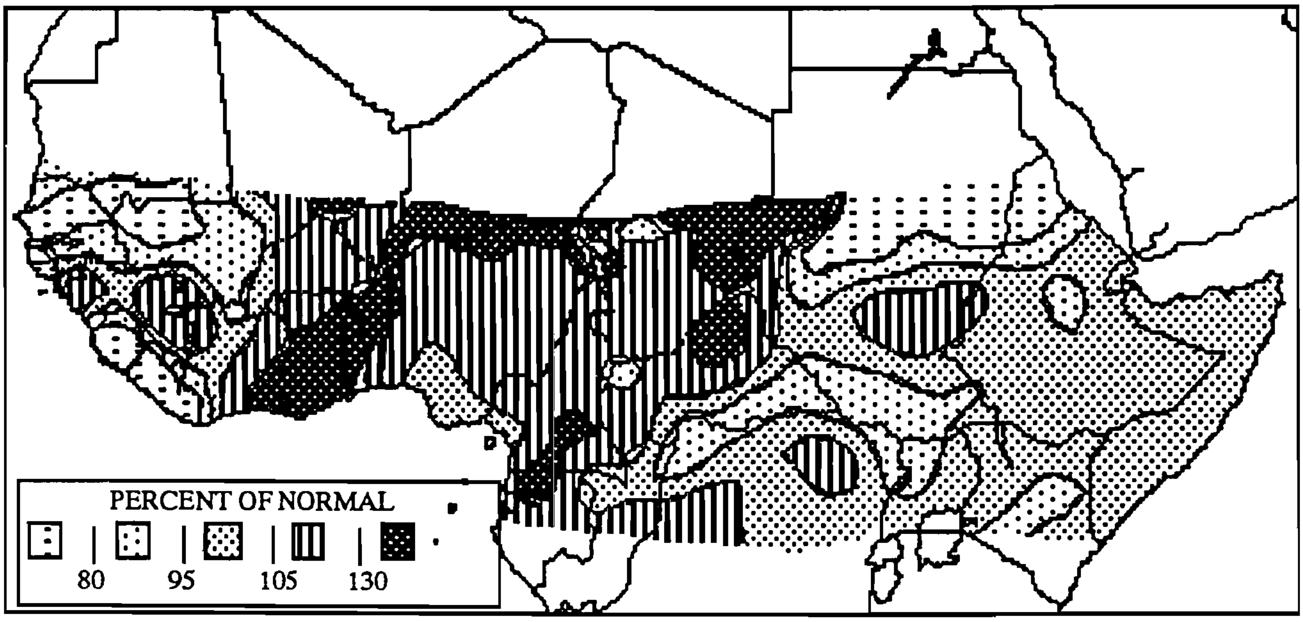
At a regional level the recent activities have included:

- micro-filming, entering to computer and quality control of historical hydrological and climatological data: data processing software: collection and processing of 10-daily data: publication of 10-daily, monthly and annual reports on the agricultural season. Completion of a climatic atlas;

GROWING CONDITIONS BASED ON AGROMETEOROLOGICAL ASSESSMENT AS OF 16 SEPTEMBER 1991

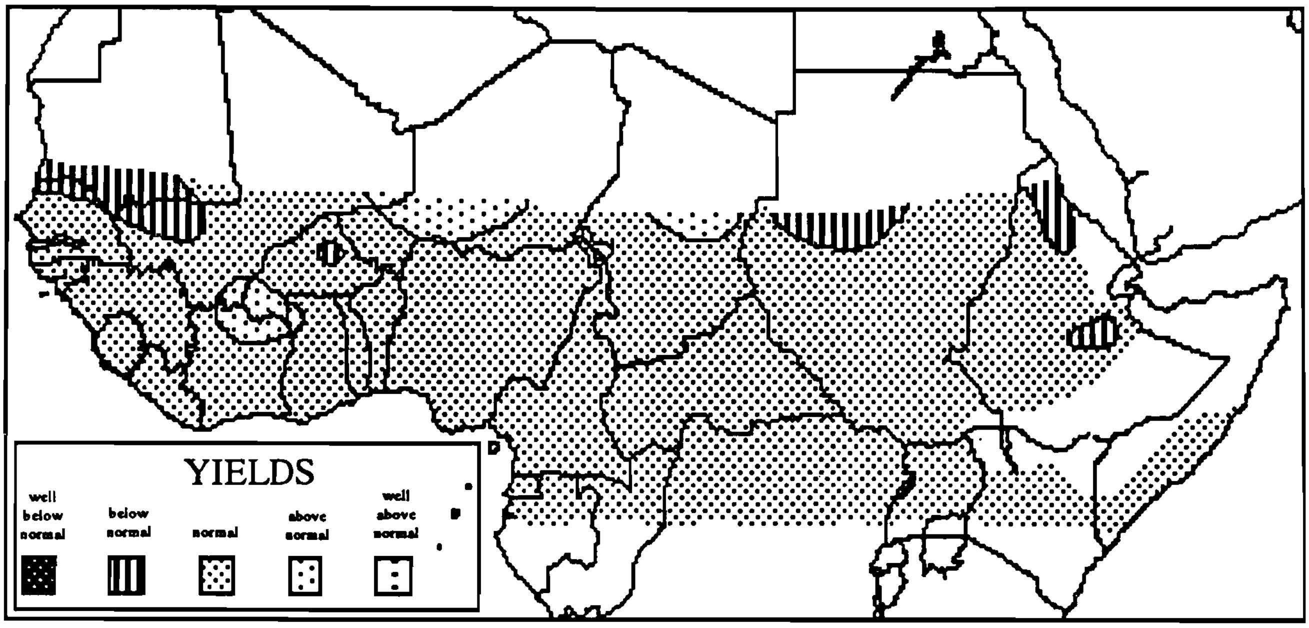
WESTERN AFRICA

CUMULATIVE RAINFALL



(Cumulative rainfall from the beginning of the rainy season to 16 September)

GROWING CONDITIONS *



(Growing conditions refer to the yield in relation to normal, assuming normal weather for the remainder of the season when the latter is not over)

* Using millet and sorghum as reference crops

- supplying relevant organisations with data as part of the early warning system to improve the estimation of crop yields: improving the system of crop monitoring at a national level: test and adaptation of agrometeorological models;

- supplying advice on agricultural activities in the 10-daily bulletins: preparing technical manuals: advising on the setting up of pilot projects;

- the completed training of 10 hydrological engineers, 9 agrometeorological engineers, 15 senior technicians in hydrology, 15 senior technicians in agrometeorology and 15 senior technicians in instruments: currently the training of 12 hydrological engineers (class 2) and 8 agrometeorological engineers (class 2): organisation of 7 seminars.

At a national level the main activities that have been undertaken are given in Table 3.2.

TABLE 3.2

National Activities - AGRHYMET Phase 3

Country	Activities
Burkina Faso	Training of staff, organisation of two seminars, data processing, publication of national bulletins, assistance to farmers.
Cape Verde	Training of staff, installation of 7 climatological stations, 4 hydrological stations and 100 raingauges.
Chad	Training of staff, installation of 9 new agrometeorological stations, 2 climatological stations, 9 raingauges and 5 hydrological stations, running of existing network, data processing, publication of bulletins, distribution of information to users.
The Gambia	Training of staff, maintenance and operation of its network of hydrological and agrometeorological stations, publication of bulletins, distribution of information to users.
Guinea Bissau	Training of staff, installation of an agrometeorological observation network.
Mali	Training of staff, installation of 2 new agrometeorological stations, data processing, publication of bulletins, distribution of information to users.
Mauritania	Training of staff, running of existing network, data processing, publication of bulletins, distribution of information to users.
Niger	Training of staff, installation of 2 new agrometeorological stations, 5 climatological stations, 15 raingauges, 70 agricultural monitoring stations and 8 hydrological stations, running of existing network, data processing, publication of bulletins, distribution of information to users.
Senegal	Training of staff, installation of 3 new agrometeorological stations, running of existing network, data processing, publication of bulletins, distribution of information to users.

Pilot projects in Burkina Faso, Mali, Niger and Senegal led to significant increase in crop yield which varied from 12% to 300% with considerable variations from crop to crop and country to country.

It is planned that the programme will move into a fourth phase with increasing reliance being placed on Sahelian staff and a corresponding reduction in reliance on staff and funds from outside of the region.

3.3.2 HYDRONIGER

HYDRONIGER is a project of the Niger Basin Authority. It is a successor to an earlier project which, following floods in 1967, established a flood warning network in Guinea and Mali. That project executed by the WMO demonstrated the feasibility of such a network, however the technology used, single side band short wave radio with voice communication, did not lend itself to a rapid response for flood forecasting.

The HYDRONIGER project started in 1979 and funding was obtained from the UNDP, EDF and the OPEC Special Development Fund. An initial evaluation of the size of network required to forecast flows for the whole of the Niger river basin had proposed that 98 station be installed. However, for financial reasons, this was reduced to 65 stations. Installation of these stations commenced in 1983 with two teams from the centre in Niamey visiting the member countries and working with them. To enable the installations to be completed within the programme a firm of consulting engineers was used for the installations in Nigeria. The installations were completed in 1986. By 1987 the project also had forecasting models from three sources: a firm of consulting engineers who had prepared models under contract to the WMO, ORSTOM, and the project staff. Using these models enabled forecasts to be made for the whole basin.

The data transmission was based on the use of the ARGOS satellite system. Under this system there are two polar orbiting satellites which are 60° out of phase. This allows a station near the equator to transmit data at intervals of approximately every 8 hours, the interval diminishing with increasing latitude. Buildings were constructed in Niamey for the International Forecasting Centre, and also for a National Forecasting Centre in each of the participating countries. Each of the national centres also has its own receiving station.

In 1988 a second phase started which was intended to consolidate the work of the first phase. Activities planned for this phase were the improved calibration of the models to the whole basin and the regular dissemination of forecasts. Partly as a result of delays in payment of funds many of these objectives have not been attained.

At present the future of the project is insecure. It is hoped that the financial benefits of the flow forecasts may lead to direct contributions from interested parties, eg the navigation authority in Mali, or that other donors may be willing to contribute to future funding.

3.3.3 Onchocerciasis Control Programme

The Onchocerciasis Control Programme (OCP), which has been active in the region since 1974, is a project funded by the WHO, day to day management of the project is based in Ouagadougou.

Onchocerciasis, commonly known as 'river blindness' is endemic in much of West Africa. The steep sections so prevalent on the region's rivers provide the ideal environment for the larvae of the

Simuliidae (black flies) some species of which are vectors of the Onchocerciasis worm which causes river blindness. Onchocerciasis affects 15 to 20 million people in the region.

One of the strategies in the struggle to control the disease is to break the chain of transmission by attacking the insect vector at its breeding sites, this has been achieved by a regular weekly programme of chemical treatment. Treatment teams move from site to site by helicopter carrying the necessary chemicals. The dosage required is dependent on the discharge in the river at the time of treatment which has led to the OCP's interest in hydrometry.

As national hydrometric agencies were generally unable to supply discharge data to the OCP at the desired sites the OCP began to provide financial and technical assistance for hydrometry. The OCP has now built up a dedicated network of monitoring stations and field teams covering nine countries. This effort has been organised by ORSTOM under contract. Much of the network now consists of the latest generation of sensors and telemetry equipment (replacing staff gauges and autographic recorders) and as such is of interest to hydrometrists in the national services in the region. Two centres, at Odiénné in Côte d'Ivoire and Lama-Kara in Togo, receive the satellite transmissions of water levels. Rating curves necessary to turn this data into flow values are kept up to date by OCP funded staff from national hydrometric agencies or OCP field teams supported by ORSTOM. The degree of involvement of the OCP in national hydrometric services varies from country to country, in the most extreme example (Sierra Leone) the only active gauging stations in the country are those of the OCP.

The key point with regard to the OCPs hydrometric activities is that they are merely a means to an end - a more efficient chemical dosing programme - not an end in themselves. The WHO expect the OCP to continue until the year 2000, however, with new methods of counteracting the disease always being sought and a prophylactic treatment already tested in Ghana, it is possible that the programme's hydrometric activities may not have such an assured future.

3.3.4 CLICOM

The CLICOM project is implemented under the World Climate Data Programme of the WMO. It is a concerted effort to improve standard climate data management and user services of meteorological departments. The project was targeted initially for developing countries where meteorological services had little or no computing facilities. For such countries the standard 'CLICOM' package consists of micro-computer hardware, software and training. The software was developed in the USA as part of that country's assistance to the WMO under its Voluntary Co-operation Programme. It provides a range of facilities for entering and retrieving climatological data.

The CLICOM software consists of a set of commercial packages integrated with specially written programs. The main commercial software package is a database package called DataEase. Though powerful, this package is easy both to use and to tailor for specific applications. The specially written software provides a climatic database structure together with tailored menus within DataEase, plus a large number of FORTRAN programs. It is available with the menus in French and in Spanish. The

FORTRAN programs are partly to provide data entry and quality control and partly to allow summaries to be provided. The CLICOM software also provides 'hooks' to enable applications software to be connected to CLICOM. The software runs on PC compatible equipment. It requires a reasonably powerful machine with a large amount of disk storage.

The database is designed to manage seven distinct types of climatological data, namely monthly, 10-day, daily, synoptic (eg three hourly), hourly, 15 minute and upper air soundings. The data base also keeps extensive station history information. The package includes facilities for quality control and for report printing.

CLICOM is still a very active project of the WMO. It has now been installed in 95 countries worldwide of which 19 are in the West African region. It is clear that the CLICOM system constitutes the most credible world standard for processing and management of climatological data and everything should be done to ensure that it is effectively utilised in West Africa. During our assessment visits it was apparent that the software was not being used to its full potential for a variety of reasons, the operational performance of the system in the region is discussed in Chapter 6.

3.3.5 DARE (DAta REscue)

The DARE project has had two distinct phases. The first - called Data Bank - was concerned with the CILSS countries only. In this project an effort was made to collect all meteorological and hydrological data for all the member countries. As a result of the interest that this generated they have started to carry out similar data collection for the rest of Africa. This second project, referred to as DARE, started in 1988.

The project works closely with the WMO, who help by contacting the participating countries and providing feed-back where this is possible. The total budget is 14 million Belgian Francs per year. This money is used to finance project over-heads and administration, handling of micro-film and micro-fiches and data entry. It also covers the costs of visits to the countries to collect data. In general the project will carry out two overseas assignments a year. The project operates as a branch of the Royal Belgian Meteorological Service called the International Data Collection Centre. A contribution of 14% of the budget is given to the WMO for their help and administrative costs. UNEP have funded the purchase of micro-filming equipment for installation in each participating country.

The normal way of operating is to make a reconnaissance visit to evaluate how much data there is. In general only the written records in the meteorological service's offices are copied. A second visit is made to film as much data as possible. During this visit the DARE team will have their own equipment and the local service will also have its own equipment and will work in parallel - in the same room if at all possible. It is DARE policy not to film everything during this visit but to leave the local service to complete or update the recording. A further visit will normally be made to ensure that all possible data has been collected.

When the project team visits a country everything is copied using micro-film in whatever order best suits the local meteorological service. This is then taken back to Belgium for development. A copy of the micro-film is made. This is used to make a micro-fiche. The micro-fiche has the data re-organised into a more logical order. A copy of the micro-fiche is sent to the country. In the case of the CILSS countries the data for all climate stations was entered into computer compatible form, if a station started as a rainfall station then became a climate station its data was entered - but not if it was only a rainfall station. For the other countries data has only been entered for one representative station every 250 000 km^2, or in the case of a small country of less than this size for at least one station. There is often a difficulty in choosing these representative stations.

The data is quality controlled. All the data is stored in ASCII format, ultimately on magnetic tapes. There has been a lot of discussion about this - both within their own organisation and with other people who take an interest in their system. They have resisted pressure to put all the data into a database as their aim is to record data for posterity and they are afraid that data stored in what is now the latest database format will be unreadable in very few years time.

CHAPTER 4

METHOD OF ASSESSMENT OF DATA COLLECTION SYSTEMS

4.1 Evaluation Framework

4.1.1 Introduction

The selection of criteria against which to evaluate the current data collection networks and data processing systems is clearly a key issue in an assessment of this type involving many countries. The data systems within each country have evolved slowly and have usually been closely matched to available development budgets and general socio-economic progress. The application of a set of standard criteria against which to judge this individual process is a crude method of evaluation and not a measure of definite progress towards the goal of better processing systems. Nevertheless, the use of an objective set of criteria forms a valuable basis for further, less systematic work of identifying gaps within the present system and ways in which the system could be improved.

The most comprehensive, objective, measure of hydrologic data systems is provided by the publication of UNESCO and the WMO, 'Water Resource Assessment Activities: Handbook for National Evaluation' (1988). This document provides the framework within which the networks and processing systems of individual countries can be measured against 'world' norms and thus allow the highlighting of areas where the systems may be deficient or over-elaborate.

However with the emphasis in the present study squarely on ensuring that adequate data is available for future resource planning, data systems within each country should be measured relative to the present and likely future data needs and the nation's ability to support the financial and manpower burden of the systems. There will be a need to assess the networks at scales other than the national, as there will always be zones within each country where there is a greater need for hydrological data, and where resources are shared between countries it may be desirable to assess networks and data availability for an entire river basin encompassing more than one country. Consequently, in addition to the evaluation methods and criteria suggested in the UNESCO/WMO publication, a more subjective and more detailed evaluation was conducted to analyse the future needs, with particular reference to the likely future data requirements within identified water development projects. Further comparisons (for example the comparison of budgets of hydrological services and likely expenditure on water development projects) were made to refine the analysis where this information has been made available. The more detailed analyses conducted were all geared towards identifying a reasonable development programme for the hydrological services over the next ten to fifteen years.

4.1.2 The UNESCO/WMO Guidelines

These guidelines were developed primarily to assess the ability of hydrological networks to provide information for water resource assessment activities, which represents only one aspect of the many uses to which hydrological data are put. Nevertheless, it is frequently the regionalised water resource assessment study that makes the greatest demands of a hydrological database, and consequently the review of data collection, processing and storage systems with a view to providing this type of data remains a valid exercise. However, it should be borne in mind that other uses of hydrologic data, such as a review of flood control measures, can make the type of demands on a data system that have not been included in the UNESCO/WMO guidelines.

Nevertheless, the document provides a very useful, objective measure of the minimum acceptable levels of activity in the following important areas:

- activities to be undertaken;
- network densities;
- provision of workshop facilities;
- quantity of equipment available;
- staffing;
- methods of data storage.

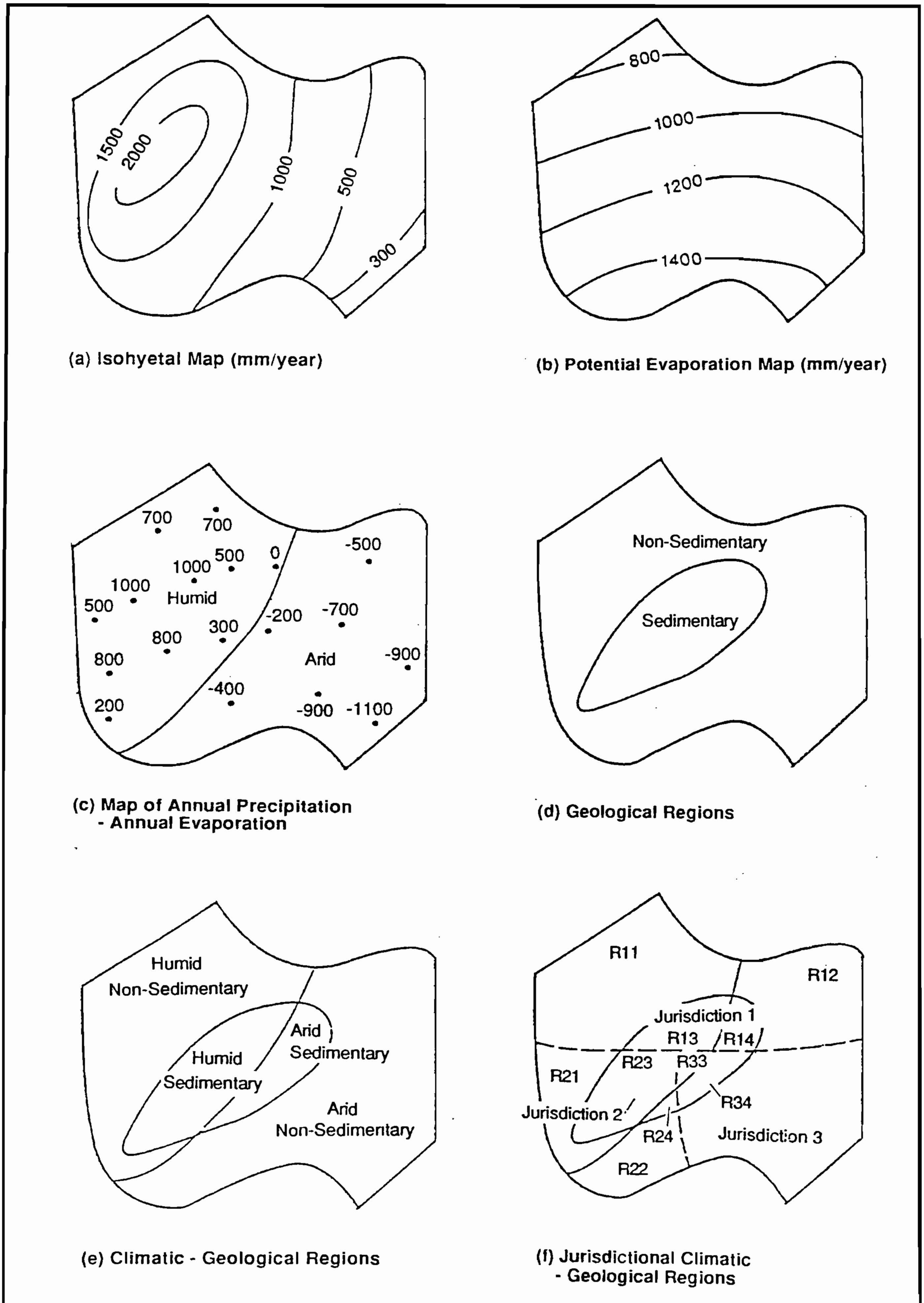
The recommended 'activity levels' in the above fields depend on climate, geology, and whether the location is in a temperate or tropical region. The classification system adopted is extremely simple. Two climate categories are identified depending on the balance of mean potential evaporation and mean rainfall on an annual basis. The terminology is perhaps rather unfortunate, the categories being referred to as 'arid' and 'humid', with the arid category applying when annual rainfall is less than evaporation. Thus in Ghana, not usually thought of as arid, 79% of the country falls into the arid category. Geological sub-division is made into 'sedimentary' and 'non-sedimentary' regions. In the West African region where ancient non-sedimentary Basement Complex is widespread, the deeply weathered nature of many of these rocks means that they do not necessarily display typical hydrological properties of non-sedimentary rocks, for example, zones in the Basement Complex may hold significant groundwater. Figure 4.1 shows how a country may be regionalised in order to assess hydrological data collection activities, with Table 4.1 showing minimum recommended activity levels for some of the more important evaluation elements.

Returning to the example of Ghana, strict adherence to the classification system leads to all four categories being represented within the country, and for the area in several categories to be made up of a number of sub-areas. This situation makes it virtually impossible to assess levels of staffing since staff are based in headquarters and a few regional offices whose administrative boundaries are in no way related to the categories in the UNESCO/WMO system.

The guidelines are also of limited use when assessing the needs of small countries, particularly the case of countries consisting of a number of small islands, such as the republics of Cape Verde and Equatorial Guinea, and São Tomé and Príncipe.

Figure 4.1

Steps in Regionalization for Hydrological Assessment



Source: UNESCO/WMO, 1988

07171/19/8

TABLE 4.1

Minimum Recommended Activity Levels for Principal Hydrological Data Collection Activities (after UNESCO/WMO, 1988)

Element	Tropical			
	Arid		Humid	
	S	N	S	N
Precipitation Stations: non-recording (number per 10^4 km^2)	6	6	20	40
Precipitation Stations: recording (number per 10^4 km^2)	1.5	1	2	2
Evaporation Stations (number per 10^5 km^2)	3	3	3	2
Surface water level stations: non-recording (number per 10^4 km^2)	1.2	2.4	12	24
Surface water level stations: recording (number per 10^4 km^2)	0.6	1	1	1
River discharge stations (number per 10^4 km^2)	1	2	10	20
Sediment discharge stations (number per 10^4 km^2)	0.7	0.4	5	3
Water quality of surface water (number per 10^4 km^2)	0.7	0.4	5	3
Groundwater level stations: non-recording (number per 10^4 km^2)	5	2	2	0.5
Groundwater level stations: recording (number per 10^5 km^2)	2	1	2	1
Groundwater quality stations (number per 10^5 km^2)	5	3	5	3
Repair and maintenance shops for meteorological equipment (number per 200 precipitation stations)	2	2	1	1
Current meters (number per 10 discharge stations)	2	2	1	1
Rating facilities for current meters (number per 200 current meters)	2	2	1	1
Repair and maintenance shops for hydrological equipment (number per 200 discharge stations)	2	2	1	1
Water sediment laboratories (number per 100 sediment stations)	5	5	3	3
Water quality laboratories (number per 100 water quality stations)	5	5	3	3
Inspectors of meteorological stations (number per 100 precipitation stations)	10	10	5	5
Hydrological field teams (2 to 3 persons) (number per 10 discharge stations)	2	2	1	1
Special survey teams surface water (3 to 4 persons) (number per 10^5 km^2)	2	2	1	1
Special survey teams groundwater (3 to 4 persons) (number per 10^5 km^2)	6	3	4	2
Superstructure staff meteorology (number per 100 precipitation stations)	3	3	3	3
Superstructure staff surface water (number per 100 river discharge stations)	4	4	4	4
Superstructure staff groundwater (number per 100 monitoring stations)	4	4	4	4

Notes: S = sedimentary N = non sedimentary

4.2 Compilation of Inventories

4.2.1 Station Inventories

Inventories have been compiled of the following parameters:

- daily rainfall;
- climate including evaporation;
- water level;
- flow gauging;
- sediment (where regular monitoring exists);
- water quality (where regular monitoring exists);
- groundwater levels (where regular monitoring exists).

Data to be included in the inventory was originally planned to encompass station location (river catchment, latitude, longitude, altitude), the type of equipment, operational characteristics, and an indication of the period for which data are available. It has not always been possible to include this information as intended, as all too frequently it could not be collected in the time available, or the information (particularly on temporal gaps) was simply not available in the agency headquarters. Computer compatible data sources were sought wherever possible, but this could only be managed in some agencies. Official publications giving station inventories were of limited value, as they were rarely up-to-date or comprehensive. The most reliable technique to obtain information, especially on data availability, was to go through station files in the data processing offices - a very time consuming task which could only be done whenever sufficient counterpart staff were available for this laborious work. Otherwise, the information was collated from computer printouts and publications supplied, updated and cross-checked from other sources such as yearbooks, engineering reports, master plan studies and agency files.

Station inventories have been reproduced in the country reports, the numbers of stations are summarised in Tables 4.2 and 4.3.

4.2.2 Bibliographies

Bibliographies were compiled for each country, two categories of document were included - firstly those collected and used for the study, and secondly those identified as being generally relevant and useful for workers in the hydrological sciences within the region. The documents within the second category have not all been located and examined: often they have been referred to in documents consulted and the reference has been reproduced. The two categories overlapped to a large degree, but the former contained documents of general background information to the countries of the region (such as national development plans, published establishment registers and expenditure estimates) while the latter contained many more documents of a hydrological nature. It was decided that the degree of overlap was such that a single bibliography should be appended to each country report.

TABLE 4.2

Numbers of Climate Stations Currently Operational

Country	Daily Rain Gauges	Auto-graphic Rain Gauges	Tele-metry Stations	Synoptic Stations	Agro-met Stations	Climate Stations
Mauritania	79	0	0	13	13	0
Mali	201	?	0	22	9	41
Niger	282	12	0	14	7	22
Chad	214	>16	0	16	19	16
Senegal	180	>12	?	12	7	11
The Gambia	33	1	0	11	16	0
Guinea Bissau	81	10	0	10	5	5
Guinea	150	27	0	12	15	0
Sierra Leone	24	7	0	7	10	1
Liberia						
Côte d'Ivoire	200	43	0	14	29	6
Burkina Faso	>137	27	0	9	>18	12
Ghana	222	20	0	22	36	56
Togo	91	25	0	9	0	18
Benin	54	10	0	6	15	0
Nigeria	>368	?	0	47	46	0
Cameroon	300	?	0	20	1	21
Central Afr Rep	105	>15	0	14	5	5
Equatorial Guinea	2	0	0	2	0	0
Gabon	109	>14	0	14	5	5
Congo	217	>14	0	13	4	7
Cape Verde	248	12	0	3	11	0
São Tomé & Príncipe	31	0	0	2	0	21

Notes: Numbers operational at the time of the Consultants' visit.
Numbers of raingauges include those at the three categories of meteorological station.
Agro-meteorological stations are defined as having sufficient data for the calculation of Penman Evaporation.

TABLE 4.3

Numbers of Hydrometric Stations Currently Operational

Country	Staff Gauges	Auto-graphic Level Gauges	Solid State Level Stations	Tele-metry Stations	Rated Stations ie Flow	Reservoir Sites
Mauritania	0	0	1	1	0	?
Mali	69	0	20	20	49	?
Niger	42	0	9	9	28	0
Chad	44	11	0	0	35	?
Senegal	25	31	3	3	36	3?
The Gambia	17	8	0	0	3	0
Guinea Bissau	14	0	0	0	5	0
Guinea	39	0	29	29	0	1
Sierra Leone	24	0	0	0	24	1
Liberia						
Côte d'Ivoire	108	28	22	22	?	84
Burkina Faso	105	60	6	5	60	11 ?
Ghana	73	35	0	0	94	1 ?
Togo	26	10	11?	11	42	2
Benin	2	8	?	23	28	0
Nigeria	>500	?	?	18	?	?
Cameroon	42	19	?	5	?	?
Central Afr Rep	45	11	0	0	33	1?
Equatorial Guinea	0	0	0	0	0	0
Gabon	10	0	0	0	10	3
Congo	51	4	?	1	?	?
Cape Verde	0	8	0	0	6	0
São Tomé & Príncipe	9	9	0	0	9	0

Notes: Numbers operational at the time of the Consultants' visit.
Staff gauge numbers do not include those installed as backup to an automatic recorder.

4.3 Identification of Data Requirements

Fundamental to any assessment of hydrological networks is consideration of the purposes for which the data will be used. Figure 4.2 indicates some of the areas in which hydrological data are used, and the relative importance of the data. The route from such theoretical considerations to a practical task, such as the definition of where more gauges should be installed, is long and complicated, being very dependent upon local circumstances, budgets, organisations and hydrological behaviour.

A practical approach to determining data requirements is to work from identified likely future water development projects and an analysis of what data these are likely to require. This approach has been adopted in the present study.

In many cases, water development schemes will be small, low-key abstractions for rural water supply or small-scale irrigation, not individually warranting a detailed resource evaluation study. In such circumstances, a regional analysis of resources would be required including, ideally, a methodology for rapidly computing resources in ungauged streams or unmonitored aquifers. This requirement is often the most demanding of a hydrological database, needing a sufficient spatial density of reliable data-points to accurately and reliably reflect the full range of catchment types within the country, especially the resource deficient areas.

A further problem is the need to assess the requirement for extensive time series data in the medium term and long term future, and the consequent need to lay the foundations for such a data collection programme now. In some instances it is easy to identify critical data collection points, for example key hydro-power development sites that will need to be exploited in the fullness of time. There will also be a need to maintain an accurate and complete data series for the major climatological and hydrometric stations as a monitor of long term climatic trends and fluctuations. The devastating consequences of the Sahel drought in the West African region have already focused attention on trends in climatic data, the implications for the region of the latest thinking on global warming is also an issue to be considered.

In some countries a major influence upon the stream flows monitored is the operation of abstraction and storage schemes upstream of the data collection point. In order to maintain an homogenous data series in time, any changes in the operation of such influences over time need to be documented, and allowed for in the computation of 'naturalised' flow sequences. Documentation to allow such naturalisation calculations is sometimes extensive, effectively multiplying the data collection effort needed for a single sampling point. Such additional work is often neglected, but becomes increasingly important as competition for resources grows.

Data on water quality is increasingly recognised as important to ensure that potable water sources meet WHO standards, to identify pollutants, and as part of erosion control studies. This data is not at present collected on a systematic basis in the region and efforts must be made to introduce such monitoring. However, such monitoring requires proper laboratory facilities and trained staff in addition to the demands of field data collection it is therefore vital to design realistic, possibly staged, monitoring programmes to keep within the agencies' likely budgets.

4.4 Identification of Gaps in Data

4.4.1 Temporal Gaps

The identification of temporal gaps in hydrological data collected is a task made much harder by the data storage and retrieval systems in widespread use within the data collection agencies of the region. Many agencies have great difficulty in producing reliable accounts of specific items of data held, especially completeness of records and quantification of any gaps in that record. This is because they tend to have only very rudimentary catalogue systems - relying heavily on published summaries to identify available data. This can often be misleading, as:

- monthly or annual data can be logged as 'incomplete' or 'missing' when only one or two daily values are lost, and;

- not all data are published, with emphasis always placed on primary stations, neglecting secondary and short term stations.

However, in most of the francophone countries data from surface water monitoring stations has been entered onto computer using the HYDROM package at least up to the end of the 1970s and in some cases since then, and it is possible to obtain catalogue information on all the data held including water levels, flow gaugings, ratings etc. Figure 4.3 illustrates two such catalogues: one for all stations in the country and one giving a more detailed breakdown of the situation for a single station. The advantages of computerised data processing for this type of activity is further discussed in Chapter 6.

Where we have had the opportunity to examine the original files in detail to develop an accurate picture of data availability, these have been presented in the appropriate country report. An example from one of the Sahelian countries is shown in Figure 4.4, it presents a very complete breakdown and clearly shows a trend towards increasing loss of data in the last decade, a typical observation.

4.4.2 Spatial Gaps

Spatial gaps in data collection networks have been identified in conjunction with the UNESCO/WMO guidelines for minimum network densities, taking into account the likely future data requirements, experience with recent water resource assessment studies and activities, and logistical constraints. There is usually a very good reason why gaps occur in data collection networks - be it a lack of suitable observers, logistical or financial problems or similar reasons - and these will have to be circumvented if further stations are to be established in the critical areas.

It has been our experience that officers of the region's data collection agencies are very well aware of any weaknesses in the networks, and the reasons for these problems. We have therefore tried to identify realistic methods for resolving the current spatial gaps in the networks, rather than simply trying to identify them.

