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GAMBIA

UNITED NATIONS
DEPARTMENT OF TECHNICAL
CO-OPERATION FOR DEVELOPMENT

# PRELIMINARY INVESTIGATION OF GROUND-WATER AND EXPERIMENTATION OF PUMPING SYSTEMS

## Project Findings and Recommendations

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# REPORT FACT SHEET

Country: GAMBIA

Date: 9 June 1986

Project title: Preliminary Investigation of Groundwater and Experimentation of Pumping Systems

Agency: United Nations

UNDP project number: GAM-82-T01

Title of report and number of volumes: Preliminary Investigation of Groundwater and Experimentation of Pumping Systems

Author: United Nations
(Agency or subcontractor)

Place and date of publication: New York, 1986

Language(s): English

Total print run: 100

Transmitted to the Government:
- [ ] by UNDP
- [ ] by Agency — Date: 9 June 1986
- [ ] by contractor — Date:

Number of copies delivered to the Government: ______

Derestriction requested:
- yes [XX]
- no [ ]

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- Agency Terminal Report [X]
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# PRELIMINARY INVESTIGATION OF GROUND-WATER AND EXPERIMENTATION OF PUMPING SYSTEMS

GAMBIA

Project findings and recommendations

Prepared for the Government of Gambia
by the United Nations
Department of Technical Co-operation
for Development
acting as executing agency for the
United Nations Development Programme

New York, 1986

## NOTES

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Abbrevations used:

| | | |
|---|---|---|
| AB | - | base line designation in mapping |
| AC | - | alternating current |
| A/C | - | Area Council |
| ADC | - | amperes of direct current |
| A.S.L. | - | above sea level |
| CEB | - | conductive electrical basement |
| CGG | - | Compagnie Générale de Géophysique |
| C.R.E.S. | - | Centre Régional pour l'Energie Solaire |
| DC | - | direct current |
| DRU | - | deep resistive unit |
| EC | - | electrical conductivity |
| ES | - | electrical soundings |
| IFSTD | - | Interim Fund for Science and Technology for Development |
| ILH | - | interlying layers of higher resistivity |
| ILL | - | interlying layers of low resistivity |
| km/sec | - | kilometers per second |
| $kW/m^2$ | - | kilowatts per square meter |
| m/s | - | meters per second |
| ohm.m | - | ohm meters |
| pH | - | alkalinity-acidity index |

NOTES (Continued)

PWD - Public Works Department

SL - superficial layer

SS - seismic spreads

TDS - total dissolved solids

VDC - volts direct current

WHO - World Health Organization

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## ABSTRACT WITH KEYWORDS

From February 1983 through July 1984, the United Nations, in co-operation with the Government of the Gambia and with the support of the United Nations Development Programme carried out geophysical surveys, monitored water wells and experimented with small-scale (village level) water pumping systems to introduce new technology for the exploration and exploitation of ground water. Seismic refraction surveys redefined the subsurface stratigraphy affecting aquifers. Electrical resistivity surveys proved useful in detecting salt-water intrusion of aquifers. Two experimentsl windmills demonstrated their feasibility in the Gambia. An experimental photovoltaic pumping installation demonstrated its feasibility if the equipment were less expensive.

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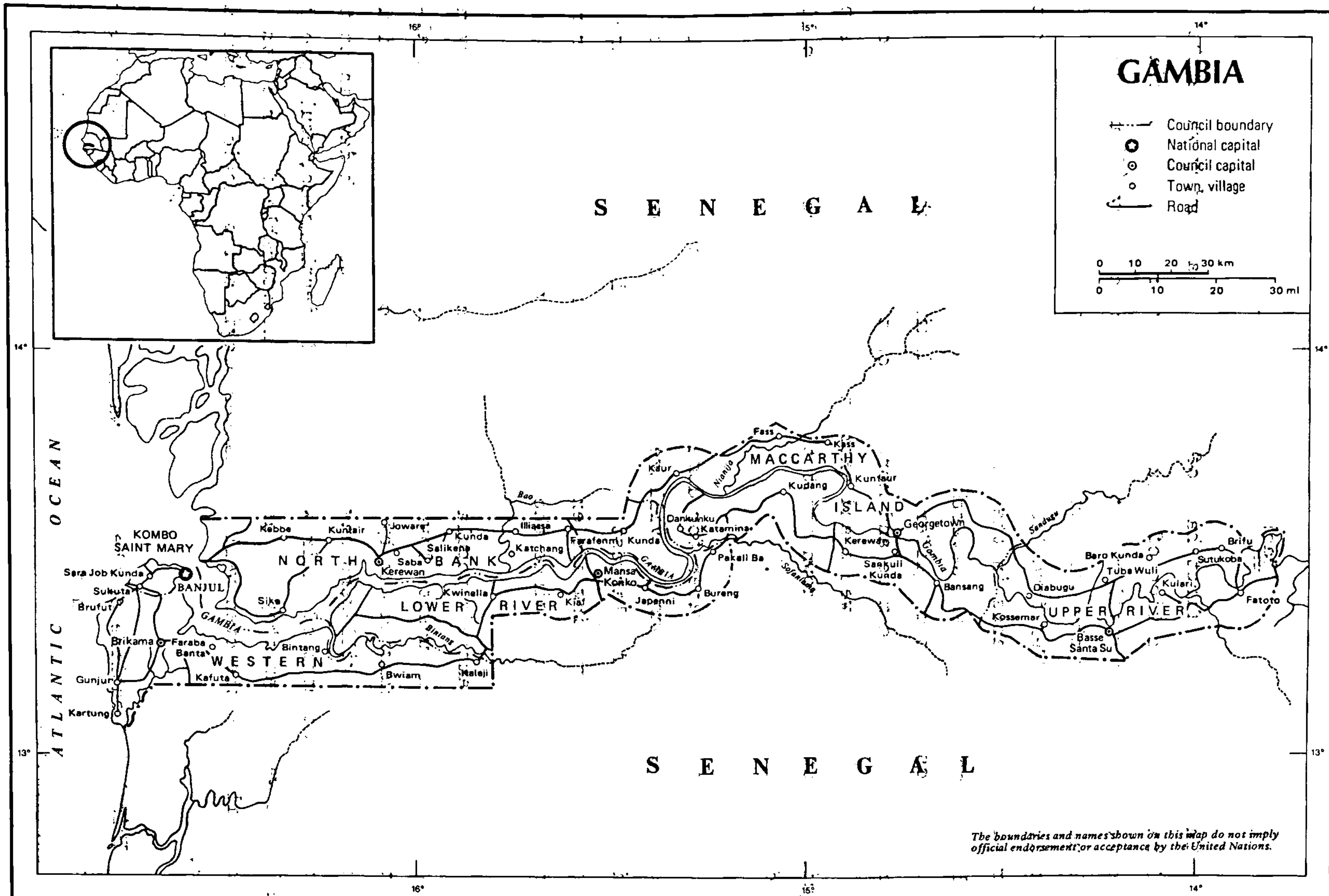


MAP NO. 3081 Rev.1 UNITED NATIONS
APRIL 1981

FIGURE 1

# INTRODUCTION

## Background and logic

The Gambia in the first half of the 1980s is a country where the exploration and utilization of ground water have reached substantial levels; but there is still much to be done. The country (figure 1), although affected by the decreasing rainfall typical of the Sahelian region, does not suffer from lack of reserves of ground water. In fact, there are only few places in the Gambia where ground water of good quality is not available. Nevertheless, the level of the first and most exploited aquifer has been sinking for the last several years. It is becoming more and more difficult and expensive to reach the water table, to dig wells and extract water. There are other, deeper aquifers, but little is known about them, especially one believed to lie at depths of 200 m and more.

The use of ground water for domestic supply as well as for cattle watering in Gambian towns and villages is common, but water piping is limited to only the few largest towns. Oil and electricity, which are used as energy for pumping are expensive: and their supply is far from being without problems, since the Gambia has only limited resources.

Most of the Gambia's population relies upon the most rudimentary means to draw water -- in buckets lowered with a rope. This hard work is almost exclusively carried out by women. Owing to this slow and laborious procedure, Gambian villagers have little water to use each day, in spite of the fact that most of their wells, if sufficiently deep, could yield much more water than they now use. Another unfavourable factor is the vulnerability of the open wells to bacteriologic and biologic contamination.

This brief outline of the ground water situation in the Gambia gives an idea of what is most necessary in the field of ground water exploration and exploitation:

- Evaluate the ground water resources of the country: for this, objective, detailed geologic and hydrogeologic studies must be carried out, based on field surveys including the drilling of exploratory boreholes.

- Replace traditional wells, which are inadequate and a hazard to health, with modern wells and boreholes.

- Find appropriate ways for pumping and distributing water from wells and boreholes. Since 90 per cent of Gambia's population live in villages without electricity, the most difficult problem is the replacement of rudimentary methods of drawing water with technology enabling water distribution on a larger scale, yet independent of the usual petroleum-based generation of energy.

Any project dealing with ground water in the Gambia has to meet the problems mentioned above, although not all can be solved by one project or at the same time. Some of them were subject to works of the Interim Fund for Science and Technology for Development (IFSTD): the Gambian Government financed project GAM-82-T01, Preliminary Investigation of Ground Water and Experimentation of Pumping Systems.

## Objectives

The main objective of the project was to introduce new technology for both exploration and exploitation of ground water. The word new must be taken as " new in the Gambia". In retrospect, a really significant achievement of the project was the determination of whether or not the tested technology is amenable to conditions in the Gambia. In parallel with introducing technology, the project aimed to make a contribution to the hydrogeologic reconnaissance of the Gambia.

In concrete terms, the objectives of the project fall into two groups, in accordance with its two-fold title:

1. Preliminary ground water investigation: Here the newly introduced technology was geophysical surface survey, not previously used in

the Gambia. A thorough monitoring of wells in the areas where geophysical survey took place was an additional activity which was to extend the hydrogeologic knowledge and documentation of the Gambia.

2. Experimenting with pumping systems. The adoption of systems for using alternative energy for ground-water pumping was a main objective; consequently, the testing of introduced systems was envisaged as well as training of local staff for their use and maintenance.

