HYDROGEOLOGIC RECONNAISSANCE

REPUBLIC OF SENEGAL

A REPORT FOR
THE UNITED STATES
AGENCY FOR INTERNATIONAL DEVELOPMENT

THE RALPH M. PARSONS COMPANY
ENGINEERS-CONSTRUCTORS
LOS ANGELES
NEW YORK

HYDROGEOLOGIC RECONNAISSANCE

REPUBLIC OF SENEGAL

A Review of Hydrogelogic Data and a Program for Research and Development of Ground Water in the Dakar-Cap Vert, Central, and Bakel-Kedougou Areas of Senegal

A REPORT FOR
THE UNITED STATES
AGENCY for INTERNATIONAL DEVELOPMENT

RECEIVED
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AFE
ENGINEERING
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Contract No. AID/afe-116
PIO/T685-Y-52-AC-3-20003-1
November 1963

THE RALPH M. PARSONS COMPANY

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NEW YORK

E R R A T A

HYDROGEOLOGIC RECONNAISSANCE

Republic of Senegal

Contract AID/afe-116

Page	Paragraph	Line	Correction
I - 6	2	2	Change 'Habit' to 'Habitat'
I - 7	4	8	Change 'Faravy' to 'Paravy'
I - 15	2	5	Change 'Diburkel' and 'Kaulack' to 'Diourbel' and 'Kaolack'
II - 4	3	5	Delete first reference to 'relative humidity'
III - 1	1	3	Change 'Eastward' to 'Westward'
III - 4	4	1	Change 'eastern' to 'western'
III - 10	5	2	Change 'Diouabel' to 'Diourbel'
III - 12	1	5	Change 'aerial' to 'areal'
III - 14	3	4	Change 'reivers' to 'rivers'
V - 5	5	1	Change 'operating' to 'organizing'
V - 6	3	2	Change 'materials. Prior' to 'materials, prior'
V - 6	3	3	Change 'project a total' to 'project. A total'
V - 11	4	7	Change '134,600' to '134,700'
V - 11	4	8	Change—Total Estimated Cost from '$1,629,800' to '$1,630,200'
V - 12	C.	2	Change '43,400' to '44,600'
V - 14	A.	6	Change '28,700' to '28,710'
V - 14	B.	6	Change '24,400' to '24,390'
V - 18	VII-A	3	Change '117,500' to '117,600'
V - 18	VII-B	4	Change '134,600' to '134,700'
V - 18	VII-B	5	Change '$1,629,800' to '$1,630,200'

The Ralph M. Parsons Company

Engineers • Constructors

617 WEST SEVENTH STREET, LOS ANGELES 17, CALIFORNIA

November 1, 1963

Department of State
Agency for International Development
Washington 25, D. C.

ATTENTION of Mr. Thomas V. Leahy
Project Engineer

SUBJECT Contract AID/afe-116-Senegal
Final Report
Our Job 3296 - Senegal

Gentlemen:

In accordance with the terms of the subject contract, we are pleased to transmit herewith our Hydrogeologic Reconnaissance of the Republic of Senegal.

This report presents the results of our field investigations in the Dakar-Cap Vert Peninsula, Central Senegal, and Bakel-Kédougou areas, which involved the review of all basic data and technical information available in Senegal concerning these areas. In addition, we evaluated the technical soundness of the work programs outlined in Sections 10, 14, 15 and 16 of the report by the Department of Public Works entitled "Program de Recherches Hydrogéologiques de 300 Million Propose à l'A.I.D." The contractual statement of work required the establishment of a program for the development and conservation of ground-water resources in those areas having the most potential for future development. In accordance with this, we have recommended a development project in the Central Senegal area.

The recommended development project in Central Senegal would:

1. Provide the basic hydrogeologic data required for planning and implementing water development projects in those areas of Central Senegal where existing facilities are inadequate to provide for present and future water demands.

2. Provide an adequate sanitary water supply in those areas of Central Senegal where municipal, village and livestock water shortages are most critical.

3. Train a small Senegalese drilling staff for the purposes of continuing exploratory drilling and water well construction programs in other areas where these activities cannot be undertaken economically by private organizations.

The details of this program are included in Chapter V of the report and include a detailed cost estimate of the work.

This report should provide the basis for the future development of water resources in Senegal and allow its planning by AID and Senegalese Government Officials.

We wish to thank you for the opportunity to carry out this assignment and we hope that we may be of further assistance in the development of water resources in Senegal.

If you have any additional questions regarding the report or the recommended development project, please contact us.

Very truly yours,

THE RALPH M. PARSONS COMPANY

By James E. Halferty

James E. Halferty
Vice President
Foreign Operations

JEH:mm

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CHAPTER I INTRODUCTION

Background
Objectives
Scope of Work
Method of Investigation
Description of Areas Studied
Acknowledgements

BACKGROUND

Prior to the commencement of the hydrogeologic reconnaissance study the Minister of Public Works (Ministère des Travaux Publics, de l'Habitat et de l'Urbanisme) submitted to USAID Senegal a document entitled "Programme de Recherches Hydrogéologiques de 300 Millions Propose à l'A.I.D.," dated May 1962. This proposal requested financial assistance in undertaking a program of hydrogeologic research and was based upon a report prepared by the Comité Inter-Etats d'Etudes Hydrauliques entitled "Program d'Etude des Ressources en Eau du Sénégal. This report contains a brief summary of the present state of hydrogeologic research and a cost estimate for undertaking some 20 recommended hydrogeologic research studies throughout Senegal. Eleven of these studies were included in proposal submitted to AID. Subsequently Mr. Leon A. Hostetter, Consulting Civil Engineer was assigned by the Tudor Engineering Company under AID Task Order 671 to review the proposed research projects and prepare a Scope of Services for a reconnaissance water resources survey of specific projects suitable for immediate implementation.

The Scope of Services recommended the assignment of two ground water geologists and one aerial photo interpreter to undertake the survey. A total of three months were allocated for completion of the survey and preparation of a report thereon. The Ralph M. Parsons Company of Los Angeles was selected to perform the survey and prepare the report. The findings and recommendations of the survey are contained herein.

RECONNAISSANCE AREAS

REGIONS ETUDIEES

Plate-Planche 1.

OBJECTIVES

The contractual statement of work required the project staff to carry out a reconnaissance type of survey for the purpose of establishing a program for the development and conservation of ground-water resources in the Dakar-Cap Vert Peninsula, Central Senegal and Bakel-Kédougou areas of Senegal with the intent of achieving the following objectives:

1. A better understanding of the extent of the basic data and information now available in Senegal concerning ground-water resources.

2. An evaluation of the technical soundness of the work programs outlined in Sections 10, 14, 15 and 16 of the report by the Department of Public Works entitled "Programme de Recherches Hydrogéologiques de 300 Millions Propose à l'A.I.D."

3. A cost estimate for a comprehensive survey and report covering all phases of ground-water conservation and use in the basin areas offering the best aquifers for future development.

SCOPE OF WORK

The Scope of Work required the Contractor to ascertain the current status of hydrogeologic research and determine the additional data needed for a thorough understanding of the ground-water problems in assigned study areas by:

1. Compiling all information concerning ground-water resources available in the files of the various government agencies and from other pertinent sources.

2. Examining and interpreting now existing aerial photos for geological and other characteristics of the basins.

3. Analyzing existing geologic, hydrologic and meteorologic information.

Based on the analysis, the Contractor was further required to prepare, in consultation with AID and the Department of Public Works and Ministry of Public Health, a Scope of Services for a comprehensive engineering-geological study and at the conclusion of the field reconnaissance submit a final reconnaissance survey report containing the following:

1. The methods of investigation and analyses.

2. A description of data and material reviewed, indicating sources.

3. A summary of recommendations.

4. A Scope of Services and cost estimate for a comprehensive engineering-geological study which will implement the recommendations of the reconnaissance survey and result in the development of a comprehensive plan for

the conservation and use of ground-water resources in Senegal.

5. The bases of technical and economic soundness of the recommended program of work.

METHOD OF INVESTIGATION

Several work items included in the contractual Scope of Work suggest that perhaps a large amount of hydrogeologic research would be required before a comprehensive water resources development and conservation program could be initiated in assigned study areas. However, it became apparent during the early stages of the reconnaissance survey that a considerable number of hydrogeologic research studies have been completed within the past few years and provide a reasonably sound technical basis for planning purposes, particularly in the Dakar-Cap Vert and Central Senegal areas. Many studies dealing with these areas are very comprehensive and well documented (191-220). Previous investigators generally have utilized all available data and employed recently developed techniques for evaluating ground-water problems. Consequently, few analytical studies were required during the course of the survey to evaluate data that was not included in previous studies. Our review of available basic data and previous reports was primarily directed toward ascertaining the degree to which applicable geologic and hydrologic methods of analysis were employed and determining the adequacy of existing data. Approximately three man-months were required to

index and review available information that is discussed in Chapter II and itemized in the Bibliography.

Discussions with representatives of the Ministère de Travaux Publics, de l'Habit et de l'Urbanisme, Comité Inter-Etats d'Etudes Hydrauliques, Ministère de la Santé, Ecole de Technicians Sanitaires, Institut Géographique National, Service Météorologique, Institut Pasteur, Institut de Recherches Agronomiques Tropicales, Travaux Publics-Cap Vert, Compagnie Général des Eaux du Sénégal and le Secrétaire d'Etat Chargé du Plan et du Développment . . . were held soon after the staffs' arrival to ascertain the nature of current research projects, water supply problems and plans for implementing proposed research and development projects. Discussions with agency representatives revealed that many of the more promising agricultural and livestock development projects proposed are not within the geographic limits of assigned study areas; but that a considerable water supply problem did exist, particularly for villages and livestock, in Central Senegal.

Many field trips were made in the Dakar-Cap Vert and Central Senegal areas to inspect water supply facilities, observe geological features and discuss water supply problems with Regional Governors and District Commandants in order to ascertain water supply deficiencies and supplemental requirements. A reconnaissance also was made of villages within a radius of 60 kilometers of Kédougou. Unfortunately the survey was conducted during the peak of the rainy season when most of the

roads and trails are impassable, thereby precluding a reconnaissance of the entire Bakel-Kédougou area.

A study of the most recent aerial photographs of Senegal was also undertaken. Objectives of the study were to ascertain the adequacy of existing coverage, applicability of the photographs to specific hydrogeologic research problems and their usefulness in delineating favorable areas for developing ground water in the more remote regions of Senegal.

At the conclusion of research studies and field reconnaissance, a proposed research and development project was presented to representatives of USAID Senegal and these agencies of the Senegal Government concerned with water resources and public health for review and tentative approval. This project is discussed in detail in Chapter V.

ACKNOWLEDGMENTS

Members of Parsons' staff wish to acknowledge gratefully the many courtesies and assistance rendered by members of the various Senegal Government agencies concerned with water resources development, the USAID Mission staff and the Bureau de Recherches Géologiques et Minières. Acknowledgment is particularly due to Dr. Joseph N'Diaye, Director du Génie Rural, for his generous assistance in providing useful background information and personally arranging many of the project's reconnaissance trips, and also to Father Faravy of the Catholic Mission at Kédougou for providing accommodations in Kédougou and his guidance to some of the more remote regions of Senegal.

DESCRIPTION OF AREAS STUDIED

Location

The Dakar-Cap Vert Peninsula, Central Senegal and the Bakel-Kédougou area comprise the assigned reconnaissance study areas. The Dakar-Cap Vert Peninsula occupies an area of about 650 square kilometers and is the most westerly land area of Senegal, situated approximately midway between the northern and southern boundaries of the Republic. The area is delimited to the east by the Thiès escarpment, which forms a natural physiographic boundary between the peninsula and Central Senegal.

Central Senegal has been defined as that area enclosed by latitudes 14° 00' to 15° 15' north and longitudes 15° 45' to 17° 00' west. In passing it may be observed that the original reference to "Central Senegal" is geographically somewhat arbitrary, possibly having been based on such factors as agricultural development, population and accessibility. In reality "Central Senegal," as defined, is an eastward extension of the Cap Vert Peninsula, situated in the west-central part of the Republic.

In contrast to the Dakar-Cap Vert Peninsula and Central Senegal areas, the Bakel-Kédougou region was not specifically defined by the original terms of reference. Since these two towns, located in eastern Senegal, approximately prescribe the northern and southern limits of continuously exposed Ordovician to Pre-Cambrian igneous and metamorphic rocks,

the entire area of these older rocks south of Bakel was considered the designated area of interest. The older rocks embrace an area of about 31,000 square kilometers and extend westward to the geologic contact separating the older rocks from younger Tertiary sediments.

General Geology and Physiography

The Republic of Senegal, some 200,000 square kilometers in area, is delimited to the west by the Atlantic Ocean, to the north and east by the Senegal River and its tributary, the Falémé, and to the south by Portuguese Guinea and the Republic of Guinea. British Gambia, located within the southern half of Senegal, forms an enclave of 10,000 square kilometers bordering the Gambie River which flows westward to the Atlantic Ocean.

Senegal is a land of little relief. The greater part of its area is a Tertiary sedimentary basin where elevations rarely exceed 50 meters. In eastern Senegal Pre-Cambrian and Paleozoic formations of greater hardness and more complex structure have greater relief, with elevations occasionally reaching 400 meters. The Thiès cuesta, or as it is often called, the Thiès escarpment, forms the most striking physiographic feature in western Senegal. This cuesta, formed by east-dipping lower-Eocene formations, gradually emerges from the plain some 18 kilometers northwest of Thiès. It extends southward, roughly parallel to longitude 17° west for about 31 kilometers before attaining its maximum elevation of 148 meters. It then gradually decreases in elevation to the southeast.

Photo 1. A common source of water supply in Central Senegal for domestic use and livestock.

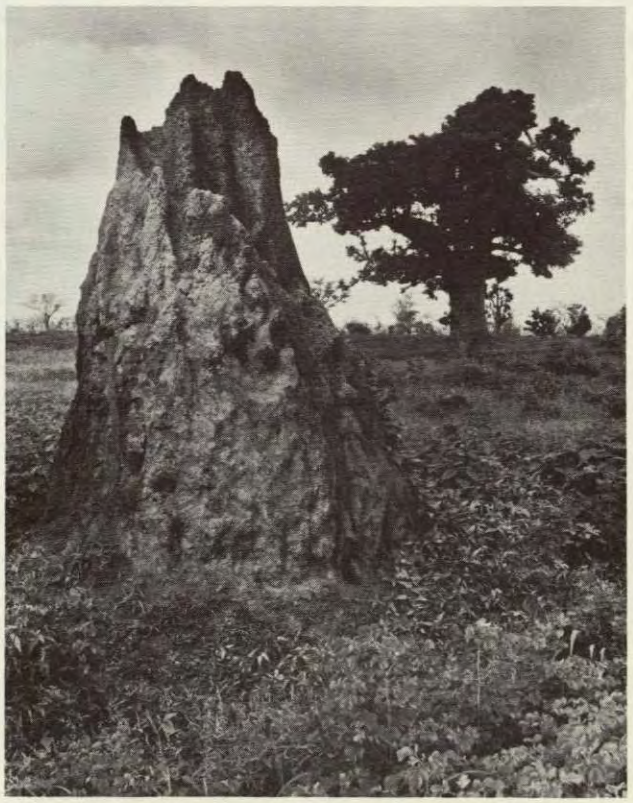


Photo 2. The greater part of Central Senegal has little relief with the exception of small gullies and many ant hills similar to this one.