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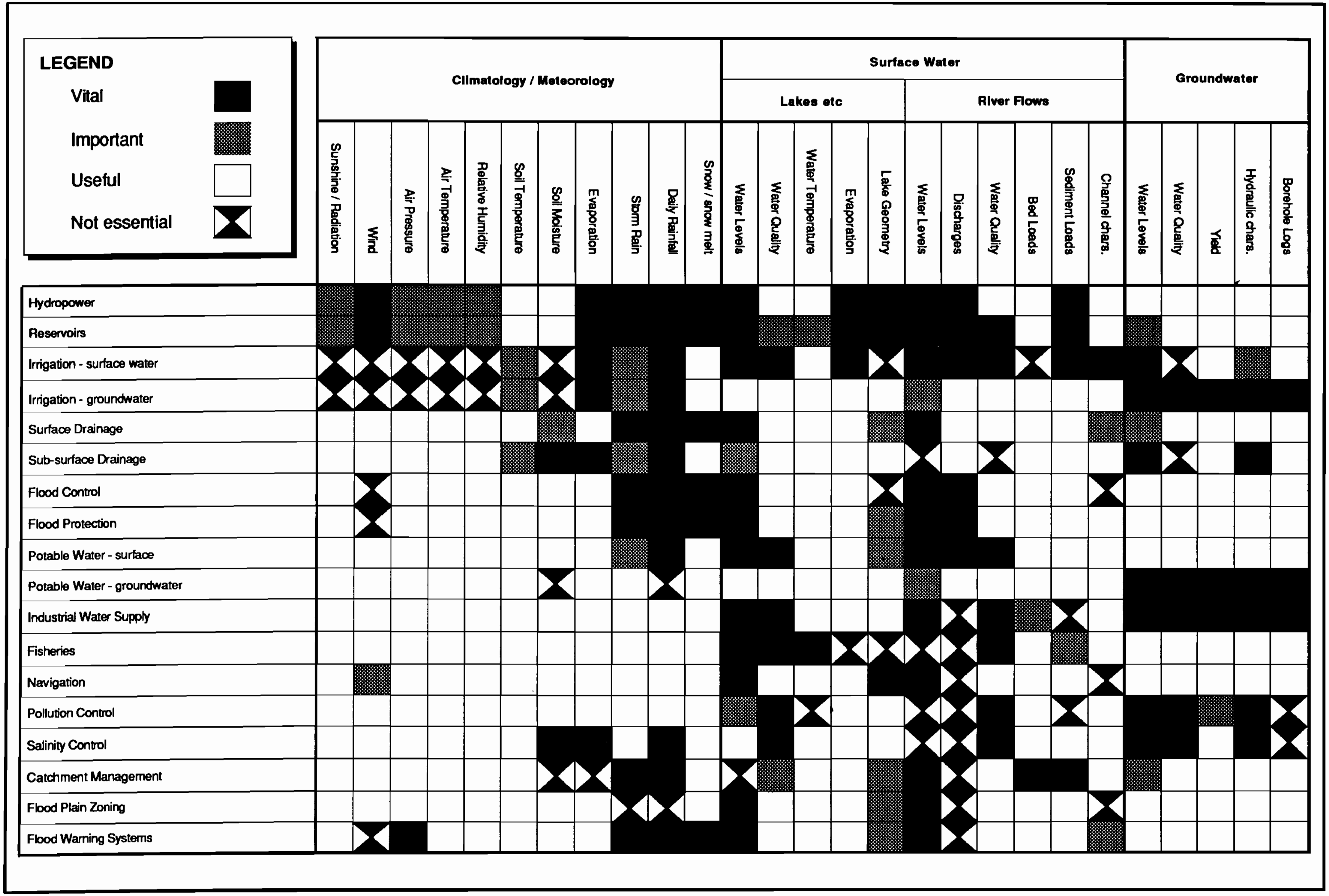


Need for Water Related Data for Development Projects

Figure 4.2

Example of Inventory Options within HYDROM

INVENTAIRE DES COTES INSTANTANEES

Pays : BURKINA-FASO   Edition du 30/05/1991 à 08H44

CAPTEUR	1950 1960 1970 1980 1990
1202700105-1	..........................++++...............
1202700107-1	............................++...............
1202700110-1	.......++++..++++++.+........................
1202700113-1	................+++++...++++++...............
1202700116-1	.......++........++++++.++++++...............
1202700119-1	........++++++++.++++++.....++...............
1202700122-1	..........................++++...............
1202700205-1	...........+++++++++++++++++++...............
1202700208-1	.......+++++++++++++++++++++++...............
1202700211-1	.......+++++++.+++++++++++++++...............
1202700214-1	....++..+.+++++++++++++.+..+++...............
1202700217-1	..............++..........+++................
1202700220-1	....++.+++++++++++++++++.....................
CAPTEUR	1950 1960 1970 1980 1990

INVENTAIRE DES DEBITS INSTANTANES

24/05/1991 à 19H37

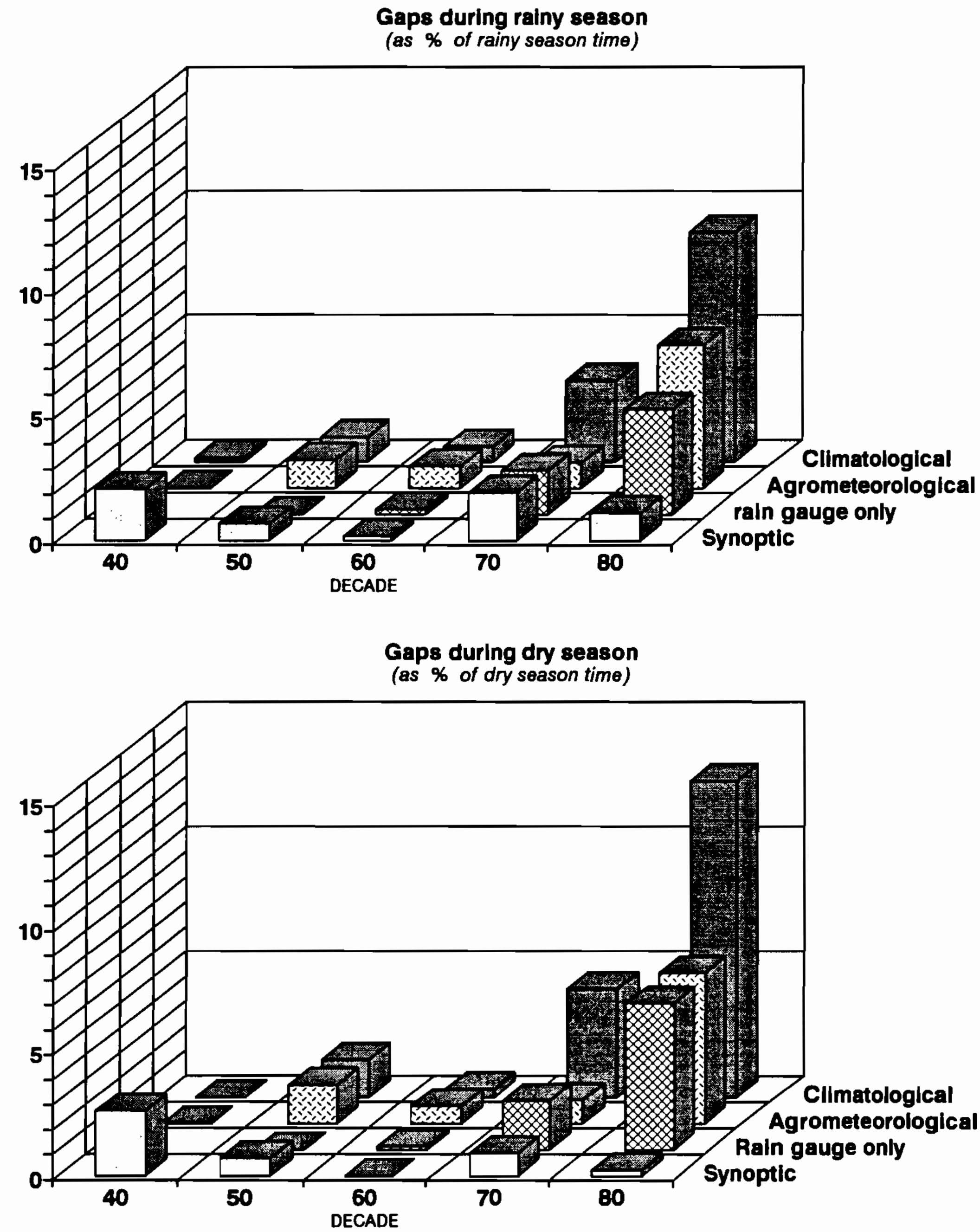
Station : 1202700229-1 NWOKUY
Rivière : VOLTA NOIRE
Pays : BURKINA-FASO
Bassin : VOLTA

Latit. 12.31.00
Longit. -3.33.00
Altit. 249M
Aire 14800.0 km2

Année	JANV	FEVR	MARS	AVRI	MAI	JUIN	JUIL	AOUT	SEPT	OCTO	NOVE	DECE
1957	-	-	-	-	+(A)	+(A)	+(A)	+(A)	-	-	-	*(A)
1958	*(A)	-	-	-	-	-	-	-	-	*(A)	*(A)	*(A)
1960	*(A)	-	-	-	-	*(A)	*(A)	*(A)	*(A)	*(A)	*(A)	*(A)
1961	*(A)	*(A)	*(A)	-	-	-	-	*(A)	+(A)	-	-	*(A)
1962	*(A)	-	-	-	-	-	-	*(A)	C(A)	C(A)	C(A)	C(A)
1963	*(A)	-	-	-	-	*(A)	*(A)	-	-	*(A)	*(A)	*(A)
1964	*(A)	*(A)	-	-	*(A)	*(A)	*(A)	*(A)	-	-	-	*(A)
1965	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1966	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	*(A)
1967	C(A)	C(A)	*(A)	*(A)	*(A)	-	*(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1968	C(A)	C(A)	C(A)	*(A)	-	*(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1969	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1970	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1971	C(A)	C(A)	C(A)	*(A)	*(A)	-	*(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1972	C(A)	C(A)	*(A)	*(A)	*(A)	C(A)	*(A)	C(A)	*(A)	*(A)	C(A)	C(A)
1973	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	*(A)	C(A)	C(A)	C(A)	C(A)	+(A)
1974	*(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	*(A)	C(A)	C(A)	C(A)
1975	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1976	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
1977	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)	C(A)
Année	JANV	FEVR	MARS	AVRI	MAI	JUIN	JUIL	AOUT	SEPT	OCTO	NOVE	DECE

C : mois complet   * : mois incomplet   - : mois manquant
+ : cote hors barème   (?) : valeur maximum du code origine dans le mois

Example Analysis of Gaps in Rainfall Records



Decade	40	50	60	70	80	Season
Climatological St.	0,0	1,5	0,3	4,4	12,7	Dry S.
	0,2	1,0	0,6	3,2	9,2	Rainy S.
Agrometeorological St.	0,0	1,5	0,7	0,9	6,1	Dry S.
	0,0	1,1	0,9	1,0	5,7	Rainy S.
Synoptic St.	2,6	0,7	0,0	0,9	0,2	Dry S.
	2,0	0,6	0,2	1,9	1,1	Rainy S.
Rain gauge station St.		0,0	0,1	2,0	5,9	Dry S.
		0,0	0,2	1,7	4,2	Rainy S.

Some of the countries in the region are at an early stage in the development of hydrological services and their data collection networks are particularly limited and may not cover the full range of parameters recommended in the guidelines.

4.5 Data Quality Checks

4.5.1 Introduction

A means of establishing the effectiveness and efficiency of the currently employed data systems is the detailed checking of some of the data that have been processed by the systems. Given the very limited time available on this study for such checking we have collected a sample of basic data for a number of representative stations within each country and these have been examined for accuracy and reliability at a number of levels.

Rigorous data quality checking is time consuming and therefore could only be done on small samples of data particularly in those countries where data was not available in computerised format. Additional insights in to data quality were obtained from comments made in engineering reports produced by consultants, and in master plan reports, plus an analysis of the quality control and data processing systems used within the agencies. As a consequence, although limited resources were given to the review of data quality, we are confident that all problem areas have been identified, and recommendations made to rectify these problems.

4.5.2 Basic Quality Checks

The first examination of the data collected was an initial inspection to check the 'reasonability' of the information.

This level of checking can be used to confirm that common sense has been used to construct rating curves, and that dry season flows in ephemeral rivers go down to zero and not a discharge associated with a particular gauge height corresponding to the new bed level of the river after particularly severe siltation. High flows were also checked and the correlation of recorded high stages and computed high discharges particularly examined to ascertain that 'sensible' high flow rating curves are used for each season.

For rainfall data, particular attention was paid to the number of rain days recorded for each gauge and the apparent accuracy to which rainfall depths have been recorded. An acknowledged problem with poorly maintained raingauges is the tendency to record zero falls for days with very light rain (indicating that the gauge was not in fact read) and to round the reading for large falls to the nearest integer number of millimetres, or even multiples of 5 or 10 mm.

Groundwater records generally comprise borehole and well completion reports, with some pumping test data, and in a few instances piezometric monitoring. The data is often not held in a central archive but is held by several agencies, drilling projects, and drilling contractors, all using different recording procedures. It is therefore especially difficult to assess quantitatively data quality. However, sample data has been examined where possible and such features as duration of pumping tests and timing of piezometric measurements in operational wells and boreholes noted. Pumping tests are often too brief to allow full analysis, water levels in operational boreholes may only reflect a temporary level due to recent pumping rather than the static level, measurements at such sites taken at dawn before the morning demand peak are the most likely to be reliable.

4.5.2 Detailed Quality Checks

More detailed checking was carried out on a limited sample, generally taken from the principal monitoring stations but occasionally including randomly selected secondary stations.

Rainfall

The quality of annual rainfall records has been assessed using both simple double mass analysis and the regional vector method. The regional vector method is objective and allows the selection of thresholds against which to assess the reliability of individual values or sequences of years. The 'regional vector' is a chronological sequence built up by combining the records of a group of stations within a region. The annual series at any station in the same region can then be compared to the regional vector to check whether it too fits the regional pattern. For thresholds we have taken a single annual value deviating from the regional vector value by more than 25% as an outlier, and a sequence of two or more consecutive years deviating by more than 15% to indicate a systematic error.

Discharge

The precision of the conversion of water levels to discharges depends on a number of factors:

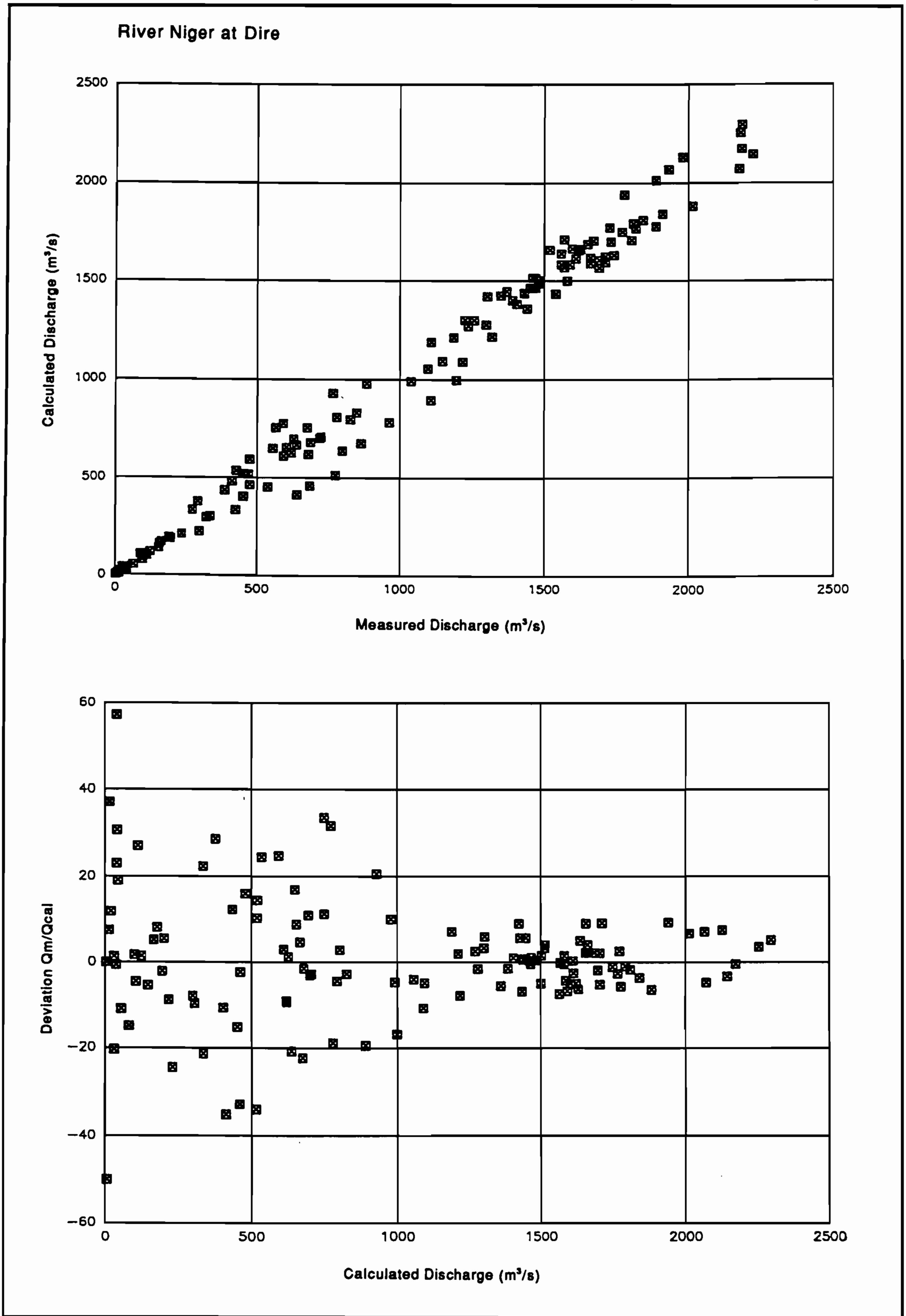
- the stability of the hydraulic control at the station;
- the range of flows measured;
- the frequency of discharge measurements in relation to the stability of the control;
- the quality of the fitted rating curve.

For a sample of stations we have evaluated the reliability of the most recent rating relationships. A comparison can be made between flow measurements (taken by current meter and assumed to be accurate) and the discharge obtained for the same water level using the appropriate rating curve. Two graphs are used in this assessment as illustrated in Figure 4.5. The first shows the degree of variance from the expected 1:1 relationship, the second highlights those ranges of discharge where the error term is greatest.

The most common problems relate to channels where the rating relationship is not stable and the agency is unable to carry out sufficient discharge measurements to maintain an up to date rating. The

Figure 4.5

Example Quality Control of Rating Curves



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difficulty of making discharge measurements at high flows in many of the regions rivers result in the use of rating relationships extrapolated well outside the range of metered flows.

4.6 Formulation of Development Recommendations

A major objective of the project has been to identify practical ways to improve the work of the hydrological data collection agencies. This can only be done by identifying:

- the present gaps in the data collected;
- the present constraints within the data collection and processing systems;
- the likely future data requirements;
- the development priorities within the data collection agencies;
- the likely scale of funding available from internal and external sources.

A preliminary assessment of these constraints was made for all data collection agencies within the region and in most cases possible directions for future development have been discussed with the directors (or senior executives) of these agencies. This work was reviewed in detail with the specialist support team and further discussed with the officials concerned where this was appropriate. In this way it was hoped to develop realistic development projects and ways to improve the working of the data collection agencies with the emphasis on trying to assemble programmes that are likely to be implemented. Where external funding of development is likely to be needed, we have identified projects containing the required elements within a format designed to assist potential donor agencies in their evaluation of any request for help.

Work has also been done to try to identify ways in which regional co-operation would provide important opportunities to improve the data systems by introducing facilities that individual countries may not be able to afford for themselves. Areas particularly suited to this type of co-operation are:

- introduction of telemetry systems to river basins;
- development of data processing techniques;
- equipment repair and maintenance facilities;
- training of professional staff and technicians.

Recommendations made have ranged from the development projects discussed above, to suggested changes in office procedures to improve data reliability. Emphasis has always been placed on trying to identify the achievable goals in the short and medium term future, and outline a strategy for long-term development. Most recommendations have arisen from our study of the way things are currently working, and perceived directions where improvements could be made.

CHAPTER 5

REGIONAL DATA COLLECTION SITUATION

5.1 Introduction

5.1.1 General

The results of our assessment are presented under three headings: data collection, data handling, and institutional aspects, in this and the following two chapters. These topics are however closely interlinked, most obviously by financial considerations, but also at a technical level since the choice between, for example, mechanical field instruments or electronic devices has implications for data management and staff training. These linkages must be borne in mind when examining the results of the assessment on a topic basis.

In the present chapter the focus is on the field activities of the national agencies and in some instances of regional organisations and projects. The chapter summarises performance across the region and identifies both specific areas of weakness at the present and areas where there is scope to enhance performance and for regional collaboration.

5.1.2 Overview of the Problems Facing Data Collection Agencies

In West Africa most of the difficulties that hamper the performance of the hydrological data collection agencies are organisational and administrative, rather than hydrological. Hydrological problems do exist, but in general terms these pale into insignificance when compared to the organisational problems. Hydrometric agencies in the region display a wide variation in the level of development of their organisations, and the range of activities routinely undertaken; in a few countries, such as Equatorial Guinea, hydrometry is in its infancy and distinct hydrometric agencies have still to be established, in other countries there are services which have a long tradition and assisted by international programmes associated with drought mitigation have reached an acceptable level of development.

A very common constraint placed upon the data collection agencies is inadequate funding. A sustained shortage of funds has led to reduced staffing levels and shortages of equipment and transport that lead to an inability to adequately service station networks established in times of less restricted budgets. Funding at present has been squeezed to such an extent that many agencies are barely able to function, and very few function efficiently.

Widespread problems within the data collection agencies include the acquisition and maintenance of equipment, and retaining the manpower skills to operate and repair it. These problems encompass computers and similar high technology equipment, but are less severe with respect to more rudimentary devices, where experience and local skills are often adequate in keeping equipment working.

Transport facilities produce frequent severe constraints on field activities. Transport problems include a lack of vehicles, lack of sufficient operation and maintenance funds to run the vehicles, and problems of maintaining gauging boats in good repair.

Manpower is rarely sufficient to allow data collection agencies to meet their obligations, with establishments being too small and manpower skills insufficient for the workload. In the current economic climate expansion of establishments is severely discouraged, and it is sometimes difficult to retain technically skilled staff due to better pay and working conditions found in private sector employment. Training of technical and professional staff is essential, but may create temporary manpower shortages while staff are on courses.

The recruitment of field staff to act as observers presents a further major challenge in some areas, as does the task of getting technicians to visit field stations. Improvements in transport, allowances and pay can go a long way to reducing these problems, but cannot always eliminate them.

Regional support programmes, such as AGRHYMET (see Section 3.3.1) and the OCP (see Section 3.3.3), are very important, in many countries virtually supporting whole areas of hydrometric activity utilising outside funding. If this support were withdrawn all surface water monitoring might cease in several countries, for example Sierra Leone and many others.

5.2 Climatology

5.2.1 Data Collection Networks

Tables 5.1 and 5.2 show a comparison of rainfall and meteorological station densities in the region against the norms given in the UNESCO/WMO guidelines (Section 4.1.2). The information presented represents either the total number of stations in an agency's inventory or the number reported as operational for this assessment; this situation reflects the information which we were able to obtain at the time of the country visit. These tables should be read in conjunction with total station numbers in Table 4.2. The full UNESCO/WMO procedure involves dividing the country into classes and making separate calculations for each class and for each type of monitoring station and associated staffing level, since this detailed breakdown is not available for all countries in the region we have also included in the tables a column for the overall density for each country.

Table 5.1 reveals a wide range in size and density of rainfall networks across the region, and there is further variation, not always shown by the tables, internally within some countries particularly those where the population is very unevenly distributed. This applies to northern countries such as Mauritania or Mali whose territories include vast areas of desert and to equatorial countries such as Congo which have extensive areas of dense forest. Such countries may have networks in their populated regions which meet the guideline figures but this is not reflected in the overall figure for

TABLE 5.1

Precipitation Station (non-recording) Densities
(after UNESCO/WMO 1988)

Country	Arid Sedimentary	Arid Non-sedimentary	Humid Sedimentary	Humid Non-sedimentary	Overall for Country
WMO Norms	**6.0**	**6.0**	**20.0**	**40.0**	
Mauritania			-	-	0.7
Mali			-	-	1.32
Niger			-	-	2.3
Chad			-	-	1.7
Senegal					9.12
The Gambia	29.2	-	-	-	29.2
Guinea Bissau					22.4
Guinea					6.0
Sierra Leone	-	-		2.0	2.0
Liberia					
Cote d'Ivoire					6.8
Burkina Faso			-	-	5.0
Ghana	5.8	11.4	31.5	12.1	9.3
Togo			-	-	18.0
Benin			-	-	8.5
Nigeria	1.7	4.1	8.3	1.7	4.0
Cameroon					6.32
Central Afr Rep					<1.61
Equatorial Guinea	-	-			0.7
Gabon	-	-			1.5
Congo	-	-			6.35
Cape Verde			-	-	615
Sao Tomé & Principe	-	593	-	211	307

Note: Nr of stations per 10^4 km^2
Station numbers as given in inventories

TABLE 5.2

Meteorological Station Densities (after UNESCO/WMO 1988)

Country	Arid Sedimentary	Arid Non-sedimentary	Humid Sedimentary	Humid Non-sedimentary	Overall for Country
WMO Norms	**3.0**	**3.0**	**3.0**	**2.0**	
Mauritania			-	-	0.2
Mali			-	-	1.8
Niger			-	-	0.1
Chad			-	-	0.4
Senegal					9.1
The Gambia	9.7	-	-	-	9.7
Guinea Bissau					2.8
Guinea					6.0
Sierra Leone	-	-	-	1.7	1.7
Liberia					
Cote d'Ivoire					13.3
Burkina Faso			-	-	10.0
Ghana	1.9	8.7	0.0	2.2	4.2
Togo					29.0
Benin					1.5
Nigeria	4.0	12.0	33.0	5.0	10.0
Cameroon					8.8
Central Afr Rep					0.3
Equatorial Guinea	-	-			0.7
Gabon	-	-			0.0
Congo	-	-			0.3
Cape Verde			-	-	7.4
Sao Tomé & Principe	-	791	-	0.0	198

Note: Nr of stations per 10^5 km^2
Station numbers as given in inventories

the country, for example the density of stations in Niger below 16°N is 6.1 which is satisfactory. The results for São Tomé and Príncipe confirm the difficulty of using this methodology for such a small country which because of its topography has a complex climate. The São Tomé densities are far in excess of the recommended minima despite the fact that there has been a dramatic decline in the number of rainfall monitoring stations in the country since 1977.

The general conclusion from the table is that for most countries, especially those with a humid climate and large areas of non-sedimentary geology, the density of raingauges fall below the recommended minima despite some countries, such as Nigeria, having large numbers of gauges. It would appear that in particular the recommended minimum of 40 gauges per 10 000 km^2 for humid non-sedimentary areas is an unrealistic level of activity for the region's agencies to aspire to.

Numbers of active rainfall stations have fallen over the last decade in many countries as a result of financial constraints, but there are several instances of on-going or newly started projects to rehabilitate networks. However, rehabilitation of all of an abandoned network may not be the most efficient use of scarce resources, it is desirable that rehabilitation projects should also include a full assessment of the overall network in terms of data needs and available resources.

Where there is scope for rationalising parts of a national rainfall network this has been discussed in the relevant country report. Emphasis has been placed on closing rainfall gauges in areas of excessive duplication, as well as those stations that are known to be unsuitable for site details or data quality, focusing instead on maintaining a full service for the remaining network.

Table 5.2 shows situation for meteorological stations (sites at which evaporation is either measured or can be estimated from other observations using empirical formulae). National meteorological station networks are generally much smaller than rainfall networks and have been less affected than the rainfall networks by the financial restrictions in recent years. Meteorological stations have a higher priority and have received support from regional projects such as AGRHYMET and ASECNA. The stations are more reliable as they are run, in general, by trained staff. Countries are more likely to meet the recommended minimum level for these stations, in fact many exceed this by a factor of three or more.

5.2.2 Data Collection Equipment

Rainfall measurement relies on manual recording. Problems with data collection from manual sites are reported for the rainfall networks of most countries in the region. Difficulties, when investigated, appear to derive largely from organisational and financial problems at headquarters or regional offices. The restrictions on field trips caused by lack of money and/or vehicles mean that observers are not kept in touch with the agency, their work is not discussed with them regularly. More serious are the many instances where observers have not been paid for long periods, or have been told that they must go to collect their wages from some designated office often far from their post. Under these circumstances it is hardly surprising that much of the data coming in to the agency from its rainfall network is in the main of poor quality.

Synoptic and certain agrometeorological stations report several times a day by telephone or radio to the headquarters of the service. However this applies only to a limited number of sites in the region. It should also be noted that the HYDRONIGER stations have automatic sensors for rainfall, data from these is passed to national receiving centres in real time at the time of passage of the ARGOS satellite. The operational success rate for these telemetry systems is discussed in detail in Appendix C in order to establish whether they offer a viable alternative to existing technology at the scale of a partial or full national network.

5.2.3 Data Quality

The absence of sufficient funds to allow the meteorological services to make routine inspection visits to rainfall sites is cause for serious concern. Such visits are normally only required once a year and they provide a vital link with the observer and allow any changes in the exposure of the site to be recorded. This information is often of great assistance in situations where the station records appear to be anomalous possibly allowing the data to be adjusted to counteract the effect of the change.

Synoptic stations in the region are generally staffed by full time employees of the meteorological agencies who have been trained to internationally recognised WMO grades. These stations have the first call on resources for repairs and replacement of equipment. Data standards are also supported regionally by the efforts of ASECNA to ensure that air safety is maintained. The quality of data from these stations is in the main satisfactory.

5.3 Hydrometry

5.3.1 Data Collecting Networks

Tables 5.3 - 5.5 show a comparison of hydrometric station densities in the region against the norms given in the UNESCO/WMO guidelines. These tables should be read in conjunction with Table 4.3 which shows the total number of stations of each type by country.

In general terms, national operational hydrometric networks have declined in size over the last decade. The data collection agencies are severely stretched to maintain even these reduced networks and systems seem close to collapse in many of the countries. Details are contained in the individual country reports. Critical problems with the maintenance of the networks are:

- insufficient funding;
- lack of transport;
- lack of adequately skilled manpower;
- lack of equipment.

As shown by the tables few countries are able to meet the minimum recommended station densities. The usefulness of the guidelines can be questioned for several countries in the region. For example,

TABLE 5.3

Surface Water Level (non-recording) Station Densities (after UNESCO/WMO 1988)

Country	Arid Sedimentary	Arid Non-sedimentary	Humid Sedimentary	Humid Non-sedimentary	Overall for Country
WMO Norms	**1.2**	**2.4**	**12.0**	**24.0**	
Mauritania			-	-	0.3
Mali			-	-	1.4
Niger			-	-	0.4
Chad			-	-	0.8
Senegal					3.7
The Gambia	5.3	-	-	-	5.3
Guinea Bissau					3.9
Guinea					3.2
Sierra Leone	-	-	-	3.4	3.4
Liberia					
Cote d'Ivoire					5.0
Burkina Faso			-	-	3.8
Ghana	2.3	1.9	13.1	5.7	3.0
Togo					4.6
Benin	4.8	1.9	-	-	2.9
Nigeria					>min
Cameroon	0.0	6.2	-	1.7	0.9
Central Afr Rep					0.9
Equatorial Guinea	-	-			0.0
Gabon	-	-	0.36	-	0.4
Congo	-	-			1.6
Cape Verde			-	-	0
Sao Tomé & Principe	-				89

Note: Nr of stations per 10^4 km^2
Station numbers as given in inventories

TABLE 5.4

Surface Water Level (recording) Station Densities (after UNESCO/WMO 1988)

Country	Arid Sedimentary	Arid Non-sedimentary	Humid Sedimentary	Humid Non-sedimentary	Overall for Country
WMO Norms	**0.6**	**1.0**	**1.0**	**1.0**	
Mauritania			-	-	0.45
Mali			-	-	0.4
Niger			-	-	0.07
Chad			-	-	0.16
Senegal					2.4
The Gambia	11.5	-	-	-	11.5
Guinea Bissau					0.0
Guinea					1.6
Sierra Leone	-	-	-	0.0	0.0
Liberia					
Cote d'Ivoire					1.5
Burkina Faso			-	-	2.2
Ghana	0.6	1.5	0.0	3.7	1.5
Togo					3.7
Benin	4.8	1.9	-	-	2.75
Nigeria					?
Cameroon	0.9	0.8	-	0.4	0.4
Central Afr Rep					0.19
Equatorial Guinea	-	-			0.0
Gabon	-	-	0.0	-	0.0
Congo	-	-			0.35
Cape Verde			-	-	20
Sao Tomé & Principe	-		-		89

Note: Nr of stations per 10^4 km^2

Station numbers as given in inventories

TABLE 5.5

River Discharge Station Densities
(after UNESCO/WMO 1988)

Country	Arid Sedimentary	Arid Non-sedimentary	Humid Sedimentary	Humid Non-sedimentary	Overall for Country
WMO Norms	**1.0**	**2.0**	**10.0**	**20.0**	
Mauritania			-	-	0.45
Mali			-	-	0.76
Niger			-	-	0.2
Chad			-	-	0.6
Senegal					1.9
The Gambia	2.7	-	-	-	2.7
Guinea Bissau					1.4
Guinea					2.7
Sierra Leone	-	-	-	3.4	3.4
Liberia					
Cote d'Ivoire					0.0
Burkina Faso			-	-	2.2
Ghana	0.8	2.3	0.0	5.7	2.6
Togo					7.6
Benin	2.2	2.0	-	-	2.06
Nigeria					?
Cameroon	0.9	0.9	-	1.3	
Central Afr Rep					0.32
Equatorial Guinea	-	-			0.0
Gabon	-	-	0.3	-	0.3
Congo	-	-			1.87
Cape Verde			-	-	15
Sao Tomé & Principe	-		-		89

Note: Nr of stations per 10^4 km^2
Station numbers as given in inventories

Equatorial Guinea does not have any surface water monitoring at present, the recommended minimum level of monitoring for the country is 52 discharge stations but it would clearly be quite inappropriate to recommend that this should be the target for a new agency starting from nothing, although it might be a suitable long term goal. Sierra Leone has entries in the tables but the stations are run entirely from external funding from the OCP (Section 3.3.3) and the collected data is not available in the country. The decline in the number of gaugings carried out each year is reflected in the lower density of discharge stations compared to levels, the recommended minimum levels are met in only one or two countries.

The process of evaluating and modifying the design of their surface water monitoring networks is an on-going activity for all the region's agencies, but two factors have recently focused greater attention on this vital task: restricted budgets, and the advent of new technologies for data collection.