## IFSTD and Government input

The international personnel component of the project was represented by a Team Leader who stayed in the Gambia during the whole time of project implementation (February 1983 - July 1984). Two consultants, one for solar energy and the other one for wind energy spent two weeks each in the Gambia. Two geophysicists, responsible for carrying out subcontracted work in the field of geophysics worked in the Gambia from May to July 1983. The Gambia counterpart component has been represented in all decisions important for the project by the Director of the Department of Water Resources. The full-time national staff of the project was represented by three trainee-assistants and two drivers.

Other persons and groups from the Department of Water Resources, worked for the project occasionally: a survey group, a chemist-analyst, and labourers at the installations. The lack of specialists within the project (no Gambian civil engineer nor hydrogeologist was available) was partly compensated by collaboration with ongoing project GAM-82-008 especially by the occasional participation of a civil engineer of this project on the most urgent tasks during the first half of 1984. All equipment, including vehicles as well as the geophysics subcontract were provided by IFSTD. The Department of Water Resources contributed office and workshop facilities, and fuel for project vehicles.

# I. ACTIVITIES

## A. Programme review and work plan

The project became operational in February 1983 with arrival of the Team Leader, Mr. V. Plesinger, to the Gambia, although a consultant in solar energy had visited the area in November 1982. In view of the relatively short time given for project implementation, 14 months, it was necessary to start field work immediately. Providing logistic support for geophysical prospection was found especially urgent because the survey had to be completed before the rainy season. At the same time, the programme of activity had to be reviewed and a new work plan prepared. A preliminary work plan had been worked out in the Rural Water Supply Division in 1982; but it was not realistic in the light of time alloted and limited resources available to the Department of Water Resources in 1983-1984.

A new work plan was approved in May 1983. It was followed, with one exception caused by a delay in the supply of photovoltaic equipment for a pilot pumping installation. This delay was the main reason for extension of the Team Leader in the Gambia to July 1984. The following are the activities provided in the work plan (the actual time of implementation is given in parentheses):

1. Preparation of logistics for geophysical prospecting (February 1983 - July 1983)
2. Geophysical prospecting and interpretation of results (May 1983 - December 1983)
3. Ground water monitoring (May 1983 - June 1984)
4. Evaluation of results of ground water monitoring (July 1983 - July 1984)
5. Site investigation for solar and wind pump installations (February 1983 - March 1984)
6. Design and installation of pumping stations (August 1983 - May 1984)

7. Evaluation of pumping possibilities (December 1983 - July 1984).
8. Preparation of reports (April 1983 - July 1984).

## B. Output

Three main activities of the project produced results exploitable immediately or in the near future: geophysical survey, ground water monitoring, and introduction of windmill and photovoltaic pumping stations.

Geophysical prospecting carried out by the Compagnie Générale de Géophysique (CGG), France, under subcontract CON 6/83, was the first-ever surface geophysical survey by electrical resistivity and seismic refraction methods in the Gambia. It not only clarified the geology and hydrogeology of five different areas of the Gambia, but also indicated the method to follow in further geophysical investigation.

Ground water monitoring of the network of dug wells in three different areas of the Gambia contributed greatly to knowledge of the phreatic aquifer used for water supply throughout the country. Observations over a year enabled us to calculate recharge and discharge, and to assess the correlation between rainfall and fluctuations of the water table. The levelling of well orifices made possible contour maps of two different areas having greater accuracy than any previous attempts.

Installation of pumping stations using alternative sources of energy provided the most significant results. Three such stations were built in different parts of the Gambia and equipped with necessary instrumentation. All of them supply water for villagers, while serving as pilot points for measuring efficiency and testing adequacy. Two of these installations are windmills, the third is photovoltaic.

The demonstration of high efficiency from certain types of windmills under Gambian conditions may be the most important achievement of the project. Before they were mounted, there was no windmill in the Gambia and the country was considered unsuitable for them owing to alleged low wind speed.

## C. Training

Three graduates of Gambian high schools were trained while working on the project. For two of them, the training was preparatory to a fellowship. Mr. Alhaji Jabbi assisted with the installation of both the windmill and photovoltaic stations. A fellowship was prepared for him in the United States, aimed at deeper understanding of photovoltaic installations. Mr. Giran Corr was trained to operate geophysical instruments. For this purpose, he took part in all geophysical work carried out by CGG in the Gambia during 1983. The project budget could not provide him with a fellowship as originally planned. Nevertheless, the idea was not cancelled, and other possibilities for a fellowship were subsequently studied within a succeeding project, "Rural water supply and ground-water development" (GAM-82-008). Mr. Baboucar N'Jie was trained in data collection, ground-water monitoring and interpretation of results of observations.

During the construction of the windmills, photovoltaic station and water-storage tanks, several employees of the Department of Water Resources were present, in part for training purposes.

## D. Reports

The following reports were produced during the project:

1. Monthly reports on project GAM-82-T01: March 1983 - June 1984 (by Team Leader)
2. Project Progress Report: February 1983 to July 1983 (by Team Leader)
3. Project Progress Report: August 1983 to January 1984 (by Team Leader)
4. Initial Photovoltaic Systems for Ground-water Pumping at Mandina Ba and Welingara (by Daniel Starley, Consultant, November 1982)
5. Report on Consultancy Visit on Water Pumping Windmills (by Peter L. Fraenkel, Consultant , May 1983)

6. Supplementary Report on Solar Photovoltaic Water Pumps (by Peter L. Fraenkel, Consultant - May 1983)
7. Progress Report of Geophysical Prospection (by Philippe Cremiere, Team Leader of Expert Team of CGG - June 1983)
8. Geophysical Survey of the Gambia Using Electrical and Seismic Methods (Final report of CGG - December 1983)

Data and information from at least three of those reports (5, 6 and 8 above) have been incorporated into this report of project findings and recommendations, and accordingly are also included in References cited.

## II. ACHIEVEMENT OF IMMEDIATE OBJECTIVES

### A. General

The brief time between finishing most activities of the project and its definitive end made it virtually impossible to produce separate technical project reports about the respective activities, different as they were. The only exception is the full report on geophysical prospection prepared by CGG. The other main activities - ground-water monitoring and installation of pumping stations with evaluation of their possibilities - are covered in this text. As far as geophysical prospecting is concerned, the detailed information is provided by the above-mentioned report, and this present text adds only comments and observations.

To have a clear view of the results of the project activities, each is analyzed separately in the following order:

1. Geophysical prospecting
2. Ground-water monitoring
3. Installation of windmill pumping stations
4. Installation of photovoltaic pumping stations

### B. Geophysical prospecting

Geophysical surveys of selected areas of the Gambia took place between 5 May 1983 and 25 July 1983. These were carried out under contract to Compagnie Général de Géophysique (CGG) of France. Two specialists with the equipment for both electrical resistivity and seismic refraction made field surveys in the Gambia throughout the period mentioned. They were assisted by Gambian labourers, hired directly by CGG. The results of the field survey are presented in the final report of CGG, Geophysical survey of the Gambia using electrical and seismic methods, December 1983. Since this detailed report is available for reference, we concentrate here only on complementary information, and some relevant observations concerning the geologic and hydrogeologic reconnaissance of the country.

1. Methods

Two methods of surface geophysical survey which are most important for hydrogeology have been used: electrical resistivity (electrical soundings (ES) and seismic refraction (seismic spreads (SS).

Electrical soundings were carried out in five profiles: one in the western part of the country(Brikama-Gunjur, figure 2), two in the central part (Kwinella-Soma and Farafenni-Missira, figure 3), and two in the eastern part (Bansang-Sankuli Kunda and Sabi-Basse-Jar Kunda, figure 4). One electrical sounding was carried out every kilometer along these lines. An AB (base) line 2,000 meters long was applied to most electrical soundings, a few were shorter (1,000 or 1,500 m). The total number of soundings in our profiles was 148. In addition, 11 other soundings were made for calibration purposes near existing boreholes.

Seismic spreads, each calling for 7 shot points and 24 geophones, were carried out in select parts of the above-mentioned profiles except Bansang-Sankuli Kunda. In those spreads which were 690 m long (15 in total) each two geophones were 30 m apart, in those which were 345 m long (3 in total) the geophones were 15 m apart.

2. Staff participation in geophysical work

The regular (non CGG) staff of the project participated in the geophysical work as follows:

1. Preparation of geologic and hydrogeologic background for geophysical survey

2. Selection of areas to be investigated

3. Collection of such relevant documentation, as geographic maps and borehole logs

4. Laying out profiles in the field; this included levelling of some points and clearing where the bush was too dense.

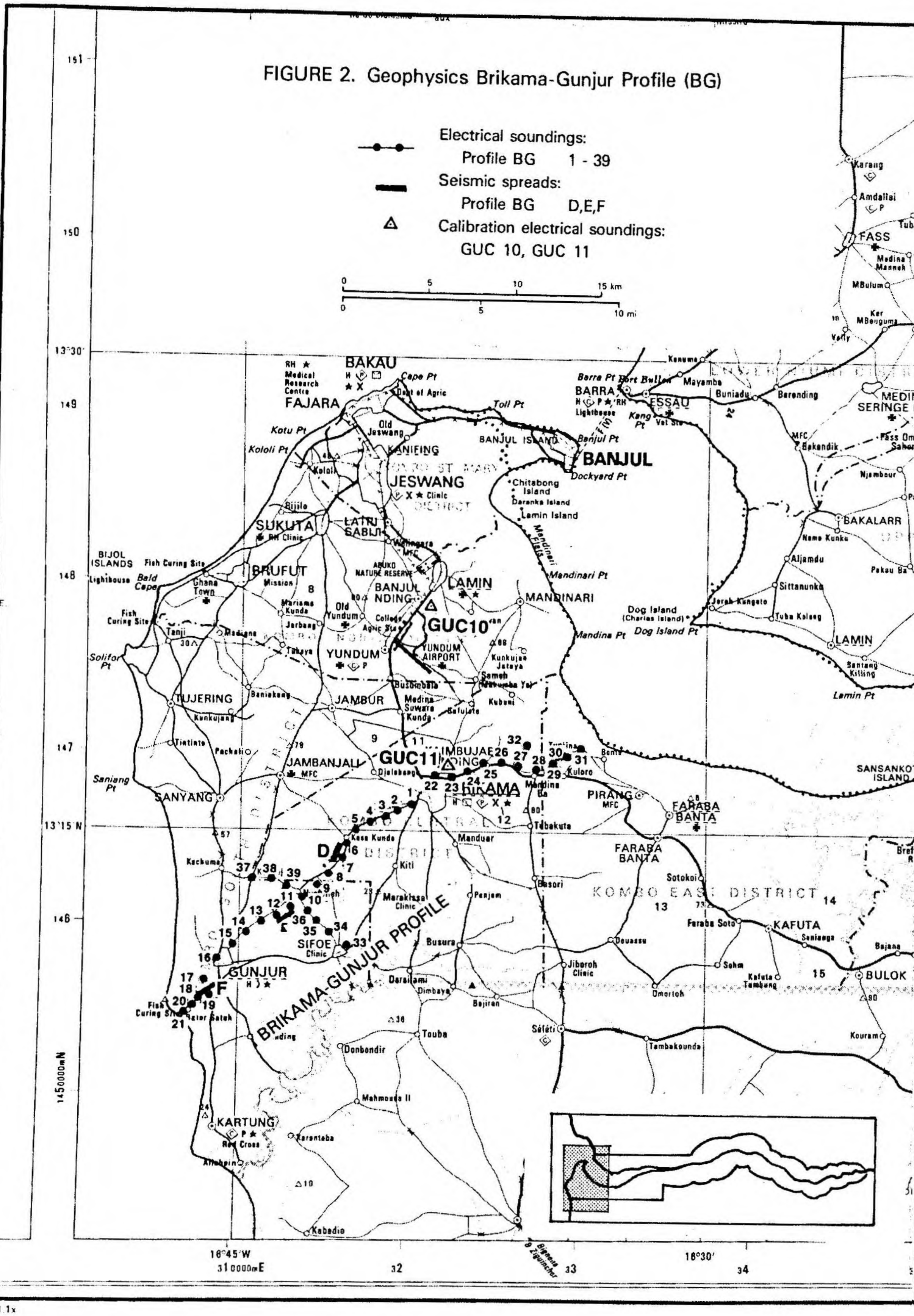


FIGURE 2. Geophysics Brikama-Gunjur Profile (BG)

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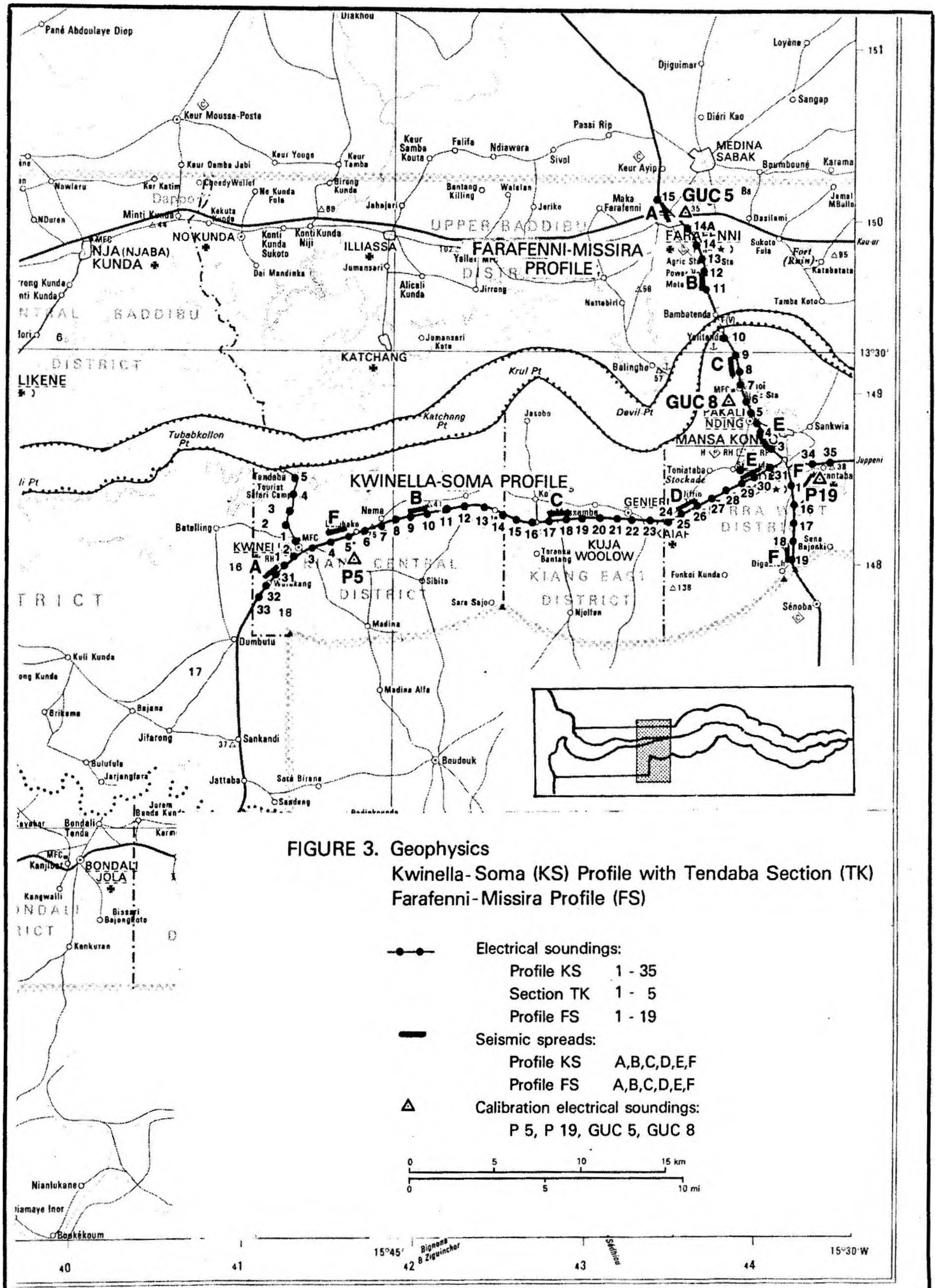


FIGURE 3. Geophysics
Kwinella-Soma (KS) Profile with Tendaba Section (TK)
Farafenni-Missira Profile (FS)

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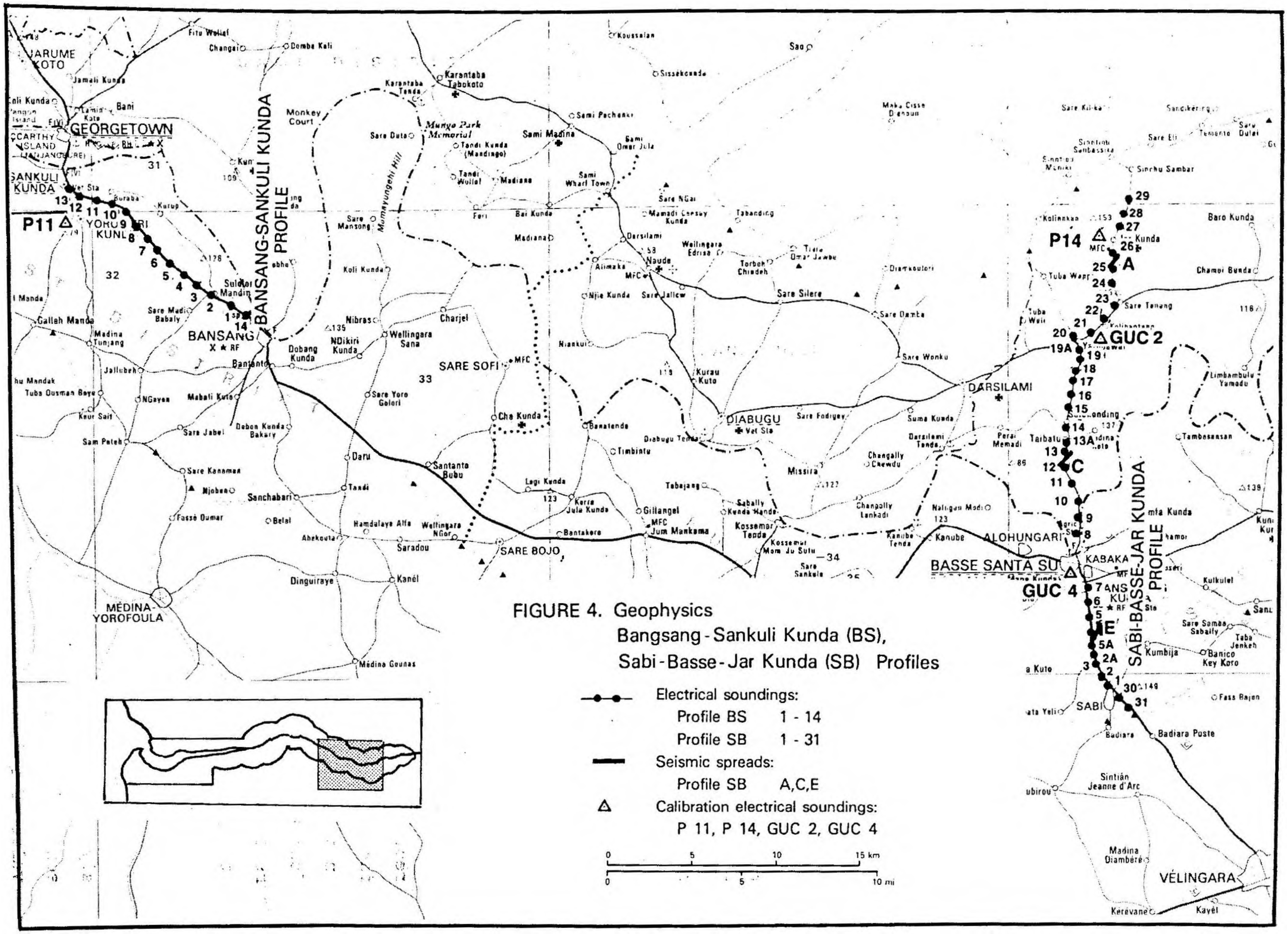



FIGURE 4. Geophysics
Bangsang-Sankuli Kunda (BS),
Sabi-Basse-Jar Kunda (SB) Profiles

Electrical soundings:
Profile BS 1 - 14
Profile SB 1 - 31
Seismic spreads:
Profile SB A,C,E
Calibration electrical soundings:
P 11, P 14, GUC 2, GUC 4

3341.3x

5. Consultation between the project Team Leader and the CGG specialists during field work; in several cases, these resulted in modifications to the programme. The most important was cancellation of several seismic spreads, and their replacement by electrical soundings in the Bansang-Sankuli Kunda area. New transverse profiles Sifoe-Kunkujang (Brikama-Gunjur area) and Kwinella-Tendabe (Kwinella-Soma area) were other results.