Sand dunes, some stable and others active, are common along the coast of Senegal and extend some kilometers inland. They are particularly common between Dakar and Saint Louis, and small lakes are sometimes present in the "niayes" (depressions between parallel dunes where the water table is close to the surface).

The interior drainage system of Senegal is quite simple and restricted to a few major streams, although drainage channels were more numerous within Recent geological times. Surface runoff now discharges to the Atlantic Ocean from four main rivers - the Senegal, Saloum, Gambie and Casamance. They are wide meandering rivers throughout most of their reaches and discharge into the ocean in very broad estuaries.

Exposed formations in Senegal include Pre-Cambrian metasediments and igneous rocks that crop out in the eastern-most part of the country and lower Paleozoic sediments that occur in a north-trending band west of the Pre-Cambrian formations. Mesozoic and Tertiary sediments form an extensive basin that occupies almost 80 per cent of the country's area. The oldest are of upper-Cretaceous age (Maestrichtian) and most are marine sediments which were deposited until Miocene times. They increase in thickness from east to west and are covered by Continental Terminal clays and sands of probable Pliocene age. The greater part of the country is mantled by an appreciable thickness of laterite and various facies of Quaternary formations. Lavas and associated pyroclastics of Tertiary and Quaternary ages are also present which crop out in the Cap Vert Peninsula of western Senegal.

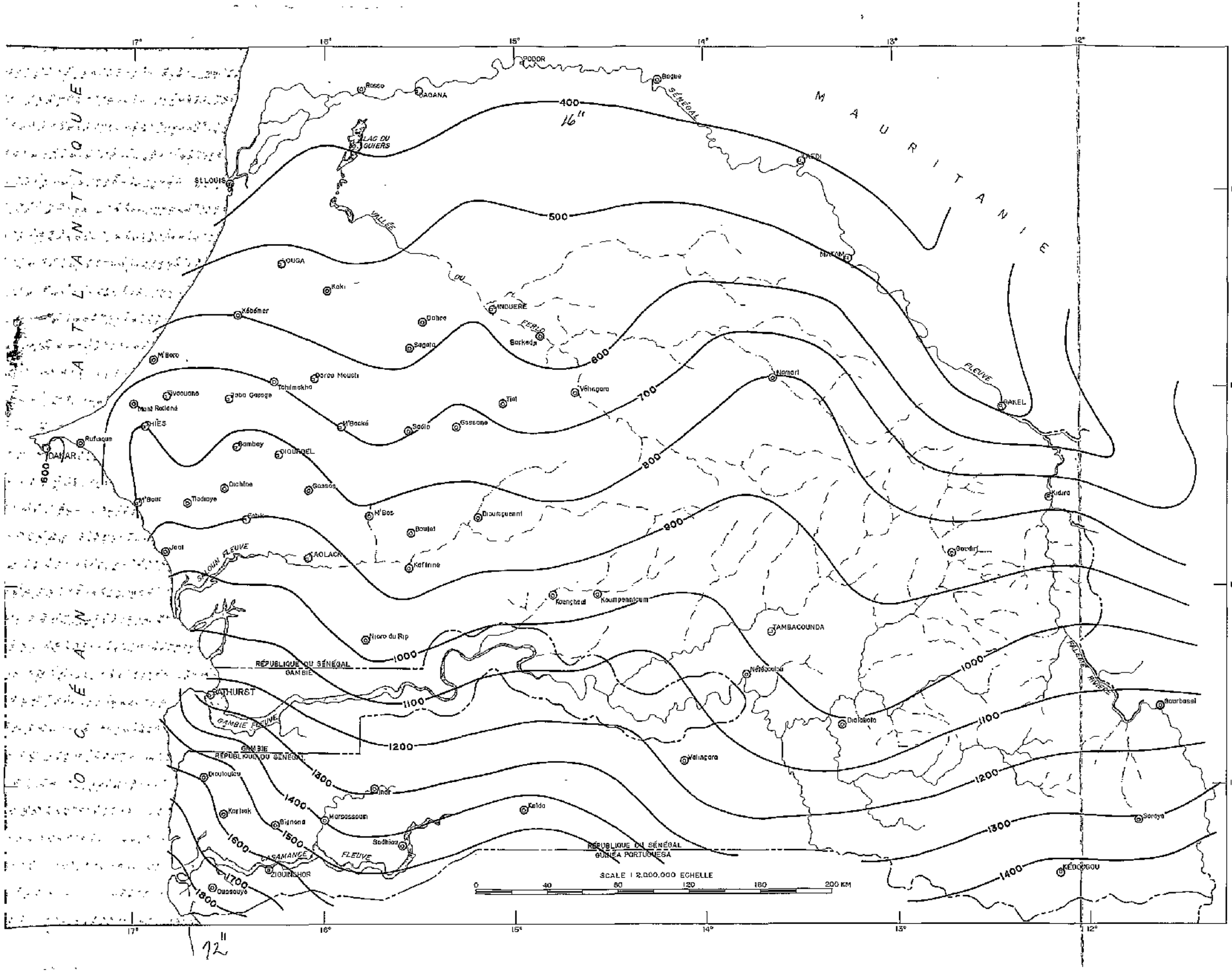
Climate

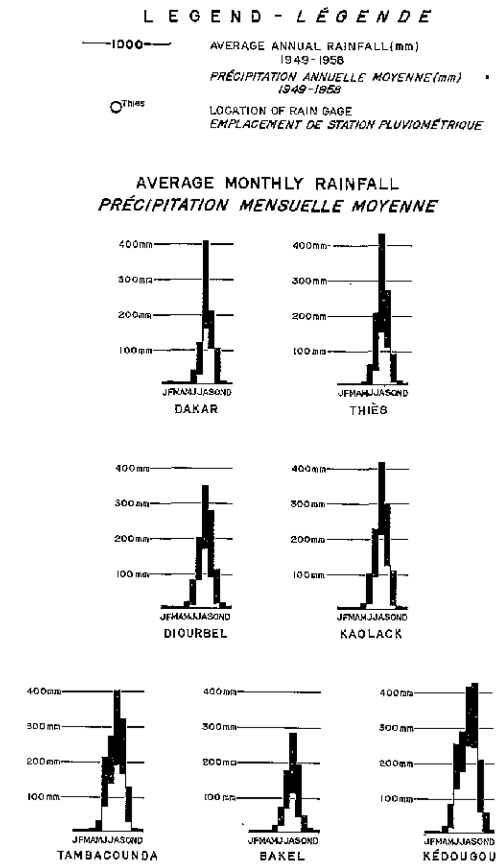
A sub-tropical climate generally prevails throughout Senegal with the exception of the northeastern part which may be considered semi-arid. Seasonal temperatures vary somewhat in coastal and interior regions. At Dakar during the cool season, December through April, average daily maximum and minimum temperatures vary from 17° to 26° centigrade, while interior temperatures vary from 15° to 40° centigrade. During the months from May through November average daily temperatures vary from 20° to 30° centigrade at Dakar and from 20° to 40° centigrade in interior regions. Temperature reaches a maximum of 30° centigrade during the month of September at Dakar and 40° centigrade during May at Tambacounda located in the central part of Senegal.

Average annual rainfall in Senegal varies from 400 mm in the north to 1500 mm in the south and reaches a maximum of about 1800 mm in the southwest corner of the country. The rainfall season is relatively uniform throughout the country. Precipitation normally occurs between the months of April and November and reaches a maximum during August. From December to March precipitation is absent or negligible. Annual precipitation averages 655 mm at Dakar, and varies from 600 mm to 1000 mm in Central Senegal and from 500 mm to 1500 mm in the Bakel-Kédougou area.

Land Use

There are about 19,730,000 hectares of land in Senegal of which about 7,600,000 hectares are cultivable. Approximately 1,850,000 hectares





ANNUAL RAINFALL
PRECIPITATION ANNUELLE

Plate-Planche 3.

are used almost exclusively for ground nuts, leaving 5,750,000 hectares which probably could, but do not now, contribute to the national economy. Crop yields are poor and there is little diversification beyond ground nuts. Yields vary from 200 to 1200 kilograms per hectare for ground nuts, 400 to over 1400 for rice and 300 to 1000 for millet. Other crop yields are poor and insufficient for domestic requirements.

The most arable land is situated in the southwest quarter of the country on either side of Gambie. Major portions of Senegal's rice, millet and ground nuts are grown there. Some nuts and millet are also raised in eastern Senegal, especially in the Kédougou district. Lands surrounding the lower reaches of the Senegal River in northern Senegal are also well adapted to rice cultivation. Soils in the somewhat arid north central part of Senegal are extremely poor and essentially unproductive.

Part of the cultivable land is used to support some 1,600,000 head of cattle and 1,100,000 goats and sheep. Classified forests also have been set aside to encourage animal husbandry. Livestock are grazed within these areas when water is plentiful but are compelled to migrate in search of water during the dry season. There is little marketing of livestock, as disease and the absence of a reliable water supply have retarded the development of a productive program.

Population

Senegal has an estimated population of 3,100,000. About 80 per cent of the population reside within 140 kilometers of the Atlantic Ocean,

including 303,000 who reside in the capital city of Dakar. Migration into Dakar during the dry season is fairly common and the annual rate of population increase, varying from 2.0 to 2.5 per cent, suggests that Dakar's population may double in 30 years. Excluding Europeans, there are six ethnic groups in Senegal dominated by the Ouloffs who constitute 36 per cent of the total population. About 95 per cent of the rural population are illiterate, and 75 per cent of the men and 97 per cent of the women in Dakar would be similarly classified.

About 85 per cent of the population are engaged in some type of agriculture, eight per cent are artisans or industrial workers, and seven per cent are in public administration or private enterprise. Rural workers are underemployed at least four or five months of the year and 30 per cent of Dakar's population are permanently unemployed or underemployed.

The average food consumption provides between 2,300 and 2,900 calories per day. This does not represent actual under-nourishment for most but there is a dietary shortage of both vitamins and animal protein. Diets do not include sufficient meat and in rural areas this deficiency is not compensated for by the substitution of fish. Death rates are high for all ethnic groups, particularly among children in rural areas.

Accessibility

An extensive network of well-maintained asphalt highways radiate from Dakar and connect major population centers in Central Senegal. Interior

Photo 3. Springs such as this one near Kédougou are often the only source of village water supply.

Photo 4. A familiar village scene in southeastern Senegal.

towns are also inter-connected by numerous paved roads and secondary dirt roads. Eastern Senegal, on the other hand, is difficult to reach overland, even in the dry season. Narrow unsurfaced roads in the area are infrequently traveled and generally poorly-serviced. During the peak of the rainfall season, June through September, much of the area is inaccessible by automobile.

Scheduled passenger and freight railroad communications are operated between Dakar and Saint Louis, to the north and the Mali frontier station of Kidira, south of Bakel in eastern Senegal. A local airline also provides access to interior regions. Flights are regularly scheduled to Thiès, Diburkel and Kaulack in Central Senegal and to Bakel and Kédougou in eastern Senegal.

Telephone communications are fairly good in Central Senegal and along the coast. Eastern Senegal is not served by the network, but radio-telephone services are available intermittently.

CHAPTER II PREVIOUS RESEARCH

Hydrogeologic Research
Exploratory Drilling
Agricultural Research
Availability of Basic Hydrogeologic Information

HYDROGEOLOGIC RESEARCH

The accompanying bibliography is rather convincing evidence of the large number of geologic investigations previously carried out in Senegal. The majority were prepared for the French West African Government (Gouvernement Général de l'Afrique Occidentale Française, Service Géologique); and following independence, by the Bureau de Recherches Géologiques et Minières (B.R.G.M.) for the Republic of Senegal. Unfortunately very few were published. The majority were prepared for government use and are available only in the B.R.G.M. libraries in Dakar and Paris. The more recent reports, written after 1950, are quite good and were prepared after extensive study and field work carried out under difficult field conditions.

Reports found to be most useful in appraising the present status of hydrogeologic research in the Dakar-Cap Vert area include reports by Degallier (195, 196, 197, 199, 208), Martin (212, 213), Gorodiski (58) and Tessier (67, 68). Reports by Degallier and Martin deal primarily with the various aquifers which supply water for municipal use in Dakar and include discussions on the hazard of sea water intrusion, safe pumping yields, the effect of ground-water extractions on water levels, water quality and ground-water replenishment.

Marchand (191), Defossez (192), Audibert (204, 217) and Degallier (207) recently have concluded hydrogeologic studies of aquifers in Central Senegal. Defossez's report deals primarily with the shallow, or

phreatic, aquifers and includes pieziometric maps based on the compilation of a tremendous amount of water level data, water quality studies and a brief appraisal of the effects of ground-water extractions.

Reports by Degallier and Audibert are primarily concerned with the deeper Maestrichtian aquifer and include discussions of aquifer transmissibility tests, very detailed water quality studies, subsurface geology, isopach studies, ground-water production, the hydraulic relationship of adjacent aquifers and the hazard of sea water intrusion in coastal areas.

Research in the Bakel-Kédougou area has not been as extensive as it has in other areas, possibly because of its inaccessibility and absence of any appreciable ground-water reservoirs. However, a number of reports have been prepared by Bassot* (83), Bois (84, 85, 89), Camus (218), Gravesteijn (91, 92) and Witschard (87, 95) that discuss the geology of the region and include various recommended methods for developing water supplies for villages and livestock. A three year mineral exploration survey, sponsored by the United Nations Special Fund, is in progress and also should provide a further understanding of geological problems in the area.

* Etude géologique du Sénégal Oriental et de ses confins guineo-maliens; BASSOT, J.P.; D.Sc. thesis, Faculté des Sciences de l'Université de Clermont-Ferrand; July 16, 1963; 331 pp., 44 diagrams, 2 geologic maps, 9 plates, 2 tables.

Hydrogeologic research has often been supplemented by geophysical surveys. In fact, many of the geologic contacts shown on the Geologic map of Senegal (88) have been based on geophysical studies. Electrical resistivity methods generally have been employed and have achieved a measure of success in determining stratigraphic relationships in areas where faults and facies changes are not of a complex nature. Some of the more recent resistivity studies (102, 106, 111, 112) have been undertaken in the Dakar-Cap Vert Peninsula for the purpose of locating ground water in limestone areas and studying fresh water-salt water relationships.