The enforced budget restraint has led to a dramatic decline in most agencies 'active' network but it appears that in most countries there has been no structured withdrawal from activities but rather that stations have dropped out of the active network because they cannot be reached by field teams or the equipment has malfunctioned and cannot be repaired for lack of funds. The consequences of this failure to take active steps to reallocate available funds to ensure that high quality data continues to be collected at key sites is to be seen in the falling standards of data reliability, particularly where the gauging programme has not been kept up.

It is essential that the region's agencies take a long term view of data collection and prioritise their activities so that it is clear which tasks may be curtailed or temporarily suspended if the financial situation demands. This perhaps best described in terms of 'primary' and 'secondary' activities. Having identified the long term primary network of water level monitoring points and all field activities required to maintain it (gauging programme, maintenance visits, equipment replacement, etc) the agency will be in a position to determine the extent of its secondary programmes. The selected primary monitoring activities should be the best compromise between the conflicting demands of remaining within budget and of providing high quality data of the type most likely to be required in the future by those planning water resources development. Clearly within the scope of this assessment, where time was severely limited, it has not been possible to make detailed recommendations for every country on the issues of network design, but each country report contains recommendations for further action on these points often in the form of proposals for externally assisted projects.

In addition to the national networks there are several examples of large scale regional networks. Ten years ago the HYDRONIGER project pioneered the introduction in West Africa of advanced technology to water level monitoring utilising 65 data collection platforms and satellite telemetry. This system was served by a primary receiving station in Niamey with secondary, less well equipped receiving stations in each of the participating countries. The OCP has a network of around 100 automatic stations linked via the ARGOS satellite system to two receiving centres at Odienné and Lama-Kara. Under an OMVS project a small telemetry network was installed in 1988 using the latest technology, it provides information to the operators of Manantali dam which can be used for forecasting flooding in the lower valley.

These projects provide a convincing illustration of the possibilities for telemetry. Certain elements of the projects, relating to organisational arrangements, logistics, and the management of staff resources can serve as a model, or a warning, to agencies concerned with future regional hydrometric projects. These aspects are discussed more fully in Chapter 7.

5.3.2 Data Collection Equipment

Profound changes have recently occurred in the methods available for data collection which in turn will lead to changes in the design of monitoring networks. A brief description of the new technologies and their implications for national networks in the region is given below and a more detailed description is included in Appendix C which particularly addresses the subject of telemetry.

The Sensors

The sensor is the most vulnerable component of any river gauging station because it is generally in direct contact with the river and therefore subject to the hazards of high velocities and large boulders or debris during floods. There are a number of alternative options:

- floats, which are by far the most used, are simple and in general reliable and robust. At certain sites the construction of the chamber can be difficult or costly but many sites are already equipped. Float systems can easily be fitted with a numeric encoder which transforms the information into a form acceptable by an electronic storage system.

- Pneumatic 'bubble' sensors are easy to install in the river but the associated bankside station is costly and its running is complex and onerous (generally utilising compressed air bottles). This approach has been around for some time and was that utilised when setting up the HYDRONIGER network.

- Piezo-resistive sensors transmit their data numerically which reduces the problems of interfacing with electronic systems and allows the interchange of sensors with the acquisition stations without recalibration.

Whichever technology is selected the sensor remains without doubt the weakest link in an automatic station.

Electronic Logging at Field Stations

The appearance of electronic field devices allows the entire process of data collection and handling to be effected directly, data is stored in the field on electronic devices and transferred directly to computer. This approach eliminates the problem of analysis of charts which is always an important cause of delay in the processing and distribution of data and often a source of errors introduced during manual taking off from charts. This revolution appears to be inevitable because the manufacture of autographic recorders is becoming more and more expensive while the price of electronic stations, which are now comparable in price, will get cheaper. The reliability of the latest generation of electronic stations (the sensor and memory device) is better than that for mechanical stations. With this greater reliability it should be possible to dispense with the usual backup of an observer at the automatic station.

Telemetry

This is the technology whereby numeric information collected and stored at the automatic stations may be transferred to users who can be situated far from the measurement site. The use of satellites gives global coverage in certain configurations. The particular advantage of this technology is the capacity to transmit the data collected rapidly from many dispersed sites to a centre or number of centres of concentration of information. To date in the region two satellite systems dedicated to the monitoring of the environment: the ARGOS system run by NOAA and used by HYDRONIGER, the OCP, OMVS, and the networks of Guinea and Benin; and METEOSAT using GOES satellites employed by the Congo-Oubangui Project and the network of ENERGA Sanaga of Cameroon. This technology is clearly well suited to the control and rapid access to all hydrological data collected on a regional level. Telemetry also allows an 'auto-surveillance' regularly and remotely checking the condition of all stations. This alerts the receiving centre to any malfunction and a field team can then be sent to investigate the problem. By obviating the need to make regular routine visits to stations for chart changing and to check that the recorder is operating correctly the use of telemetry can ease some of the logistic problems which presently determine the scale (in terms of station numbers) and geographic spread of networks. The costs of such systems are discussed in Appendix C.

Consequences for network design

Most hydrometric agencies would wish to operate a number of automatic recording stations within their overall network, but in many cases it would be hard to justify automating the entire network. Sites selected for the installation of automatic recording are often the key sites in the national network and as such constitute primary stations; where large rivers which change level only slowly are key sites manual recording may remain a perfectly adequate method these too would be primary sites. As discussed in Chapter 6 most hydrometric agencies are now utilising computers for some of their data processing activities so that they should be equipped to process the data held by the electronic loggers. The principal consequence of an agency switching from mechanical to electronic recording would be a reduction in the number of staff, observers and data processing staff. Logistic support would remain much the same.

The introduction of telemetry is a further step which can be taken at the time that electronic recording is introduced or added at a later stage. Telemetry is an obvious requirement only where real time or near real time data is required for operational use, as for flood forecasting in the headwaters of the Niger. However, as discussed above there can be significant benefits even when the data only needs to be collected say monthly, these benefits deriving from the fact that the operational status of the station can be checked from the headquarters.

5.3.3 Flow Gauging Techniques

Most countries in the region rely upon the traditional approach to measuring river discharges through the use of current meters. On major rivers gauging is usually undertaken from a boat or bridge, cableways are not common. The tidal reaches of many of the region's rivers stretch far inland, over 500 km in the case of the Gambia, gauging the freshwater flow in these reaches is particularly difficult. In the arid north of the region rivers are often ephemeral exhibiting a rapid response to runoff and unstable alluvial channels. Gauging flood flows is a problem everywhere.

Visits to take these measurements should be made regularly and this is frequently the expressed policy of the data collection agency. However, with recent increased pressures on resources and the repercussions for the status of transport and the availability of field allowances, in most instances visits are much more widely spaced than is generally desirable, particularly for those sites furthest from the office at which the gauging team is based. In such circumstances there is an implicit increased reliance upon the stability of the rating relationship that is not always wise, or demonstrated by previous behaviour.

There has been no evidence seen of any attempt to plan the annual gauging programme on the basis of an assessment of where the gauging is most needed. By identifying those gauging stations that have shown a stable behaviour in the past and which as a consequence require little or no further gauging, more effort can be made to calibrate the less stable sites - therefore allowing deployment of resources where they are most valuable.

The maintenance of flow gauging equipment is another area where serious problems have been identified. Many agencies possess ageing current meters in need of urgent maintenance before they can give reliable service. Calibration of the older models of current meter is required on a regular basis and is seriously neglected. There is no facility in the region and so the meters must be returned to their manufacturers periodically, obtaining the hard currency necessary for this presents problems to many agencies and the equipment is out of service for a lengthy period. The use of current meters with plastic impellers should improve this situation in the future. Similar problems are known to exist with cableway installations, boats, and winches and other equipment assuming that they are in a condition which can be restored.

At present there is little use of other techniques for measuring flows or of estimating flows retrospectively from the evidence of trash marks. It is at the highest flows that current meter gauging is most difficult to perform and, given the importance of obtaining as many estimates of such flows as possible in order to calibrate the station over the full range of likely flows, alternatives such as floats or post-flood hydraulic calculations can provide additional information which will considerably improve the quality of the rating and thus the derived flows at the site.

5.3.4 Data Quality

Reliable data are the culmination of good field hydrometric data collection and good data processing. An assessment of basic data reliability is really needed before any work to assess surface water resources is carried out. In some of the countries in the region hydrometric activity has now declined to such an extent that insufficient field data are being collected to allow an objective assessment of data reliability. Examples of this process are the lack of flow gauging data from Nigeria for the current year and the much reduced gauging programmes in Niger and Gabon; but examples could be quoted for most of the countries in the region (see individual country reports). There can therefore be no definitive assessment of data reliability.

Subjective assessments of the quality of data being produced by the data collection agencies of the region has indicated that as yet the reduced field programmes have not resulted in obvious, severe problems with inaccurate information being produced. However, concern has been expressed over the ability of the agencies to sustain this state of affairs in the face of dwindling resources. There is some evidence of difficulties where insufficient attention and supervision have been provided during the processing of data.

The state of data processing within the hydrometric data collection agencies is currently in a state of flux, as facilities and techniques are adjusted by degrees with the advent of affordable computer systems. The changes are in general piecemeal and largely dependent upon the acquisition of elements of computer hardware within aid packages. Accurate processing of hydrological data requires careful supervision by experienced hydrologists: a factor not always available in the existing data processing set-ups. A tendency to treat the acquired computerised data processing systems as an alternative to the need to provide close, experienced supervision to the work has been identified and should be strongly discouraged. One way to view the improved processing systems is to make the supervisor much more effective in his role of scrutinising the information produced, allowing much more powerful quality control procedures to be used to ensure overall data quality. In particular the data entry can be undertaken in the provincial offices by those technicians responsible for data collection. Portable computers are now sufficiently robust (especially those machines of low performance which are suitable for this type of operation). The specialised hydrological software is well adapted to this initial phase of data handling and allows the entry of data from recorder charts, discharge measurements and the calculation of flows with tables and graphs permit management of the progress of the work.

5.4 Groundwater

5.4.1 Introduction

Whilst routine monitoring at a defined network of sites is the norm for meteorological and hydrometric agencies the situation is rather different in the groundwater sector. The collection of groundwater data for the purpose of monitoring the resource, while recognised as an important component of groundwater management, has not generally been a priority for any of the countries of the region. Efforts have been concentrated on assembling constructional and hydrogeological data from existing and new boreholes, wells and, in some instances, springs. However, as groundwater becomes more heavily utilised the need for monitoring will become essential, to ensure that derogation, both in terms of quality and quantity, does not occur.

5.4.2 Inventories of Springs, Wells and Boreholes

The principal activity in the groundwater sector throughout the region has been the installation of wells and boreholes for water supply under externally funded projects. A feature of this activity has been the number of different donors involved within a single country. These projects have been a valuable source of hydrogeological data but co-ordination of data collection is generally poor. Few countries have standard procedures or reporting requirements and the required investigatory work is largely undertaken by the projects themselves, often using different techniques from one another. The result is that in many countries a substantial body of data has been built up in project inventories which are not directly compatible. Such project data is frequently not collated by any central agency and the processing and storage of the data on a national basis is at a very preliminary stage. Aspects of data handling are discussed in Chapter 6.

5.4.3 Monitoring

Since groundwater is rightly included in full hydrological assessments of areas, regions and countries, there have been several attempts at defining the desirable densities of points for routine monitoring. Unfortunately groundwater resources do not lend themselves to such treatment; their complexity is too great for such simplified treatment and each case should be treated on its own merits. The UNESCO/WMO recommendations on the minimum level for groundwater activities are shown in Table 4.1, these recommendations are aimed at providing data for regional resource studies rather than at resource development projects. For example, the recommended number of monitoring stations in arid, sedimentary areas is 5 per 10^4 km^2 for water levels and 5 per 10^5 km^2 for quality. The need for special survey teams and a superstructure of specialist staff, equipment and laboratories is also set out.

Groundwater resource monitoring includes the routine measurement of groundwater levels, groundwater quality, and groundwater abstraction. Water quality monitoring is discussed in Section 5.6 below.

Table 5.6 shows the operational status of piezometric networks in the region. The information presented represents either the total number of stations in an agency's inventory or the number reported as operational for this assessment; this situation reflects the information which we were able to obtain at the time of the country visit. In addition to the national networks there is a regional network started in 1985 by the OMVS to monitor the fluctuations in water table in the valley of the Senegal river. This regional network has 1 150 monitoring sites of which 569 are dedicated piezometers. Records are held in St Louis, Senegal.

TABLE 5.6

Operational Status of Piezometric Networks

Country	Monitored Sites	Notes
Mauritania	0	Have been some 400 (of which 275 operated by the OMVS)
Mali	2107	Information on status post 1990 not available
Niger	0	400 planned
Chad	66	Measurement twice a year, all used for supply
Senegal	471+	Project based, difficulties when funding ceases
The Gambia	155	16% read monthly rest 3 monthly, all used for supply
Guinea Bissau	0	Past projects
Guinea	27	Kamsar area only
Sierra Leone	1	Network recommended under this assessment
Liberia	-	
Côte d'Ivoire	4	In coastal sedimentary basin only
Burkina Faso	422	143 purpose built, on one project 47% read weekly, 41% daily, 2% recording
Ghana	12	Accra Plains only, national network planned
Togo	0	3 project based networks have operated now ceased
Benin	56	Project based, further 17 in progress
Nigeria	?	No formal monitoring, many organisations poor coordination of data collection
Cameroon	0	In north, project based, none lasted > 5 years
Central Afr Rep	?	Used for water supply, read every 2-3 months
Equatorial Guinea	0	No groundwater service
Gabon	0	
Congo	65	2 areas, all used for supply, most read daily
Cape Verde	many	Restricted to Santiago, Sao Antao, and Sao Nicolau islands
São Tomé & Príncipe	0	No groundwater service

Notes: Numbers operational at the time of the Consultants' visit.

Some countries have had quite extensive networks in the past which are not operational today. These networks were established under externally funded projects and proved unsustainable once the project ceased and the responsibility for monitoring was passed to a national organisation. Figure 5.1 illustrates the history of intermittent support for groundwater monitoring in one of the Sahelian countries.

The drilling of a borehole solely to fulfil a monitoring role is rarely undertaken because of the cost. Where boreholes are incorporated in a regular monitoring programme, and across the region few are, they are either operational sources or were originally drilled for operational supply use and were found on completion to be unproductive. In the former case measurements of depth to water table or yield will not be representative of the surrounding aquifer outside the zone of influence of the pump. The value of the data is consequently reduced and additional analysis of results is necessary which adds to the burden of obtaining data, although if the measurements are taken at dawn sufficient time may have elapsed since last use to provide more representative results. An unproductive well is of course also unrepresentative of local groundwater conditions.

As discussed in Section 5.3.1 there is a very real need, given the prevailing financial situation, to design monitoring networks (including both data collection and associated processing requirements) to match the anticipated level of funding and staff establishment in the long term. Activities need to be prioritised. Monitoring may continue to have a lower priority than borehole construction for many agencies, but it is still useful to rank possible monitoring activities. For example the frequency of measurement might be daily, or even continuous, from a limited number of 'primary' sites selected in areas of particular hydrogeological interest and only two to four times a year from a number of further 'secondary' sites. Network design should also take into account the additional analysis and lower reliability of data obtained from operational water supply sites in comparison with the cost of constructing dedicated boreholes or wells.

Areas of particular hydrogeological interest would include aquifers at risk of saline intrusion and where demand has, or is predicted to rise substantially. Examples of such areas are the aquifers supplying the coastal cities such as Lomé and Cotonou, and the town of Maiduguri in the Chad basin of Nigeria, where a rapid rise in population has led to a sharp decline in water table. Sampling points elsewhere could be chosen according to UNESCO/WMO guidelines and on the basis of aquifer type and amount of use.

In most countries the total quantity of groundwater abstracted can only be estimated very approximately; the overall number of abstraction points may not be known and the number of these actually operational at any one time is rarely available. Monitoring of pump operation and maintenance would not only improve the reliability of abstraction data but would also, when backed up by repair teams, equipment and workshops, increase the effectiveness of the various water supply projects serving both the rural population and urban centres.

For most of countries it is probably unrealistic to expect scarce financial resources to be directed towards setting up sophisticated monitoring networks, unless legal instruments are available to oblige the water supply utility to undertake a basic level of monitoring at each of its abstraction points. This option is most likely to be effective where the utility charges customers for the supply.

5.5 Fluvial Sediment Yield

There are very significant difficulties in monitoring fluvial sediment yields especially with the marked seasonal distribution of rainfall found in much of the West African region. Difficulties include:

- the requirement for substantial laboratory back-up to support field measurements;
- the temporal distribution of sediment transport, which means that intensive field activity is needed at the beginning of the wet season, often in remote, inaccessible locations;
- the need to measure bedload in addition to suspended load requiring different techniques;
- the difficulty in analysing results of data collected and interpreting them in terms of parameters required by planners, eg rates of erosion in a catchment, or annual deposition in reservoirs.

Few countries attempt any systematic monitoring of sediment, although some monitoring has been, or is, undertaken on a project basis.

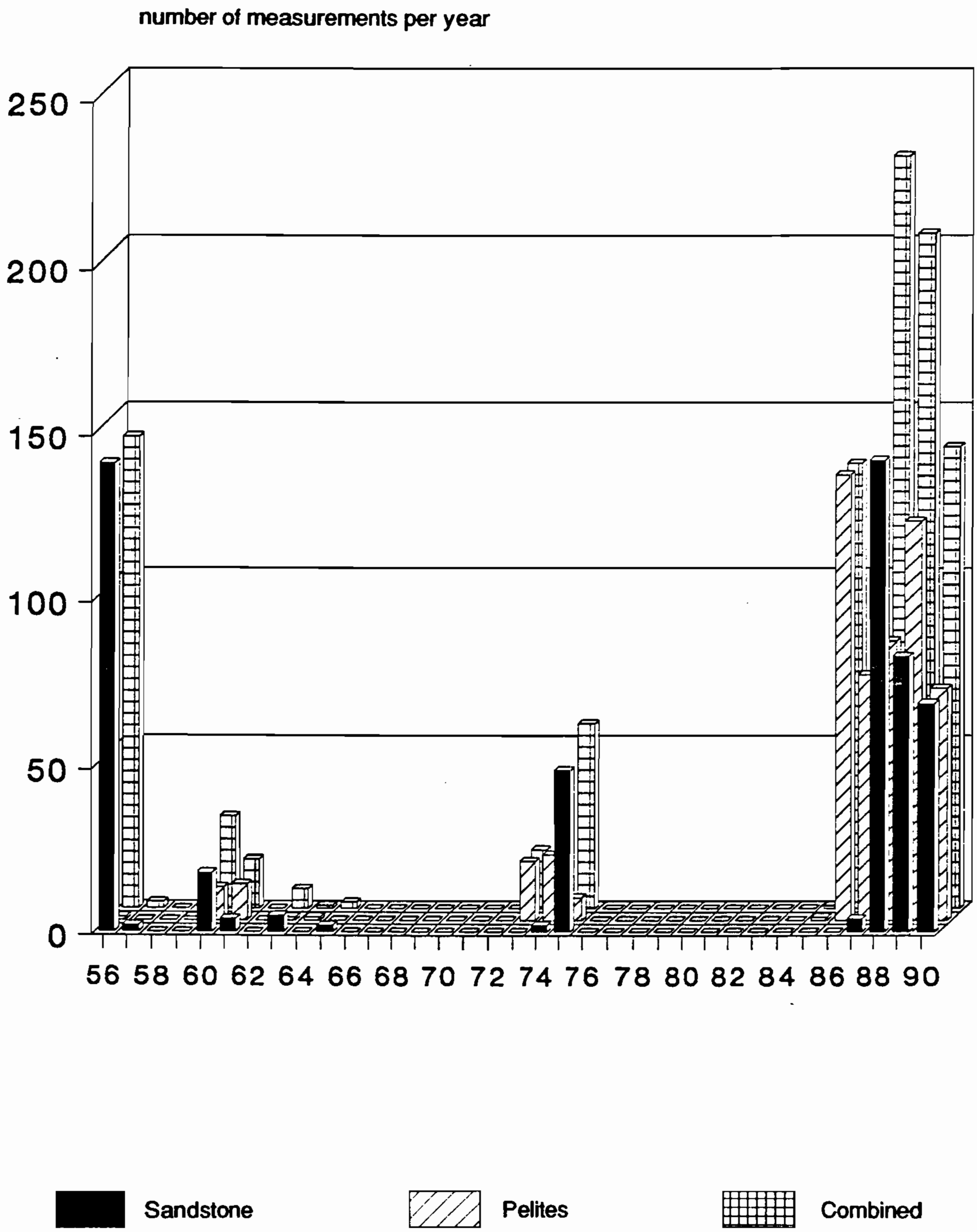
Sediment, whether as instantaneous load or yield for a season or year, can be a very important parameter in the sizing of reservoirs, in determining the need for sediment exclusion works at direct abstraction points, and filtration facilities at treatment works. For these purposes measurements are needed at the proposed site of the new works; this type of requirement is better met by a project based approach than by a general national monitoring programme based around the surface water monitoring network. The effects of land use change on erosion is also a topic of great interest in the region, but to study such processes requires a dense network of monitoring points.

In terms of the day to day operation a sediment monitoring network, at something approaching the minimum recommended level from the UNESCO/WMO guidelines, is currently beyond the capacity of any of the region's hydrometric agencies in the present financial circumstances. Sediment monitoring could therefore be regarded as a secondary activity by the agency because of the difficulty of producing reliable data at the sites of interest to users of the data. In the present financial climate sediment monitoring would seem to be more appropriately handled either as part of a project or as a research programme.

5.6 Water Quality

Networks of gauging points to monitor the quality of surface water bodies are not well developed in the region. Most countries recognise their failure to develop networks to monitor environmental water quality, to safeguard surface water abstractions or to monitor potential pollution sources and have outline plans to rectify the situation. To date, most water quality monitoring is closely linked to

Example of the Availability of Piezometric Records



potable water supply schemes, to assist in regulating abstractions and to ensure quality of the supplied water.

There are similar difficulties with the establishment and continued maintenance of effective water quality monitoring to those described for sediment monitoring, with the need for reliable laboratory support paramount. There are also problems with perception: water quality monitoring is sometimes perceived as a luxury that only developed countries can indulge in and afford. There can also be strong commercial and economic pressures to avoid effective pollution monitoring of major industries.

The need for a network of water quality monitoring points to understand and monitor the 'background' environmental changes is not yet fully accepted, although the potential benefit of such data collection at a few key points within each country is fairly readily explained. Beyond such a rudimentary network there is a need to operate stations to monitor the quality of abstracted water in situations where this may have an important influence on the water treatment or the water users (high fluoride levels in rural water supplies have been identified in several countries at levels in excess of WHO recommendations), and also operate stations to monitor potential sources of pollution.

5.7 Scope for Regional Co-operation in Data Collection

5.7.1 Climate

At the global scale the WMO is a good example of the international nature of weather and climate. Weather systems do not stop at national frontiers. High levels of collaboration in the meteorological and climatological spheres are already a feature of the region. The impetus for this was largely the devastating Sahel drought which brought together national and international agencies in a concerted effort to make data available for planning the timely distribution of food aid and other assistance. The AGRHYMET project is a remarkable collaborative effort involving many countries and contributing to the FAO GIEWS project. Mention should also be made of ASECNA, which assists with aviation meteorology, and CIEH.

Training is obviously an area where regional collaboration can benefit the national agencies. The AGRHYMET centre in Niamey, ASECNA in Dakar, and CIEH in Ouagadougou provide examples of this, however there are also examples in the region of national centres with a high reputation offering training to nationals of neighbouring countries such as the Meteorological Training School in Lagos.

The WMO actively promotes the concept of regional centres, such as in Niamey and Nairobi, and the African Centre for Meteorological Applications and Development (ACMAD) to be based in Niamey. The provision of such a central facility or facilities in the region has the added bonus of acting as a focal point for additional resources and the cross-fertilisation of ideas. As with any collaborative effort in this region there is a need to make appropriate arrangements to involve all the linguistic groups.

5.7.2 Surface Water

As described in Chapter 3 there have been a number of efforts at regional collaboration involving data collection most frequently associated with a river or lake basin. These projects all collect data for an immediate operational task: reservoir management on the OMVS project, flood forecasting on the HYDRONIGER project, chemical dosing on the OCP, etc. A feature which these projects share in common is the use of telemetry and a standardisation within the project on a particular type of field equipment.

Ten years ago the HYDRONIGER project pioneered the introduction in West Africa of advanced technology to water level monitoring in 8 countries utilising 65 data collection platforms and satellite telemetry. Problems experienced with this technology, particularly the field sensors, has been valuable for the design of later systems in other parts of the region. Lessons have also been learned from institutional aspects of this programme.

As with climate, training is an area in which collaboration can be beneficial. CIEH has established two training schools, EIER for engineers and ETSHER for technicians in Ouagadougou. Training can also be obtained at the AGRHYMET centre in Niamey. National centres in Ghana (WRRI) and Nigeria (NIWR) have offered places to students from other parts of the region. In addition to achieving common approaches through shared training programmes there is considerable scope for the preparation of guidelines on procedures which, by harmonising data collection, would permit greater data exchange should international development projects arise requiring data for several countries.

5.7.3 Groundwater

Regional collaboration to date has been more limited in the field of groundwater, however there is considerable scope for developing greater contacts between agencies across national and linguistic boundaries.

The main areas of potential are the widening of scope of training programmes and standardisation of procedures. The CIEH training schools and the Groundwater Section of the NIWR in Nigeria could offer a wider range of courses. A particular need is to develop practical courses for technicians and drilling assistants.

CHAPTER 6

DATA HANDLING

6.1 Present Data Handling Techniques

6.1.1 Overview of Systems Currently Used

The data collection agencies of the region are mostly in a transition period with respect to data handling techniques: in the process of moving from traditional manual systems towards the adoption of computer based systems. Not unnaturally, the movement takes place at different times and different rates across the region; most of the agencies visited had access to computers but none had a completely satisfactory computer-based system. Many agencies were actively up-dating their computer systems at the time of our visits.

Data handling systems cover a wider range of activities than a narrow definition of computer-based data processing would suggest. These systems encompass activities from the noting of readings by observers, through the handling procedures to the central data processing facility, data storage, filing, retrieval and publication. In certain cases, the entire system can be computer-run, especially where data telemetry systems are used to transfer information from the field, for example stations in the network of Benin and stations on the Senegal River maintained by the OMVS.

Good data handling systems are fundamental to efficient data collection agencies, and usually good data handling is more readily achieved through the widespread use of computers. But this is not a prerequisite for, nor a guarantee of, a good system, as examples from within the region can show.

The financial constraints on national services have had an adverse effect on the recent performance of their data handling systems. Problems with data handling are legion, and often stem from a number of fundamental causes, such as:

- poor administrative procedures;
- piecemeal development of data handling systems which may introduce areas of incompatibility and duplication;
- inadequate manpower skills and resources;
- inadequately thought out and inefficient data storage systems;
- poor facilities;
- inadequate supervision of work;
- lack of support and maintenance of computers and software.

The introduction of computer-based data handling procedures presents an opportunity to review the entire data chain for problems and methods of improving procedures - an opportunity that has not always been used in the past.

A major development in data handling techniques within the region in recent years has been the widespread introduction of specialised software for meteorology and surface water: the WMO 'CLICOM' processing system for meteorological data and the HYDROM system for hydrological data. In the field of groundwater, databases written using well known commercial packages such as dBase are now widely available. The current status of computer applications within the agencies is shown in Table 6.1. The widespread introduction of the same packages provides an opportunity to create regional standards for efficient data processing, improved data storage and retrieval systems, and an opportunity for more effective data publication. However, the CLICOM and HYDROM software is not fully utilised in some countries, for such diverse reasons as the non-compatibility of hardware, the lack of training for technicians, or a lack of motivation on the part of the managers. These aspects are discussed in more detail in Section 6.3.

In the anglophone countries hydrometric data handling methods stem largely from advice and publications provided by the USGS in the 1960s, with minor adaption to fit more closely to national administrative procedures and capabilities. These systems were usually developed to be supervised by very few individuals, and as a consequence data processing tends to be highly centralised. In the francophone countries the techniques for data collection and processing were established by ORSTOM (see Section 3.2.8). Data processing is always centralised in the capital, even where data collection is decentralised, as in Côte d'Ivoire. Historically the necessary facilities, such as photocopiers and their predecessors, were of limited availablility elsewhere, the introduction of computers reinforced this situation since the first computerised processing was based on large mainframe systems which were located in the capital. Decentralisation of the primary phase of data processing is just begining, for example the recent WMO project in Côte d'Ivoire, and the advent of cheap robust computers is a key factor in this change.

6.1.2 Raw Data Handling

Most hydrological data are sent to the data processing facility in the form of monthly reports on pre-printed forms, from which data are transcribed for further use. Observers will usually keep a manuscript or carbon copy of the data sent in a register at the site for cross-checking, or repeating reports if the original goes astray. The postal service is frequently used but in some countries data from manual stations is collected during field visits, which are used by all agencies to collect charts from autographic stations. Arrival of data is usually checked in a register, to allow immediate identification of stations that have not reported.

Alternative methods of data transmission include the use of radio, and where reliable telephone and latterly facsimile, these are used to reduce the time lag between observation and reporting, especially for synoptic climate stations used for forecasting and contributing to the AGRHYMET project bulletins. Telemetry systems to transmit data directly to data processing computers are installed in the Niger and Senegal basins, in Benin, in the participating countries of the OCP, and on a small scale in Guinea, the Central African Republic and Congo.

TABLE 6.1

Current Status of Computerised Data Processing

Country	Agencies responsible for Meteorology	Agencies responsible for Surface Water	Agencies responsible for Groundwater
Mauritania	CLICOM, PLUVIOM	HYDROM	FILING ASSISTANT, GES/GROUNDWATER, HYDRO (dBase 3), PROSPER (dBase 3), SAPHYP (dBase 3)
Mali	CLICOM, SAISPL	HYDROM	ATLAS, HVPRO (dBase3), SIGMA (dBase 3), Lotus
Niger	CLICOM	HYDROM	dBase4
Chad	CLICOM,SUIVI (dBase3), AGROM (dBase3)	HYDROM, DIXLOIS	PROGRES, SUPER (dBase4), SOLAIRE (dBase4)
Senegal	CLICOM	HYDROM	SURNAP,GOREE-BOCAR
The Gambia	CLICOM	HYDROM	dBase4 and PARADOX 3
Guinea Bissau	CLICOM, PLUVIOM, CLIMAT	HYDROM	GRIVEL, BADGE (dBase3), Symphony
Guinea	CLICOM	None	PROSPER (dBase 3)
Sierra Leone	CLICOM	None	None
Liberia	-	-	-
Côte d'Ivoire	CLICOM	HYDROM, specialised software for Wang and IBM mini	dBase 3 database on Wang
Burkina Faso	CLICOM	BILTU, HYDROM, dBase 3 & 4	BEWACO (Dataflex), dBase
Ghana	CLICOM	Not yet decided, probably G06 HOMS	Databases
Togo	CLICOM	HYDROM (at ORSTOM, Lome)	AQUABASE, GDM
Benin	CLICOM, PLUVIOM	HYDROM, DIXLOIS	HYDROBASE, PROGRES
Nigeria	CLICOM	HYDATA and HYMOS	
Cameroon	CLICOM ?	HYDROM, TIDHYP	dBase 3
Central Afr Rep	CLICOM	HYDROM (only just installed), Lotus	SIRECAF (dBase 4+)
Equatorial Guinea	CLICOM (ASECNA office)	n/a	n/a
Gabon	CLICOM (ASECNA office)	None	None
Congo	CLICOM, MENUARGO	HYDROM	None
Cape Verde	CLICOM, GS06, RIS (dBase3)	HYDROM, GS06	BIRCA, dBase 3, JACOBFIT, Lotus
São Tomé & Príncipe	none	none	n/a

Notes: CLICOM - WMO climatological processing software (Section 3.3.4).
HYDROM - hydrological software developed by ORSTOM, France.

6.1.3 Data Processing

The organisation of data processing systems in general has room for improvement. Many countries have backlogs of data to be processed, and have significant time delays between arrival of data and completion of processing. The absence of these problems is not well correlated with the presence of computers since they can be caused by inadequate data entry facilities to the computer system.

The introduction of new computer systems will often create the need to enter historic data into a usable, compatible format which can be a very time-consuming activity, and there is a danger of introducing errors. Most agencies are stretched to maintain the processing of incoming data and cannot afford the additional burden of computerising historic records without external assistance. Bilateral assistance led to a project to prepare an exhaustive inventory of the rainfall data existing in francophone West Africa and to computerise these records, the project started in 1973 and was managed by CIEH with ASECNA and carried out by ORSTOM. The project was carried out in two stages: the first preparing data sets for stations from their inception to 1965, and the second from 1966 up to 1980. The process involved the microfilming of the original daily records, the entry of the data onto computer, detailed quality control, and finally publication of the data in 1989. The project output consisted of the finalised data sets in the form of data books, microfiche of original data sheets, and data files in a format compatible with the software package PLUVIOM.

There is a growing recognition that hydrometric data processing should closely involve the meteorologists, hydrologists, and hydrogeologists familiar with the monitoring sites. This would often mean that field or regional offices of the data collection agency (where such staff are based) need to be more fully involved with the data processing work. The advent of the computer age has tended to centralise processing to a special unit within the organisation largely without practical hydrology experience. The advent of cheaper and more robust computers should allow de-centralisation of this work, leading to a fuller involvement of the field experts.

6.1.4 Quality Control Procedures

Quality control of hydrologic data should begin with regular site inspections, re-calibration of instruments and similar checks. These are rare in the region, due to insufficient resources rather than a lack of understanding of the importance of such procedures. Observer training and checks on observer techniques are areas that are also largely ignored. In practice quality control procedures tend to begin with receipt of returns in the data processing unit at headquarters.

Upon receipt of data there will usually be a visual inspection of the return to check for unexpected values, obvious transcription errors and the like. Occasionally, data will be cross checked with returns from adjacent stations or compared with seasonal norms. Standard practice would then be to raise any data queries with the observer in correspondence, or at the next inspection visit. However with limited budgets many of the agencies do not have enough staff to check as well as register incoming data or the transport for field visits.

Following acceptance of the field return, the data would be transcribed, either on to standard summary forms/ledgers or entered on to computers, with arithmetic means calculated, maxima and minima identified and similar rudimentary analysis. There is evidence that in some agencies there is no checking of this transcription. Further processing, such as the conversion of stage heights into discharges, is likely to be delayed until a full set of values is obtained for an entire year at any station. Quality control at this stage is variable, dependent upon the care with which office procedures were established and are maintained. Frequently it is limited to a cursory supervision, and visual checks on the computed output. Rarely are objective quality control checks used, such as double mass curve analyses or correlation with adjacent records.

Even when computers are used for the bulk of the processing effective quality control analysis on the information generated is not carried out either because of limitations in the software employed or the technicians have not mastered the use of the checking routines where these are built into the software.

6.1.5 Data Storage and Retrieval

Given the range of experience with computerised data management systems across the region it is not surprising that there is considerable variation in the degree to which current and historic data are stored on computer. For this assessment we requested certain sample data and basic information for the compilation of inventories, and the format in which this was supplied, if it was supplied at all, reflects the effectiveness of present practices.