6. Commenting on a draft of the Final Report of CGG. The comments were worked out by the Team Leader in collaboration with the expert staff of the project GAM-82-006.

7. One Gambian trainee took part in all field operations, as well as that part of the elaboration of the results which took place in the Gambia.

## 3. Scope of methods

Since there has not been any geologic or hydrogeologic survey carried out with deep boreholes in the Gambia (except for a limited part of the Kombo Peninsula), the main result expected from the surface geophysical survey was to obtain more information about deeper parts of stratigraphy. The other two kinds of information expected were: to what extent the results of the geophysical survey can be utilized for hydrogeologic work in shallower parts of the subsurface (most dug wells in the Gambia being not deeper than 35 m, drilled wells not more than 100 m), and how suitable the methods are for detection of salt-water intrusion.

The electrical soundings proved to be a source of information the reach of which is as deep as 300 m. The discovery of a continuous surface dividing the rocks of higher resistivity (DRU, Deep Resistive Unit in the CGG final report) from those of higher conductivity (CEB, Conductive Electrical Basement in the CGG final report) is one of the real immediate achievements of the surface geophysical survey of CGG. The other one is delimitation of areas the groundwater composition of which is influenced by sea water intrusion.

The results of the seismic refraction survey are, however, of less significance. Although the final report of CGG says the quality of the seismic records is good for the whole survey, this is not true for the value of information obtained. One principal achievement is negative:

there are no markers (layers with considerably different velocity of propagation of seismic waves, compared with overlying and underlying layers) in the Gambian subsurface down to approximately 250 m. In other words, little or none of the data from the seismic refraction surveys contributes to our knowledge of the hydrogeology.

It was because of the lack of results from seismic spreads that it was decided to replace at least a part of them with electrical soundings. Accordingly, the new profile of electrical soundings in the Bansang-Sankuli Kunda area was taken.

## 4. Shallow subsurface

We consider as shallow those sedimentary layers reached by existing drilled and dug wells: that means from the surface to approximately 100 m in depth. In these parts we can compare the results of the surface geophysical survey with well logs.

The composition of the superficial layers differs from point to point, yet generally sediments of continental origin (fluviatile and aeolian) can be found in almost all of the Gambia. They create sequences of sand, silt and clay with occasional limestone bands and a characteristic surface layer of laterite.

The geologic age of these series is recent, Pleistocene and Pliocene. The base of the complex is mostly clay of Pliocene age. But much of the underlying series, which are a produce of Miocene marine sedimentation are clays and marls. It is thus difficult to know whether boreholes 80-100 m deep have reached the Miocene layers, or are still in Pliocene.

From the hydrogeologic point of view, what is important is that under these more or less clayish series there are sequences of clastic sediments (sand, sandstone), mostly probably of Miocene age. The hydrogeologic scheme of the shallower parts of the Gambian subsurface strata can thus be generalized as follows:

1. From the surface to 5 - 35 m an unsaturated zone, underlain by,

2. A phreatic aquifer consisting of 10 - 40 m of permeable sediments, underlain, though not everywhere, by
3. An aquitard or aquiclude of thin (few cm) to 30 m of semipermeable or impermeable sediments, over
4. A semiconfined or confined aquifer of differing thickness.

Where the aquiclude (3 above) is not present as proved by a few boreholes, there is no reason for considering two aquifers (2 and 4 above) and the existence of only one, phreatic, is justified.

Geophysical surface investigation did, however, provide some new information about these relatively shallow parts of subsurface (figure 5).

The first concerns the surficial layers (SL in the CGG final report). The thickness of the surficial layers of SL ranges from 10 to 35 m. They represent, almost without exception, the most electrically resistant parts of a vertical section (1,000 to 50,000 ohm meters). The passage to lower resistivities at 10 - 35 m is obviously a signal of interference by the water table. In the case of seismic spreads, the zones of low velocity of seismic waves (0.5 to 1.6 km/sec) which were common at the same depths (from the surface to 10 - 35 m) have the same significance. However, higher velocities occur in places within this zone. These have been interpreted as laterite layers of considerable thickness.

The information about layers underlying the surficial layers (SL of CGG) is less consistent and the interpretation can be ambiguous. What is called the Deep Resistivity Unit (DRU) in the CGG report may be interpreted as a complex with predominantly sandy components, and thus a potentially good aquifer thickness of 100-200m). But this complex probably contains many more differentiated rock sequences, some of which would be less favourable for ground-water flow. The upper parts of DRU may correspond to Miocene sand and sandstone; but farther down, marl and limestone should prevail, characteristic of Eocene marine sediments, as in adjacent parts of Senegal (Kruger, Etude Hydrogéologique du Casamance).

In most parts of the profiles for western and central Gambia, and

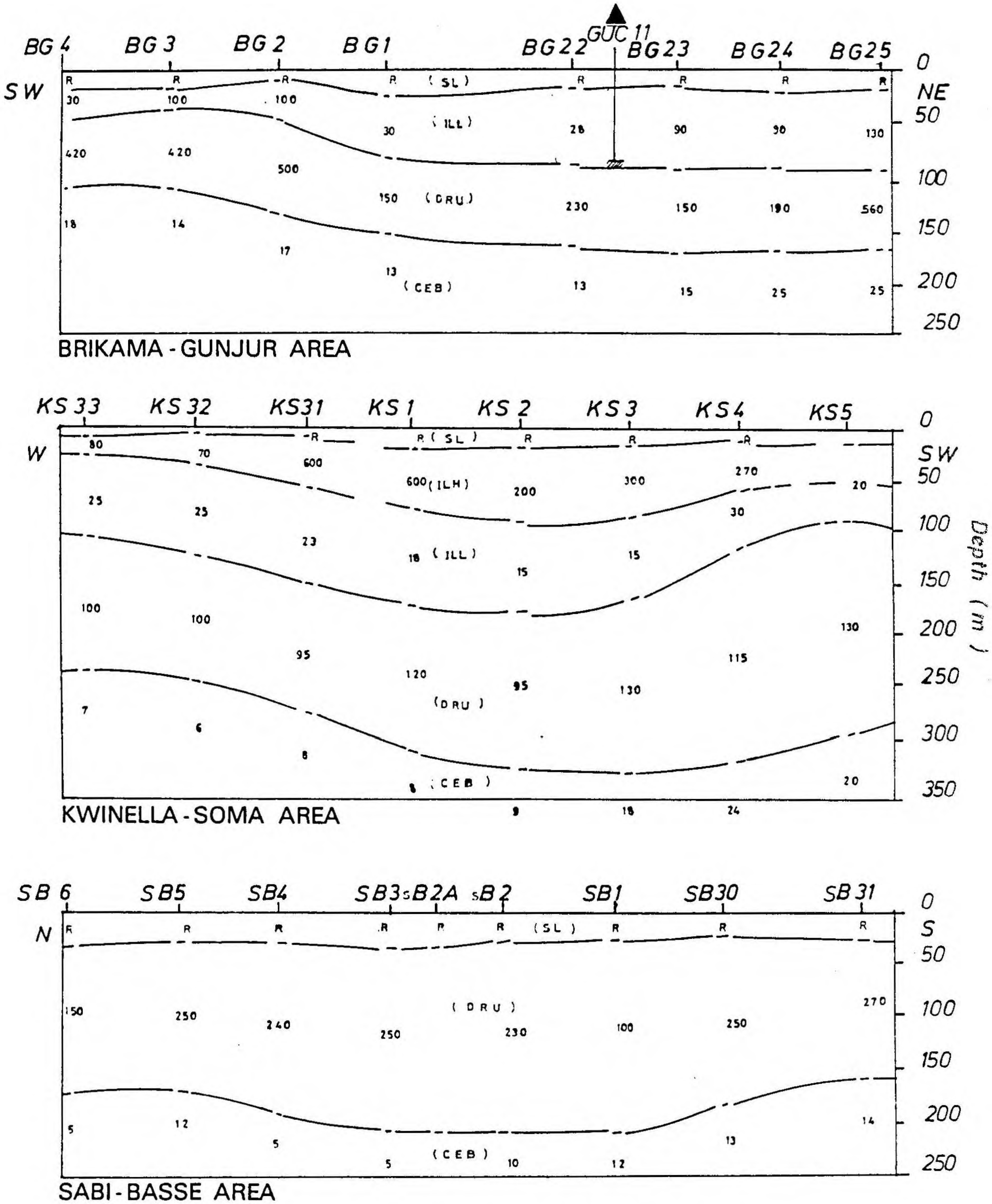



FIGURE 5. Resistivity profiles in different areas (electrical soundings)

R - River deposits
SL -- Surficial Layers of high resistivity
ILL - Interlying Layers of Low resistivity
ILH - Interlying Layers of Higher resistivity
DRU - Deep Resistivity Unit
CEB - Conductive Electrical Basement
100' Resistivity in ohm-m
▲ Location of well near the line

the profile for the northern part of Basse, a more conductive electrical unit lies between SL and DRU, its resistivity ranging from 10 to 150 ohm meters and thickness from 20 to 100 meters. This part of the sedimentary complex is anisotropic, and the change in resistivity indicates either sand or clay predominance in the Pliocene-Pleistocene series. There is, however, no reason to deny that these changes of resistivity might be related to changes of ground-water chemical composition.

5. Deeper subsurface

Two units are characteristic for deeper parts of all areas studied. We have already mentioned the Deep Resistivity Unit (DRU) of CGG which can reach depths of 300 m and more (near Kwinella central). However DRU typically lies up to 250 m. Secondly, we have the deeper underlying Conductive Electrical Basement (DEB) of CGG. The boundary between these two units is strongly marked in all parts of electrical profiles carried out by CGG except for those influenced by salt water intrusion. While the overlying DRU has resistivities ranging from 100 to 500 ohm-m, the resistivity of the underlying CEB reaches in few places as little as 30 ohm-m.