EXPLORATORY DRILLING

Most of the exploratory drilling in Senegal has been restricted to the Dakar-Cap Vert Peninsula. Drilling in this area has been undertaken primarily for the purpose of locating additional sources of water in limestone aquifers for municipal use in Dakar and constructing piezometers in coastal areas to implement sea water intrusion studies.

Although exploratory drilling has not been undertaken throughout most of Senegal, because of very high drilling costs, a considerable number of deep production wells have been drilled. Electric logs and detailed lithologic logs generally were made during drilling and have provided useful information for structural and stratigraphic studies of the deeper aquifers (217). A limited number of deep exploratory oil wells have also been drilled which provide some information on deeper

formations. There is a considerable need for additional exploratory drilling, particularly in areas where the phreatic aquifer could be utilized to provide water for agricultural and livestock development projects.

AGRICULTURAL RESEARCH

A considerable number of soil and agricultural research studies have been made in Senegal, and some of the more recent reports (301-315) have been included in the Bibliography. At present most of the agricultural research in Senegal is conducted at the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières at Bambey in Central Senegal. The Institute is well equipped and staffed and has been conducting research studies for the past ten years. The Institute has conducted a variety of lysimeter, consumptive use, soil, water quality and evaporation studies which should be of considerable value in future hydrogeologic studies of the phreatic aquifer in Central Senegal.

AVAILABILITY OF BASIC HYDROGEOLOGIC INFORMATION

Meteorologic Data

A considerable amount of climatological information is available in Senegal. The Service Météorologique regularly publishes summaries of collected data (194, 216) that are readily available. There are 11 principal observation stations that record, rainfall, temperature, relative humidity, solar radiation, relative humidity, cloud cover, wind direction and velocity, vapor tension and atmospheric pressure.

Photo 5. Conventional cable tool rig employed in Senegal for drilling deep wells in limestone regions.

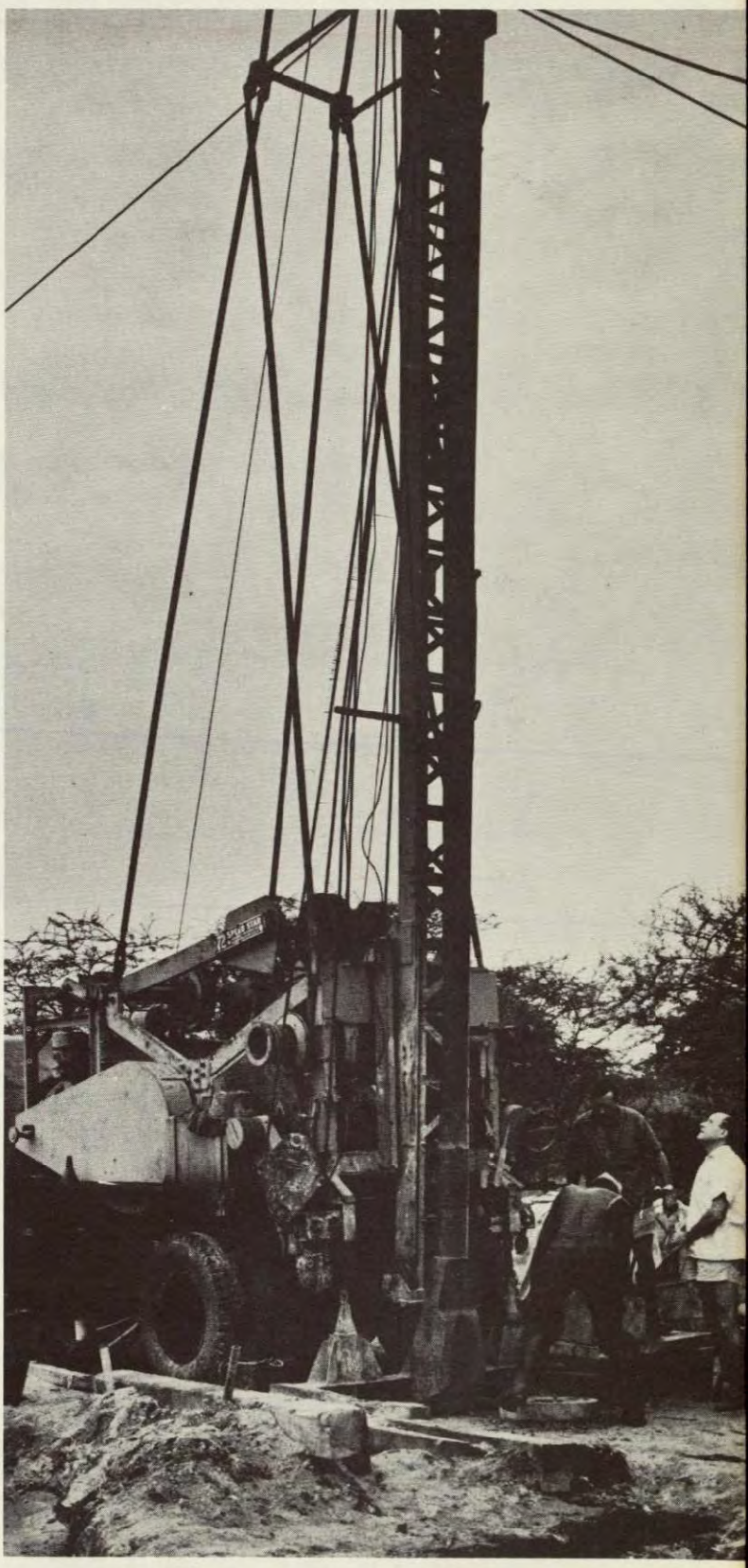


Photo 6. Modified cable tool rig used for drilling shallow large capacity wells in unconsolidated materials.

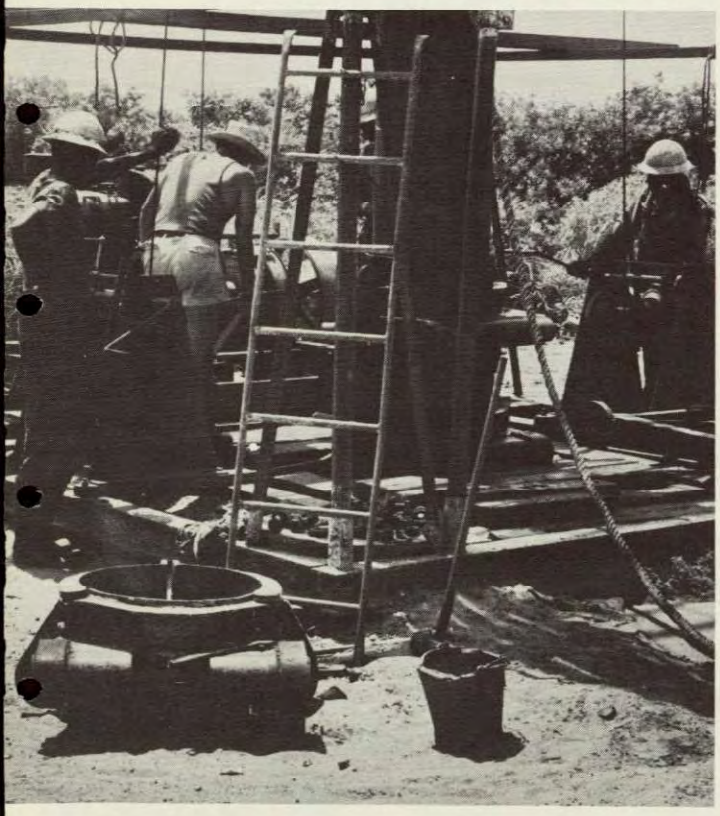


Photo 7. Millet cultivated by traditional and modern methods at the Institute de Recherches Agronomiques, Bambey.

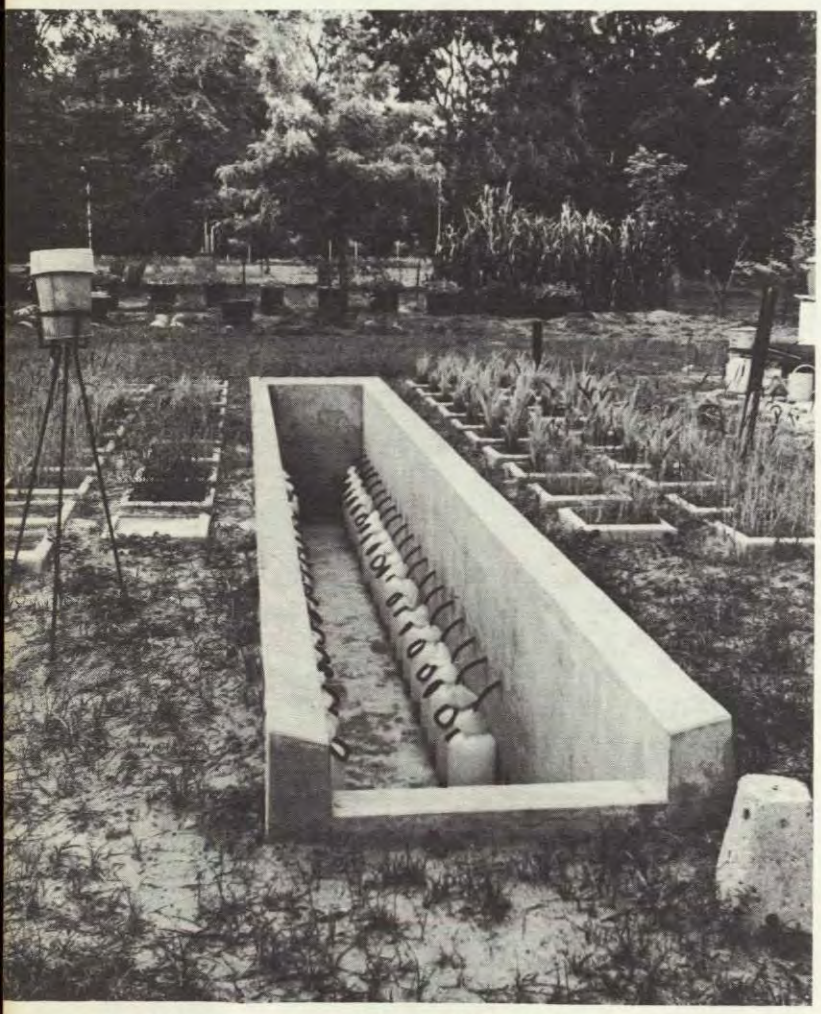


Photo 8. Lysimeters used for studying the effects of various fertilizers, IRA, Bambey.

Photo 9. Lysimeter installations at the Institute de Recherches Agronomiques, Bambey. Used for studying plant response to various waters in Senegal.

In addition, there are some sixty rain gages in Senegal which are read twice daily. Thirty-four of these gages have been in operation for at least 30 years. About 75 per cent of the stations are located in the western half of the country and provide excellent coverage in the Central Senegal.

Geologic and Topographic Maps

The most complete geologic map of Senegal (88) was published by B.R.G.M. in 1962 at a scale of 1:500,000. Although the map has been published at a rather small scale, an accompanying report gives a fairly complete description of mapped formations. A number of larger scale maps of small areas, prepared in conjunction with special geologic studies, are also available. Reports on studies that contain geologic maps are annotated in the Bibliography. Although few large scale maps are available, surface geologic mapping in the Dakar-Cap Vert and Central Senegal areas appear to be adequate for most hydrogeologic studies.

Topographic maps at scales of 1:200,000 and 1:250,000 with 10 and 20 meter contours are available for all of Senegal and may be obtained from the United States Army Map Service and the Institut Géographique National. Larger scale maps, published at a scale of 1:50,000 covering the Dakar-Cap Vert Peninsula and a small part of Central Senegal are also available. Although contour intervals are too large for most analytic ground-water studies, surface elevations can be obtained easily from the many bench marks that have been erected along principal highways and some of the secondary roads.

Aerial Photographs

Complete aerial photographic coverage of Senegal is available at a scale of 1:50,000. Photography was undertaken from 1952 to 1954 by the Service Géographique National. The Service has also recently photographed various towns at a scale of 1:6,000 for town planning and road engineering.

The usefulness of the 1:50,000 photographs is rather limited. Such small scale photographs are useful for photo-geologic studies of those areas in eastern Senegal where geologic structures are very apparent and large outcrops occur. They also could be used for engineering investigations of dam sites and reservoirs. Unfortunately, they are not very satisfactory for locating alluvial deposits within and adjacent to stream channels. In Central Senegal they could be used for estimating areas of land cultivated 10 years ago, but crop identification would be difficult because the photographs were taken during the dry season when small cultivated plots cannot be distinguished from native vegetation.

If aerial photographs are to be used in future programs it is recommended that they be made at a scale of 1:25,000. Photographs at this scale would permit measurement of land areas, crop identification, location of wells, and the identification of phreatophytes as a guide for locating shallow aquifers in eastern Senegal. They also would be useful for a variety of irrigation and engineering projects. The cost of an aerial survey of the Bakel-Kédougou area would be about $100,000;

similar coverage of the Dakar-Cap Vert and Central Senegal areas would cost about $75,000.

Water Analyses

There are about 23,000 puits (hand dug wells) in Senegal and about 4,300 wells, which have been either fully or partially drilled by mechanical methods. However, only about 65 drilled wells have penetrated Paleocene or Maestrichtian aquifers. Water samples have been collected from about 40 per cent of the puits, and chemical analyses are available in the files of the B.R.G.M. and the Interstate Hydrology Office. The percentage of sampled puits in the Dakar-Cap Vert and Central Senegal areas is somewhat higher and all of the deeper drilled wells have been sampled.

Drilling Logs and Water Level Records

The B.R.G.M. maintains most of the water well records in Senegal. Drilling logs normally are not available for the shallow wells, but many of them have water level measurements. Stratigraphic and electric logs are available for most of the deeper drilled wells, particularly those penetrating the Maestrichtian formation.

Locations have been plotted on topographic base maps of varying scales and dimensions, and wells have been cross-indexed by name and registration number. Recorded information includes: dates and results of water analyses, water level measurements, ground elevation, well description, geographic coordinates and results of production tests.

With the exception of deep wells in the Dakar-Cap Vert area, very few shallow wells have been measured or sampled since early 1959. In the Bakel-Kédougou area about 250 puits have been registered, but only about three per cent have water level measurements and water analyses. In Central Senegal 3500 puits have been registered; 90 per cent have one water level measurement and 10 per cent have two measurements. About 95 per cent of the 860 puits in the Dakar-Cap Vert area have one water level measurement and 10 per cent have two measurements.