In certain countries it was possible to obtain information on disk during the country visit (eg. Benin and Congo), however the primary source of processed data from many of the data collection agencies visited was on paper. Sometimes these were hand-written ledgers, on other occasions loose sheets within a file. In agencies with several years experience of computerised processing fresh computer printout was the easiest way to retrieve hydrological data, agencies only recently started on the path of computerisation do not have enough historic data on system to utilise this option. In a number of instances historic data on 'master' computer printouts from defunct mainframe processing systems was photocopied for our use.

One of the most disconcerting aspects of the present data storage and retrieval systems was revealed when we sought to compile data inventories, and it was found that there was often no simple way of finding out what data existed for any particular station. Where a computerised system was employed technicians were often more familiar with the routines for data processing than those for data management and archiving. Where specialised software has been used to computerise all national records, as is the case for rainfall in francophone countries (Section 6.1.3) and staff can operate the system to its full potential such inventory information should be readily available (see Figure 4.3).

In the present systems, the key methods of disseminating data to those who need to use it is through the use of photocopiers, or through published yearbooks, monthly or 10 daily bulletins and data summaries. Yearbooks, especially for earlier years, tend to be in short supply, so data are sometimes provided as photocopies from a yearbook.

A particular concern is the vulnerability of much of the original data to loss through fire, water damage, being eaten by ants, being sold as waste paper or any similar fate. The activities of the on-going DARE project are very important in this respect (see Section 3.3.5), but the project covers only meteorological data and does not cover all the countries of the region. The CIEH project completed in 1989 which prepared a detailed inventory of rainfall data in 13 countries from station inception to 1980 including microfiche, data books and computerised data bank is also a valuable safeguard. With the advent of computers, data can be stored in more than one location, but this, in itself, is no guarantee of survival. The Nigerian experience with the hydrological data bank at the NIWR Kaduna, and Ghana's millions of currently unreadable computer cards of climatological data bear witness to the potential fallibility of computer systems.

6.2 Data Storage and Processing in the Future

6.2.1 Basic Requirements

Future systems should meet certain minimum requirements in a number of areas. Some critical features of such systems would include:

- reliability: there should be sufficient backup of the storage methods that one catastrophe (such as a compiler breakdown or fire) would not destroy data completely, and the basic systems should continue to function in adversity, such as computer breakdown or staff shortages;

- speed: the data should be promptly processed and available for retrieval from the system within a few months of collection;

- flexibility: the system should be adaptable to current administrative processes (to reduce the trauma of the introduction of new systems) and to likely future developments;

- ease of use: the system should be operable by a minimum number of trained staff; and operable by staff that constantly change;

- involvement of field staff and supervisors: the system should allow close supervision of the data processing procedures by officers external to the data processing unit, providing the necessary tools to assist their involvement;

- quality control: a powerful range of quality control procedures should be included in the data processing procedures;

- ease of data retrieval: data storage must be organised to facilitate rapid retrieval of information for a range of search patterns, for example all data for one station, all data for one year, catalogues of available data for one region;

- software support: for all computerised systems it is essential that adequate support and training be available and that upgrades should be provided regularly to correct bugs and to take account of new technology, for example the replacement of plotters by laser printers or autographic recorders by electronic devices.

6.2.2 Evolution of Future Systems

Future data systems within the data collection agencies will, inevitably, be tied to the acquisition of computer hardware and specialist software. This acquisition is also likely to be part of an externally funded project. However, a data storage and processing system is larger than a computer and its software, and should include control of the inputs and outputs to the machine, operation of backup systems and similar activities.

The acquisition of a new computer and software will often provide a good opportunity to overhaul the full data handling systems, especially if advice on this process can be provided as an element of the project to supply and install the computer. However, there are major dangers in abrupt changes to data systems, and careful consideration must be given to the ability of the observers and technicians operating the existing system to fully adapt to the new procedures. Extensive retraining, a gradual introduction of new methods and similar steps should be considered, along with efforts to make the new system as similar as possible to the old for those less closely involved with the actual data processing.

6.3 Computerised Data Handling

6.3.1 Introduction

Computerised data handling has already been introduced to many of the region's hydrometric agencies, see Table 6.1, although full computerisation is still to be achieved anywhere. The case for computerising the processing and storage of hydrometric data can be summarised as follows:

- ready access to data;
- easy to select data for analysis;
- rapidity of processing.

If the conversion of data handling to computerised systems is to be judged a success it must show an improvement over the existing manual systems. However a necessary pre-condition of a successful data handling system, whether manual or computerised, is good management and a sufficient number of well trained staff. In a situation where the existing manual systems are overstretched or poorly supervised the introduction of computers cannot provided the whole solution. In fact under certain circumstances the introduction of computers might worsen the situation, particularly with respect to the long term safe storage of data.

It must be recognised that computers are not yet in widespread usage in the West African countries and that as such there are difficulties in introducing computers to a government agency in the region which would not be expected in countries where the computer has permeated almost every aspect of daily life. The computer operator in West Africa is largely on his own to resolve any problems which occur whether with hardware or software. Manufacturers 'help lines' and support services do not reach the region and the entire processing operation of an agency may be brought to a halt by relatively minor technical problems. As computers become more widespread and computer sales and repair facilities develop computerised data handling for specialised tasks such as hydrometry will become easier.

6.3.2 Meteorological Data Handling

As can be seen from Table 6.1 a feature of the development of computerised data handling within the national meteorological services is the extensive provision of one particular system - CLICOM. The CLICOM system was developed at the NOAA National Climatic Data Centre in the USA in support of the WMO world climate data program (see Section 3.3.4). The system is being actively promoted by the WMO in the form of program distribution and training seminars and is becoming something of a de facto international standard. The experience of this WMO programme, which has provided CLICOM to 70% of the regions's meteorological agencies, is obviously of great value when planning the introduction of data processing of this type to the agencies responsible for surface and groundwater.

On our visits to the meteorological agencies we were able to judge the effectiveness of the system in each office, (the 'system' here comprising the hardware, the CLICOM software, and the trained operators). The general conclusion was that the systems were far from fully operational and that vital support was lacking. It would appear that the WMO programme has not made sufficient allowance, in the form of training and backup support, for the inexperience with computers in the region.

Examples of problems encountered range from bugs in the software (particularly the French language version) - menu entries in the wrong language, disappearing data not apparently stored after entry - to hardware problems - difficulties with the optical disks used for data storage. There is also clearly a problem of inadequate training in many offices which could frustrate efforts to fully implement the system even if there were no inherent deficiencies in the software or difficulties with hardware.

6.3.3 Hydrological Data Handling

Whilst the meteorological services have been supplied by the WMO the services responsible for surface water data collection have received assistance with the introduction of computerised processing under bilateral aid. Table 6.1 clearly shows that one package, HYDROM, has been provided in numerous countries, but since its introduction reflects the pattern of French aid it is unlikely to be adopted outside the francophone countries, although The Gambia which is a member of the AGRHYMET project has received the system. HYDROM is only one of a number of similar packages designed for this application, most of the other packages are also associated with national research organisations in Europe (for example, HYDATA - the Institute of Hydrology, UK). It is unlikely that the existence of more than one processing system in the region will hinder the exchange of information between countries and/or regional projects since data can usually be imported or exported in ASCII format.

In the region there are examples of both national agencies and regional projects which utilise electronic field stations in conjunction with satellite transmission (Section 5.3) and which are therefore able to transfer the data directly to the processing software. This has the benefit of cutting out a manual step in the data handling - typing in the data, taking off data from charts, etc - which considerably speeds up the handling and removes one potential source of errors.

With the advent of cheap robust computers and the user friendliness of software such as HYDROM capable of managing all the primary tasks of data entry, simple checking, archiving, and the processing of current meter measurements and rating analysis there is an opportunity to decentralise aspects of data handling to be undertaken by staff in regional offices.

6.3.4 Groundwater Data Handling

A feature of groundwater records is the very large number of sites usually involved, particularly when compared with, for example, the number of river gauging stations in a national network. This type of information is best handled by commercial relational database packages of which there are a number such as the popular dBase from Ashton Tate.

Using dBase it is straightforward to set up a groundwater database allowing for a large number of parameters at each site tailored to the individual requirements of the national agency, and relatively straightforward to design input and output formats. It is perhaps as a result of this ease of use that even within one country there may be two or even more separate databases of groundwater information each associated with a particular project. As Table 6.1 shows a feature of the groundwater sector is the number of databases within a single country. There are few examples of linkages between these databases and thus the data remains compartmentalised on a project basis and it is difficult to bring together elements of this data for further analysis. Given that most of these databases have been prepared by using proprietary software it should be possible for a competent programmer to write the necessary routines to link the existing databases. Such skills are not currently available within most of the region's agencies. However CIEH have recently taken steps to rectify this situation by publishing interface software developed with the assistance of consultants.

6.3.5 Observations

A number of observations can be made on the current status of computerised data handling in the region:

- hardware support is minimal and a very real problem despite the robustness of the latest generation of microcomputers;

- hardware choices are generally determined by the donor and do not necessarily take account of existing equipment or the limited repair facilities available in most countries;

- processing is generally highly centralised and maintained by a few trained staff in the headquarters or the project office;

- staff turnover is high in many agencies (computer skills are readily marketable), and new computer operators frequently have to be trained;

- quality control is variable, and there are even instances of databases on which no checking for transcription errors has been undertaken, this is potentially a serious deficiency because of the tendency to regard data printed out by the computer as correct;

- where technical assistance has been provided long term, or the database has been maintained as part of a specific project, the systems have operated relatively successfully, but where, as with many of the CLICOM installations, insufficient support has been provided the system has not fulfilled its potential;

- some of the region's agencies who introduced computerised processing to parts of their operations in the era of mainframe systems have been unable to transfer the information captured on the mainframe system to the microcomputer and have as a consequence to re-enter the data with the attendant risk of introducing errors;

- the operation of computerised systems for the entry of up-to-date data is relatively successful where it has been introduced (with certain exceptions), but to computerise all the historic data held by each agency is an enormous task which is generally beyond the capacity of the staff of computer operatives and the number of machines, in CIEH member countries the capture of historic rainfall records on computer was accomplished under an assistance programme;

- it is not clear that the long term storage of computerised data is being properly addressed, as technologies change old storage media may become obsolete, magnetic media deteriorate over time, etc.

Above all computer data handling systems require good management. They are more demanding of management than the manual systems they replace. Essential management activities include: ensuring the routine backup of data, organising the regular checking of archive data to ensure that the storage medium has not deteriorated, maintaining the reliable supply of consumables, arranging the regular servicing of equipment, planning for the continued upgrading of equipment and software taking account of the need to maintain continuity/compatibility, organising staffing to ensure that sufficient adequately trained operators are available to run the system and that their work is supervised by a qualified professional to ensure that all quality control checks are carried out. A failure of any one of these may endanger the long term security of the data.

6.4 Publication and Dissemination of Data

6.4.1 Present Policies

The traditional method of publishing and distributing hydrological data has been through the use of yearbooks, producing an annual summary of daily data for the majority of reliable gauges and periodic data summaries. This method is still aspired to in much of the region, especially in hydrometric agencies, but the workload involved in the preparation of such documents is large, leading to considerable delays in publication.

The advantages of this technique are the wide distribution and availability of information, with its consequent reduction in data requests to the agency from users, and the discipline of having to process all data before the publication date. Disadvantages are the work involved in producing the document, and the tendency to regard data published in each book as accurate and unchangeable. This latter aspect can have serious consequences: the data being readily available to the public means that people with no background in hydrology can use the data without discussing its limitations with the collection agency, and without appreciating the sometimes large uncertainties in computed discharges.

More recently, key meteorological data have been published, in a somewhat restricted manner, at much more frequent intervals usually 10-daily. This has largely been the result of the AGRHYMET project in support of the FAO 'Global Information and Early Warning System' project, with its requirements for regular and up-to-date summaries of agro-meteorological conditions.

Otherwise, data are distributed in response to specific data requests, largely in the form of photocopies of master data summaries, or transcribed information. Data requests are not very numerous, as frequently the main users of data are from within the same ministry or department as the data collection agency. Increasing use is being made of computer outputs, either in printed form or on floppy disk, but this is yet to become widespread.

6.4.2 Future Developments

The key to the future methods of data distribution will be the computer, with its ability to rapidly select stored data and reprint it. Provided the data storage system is designed correctly, and sufficient supplies of computer stationery remain available, printout is likely to be a satisfactory form of presentation of data for many users in the future. Other data distribution systems, such as the use of floppy disks to supply data in a directly usable form, will be more and more utilised. However there may be difficulties of compatibility if appropriate co-ordination measures are not taken between different projects.

This is not to say that the publication of data should not be continued, and it is believed that the publication system has a very important role to play in advertising the data availability, explaining how it could be obtained and informing a wider audience of key parameters of hydrological behaviour. It is anticipated that the format of the new style of publication might be along the lines of an annual report, containing such elements as:

- key station data summaries similar to those of the present generation of yearbooks;
- catalogues of data held for other stations;
- information on how to obtain data not published;
- accounts of applied research, data reviews and any reprocessing undertaken during the year.

These publications should be produced as rapidly as possible after the end of the water year, and within the 12 months following the period to which it pertains as an absolute maximum.

The use of this format should retain the 'advertising' advantages of the present yearbooks, be much quicker to produce, be more informative and yet ensure that for detailed information users come to the hydrometric agency, allowing those responsible for data collection and processing the opportunity to explain any uncertainties or reservations concerning the quality of the data, and advise on its use for the proposed applications.

CHAPTER 7

INSTITUTIONAL DEVELOPMENT

7.1 Introduction

Two types of institution are examined in this chapter: the national agencies responsible for data collection in the fields of meteorology, surface water, and groundwater; and the most important of the regional institutions and projects, that is AGRHYMET, CIEH, the OCP, the OMVS, and HYDRONIGER. Whilst the examination and recommendations for further development for the national hydrometric agencies are the result of detailed assessment for each service in each country, the examination of the regional organisations and projects has been conducted at a less detailed level.

The examination of existing regional organisations/projects was carried out as part of the process of developing our ideas for suitable organisational structures for new regional projects identified during the overall assessment study.

The present state of health of organisations in the water sector, whether national or regional, is directly related to the adverse economic situation prevailing throughout the West African region for the last decade. At times of economic stringency hydrometric data collection is often accorded a very low priority when limited funds are to be allocated. If these organisations are to develop there is a need to increase regular annual funding. In recognition of the fact that the importance of the services performed by these agencies to national and regional planning is everywhere undervalued we have included a section discussing the financial justification for these activities.

7.2 Financial Justification for Hydrological Data Collection

Recent experience has shown that hydrological data collection agencies are a common target for emergency budget trimming exercises periodically forced upon governments. This results in considerable uncertainty over whether funds for equipment, repairs and maintenance, and day to day running costs would actually be available when required. Consequently, organisations are reluctant to commit themselves to local currency expenditure of this type, and the momentum and morale of the agency suffers. Recent economic problems throughout the region have led to very large budget cuts in real terms, forcing most agencies into recession and damaging data networks. Strong revival will only come when budgets are increased, allowing equipment (monitoring equipment, vehicles, and computers) to be restored to an operational level. Whilst this is an essential first step the effort will be wasted unless it is accompanied by assured financing for running costs (maintenance, repair and progressive replacement of equipment, fuels, payments to observers and technicians) for a period of ten years.

In order to lobby more strongly for larger budgets, the economic benefits that arise from good quality data need to be known in order that decision makers can be made aware of the hazards of designing projects without hydrological data or on the basis of inadequate data.

In the past few years a number of studies have been undertaken (WMO,1990) to place either a value on the collection of surface water data, or to establish norms for the number of stations required.

The UNESCO/WMO (1988) 'Water Resources Assessment Activities - National Evaluation' was one such attempt at assessing national network design by establishing world norms. This is discussed in Chapter 4. However, only minimum standards were set, and as it was almost impossible to differentiate between good quality stations and poor quality stations, the methodology is unlikely to be of significant value in providing national authorities with a definitive tool for assessing the justification for expenditure on data collection services. Tables 5.1 to 5.5 do however indicate a wide range of station densities across the region; although in most cases such factors as density of population, size of country, and economic constraints tend to be the dominant factor. The methodology does highlight areas where national authorities are failing completely to provide a service, monitoring of sediment and water quality for example.

Benefit-cost analyses have been undertaken in recent years to try and value the benefits from data collection. One such study was undertaken by the Australian Water Resources Council (AWRC, 1988). This study aimed to demonstrate the value of surface water resource data by identifying the many and varied uses to which the data are put. Figure 4.1 illustrates the general field of applications. The report also dealt with the cost of collection of data, a review of existing benefit-cost studies and the costs of water development projects.

The first step in assessing the financial justification for hydrological data collection is an evaluation of capital and recurrent expenditure on water resources development projects and works where an input of water resources data is an essential requirement (see Figure 4.1). The second step is an evaluation of the benefits of this data and the extra costs incurred should the information not be available or not be to a satisfactory level of reliability. For example, if flow data or rainfall data were not available then additional safety factors would have to be built into the design of a spillway for a new dam, so increasing costs. A quantitative evaluation of this type has been undertaken for Canada (Acres, 1977).

Table 7.1 taken from the AWRC study shows the breakdown of estimated annual expenditure on projects in Australia where hydrological data was required as part of the design process. The benefit factor associated with each category of project reflects the importance assigned to hydrological data. The overall benefit-cost ratio was estimated as 6.3. Clearly when the methodology is transferred to other countries with different climatic and economic conditions and a different mix of water development projects the benefit factor assigned to a particular type of project could change. For example the benefit factor assigned to flood forecasting in the Canadian study was double that utilised in the Australian example.

TABLE 7.1

Expenditure on Structures and Projects Sensitive to Hydrologic Design in Australia (after AWRC, 1988)

Item	Estimated Expenditure (A$ million)	Benefit Factor %	Estimated Benefit	Cost of Hydrometric Services (A$ million)
Drainage for all roads (excluding urban drainage)	330	10	33	
Urban drainage	70	5	3.5	
Drainage for railways	40	10	4	
Water Supply	600	5	30	
Irrigation	200	10	20	
Spillway modification	100	10	10	
Small farm dams	20	10	2	
Flood protection	20	5	1	
Flood forecasting	150	5	7.5	
Hydropower	30	5	2	
TOTAL	1 560		113	18

As part of the companion hydrological assessment covering the SADCC member countries a simplified version of the methodology developed in the above mentioned Australian and Canadian studies was used to make preliminary benefit-cost estimates for hydrometric activity in each country (MacDonald, 1990). The simplifying assumptions mean that the results of this exercise should be treated as giving the correct order of magnitude only. The estimated benefit-cost factors for the African countries were generally substantially higher than for either Australia (6.3) or Canada (9.3). This is to be expected as in the SADCC countries current expenditure on hydrometry is low, squeezed as in the West African countries by economic difficulties, and because anticipated developments in the water sector are limited in countries where infrastructural development is well advanced. The factors obtained for the SADCC countries ranged from 4 to 69 which clearly indicated that significant benefits would be derived if each country spent more on hydrological data collection.

The results of this type of analysis serve to confirm the widely held view amongst those employed in the water resources sector in West Africa that funding for hydrometry should be increased. Benefit-cost ratios for the West African countries would be expected to fall into the same range as shown for SADCC countries.

An interesting development in Ghana is worth reporting. The Volta River Authority (VRA), which has a steady income from sales of power generated at Akosombo and Kpong dams, has been persuaded to develop collaborative projects with the national agency responsible for surface water data collection, whereby the agency, whose own budget is severely restricted, has been able to resuscitate parts of the monitoring network in the Volta basin. In this case then, a user of hydrological information, the VRA, has accepted that the data collection and processing activities of the national hydrometric agency are of value to it and that the cost of contributing to the agency's budget to ensure the continued supply of reliable data is worth bearing.

Among West African countries a significant part of the expenditure on data collection is undertaken on specific project studies. The implications of this in terms of the role of the national hydrological agencies and their budgets for data collection require consideration. The agencies may benefit from financial assistance and training during the lifetime of a project but projects may also have a deleterious effect on their operations in the longer term. For example, when a feasibility study is completed it is usually recommended that data collection should continue at the site to provide further information for later phases in the project should it go ahead, however additional funds are rarely made available to the agency which inherits the responsibility. The agency, with limited means at its disposal, may have to reduce another area of its operations in order to cover the additional work. Perhaps more insidious is the fact that project studies may result in the attention of both agency staff and planners being diverted away from the vital task of collecting long term, continuous records from a national network of representative stations. Such records are needed:

- to sample extremes of rainfall, floods and droughts;
- to detect the effect of changes in land use;
- to provide data to improve statistics for long term mean and statistical distribution;
- to monitor long term trends in climate; and
- to study long term aquifer recharge from rainfall.

It is important to stress that information collected from a short study (feasibility and design studies rarely exceed one year these days) does not, and cannot, supersede long term records. Project studies cannot therefore replace a basic network and are only supplementary to it.

7.3 National Services

7.3.1 The 'Ideal' Data Collection Agency

Development of the region's national data collection agencies should lead them towards the goal of the 'ideal' organisation. Amongst its principal attributes would be:

- a dynamic self-rejuvenating system, whereby young entrants to the organisation would receive, largely internally, the training and experience to replace senior staff, in the continuing cycle of development;

- production of reliable, accurate hydrological data for a network sufficiently dense to provide estimates of hydrological behaviour at any point in the country to an acceptable accuracy;

- easily accessible data for external use and analysis;

- a core of applied scientific researchers within the organisation with established links to universities and international organisations to act as a centre for technical knowledge concerning national hydrology.

Although attainment of such a position may be a long way off, there are clear directions for the national organisations to recognise as the paths to follow and to plan development accordingly.

7.3.2 Organisational Structures

Most national data collection agencies form part of government departments, run directly by ministries and controlled by established civil service rules, regulations and habits. These are frequently strong restraints on the development of the agency, and stifle its evolution. A much more flexible approach can come from the establishment of the agency as a semi-autonomous body, under a much more powerful Director but still subject to government approval and indirect control. The agency would then be able to compete for good staff in the national market place, and offer more flexible career structures. Funding, being indirect, would be more secure in the short term (but still subject to medium- and long-term uncertainties and national economic problems).

There is a perception that most data collection agencies in the region have too rigid and hierarchical a management structure, leading to a lack of motivation and enthusiasm amongst junior staff, and too little devolution of responsibility. It is believed that more modern management techniques, that will usually be easier to introduce in a semi-autonomous organisation, could greatly improve productivity of junior staff.

Clarification of organisational roles and responsibilities is also essential to avoid unnecessary duplication of work. In several countries, two or three agencies run rainfall networks in parallel, with minimal co-ordination of efforts and reluctant exchange of data. Who operates the rainfall stations is not an important issue, (although savings might accrue if a single agency were responsible) but it is vital that one agency is responsible for handling the data and that all field data should be sent directly to the concerned office to minimise delays in the processing work.

There has been a tendency in some countries to experiment with different institutional arrangements in the water resources sector, these re-organisations have generally proved very disruptive and there are examples of loss of historic data during office moves. At the time of our visits to a number of countries the water sector was either undergoing re-organisation, had just been re-organised, or was under threat of re-organisation. This complicated the assessment, and in particular caused difficulties in identifying and developing project proposals for improving or increasing hydrometric activity.

7.3.3 Equipment

The procurement of hydrological instruments and computer equipment for the region's data collection agencies has usually in the past been tied to aid projects - often being supplied under bilateral aid as a grant. This type of approach has the disadvantages of:

- several makes of equipment in use within the agency, with consequent duplication in effort to learn how to operate, service and maintain it;

- often poor to non-existent support for repairs, maintenance and supply of spare parts;

- little control over the specification of equipment, and occasional supply of equipment ill-suited for its intended environment.

In future procurement more attention must be paid to local backup facilities to ensure that the equipment supplied - even as a gift - can be kept in a serviceable condition. Bilateral aid agencies should become more sympathetic to these problems, and develop methods to ensure appropriate equipment is made available. Options would include:

- giving maintenance requirements, and local capability to meet such requirements, a much more prominent place in the evaluation procedures by which hydrological and computer equipment is selected;

- encouragement of manufacturers, whose equipment has proved itself in the field under similar environmental conditions, to establish assembly plants within the region, with initial firm orders to encourage the initiative, in order to ensure local support for products;

- including effective training on equipment maintenance with supply orders;

- including funds for spare parts and guarantees of their availability, and provision for maintenance engineers to visit the region to rectify equipment malfunction.

7.3.4 Transport

Transport facilities - or the lack of them - are a major influence on activities in the hydrological sector, with problems reported in virtually every agency visited. The traditional means of field transport has been the use of four-wheel drive 'Land Rover' type vehicles that are expensive to acquire and expensive to operate. The availability of cheaper 'pick-up' style alternatives with four-wheel drive, and a general improvement in road networks offer the possibility of lowering the cost of transport provision in the future.

Consequently there are considerable potential savings in the operating costs of transport. Options identified are:

- greater use of vehicles such as pick-ups for field duty;
- use of motorcycles for activities such as site inspections, recorder chart changing, etc.

In certain circumstances it is possible to envisage solutions which are commonly used in developed countries, for example:

- the hiring of additional transport at times of peak demand (usually the wet season);
- encouragement of the use of private vehicles by offering officers loans to purchase vehicles and realistic mileage rates to use them on official duty.

However it is clear that arrangements of this type would be unrealistic in many countries at the present time.

Some agencies are also looking into the use of telemetry for remote sites as this would allow the instrument condition to be established and data retrieved without the need for a field visit. Field visits would still be essential to maintain gauging programmes, and to repair equipment identified by the telemetry as malfunctioning, but the number of field visits and the total distance travelled during a year is far less for a telemetry system than for a conventional network.

7.3.5 Manpower

Manpower represents another major problem area to the present operation of the data collection agencies, especially the recruitment, training and retention of the high calibre of staff needed to operate and develop the agency. Recruitment of the right sort of staff needs changes in a number of areas if self-rejuvenation is to be achieved, including:

- changes of disciplines and syllabi of undergraduate courses;
- widening the recruitment base to include earth scientists, physical scientists and mathematicians;
- improvement in salaries, fringe benefits and working conditions;
- an improved perception of the importance of the data collection agency, and the role it is to play in national development.

In addition to such changes, more emphasis is needed to be given to the continuing education of employees in terms of intensive vocational courses, diploma and postgraduate courses, attendance at national and international seminars and conferences. Intra-regional staff exchange to provide incentives for the individuals concerned and to provide a means of exchanging ideas on techniques and data analyses could prove to be beneficial. The basic requirement is a change of attitude: for the management to regard the staff of the data collection agency as its primary resource and to treat them accordingly.

7.4 Regional Organisations and Regional Projects

7.4.1 Introduction

In developing proposals for regional projects (ie involving more than one country) we looked in some detail at the existing examples of regional organisations and their associated projects in an attempt to highlight those aspects of these bodies which have demonstrably been successful and to identify features which have not worked well for a variety of reasons. The following sections deal with the international basin development authorities (NBA, OMVG, OMVS, and LCBC) as a group, and in detail with the most significant regional structures: the projects AGRHYMET, the OCP, HYDRONIGER; and the CIEH.

The analysis utilises a technique taken from business studies referred to by its acronym SWOT which examines the present status of the organisation and its activities in terms of 'strengths' and 'weaknesses', and its future prospects in terms of 'opportunities' and 'threats'. This approach highlights those attributes which may be built upon for the future and those which are detrimental and must be dealt with to improve the organisation's performance.

7.4.2 SWOT Analysis - International Basin Development Authorities

The international basin development authorities cover as a minimum the geographic area of the named river catchment, often having a larger responsibility for the entire territory of all their member states. Thus the OMVG may be concerned with water sector development outside the actual catchment of the Gambia River but within the territory of Guinea Bissau, which is a member by virtue of having 0.06% of its territory within the Gambia River catchment. These organisations may also take a wider role encompassing development outside the water sector but within their geographic area. The SWOT analysis which follows is limited to those aspects of these organisations which affect their role in hydrometric data collection and water development projects. The analysis has not been carried out for each organisation individually but on the basis of our perception of their shared characteristics.

STRENGTH	WEAKNESS
Encourage collaboration between national agencies. Exchange of information, and training benefits from national staff seconded to the organisation. Successful in obtaining donor support for development studies in water sector. Management of the inputs to such studies (experts, computer programs).	Funding arrangements: donor financing for studies, with contributions from members (financial or counterpart) for running costs. Withholding of member's contributions due to economic difficulties. Withholding of contributions for political reasons, hostage to other national aims. Disparity between members in terms of benefit/cost ratio for agency activities. History of mismanagement of funds.

OPPORTUNITY	THREAT
As water becomes increasingly scarce competition between uses and users, both national and international, make international co-operation essential. Many countries have undertaken 'structural adjustment' programmes which should improve their economic situation and development projects, which had been placed on hold, are being re-examined.	Lack of funding, the organisation's activities not seen by individual members as value for money. Unwillingness of donors to put project funding through an organisation thought to be lacking wholehearted member support.

The SWOT analysis naturally highlights the importance of international co-operation in planning the utilisation of the water resources in a shared basin particularly as demand for water is rising everywhere and competition for the finite resource becomes more intense. However it is not clear from this analysis that the type of organisation examined, which has significant running costs to maintain facilities and staff, is necessarily the best way to achieve the desired levels of co-operation. In fact dissatisfaction with the perceived value for money that members feel has in the past led to disputes and withholding of contributions.

7.4.3 SWOT Analysis - The AGRHYMET Programme

STRENGTH	WEAKNESS
Successful in involving country agencies in the programme. Training of country staff key element. Successful implementation of 10-daily bulletins containing agro-meteorological data feeding into the FAO GIWES.	After 20 years still require large inputs of outside technical assistance.
OPPORTUNITY	**THREAT**
Further develop capability of the centre in Niamey to carry out analysis and research based on the continuing data inflow.	Danger of increasing effort at the centre at the expense of the national programmes and thereby loosing the crucial support.

In this case the SWOT analysis highlights a number of positive points which can be incorporated when designing new regional projects.

7.4.4 SWOT Evaluation - OCP

The Onchocerciasis Control Programme of the WHO is discussed in Section 3.3.6, this section deals with the operation of the hydrometric network associated with this health programme.

STRENGTH	WEAKNESS
Regional network of monitoring stations and field teams operating in 9 countries. Good management of staff, successful integration across national boundaries. Operational use of telemetry on a grand scale. Major stock of automatic stations (100 field stations and 2 receiving stations)	Maintenance of the hydrological network and the preparation of a hydrological data base is not an explicit objective of the project. The telemetry network, field teams, and data analysis are managed by an expatriate project team. The hydrological data collected is not stored in a data bank.
OPPORTUNITY	**THREAT**
Funding guaranteed to year 2000. Possibility for the organisation of institutional safeguard of telemetry data via the international agencies WHO and WMO. Compatibility of project stations and equipment with other projects with which links could be developed.	Difficulties of agreement/co-ordination between agencies, both international and national, in the water and health sectors. That new developments in the treatment of Onchocerciasis may render dosing rivers unnecessary. Difficulty in maintaining the network if the OCP is terminated.

The OCP's particular need for up to date and reliable information on river flows on a regional basis in order to maintain an effective programme of chemical dosing has led it to install an advanced hydrometric network on a large scale and today it is a leader in the field of hydrological telemetry in the region. The benefit to the OCP of this approach in terms of the effectiveness of the dosing programme has been such that the telemetry equipment has paid for itself within two years.

The OCP has demonstrated that, given good management (provided in this case by outside experts) and assured funding, the latest generation of hydrological equipment linked by satellite can be robust and reliable in operation and, combined with a regular field programme, can produce hydrological data of high quality in the difficult physical environment of the region.

However, because the OCP is primarily a health programme the hydrological data collected is so specific to the project needs that it is of little or no value to planners in the water sector, indeed the data is not further analysed or stored. The water level data is transmitted to two centres (Odienne, Côte d'Ivoire and Lama-Kara, Togo) either by satellite in the case of certain stations or by conventional means from non automated stations (such as in Sierra Leone or Ghana). The data is processed to obtain the vital discharge data for the chemical teams and is then discarded. The information on rating curves is retained but is not made available to the countries' national hydrometric services.

Should the OCP turn to alternative approaches to disease control it might no longer have a need for hydrometric data. The network could possibly be transferred to another agency and its function changed to provide water resources data, a large number of OCP stations would merit a place in a general network monitoring African rivers and the introduction of procedures to process and archive the telemetry data as a computerised database would require the minimum of supplementary effort.

7.4.5 SWOT Analysis - The HYDRONIGER Project

STRENGTH	WEAKNESS
Telemetry network monitoring water levels throughout the basin (65 stations). Centre in Niamey with receiving facility and computer systems. National receiving centres. Developed and calibrated flood forecasting models.	After 15 years still require large inputs of outside technical assistance in support of the network of DCPs and computers. Outdated equipment (sensors and receiving stations) Failure in some countries to get forecasts and telemetry data to the 'right' users. Actions of the NBA (under whose auspices the project is run) have a considerable impact, the NBA has been much criticised for its performance - see Section 3.2.1 Unhappy history of financial mismanagement leading to changed policy on how contributions are received by the project.

OPPORTUNITY	THREAT
Widen scope of project from flood forecasting to water resources monitoring.	Lack of support from the national hydrometric agencies. Financial difficulties due to countries withholding contributions because they see too little benefit. Countries view that water resources data should not be shared, fear of neighbours knowing details of water use etc. Links between the project and the NBA are not substantially improved.

The SWOT analysis for this project is far from positive particularly with regard to its potential in the future. Difficulties are anticipated for any attempt to expand from flood forecasting to a wider role in resource monitoring. The relationship between the project and the NBA has been largely unsatisfactory and it is difficult to see much potential for expansion unless more satisfactory arrangements can be guaranteed in the future. Donors and participating countries have become frustrated by inefficiencies in the institutional arrangements for the project and in particular with the performance of the NBA. There are many lessons on institutional matters to be learned from the difficulties experience by this programme over the years.

7.4.6 SWOT Evaluation - CIEH

STRENGTH	WEAKNESS
Organisation of 14 member states. Well established. Proximity to CILSS headquarters. Recognised and supported by international funding agencies (World Bank, UNDP, French and Dutch aid, etc). Has undertaken more than 200 studies and published the results. Widespread dissemination of study results. Well provided documentation centre.	Financing problems due to halting of contributions from several member states. Membership almost exclusively francophone and dominated by Sahelian countries.

OPPORTUNITY	THREAT
To expand membership to include equatorial francophone countries, and possibly to include non-francophone countries. To expand the activities of the training schools, EIER for engineers and ETSHER for technicians, in the water sector to make them more regional. Continue role of establishing guidelines and practice manuals for hydrology and groundwater data collection, analysis and storage. To build further on experience in the setting up and management of development projects.	Financing problems. Organisation seen by countries in the equatorial region as being dedicated solely to the problems of arid countries.