Demonstration of such a clearly pronounced limit can be considered as the main achievement of the latest geophysical survey. Nevertheless, neither geologic nor hydrogeologic interpretation of the phenomenon can be definitive with no documented borehole at our disposal. The problem is that the resistivity range from 100 to 500 ohm-m may characterize both sandstone and limestone. The latter, in the form developed in adjacent parts of Senegal, do not provide adequate conditions for a good aquifer. Conditions in the Gambia, especially in its southern part, are probably similar to those of Casamance. In that case DRU corresponds to upper Eocene limestones and marly limestones, and it does not have the hydrogeologic potential suggested by CGG in its final report. The boundary between DRU and CEB should mark an abrupt change in the petrography of the sedimentary complex. Such a change would most likely be thick layers of plastic marl, in the middle and lower Eocene beds of Casamance. Seismic waves propagate in similar velocities in both limestone and marl: and that is why it was impossible to identify this abrupt lithologic change by seismic refraction.

An important aquifer of West Africa is in Maestrichtian complex (uppermost rocks of Late Cretaceous age). This stratigraphic unit with predominantly sandy sediments should underlie the Tertiary complex throughout the Gambia. Unfortunately, the geophysical survey gave no evidence of the Maestrichtian sandstones whatsoever. They had been expected principally in the Basse profile, and especially in its Basse-Sabi part; there are indications from nearby localities in Casamance (Welingara 10 km from Sabi, Badion 25 km from Basse) that the roof of the sandstone formation is less than 200 m beneath the surface.

## 6. Salt-water intrusion

In two areas salt water intrusion was studied: one near the coast on the Brikama-Gunjur profile, and the other along the river Gambia in the Farafenni-Missira profile. An additional transverse profile from Kwinella to Tendaba was made to test for the presence of salt water near the river. As was supposed, it was the electrical resistivity method that brought good results in testing for salt intrusion, because the resistivity of layers is highly sensitive to the salt content of water. Wherever the resistivity of the superficial layers is less than 15 ohm-m, salt or brackish water can be inferred. Similar resistivities are characteristic for CEB, but the CGG results clearly show that we are unlikely to encounter CEB closer than 100 m beneath the surface in any part of the Gambia.

Because there can be no plausible explanation for low resistivity within 100 m of the surface other than salt water, electrical soundings can be useful for the delimitation of salty and brackish ground water both along the coastline, and along the river and its tributaries. Only the lowest resistivities (under 5 ohm-m) should be interpreted as indicating real salt water; those between 5 and 15 ohm-m mostly characterize brackish water.

An instructive case of the delimitation of the salt-brackish water in sediments can be found on the Farafenni-Missira profile (figure 6) between the electrical soundings FS 6 and FS 7. The superficial layers (SL) have a high resistivity typical of most Gambian territory. Underlying them, there is a thin layer whose resistivity ranges from 12 to 60 ohm-m, corresponding probably to some clayish part of the Pliocene-Pleistocene sequence. Higher resistivities come in what is probably sand. This is obviously a water-bearing formation with good, non-salty water. Suddenly at about 70 m depth at point SF 7, and about 90 m at point SF 6, the resistivity falls to only 6 and 10 ohm-m respectively. Because these low figures cannot indicate CEB at such shallow depth, they indicate conductive brackish water with a high salt content. This is confirmed by the results of borehole GUC 8 in Jenoi, not far from the profile line. The bottom part of this 81-m-deep drilled well had to be sealed off because of brackish water intrusion.

Regardless of the irregular permeability, it is clear that the interface, or zone, dividing salt water from fresh water extends from the surface bodies of salt water to the bottom of the semi-confined aquifer, being much larger near this bottom than near the water table or piezometric head. Fresh ground water thus overlies brackish and salt water up to a certain distance from the surface salt water bodies. Surface geophysics can, thus, be helpful in the delimitation of the depth and the extent of the interface, which is a basic hydrogeologic task for a considerable part of the Gambia.

## C. Ground-water monitoring

### 1. Background

The phreatic aquifer in the Pliocene-Pleistocene sedimentary series is the most widely used source of ground water in the Gambia. The importance of a most detailed reconnaissance of this aquifer is obvious, especially if we consider that extraction of water will be continually increasing.

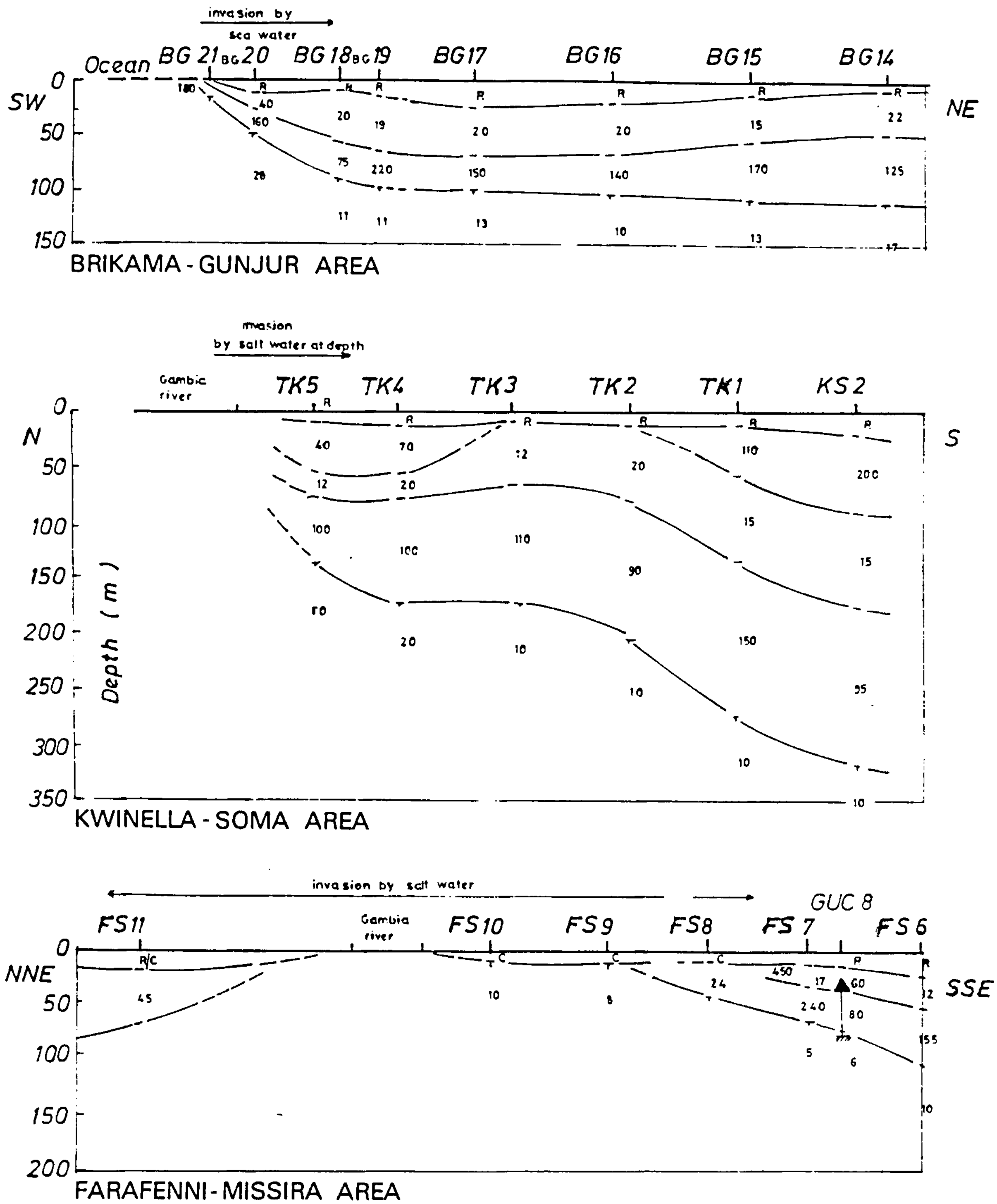



FIGURE 6. Resistivity profiles, salt-water intrusion

100 Resistivity in ohm-m
▲ Location of borehole near the line

## 2. Selection of wells

A total of 90 wells were monitored: 29 in the Brikama-Gunjur area, 37 in the Kwinella-Soma area, and 24 in the Sabi-Basse-Jar Kunda area. Wells were selected to cover each area as regularly as possible, so there was usually only one well selected in each village. If there was considerable distance between villages, a search was made for some intermediate well possibly put in for gardening or irrigation. This method of selection influenced the kind of wells monitored. The Gambia being virtually a country of dug wells with a density of more than one well per square kilometer, diversity in the way the wells were constructed is considerable.

Almost all wells dug by villagers belong to the category of traditional wells. They are unlined, with the wet-dug part only about 1m below the water table. Frequent redigging is usually necessary for their continued existence. There are also cement-lined wells. First, in the so called Public Works Department (PWD) wells, which pioneered a modern method of construction with lining but which rarely reached more than 1.5 m below the water table, the only entry of water is through the bottom. Second are Area Council (A/C) wells which introduced side-entry by perforation in caissons: the depth of these is the same as for PWD wells. Third, so-called United Nations (UN) wells: produced as part of a UNDP-UNICEF project, wherein modern mechanization has been used to enable deeper wet-digging. It is, however, difficult to understand why so few of them have a water column greater than 2 m.

The most reliable rule for a monitoring programme would be to use only modern cement-lined wells with a column of water of at least 4 m. Such wells, however, are still so rare that it is impossible to find enough to provide a satisfactory network. There were thus 45 lined and 45 traditional wells monitored; 18 of the 45 lined were UN wells: but only 7 had more than 2 m of water and only one more than 4 m.

All monitored wells were open and none were equipped with a pump. The only extraction of water from those wells is by buckets and other vessels on a rope. Pulleys are not commonly used in the Gambia. Our observations are that it is rarely possible to extract more than 2000 liters in an hour using this rudimentary method. Although such an extraction rate (0.1 liter per second) might occur only for two or three hours a day, we tried to avoid the most heavily used wells, since the water level in them fluctuates considerably.

## 3. Technical data

The interval between two measurings was one month in the Brikama-Gunjur area and one, two or three months in the other two areas. The first data were collected in May - June 1983, the last in June 1984. A period was, thus, covered from the end of the 1983 dry season through the 1983 rainy season, and then up to the end of the 1984 dry season.