Water Use

Very little information on water production from shallow wells is available. However, most wells have been located, and since estimates of population and livestock have been made, reasonably valid estimates of consumptive use could be made. Most of the larger towns in Central Senegal such as Thiès, M'Bour and Kaolack obtain their municipal water supply from wells penetrating the Maestrichtian formation. Totalizing flow meters are usually installed and production measurement maintained by well attendants. Water production from municipal wells in the Dakar-Cap Vert area has been measured systematically for many years and production records are readily available in the files of Travaux Publics du Cap Vert. There is very little irrigation of crops in the assigned study areas and the use of ground water for such purposes is primarily restricted to very small gardens.

Photo 10. Storage reservoir and well pump house at Tivouane, typical of many of the larger towns in Central Senegal.

Photo 11.

This dug well near M'Bour is typical of those supplying water for village use and livestock. The drums in the foreground are used by individual families for storage.

CHAPTER III HYDROGEOLOGY

General Geology

Occurrence and Use of Ground Water

GENERAL GEOLOGY

Dakar-Cap Vert Peninsula

The Dakar-Cap Vert area juts into the Atlantic Ocean from about longitude 17° 00' west forming a peninsula consisting of a rocky point tied to the mainland by a tombolo. Eastward from the mainland the north coast of the peninsula is flat and sandy up to Yof where seacliffs are cut in the volcanic and sedimentary rocks of the Dakar-Ouakam region. From Hann eastward, the south coast is similarly flat with occasional rocky sectors alternating with lagoonal beaches.

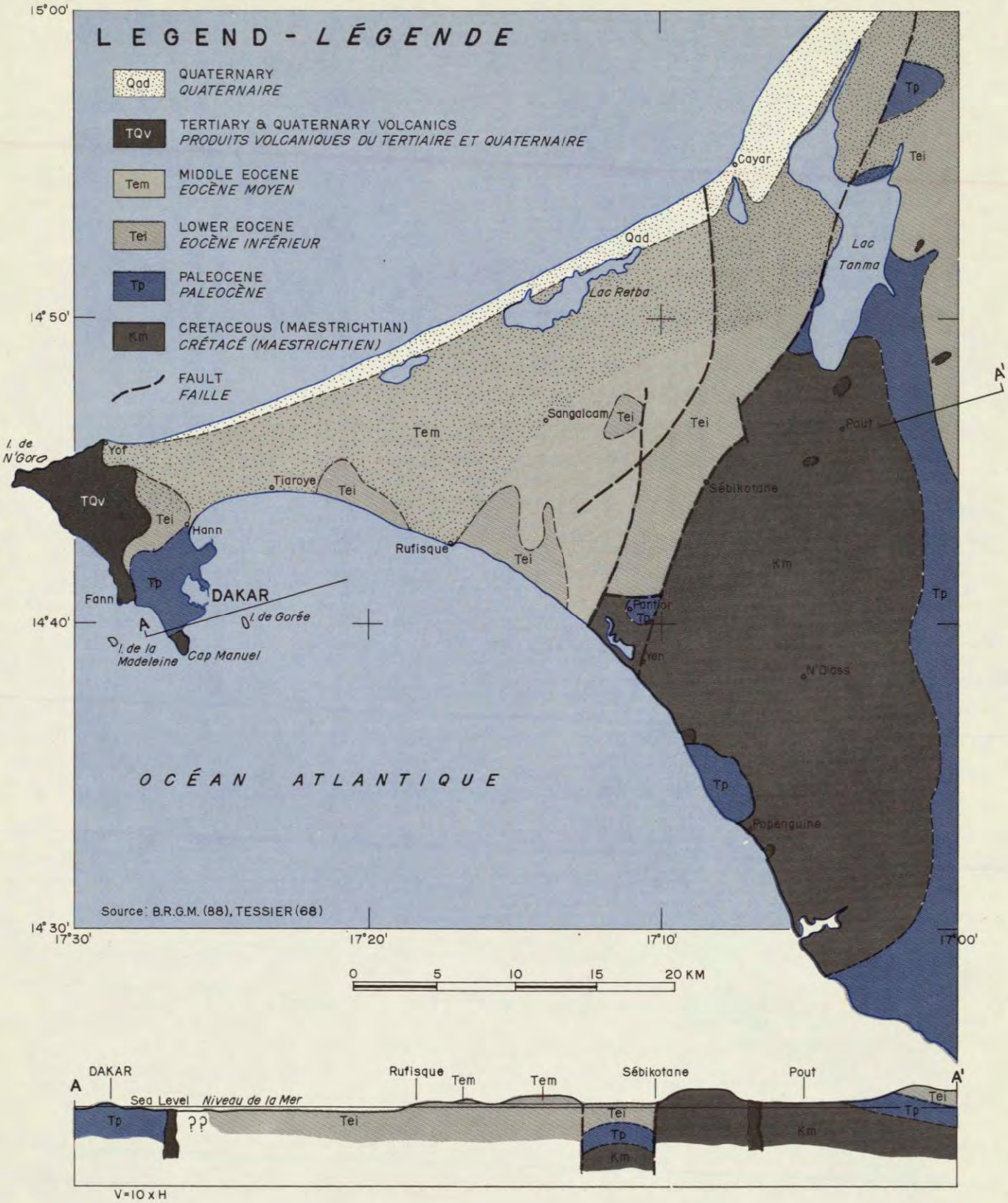
The Dakar-Cap Vert area exhibits little relief. The highest elevations are those of the Mamelles, two remnants of a volcanic cone northwest of Dakar; which barely rise to an elevation of 100 meters. Two prominent linear features of the peninsula are the fault-scarp of the Sébikotane-Yen fault and the Thiès cuesta. Both features have an approximate north-south orientation and the latter forms a natural physiographic boundary of the Cap Vert Peninsula.

The Cap Vert Peninsula can be separated into various physiographic units. Two of the most evident are the rocky point of the Dakar area and the sandy, dune covered zone of the northern part of the peninsula with its characteristic "niayes." The N'Diass massif, a dome with some horst characteristics, occupies the greater part of the southeast quarter of the peninsula. It is bounded to the west by flat limestone terranes

and separated from the Thiès cuesta to the east by an old river valley. There are no permanent rivers within the area.

The oldest rocks exposed in the area occur within the Maestrichtian formation of Cretaceous age. The Maestrichtian formation is of paramount importance as it is Senegal's most important aquifer. Its only surface exposure in Senegal is the N'Diass massif of the Cap Vert Peninsula but it underlies the greater part of the extensive sedimentary basin to the east. The Maestrichtian consists mainly of slightly consolidated sands with some cemented sandstone horizons, sandy limestones and clay shales. Northeast of Rufisque it is present as a sandy clay and clay. It is 1800 meters thick at Rufisque but its thickness has not been precisely determined throughout most of Senegal because of the small number of deep drill holes and limited paleontologic data.

Paleocene formations, mainly limestone with minor intercalations of sandstone and marl are exposed around the N'Diass massif. Their thickness is variable (50-100 meters) and facies become sandier to the east. In the Cap Vert area the predominant member is limestone that is fossiliferous and karstic in character. Paleocene limestone underlying the Eocene between the two main faults, which delimit the Sébikotane block, has been elevated by an east-west fault and exposed in the Pantior gully. These limestones dip south and are probably exposed on ocean floor south of Yen. Eocene formations containing various horizons of limestone, marl and phosphatic clays occur in the Thiès escarpment and similarly



GEOLOGY OF THE CAP VERT PENINSULA

GEOLOGIE DE LA PENINSULE DU CAP VERT

Plate-Planche 4.

Photo 12. Laterite capping Quaternary lava flows at the western tip of the Cap Vert Peninsula. The Mamelles, remnants of a Quaternary volcano appear in the background.

Photo 13. Scoraceous lavas of Quaternary age at Fann Point. A well developed marine terrace appears in the background.

north and west of the N'Diass massif. Some Tertiary volcanics, lavas and pyroclastics, are exposed from Fann to Dakar and on the outlying islands.

Intense laterization was widespread at the beginning of the Quaternary period. However, erosive agents subsequently destroyed the laterite crust in most parts of the Cap Vert Peninsula, although it is still present in Dakar and in the N'Diass massif. The Mamelles' volcanic activity occurred during this period also, producing at least five flows and abundant tuffs and breccias. Fluctuations of sea level during Quaternary time are also evident as marine terraces at elevations varying from 3 to 25 meters have been identified.

Faulting is rather common in the area although in many cases has been based on geophysical interpretations. Most of the faults appear to trend northeasterly. Tessier (68) suggests that a series of fault block movements are responsible, among other factors, for the present Thiès escarpment and N'Diass massif, as well as for the present position of the Paleocene limestones of the Sébikotane-Yen block. Generally faults have been found to form barriers to ground-water flow.

Central Senegal

The Central Senegal area is delimited by longitudes 15° 45' and 17° 00' west and by latitudes 14° 00' and 15° 15' north, and may be considered the easterly extension of the Dakar-Cap Vert area. It is bordered to the southwest by the coast with its barrier beach broken by two points

of more resistant Eocene formations. South of Joal are the mangrove swamps and tannes at the mouth of the Saloum River. Average elevation seldom exceeds 20 meters.

The area can be divided into four physiographic units. The Thiès cuesta and its backslope, known as the Thiès plateau, are two main units in the northwest part of the area. A portion of this sector bordering the ocean also includes an appreciable area of dunes and "niayes." The southwest part of the area east of the mouth of the Saloum forms a third unit, a network of salt-marshes in which tidal effects are felt for great distances. Here sea water invades wide areas barren of vegetation, known as "tannes," which appear to be increasing in areal extent. The fourth unit is a sandy plain of little relief whose elevation decreases southward and occupies over 60 per cent of the area.

There are no perennial streams, but in areas where stream channels have been eroded below the water table small ponds or "marigots" form during the dry season. However, by the end of the dry season effluent seepage ceases and ponded water evaporates.

Central Senegal is located along the eastern margin of a broad basin which extends from the Thiès escarpment eastward to the Paleozoic and Pre-Cambrian rocks of eastern Senegal. The Maestrichtian formation of Cretaceous age underlies the entire basin and in Central Senegal occurs at depths ranging from 100 meters to 400 meters. It is not exposed in Central Senegal, but does outcrop west of the Thiès escarpment and

possibly some distance offshore south of Yen. The upper 80 meters consist of sandy limestones and marls which overlie more or less argillaceous and calcareous sands with occasional hard sandstone lenses. The lower Maestrichtian is much coarser and forms the largest groundwater reservoir in Senegal. Thickness varies from about 300 meters at Kaolack to 500 meters at Thiès and averages about 400 meters in Central Senegal.

Exposures of older rocks are relatively rare and only those of Paleocene age or younger are to be found. Coarse Paleocene limestones are exposed along the foot of the Thiès cuesta scarp and in the vicinity of M'Bour. Thickness is estimated to be of the order of 20-30 meters. In the rest of the area the Paleocene is covered by Eocene and younger sediments, which are the most extensive. Continental Terminal formations overlie the middle and upper Eocene in the southeast corner of the area.

More recent geologic events of the Tertiary are, in many respects, similar to those which occurred in the Dakar-Cap Vert area. Phosphatic laterites were formed, followed by volcanic activity and erosion of the laterite. The Quaternary period is also marked by laterization and the deposition of the lacustrine limestones that overlie the upper-Eocene in the northeast corner of the area. Sand dunes were also formed and marine invasions occurred although they did not extend inland to areas which are now above three meters in elevation.

Bakel-Kédougou

The Bakel-Kédougou area forms an arcuate zone of Pre-Cambrian and Paleozoic formations that rims the eastern part of Senegal. The overall physiographic appearance of the area is that of a flat plain with slight undulations. Those sectors underlain by unmetamorphosed Paleozoic sediments rarely rise to 100 meters and even the more resistant metamorphic and igneous rocks rarely exceed elevations above 200 meters. Some hills in the area to the west of Kédougou exceed 400 meters but these are composed of post-Devonian diabases and occasionally of Pre-Cambrian volcanics. Those low hills, mostly in sandstones and quartzites, that break the monotony of the plain are oriented parallel to the structure. Some of the hills east of Kédougou and close to the Falémé River contain hematite iron ore. The southern border of this province is the scarp cut in the massif of Guinea which extends to the south.

A thick extensive laterite, often ferruginous, effectively masks the underlying formations. Streams have cut deep gullies through the laterite to elevations below 50 meters, forming a large number of deep, sharp cuts in an otherwise flat plain, often exposing older rocks.

The main rivers of the area are the Senegal to the north, the Falémé to the east, and the Gambie with its important tributary, the Niokola Koba, to the west. Much of the area is drained by a fairly large number of ephemeral streams which provide the primary source of water for inhabitants and livestock.

Pre-Cambrian rocks are exposed in the southeast third of the Bakel-Kédougou area. These rocks show a relatively low degree of metamorphism, rarely extending beyond the mica-schist facies. The most abundant are mixed schists containing sericite, talc, muscovite, and impure quartzites. Minor crystalline limestones, contemporaneous in age, occur as isolated patches among these metamorphic rocks. Northeast trending bands of metamorphosed volcanics containing minor ultrabasic bodies with associated pyroclastics occur to the north of Kédougou. Granitic intrusives, the more extensive being paratectonic, make up approximately one-third of the Pre-Cambrian rocks and in places have intruded the metasedimentary series of rocks in the area.

Basal Paleozoic formations include a conglomerate, sandstone and shale series (Infra-Cambrian) exposed in the escarpment along the southeast border of Senegal. Overlying Cambrian and Ordovician rocks consist of a volcanic sedimentary assemblage followed by tillite, limestones, shales and sandstones. Intense folding along north trending axes resulted in the dynamometamorphism of important bands of these sediments which were long considered to be Pre-Cambrian in age. Some diabase sills, post-Devonian in age, stand in relief to the west of Kédougou.

OCCURRENCE AND USE OF GROUND WATER

The purpose of this section, as in the case of the preceding section on General Geology, is to briefly describe existing knowledge and point out limitations of available information. There are a number of reports available on the occurrence and use of ground water in Senegal that have provided a good technical basis for the following review.

Dakar-Cap Vert Peninsula

Ground water pumped for municipal use in Dakar is obtained from three sources: a sub-basaltic, semi-confined sandy aquifer of Eocene age north of Dakar, an unconfined sandy aquifer in the vicinity of Tiaroye, and the Sébikotane limestone aquifer of Paleocene age located between the two northeast trending faults shown on the geologic map.

All aquifers are replenished by the infiltration of rainfall on the peninsula and subject to the intrusion of sea water when water levels decline below sea level. Travaux Publics du Cap Vert has installed a series of piezometers in coastal areas where sea-water intrusion has occurred, to observe water level fluctuations and salinity changes. Data obtained from the piezometers has been most helpful in determining the volume of water that can be safely pumped from the ground-water reservoir without inducing sea water into the aquifers. Although an attempt has been made to limit pumping to estimated annual replenishment, it seems unlikely that this practice can continue for many more years as future water demands most certainly will exceed safe pumping yields.