CIEH should be taken into account when considering the design of any regional project to strengthen hydrometry. It has been in existence for a number of years and is well known and respected by member states for its co-ordinating role, despite the fact that economic difficulties have led some members to stop contributing to its financing. CIEH has the potential to form a centre for aspects of regional projects, particularly in the fields of training and the formation of data banks.

7.4.7 Lessons for the Design of Regional Projects

Since their inception the international basin development organisations have each commissioned consultants to undertake several major studies to investigate development possibilities within their geographic area. These studies generally date from the early years of each organisation. In the last decade the international basin organisations have suffered from severe financial difficulties, reflecting weakness in the economies of member countries, and their activities where funded from member's contributions have virtually ceased. The AGRHYMET and OCP programmes which are almost entirely funded through international donors have been less affected by the region's financial problems. This is also the case for HYDRONIGER although international contributions have been reduced because of a lack of confidence on the part of the donors in the NBA.

The international basin organisations have usually had a brief covering the whole spectrum of development. They have developed facilities (purpose built offices, computer systems, vehicles, etc) and built up large staff establishment (often using national quotas) which have led to high running costs. When they were responsible for a large number of ongoing activities these high running costs were accepted, however today they are widely regarded as unacceptable. The NBA has already had one restructuring in an attempt to slim the establishment and make it more cost effective. In some river basins in Africa the approach adopted has been to set up a 'joint permanent technical committee' which meets perhaps once or twice a year to discuss water sharing issues. Such an approach is highly focused, involves a only small committee of technical and political people, brings together the people who are responsible for national policy making in the water sector, and involves only a small administrative cost. The closest example to this approach in the region are the periodic meetings of IHP national committees to discuss the shared water resources of the Volta Basin.

Another feature of these international organisations is the importance of a few talented and enthusiastic individuals to the success of the organisation. The recent resuscitation of the LCBC reflects this type of situation. National policies governing the selection of candidates for key roles in these regional organisations may be crucial in determining whether such highly motivated individuals are seconded to the international organisation, and as to whether these individuals themselves see a spell in such an organisation as furthering their career.

The exigencies of the drought situation prevailing in 1973 when AGRHYMET was being developed contributed to the high level of collaboration between participating countries. National feelings were set aside in the emergency since collaboration was seen to offer greater prospects for assistance. This situation apart, water resources information is often regarded as a state secret not to be divulged to anyone outside the country. In the early days of HYDRONIGER the project nearly foundered because of the suspicion that data from HYDRONIGER could be utilised by other countries in any dispute over the sharing of resources. These concerns are deeply rooted and widespread. In the case of HYDRONIGER fears of this sort may prevent the project from moving into the field of water resource monitoring as opposed to just monitoring flood water levels.

A key factor in the success of a long term support programme is that the participating countries should be actively involved at the level of the hydrometric agency staff. It appears that this model is well developed in AGRHYMET and generally poorly developed in HYDRONIGER. National contributions to a project are more readily made if the expenditure is being made at home, and if the benefits can be readily seen.

The concept of regional co-operation in the planning of water resource development in the shared basins is widely supported in West Africa although there is still a tendency to regard certain data as of strategic value and therefore to be kept as a state secret. In times of financial stringency the cost of any collaboration must be kept as low as possible in relation to the positive benefits to each participant. This means that the forces for decentralising co-operative activities are strong, institutional structures and projects will enjoy greater support of their members if they are organised such that a large amount of the available funding is spent in the countries themselves or on training their staff and the cost of running any headquarters is kept to a minimum. Success in regional collaboration depends on the institutions/projects adopting a highly professional approach to technical and financial matters and particularly liaison with the national agencies to whom they are providing a service.

7.5 Summary of Institutional Issues

National services are generally unable to plan their requirements effectively, whether for long term capital expenditure, day to day running, or staff development, because in large measure they lack control over their finances whether local or international in origin. The international basin agencies, and the CIEH have also experienced financing problems. Management standards reflect this lack of control of funding. To many in the region it appears that the hydrometric services have entered a downward spiral, starved of funds they are able to achieve less and less and this underperformance is then taken as justification for further reductions in funding. Staff morale is consequently low.

In order to break the mould of underfunding and underperformance it is necessary to attack the problems of the low priority accorded to hydrological data collection in national budgets and the intermittent, stop-go pattern of international support.

As discussed in Section 7.2 hydrological data collection is generally undervalued outside the community of professionals in the field. This lack of awareness of the value of hydrometric data, combined with the economic difficulties experienced in the region, has forced many national services to curtail their activities to the point where vital long term continuity is jeopardised. This assessment has identified the need for vigorous self-promotion by hydrologists not only among their professional colleagues but also, and most importantly, to influence politicians and decision makers. To make a convincing case for increased funding it will be necessary to show that meteorologists, hydrologists and hydrogeologists have taken the most professional approach to the planning and management of their services and that money allocated to hydrometry is money well spent. The aim must be to create a 'virtuous' upward spiral whereby the achievement of high standards of performance results in more funds being made available allowing the agency to offer enhanced services to users.

A more professional approach to the planning and management of both national hydrometric services and regional co-operative ventures would need to incorporate among others the interlinked features shown in Figure 7.1. The concept of the 'customer' and customer needs will not necessarily be easy to take on because in most countries both the hydrometric services and the principal users of the data are generally branches of government, frequently part of the same ministry. However it is essential that the agencies are seen to be responsive to user requirements rather than just keeping up long standing practices. Staff appear in every box in Figure 7.1 because the quality of service that the agency can offer is strongly linked with staff motivation and the level of training.

Privatisation has already become an issue in some countries, for example Nigeria. This may be seen by local politicians simply as a way of cutting government spending and they may have an unrealistic view of the ability of hydrometric agencies to pass on their costs to customers. Full privatisation, or semi-autonomous agency status, offers the possiblility of discarding restricting civil service rules, affecting say field allowances or promotion prospects, but introduces further uncertainties with regard to sustainable funding.

The design of both country and regional projects has taken account of the crucial importance of breaking the downward spiral. The country projects address the issues of manpower development, new technologies for data collection and processing, and the place of technical assistance, in a manner appropriate to the situation in each country. In investigating potential regional projects we have targeted the problems of raising the profile of hydrological services and the need to schedule international assistance so that the national agencies can plan their activities on a longer term basis than previously. These two issues are seen as fundamental, affecting the hydrometric agencies in all countries in the region.

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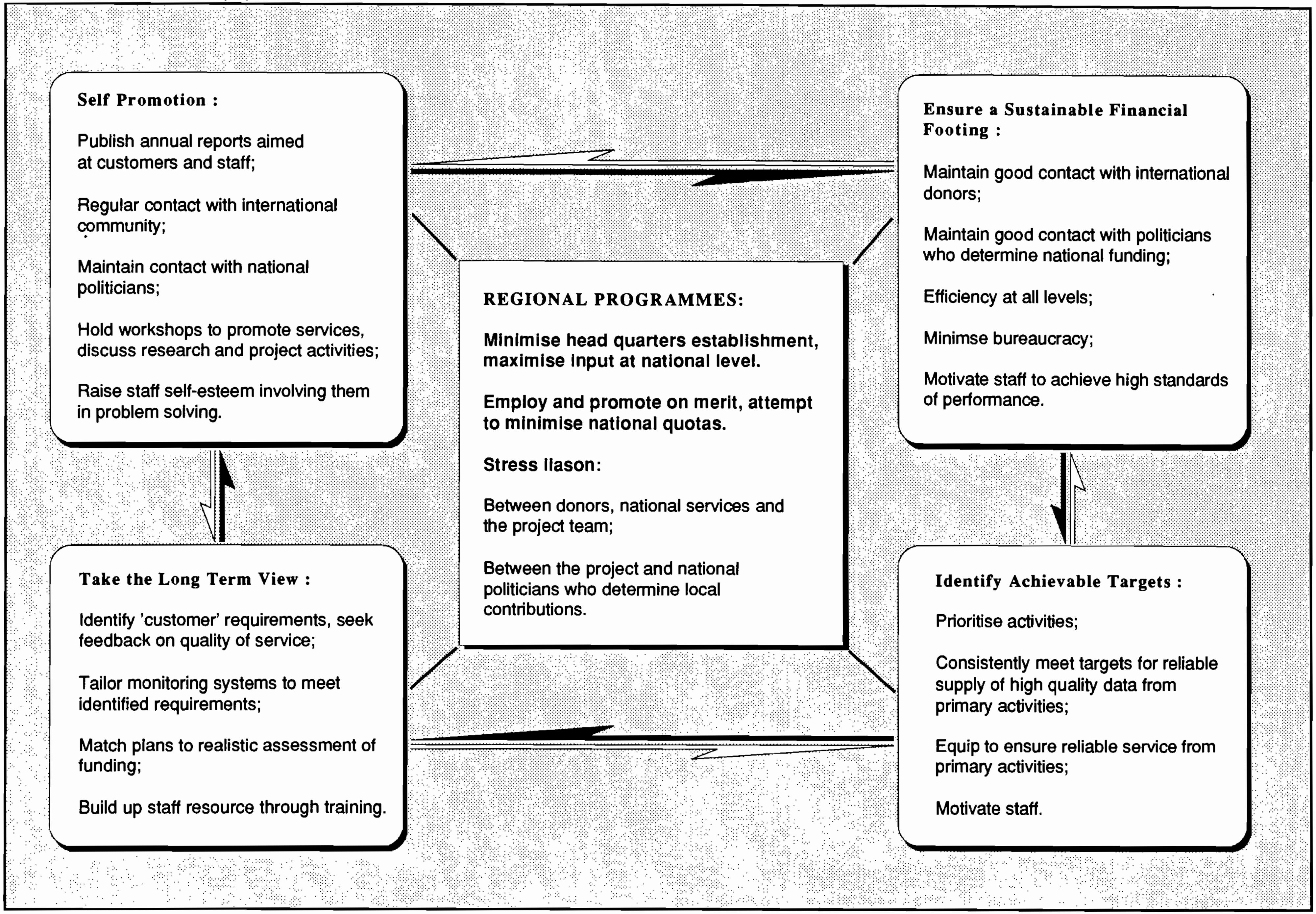

Figure 7.1 Management Objectives for National Hydrometric Agencies and Regional Programmes

CHAPTER 8

RECOMMENDATIONS

8.1 The Way Forward

It is becoming increasingly recognised by the international community that water is a major key to development. The central role of any hydrometric service is to provide the data on which water related projects can be designed. If this data is accurate then such projects will be optimal in terms both of yield and economics; if it is of poor quality then either money will be wasted by investing in projects which do not have the natural river flows or groundwater resource to support them, or resources will squandered by failing to develop them in an effective way. What the Sub-Saharan Africa Hydrological Assessment has shown is that in many West African countries data able to satisfy the needs of development are not being produced.

As developing countries have striven towards managed economies, often relying on aid or international credit mechanisms, so budgetary considerations have become increasingly prominent, particularly in the public sector which includes the water resources agencies. In the field of hydrometry, numerous technical assistance projects have attempted laudable contributions to the expansion of hydrometric activities, often in the form of capital (typically offshore goods and services), expert assistance, and training for counterpart staff. But in general, technical assistance programmes have not taken full account of the limited capacity of local water development agencies to absorb and sustain work particularly that initiated on a project footing. In spite of many short term projects in countries in the region which have addressed and sometimes solved specific technical problems, the overriding constraints on the monitoring and assessment of national and regional water resources are financial and managerial. In simplistic terms, most developing countries, especially in Africa, have neither the money nor the qualified manpower to monitor their water resources properly.

Water resources monitoring services in the region are generally operating at very low levels of efficiency. Few countries now have services which can be compared favourably with those existing 10-20 years ago. No country yet has a service which is adequate as a basis for sustaining the many water developments which can be expected in the region in coming decades. This situation would be serious even for countries with stable populations, but in many West African countries the populations are expected to double every 20 years. Water scarcity will become a major constraint on development and the raising of health standards in the north of the region. The combined effects of the population explosion in Africa and changes in climate (whether random irregularities such as the drought of the 1970s and 80s, or long term change such as might be caused by global warming) should be viewed with the utmost concern.

The assessment has shown up a marked contrast between the current status of the surface water and groundwater services and the generally improving status and efficiency of the meteorological services in the region whose synoptic activities are being significantly upgraded through the activities of ASECNA, the CILSS/WMO AGRHYMET Programme and other projects. (However, the monitoring of rainfall outside the synoptic network has generally become degraded in recent years (see Figure 4.4) and in certain countries the agrometeorological network is still embryonic.) The reasons for this difference in status include:

- Meteorology is seen as essential for safety in air transportation, which has been one of the most rapidly growing industries in the past few decades.

- Meteorology is more readily perceived in global terms.

- The perception created by the media and aid funding agencies that the recent Sahel drought of the 1970s and 1980s was simply manifest as reduced rainfall. Its effects on water resources, river flows and groundwater, have not yet been completely digested or evaluated.

- The decline in FAO activity in water resources studies and funding since the 1970s has left a gap in the support to the hydrological and groundwater sectors not completely filled by any other agency, even though the UNDP/UNDTCD and the WMO have provided and continue to provide firm and increasing support to meteorological, hydrological and hydrogeological services.

- Hydrological services in the region are generally subordinate components of sectoral agencies such as Ministries of Public Works or Agriculture; they are perceived as having low national priority at times of financial constraint, whereas meteorology generally enjoys a higher profile, particularly with regard to aviation, agriculture, and disaster relief.

Proper monitoring and management of water resources is a demanding task requiring commitment and competence at all levels. It is unfortunately the case, and is likely to remain so, that working environments in water agencies in developing countries are generally unattractive, particularly in terms of pay, job satisfaction and opportunities for advancement. Although there is a slow trend in certain countries towards thinning civil service establishments, concentrating skills and improving individual rewards and incentives by the more efficient use of public funds, a general shortage of motivated skilled manpower is likely to persist in the foreseeable future. We believe the best prospect for more effective monitoring and management of water resources lies in a range of measures including:

- carefully tailored training programmes;

- the establishment of computerised systems for the handling, storage and analysis of data;

- some automation of field data collection using electronic data storage allowing direct transfer to computers and the telemetry transmission of data in real or near real time;

- urgent support, in terms of money and manpower, of field and data processing activities.

The <u>**Hydrometry Development Programme for West Africa**</u> has been formulated from this perspective and all the recommendations that follow are aimed at equipping water resources monitoring agencies to fulfil their functions effectively on a planned and sustainable basis. A period of 10-15 years of committed direct assistance is needed with large and systematic infusions of capital goods, expertise and training, designed to meet the needs of each country. Our recommendations cover all aspects for water resources monitoring from basic field procedures, data management, data processing, data presentation and applications of the data. Throughout, we have been mindful of the financial and administrative implications for each country and therefore improved management and planning are frequently stressed.

8.2 Hydrometry Development Programme for West Africa

The programme will comprise a series of country and regional projects. The country projects are carefully designed to strengthen weak spots and to achieve accepted standards of operation. The standardising of data management and processing procedures within the region is a goal of the regional projects so that member states may freely exchange ideas, discuss problems together, exchange data and software as and if the need arises, and generally promote regional co-operation.

With such a large number of countries and associated projects it is recommended that a regional co-ordination programme be established in order to support and monitor progress. We have brought these elements of support and co-ordination together into the first regional project (see Figure 8.1) which has been named the 'Umbrella Project' in that it arches over all the country projects associated with data collection and data processing, ie all the aspects of data management required to ensure that reliable data is available on a regular basis for input to the planning process in the water resources sector. From an early stage the Umbrella Project would seek a consensus on hydrometric procedures particularly with regard to the management and processing of data. Wherever practicable, it would encourage uniformity of computer hardware and software.

The objectives of the Hydrometry Development Programme (HDP) are:

(i) to assist in the review, repair, rehabilitation and support of the hydrometric data collection networks.

(ii) To build-up the ability of the data collection agencies to carry out all necessary field work systematically to accepted standards.

(iii) To introduce at a national and regional level the concept of primary networks of limited size which can be assured continuity of funding within national budgets, with representative sites selected using objective criteria based on an analysis of historic records (duration and quality), the variablility of hydrological regime (spatial variation), and the needs of development (uses and environment considerations). A regional project has been developed to achieve this objective at the regional scale.

(iv) To preserve hydrometric data collected to date by providing or upgrading computerised storage and archiving facilities in each country.

(v) To encourage the use of standard computerised data quality control procedures.

(vi) To encourage the use of standard computerised data management and data processing procedures leading to timely distribution of statistical summaries.

(vii) To develop a capacity for applied hydrological analysis within each country in order to underpin development planning and water project design.

The aim will be effective national hydrometric data collection agencies that will ultimately become self-sufficient in well-trained manpower and technical know-how, providing tailored information necessary for the implementation of water development and other related projects. The agencies will be characterised by up-to-date operational hydrometric databanks freely compatible throughout the region, simplifying data exchange and compilation of basin-wide hydrometric data;

It must be stressed that to develop water resources effectively and efficiently a satisfactory level of continuous data collection is required. In Africa the situation is critical. In many countries lack of funding is resulting in the run down of hydrometric services. Population in Africa is undergoing rapid expansion and projections forsee a doubling within 25 to 30 years. When one considers this rapid increase and a forecast reduction in water resources due to global warming, a crisis of dire proportions appears inevitable in many African countries.

These proposals are elaborated in the following sections. The Umbrella Project is discussed in Section 8.3 together with the other regional projects. National proposals are summarised in Section 8.4, details of these projects are to be found in the individual country reports. Financial estimates for the projects are summarised in Section 8.5. The regional projects are presented in Appendix A in a standard format based on UNDP guidelines (Mott MacDonald et al, 1990).

8.3 Regional Projects

8.3.1 General

Five regional projects are foreseen. The first, the 'Umbrella Project' is designed to establish a small co-ordination team for the Hydrometry Development Programme with the purpose of providing a continuing presence of technical expertise within the region for a period of 10-15 years. This project is based on a number of elements found to be sucessful in the AGRHYMET programme (see Section 7.7).

The second regional project aims to strengthen two or three regional training centres, supporting at least one francophone and one anglophone institution, by offering regular technical courses in the fields of hydrometry and groundwater, mainly aimed at technicians.

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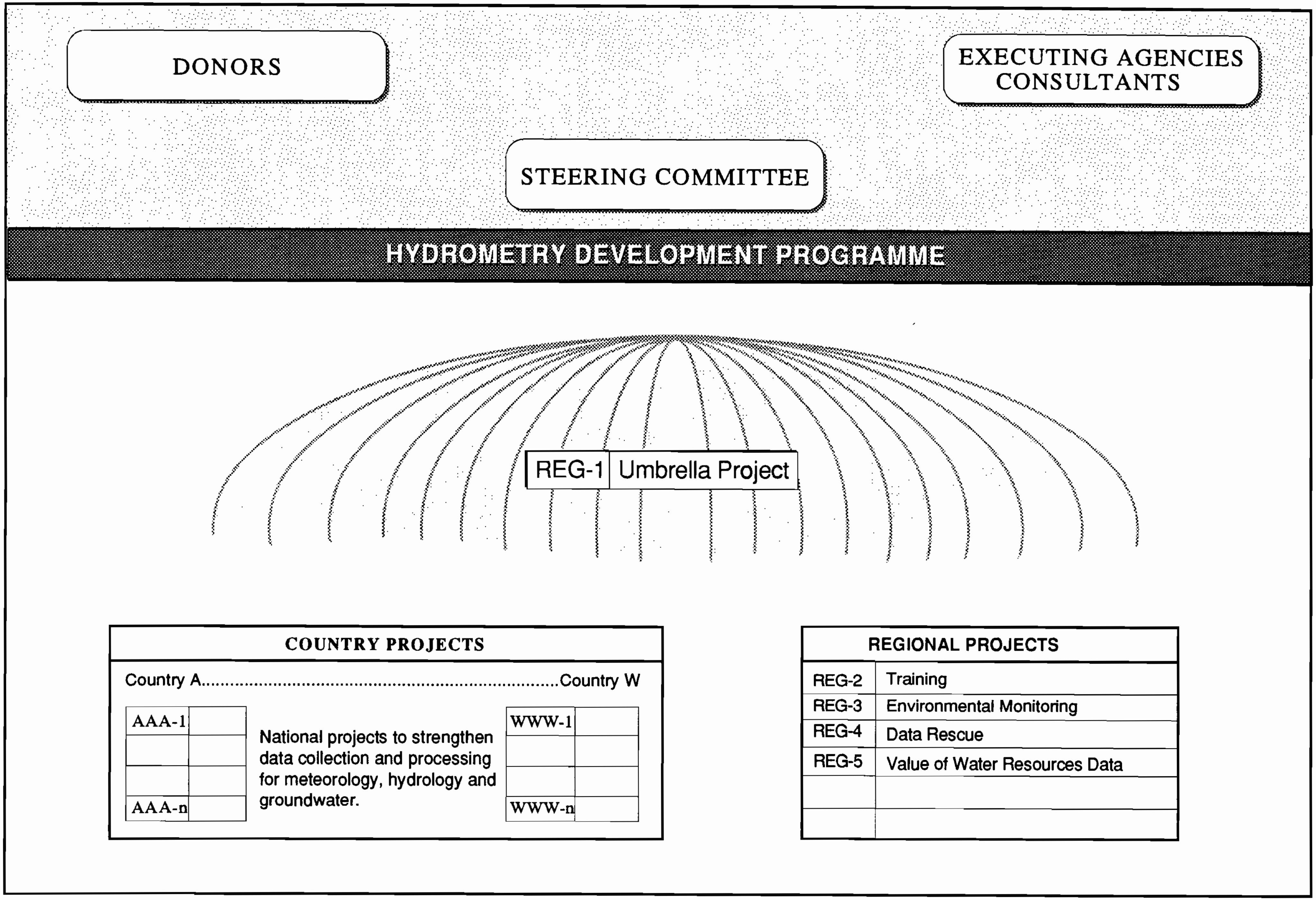

Figure 8.1 Organisation of the Hydrometry Development Programme

The third regional project has been developed specifically as a part of a larger programme for advanced hydrological and environmental monitoring proposed for the whole of sub-Saharan Africa. The continent-wide programme is intended to be established in stages, and this regional project for West Africa could form the initial phase of the larger programme. The objective is to establish a minimum network of high quality benchmark stations using telemetry to provide a continuous flow of environmental data for regional and international distribution.

The fourth regional project is concerned with the rescue of the large volumes of historic data held by the various hydrometric agencies in the region. The project is largely concerned with the preservation of data on surface water and groundwater since there have already been similar projects for rescuing meteorological data (DARE project, Section 3.3.5, and the CIEH sponsored collection and storage of rainfall data for member countries, Section 6.1.3).

The fifth project addresses the problem of promotion and raising the profile of data collection services. It is a study which aims to provide participating countries with tools for evaluating quantitatively the minimum financing requirements of water resources data collection services in relation to present and future water development. The study would also examine the likely consequences for water sector planning of population growth, climate change and environmental deterioration, all of which can be expected to contribute to a greater need for monitoring.

Summary details and estimated costs for the regional projects, referred to as REG-1 to REG-5, are shown in Table 8.1. Greater detail is included in Appendix A where these projects are prepared according to the standard format.

8.3.2 Hydrometry Development Programme 'Umbrella' Project

(a) Objectives

The Umbrella Project is intended through its co-ordination role to achieve the principal aim of the Hydrometry Development Programme to upgrade the collection and processing of data by the national hydrometric agencies to ensure that reliable data are available from, as a minimum, a number of first-order stations in every country, and to secure these services in the long term.

The Hydrometry Development Programme has identified the need for a large injection of funds if complete breakdown of the data collection systems is to be avoided. Clearly hydrometry is only one of the concerns of the donor agencies, to increase the share of the total pool of aid funds going into the water sector, and hydrometry in particular, will require a well organised and sustained campaign to keep the difficulties facing the hydrometric agencies, and the value of hydrometric data in the planning process, high on the agenda of those who allocate funds. It is our opinion that the cause of hydrometric data collection in the region will be better served by establishing an entity which can act on behalf of the national hydrometric agencies in attempting to raise the profile of this crucial activity.

TABLE 8.1

Hydrometry Development Programme for West Africa -Proposed Regional Projects

Ref	Title	Executing Agency	Objectives	Total Duration (months)	Inputs (months)			Costs (US$ thousand)			Total US$ million
					Foreign Experts	Regional Experts	Volunteers	Staff	Equipment	Training	
REG-1	Umbrella Project	World Bank or UNDP	Co-ordination and long term support for the Hydrometry Development Programme of national and regional projects	120	276	-	120	6 646	945	100	7.69
REG-2	Regional Training Centres	CIEH/NIWR/WRRI	To develop courses, train lecturers, and provide training places for technicians in the fields of hydromery and groundwater	60	74	64	-	3 014	500	-	3.51
REG-3	Advanced Hydrological and Environmental Monitoring Programme: Component for West Africa	WMO	To maintain a small network to assure the flow of reliable data for long term environmental monitoring in the region	120	149	-	-	3 246	1 080	160	4.49
REG-4	Data Rescue Programme for Hydrological and Groundwater Data	UNDP or WMO	To ensure the preservation of original records and develop guidelines for the safe storage of computerised data	60	42	-	72	1 167	220	400	1.79
REG-5	Assessment of the Economic and Social Benefits of Water Resources Data Collection in West Africa as a Justification for Increasing Funding to Hydrometric Services	World Bank or UNDP	To provide a tool for evaluating quantitatively the minimum financing requirements of data collection services	12	33	-	-	541	20	-	0.56

Hydrometric agencies across the region display very different levels of development between countries and between the climate, surface water and groundwater sectors. It is felt that, given the already well developed collaboration in many fields, that there is considerable scope for further interchange of information and experience between agencies. There is a particular benefit to be gained by the smaller/less developed agencies in learning from problems encountered by the more established agencies, for example in the selection of appropriate instrumentation (in the way that the OCP was able to learn from the difficulties exprienced with the HYDRONIGER telemetry system).

Efforts will be made to introduce the concept of primary and secondary operations throughout the region stressing the key role of a small representative and reliable primary network in the provision of vital data for planning. An agency adopting this approach would apportion its annual budget such that the continued operation of the primary network is guarranteed before other activities are funded. The Umbrella Project can assist in prioritising stations and activities in order to establish such a two tier system.

With its well developed contacts with the donor agencies, and its knowledge of the regional hydrometric situation, the Umbrella Project would be in a position to advise national agencies on the preparation of project proposals and to assist in attracting funding.

The Umbrella Project would provide a centre for assistance in the fields of equipment maintenance, training on new equipment, assistance with computers and specialised software, the selection of appropriate instrumentation etc.

Finally, the Umbrella Project is deliberately intended to take a longer term view of all aspects of hydrometric activity than can usually be accomplished within the normal framework of two to three year assistance projects.

(b) Major Activities

These can be categorised as follows:

Co-ordination of the Hydrometry Development Programme Components

To provide a central focus for the HDP assisting particularly with the scheduling of regional and national projects. To assist national agencies in their dealings with the donor agencies and with the regional projects planned under the HDP.

Promotion

To maintain close relations with all the key donors in the water resources sector to ensure that hydrometry in West Africa, in all its aspects, obtains an adequate share of available funds from year to year.

Training

Where new technology, such as telemetry or new software for data processing, is to be introduced through a country project the Umbrella Project's staff of experts can provide short training inputs in-country with emphasis on on-the-job, hands-on training using the agency's own facilities. The project's staff would also have an input at the regional training centres associated with the project REG-2.

Standardisation

To review regional and international experience in hydrometric instrumentation, field practices, office procedures etc and to bring together examples of 'best practice'. In general there is closer harmonisation between agencies in the francophone countries due to the long standing co-operation with ORSTOM and the efforts of CIEH. Lessons learned, eg with the field sensors used in telemetry systems for surface water monitoring, can be shared to avoid the repetition of costly mistakes.

Maintenance

There is a problem in maintaining specialised instruments throughout the region which has been discussed in Section 7.4, the more sophisticated the equipment the less likely that repair can be affected in-country. By encouraging a degree of standardisation in procurement, see above, and by grouping together a larger number of users the Umbrella Project will attempt to negotiate with suppliers for local repair points or the inclusion of training in maintenance as part of any procurement package.

Computer Hardware and Software

The region's agencies are still at an early stage of involvement with computers, although some countries have in the past used a central government computer facility, this inexperience means that often quite trivial problems can bring the data processing system to a halt. There has been little support available, even where packages such as CLICOM have been introduced in many countries. The Umbrella Project will have experts on computer hardware and hydrological data processing systems to provide such assistance. They will also have a role in determining whether existing databases can be linked and on how to recover data entered on machines which are now defunct.

Assistance to Ensure the Regular Supply of a Minimum of Reliable Data

In recognition of the fact that there are some goals for data collection which have an international dimension the Umbrella Project will maintain close links with the the project REG-3 and will seek to promote reliable data collection, processing and distribution for a minimum first order network of monitoring sites within countries and agencies which are not participating in the REG-3 programme by providing advice on the selection of suitable sites and defining priority activities and by careful attention to scheduling of projects within the HDP. Gaps will inevitably develop in the implementation schedules for individual countries a feature of external assistance which has caused so many problems for the national agencies in the past; it is possible to envisage a role for the Umbrella unit which involves a degree of fund management whereby the Umbrella project could act as the executing agency for a 'bridging period' to ensure the maintenance of primary activities against future funding earmarked for the country programme. Such a direct role in fund management could have a number of advantages for the overall Hydrometry Development Programme and the national agencies but it could be seen by some as an additional layer of bureaucracy.

(c) Location

Given the number of countries involved in the HDP it is essential that the key project should be centred where facilities (communications, travel, etc) are the best available. There is obviously a difficulty in deciding whether the centre should be in an anglophone or a francophone country. The Umbrella Project could be operated from Abidjan, Côte d'Ivoire, since this is a major centre for the donor agencies, the World Bank and many UN agencies with whom the project would be strongly associated.

It would have a lifespan of say 10 years initially with possible extensions of 5 years at a time depending on the outcome of periodic reviews. The unit would serve as a regional base for consultants and experts who would contribute to individual country projects.

The Umbrella Project could be attached to, or associate with, existing regional organisations. However, in the absence of any regional organisation representing all the 23 countries, there is no obvious candidate institution with which to link.

(d) Staff

The Umbrella Project would be staffed primarily by senior experts who would spend a significant amount of time away from the project headquarters fulfilling inputs to country programmes. It would also be a distinct advantage if these experts were recruited from a single organisation and could draw on the technical managerial experience of that organisation. The experts would carry out the following functions:

Project Director	Planning, policy, funding requirements, strategy, co-ordination, country projects liaison, procurement, training and scholarships.
Financial Manager	Funding requirements, co-ordination
Data Collection Experts: Hydrology, Groundwater and Meteorology	Training, field network development, operational procedures, country project inputs.
Data Processing/Computer Experts	Training, support on hardware and software, programming, country project inputs.

In addition a small number of local staff would be employed at the project office as computer operators, driver, secretary, administrator etc. The cost of the Umbrella Project is discussed in Section 8.5, further details are presented in Appendix A.

8.3.3 Training Programmes for Technicians and Professionals (REG-2)

The Training Programme would aim to broarden the scope of courses on offer in the region with particular emphasis on short practical courses. It has been decided that it is most apropriate to provide this training by expanding the activities of two or possibly three established training centres within existing academic/training institutions in the region; one from the anglophone countries and one from among the francophone bodies. Whilst the difficulties of the three lusophone countries and Spanish speaking Equatorial Guinea are recognised it was felt most appropriate to introduce courses in these languages at the selected francophone centre. The purpose of the programme is to strengthen these centres by offering appropriate 1-4 month courses on various aspects of hydrology, meteorology, hydrogeology, sediment, water chemistry, water flow, data management and data analysis.

A variety of courses are envisaged ranging from generalised basic training in operational hydrology and hydrogeology to more detailed treatment of specific technical areas such as current meter measurements, sediment monitoring, laboratory procedures, the use of computers and particular specialised data processing packages etc. Meteorological training, other than introductory material related to water resource development, is not included as this is already offered by the AGRHYMET centre. If there is a demand for training in the use of CLICOM the project team could arrange for this to be offered at the AGRHYMET centre under the support of REG-2.

The supported centres will not necessarily have exactly the same courses on offer, this will depend on the demand for various subjects at each centre and their areas of special competence.

At the outset, staffing at the centres would be supported mainly by international experts, but contributions from West African experts would be actively sought and encouraged.

8.3.4 Advanced Hydrological and Environmental Monitoring Programme (REG-3)

Proposals have been made for a continent-wide programme for Africa to support monitoring of environmental parameters making use of advanced technology in station instrumentation and data transmission. These arise from international concern with environmental issues which are global in scale such as climatic change, ecological degradation, etc; water development in Africa also raises many environmental concerns in which there is an international interest. West Africa already has considerable experience with telemetry for hydrological data collection starting with the HYDRONIGER project in 1979 and now including several networks commissioned for various purposes. The project REG-3 is envisaged as the first stage in this continent-wide programme building on the region's experience to install and operate a pilot for the larger programme. The objective is to establish a minimum network of high quality benchmark stations using telemetry to provide a continuous flow of environmental data for regional and international distribution.

The project would be organised around a regional receiving centre which could be based in the same location as the Umbrella Project. The network of field stations would be selected to provide a representative sample of hydrological regimes. The programme could incorporate the reception of data from existing telemetry systems if the sites in the existing networks were representative and fitted the design of the new network, thus a site in the Benin system might be included and sites from the OCP, HYDRONIGER and OMVS projects. New sites would be installed as necessary. It is not intended that the programme should include large numbers of stations, the regional scale precludes this. The emphasis is on maintaining reliable data transmission, and on maintaining a field programme adequate to ensure good calibration of all the selected sites.

At the receiving centre the incoming data would be processed by specialised software with the objective of making high quality hydrological data available with the minimum of delay.

After a first stage lasting about two years the project would be assessed and recommendations put forward for the remainder of the continent-wide programme.

8.3.5 Data Rescue Programme (REG-4)

The objectives of the project are to ensure the preservation of historic records and to set up systems on a national basis to assure the safe keeping of data being collected now and in the future both on paper or electronic media. The project will address the particular problems of establishing means of protecting information now being entered on computerised systems. The project team would establish close liaison with the regional Umbrella Project whose activities include a support to computer managers and the issuing of guidelines and standards on a wide range of topics related to data processing and storage systems.

8.3.6 Assessment of the Economic and Social Benefit of Water Resources Data Collection in West Africa (REG-5)

At present Governments have no means of estimating, and little idea of, the value of data collection services. With rapid population growth and likely changes in climate due to global warming, increased demands for water will require a new assessment of the minimum data collection services commensurate with supplying the basic minimum data to design water resource development projects.

The project is envisaged as a 12 month study by consultants largely carried out in their home office but with an initial information gathering phase in the region. The project would liaise with the Hydrometry Development Programme Umbrella Project throughout the study, but particularly during the initial phase and most importantly at the end of the study to determine the best method of introducing the study results to the directors and managers of the national agencies in the region.