Field measurement of temperature, electrical conductivity and acidity were carried out in the same time as water-level measurings, but with less frequency. Chemical analyses of samples taken from the selected wells were carried out during the first phase of monitoring. Six samples from different wells were analyzed from each area, so that the total number of analyses was 18. All wells in the Brikama-Gunjur area and almost all wells in the Kwinella-Soma area were levelled - 62 wells in all. The point, the altitude of which was levelled, is always the highest edge of the parapet of the well.

During their travel through the Gambia, the staff of the project took a number of measurements on the wells outside the three areas mentioned. These were mostly aimed at comparing previous records (some of them as long ago as 1973) with the present state. The altitude of 8 wells lying outside the three areas was measured to give a basis for the estimation of the altitude of the water table in different places of the Gambia.

## 4. Fluctuation of water level

None of three areas studied was significantly influenced by pumping either for potable water supply or for irrigation: the variations of ground-water levels may be thus generally correlated with climatic data with no error ensuing from major artificial discharge. The water level in most wells, however, varies within a certain range each day, in response to daily water use. The inaccuracy arising from this fact can be hardly avoided by any monitoring programme, it being virtually impossible to measure all wells before the daily cycle of village life starts. In fact, most measurements are taken at a time of day when the level should be at its lowest. As mentioned above, our selection of wells has taken this fact into consideration, and we tried to avoid the wells really heavily used. In most selected wells, the daily variation of level is less than 0.5 m.

The recharge of the phreatic aquifer in the observed areas is due to rainfall only, excepting narrow bands adjacent to the sea in the Brikama-Gunjur area and along the river Gambia in the Kwinella-Soma area where the drawdown of the level of salty surficial water causes temporal recharge from surface water.

The reaction of the ground water level to rainfall is fast, provided that the rain is steady and substantial. Nevertheless, according to our observations, the minimum quantity of approximately 100 mm of rain per month may be considered as a necessary condition for a rise of the ground-water level in Gambian territory. Smaller amounts, as observed in June, July and October 1983 in Brikama-Gunjur area and in June and October in the two other areas, are affected by evapotranspiration and especially by balancing previous soil moisture deficit with the result that no significant amount of water can reach the water table. Taking into consideration the fact that there are only three months in the Gambia with normal rainfall commonly higher than 100 mm (July, August and September), the conclusion is that the rise of ground-water level during these three months must be three times faster than its drawdown in the other nine months, if the original level is to be reached.

## 5. Recharge of the phreatic aquifer

The average drawdown of water table during the dry season is 0.10 m per month according to our observations from 90 wells. Provided that the discharge continues on the same scale in these productive months, we therefore need a contribution of 0.4 m on each of the 3 productive months to equalize losses.

The following calculation indicates the amount of rainfall to maintain the water table at the same level from year to year in Gambian conditions.

Specific yield (the percentage of water in the rock or soil which can be drained) of the soils containing the phreatic aquifer in the Gambia is about 10 per cent, the main components being sand and silt. To raise the water table by 1.2 m (12 x 0.1 m), it is thus necessary to infiltrate into the aquifer the amount of water corresponding to 120 mm of rainfall.

In the climatic and geologic conditions of the Gambia, most water falling in rain (about 75%) is taken out by evapotranspiration. The 25 per cent left is divided, more or less equally, between surface runoff (12.5%) and infiltration (12.5%). So an eight times higher rainfall (100% = 8 x 12.5%) is necessary to give us the required quantity of infiltrated water (i.e., for 1 $m^3$ of ground water in phreatic aquifer, 8 $m^3$ of water must fall in rain.) In our case, a rainfall of 960 mm is needed according to conclusions presented above (960 mm = 8 x 120 mm).

## 6. Hydrogeology of phreatic aquifer

If the rate of the drawdown of water table is some 0.1 m per month and if the average specific yield of soils which are the bed of the phreatic aquifer is 10 per cent, then from each square kilometer 10,000 $m^3$ of water disappear every month. The area of the Gambia (less rivers and swamps) being about 8,000 $km^2$, the discharge reaches about 80 x $10^6$ $m^3$ per month.

Of this amount, only a small part is due to human use of the aquifer.

The abstraction can be hardly calculated with accuracy, but it is not higher than 1.25 x $10^6$ x $m^3$ per month, even if we include human, livestock, and irrigation needs.

There are several possible explanations for what is happening to the rest of the ground water (more than 98% of it) released from the phreatic aquifer. One - evapotranspiration from the water table - can be excluded because of the depth of ground water under the surface. The second - ground-water discharge into surface-water bodies - certainly exists: as it can be seen in the maps of water table, the direction of the ground-water flow is towards the sea (Brikama-Gunjur area) or to the river (Kwinella-Soma area).

Finally, there can be leakage into the deeper aquifers, provided the piezometric surface of these aquifers is lower than the water table. The existence of this phenomenon could be proved only by detailed hydrogeologic studies based on boreholes; however, such leakage is probable, as is the drainage of these aquifers towards the sea.

## 7. Chemistry of ground water

Chemical analyses were made at the Department of Water Resources Laboratory in Abuko. Field measurements of conductivity and acidity were carried out with portable apparatus.

No significant difference in chemical composition was found in samples from western, central or eastern parts of the country. The characteristics of water of the phreatic aquifer are known from previous studies, and there were no variations during our monitoring programme.

The water of the phreatic aquifer is generally soft, with low mineral content (TDS does not exceed 100 mg $l^{-1}$ and mostly is considerably lower). The reaction of the water is without exception acid pH ranges from 4 to 6). Although most components are generally present in values which do not exceed the accepted WHO standards for drinking water, there are exceptions. Some of them do not mean directly a health hazard (e.g., acidity, higher content of iron ions, colour), being more unpleasant than dangerous. However, one really negative finding was a higher content of nitrates: in a third of the analyses they occur in such high concentration as to pose a danger for infant feeding. The nitrates can originate in decomposition of organic substance contained in soil, but their presence can also result from over-application of nitrate-based fertilizers near the wells.

Unacceptably high concentrations of ammonia are also common - a clear indication of pollution from the surface. No excessive amount of chloride ions was found even in samples taken from wells near the Atlantic or the saline estuary of the river. There were no considerable changes of electrical conductivity in samples taken from one well in various months.

Generally, the chemical character of ground water from the phreatic aquifer is another indication that the only source of water is rainfall. The relatively short distance from the surface to the aquifer, pressure and thermal conditions, as well as the composition of sediments do not provide bases for higher mineralization.

## 8. Brikama-Gunjur area

There were considerable differences among the patterns of fluctuation of ground water in western, central and eastern parts of the Gambia. The reason must be seen in different rainfall conditions during the wet season but also in the differing composition and hydraulic properties of sediments.

Brikama-Gunjur area represents the southern part of the Kombo Peninsula. In total, 29 wells on about 270 $km^2$ were observed. A representative meteorological station for the area is Yundum; the rainfall is recorded also in various villages of Kombo. All records indicate that the 1983 rainy season in the Kombo Peninsula was the weakest ever recorded. Only 416 mm of water fell in Undum which has a 37-year average of 1,138 mm. Only in August, of all rainy months, was the rainfall higher than 100 mm. The composite diagram in figure 8 shows a fluctuation pattern for the area. The figures are the averages of rise or drawdown in every month in centimeters, calculated on the basis of all recorded wells in the area. Zero-value is attributed to the month of June 1983 and corresponds to the measurements noted before the rains started.

It can be seen that there was no rise of water table in the area from June 1983 to May 1984. The only exception is August 1983 when the continual drawdown was temporarily braked; but even that recharge was very low. The rule pronounced in Chapter II, C. 4 is clearly illustrated by the second part of the composite diagram, showing rainfall in Yundum in 1983: that there is no recharge of the phreatic aquifer if the rainfall does not exceed 100 mm per month.

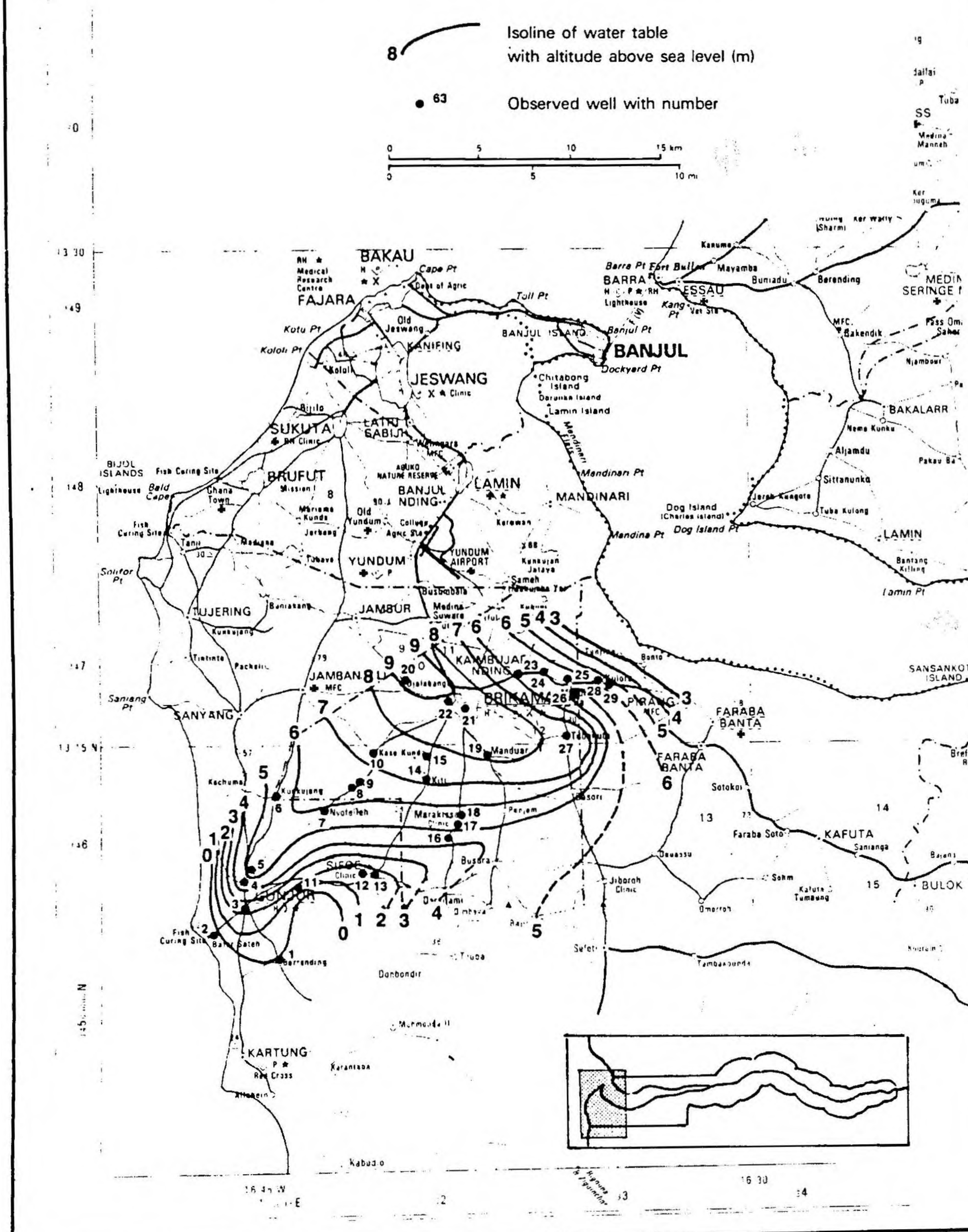
The rate of drawdown being approximately 0.08 m per month, the phreatic aquifer proves to be contained in sediments with a specific yield above average for the Gambia.