During 1962 about 21,000,000 cubic meters (57,000 cubic meters per day) were pumped from the three aquifers. Annual production from these sources since 1952 are given in the following table

MUNICIPAL WATER CONSUMPTION AT DAKAR
(In Cubic Meters Per Year)

Year	Source			Total
	Mamelles	Tiaroye	Sébikotane	
1952	6,935,000	3,794,988		10,729,988
1953	6,935,000	4,872,931		11,807,931
1954	6,935,000	5,075,005		12,010,005
1955	6,935,000	6,457,310		13,392,310
1956	6,935,000	6,138,140		13,073,140
1957	6,935,000	6,257,200		13,192,200
1958	6,935,000	5,361,400		12,296,400
1959	6,205,000	3,036,800	4,600,000	13,841,800
1960	6,205,000	874,500	11,822,700	18,902,200
1961	6,205,000	3,102,500	11,463,800	20,771,300
1962	6,205,000	3,489,400	11,012,700	20,707,100

Water distribution in Dakar is managed by a private company (Compagnie Général des Eaux du Sénégal) and facilities are operated and maintained by a government agency (Travaux Publics du Cap Vert). Representatives of these agencies have prepared estimates of future water demands based on population growth and anticipated water demands in the Dakar area. Their estimates indicate that about 80-85,000 cubic meters per day will be required by 1973, which will require a considerable expansion of existing facilities.

It is possible that additional water could be obtained from the eastward extension of the Tiaroye aquifer; but considering the hazard of sea water intrusion, its dependability is very questionable.

A much more dependable supply, probably can be obtained economically from the Maestrichtian formation in the vicinity of Pout and Thiès.

Central Senegal

Ground water in Central Senegal is obtained from two sources, the shallow phreatic aquifers and the deep Maestrichtian formation. Most of the villages in the area obtain water from phreatic aquifers, and the larger towns utilize the Maestrichtian formation. Reports describing these aquifers have been prepared by Defossez (192) and Audibert (204, 217).

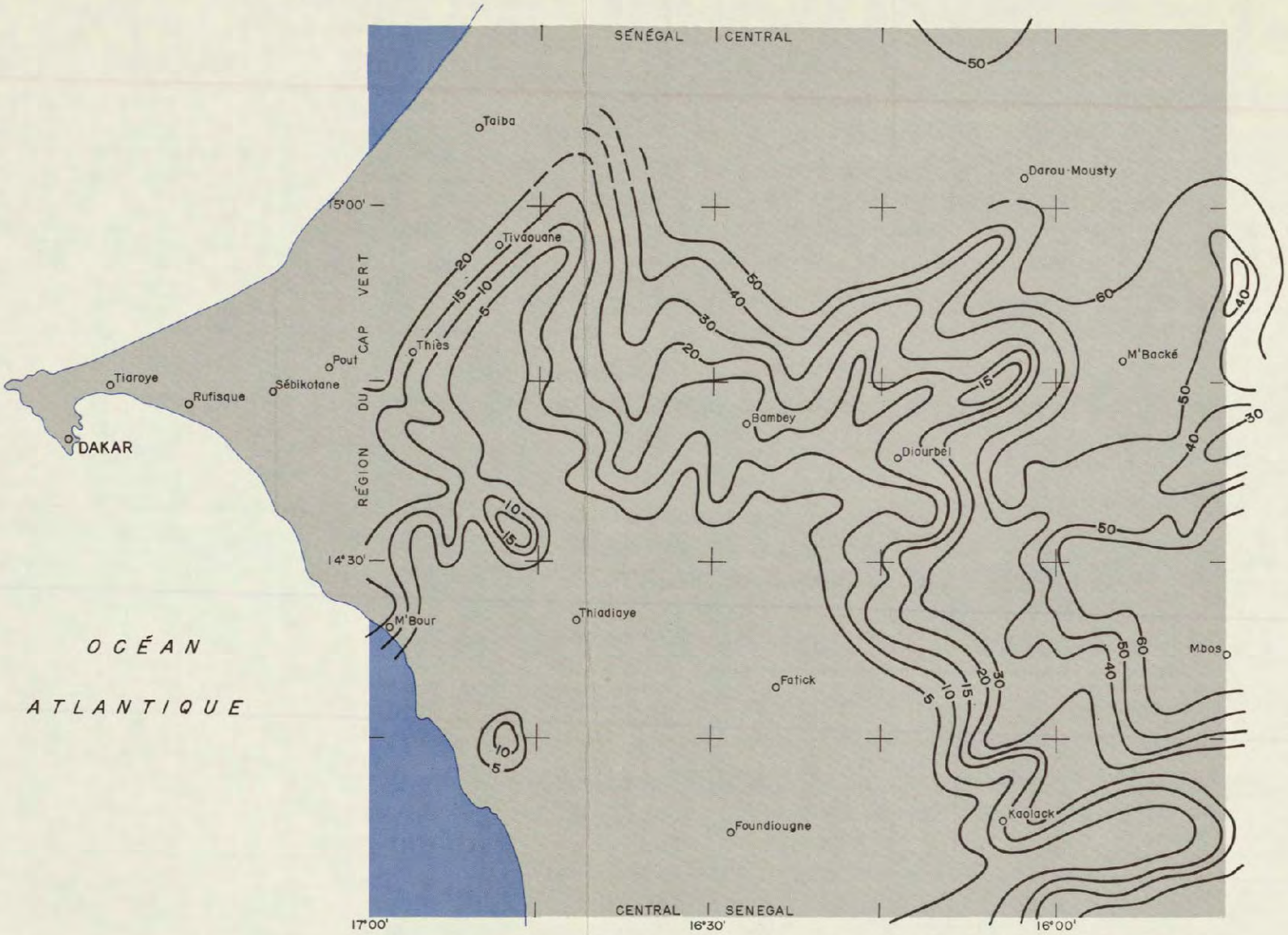
The phreatic aquifers vary considerably in lithologic character and include sands, marly sandstones, marls, limestones, and interbedded marly limestones, varying in age from lower Eocene to Pliocene. The more permeable water bearing deposits are located west of Diourbel where sandy aquifers and permeable limestones occur. East of Diourbel shallow wells penetrate less permeable marls and limestones.

Replenishment occurs primarily from the direct infiltration of rainfall, and streams are believed to contribute very little recharge to the aquifers. Depths to the water table vary from 5 meters in the western part of the area to 60 meters in the north-east part as shown on the following map. Subsurface movement of ground water is generally eastward from the Thiès cuesta.

Quality of water is generally very good throughout most of the area. West of Diouabel total dissolved solids vary from 300 to 600 parts per

Photo 14. This hand dug well at Thies is typical of many others in Central Senegal.

Photo 15. The phreatic water table exposed by phosphate mining operations at Taiba.



DEPTH IN METERS TO PHREATIC WATER TABLE - 1958
PROFONDEUR EN MÈTRES AU NAPPE PHRÉATIQUE - 1958

0 10 20 30 40 50 KM

DEPTH TO PHREATIC WATER TABLE
PROFONDEUR DE LA NAPPE PHREATIQUE

Plate-Planche 5.

million. East of Diourbel quality is somewhat poorer. In this area total dissolved vary from 500 to 1200 parts per million.

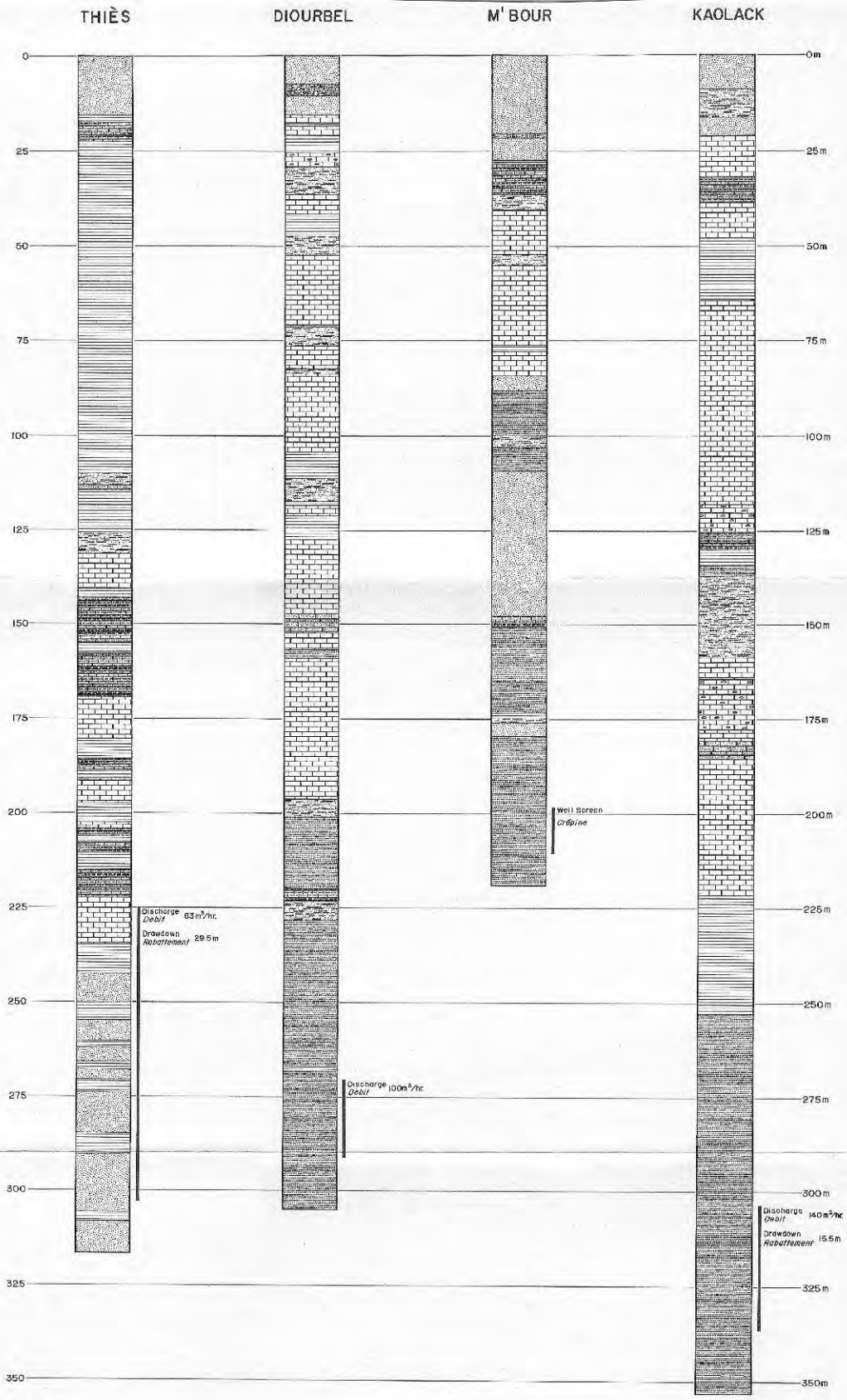
Very little information is available on aquifer coefficients and well capacities, nor have previous studies included an hydrologic balance. However, there is evidence suggesting that the phreatic aquifers could provide a dependable source of water supply. Many of the Cercle Commandants interviewed during the field reconnaissance reported that even though water levels sometimes decline during the dry season they usually recover during the rainfall season. Some of the phreatic aquifers also appear to be very permeable. The Director of Institut de Recherches Agronomiques at Bambey reported that water levels in irrigation wells there have not declined during the past 10 years of operation. Although additional research on the phreatic aquifers should be undertaken, members of Parsons' staff are in agreement with Defossez and Elouard (192) who have concluded in their report on the phreatic aquifers . . . "Utilization of the phreatic aquifers should not be overlooked for production is often adequate and relatively inexpensive for local requirements. Where demands are great the confined Paleocene and Maestrichtian aquifers, whose supplies are abundant, should be exploited."

The Maestrichtian formation underlies the entire Central Senegal area and the greater part of Senegal and includes a very thick aquifer comprised of medium-grained sands and sandstones. The top of the more permeable sands and sandstones occurs at depths varying from 100 to 400 meters in Central Senegal where thickness varies from 250 to 500 meters.

Most of the sediments were deposited in a detrital basin and are essentially undeformed. The only apparent structure occurs in western Senegal where the formation has been uplifted and is now exposed west of Thiès in region of Cap Vert. The Maestrichtian is underlain by saline deposits throughout most of its aerial extent and may be exposed to sea water some distance off-shore from southwestern Senegal. However there appears to be little danger from contamination except in the Saint Louis area.

Water quality zones have been well defined but the evolution of geochemical relationships has not been studied in detail. Ground water in the eastern two-thirds of Central Senegal is sodium chloride in character and contains from 1000 to 2000 mg/liter total dissolved solids. In the western one-third of the area calcium carbonate waters are most common, containing an average of about 500 mg/liter total dissolved solids.