The project would employ a wide range of experts in the fields of hydrometry, climate modelling, demography, and economics.

8.4 Country Projects

8.4.1 General

The Sub-Saharan Africa Hydrological Assessment Project has revealed several problem areas in the hydrometric activities of countries in West Africa and has identified potential projects. General considerations involved in the project identification are summarised below while more detailed descriptions are to be found in the individual Country Reports. Financial aspects are discussed in Section 8.5.

8.4.2 Summary of Projects

A total of 153 country projects have been identified, they are subdivided by type of activity and priority in Table 8.2. In some cases, more than one project has been proposed for a single agency. There is a danger that local staff resources will be inadequate to support and benefit from the proposals, and therefore careful management and phasing of the projects by local directors, with assistance from the Umbrella Project, is a prerequisite.

TABLE 8.2

Country Projects by Type and Priority

Type	Priority A	Priority B	Total
Institutional strengthening	63 385 000	4 811 000	68 196 000
Data collection	31 561 000	1 093 000	32 654 000
Data processing	5 606 000	641 000	6 247 000
Studies	7 244 000	19 938 000	27 182 000
Total US $	107 796 000	26 483 000	134 279 000

To be effective, the proposed projects should be built into the workplans of the agencies involved and counterpart staff should be identified and committed from the outset. Potential clashes with existing workplans and training arrangements must be identified and allowed for before new projects commence. This is no easy task as the gestation period of many projects is typically 2-3 years in which time staffing arrangements and commitments within the agencies are apt to change.

For this reason, co-ordination of assistance to the agencies and training opportunities, particularly as they affect the availability of counterpart staff, is seen as essential and is a primary function of the Umbrella Project. Effective co-ordination should be based on development plans for the agencies over periods of, say, 5 years. New proposals should be considered in relation to these development plans rather than be treated in isolation irrespective of existing projects and staff commitments.

The common aim of the projects identified here is to promote effective water resources monitoring and management services. They necessarily include major training components and considerable inputs from experts. The inputs will be mostly technical assistance (TA) and the duration of the TA visits will vary from country to country.

In each case, the inputs will cover some or all of the following items:

- purchase of equipment for rehabilitation and development of the data collection network;

- purchase of vehicles, boats, and portable equipment to strengthen field operations;

- purchase of computer hardware;

- provision of software;

- assistance with the adaptation of software to the local environment, training in its use and establishment of data quality control procedures;

- training of technicians in sound hydrometric practice.

- training in hydrological data processing;

- training in meteorological, hydrological and groundwater analysis techniques;

Each country would normally be expected to provide:

- office accommodation and local transport for short term consultants and experts;
- secretarial assistance;
- candidates for training;
- counterpart staff to work with experts and consultants;
- fuel and maintenance of project vehicles.

8.4.3 Personnel

The project summaries in the Country Reports give an indication of the field of expertise of the proposed experts. At this stage it is not possible to produce a detailed job description for each post but a few general points apply:

- breadth of experience is of as much importance as skill in the particular area specialisation;

- a minimum of 5 years relevant experience will normally be required;

- experience in the region preferred;

- in projects with more than one expert the team leader should have a minimum of 10 years relevant experience;

- all experts should have a good command of English or French as appropriate, for projects in the Lusophone countries knowledge of Portugese would be an advantage as would a knowledge of Spanish for experts involved in projects for Equatorial Guinea.

Some of the short expert inputs to country programmes can be filled by staff from the Umbrella Project.

In the project proposals expert staff are identified as 'international' to differentiate these externally funded inputs from the required counterpart inputs.

8.5 Financial Estimates

8.5.1 Assumptions

In order to ensure that all the projects identified during this assessment were costed on a comparable basis we have made certain assumptions regarding costs which have been applied to all the project proposals both national and regional. The rates selected may appear to be on the high side in some cases, however we feel that given that some of the projects identified will probably be running in 10 years time it is advisable to make conservative assumptions.

Costs for international expert staff (salary, social costs, and overheads) have been simplified. To be conservative the rates adopted cover the cost of hiring expatriate experts; this does not preclude the use of African experts should suitable candidates be available. The rates used are as follows: experts with 5 to 10 years experience US$ 16 000 per month overseas and US$ 13 000 in their home country, senior experts with more than 10 years experience US$ 20 000 per month overseas and US$ 16 000 in their home country.

Subsistence rates for international staff have been costed at the UNDP daily allowance rate for short tours; the rates are those applicable at the time of the country visit, or in December 1991 for regional projects. For longer tours a flat rate of US$ 2 500 per month is used. For some of the regional projects, rates are given as 'local' and 'regional'. 'Local' refers to the rate at the central office of the project and 'regional' refers to an average rate for the other participating countries.

Travel costs have been based on full fare economy flights between Europe and Africa with a further 25% added to cover insurance, freight, etc (no allowance has been made for possible additional costs involved if the experts are based outside Europe). A round trip ticket is used for each short mission.

One ticket per year is assumed for each long tour. For some regional projects, fares are given as 'international' and 'regional'. 'International' refers to the cost of a ticket from the expert's base to West Africa, and 'regional' refers to the cost of a ticket for travel within the region.

A fixed, all-inclusive rate of US$ 5 000 per month has been used for 'volunteers'.

Project budgets cover the requirements for international financing. They do not include any allowance to cover day to day operational costs of the national agency benefitting from the project.

8.5.2 Overall Budget for the HDP

The total cost of the national and regional projects identified in the ten year Hydrometry Development Programme for all the twenty three West African countries will be in the region of US$ 150 million.

This seemingly high value must be judged against the costs of major projects in the region which rely heavily on water resources data at the design stage. The Volta River project for example, were it being constructed now, would cost about US$ 5 billion. The region, devastated as it has been by the prolonged Sahel drought, has a number of completed schemes which have failed to achieve their potential because of the extreme changes in the hydrological regime. The irrigation schemes in Nigeria and Chad designed to take water from Lake Chad are notable examples. The cost implications of errors in yield estimation due to lack of data outweigh by several orders of magnitude the cost of data collection.

The cost of adequate hydrometry in each country to support major engineering and development projects is extremely small in project terms. Hydrometry must of course be undertaken as a routine national operation either drawing on scarce national funds or supported by international funding. It is not possible to estimate reliable resource yields solely on a project basis over a short study period.

There is an international interest in hydrometric data collected in the region, particularly for research aimed at investigating evidence for man's influence on the environment, and the global climate in particular.

The Hydrometry Development Programme has four potential regional projects apart from the Umbrella project and up to 153 possible country projects. The first phase of the Hydrometry Development Programme would be the establishment of the Umbrella project and the priority task would be to co-ordinate the scheduling of projects, in close collaboration with the national agencies and the identified donors/executing agencies. In later years the Umbrella project, whilst maintaining its co-ordination role constantly reviewing the progress of other projects in the programme, would take a more active role in supporting national projects with direct inputs.

The Umbrella project would maintain a core of staff in the region who would be available to undertake inputs to other regional or country projects. Thus, particularly in planning inputs to the other four regional projects, possible links with the Umbrella project staff have been identified. For example, the regional training project REG-2 is designed to draw on the Umbrella unit for short inputs in the later stages of the project.

In costing the Umbrella project we have not attempted to identify any double counting of costs which would occur if an Umbrella project expert is utilised on a national project, however it is certain that savings can be made in terms of the overall Hydrometry Development Programme, whether in the country project or in the Umbrella project budget, once the scheduling of projects and their associated requirements for experts is completed.

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Wigley, T M L et al	1992	Developing climate scenarios from equilibrium GCM results; Climate Change.
WMO	1990	Economic and Social Benefits of Meteorological and Hydrological Services, Proceedings of the technical Conference Geneva 26-30 March 1990; WMO-No 733.
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World Bank	1986	Population Growth and Policies in Sub-Saharan Africa.

APPENDIX A

REGIONAL PROJECTS

Country:	Regional, West Africa
Date:	November 1991
Project No.	REG-1
Proposed Title:	Hydrometry Development Programme for West Africa Umbrella Project
Implementing Agency:	World Bank or UNDP
Estimated Duration:	10 years
Tentative International contribution:	US$ 7 691 700
Estimated counterpart costs:	To be determined
Source of funds:	To be decided

I. Development objective and its relation to the country programme

The development of water resources is a key issue in each of the twenty three countries in the West African region. The growth of population in these countries and the need to both provide for their basic needs and to raise the level of their standard of living will ensure that water resources development is at the top of the agenda in the future.

The region's hydrometric agencies have benefited in the past from numerous support projects aimed at improving the quantity and quality of data collection. There has been no clear vision or policy among the international donors for the long term security of the agencies and their monitoring activities. Past projects often appear to have been conceived in isolation without regard to the consequences of a stop/start regime on an agency's effectiveness, this is usually the result of delays in starting follow-up programmes. A common pattern can be seen where monitoring improves during a supported phase only to decline once the support is concluded. A fundamental objective of the Hydrometry Development Programme for West Africa is to provide continuity of assistance over a longer time frame than the usual strengthening project thus ensuring that the region's hydrometric agencies can plan for and achieve steady development.

The available aid money for water resources development and hydrometry in particular is limited and will remain so in the foreseeable future. The country by country assessments have identified many projects to raise the level of monitoring for water resources in individual countries, all of which are competing for the same funds. It is intended that the Hydrometry Development Programme should provide a single focus - the clear vision or target for the future so obviously lacking in aid provision in this sector in the past - for sustained assistance to data collection and processing for the whole region.

The 'Umbrella Project' is designed to establish a small co-ordination team for the Hydrometry Development Programme with the purpose of providing a continuing presence of technical expertise within the region for a period of 10-15 years. The Umbrella project would have a lifespan of say 10 years initially with possible extensions of 5 years at a time depending on the outcome of periodic reviews. The unit would serve as a regional base for consultants and experts who would contribute to individual country projects.

The Hydrometry Development Programme is based on a number of elements found to be successful in the long running AGRHYMET programme, particularly in the co-ordination of regional and national components of the programme. Careful attention has been paid to the institutional structure of the programme, drawing on the results of a detailed evaluation of a number of regional organisations and projects, and the different perspectives of the national agencies and the bilateral or multilateral donors on many issues such as the balance between country and regional projects or the extent of expatriate inputs vis a vis inputs of capital goods. The Umbrella unit is designed to provide a demonstrably efficient, cost effective link between all the components of the Hydrometry Development Programme rather than an expensive prestige project.

II Major Elements

The small team of experts employed by the Umbrella project would be responsible for the following activities:

(a) Institutional Role

- Co-ordination - between the donors and the countries, between the regional projects, between country projects and regional projects. In line with current thinking most country projects within the Hydrometry Development Programme are shorter than three years in duration, the Umbrella project by contrast runs for a minimum of 10 years it can therefore provide a dependable link between donors and national bodies in the event in gaps developing in the scheduled implementation of a country programme.

- Assist donors and countries in scheduling the implementation of projects to ensure continuity, to avoid conflicts between the needs of training and maintaining day to day operations.

- Assist countries in identifying further assistance needs, formulating them in a form suitable for donor financing; the Umbrella project staff with their contacts with the donors are well placed to advise on project preparation.

- Gaps will inevitably develop in the implementation schedules for individual countries a feature of external assistance which has caused so many problems for the national agencies in the past; it is possible to envisage a role for the Umbrella unit which involves a degree of fund management whereby the Umbrella project could act as the executing agency for a 'bridging period' to ensure the maintenance of primary activities against future funding earmarked for the country programme. Such a direct role in fund management could have a number of advantages for the overall Hydrometry Development Programme and the national agencies but it could be seen by some as an additional layer of bureaucracy.

(b) Technical Role

- Focus for regional assistance in the field of data collection and processing. To develop a programme for issuing guidelines on equipment purchase having regard to the suitability of the equipment for its intended use, the availability of maintenance facilities, the possibility of upgrading existing equipment to match new standards, to advise on regional experience in the use of certain equipment.

- As computers are slowly becoming more widespread there are increasing problems associated with their use. The region's agencies are often unable to deal with software and hardware problems in-house and there is at present no regional assistance mechanism. The project team would include computer specialists who would be available to assist with the many minor problems which can stop data processing completely, eg inability to print out from CLICOM.

- It is recognised that many countries have networks which are beyond their capacity to fund or manage satisfactorily - the resource is spread too thin to be effective. It is intended that this project, in conjunction with the project REG-3, should support monitoring at a limited number of sites in each country, a 'primary' or 'first-order' network, which can be sustained in the long term. This would not preclude national agencies maintaining other stations from other sources of funding but would ensure long term continuity at the chosen sites.

- Specialist team able to support training institutions and country projects.

III Project strategy

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

The national agencies responsible for meteorology, hydrology, and groundwater in the 23 countries in West Africa would be the primary beneficiaries. The project would support national projects intended to enhance the activities of these agencies in the fields of data collection and processing and would assist in organising the maintenance of a minimum network of monitoring points and processing activities to ensure that a steady flow of reliable data is made available for water resources planning by national and international agencies.

The project, organised as it is over a relatively long time scale, will benefit the agencies by offering continuity of support in the long term.

2. Target Beneficiaries?

The target beneficiaries are all those people in the region whose standard of living will be improved by future developments in the water sector. The benefits will be felt in the water supply, agricultural, and industrial fields.

3. Implementation arrangements for the project.

The structure of the Hydrometry Development Programme has been based on the findings of the Sub-Saharan Africa Hydrological Assessment for West African Countries after an evaluation of existing regional and national projects. It has many features in common with the AGRHYMET programme, particularly in the co-ordination of regional and national components of the programme. In the Hydrometry Development Programme this co-ordination is maintained by the Umbrella Project.

In order to hold down costs and to maintain a tight focus the core team is deliberately small and the project offices low key with a minimum establishment. The Hydrometry Development Programme covers 23 countries and it is essential for its efficient functioning that the Umbrella unit be based where good facilities (reliable electricity supply, good telecommunication and travel links with other countries in the region, etc) are available.

The Hydrometry Development Programme has four potential regional projects apart from the Umbrella project and up to 153 possible country projects. The first phase of the Hydrometry Development Programme would be the establishment of the Umbrella project and the priority task would be to co-ordinate the scheduling of projects, in close collaboration with the national agencies and the identified donors/executing agencies.

In later years the Umbrella project, whilst maintaining its co-ordination role constantly reviewing the progress of other projects in the programme, would take a more active role in supporting national projects with direct inputs.

The Umbrella project would maintain a core of staff who would be available to undertake inputs to other regional or country projects. Thus, particularly in planning inputs to the other four regional projects, possible links with the Umbrella project staff have been identified. For example, the regional training project REG-2 is designed to draw on the Umbrella unit for short inputs in the later stages of the project.

In costing the Umbrella project we have not attempted to identify any double counting of costs which would occur if an Umbrella project expert is utilised on a national project, however it is certain that savings can be made in terms of the overall Hydrometry Development Programme, whether in the country project or in the Umbrella project budget, once the scheduling of projects and their associated requirements for experts is completed.

4. Alternative implementation strategies

The possibility of combining this project with other projects proposed as a result of the hydrological assessment was considered but it was felt that the proposed activities were such that they could be carried out independently of the other projects. The possibility of using more part time experts to reduce the overall cost was considered but it was deemed essential that for continuity such a major project must have a number of full time experts for key management posts.

IV Host country commitment

1. Counterpart support

The level of counterpart staffing across the region is relatively good, in most agencies it is sufficient to ensure that a reasonable level of service is provided. However some departments already suffer from the absence of staff who are attending long-term training overseas. Great care will have to be exercised to ensure that the proposed project does not aggravate this situation.

2. Legal arrangements and future staffing

Not an issue.

V Risks

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

This project is the core project of the Hydrometry Development Programme, a very large group of national and regional projects, proposed as a result of the Hydrological Assessment of West African countries. The start of the project is dependent on a positive decision by donors and countries to go ahead with all or part of the Hydrometry Development Programme.

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

This project is the core of a long term (10-15 year) programme of support and assistance to 23 countries in West Africa, its success will depend on the sustained support of donors and participating countries.

VI Inputs

1. Skeleton Budget

As noted above there is considerable potential for savings in the costs of the overall Hydrometry Development Programme by utilising staff from the Umbrella unit to fulfil the identified expert inputs in country and regional projects. since it is not possible to identify such sharing of staff resources at this stage it has been necessary to cost the Umbrella project as an independent project ignoring any potential savings; this results in a project cost profile which appears to be weighted heavily in favour of international staff costs when compared to other projects proposed under the Hydrometry Development Programme which have a much higher ratio of capital goods to staff costs.

During the first stage of the Umbrella project and thus the first stage of the Hydrometry Development Programme the Umbrella project team would be involved in the scheduling of projects and would be able to identify inputs which could be filled to advantage from the Umbrella project.

Personnel

	Input months	Rate US$/month	Amount US $
Director	108	20 000	2 160 000
Data Collection: Hydrology (2 staff)	48	16 000	768 000
Data Collection: Groundwater (2 staff)	24	16 000	384 000
Data Collection: Meteorology	12	16 000	192 000
Financial Manager	60	20 000	1 200 000
Short-term Consultants	24	20 000	480 000
Volunteers	120	5 000	600 000
Subsistence	276	2 500	690 000
Travel to/from duty station		2 600	122 200
Travel for country visits			50 000
Sub-total			6 646 200

Training

Item	Amount US$
Preparation of training materials and guidelines	100 000

Equipment

Item	Amount US$
Transport	45 000
Office Facilities	60 500
Office Running Costs	840 000
Sub-total	945 500

TOTAL	US$ 7 691 700

2. Policy issues

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

Appendix 1 - International Personnel

1. Qualifications and Duties

Director

The director should have a degree in engineering or a natural science from a recognised university. A post-graduate degree in hydrology would be an advantage. The director should also have at least 15 years experience in operational hydrology and water resources, which must include a minimum of five years in a management role. The director should have a good command of both English and French languages and some knowledge of Portuguese and Spanish would be an asset.

The main role of the director would be to ensure the effective co-ordination of the activities of the project team with staff of national agencies and with the donor agencies. He would be expected to initiate the project and at an early stage to develop a programme of activities, procurement and training. During the course of the project he would be responsible for keeping the project to the programme or modifying the programme in the light of experience.

Hydrometrists

Two hydrometric posts have been included, the division of responsibilities between the two candidates would be agreed by the director. The hydrometrists should have a degree in engineering or a natural science from a recognised university. A post-graduate degree in hydrology would be an advantage. They should have at least 10 years experience in operational hydrology, and at least one should also have experience in the operation of telemetry systems. They should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset.

The duties of the hydrometrists would include assisting national agencies in matters pertaining to data collection for surface water. They would advise on the suitability of different types of instruments for local conditions with the aim of introducing a degree of standardisation. Their duties would also include assisting national agencies in matters pertaining to data processing for hydrology. They would advise on the suitability of different types of hardware and software for local conditions with the aim of introducing a degree of standardisation. They would organise training programmes to assist national agencies in the adoption of new types of field and computer equipment and software.

Hydrometrists - Groundwater

Two groundwater posts have been included, the division of responsibilities between the two candidates would be agreed by the director. The groundwater experts should have a degree in geology or a natural science from a recognised university. A post-graduate degree in hydrogeology would be an advantage. They should have at least 10 years experience in the operation of groundwater data collection. They should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset.

The duties of the hydrogeologists would include assisting national agencies in matters pertaining to data collection for groundwater. They would advise on the suitability of different types of instruments for local conditions with the aim of introducing a degree of standardisation. Their duties would also include assisting national agencies in matters pertaining to data processing for groundwater. They would advise on the suitability of different types of hardware and software for local conditions with the aim of introducing a degree of standardisation. They would organise training programmes to assist national agencies in the adoption of new types of field and computer equipment and software.

Meteorologist

The meteorologist should have a degree in meteorology or a natural science from a recognised university. A post-graduate degree in meteorology would be an advantage. He should have at least 10 years experience in operational meteorology. He should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset.

The duties of the meteorologist would include assisting national agencies in matters pertaining to data collection for meteorology. He would advise on the suitability of different types of instruments for local conditions with the aim of introducing a degree of standardisation. His duties would also include assisting national agencies in matters pertaining to data processing for meteorology. They would advise on the suitability of different types of hardware and software for local conditions with the aim of introducing a degree of standardisation. They would organise training programmes to assist national agencies in the adoption of new types of field and computer equipment and software.

Financial Manager

The financial manager should have a degree in economics or accountancy from a recognised university, and a professional qualification in accountancy from an internationally recognised institution. The financial manager should also have at least 15 years experience in the water resources sector which must include a minimum of five years in a management role. He should have a good command of both English and French languages and some knowledge of Portuguese and Spanish would be an asset.

The main role of the financial manager would be to assist the Project Director in ensuring the effective co-ordination of the activities of the project team with staff of national agencies and with the donor agencies. He would be expected to provide assistance to agencies in the formulation of project proposals and in negotiating with donor agencies to bridge gaps between the scheduling of projects.

Specialists

A small number of specialist inputs are envisaged during the lifetime of the project. Whilst it is not possible to be specific at this stage as to the precise requirements for these inputs the candidates should all possess a high level of expertise in their particular field.

Volunteers

The volunteers should have a relevant degree from a recognised university or some experience in a relevant field. They should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset. The volunteers would provide a vital element of continuity to the project maintaining the support functions of the unit in the gaps between inputs from the specialists.

Appendix 2 - Training

The project has no specific budget item for training. Much of the time of the experts will be spent in on-the-job training and in providing lecturers and training material under national projects associated with the umbrella project. A budget of US$ 100 000 has been allowed for the preparation of training materials and the printing and distribution of guidelines and standards to national agencies.

Appendix 3 - Equipment

The equipment budget covers the equipment required to set up the Umbrella Project office.

Item	Quantity	Unit Cost (US$)	Amount (US$)
Transport			
Saloon + spares	3	15 000	45 000
Sub-total			45 000

Item	Quantity	Unit Cost (US$)	Amount (US$)
Office Facilities			
Microcomputer 386/40 MB memory	6	6 000	36 000
Laser printer	2	1 500	3 000
Dot matrix printer	2	750	1 500
Uninterruptable power system	6	1 500	9 000
Software			5 000
Photocopier	1	5 000	5 000
Fax machine	1	1 000	1 000
Sub-total			60 500
Office Running Costs			
Support staff	120	2 000	240 000
Rental and Building Services	120	5 000	600 000
Sub-total			840 000
TOTAL			945 500

Country:	Regional, West Africa
Date:	November 1991
Project No.	REG-2
Proposed Title:	Training Programmes for Meteorology, Hydrology and Groundwater Technicians and Professionals
Implementing Agency:	Comité Interafricain d'Etudes Hydrauliques (CIEH), Ouagadougou, Burkina Faso National Institute for Water Resources, Kaduna, Nigeria Water Resources Research Institute, Accra, Ghana
Estimated Duration:	5 years
Tentative International contribution:	US$ 3 514 000
Estimated counterpart costs:	To be determined
Source of funds:	To be decided

I. Development objective and its relation to the country programme

The development of water resources is a key issue in each of the twenty three countries in the West African region. The growth of population in these countries and the need to both provide for their basic needs and to raise the level of their standard of living will ensure that water resources development is at the top of the agenda in the future.

There is considerable variation both in the availablility of training in water related disciplines, the type of courses offered, and the requirements for training among the countries of the region. Training local staff in the specialised disciplines of meteorology, hydrology, and hydrogeology has largely been funded and organised on a project basis and has generally been dependent on overseas training institutions, although some of the larger regional programmes such as AGRHYMET have been of sufficient size to justify the establishment of their own training facilities. The francophone countries have achieved a considerable degree of collaboration on training provision within the region through CIEH, the EIER and ETSHER, and the AGRHYMET centre. National centres have sucessfully developed in both Ghana and Nigeria and these also offer places to trainees from neighbouring countries. There is no provision for Portuguese or Spanish speakers. The technical level, and length, of courses is variable between institutions. There is an identified need for the provision of short courses, particularly at the technician level.

The proposed programme does not seek to replace existing institutions but is aimed at increasing the range of provision within the region particularly to those disadvantaged by language. Due to the difficulties of language we have recommended that the project should focus on two centres (possibly three), one francophone and one anglophone, and, taking account of their current strengths, provide experts to develop new courses and to ensure that sufficient equipment is available for specialised practical training, for example in such areas as geophysical investigations.

By developing common courses which are tailored to the particular needs of the national agencies the project will play an important part in standardising techniques between countries which will benefit those planning the use of shared resources.

II Major Elements

The objectives of the project are to support existing training courses offered by the two implementing institutions and to extend and enhance the courses on offer. We have recommended the development of two/three existing centres: 1) Francophone, in Ouagadougou the two training schools EIER and ETSHER which are closely linked to CIEH, 2) Anglophone, in Kaduna the National Institute for Water Resources and/or in Accra the Water Resources Research Institute. Historically they have had strengths in slightly different areas, the Institute in Kaduna for example has a well established training centre specialising in groundwater development, whilst CIEH has a recognised capability in databases (HYDROM in particular). The following elements are common to the overall project rather than specific to one of the institutions.

- Groundwater is currently poorly represented on training courses and there is a shortage of skilled technicians and professionals in many countries of the region. The aim is therefore to develop a range of courses, from one month to one year, covering basic concepts in hydrogeology and specialised aspects of drilling, drawdown test interpretation etc.

- Existing facilities for training in both Portuguese and Spanish are extremely limited. Technicians are unlikely to be able to cope with courses in a second language and the length of course would have to be extended. The intention is to offer courses in both these languages through the Ouagadougou centre by providing lecturers in these languages.

- Sustainability of the training programmes in the long term depends on the availability of experts from the region with the necessary skills to maintain the courses. The project is designed to phase in the use of regional experts and to equip them with the necessary teaching skills.

- Training in the past has tended to focus on the needs of professionals. This project, whilst supporting courses for professionals, will contain a major component targeted at technicians. The bias of the courses will be towards the practical, particularly where new techniques or equipment are involved. The programme will emphasise short courses since many agencies are short staffed and cannot spare key personnel for long periods, also larger numbers of staff can be offered places each year.

Table 1 lists the range of topics for courses which the regional training project would support.

III Project strategy

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

The national agencies responsible for meteorology, hydrology, and groundwater in the 23 countries in West Africa would be the primary beneficiaries. The project would support the activities of these agencies in the fields of data collection, processing, and analysis by enhancing the skills of staff at all levels. In the long term the steady build up of a cadre of well trained staff within each agency will result in the agency providing a better service to its customers, those involved in national planning for water resources development.

The project, organised as it is over a relatively long time scale, will benefit the agencies by offering continuity of support in the long term.

TABLE 1

Range of Topics to be Offered by Hydrometry Training Centres

1 Basic Subject

- Mathematics
- Statistics
- Introduction to computers
- Surveying
- Map reading and air-photos

2 Introduction to Hydrology

- Subject of hydrology
- Hydrological cycle and hydrological processes
- Drainage basin characteristics
- Hydrological extremes
- Open channel hydraulics
- Modelling hydrological processes

3 Meteorology

- Introduction to meteorology
- Air circulation in the topical regions
- Meteorological observation site
- Precipitation
- Other climatic data
- Evaporation and evapotranspiration
- Representation on maps and graphs

4 Hydrometry

- Basic hydraulics
- Stream gauging
- Water level measurement
- Site selection
- Operation and maintenance of equipment
- Calibration of hydrometric equipment
- Discharge rating

5 Hydrogeology

- Introduction
- Basic hydrology
- Soils and soil water
- Groundwater movement
- Pumping test analysis
- Groundwater exploration
- Groundwater extraction
- Groundwater resources

6 Water Quality

- Introduction
- Basic chemical definitions
- Physical characteristics
- Water quality parameters
- Chemical classification of waters
- Sampling and preservation
- Basic water analysis

7 Computers for Data Management

- Introduction to spreadsheets
- Introduction to databases
- Use of CLICOM
- Use of HYDROM
- Use of HYDATA/HYMOS or other
- Use of dBase 3 and 4 databases developed
- for groundwater
- Management of data archiving
- Introduction to GIS
- Computer aided cartography

8 Computers for Data Analysis

- Control of transmitted data
- Data processing
- Missing data
- Data storage and retrieval
- Basic analysis
- Floods and droughts

9 Water Resource Development

- Hydrological data networks
- Water resources assessment
- Design floods
- Utilisation of water resources by man
- Water supply and sanitation
- Water resources management

2. Target Beneficiaries?

The target beneficiaries are all those people in the region whose standard of living will be improved by future developments in the water sector. The benefits will be felt in the water supply, agricultural, and industrial fields.

3. Implementation arrangements for the project.

There are a number of institutions in the region which provide training in water related subjects at a variety of levels. It was decided that given the problems of language the most effective solution would be to select two centres (possibly three), one francophone institution and one anglophone institution, for further development as regional centres. Whilst desirable further centres for Portuguese or Spanish tuition were not felt to be justified, however, courses in these languages should be offered at the francophone centre on a regular basis.

The project is designed to run in three phases with a degree of overlap between them:

- Phase 1, development of new training courses, ordering and installation of equipment, administrative arrangements.

- Phase 2, training courses run by international specialists, largely technical training but to include a component to train West African specialists as lecturers.

- Phase 3, training courses to be run by local specialists with occasional support as necessary from experts employed on the 'Umbrella' Project (REG-1).

Most country projects proposed as part of the Sub-Saharan Africa Hydrological Assessment have a budget allocation for training which can be used to cover the cost of students attending the new courses.

4. Alternative implementation strategies

Many of the projects identified in the course of the Sub-Saharan Africa Hydrological Assessment for individual countries have a training component. It would have been possible to increase the budget allowed for training within projects for those countries where training facilities are limited in order to finance more students on courses outside the region. It was felt that the present proposal which is designed to enhance local facilities was more desirable in the longer term.

The possibility of using full time experts for the life of the project was considered but it was felt that the extra cost would not be justified and that there were important long term benefits to training and then employing local lecturers.

IV Host country commitment

1. Local support

The selected organisations should provide the necessary administrative staff and office support to manage the enlarged intake of students.

2. Legal arrangements and future staffing

There may be a danger that those trained as lecturers under this project may obtain employment elsewhere thus becoming unavailable to the training centre. In these circumstances it may be necessary to place some restriction on those who will benefit from this particular training to ensure that perhaps they continue to make themselves available to the training centre for a set period after training, or perhaps forcing their prospective employer to repay a part of the training cost to the training centre if they plan to leave within a set period after their training.

V Risks

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

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

The wholehearted support of the selected training institutions will be essential to the successful implementation of the project particlularly at the outset.

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

As stated above this project is one of a number of complementary regional and national projects. Meticulously co-ordinated management of the execution of all the projects is essential to ensure that trainees from country projects are made available to attend courses on schedule. It is also essential that candidates for training are properly selected to ensure that the chosen courses are suitable and the training benefit is maximised.

VI <u>Inputs</u>

1. Skeleton Budget

Personnel

a) International

Phases I and II	Input months	Rate US$/month	Amount US $
Team Leader	32	20 000	640 000
Hydrology experts	15	20 000	300 000
Groundwater experts	15	20 000	300 000
Meteorology experts	6	20 000	120 000
Computer specialist	6	20 000	120 000
Subsistence		2 500	185 000
Travel			120 000
Sub-total			1 785 000

b) West African Experts

Phases II and III	Input months	Rate US$/month	Amount US $
Team Leader Phase III	22	16 000	352 000
Hydrology experts	15	16 000	240 000
Groundwater experts	15	16 000	240 000
Meteorology experts	6	16 000	96 000
Computer specialist	6	16 000	96 000
Subsistence			160 000
Travel			45 000
Sub-total			1 229 000

Training

On-the-job training on teaching methods will be given.

Equipment

The equipment budget is to provide the centres with sufficient specialised instruments to allow them to provide hands-on training for those attending the courses. The existing centres have a certain amount of equipment already and this budget would allow them to obtain any equipment necessary to meet the needs of their extended lecture programmes.

An budget of US$ 500 000 has been allowed (this is very approximate).

TOTAL	US$ 3 514 000

2. Policy issues

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

Appendix 1 - International Personnel

1. Qualifications and Duties

The qualifications of team members will depend on the type and level of training courses that they will be responsible for. Many of the short courses aimed at technicians are intended to be very practical and the trainer for such courses should have extensive experience of field operations or the particular computer software/hardware setup. Where academic qualifications are of greater importance team members should have a degree, or post-graduate degree, in meteorology, hydrology, hydrogeology, engineering, a natural science, or computer science from a recognised university.

They should have at least 10 years experience in the operation of data collection and processing systems in their field of expertise. Previous experience of giving training would be an advantage, but would be essential for the nominated team leader. Where the experts are from outside the region they should preferably have experience of working in West Africa.

They should have a good command of at least one of the four languages: English, French, Portuguese, or Spanish.

The Team Leader should have spent part of his career working in a recognised training institution, experience in curriculum development would be an advantage.

Appendix 2 - Training

The project has no specific budget item for training.

Appendix 3 - Equipment

The equipment required cannot be determined precisely at this stage, but equipment will be required in the following fields:

- computers and peripherals;
- specialised software in common use eg CLICOM, HYDROM etc;
- relevant commercial software eg database, spreadsheet, word processor etc;
- meteorological equipment;
- hydrometric equipment;
- drilling equipment;
- groundwater monitoring equipment;
- water quality testing equipment;
- teaching materials.

Country:	Regional, West Africa
Date:	November 1991
Project No.	REG-3
Proposed Title:	Advanced Hydrological and Environmental Monitoring Programme: Component for West Africa
Implementing Agency:	World Meteorological Organisation
Estimated Duration:	10 years
Tentative International contribution:	US$ 4 486 500
Estimated counterpart costs:	To be determined
Source of funds:	To be decided

I. Development objective and its relation to the country programme

The development of water resources is a key issue in each of the twenty three countries in the West African region. The growth of population in these countries and the need to both provide for their basic needs and to raise the level of their standard of living will ensure that water resources development is at the top of the agenda in the future.

The collection of high quality hydrometric data on a continuous basis is essential for the planning of water development projects, but also for the monitoring of environmental conditions in the long term. With the current emphasis on the need for 'sustainable' development in Africa it is more important than ever to have a constant flow of data on a wide range of environmental parameters, including those which fall within the field of hydrometry (rainfall, temperature, wind, radiation, river flow, depth to water table, water quality, etc).

Data collection agencies in the region are subject to severe financial constraints and the level of hydrometric activities has declined to the point where they can no longer guarantee the continuous flow of high quality data even from a limited part of their networks. The findings of the Sub-Saharan Africa Hydrological Assessment Study and a recent WMO/UNESCO report on progress in implementing the Mar del Plata Action Plan indicate that the problem is the same throughout Africa.

This has led to the development of a proposal for a continent-wide programme to support monitoring of environmental parameters making use of advanced technology in station instrumentation and data transmission. Initiating a programme of this scale poses major logistical and organisational problems, it has therefore been recommended that the programme should be phased, starting initially with a single regional network. Given the experience gained on several regional projects which have used automatic monitoring stations and satellite transmission systems (HYDRONIGER, the Onchocerciasis Control Programme, the OMVS project at Manantali), West Africa would seem to be the ideal area to start the first phase of the continental programme. This West African environmental monitoring project has therefore been designed to fulfill the objectives of the first phase of the larger programme.