The contour map of a ground-water surface (figure 7) is constructed on the basis of the levelling of all monitored wells and corresponds to the situation in June 1983. Existence of ground water elevation around Brikama is the most pronounced feature of this map, as well as increasing declivity of the water table toward the seashore. The hydraulic gradient varies from near zero in the surroundings of Brikama to $1.5 \times 10^{-3}$ in the Gunjur area.

9. Kwinella-Soma area

The Kwinella-Soma area covers some 330 $km^2$ of south bank of the river Gambia in the central part of the country. There were 39 wells recorded here in 1983- 1984, 33 of which were levelled. Meteorological station Jenoi lies in the eastern part of the area. According to the records of this station, the rainfall in 1983 was 489 mm - the second lowest in recorded history. It rained more in the

FIGURE 7. Contour map of water table, Brikama-Gunjur area

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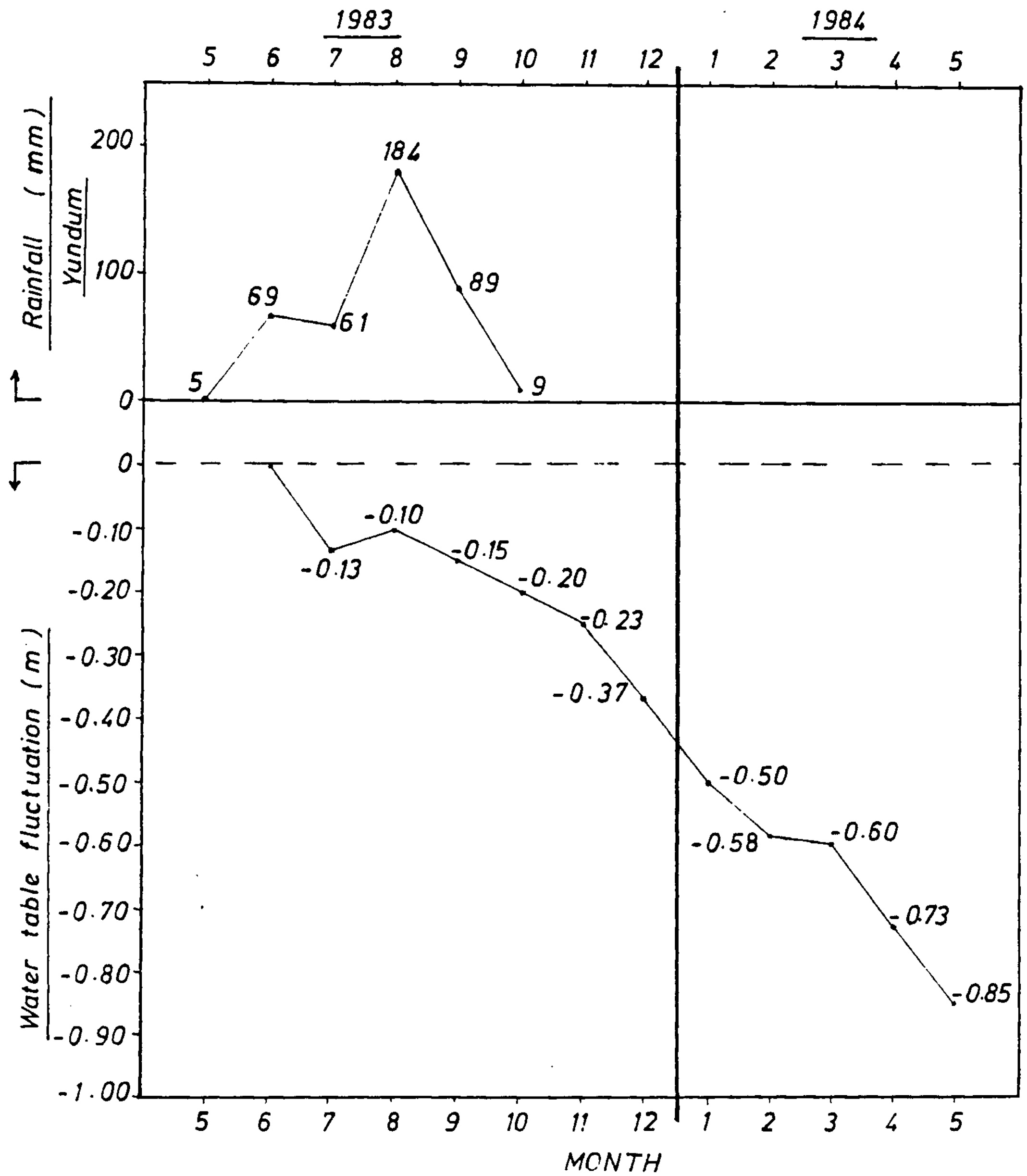


FIGURE 8. Rainfall and drawdown of water table
Brikama - Gunjur area, 1983 - 1984

Rainfall: Meteorological station Yundum
Drawdown: Average from 29 wells in Brikama - Gunjur area
(zero = water level before the start
of rainy season 1983)

western part of the area (Kwinella 591 mm).

The distribution of the rains in time differed from that of the Kombo Peninsula: July was a relatively rainy month (161 mm, Jenoi; 222 mm, Kwinella), so the water table did not continue sinking as in the case of Kombo, but went up. This higher level was maintained for two more rainy months, then a drawdown started.

The average rate of drawdown of the water table is 0.1 m per month (figure 10). The highest seasonal fluctuation recorded was in the village of Kolior (2.44 m and 2.82 m in two different wells). These figures suggest a low specific yield of the sediments in which the wells were dug.

The 33 levelled wells served as basis for a contour map of the table (figure 9). As it shows, the water declines gently from south to north toward the river Gambia, the average hydraulic gradient being about $8 \times 10^{-4}$.

This water level map (as well as figure 7) differs from those in the reports of Gitec (1980) and that of Rural Water Supply Division (1983). Even if we allow for changes due to secular and seasonal variations, the differences should not be so great. If our map is correct, it may be inferred that the earlier mapping had not included levelling of points in the field.

## 10. Sabi-Basse-Jar Kunda area

Although the rainfall in 1983 was below average in eastern Gambia, the difference against the average was less than in other parts of the Gambia. In Basse 737 mm of rain fell, the 32-year average being 1,005 mm.

The rainfall in July 1983 measured at the Basse station (figure 11) was even above average: 267 mm. The rise of water in wells corresponds to this fact: the level goes up abruptly and this continues from July to September. In October, the rain was again less than 100 mm (62 mm