There are about 20 wells in Central Senegal which produce water from the Maestrichtian and water levels, which average about two meters above sea level, have not declined appreciably since pumping commenced. The location of wells producing water from Maestrichtian-Paleocene aquifers and volumes pumped during 1960 is shown on the following plate. The aquifer is confined by marls throughout most of Senegal, but some localized vertical movement does occur in central Senegal where the Maestrichtian is in contact with overlying Paleocene limestones. Recharge is believed to occur in eastern Senegal along the Senegal River near Bakel,

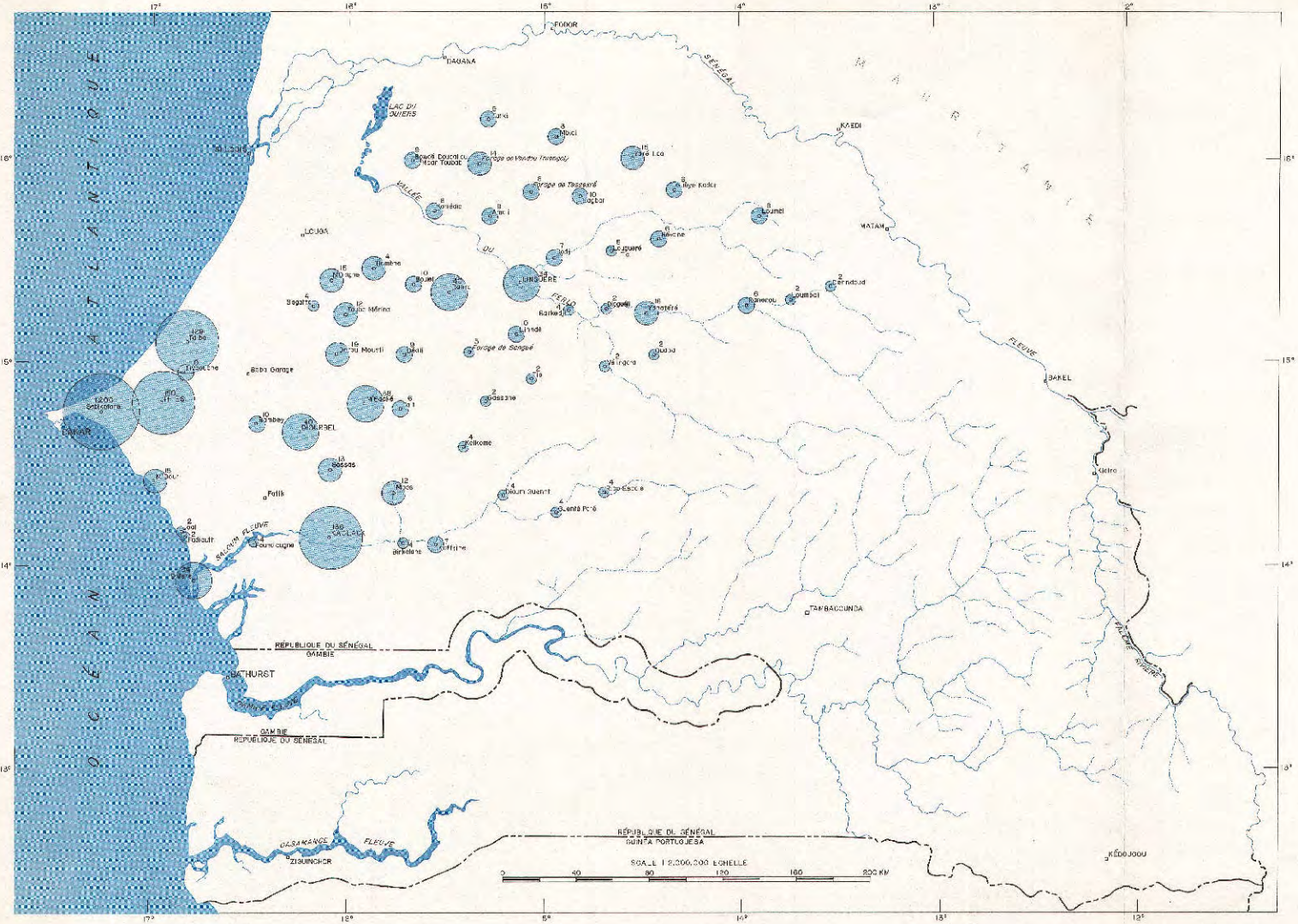


LEGEND - LÉGENDE

GRAVIER	SABLE	GRÈS	ARGILE SCHISTE ARGILEUX	SCHISTE ARGILEUX GRÉSEUX	CALCAIRE	CALCAIRE GRÉSEUX	CALCAIRE SILICEUX	CALCAIRE ARGILEUX
GRAVEL	SAND	SANDSTONE	SHALE-CLAY	SANDY SHALE	LIMESTONE	SANDY LIMESTONE	SILICEOUS LIMESTONE	ARGILLACEOUS LIMESTONE

GRAPHIC LITHOLOGIC LOGS
COUPES LITHOLOGIQUES DE PUITS

Plate-Planche 6.



LEGEND - *LÉGENDE*

VOLUMES PUMPED IN 1960
VOLUMES POMPÉS EN 1960

IN UNITS OF 10,000 M^3
EN UNITES DE 10,000 M^3

- 1-5
- 5-10
- 10-25
- 25-50
- 50-100
- 100-150
- >150

SOURCE: *HYDROGÉOLOGIE DE LA NAPPE MAESTRICHTIENNE DU SÉNÉGAL B.R.G.M. 1962*

GROUND WATER PRODUCTION
PRODUCTION DES EAUX SOUTERRAINES

Plate-Planche 7.

near the margin of the basin in southeastern Senegal and in the N'Diass Massif area south of Sébikotane.

Very few aquifer transmissibility tests have been made because of the very high cost of constructing observation wells. The most reliable test reported was made at Kaolack where aquifer transmissibility was found to be 1.47×10^{-2} m^2/S (3.30×10^5 gal/day/ft.) with a storage coefficient of 2.8×10^{-4}. Transmissibilities of this magnitude are characteristic of thick extensive aquifers and appear reasonable in this case. Other indications of the Maestrichtian's large reservoir capacity include a study of the long term pumping of wells (207). This study revealed that, after pumping some 23 million cubic meters of water from 50 wells within an area of 50,000 square kilometers during a nine year period, the water table declined only 0.5 meters (0.15 feet per year).

Previous studies of the Maestrichtian have been handicapped by the absence of observation wells to permit the determination of aquifer transmissibilities and storage coefficients and a limited number of accurate well elevations to permit the preparation of a good piezometric map. There also appears to be a limited knowledge of replenishment areas, and the hydraulic relationship between the Maestrichtian fresh-water sands and overlying Paleocene limestones and underlying saline deposits. The construction of piezometers or observation wells in the vicinity of existing producing wells would provide usefull information, particularly

in areas where withdrawals are greatest. However, this research should be subordinate to studies of the phreatic aquifers.

Bakel-Kédougou

The Bakel-Kédougou area is underlain by Pre-Cambrian and Paleozoic formations, situated to the east of the large Tertiary basin of Senegal, that are generally unfavorable for the occurrence of ground water. The area is drained by three main rivers, the Gambie which drains southeast Senegal, the north flowing Falémé whose tributaries interfinger with those of the Gambie, and the Senegal which drains the northern part of the area.

The area is essentially undeveloped because of its inaccessibility during the rainy season, poor soils, and water shortage during the dry season. The presence of the tsetse fly and water borne parasites in the vicinity of the major reivers and streams may also have discouraged habitation. Previous studies of the area have been of a reconnaissance nature and do not include quantitative information regarding water use and requirements. Unfortunately the most recent report (218) on the area was being prepared in B.R.G.M.'s Paris office during the Reconnaissance and basic data was not available for review.

Pre-Cambrian schists, quartzites, granitic intrusives, and meta-volcanics in the area do not include a recognizable aquifer. In some areas joint systems may favor their water bearing capacity, however, the presence of wells producing water from these rocks was not noted in studies of available data. Some of the Paleozoic sandstones and shales yield water to a few wells, but usually at rates less than five cubic meters per hour.

Laterite deposits cover most of the southern part of the area and are often sufficiently permeable to yield ground water. Granite laterites generally have a higher permeability than schist laterites, although the transition zone between unaltered schists and laterites occasionally forms a fair aquifer.

Isolated alluvial deposits in the vicinity of stream channels contain the best aquifers of the area. The alluvium consists mainly of sands, clays, and beds of lateritic gravel. These deposits sometimes occur in depressions along the inside curve of meanders, at tributary junctions, and in areas where laterite deposits have been deeply incised. The permeability of these deposits is quite low and rarely exceeds 0.5×10^{-4} meters per second.

Most of the villages obtain water from shallow dug wells, flowing streams during the rainfall season, and springs which occasionally have been developed to increase their flow. Many of the springs and streams do not yield water during the dry season and inhabitants commonly complain of traveling considerable distances for water. Some of the villages are unfavorably situated but many could obtain water during the dry season, if requirements are not excessive, by further development of known resources. In the Kédougou area an increased supply could be obtained by developing springs, the construction of small earth dams, and the construction of samll diameter wells equipped with hand operated pumps in areas where alluvium and thick laterite deposits occur.

CHAPTER IV RECOMMENDATIONS

Dakar-Cap Vert Peninsula

Central Senegal

Bakel-Kédougou

RECOMMENDATIONS

One of the objectives of the hydrogeologic Reconnaissance was to . . . "evaluate the technical soundness of the work programs outlined in Sections 10, 14, 15 and 16 of the report by the Department of Public Works entitled "Programme de Recherches Hydrogéologique de 300 Millions Propose à l'A.I.D." Section 16 of this proposal refers to Dakar-Cap Vert Peninsula, Sections 14 and 15 refer to Central Senegal, and Section 10 refers to the Bakel-Kédougou area. In reviewing these programs we have considered applicability of existing data and technical soundness, immediate benefits to be derived, the relation of the program with other research activities, and the possibility of an alternate program that would yield more immediate benefits.

Dakar-Cap Vert Peninsula

The work program outlined in Section 16 is essentially one of continuing hydrogeologic research and exploration for additional ground water to supplement Dakar's municipal water supply. Previous work of this nature has been performed by the Compagnie Général des Eaux du Sénégal, Travaux Publics du Cap Vert, and the Bureau de Recherches Géologiques et Minières. Although the program is technically sound in its research objectives, the funds required to implement the program could be used for exploration in other areas and achieve the ultimate objective more beneficially. It does not appear that the Cap Vert Region contains sufficient ground-water resources to supply Dakar indefinitely; however, a dependable supply does exist in the vicinity of Pout and Thiès, and

it is recommended that research and exploratory drilling be undertaken in this area rather than in the Dakar-Cap Vert area.

Central Senegal

The four year work program outlined in Sections 14 and 15 is similarly one of continuing research, and although the objectives are technically sound and most desirable, very little immediate benefit would be derived. At present, the Maestrichtian formation is essentially undeveloped and is known to contain substantial volumes of ground water. Many of the research objectives could be attained more advantageously by undertaking development projects and maintaining a surveillance of the ground-water basin, rather than delaying development for the purpose of basic research. In fact, many of the hydrogeologic parameters of the basin probably cannot be determined with any degree of accuracy until after decades of exploitation. Furthermore, the shallow phreatic aquifer has a considerable potential and should be developed more fully in areas where supplies are abundant.

Further consideration of the work program as outlined in Sections 14 and 15 of subject reference is not recommended. However, certain aspects of the program are given consideration in the alternate recommended Development Project outlined in Chapter V.

Bakel-Kédougou

It was not possible to properly evaluate the work program outlined in Section 10 because the survey was conducted during the peak of the

rainy season when access roads and trails were impassable, which limited field reconnaissance to the Kédougou area, and the existing aerial photographs were found to be inadequate for the accomplishment of project objectives. Consequently recommendations regarding the soundness of the work program are essentially based on a review of available reports and a brief reconnaissance of the Kédougou area.

The work program as outlined will require the expenditure of $300,000 for hydrogeologic research which includes about $120,000 for two deep exploratory borings. Although the research aspect of the program will probably yield information that ultimately would be useful in planning small water development projects, the expenditure of $120,000 for deep exploratory borings does not appear technically or economically sound, as the possible existence of a substantial ground-water reservoir is very remote. Considering that several previous investigations in the area have provided a sufficiently sound technical basis for planning small village water development projects the expenditure of additional funds for more research does not appear justified.

CHAPTER V DEVELOPMENT PROJECT

Applicant
Recommended Project
Project Schedule
Scope of Services
Project Cost Estimate
Technical and Economic Soundness
Benefits

APPLICANT

The Ministère de Travaux Publics is, at present, the authority responsible for the administration of water resources research and development projects. However, the formation of a "Ministry of Water Resources" is now under consideration, and presumably the recommended project, described in the following section, would be carried out under the auspices of the "Hydraulic Division" of this government agency. Since Division functions have not been firmly established it has not been possible to include, in the report, structural description of the "Ministry."

RECOMMENDED PROJECT

Purpose

The recommended project combines the elements of research, development and training, and in its objectives, includes some of the research objectives desired in the Cap Vert and Central Senegal areas. The purposes of the project are threefold:

1. To provide the basic hydrogeologic data required for planning and implementing water development projects in those areas of Central Senegal where existing facilities are inadequate to provide for present and future water demands.

   research for planning projects of g.w. dev.

2. To provide an adequate sanitary water supply in those areas of Central Senegal where municipal, village and livestock water shortages are most critical.

   from shallow aq.

3. To train a small Senegalese drilling staff for the purposes of continuing work commenced during the project and carrying out exploratory drilling and water well construction programs in other areas where these activities cannot be undertaken economically by private organizations.

Objectives

The objectives of the project include undertaking a program of limited hydrogeologic research and exploratory drilling for the purpose of establishing necessary hydraulic parameters and design criteria for the construction of water wells in those areas where needs are most critical, and the construction of a limited number of wells in those areas where the development of ground water can be undertaken on a technically and economically sound basis. The specific objectives of the project include:

1. Determine those geologic and hydrologic parameters of the shallow phreatic aquifers required for the construction of producing water wells in those areas of Central Senegal where previous studies have indicated the presence of a substantial ground-water reservoir.

2. Determine the technical feasibility of developing Paleocene or Maestrichtian ground-water resources in the Pout-Thiès area for supplementing Dakar's water supply.

3. Determine aquifer transmissibility storage coefficients and other hydrogeologic parameters of the Maestrichtian formation in those areas of Central Senegal where data necessary for the planning of specific water development projects is either absent or inadequate.

PIO/T phreatic aquifers instead

DOT

4. The construction of water wells in those areas of Central Senegal where municipal, village and livestock water requirements are most critical, by utilizing those aquifers that can be most economically developed.

5. Provide the Republic of Senegal with a trained drilling staff and the minimum necessary drilling equipment required for undertaking limited exploratory drilling and water development projects that cannot be undertaken economically by private organizations.

Scope of Work

The achievement of project objectives will require the services of an engineering and construction Contractor who is well qualified by previous experience in similar hydrogeologic research and ground-water development projects. The project will also require the participation of those government agencies of the Republic of Senegal responsible for the planning and administration of hydrogeologic research and water development projects who will provide personnel required for the training program and other project facilities. Since about 50 per cent of

the project objectives include basic research and exploratory drilling, a specific work program and project schedule cannot be precisely outlined and planned. However, it is believed that the following items of work can be accomplished with an 18-month period.

1. Review previous hydrogeologic reports and available data and, in consultation with participating agencies of the Republic of Senegal, select specific sites for constructing water production wells.

2. Drill about ~~20~~ 10 exploratory test and observation wells to a maximum depth of ~~200~~ 150 meters to determine geologic and hydraulic characteristics of the phreatic aquifers. About ~~10~~ of these wells will be of sufficient diameter to permit the installation of a production test pump.

3. Drill five exploratory borings in the vicinity of production well sites to a maximum depth of 700 meters to determine geologic and hydraulic characteristics of the Maestrichtian formation and establish design criteria for production wells. The wells will be of sufficient diameter to permit the installation of small diameter casing for the continuous measurement of the piezometric water surface.

4. Design and prepare specifications for permanent water supply wells.

5. Construct 10 water supply wells for either municipal or livestock use. It is assumed that five of these wells will utilize the Maestrichtian formation as a source of water supply. For purposes of cost estimating it is assumed these wells will yield 140 to 180 cubic meters per hour.

6. Construct 30 village sanitary water supply wells equipped with hand pumps capable of yielding about 2 cubic meters per hour from depths varying from 5 to 50 meters.

7. Train the assigned Senegalese drilling staff in the operation and maintenance of rotary and cable tool drilling equipment.

8. Determine the technical and economic feasibility of undertaking irrigation projects in Central Senegal, based on an evaluation of previous soil studies and agricultural research, transportation facilities, market potential and adequacy of available water supply.