II Major Elements

To ensure a more reliable and continuous flow of hydrometric and environmental data it is suggested that a minimum network, regional in scale, of key stations be selected to act as continuously operating, high quality benchmark stations against which data from the existing networks may be tested and verified.

- identify the locations of these benchmark stations, incorporating existing stations where possible;
- select and procure monitoring instruments, bearing in mind the need for reliable operation in often difficult operating conditions and maintenance requirements;

- select and procure all necessary equipment for data transmission, reception, and preliminary computerised processing;
- establish a field programme in close collaboration with national agencies to (a) install all equipment, and (b) to make routine visits to each site for maintenance and to allow current meter measurements to be taken;
- establish data processing, archiving, and publication systems such that the data can be made available to users with the minimum of delay;
- training;
- on completion of first trial phase carry out project appraisal and make recommendations for the large continent-wide programme;
- in later stages of the project establish data sharing links with parties with interests in the field of large scale environmental changes.

III Project strategy

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

The project would assist directly in maintaining a minimum network of monitoring points using advanced technology, and the associated processing activities to ensure that a steady flow of reliable data is made available for environmental monitoring by national and international agencies. The national agencies responsible for meteorology, hydrology, and groundwater in the 23 countries in West Africa would benefit from training and a transfer of know how.

The project, organised as it is over a relatively long time scale, will benefit the agencies by offering support in the long term.

2. Target Beneficiaries?

Benefits will be felt both inside and outside the region as data vital to international research into global environmental issues is made available on a routine basis.

3. Implementation arrangements for the project.

The project would be run from a regional centre which would house the main receiving station and the associated computer equipment required to process the incoming signals and prepare them for distribution. The preferred location is close to/within the office of the proposed regional Umbrella Project (REG-1).

The project will be carried out in two stages:

- A first phase lasting approximately two years allowing for system design, procurement, installation of field and processing equipment, and a period of operation. At the end of this stage the project team would carry out an appraisal of both the technological and institutional aspects leading to recommendations for the design and implementation of the planned continent-wide monitoring system.

- Operational phase collecting and distributing the environmental data for the West African region. As a data series of sufficient length is built up the project will begin analysis and interpretation of the data. During this phase the project will establish links with parties interested in environmental change, both those from within the region itself and from the international community, to ensure that the focus of the monitoring activity adequately reflects current concerns and meets recognised needs. These links will also form a model for the planned continent-wide programme.

Strong links with an overseas research establishment would be advantageous, particularly in the early stages of the project.

4. Alternative implementation strategies

An alternative arrangement would be for the environmental monitoring to be organised by the proposed regional Umbrella Project with national agencies sub-contracted to supply the required field services, but this would forgo the benefit of participating in the planned continent-wide monitoring system.

IV <u>Host country commitment</u>

1. Counterpart support

It will be necessary for national agencies to provide sufficient staff to support the field programmes. The project will cover the cost of field programmes carried out by the agencies (excluding staff salaries).

2. Legal arrangements and future staffing

No special arrangements are envisaged.

V Risks

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

This project is both a part of a planned advanced environmental monitoring programme covering the whole of sub-Saharan Africa proposed as a result of the overall Sub-Saharan Africa Hydrological Assessment Study, and a component of the proposed Hydrometry Development Programme for West Africa. The planning of all components will have to be carefully co-ordinated, especially with country projects, to ensure that all the countries involved are in agreement and are prepared to commit the necessary counterpart staff.

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

The project is intended to last for 10 years; the continued commitment of participating countries to the project will be crucial to its success. Problems might also occur after the initial phase if there is a major delay in starting the remainder of the continent-wide monitoring programme. This is an issue which can only be resolved by the WMO, the executing agency for both projects.

VI Inputs

1. Skeleton Budget

Personnel

	Input months	Rate US$/month	Amount US $
Project Manager (data processing)	108	20 000	2 160 000
Telemetry and Field Expert	24	16 000	384 000
Short-term Consultants	5	20 00	100 000
Subsistence	137	2 500	342 5000
Travel to/from duty station			40 000
Travel for country visits			220 000
Sub-total			3 246 500

Training

Budget for training of national staff in use and maintenance of telemetry equipment US$ 160 000

Equipment

Item	Unit	Rate US$	Amount US$
Data Collection Platform + spares	20	15 000	300 000
Receiving station + spare parts	2	40 000	80 000
Vehicles - 2 saloon	2	15 000	30 000
Computers			20 000
Running/maintenance cost per field station			450 000
Running/maintenance cost receiving centre			100 000
Transmission cost			100 000
Sub-total			1 080 000

TOTAL	US$ 4 486 500

2. Policy issues

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

Appendix 1 - International Personnel

1. <u>Qualifications and Duties</u>

Project Manager

The project manager should have a degree in engineering or a natural science from a recognised university. A post-graduate degree in hydrology would be an advantage. The project manager should also have at least 15 years experience in operational hydrology, which must include a minimum of five years in a management role. The director should have a good command of either English and French languages, but preferably of both, and some knowledge of Portuguese and Spanish would be an asset.

The main role of the project manager would be to ensure the effective day to day running of the project and co-ordination of the activities of the project with staff of national agencies. He would have an important role in the selection and procurement of suitable equipment for the network and the central processing facility. He would also be responsible for the arrangement of a routine maintenance programme and the regular inventorying of stock of spare parts to safeguard the operation of the network.

Telemetry and Field Experts

These experts should have a degree in engineering or a natural science from a recognised university. A post-graduate degree in hydrology would be an advantage. They should have at least 5 years experience in operational hydrology, at least one should also have experience with the operation of telemetry systems. They should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset.

The duties of these experts would be to supervise the installation of the new equipment, to carry out a regular programme of discharge measurements to keep the rating at each site up to date.

Specialists

A small number of specialist inputs are envisaged during the lifetime of the project. Whilst it is not possible to be specific at this stage as to the precise requirements for these inputs the candidates should all possess a high level of expertise in their particular field.

Appendix 2 - Training

Twenty short specialised courses have been allowed for. The training would be organised under the regional training project REG-2.

Appendix 3 - Equipment

With regard to transmission cost the budget figure of US$ 100 000 is dependent on the technology finally selected.

Item	Quantity	Unit Cost (US$)	Amount (US$)
Office Facilities			
Microcomputer 386/40 MB memory	2	6 000	12 000
Laser printer	1	1 500	1 500
Dot matrix printer	1	750	750
Uninterruptable power system	2	1 500	3 000
Software			2 750
Sub-total			20 000

Country:	Regional, West Africa
Date:	November 1991
Project No.	REG-4
Proposed Title:	Data Rescue Programme for Hydrological and Groundwater Data
Implementing Agency:	UNDP or WMO
Estimated Duration:	5 years
Tentative International contribution:	US$ 1 787 000
Estimated counterpart costs:	To be determined
Source of funds:	To be decided

I. Development objective and its relation to the country programme

Long term data are a crucial element of water resource planning. There is considerable concern that original data is not being stored in satisfactory conditions and that there is danger that in the future this data will be lost. The introduction of computerised data processing has increased this concern rather than lessened it.

In the field of meteorology there is an ongoing project, DARE, run by the Belgian Meteorological Office, which has for a number of years been carrying out a programme of systematically taking microfilm copies of meteorological data for primary stations in West African countries. This process started in the CILSS member states and has since been extended. In this project microfilm equipment has been introduced, with training, to the meteorological service in each country and after a visit by the DARE team the service is expected to continue the microfilming on a regular basis.

Similarly a regional project under the auspices of the CIEH and ASECNA collated rainfall records for 13 francophone countries and after lengthy procedures to check the quality of the information made the data available both as mircrofiche, books, and as part of a computerised database. This project dealt with rainfall data only and included all records from station inception up to 1980.

To date such comprehensive efforts have not been undertaken in the fields of surface water and groundwater data, and it is this lack that this project seeks to remedy.

II Major Elements

The objectives of the project are to ensure the preservation of historic records and to set up systems on a national basis to assure the safe keeping of data being collected now and in the future whether on paper or electronic media. The project will address the particular problems of establishing means of protecting information now being entered on computerised systems. The project team would establish close liaison with the regional Umbrella Project whose activities include a support to computer managers and the issuing of guidelines and standards on a wide range of topics related to data processing and storage systems.

The objective is to assist national agencies in maintaining their records and account will be taken of current practices when recommending new procedures for implementation.

The project can be considered in two parts: (a) the preservation of paper records, and (b) the safeguarding of computerised records.

(a) Paper Originals

- To microfilm historic data from hardcopy originals (from ledgers, loose pages in box files, charts, rating graphs etc);

- To return the data in the form of sorted and catalogued microfiche to the national agency.

(b) Computerised Records

- To gather punch cards from early computerisation and to examine the possibility of having them read;

- To examine the serious problems of arranging permanent storage of electronic data.

- Develop guidelines for managers of computerised data handling systems covering the expected lifetime of different forms of storage (tapes, floppy disks, optical disk etc), a systematic procedure for routine checking of viability of disks etc, catalogue systems for files, directories, disks etc;

- In collaboration with the computer support team of the Umbrella Project investigate means of safeguarding the data long term by developing specifications for new systems that ensure upwards compatibility with current systems (avoiding in the future a repetition of the 'lost' data stored on punch cards which cannot be utilised by the present generation of hardware).

III <u>Project strategy</u>

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

The national agencies responsible for meteorology, hydrology, and groundwater in the 23 countries in West Africa would be the primary beneficiaries. The project would support national activities of these agencies in the fields of data storage and archiving.

2. Target Beneficiaries?

The target beneficiaries are all those people in the region whose standard of living will be improved by future developments in the water sector. The benefits will be felt in the water supply, agricultural, and industrial fields.

3. Implementation arrangements for the project.

The project is designed to run for 5 years.

Particularly with regard to the problems of preserving paper originals this project has drawn heavily on the methods of the DARE project for meteorological data which has now run for over 5 years. The DARE approach aims to introduce microfilming techniques to the national agency as an on-going method of safeguarding data through on-the-job training. The national agencies supply the DARE centre with the microfilmed data which undergoes secondary processing to ordered and catalogued microfiche before being returned to the country. The present project is organised on a similar basis aiming to provide equipment and training for microfilming in each participating country and providing a centralised service to undertake the secondary processing.

For computerised records the approach is rather different. Many of the region's agencies have specialised software packages for data handling, these often incorporate sub-programs to automate the cataloguing and archiving of data but the Sub-Saharan Hydrological Assessment Study revealed that the operators and managers frequently did not have sufficient training to utilise these systems to their full potential. Additional training is therefore a key element which will be organised throught the regional training project REG-2. At the project headquarters the focus of work will be the preparation of guidelines on storage and retrieval systems in collaboration with the regional Umbrella Project REG-1.

4. Alternative implementation strategies

The possibility of combining this project with other projects proposed as a result of the hydrological assessment was considered but it was felt that the proposed activities were such that they could be carried out independently of the other projects.

The possibility of using full time experts for the life of the project was also considered but the extra cost was not felt to be justified.

IV Host country commitment

1. Counterpart support

The project aims to establish a routine archiving procedure which can be maintained beyond the lifetime of the project. Counterpart staff will be essential to the success of the project. In most agencies manpower resources are sufficient to ensure that a reasonable level of service is provided. However some departments already suffer from the absence of staff who are attending long-term training overseas. Care will have to be exercised to ensure that the proposed project does not aggravate this situation.

2. Legal arrangements and future staffing

The type of training involved is not likely to be marketable outside the agency so that it is not anticipated that any special legal arrangements would be required.

V **Risks**

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

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

2. **Factors which could over time cause major delays or prevent achievement of the project's outputs and objectives**

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

VI **Inputs**

1. **Skeleton Budget**

Personnel

	Input	Rate US$/month	Amount US $
Team Leader/Hydrologist	24	16 000	384 000
Volunteer - surface water	36	5 000	180 000
Groundwater expert	12	16 000	192 000
Volunteer - groundwater	36	5 000	180 000
Meteorologist	3	16 000	48 000
Computer specialist	3	16 000	48 000
Subsistence	42	2 500	105 000
Travel			30 000
Sub-total			1 167 000

Training

	Amount US$
Short courses in the region - 50 Training on-the-job	400 000
Sub-total	400 000

Equipment

Item	Nr	Rate US$	Amount US$
Microfilm and microfiche equipment + spares and consumables	25		100 000
Computer peripherals and consumables	25		100 000
Computer + peripherals for project team	2		20 000
Sub-total			220 000

TOTAL	US$ 1 787 000

2. Policy issues

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

Appendix 1 - International Personnel

1. <u>Qualifications and Duties</u>

Team members should have a degree in meteorology, engineering or a natural science or computer science from a recognised university. They should have at least 5 years experience in operational hydrology. One should have at least 5 years experience in the development of software for data management. They should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset.

Appendix 2 - Training

The project has budget for up to 50 short training courses, it is anticipated that these will be organised through the regional training project REG-2 which will ensure that the courses are tailored to the particular requirements of this project, specifically training in the use of existing software for safe storage and easy retrieval of computerised data records. Time will also be spent in on-the-job training particularly in the use of microfilming equipment.

Appendix 3 - Equipment

The equipment will include items for the national agencies and for the project team: microfilming equipment, computer peripherals such as optical disk drive, and computer facilities for the project team.

Country:	Regional, West Africa
Date:	November 1991
Project No.	REG-5
Proposed Title:	Assessment of the Economic and Social Benefits of Water Resources Data Collection in West Africa as a Justification for Increasing Funding to Hydrometric Services
Implementing Agency:	World Bank or UNDP
Estimated Duration:	12 months
Tentative International contribution:	US$ 561 500
Estimated counterpart costs:	To be determined
Source of funds:	To be decided

I. Development objective and its relation to the country programme

The development of water resources is a key issue in each of the twenty three countries in the West African region. The growth of population in these countries and the need to both provide for their basic needs and to raise the level of their standard of living will ensure that water resources development is at the top of the agenda in the future.

In early 1990 the WMO held a technical conference on the subject of the 'economic and social benefits of meteorological and hydrological services' with the objective of providing directors and managers of national services with material and knowledge that could be used to promote the development of their services and to help them to more effectively demonstrate to their governmental authorities and the public the benefits that can be gained through improved meteorological and hydrological services. Of the 67 countries attending the conference 7 were from the West African region. This conference reflects both the WMO's concern with the sustained funding of such technical services, and the interest of meteorological and hydrological agencies in the region in learning from the experience of other countries in the promotion of their services.

In the light of mounting global concern in connection with climatic change and environmental degradation, and the emerging questions of marketing, commercialisation, management and financing the WMO conference recommended further studies to develop methodologies for assessing economic and social benefits and test them in individual countries. Developing means of increasing the financial resources available to water resources agencies was made the first component of the 1991 WMO/UNESCO plan 'Progress in the Implementation of the Mar del Plata Action Plan and a Strategy for the 1990s'.

The WMO conference papers represent the latest thinking on several important issues, predominantly by meteorologists although there were several contributions on surface water information services, groundwater data collection services were however not addressed.

The directors of national services in the fields of meteorology, hydrology and hydrogeology have a decisive role to play in the development of and promoting the status of their services. They must convince non-technical politicians of the merits of their case for funding on the basis of their contribution to national good. At present Governments have no means of estimating, and little idea of, the value of data collection services. With rapid population growth, environmental changes, and likely changes in climate due to global warming, increased demands for water will require a new assessment of the minimum data collection services commensurate with supplying the basic minimum data to design water resource development projects.

The project will provide participating countries with tools for evaluating quantitatively the minimum financing requirements of water resources data collection services in relation to present and future water development in their respective countries. It will also prepare promotional material for use by national agencies in their attempts to influence decision makers and budget holders.

II Major Elements

- Evaluate present expenditure on water resources data collection and processing in each participating country. This will include costs both for operation of the basic network and data collection for specific projects, and determining the source of funding.
- A literature review of cost/benefit studies and other methods of economic evaluation for water resource data collection leading to adapted benefit factors, where necessary, to meet the region's individual climatic and development circumstances.
- Assess possibilities for commercial activities in those countries where there are indications that cost recovery from customers may become a requirement.
- Evaluate the water resources implications of environmental degradation and land use change.
- Evaluate the influence of global warming scenarios on temperature and rainfall and assess the implications for water resources.
- Evaluate the implications for water resources of population growth, with its increased demands for water.
- Evaluate national water resources relative to future demand scenarios.
- Assess the economic and social benefit of water resources data collection now and for envisaged needs in the future.
- Make firm recommendations on investment in data collection required in each country to provide information needed to design adequate water development projects.
- Prepare material aimed at target groups, such as politicians, for use by national directors in promoting their agency and its funding requirements. Advise on promotional activities.

III Project strategy

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

The inital gains from this project would be for those planning the water resources and other aspects of development in each country. The national hydrometric agencies would also benefit from firm guidelines to establish budgets for their services which would in turn lead to better run services and better availability of data for the planning and operation of water related projects.

2. Target Beneficiaries?

The target beneficiaries are all those people in the region whose standard of living will be improved by future developments in the water sector. The benefits will be felt in the water supply, agricultural, and industrial fields.

3. Implementation arrangements for the project.

The project is envisaged as a 12 month study by consultants largely carried out in their home office but with an initial information gathering phase in the region. The project would liaise with the Hydrometry Development Programme Umbrella Project throughout the study, but particularly during the initial phase and most importantly at the end of the study to determine the best method of introducing the study results to the directors and managers of the national agencies in the region.

The project would employ a wide range of experts in the fields of hydrometry, climate modelling, demography, and economics.

4. Alternative implementation strategies

An alternative implementation strategy would be to have a series of national projects dealing with the same topics. This would be more expensive and would not give the regional perspective provided by this project.

IV Host country commitment

1. Local support

During the course of the Sub-Saharan Africa Hydrological Assessment project the participating countries have provided the back-up and and access to the data expected of them. We would anticipate therefore they would welcome and support the proposed project.

2. Legal arrangements and future staffing

Not an issue.

V Risks

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

The project will be run in conjunction with the Umbrella Project, REG-1, and its starting date should be co-ordinated with that project.

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

The success of the project will depend in large measure on the willingness of participating countries to release the necessary information to allow the study to be undertaken.

VI Inputs

1. Skeleton Budget

Personnel

	Input	Rate/month US$	Amount US$
Home Office			
Team Leader/hydrologist	10	16 000	160 000
Water Resources Planner	3	13 000	39 000
Groundwater Expert	3	13 000	39 000
Climatic Modelling Expert	3	13 000	39 000
Demographer	1	13 000	13 000
Economist	4	13 000	52 000
Overseas			
Team Leader/hydrologist	2	20 000	40 000
Water Resources Planner	2	16 000	32 000
Groundwater Expert	2	16 000	32 000
Demographer	1	16 000	16 000
Economist	2	16 000	32 000
Subsistence	9	2 500	22 500
Travel			25 000
Sub-total			541 500

Training

No budget item.

Equipment

An allowance of US$ 20 000 has been made.

TOTAL	US$ 561 500

2. Policy issues

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

Appendix 1 - International Personnel

1. Qualifications and Duties

It is regarded as essential that all members of the team should have experience of working in Africa. Team members should have an appropriate degree from a recognised university. A relevant post-graduate degree would be an advantage. The team leader should have at least 10 years experience in operational hydrology. Other members of the team should have at least 5 years experience in their field of expertise. They should have a good command of either, but preferably both, English and French languages and some knowledge of Portuguese and Spanish would be an asset.

Appendix 2 - Training

The project has no specific budget item for training. However, it is to be hoped that following successful formulation of a methodology for benefit-cost analysis appropriate to the water sector in the region that the approach could be introduced in the form of either short courses or workshops organised under the auspices of the regional training project REG-2 in conjunction with the regional Umbrella project REG-1.

Appendix 3 - Equipment

The equipment budget covers the provision/hire of vehicles and computer facilities within the region for the duration of visits, and home office running costs for computers etc.

APPENDIX B

GLOBAL CLIMATE CHANGE IN THE 21ST CENTURY

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APPENDIX B

GLOBAL CLIMATIC CHANGE IN THE 21ST CENTURY

B.1 Introduction

The 1980's has been the warmest decade since the commencement of widespread instrumental meteorological measurements in the 19th Century, and possibly since the middle of the last interglacial 120 000 years ago. Globally, the 1980s have been about 0.2°C warmer than the 1950s and about 0.5°C warmer than the 1900s with 1990 being the single warmest year (Jones et al., 1988a; Jones and Wigley, 1991).

The cause of the warming is not yet known unequivocally. The strongest candidate is the increasing global concentrations of atmospheric trace gases, mainly carbon dioxide, methane, nitrous oxide, halocarbons (especially chlorofluorocarbons (CFCs)), and tropospheric ozone. These gases are collectively known as greenhouse gases being transparent to incoming short-wave radiation and effective absorbers of outgoing long-wave radiation. Their net effect is to absorb energy in the lower layers of the atmosphere thus causing surface air temperatures to rise. This phenomenon is known as the greenhouse effect.

This Appendix summarises current evidence for, and future projections of, global warming, and argues that this likely global climate change must be an important consideration when assessing future water resources in regions such as West Africa. The first part of the Appendix considers the changes in global-mean temperature, precipitation and sea-level which have occurred over the last 100 years, and the second part changes in these three parameters projected over the next 5-100 years.

B.2 Historical Changes in Global-Mean Climate

Changes in global-mean temperature can be estimated by combining together meteorological observations from the land and ocean areas of the Earth, the bulk of which were originally obtained as routine data for weather forecasting purposes. The marine data are particularly important, because they represent some 70% of the Earth's surface area (although coverage of this area is incomplete, simply because it is limited to the regions where ships travel). Many hundreds of millions of observations contribute to area-average estimates spanning the last 100 years or so. Before they can be used, these data must be examined critically for inhomogenities, ie for variations arising from non-climatic sources, such as changes in station location, observing times, measurement practise and effects such as urban warming[1]. Jones et al (1986) have produced the most comprehensive analysis to date. They show that the near-surface air temperature averaged over the globe has increased by

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[1] *As assessment of the magnitude of such biases and a discussion of their significance for the global-mean temperature time series can be found in Jones et al., (1991). There remains an unresolved uncertainty in the consistency of late nineteenth century ocean temperatures, which may affect the scale of global warming since 1860 by ±0.1°C.*

about 0.5°C since the late 19th century. Figure B.1 illustrates this by showing annual time series of hemispheric and global-mean temperatures. It is clear that the recent global-scale warming has not been a continuous upward trend; nor has the warming been spatially homogeneous, and trends have varied substantially from region to region. Over the past 20 years, for example, much of the North Atlantic and western Europe has undergone a slight cooling (Figure B.2; Jones et al, 1988b).

This cooling, and indeed the cooling that is evident in the northern hemisphere time series shown in Figure B.1 between 1940 and 1975, appears initially to be inconsistent with the greenhouse hypothesis. Although the cooling is undoubtedly real, it cannot however be taken as evidence that there is no greenhouse effect, nor even that the magnitude of the greenhouse effect is small. Rather, it is a graphic illustration of the extent and magnitude of natural climatic variability, the noise against which the greenhouse signal must be detected, and upon which future greenhouse warming will be superimposed.

Parallel changes in global-mean sea-level have also occurred (Table B.1). Compilations of tide gauge data from over 300 sites worldwide show a rise of about 12 cm since the late 19th century (Barnett, 1984). As with global-mean temperature, such as rise has been neither a continuous upward trend nor spatially homogeneous.

TABLE B.1

Historical Changes in Global-mean Climate

	Surface Air Temperature (1890-1990)	Sea-level (1890-1900)	Terrestrial Precipitation (1951-80)
Global	+0.5°±0.1°C	+12.5cm±2.5cm	-1.2%
Northern Hemisphere	+0.4°C		-4.1%
Southern Hemisphere	+0.7°C		+3.5%

Changes in global-mean precipitation are more difficult to assess for two reasons. First, long time series of precipitation measurements are restricted to land based sites, thus immediately between 60% and 70% of the globe is excluded from any historical analysis. Second, the greater spatial and temporal variability of precipitation make reliable estimates of global-mean precipitation in mm units hard to calculate. The most comprehensive analyses published to date are presented in Bradley et al (1987), Eischeid et al (1991) and Hulme (1992). Some results, are shown in Table B.1. These suggest a marked difference in precipitation trends between the north (decreasing) and southern (increasing) hemispheres. Again, the high noise/signal ratio of precipitation means that no definitive greenhouse signal may be discerned from these trends, although at least in the case of the African

Sahel a plausible mechanism for linking decreased precipitation and warmer oceans has been proposed (see Section 2.2).

B.3 Uncertainties in Predicting Future Global-Mean Climate

The magnitude of the projected change in global-mean climate in the 21st century depends on four key factors: the rate of increase in the emission of greenhouse gases; the estimated sensitivity of the global climate system to greenhouse-gas-induced thermal forcing; the time required for the climate system to approach equilibrium (ie the magnitude of the thermal inertia effect of the oceans); and the magnitude of any non-anthropogenic climate forcing, such as caused by volcanic eruptions or solar variability. Uncertainty exists on all four counts.

B.3.1 Global Greenhouse Gas Concentrations

Carbon dioxide (CO_2) currently contributes about 55% of the anthropogenic greenhouse effect (Houghton et al., 1990). The concentration of atmospheric CO_2 has risen from 315 parts per million by volume (ppmv) in 1958 to 355 ppmv in 1991, and is currently increasing at about 0.4% per year. Future growth rates will depend on the global growth in energy demand and the fuel mix used to meet that demand. Although industrialised nations are largely responsible for past and current CO_2 emissions, future energy demand and energy policies in the Less Developed Countries (LDCs) will become increasingly important in determining future CO_2 levels. In 1980 LDCs accounted for only about 13% of global carbon emission, but using 1980 energy consumption growth rates, the LDCs would surpass the industrialised nations in carbon emissions by 2010 (Darmstadter, 1986). China, for example, currently meets 76% of its energy demand by burning coal. Energy consumption is currently only 0.8 kw per person, but is anticipated to rise to 2.5 kw per person by 2030. Even if China were successful in launching a nuclear power programme, this would result in China alone emitting 3 billion tons of carbon by 2030, 60% of the current global carbon emission from fossil-fuel burning.

Emissions of methane and nitrous oxide are similarly linked to rates of future economic and population growth and to the pathways chosen for agricultural and economic development. Methane especially is linked to population growth since it derives largely from anaerobic processes associated with increasing number of ruminants, expanded rice paddy production, and from biomass burning related to agricultural expansion. Current concentrations and growth rates of greenhouse gases are shown in Table B.2 and the range of future projections of their collective concentration is indicated in Figure B.3 (top left). Four future emissions scenarios used by the IPCC (Houghton et al, 1990) are shown, together with the concentration (~560 ppmv CO_2-equivalent) at which pre-industrial levels of greenhouse gases will have doubled. Under the Business-as-Usual scenario the date by which this doubling of pre-industrial CO_2-equivalent is reached is about 2020.

B.3.2 Global Climate Sensitivity

Climate sensitivity is usually judged by the equilibrium global-mean temperature change that would eventually occur if the CO_2-equivalent level were doubled, denoted by ΔT_{2x}. This must be determined using some form of climate model. Its value depends critically on a variety of feedback processes which exist within the climate system. An example is the water vapour feedback. If the world warms, more water will evaporate from the oceans adding water vapour to the atmosphere. Since water vapour is a greenhouse gas, this will increase the greenhouse effect and cause further warming. Numerous other feedback mechanisms exist involving, for example, clouds, sea ice, snow cover and the ocean circulation, although some of these feedbacks may be negative (Mitchell et al, 1990). Since their quantitive effects are uncertain, the magnitude of ΔT_{2x} is also uncertain. The current best estimate is that it lies within the range 1.5 - 4.5°C, with a best-guess of 2.5°C (Houghton el al, 1990). Figure B.3 (top right) shows the realised transient warming for three climate sensitivities, one low (1.5°C), one best guess (2.5°C) and one high (4.5°C), under the Business-as-Usual emissions scenario. Thus for the year 2020, assuming a Business-as-Usual scenario, the range of realised warming over 1850 is from 1.4°C (low climate sensitivity) to 2.8°C (high climate sensitivity) with a best guess warming of 1.9°C.

B.3.3 Global Climate Inertia

The global climate system does not respond immediately to an imposed forcing. An important distinction has to be drawn therefore between the equilibrium response and the transient (or time-dependent response) of the climate system. Whilst a doubling of CO_2 -equivalent might produce an equilibrium global-mean warming of 3.0°±1.5°C, this warming would only be reached some time after the CO_2 doubling date. This difference between equilibrium and transient response is due to ocean thermal inertia. Oceans heat and cool only slowly and since they play a key role in determining the state of global climate, global-mean air temperatures will not equilibrate until the ocean temperatures equilibrate. Recent modelling of the effect of ocean thermal inertia suggests that equilibrium warming might lag the transient response by at least 40 years (Wigley, 1988). If strict global emission controls come into force (Grubb, 1989) then the equilibrium warming might never materialise.

B.3.4 Non-Anthropogenic Climate Forcing

Global climate is subject to a range of natural perturbations which may be either external or internal to the climate system. As yet some of these remain imperfectly understood (eg the effect of solar variability, Pittock (1983), or else they remain unpredictable (eg the effect of volcanic eruptions, Sear et al, 1987). Whilst some model experiments of future climate change have considered such natural forcing of the climate system (eg Hansen et al, 1988), we cannot effectively eliminate this element of uncertainty from our projections of 21st century climate change. For example, the eruption of Mt. Pinatubo in the Philippines in June 1991 injected the largest volume of dust aerosol this century into the stratosphere. Global-mean temperature in 1992 and maybe 1993 is anticipated to fall by between 0.1° and 0.2°C as a result.

TABLE B.2

Greenhouse Gases

Greenhouse Gas	Important Sources	Current Concentration (ppmv)	Recent Increase % Per Annum (1980-1989)	Relative GWP Per Molecule (100-year horizon)	% Contribution to global forcing (1850-1989)
Carbon dioxide	Fossil fuels combustion Biomass destruction	355	0.4	1	58
Methane	Rice paddy cultivation Permafrost thawing Waste tip decomposition Livestock	1.7	1	21	18
Nitrous oxide	Fertilizers Petrol combustion	0.31	0.3	290	5
Tropospheric ozone	Petrochemical plants Power plants	0.06	1.5	~2000	5
Choloroflourocarbons (eg CFC-11)	Coolants Aerosol sprays Foam packaging production	0.00026	5.0	3500	14

Note: GWP Global warming potential

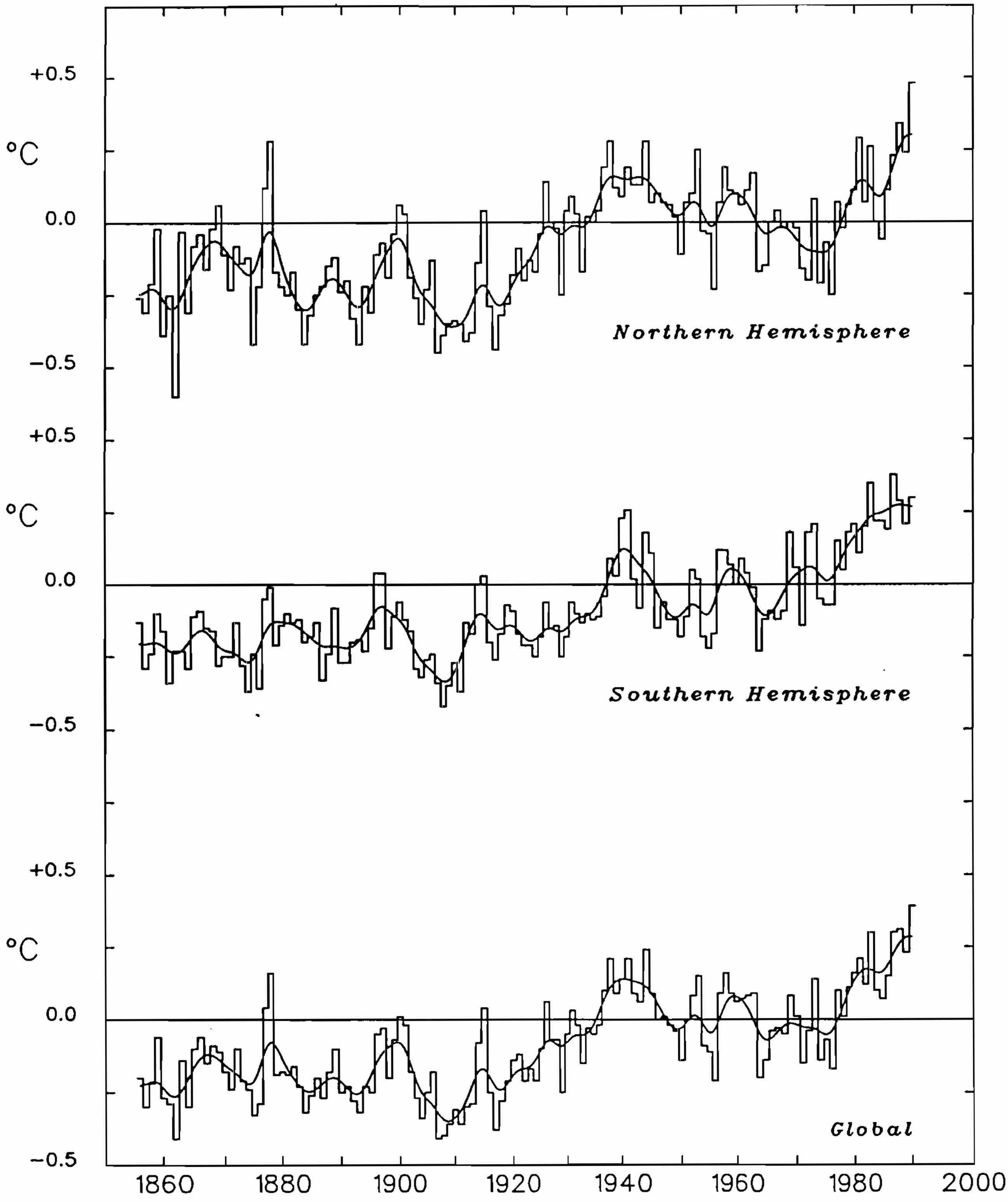
Sources: Global Climate Change, UK Department of Environment, 1989; Houghton et al, 1990

B.4 Global-Mean Climate in the 21st Century

Having considered these four uncertainties in projections of future global climate change, what conclusions may we reach concerning global climate in the 21st century? Figure B.3 (bottom) summarises the projections of changes in global-mean temperature and sea level under the four IPCC emissions scenarios. It should be noted that the temperature and sea-leave projections are for global-mean figures and reveal nothing about the regional patterns of such change. There will undoubtedly be regions where precipitation, for example, decreases following a doubling of CO_2-equivalent (see Section 2.2).

Figure B.1

Global and Hemispheric - Mean Annual Surface Air Temperature 1856 - 1990

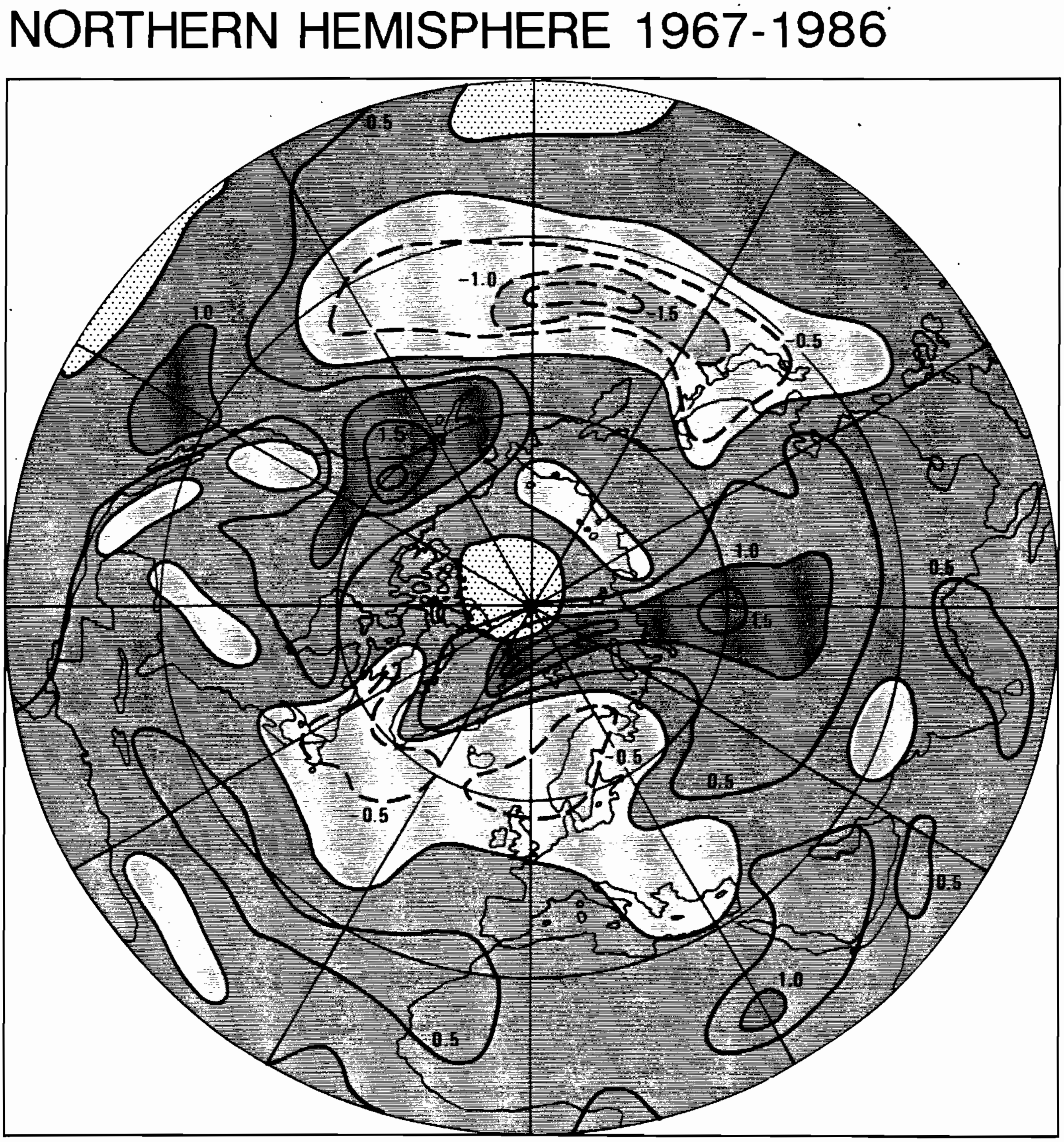


Global and Hemispheric-mean annual surface air temperatures 1856 to 1990 expressed as °C anomalies from 1951 to 1980 reference period.

07171/19/B

Figure B.2

Mean Annual Temperature Trend 1967 - 86 for the Northern Hemisphere



Source: Jones et al 1988b

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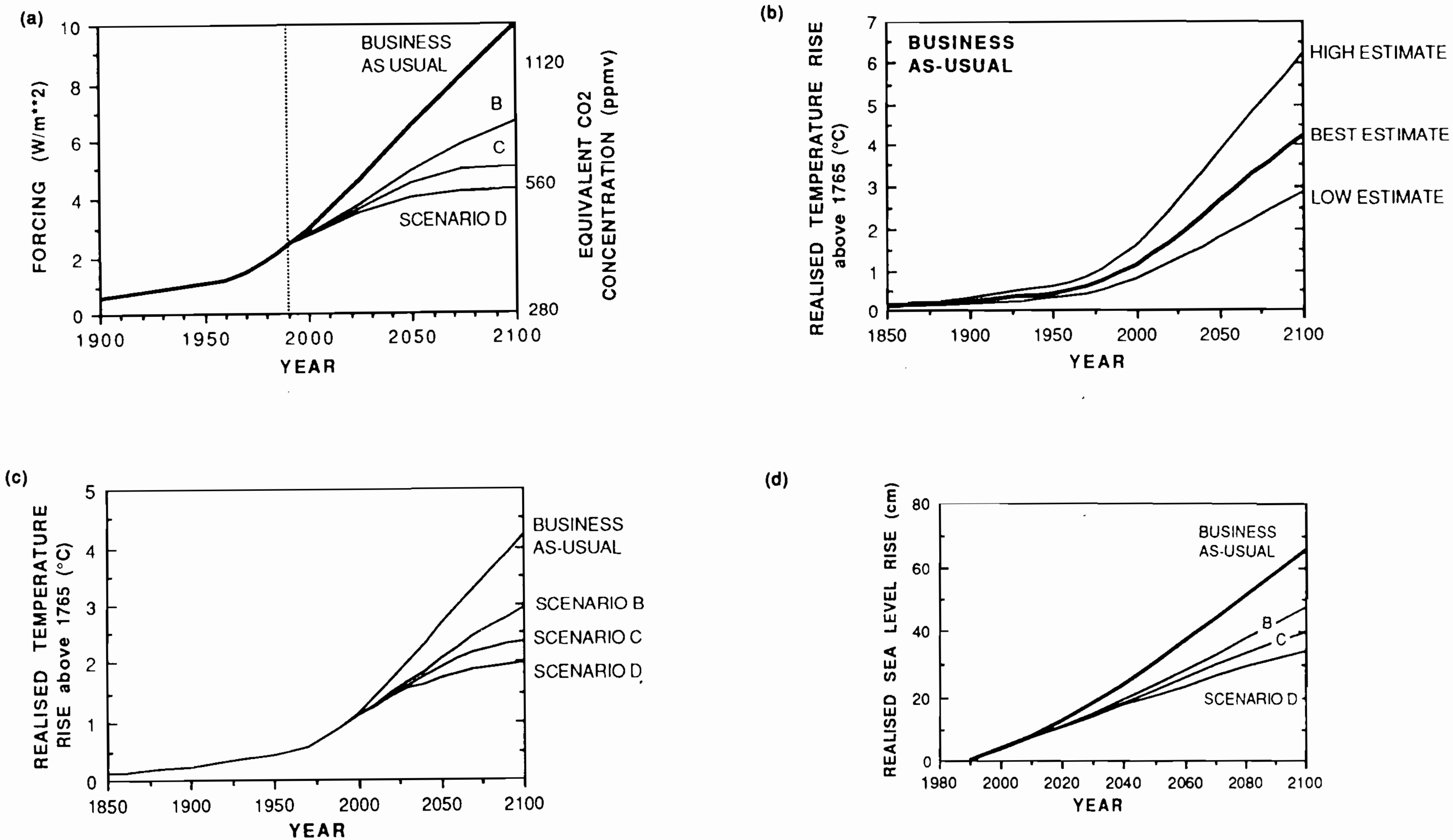
Figure B.3
IPCC Emission Scenarios - Predictions



(a) Increase in radiative forcing since 1990 due to greenhouse gas emissions, and that predicted to result from the four IPCC emissions scenarios, also expressed as equivalent Co_2 concentration; (b) simulation of the increase in global-mean temperature from 1850 to 1990 and predictions of the rise between 1990 and 2100 resulting from the IPCC 'Business as Usual' emissions for three different climate sensitivities; (c) as (b) but predictions for the four IPCC emissions scenarios and a best-guess (2.5°) climate sensitivity; (d) model estimates of sea-level rise from 1990 to 2100 for the four IPCC emissions scenarios.

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APPENDIX C

NEW TECHNOLOGY FOR SURFACE WATER HYDROMETRY IN AFRICA

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APPENDIX C

NEW TECHNOLOGY FOR SURFACE WATER HYDROMETRY IN AFRICA

C.1 Introduction

Hydrometry can be defined as the body of technologies and methodologies which permit the measurement in the field of relevant hydrological parameters and their transfer to data banks for archiving.

The first hydrometric parameter to be collected was the water level at selected sites. At first this was done manually (or rather 'visually') by observers, the traditional 'gauge readers'. Entered into observation notebooks, these data were periodically collected by hydrological field teams or posted or sent by other means to the central hydrological service for archiving.

The introduction of autographic water level recorders allowed continuous collection of data on a paper medium but it was still necessary to collect the charts and transfer them to the headquarters, and additional work was involved to process them. Furthermore, the unreliability of the equipment, the mechanical parts of which were liable to random malfunctioning, meant that it was always desirable to maintain human observers who were responsible for the good working order of the instrument. Otherwise frequent visits to unattended equipment were essential.

Hydrometry has been revolutionised by the arrival of technologies which permit the connection of the sensor and the in situ collection unit to a transmission unit at another site (headquarters, regional office, etc.). It has become possible, not only to know the hydrological conditions in real time, but also (and of great importance) to be certain of the good working order of the sensor and, if incorporated in the design, the status of the whole of the collection process, thus exercising a true 'autosurveillance' of the whole collection process.

Hydrological measuring is a chain of collection activities linked as follows:

MEASURE <-> ACQUISITION	<-> COLLECTION <-> <-> TELEMETRY <->	<-> ARCHIVE

Each of these components may be examined in isolation but it must be recognised that the strength of the chain is only as great as the weakest link. In this appendix we examine what improvements would result from the introduction of new technologies to certain links in the chain by:

- reviewing the benefits of the new 'intelligent' sensors and the new storage techniques using electronic media in operational hydrology;

- examining the different approaches to collection or telemetry;

- describing the different modes of transmission;

- examining the comparative advantages of polar orbiting satellites (ARGOS) and geosynchronous satellites (METEOSAT) for hydrometry;

- giving examples of hydrological networks managed with strong support from satellite telemetry;

- discussing the connection between the telemetry data and the computerised hydrological data bank, leading to an examination of appropriate structures for these data banks;

- discussing the development, within a geographical and regional policy framework, of hydrological networks incorporating telemetry.

C.2 New Technology in Hydrometry

Two considerable improvements in equipment have recently become available on the market under various trade names. They concern the field sensors and the recording equipment:

The sensors

The traditional floating water level sensors showed serious disadvantages, especially on a difficult site, since, in order to shelter them, it was necessary to install vertical covers over the whole range of possible water levels. Even in the best cases (good site), installation was costly and technically demanding. The structures thus set up were, furthermore, exposed to the disastrous effects of flooding. In order to ensure the sensitivity of the float gauges, it was necessary to take measures which were difficult to reconcile with the risk of fluctuations in water level.

The improvements in installation conditions which came with the arrival of pneumatic pressure sensors were compromised by other constraints: the calibration of these instruments required very qualified technical staff, loss of air occurred too easily and reduced the time that the instruments could operate without restocking, and the transport of high pressure bottles could be dangerous or difficult.

The introduction on the market of pressure sensitive piezo-electric sensors at the beginning of the 1980s brought about some interesting developments for the hydrologist since they put at his disposal reliable data in a numerical form (provided that corrections in temperature and atmospheric pressure are automatically transmitted), which could be transported over some distance by a strong, supple and easily protected cable. It became possible to disassociate the measurement site, where the strong and small sensor was installed in the best hydraulic conditions, and the site for the collection (or transmission) of the data.

Currently on the market there are reliable piezo-electric sensors, without drift, well adjusted for temperature and atmospheric pressure, and accurate to more than half a centimetre, which provide data in numerical form compatible with computer connections of the RS 232 type for example.

The acquisition of data:

All field hydrologists are familiar with problems of graphical recording on chart or paper tape both of which are very sensitive to climatic conditions, temperature and, above all, humidity. Originally there was also the disadvantage of the necessity for manual processing, which was difficult and demanding, even with the assistance of modern digitisers.

The arrival of fairly robust collection stations, which performed well and were cheap to install on site, was a considerable advance for hydrometry. Acquisition is achieved using the medium of a computer, either using tapes or magnetic disks which can be retrieved just as they are, or by reading with a portable micro-computer, or using the modern interchangeable or detachable cartridges, EPROM or EEPROM.

The transfer of data into computerised data banks, whether they contain raw or processed data, is made considerably easier since it can be done almost entirely automatically.

The availability of the data in digital form allows incremented messages to be created easily in real time, and in any format.

Another considerable advantage is intelligent data collection. It is no longer necessary to set a fixed time step for the measurement, which would lead to the accumulation of a multitude of identical data at low flow (in the case of a short time step), or to hide the detail of short duration floods (in the case of too long a time step).

It is possible to modulate the rhythm of 'intelligent' collection according to different modes: for example, the collection station can 'scrutinize' the sensor every minute, but decide only to store a measurement if it is different from the preceding measurement by a specific amount (1 cm for example), a technique which allows detailed information to be stored whilst avoiding the storage of redundant data and the saturation of the storage memory. Only the 'significant' points, decided according to programmable criteria, are therefore archived.

Finally, there is the robustness of the collection stations, which possess no mobile or fragile mechanical parts which makes them very reliable.

C.3 Collection and/or Transmission of Data

The appropriate type of collection (or of transmission) obviously depends a great deal on the type of hydrological network and its aims. It is first necessary to know which data to collect, for what purpose, and therefore how frequently.

If the availability of the hydrological data is not urgent, if it is only necessary to feed a data bank to be consulted later, the traditional collection by post (if it exists) or during network rounds is quite sufficient.

If, on the other hand, access in real time is necessary for a particular use (protection of inhabitants against the effects of flooding, management in real time of an hydraulic structure), then telemetry becomes necessary.

In all cases, it must be remembered that telemetry will at the same time enable the remote surveillance of all the equipment and therefore control of all the collection chain, a function which is usually ensured on traditional networks by control and maintenance visits. Important savings on the maintenance of the network (transport and travelling costs) must result from this, savings which have to be compared to the extra cost of the telemetry equipment and to the cost of maintaining the whole system. The context and level of development of the country where the system is kept must of course be taken into consideration, but experience has shown that this new equipment is at least as reliable and robust as its mechanical predecessors, easier to install and use, and the local staff adapt to it very quickly, especially if they have attended long and well-targeted training courses.

C.4 Telemetry in Hydrometry

The first application of telemetry for hydrology was the 'limniphone', which just after the second world war made it possible to hear the gauge datum via a telephone number, this datum mechanically determining the track of a disk (or a magnetic tape) on which was recorded the corresponding datum.

The first telemetry networks therefore used the telephone network (or dedicated lines) in order to send the information. In addition to the fact that telephone connections are rarely to be found near water level recording stations in Africa, it must be acknowledged that telephone connections are often the first to be damaged in extreme climatic conditions where one relies on telemetry for transmission of hydrological data in order to be aware of the extremes and to protect oneself against them.

It was necessary to make up for the lack of telephone connections, or for their insufficiency, and this was the beginning of radio transmission networks. This methodology is particularly well adapted to small networks, where it is not necessary to plan for costly relays between the automatic water level recorder data collection platforms (DCPs) and the receiver/concentrator station. On the other hand, it is much less adapted to the large areas of African hydrology, the scale of which requires numerous relays in series. Radio transmission networks have operated: for example one was used for flood warning and water level on the Upper Niger during the 1950s, and another established for the same purpose in the Benue basin. But all these networks were difficult to maintain and were successively abandoned.

There are also synoptic meteorological networks equipped with BLU radio. It must be said that in this particular case the situation is much more favorable, since these stations are situated in towns or near them, and therefore on sites provided with electricity and permanent staff. Everyone is aware how the constant management problems with this type of equipment, and its requirements in qualified staff and operating means, and its dependence on the availability of plenty of electricity with all the attendant drawbacks of ensuring the supply.

The advent at the beginning of the 1970s of the satellite as a telecommunication relay between two points on the surface of the earth (EOLE system), and then its standardisation through modern systems such as ARGOS, METEOSAT or GOES, are also important stages in the development of hydrometry, especially in Africa where these modern means of transmission seem particularly suitable.

To transmit hydrological data it is now possible in Africa to use two different satellite transmission systems: the METEOSAT and the ARGOS systems. These two systems are in fact more complementary than rivals and the choice between them depends largely on the conditions of use and the type of data to be transmitted.

C.5 Satellite Systems

C.5.1 The METEOSAT System

The METEOSAT system uses a geostationary satellite (or more precisely geosynchronous, ie. having the same angular speed of rotation as the earth) situated above the Gulf of Guinea at 36 000 km altitude, which permanently sees the terrestial hemisphere (in practice 2/3 of it) containing the whole of Africa. This specific location enables it at all times to relay transmissions coming from this half of the world. The METEOSAT system would therefore be first choice to carry out surveillance of rapidly evolving phenomena which require immediate return of information: seismic monitoring, protection against flooding from small mountain basins, monitoring of nuclear power stations, etc..

The METEOSAT message can reach a length of 640 octets (5104 bits on a normal channel and 184 bits on a warning channel) and therefore permits the transmission of a large quantity of information. It would be chosen particularly to transmit messages coming from multi-sensor DCPs such as automatic meteorological stations.

The limitations:

The satellite is situated 36 000 km away from the earth and the power of the emitters must take this distance into account. The emission antennae currently in use must also be directed with great precision towards the satellite.

The manager of the satellite (EUMETSAT) imposes on each user a particular working frequency and different hourly intervals for emission for each platform which must be respected within a few seconds; this gives the internal clock of the platforms little leeway.

The direct reception of data is possible at any site. This is achieved using a parabolic antenna, 2 m in diameter, directed towards the satellite. Such a station for direct reception is therefore not very mobile.

As a result of the various constraints listed above, METEOSAT emission platforms for an operational programme cannot be situated at isolated sites, they must be situated on sites quickly accessed at all times, because a shift of more than 10 seconds in the emission hour is not acceptable. Further, the initialisation of the emitters requires the use on site of a portable computer, operated by specialised staff.

The hydrological platforms currently available cost US$ 14 700. The emitter fitted in this equipment alone costs US$ 5 000.

The annual operating rent for direct reception in an 'overall' contract (ie. a prepaid lump sum subscription) comes to US$ 1 100 per collection platform for one emission per day (see Section C5.3 for a comparison with ARGOS).

The present METEOSAT networks in Africa:

SONEL, the Electrical Energy Society of Cameroun, operates a network of about 40 METEOSAT platforms transmitting water level data and meteorological parameters. These platforms emit every 6 hours and the data is used to manage hydroelectric works and assist in river navigation.

The Ministry of Research and Technology entrusted ORSTOM (through an initiative programme) with a project to set up an hydrological data transmission chain using the METEOSAT satellite. This operation is being carried out in the Congo basin and two prototype hydrological platforms (of the eight planned for the long term) have been in use since July 1990. The final platforms, which may be equipped with about 10 sensors, are nearing completion by the manufacturers and will be installed at the beginning of 1992 in the Central African Republic, the Congo, and if possible Zaire, on the River Congo and its main tributaries.

One of these prototype platforms situated at Limassa on the Oubangui was installed with the collaboration of the Bangui Navigable Waterways Service in July 1990. This station, which has run without failure since its installation and with no maintenance, must be replaced by an updated model. The data collected by the ORSTOM direct reception station in Bangui were transmitted daily to the Navigable Waterways Service to assist river navigation.

C.5.2 The ARGOS System

The ARGOS transmission system uses two polar orbital satellites (TIROS from the NOAA Satellites) placed in a polar orbit, the planes of which are shifted by 70^0, situated at an altitude of about 800 km. These satellites describe a complete revolution every 100 minutes. During their rotation, they receive messages emitted by all the platforms visible on their trajectory. These messages are stored on board and are recovered in block as the satellites pass specialised reception and processing stations which subsequently distribute them by various media (post, fax, telex, modem, etc...).

A second function enables the satellite to immediately re-emit to the visible land area all the messages received from this same zone. It is this 'mirror' function which is used in hydrological applications thanks to direct reception stations.

This transmission system is much used for applications using deferred time data and short messages. This applies to remote monitoring or remote management operations for hydrological networks over medium or large surface areas. It is also the oldest operational system, since the first operational system was the HYDRONIGER network (1984), only preceded in hydrology by the test conducted by ORSTOM in Senegal and Guyana.

All the ARGOS platform emitters around the world work on the same frequency and emit a message every 100 to 200 seconds without the need for synchronisation with the satellites. The system is based on each beacon visible from the satellite having random access to its channels. This characteristic simplifies the implementation on the ground (the ground platforms are delivered as a turnkey product ready to install) and reduces the cost of the equipment. An ARGOS emitter costs US$ 1 100 for a piece of equipment less that 15 x 5 cm. The relative proximity of the satellites requires less power and compact omni-directional antennae which are often totally integrated into the collection station. A solar panel is sufficient for the electricity supply.

A hydrological platform equipped with ARGOS transmission, totally independent and ready to install, currently costs US$ 8 450. This equipment can also transmit rainfall information. The small size of this equipment makes it easy to transport and install in areas which are not easily accessible. It also means that the equipment is easily moved and therefore reusable on temporary sites and can survey for example, during a critical period, a water level in any place where it can be set up in a few hours.

Because of the ease of implementation and the fact that they do not need any adjustments on the ground during installation, this method of transmission is very suitable for operations requiring isolated equipment in areas with very difficult access.

The use of direct reception allows the receipt of data from platforms situated within a radius of over 3000 km several times a day. For the use of direct reception integrated into a global contract, the annual rent per platform was US$ 515 in 1991.

The Direct Reception Stations (DRS) are equipped with small omnidirectional antennae. This receiver equipment can also function with an autonomous supply and can be installed in mobile equipment such as boats. A portable DRS can be carried in a suitcase and the price is not more than US$ 27 500.

The constraints:

Because of the mobility of the satellites and their restricted number, this mode of transmission does not allow a permanent link between the emitter platforms and the direct reception stations on the ground. The number of satellite passages visible in good conditions from a platform on the ground diminishes with latitude (there are about 10 'good' passages per day in the temperate latitudes and only six or seven at the equator). In good latitudes the interval between two passages may be five hours at the most, but the time of passage in a specific place is more or less the same every day. Taking this into account, this mode of transmission cannot be used for surveillance of rapidly changing phenomena which require a permanent or 'real time' type link. Moreover, the ARGOS message is limited to 32 octets (256 bits) and is therefore only suitable for the transmission of short messages.

Experiences in hydrology:

ARGOS transmission has been used in hydrology for about ten years in the remote management and remote surveillance of hydrological networks :

In West Africa, the HYDRONIGER network has 65 stations in eight countries. It has been running for eight years and allows the forecasting of floods in an as yet undeveloped basin (with the exception of the Sélingué dam). This is the first and the oldest network in Africa and at that in the tropical world. The telemetry component has always worked remarkably well with over 95% success rate. The only maintenance problems are due to the pneumatic water level recorders which are always delicate.

The OCP hydrological telemetry network designed and put into operation by ORSTOM hydrologists and which includes about 100 automatic water level recorders and ARGOS DCPs, gives teams fighting against onchocerciasis, the ability to be constantly aware of the hydrological condition of rivers in the areas to be treated and therefore they are able to optimise the use of helicopters used for treatment by adjusting the amount of insecticide added to the project rivers. This network is equipped with the most modern automatic water level recorders (the development of which it has contributed to) and has been working continuously since 1986. The maintenance and management of its equipment is well run; this is generally done by local teams suitably trained as part of the project. The equipment is being constantly improved and is now considered very reliable.

The national network of Benin is equipped with about 20 telemetry stations acquired and installed as part of a hydrometric network rehabilitation contract financed by the FAC. This selection was preceded by an economic analysis which indicated that the maintenance of a telemetry network would be less costly than a traditional network, once, of course, initial funds had been secured from outside. This seems to be what the first three working years of this modern network show. Other 'psychological' benefits may be credited to these telemetry networks: the managers see the networks functioning in real time and this gives them the necessary responsibility, and are therefore able to reply immediately to any enquiries from their administrative or political leaders.

The OMVS also has an ARGOS transmission network, so it is able to manage in real time the Manantali and the Diama dams. The natural flows which come from the unregulated Falémé River can be forecast several days in advance, so the flows of the Bafing can be regulated by releases from the Manantali dam. Thus an 'artificial' flood, guaranteeing the permanence of flood recession crops, has been managed for the last three years, while at the same time economising on the inter-annual reserves of the Manantali dam.

The necessity, in Guinea, of carrying out an hydrological study with an immediate groundwork phase for a project to construct an hydro-electric dam on the Fatala or the Konkouré, was an opportunity to quickly install five ARGOS DCPs on sites with very difficult access and to monitor them, in the absence of any local supervision, for three years in very good conditions with the guarantee of results unimaginable without this satellite monitoring.

These different examples show the adaptability of the ARGOS system and its particular qualities which make it the system par excellence for satellite surveillance, and a valuable complement to the METEOSAT system for transmission at slightly delayed times, whenever the required transmission times are not too restricting, or the size of the basin under investigation is such that the flood warning is not calculated in minutes or half-hours but in hours or days.

Ongoing studies concerning the construction and launching of a satellite in a low equatorial orbit (1000 km altitude, passage every two hours) have been initiated by ORSTOM and are led by the CNES with the close collaboration of the CLS-ARGOS company. Such a satellite would certainly be adapted to an African environment and would enable the ARGOS technology to reach practically the same standard of performance as the METEOSAT, since only one passage every two hours (with only one satellite) would give access at almost real time, even for small or average sized basins.

C.5.3 METEOSAT and ARGOS Compared

We have assembled in the following tables a comparison between the ARGOS and METEOSAT systems applied to an hydrological environment.

The information presented here relates only to the principal networks known to be operational.

- Technical characteristics compared :

ARGOS	METEOSAT
AREA OF COVERAGE	
Totality of the globe	Area of visibility of the satellite 1/3 of the globe between 65° latitude north and south
GENERAL CHARACTERISTICS OF THE EMITTER	
Length of message transmitted - 256 bits max Periodic emission : (every 200 seconds) Fixed frequency 401.65 MHz Address of the platform allocated by the ARGOS system	Length of message transmitted : - 5104 bits (normal channel) - 184 bits (warning channel) Emission at fixed time (normal channel) Instantaneous emission (warning channel) 66 channels of different frequencies exist on the satellite starting from 402 MHz Frequency and emission time are fixed by the ESA (European Space Agency)
RECEIPT OF DATA	
1) By a specialised Centre (ARGOS Centre in USA and in France) with dissemination of the results to the users by telex, posting of listings or magnetic tape, by consultation of the data bank by modem 2) By a local direct reception station	1) By the ESA specialised Centre at Darmstadt, Germany with dissemination of the results to users by the GTS network by telex, listing or magnetic tape, by consultation of the data bank by modem 2) By a direct reception local station

- Criteria for the selection of the satellite transmission mode :

Criteria	ARGOS	METEOSAT
Flood warning :		
Small basins less than 50000 km²	NO	YES
Large basins more than 50000 km²	YES	YES
Difficult access :	YES	NO
Long messages :	NO	YES
Less qualified site staff :	YES	NO
Fixed direct reception	YES	YES
Mobile direct reception	YES	NO
Low cost of rent :	YES (??)	NO
Low cost of material :	YES	(NO)
Permanent visibility ("real" time) :	NO	YES

- 1991 Costs for Satellite Transmission

ARGOS global contract	
Direct reception Databank	US$ 500 US$ 2 200
METEOSAT global contract	
Emission every hour Emission every 3 hours Emission every 6 hours Emission every 12 hours Emission every 24 hours	US$ 6 600 US$ 2 200 US$ 1 850 US$ 1 450 US$ 1 100

- Experience with Telemetry in Hydrology

ARGOS	
Amazon River, Brazil	18 stations
HYDRONIGER network	65 stations
WHO OCP network	100 stations
OMVS network	15 stations
Benin network	20 stations
Guyana network	20 stations
Guadaloupe network	15 stations
network in France	20 stations
METEOSAT	
SONEL of Cameroon network	40 stations
Congo River network	8 stations

C.6 Links with Data Banks

It is possible for raw data received from either ARGOS or METEOSAT receiving stations to be transferred directly and automatically to a computerised data bank. However, since this incoming data has not been subject to any quality control or elimination of redundant data, such a data bank should be considered a temporary storage. For the data to be regarded as definitive it must undergo quality control checks and be tranferred to another reference database.

It is essential to keep these two types of data bank separate, for additional security they may be stored on separate microcomputers. Such a situation exists at the direct reception stations of the OCP at Odienné and Lama Kara where the raw data transmitted by the satellite is stored temporarily in data banks until required for analysis and then tranferred into a HYDROM database on a second microcomputer which is the basis for all the calculations to determine the discharge information required for the insecticide treatment.

In summary the storage of the raw data acquired in real time must be kept separate from the database of reference data. The reference database should itself be distinct from any bank of processed data prepared by a project. Clearly however when a project requires real time data it is not necessary, or recommended, that the data should pass through a reference databank before being used.

C.7 Conclusions

There are around 200 hydrological stations in Africa equipped with DCPs for either ARGOS or METEOSAT, mainly the former. This provides a good base for the establishment of a large scale network for the automatic monitoring of hydrological parameters. The responsibility for the maintenance of these 200 stations is divided among the various national services, regional projects or organisations which own them. This is a good thing since experience shows that very large systems are difficult to manage and rarely durable.

The individual networks are compatible and the organisations are able to exchange data via the satellite, for example data from one of the HYDRONIGER stations is received by the SRDA of the OCP and can be decoded and utilised and vice versa. This open availablity of data is to be encouraged since it is in the interest of all and is the basis for the long term security of irreplacable archives, which these days include computerised databanks.

However present data banks are too often incomplete and, as far as those that are operational are concerned, held outside the region. One of the concerns of the overall Sub-Saharan Africa Hydrological Assessment has been to take account of all these realities; this is reflected notably in the proposal for a continent-wide project to establish a network utilising telemetry and allowing automatic surveillance to ensure a real 'watch over the hydrological parameters in Africa'. Such a system would ensure and safeguard a sufficiently detailed knowledge of hydrology in Africa, which is essential both for the African population for their own development, given the present context of shortage (if not scarcity) of water resources, and to the rest of the world's population which has a concern for the climatic future of the Earth. A climatic future which it is only possible to understand (and perhaps anticipate) if hydrological parameters are known and monitored constantly over the whole of the globe, which is obviously not the case at present in Africa.

07171/19/B

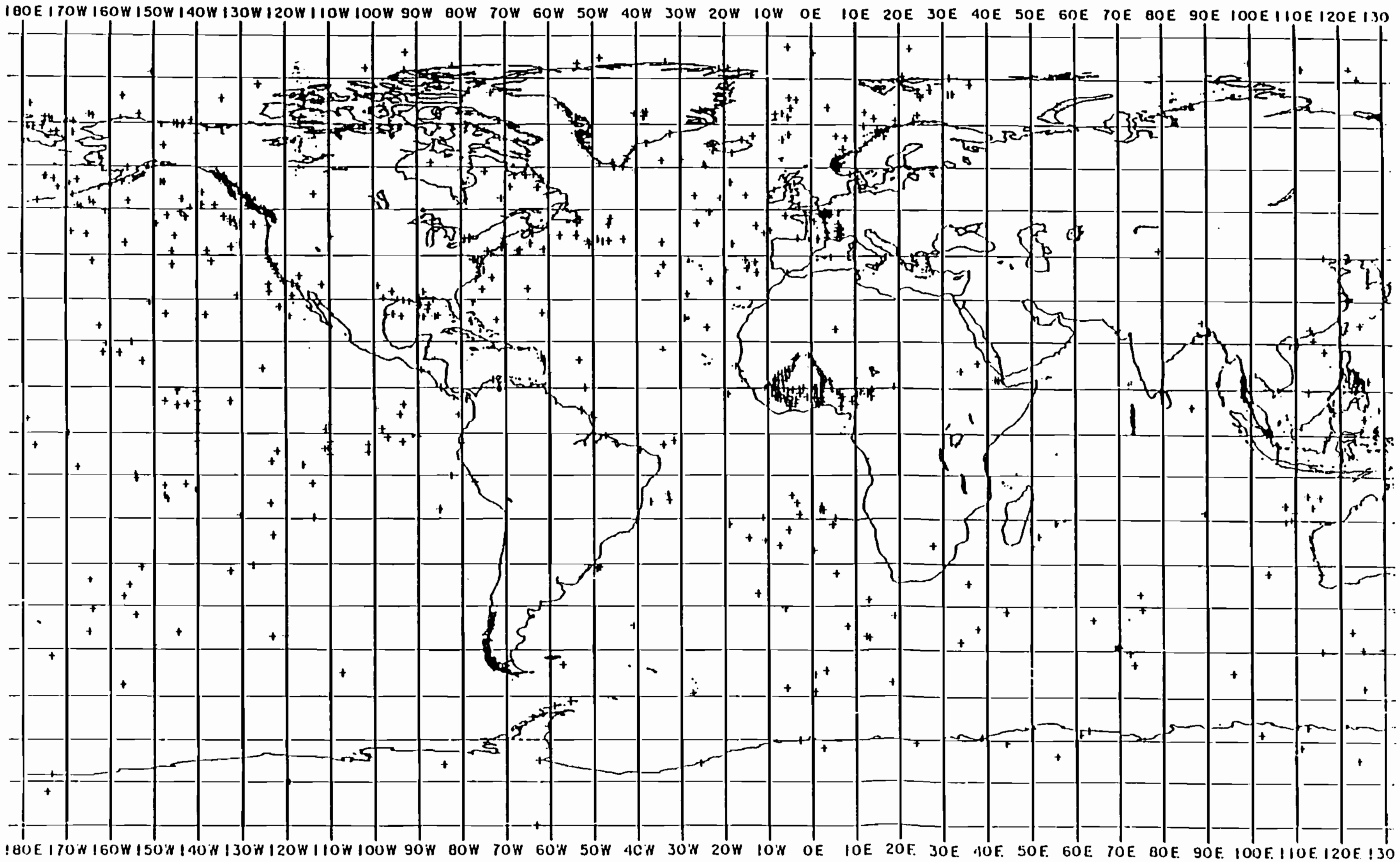

Figure C.1
Location of Terrestrial and Maritime Stations in the ARGOS System(Situation in June 1991)