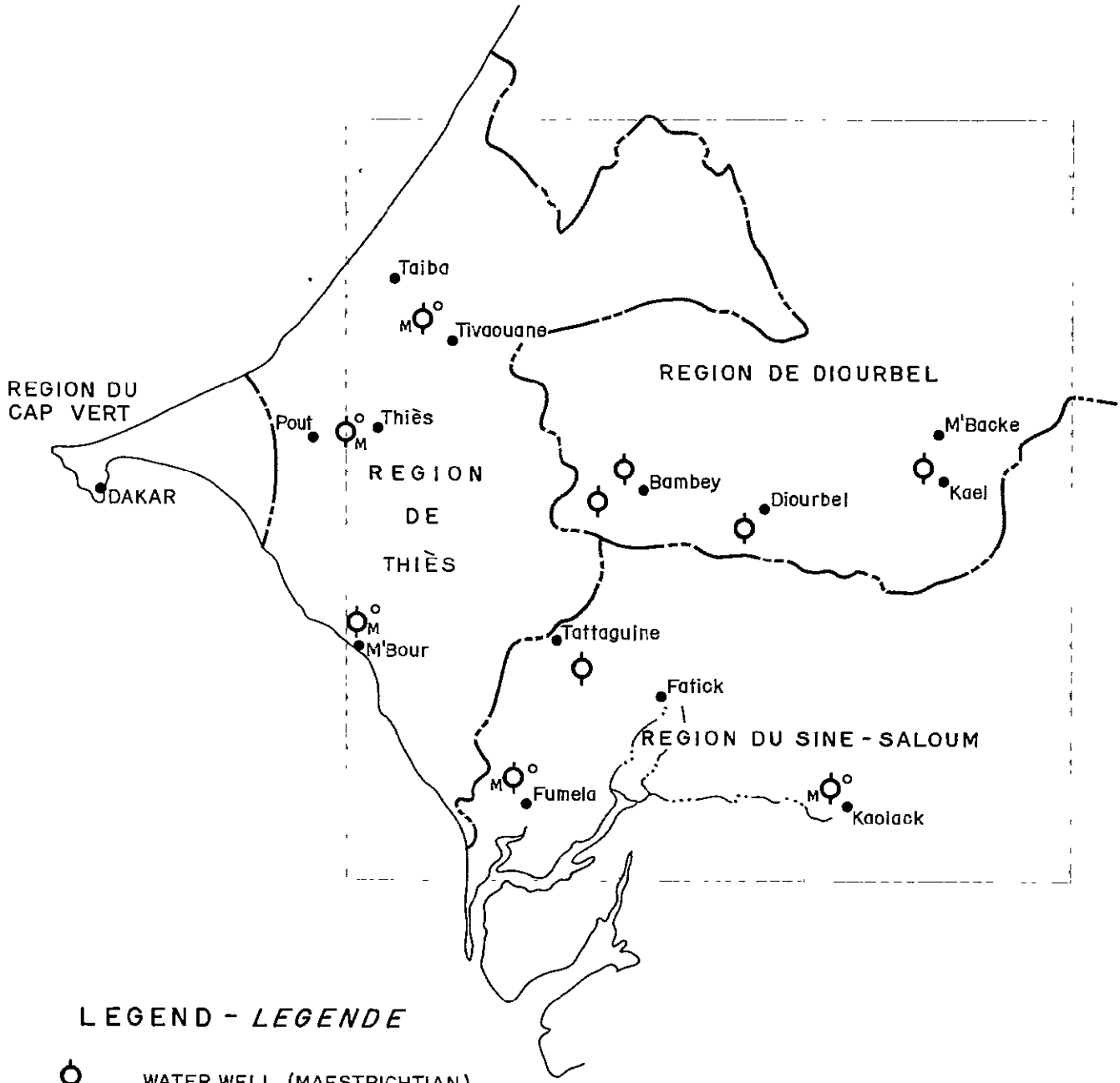
9. Assist the "Ministry of Water Resources" in operating a Drilling Division which will continue the exploratory drilling and well construction activities commenced during the project.

10. Prepare a final report which will include an evaluation of those hydrogeologic factors that affect the occurrence, movement and replenishment of the phreatic aquifers in Central Senegal based on new information acquired during the course of the project. The report also will include a recommended program for the economic development and conservation of ground water in the phreatic and Maestrichtian aquifers of Central Senegal, including the technical and economic feasibility of irrigated agriculture.

The tentative sites selected for Maestrichtian test borings and water supply wells and constructing other municipal or livestock water supply wells are shown on the following map.

PROJECT SCHEDULE

About five months will be required for processing project personnel and the procurement and shipping of required equipment and materials. Prior to the commencement of the project a total of 18 months will be required to complete the project commencing with the arrival of the hydrogeologic staff and project equipment in Senegal. The first phase will require about four months to obtain the necessary information for the design of production wells. During this phase the Contractor will prepare specifications, purchase, and arrange for shipment of all required materials from point of origin to Senegal. Hydrogeologic research will commence



LEGEND - *LEGENDE*

WATER WELL (MAESTRICHTIAN)
FORAGE (MAESTRICHTIEN)

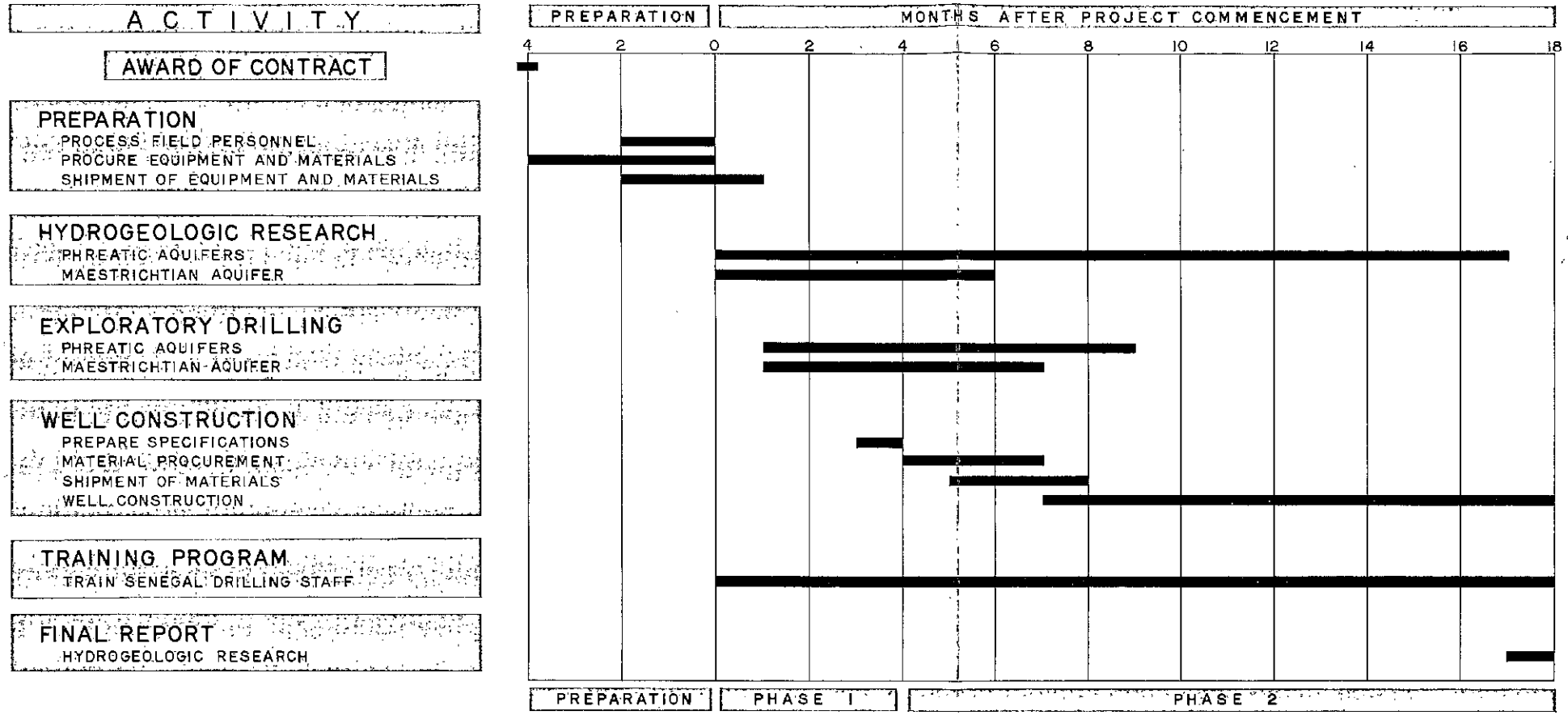
OBSERVATION WELL
PIÉZOMETRE

WATER WELL
FORAGE

PROJECT LOCATION
LOCAL DU PROJET

Plate-Planche 8.

SCHEDULE OF PROJECT ACTIVITIES



PROJECT SCHEDULE

Plate-Planche 9.

upon the staff's arrival and continue through all phases of the project. The second phase will require about 11 months and consist essentially of constructing water supply wells. Agricultural research studies will require about two months and will be undertaken during the second phase. At the conclusion of research studies the hydrogeologic staff and the agricultural economist will prepare a final report for submission to participating agencies.

SCOPE OF SERVICES

Hydrogeologic Research and Drilling Services

The Contractor will provide all personnel required for general administration, hydrogeologic research, and supervision of exploratory drilling and well construction in order to achieve the objectives of the project and accomplish those items of work included in the Scope of Work. The Contractor's field staff will consist of the following members:

1. Project Manager
2. Senior Hydrogeologist
3. Engineering Hydrologist
4. Agricultural Economist
5. Junior Hydrogeologist
6. Drilling Superintendent
7. Office Manager
8. Drillers, (3) rotary, (2) cable tool

Members of the Contractor's field staff shall be well qualified in their respective professions and vocations. At least one member of the hydrogeologic staff and one member of the drilling staff shall speak fluent French.

The Contractor also will provide all personnel required for maintaining a field office and mobile field camp. Personnel employed in these activities shall be well qualified and selected from local residents of Senegal.

The Contractor also will provide all technical and supporting services required to carry out the hydrogeologic research, exploratory drilling and well construction activities of the project.

Procurement

The Contractor will provide all services for the preparation of specifications, purchasing, and procurement of all equipment and materials required for the project. One rotary drilling rig capable of drilling exploratory test wells to depths of at least 700 meters and one cable tool rig capable of drilling water wells to depths of 200 meters will be included in equipment purchased.

Training

The participating agency of the Republic of Senegal will provide 20 trainees to work under the supervision of the Contractor and one liaison officer who will assist the Contractor in achieving the objectives of the project. The trainees will perform all work required by the Contractor that is associated with the drilling, testing and construction of exploratory borings and water supply wells. It is desirable that the trainees have some previous experience in well drilling and possess the physical ability and mechanical aptitude required for the vocation. The trainees should also be capable of

reading and writing French. The Contractor will participate in the selection of each trainee and the Contractor will be authorized to dismiss any trainee whose services are unsatisfactory.

Warehouse, Field Office and Storage Facilities

The participating agency of the Republic of Senegal will provide the warehouse and storage facilities required for the stock-piling and warehousing of all equipment and materials required for the project. In addition, the agency will provide a field office for the Contractor's field staff and the necessary utilities and services required for the operation of the field office, including electricity and water.

Exemptions and Right-of-Way

The Republic of Senegal will exempt the Contractor as well as members of his field staff and their families from the payment of all taxes, levies and duties on personal possessions, salaries, profits, materials, equipment and fuels during the course of the project. In addition, the participating agency will provide for the access and use of all lands required for achieving the project objectives.

Operation and Maintenance

The participating agency of the Republic of Senegal will assume the responsibility of operating and maintaining all works constructed during the course of the project. In the event water storage or distribution facilities are required for constructed wells, they will be provided by the Republic of Senegal.

PROJECT COST ESTIMATE

Basis for Preparing Cost Estimate

The proposed project has been divided into seven major cost categories: Contractor's field staff, local staff, field operating expense, exploratory drilling and well construction, technical equipment and services, shipping expense, and cost of services to be provided by the Republic of Senegal.

The Contractor's senior field staff will consist of five technical men, one office manager, five drillers, and one consulting agricultural economist. Home Office services will include general administration and clerical work. It is assumed that one hydrogeologist and the five drillers will be on single status as they will work continuously in the field.

The Contractor's local staff will consist of Senegal residents who will be employed to maintain the mobile project field camp and assist the senior staff in the Dakar office.

Field operating expenses include those items required to operate the Dakar office, all field camp equipment and facilities, and subsistence costs for the Senegalese drilling trainee staff.

Exploratory drilling and well construction costs include all equipment, materials and services required for the exploratory drilling and well construction program. Most of the equipment and materials will be purchased in the United States, however, some of the materials such as fuel, gravel and cement will be purchased in Senegal.

Technical equipment and service costs include the cost of all scientific and technical equipment required by the hydrogeologic staff, and technical services that cannot be economically provided by the Contractor. This category also includes the cost of providing specifications for equipment and materials required for the project, purchasing and inspection.

Shipping expense includes the cost of shipping all equipment and materials required for the project from the source of supply to Dakar.

The cost of services to be provided by the Republic of Senegal includes the salaries of 20 drilling trainees and one liaison officer, office facilities at Dakar, and warehouse and storage facilities in the vicinity of Dakar.

Summary of Costs

Item	Description	Amount
I	Contractor's Field Staff	$ 662,300
II	Contractor's Local Staff	77,900
III	Field Operating Expense	17,100
IV	Exploratory Drilling and Well Construction	602,200
V	Technical Equipment and Services	63,000
VI	Shipping Expense	73,000
VII	Services Provided by Republic of Senegal	134,600
	TOTAL ESTIMATED COST	$1,629,800

Estimate of U.S. Dollar or Equivalent Dollar Costs

I. Contractor's Field Staff

A. Field Personnel	Monthly Salary	Man Mos.	Sub-Totals	Totals
1. Project Manager	$ 1,500	18	$ 27,000	
2. Sr. Hydrogeologist	1,200	18	21,600	
3. Engr. Hydrologist	1,200	18	21,600	
4. Jr. Hydrogeologist	900	18	16,200	
5. Office Manager	900	18	16,200	
6. Drilling Supt.	1,100	18	19,800	
7. Drillers (5)	900	90	81,000	
		198	203,400	
Overseas Differential - 15%			30,500	$ 233,900
B. Home Office Personnel				
1. Project Manager	1,500	4	6,000	
2. Administration	500	18	9,000	
3. Clerical and Miscellaneous	250	18	4,500	19,500
C. Payroll Costs and Welfare Benefits				
1. Field salaries ($203,400) x 20%			40,700	
2. Home Office salaries ($19,500) x 20%			3,900	43,400
D. Consulting Services				
1. Agricultural Economist 2 months @ $4,200 per month				8,400

		Sub-Totals	Totals
E. Transportation (Including Return)			
1. Personnel (Air) 5 families with 2 minor children and 7 single status = 44 one-way air fares @ $537		$ 23,600	
2. Personnel effects (Air Freight) 2700 lbs. air freight @ $2.50/lb.		6,800	
3. Household goods (Sea Freight) 18,000 lbs. sea freight @ $1.25/lb.		22,500	
4. Automobiles (Sea Freight) 4 automobiles @ $600 each		2,400	
5. Per diem, 108 travel days @ $8/day	Say	900	$ 56,200
F. Housing and Subsistence			
1. Temporary per diem - 26 individuals @ $10/day for 40 days		10,400	
2. Quarters - 5 families @ $3200/year		24,000	
6 single status @ $2400/year		21,600	
3. Utilities - 5 families @ $200/month		18,000	
4. Subsistence - 6 Field Staff @ $100/month		10,800	
5. Schooling - 10 children @ $100/month		15,000	99,800
G. Out-of-Pocket Expenses			
1. Miscellaneous travel & preparation Expenses 26 individuals @ $50 each		1,300	
2. Postage and cables @ $100/month		1,800	
3. Miscellaneous supplies @ $50/month		900	4,000
H. Overhead			
1. Field salaries ($203,400) x 67%		136,300	
2. Home Office salaries ($13,500) x 75%		10,100	146,400

I. Fee

22.80% of salaries

8.1% of total personnel costs → 49,500

Total Cost of Providing Project Personnel $ 662,300

II. Contractor's Local Staff

A. Field Personnel	Monthly Salary	Man Mos.	Sub-Totals	Totals
1. Camp Manager	$ 400	18	$ 7,200	
2. Cook	40	18	720	
3. Cook Helper	35	18	630	
4. Laborers (4)	30	72	2,160	
5. Mechanic	400	18	7,200	
6. Truck Driver (2)	300	36	10,800	28,700
B. Dakar Office Personnel				
1. Secretary	325	18	5,850	
2. Typist	300	18	5,400	
3. Bookkeeper	150	18	2,700	
4. Warehouseman	350	18	6,300	
5. Asst. Warehouseman	200	18	3,600	
6. Janitor	30	18	540	24,400
C. Welfare Benefits				
46.75% of Salaries				24,800

Total Cost of Contractor's Local Staff $ 77,900

III. Field Operating Expense	Sub-Totals	Totals
A. Dakar Office		
1. Office space (To be provided by Senegal Government)		
2. Equipment	$ 2,000	
3. Utilities (To be provided by Senegal Government)		
4. Air conditioning units (3)	1,000	
5. Expendable supplies	900	
6. Cables, postage, etc.	900	$ 4,800
B. Field Camp Equipment		
1. Office trailer	3,000	
2. Generator	1,500	
3. Air conditioner (1)	300	
4. 10 Tents @ $200	2,000	
5. Furniture, bedding, & cooking equipment	1,500	8,300
C. Subsistence		
1. Contractor's Staff (Included in Item I-F)		
2. Senegalese Staff, 27 men for 18 months	4,000	4,000
Total Field Operating Expense		$ 17,100

IV. Exploratory Drilling and Well Construction	
A. Drilling Equipment	
1. Failing 2500 (or equal) (1)	77,000
2. Drill pipe, tools, spares for Item 1.	25,000
3. Stardrill-Keystone 81 (or equal)	35,000
4. Tools and accessories	9,000

		Sub-Totals	Totals
A.	Drilling Equipment (Continued)		
	5. Welders (3)	$ 6,000	
	6. Electric generators (3)	4,500	
	7. Air compressor (1)	14,000	
	8. Test pump, with diesel engine driver (2)	13,500	
	9. Miscellaneous spare parts	5,000	$ 189,000
B.	Transportation Equipment		
	1. Heavy duty truck and trailer (1)	29,000	
	2. Medium duty truck (1)	12,000	
	3. Pickup trucks (3)	10,000	
	4. Water truck (1)	13,000	
	5. Jeeps (3)	6,500	
	6. Station wagon (1)	3,000	
	7. Operation and maintenance	25,000	98,500
C.	Consumable Drilling Materials		
	1. Bits	70,000	
	2. Drilling mud and chemicals	40,000	
	3. Welding rod	12,000	
	4. Fuel and lubricants	30,500	152,500
D.	Well Construction Materials (Production and Piezometers)		
	1. Well casing	65,000	
	2. Well screen	28,500	

	Sub-Totals	Totals
D. Well Construction Materials (Continued)		
3. Pump and motors, complete assembly 5 electric, 5 diesel	$ 50,000	
4. Pumps, hand, with column pipe (30)	4,500	
5. Gravel	4,200	
6. Cement	3,500	$ 155,700
E. Local Project Services		
1. Equipment Rental (heavy duty)	3,000	
2. Material Transportation	2,000	
3. Material handling	1,500	6,500
Total Drilling and Well Construction Cost		$ 602,200
V. Technical Equipment and Services		
A. Technical Equipment		
1. Hydrogeologic	1,500	
2. Drafting	500	2,000
B. Technical Services		
1. Water Analyses	1,500	
2. Carbon 14 and tritium analyses	1,000	
3. Surveying	10,000	
4. Electric logging	4,000	16,500
C. Home Office Project Services		
1. Purchasing and Inspection	42,000	
2. Specification preparation	2,500	44,500
Total Cost of Technical Equipment and Services		$ 63,000

		Sub-Totals	Totals
VI.	Shipping Expense		
	A. Ocean Freight		
	1. Equipment	$ 35,000	
	2. Well construction materials	20,000	$ 55,000
	B. Railroad Freight		
	1. Same as Item A-1 and A-2	10,000	10,000
	C. Air Freight		
	1. Equipment and water samples	3,000	
	2. Emergency supplies	5,000	8,000
			$ 73,000

VII. Services Provided by Republic of Senegal

	Rate	Man Mos.		
A. Personnel Salaries				
1. Drill Crew Trainees (20)	200	360	72,000	
2. Liaison Officer (1)	450	18	8,100	
3. Welfare benefits (46.75%)			37,500	117,500
B. Dakar Facilities	Rate	Mos.		
1. Office	$300/mo.	18	5,400	
2. Office utilities	$150/mo.	18	2,700	
3. Warehouse and storage	$500/mo.	18	9,000	17,100
Total Cost of Services Provided by Republic of Senegal				$ 134,600

TOTAL ESTIMATED PROJECT COST $1,629,800

TECHNICAL AND ECONOMIC SOUNDNESS

The hydrogeologic research and water development objectives of the project are based on a considerable amount of previous research. The accompanying bibliography contains 315 references to previous studies that have provided the technical basis for preparing the recommended project and scope of services. There is, in fact, a tremendous gap between hydrogeologic research and water development. Research was sufficiently advanced a number of years ago to permit the planning and implementation of many development projects. Most of the research and development objectives of the project are also those recommended in previous reports (192, 198, 204, 207) and were included in the original proposal.

One of the primary factors that appears to have delayed the implementation of water development projects is the very high cost of constructing water wells. The cost of employing one of the two major drilling contractors in Senegal for exploratory drilling and constructing water wells is approximately 3 to 5 times the cost of employing foreign drilling contractors. For example, the cost of constructing a deep Maestrichtian well, such as the one at Taiba, is about $250,000. There is some doubt that the proposed "Drilling Division" will be capable of economically undertaking large exploratory drilling and water development projects. However, if the objectives are sufficiently limited in scope, the cost of administration should not be excessive.

The major cost items are related to accomplishing the research objectives of the project - providing basic hydrogeologic information for planning and implementing water development projects, including the supplementing of Dakar's municipal water supply. The additional cost of installing permanent casing and well pumps, instead of abandoning the test boring after data is obtained, represents only about 15 per cent of the total project cost. Consequently, the primary benefits obtained by providing a sanitary water supply adequately justify this additional cost. In fact, the cost of the entire project, which incidentally includes five producing Maestrichtian wells, is only slightly in excess of the cost of constructing the same number of Maestrichtian wells by employing local contractors.

BENEFITS

Tangible benefits resulting from the hydrogeologic research portion of the project may not be realized for many years. The primary benefits that would ultimately accrue from a successful research and exploratory drilling program in the Pout-Thiès area for the purpose of supplementing Dakar's water supply would be difficult to ascertain definitely at this time. However, the magnitude of additional water requirements for the next 10 years are not excessive, and there should be little difficulty in obtaining the additional water required.

The Director of Génie Rural has prepared an inventory of population, livestock and respective water requirements in Central Senegal. The

inventory includes some 28 large capacity wells required to provide water for municipal and livestock use and about 110 small capacity village water supply wells. Since there is little marketing of livestock, it would be difficult to appraise the benefits which would arise from providing additional water, however, the primary benefits of the village water supply program are more apparent. Many of the existing hand dug wells have insufficient yields, are unsanitary and, during summer months, yield very little water. The proposed project does not attempt toprovide all villages with small capacity sanitary wells, but rather to introduce a more reliable method of providing a dependable sanitary water supply. The cost of constructing these wells by cable tool drilling is probably about equal to cost of traditional construction. In those areas where villagers obtain their water supply from springs and small streams, water borne parasites are most common. The proposed program should immeasurably contribute to minimizing this public health hazard.

CHAPTER VI BIBLIOGRAPHY

Reports

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MAPS

TOPOGRAPHIC

SENEGAL

Gambie; 2697; 1:1,000,000
W 11° 44'-18° 00', N 12° 00'-16° 15'
IGN; 1960

Sénégal; 2658; 1:1,000,000
W 11° 44'-18° 00', N 16° 00'-20° 15'
IGN; 1960

Sénégal-Niger; 2696; 1:1,000,000
W 5° 44'-12° 00', N 12° 00'-16° 15'
IGN; 1960

République du Sénégal; 1:500,000
W 11° 30'-17° 30', N 12° 30'-16° 30'
IGN; 1960

DAKAR-CAP VERT

Dakar, ND-28-5; 1:250,000
W 16° 30'-18° 00', N 14° 00'-15° 00'
USAMS; 1956

Mekhé; ND-28-1; 1:250,000
W 16° 30'-18° 00', N 15° 00'-16° 00'
USAMS; 1955

Dakar; ND-28-XIII; 1:200,000
W 17° 00'-17° 50', N 14° 00'-15° 00'
IGN; 1957

Bargny; (Dakar et Environs); 1:50,000
W 17° 00'-17° 50', N 14° 25'-14° 45'
IGN; 1956

Dakar; (Dakar et Environs); 1:50,000
W 17° 15'-17° 33', N 14° 37'-14° 52'
IGN; 1960

IGN - Institut Géographique National, Paris
USAMS - United States Army Map Service, Washington
ASGA - Association des Services Géologiques Africains, Paris
BRGM - Bureau de Recherches Géologiques et Miniéres, Dakar

Kédougou; ND-28-16; 1:250,000
W 12° 00'-13° 30', N 12° 00'-13° 00'
USAMS; 1955

Bakel; ND-28-XVIII; 1:200,000
W 12° 00'-13° 00', N 14° 00'-15° 00'
IGN; 1956

Dalafie; ND-28-XII; 1:200,000
W 12° 00'-13° 00', N 13° 00'-14° 00'
IGN; 1956

Kédougou; ND-28-VI; 1:200,000
W 12° 00'-13° 00', N 12° 00'-13° 00'
IGN; 1958

Kossanto; ND-29-VII; 1:200,000
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Stadougou; ND-29-I; 1:200,000
W 11° 00'-12° 00', N 12° 00'-13° 00'
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AFRICA

Esquisse structurale provisoire de l'Afrique; 1:10,000,000
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Carte géologique internationale de l'Afrique; 1:5,000,000
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WEST AFRICA

Carte géologique de l'Afrique Occidentale; 1:2,000,000
BRGM; 1960

SENEGAL

Carte géologique de la République du Sénégal et de la Gambie; 1:500,000
W 11° 30'-17° 30', N 12° 30'-16° 30'
BRGM; 1962

DAKAR-CAP VERT

Dakar-E; ND-28-XIII-E; 1:200,000
W 17° 00'-17° 30', N 14° 00'-15° 00'
BRGM; 1951

AERIAL PHOTOGRAPHS

DAKAR-CAP VERT (Dakar to longitude 17° 00')

Mission 078-ND-28-XIII-DAKAR (1954)

CENTRAL SENEGAL (Latitude 14° 00' to 15° 15' N; longitude 15° 45' to 17° 00' W)

Mission 079-ND-28-XIV-THIES (1954)

Mission 080-ND-28-XV-KAFFRINE (1954)
(W 1/4 of coverage)

Mission 083-ND-28-XX-LOUGA (1954)
(S 1/4 of coverage)

Mission 084-ND-28-XXI-LINGUERE (1954)
(SW 1/4 of coverage)

BAKEL-KEDOUGOU

Mission 072-ND-28-VI-KEDOUGOU (1954)

Mission 077-ND-28-XII-DALAFI (1954)

Mission 058-ND-28-XVIII-BAKEL (1952)

Mission 058-ND-28-XXIV-SELIBABI (1952)
(Coverage E of Sénégal R)

Mission 044-ND-29-VII-KOSSANTO (1952)
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Mission 041-ND-29-I-KENIEBA (1952)
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Paris, France

Kayar; (Dakar et Environs); 1:50,000
W 17° 00'-17° 15', N 14° 45'-15° 05'
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Thiès; (Dakar et Environs); 1:50,000
W 16° 50'-17° 00', N 14° 40'-14° 55'
IGN; 1956

CENTRAL SENEGAL

Kaolack; ND-28-6; 1:250,000
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USAMS; 1958

Koutiaba; ND-28-7; 1:250,000
W 13° 30'-15° 00', N 14° 00'-15° 00'
USAMS; 1955

Louga; ND-28-2; 1:250,000
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Yonoféré; ND-28-3; 1:250,000
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USAMS; 1955

Kaffrine; ND-28-XV; 1:200,000
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Louga; ND-28-XX; 1:200,000
W 16° 00'-17° 00', N 14° 00'-15° 00'
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Thiès; ND-28-XIV; 1:200,000
W 16° 00'-17° 00', N 14° 00'-15° 00'
IGN; 1961

Yang Yang; ND-28-XXI; 1:200,000
W 15° 00'-16° 00', N 15° 00'-16° 00'
IGN; 1957

BAKEL-KEDOUGOU

Bakel; ND-28-8; 1:250,000
W 12° 00'-13° 30', N 14° 00'-15° 00'
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Dialocoto; ND-28-12; 1:250,000
W 12° 00'-13° 30', N 13° 00'-14° 00'
USAMS; 1955

Carte géologique de la Presqu'île
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W 17° 22'-17° 35', N 14° 40'-14° 48'
BRGM; 1951

CENTRAL SENEGAL

Thiès-O; ND-28-XIV-O; 1:200,000
W 16° 30'-17° 00', N 14° 00'-15° 00'
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