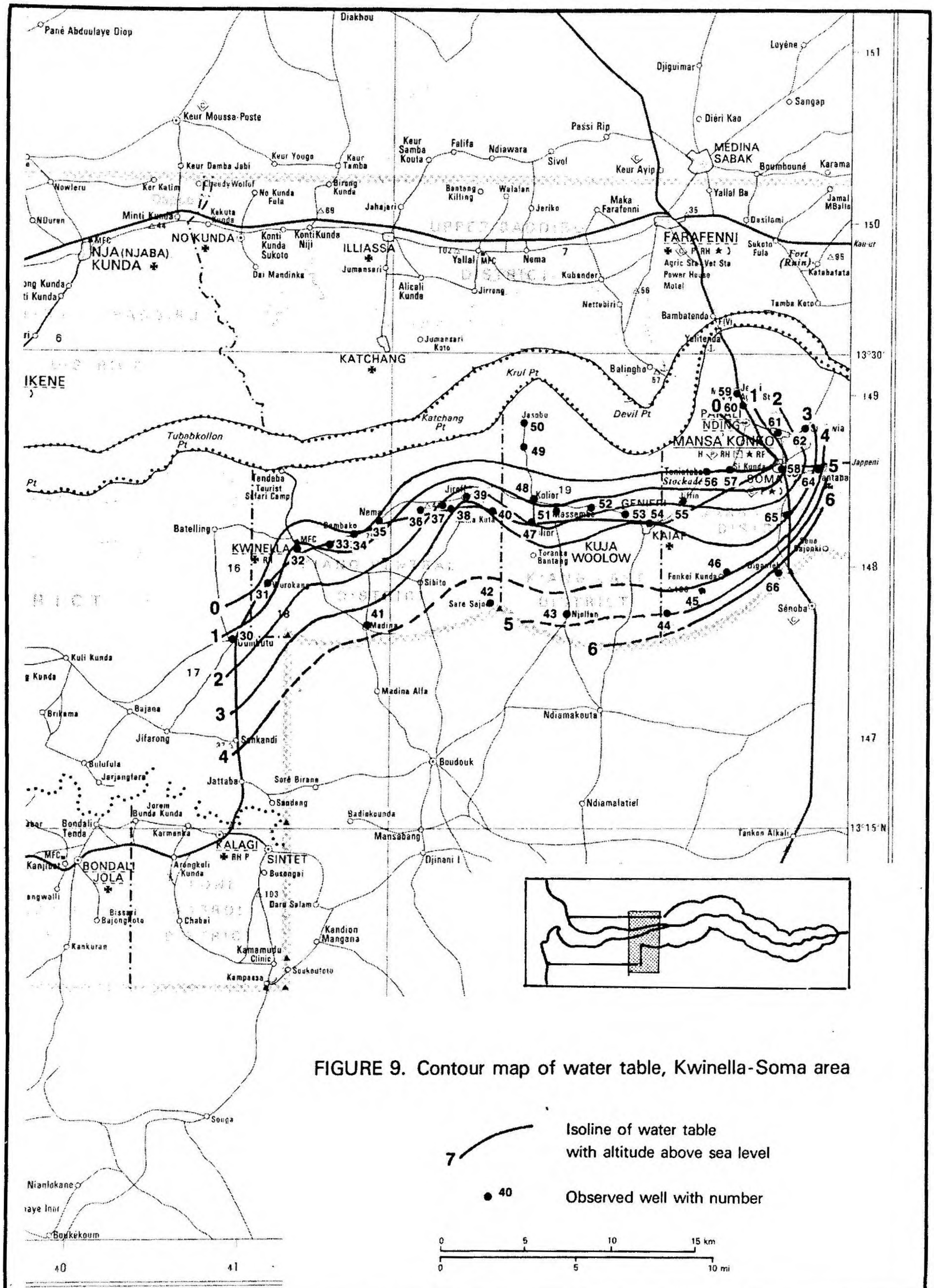


FIGURE 9. Contour map of water table, Kwinella-Soma area

3341.5x

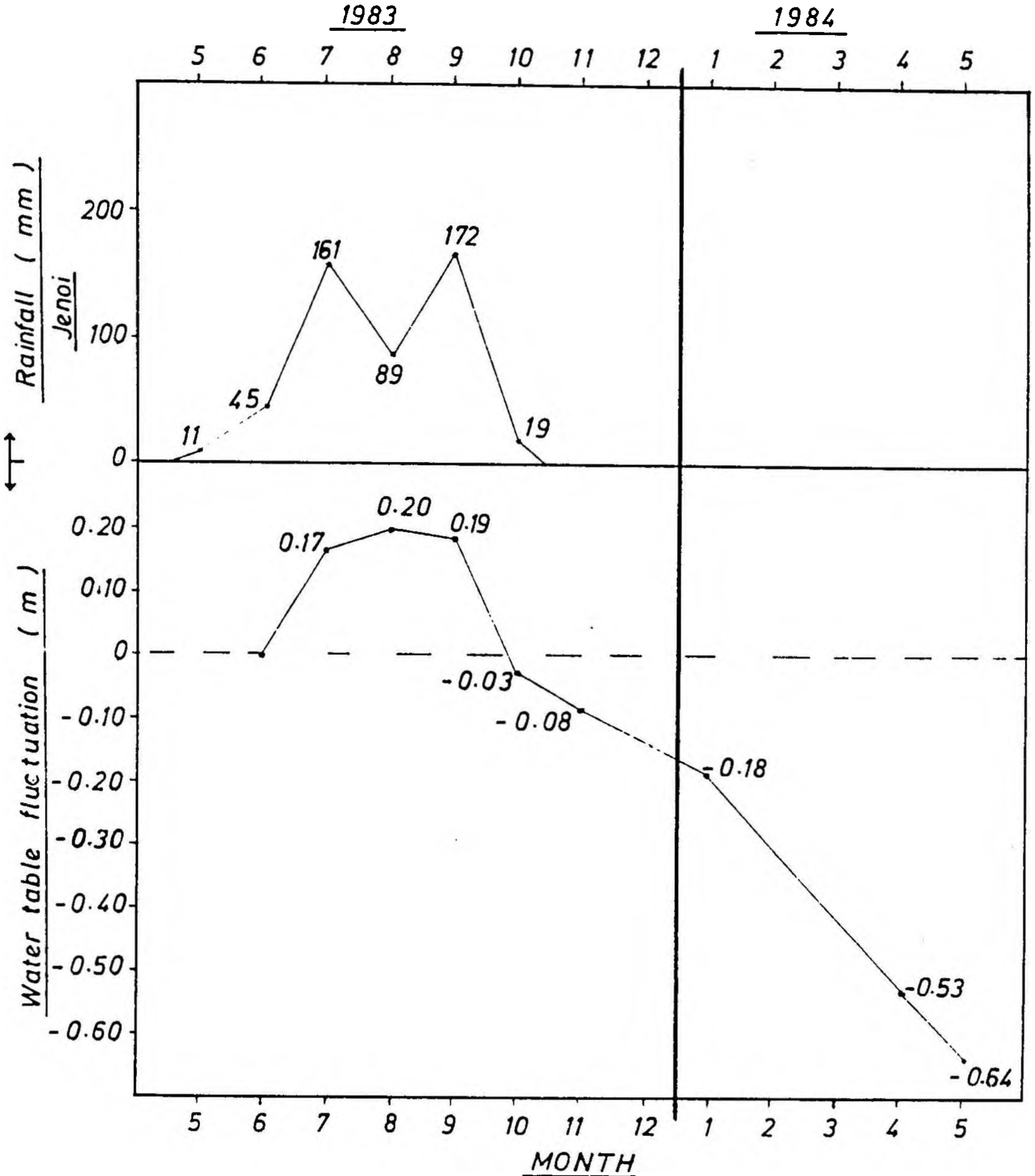


FIGURE 10. Rainfall and drawdown of water table
Kwinella - Soma, 1983 - 1984

Rainfall: Meteorological station Jenoi
Drawdown: Average from 37 wells in Kwinella-Soma area
(zero = water level before the start
of rainy season 1983)

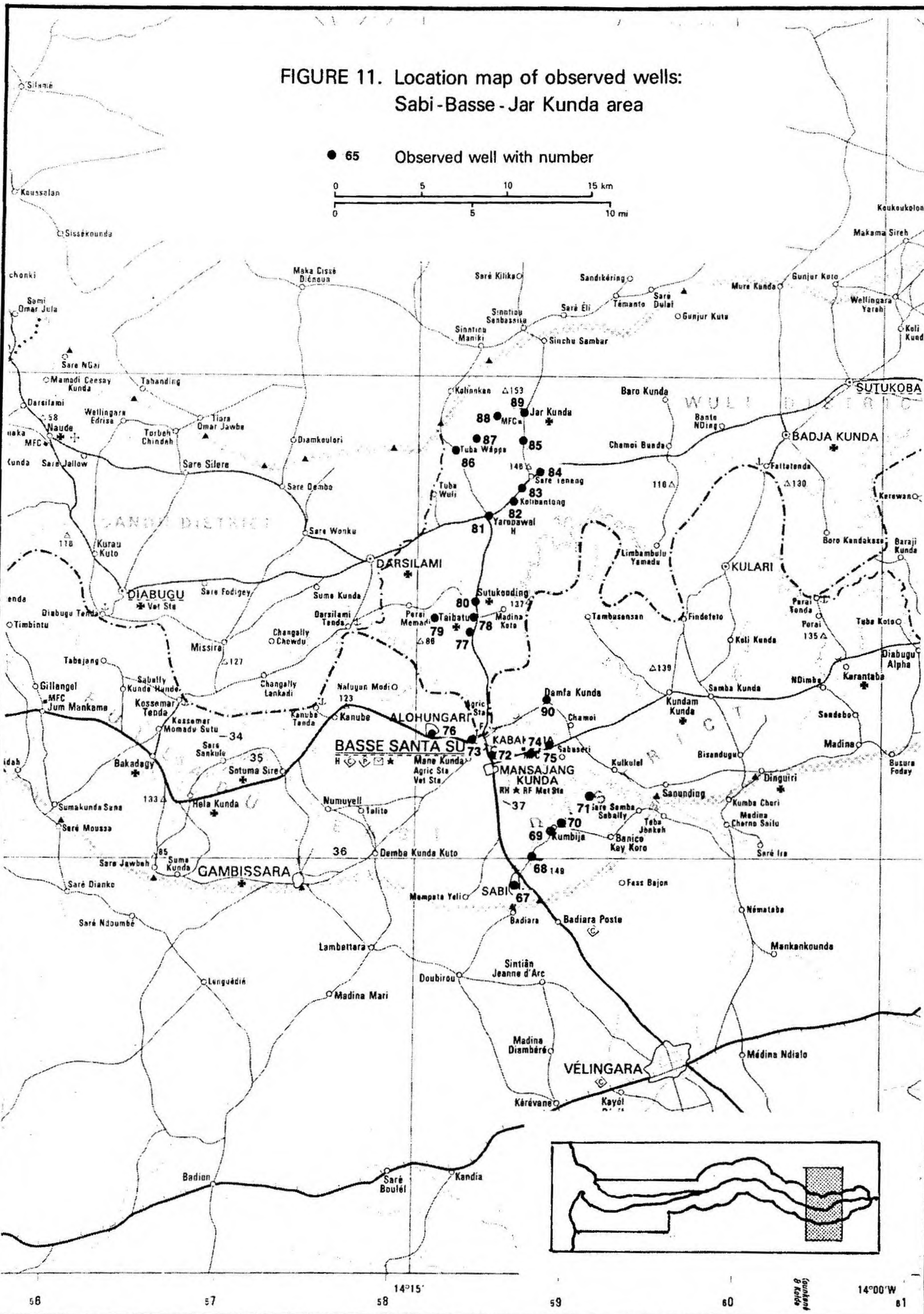

FIGURE 11. Location map of observed wells:
Sabi-Basse-Jar Kunda area
● 65 Observed well with number
0 5 10 15 km
0 5 10 mi
BASSE SANTA SU
MANSAJANG KUNDA
DIABUGU
DARSILAMI
GAMBISSARA
VÉLINGARA
SUTUKOBA
BADJA KUNDA
KULARI
ALOHUNGARI
SABI
KABA
Jar Kunda
Sutukoding
Yarobawal
Damfa Kunda
14°15'
14°00'W

3341.6x

in Basse station) and the rise of the water table stopped. Both the rise and drawdown of water level in the Basse area (figure 12) are faster than in the other areas. This can be explained by the somewhat different composition of sediments which are supposed to have lower specific yieldsthan those in the western and central parts of the country.

The average rate of drawdown is 0.16 per month. No fewer than 8 of 24 wells observed had a seasonal fluctuation greater than 2 m, one even more than 3 m. Wells dug in sediments with low specific yield must be counted, however, even high daily fluctuation caused by intensive extraction of water during the morning and evening hours.

11. General observations

The main purpose of the measurement taken in other parts of the Gambia was to compare the results of what was done in three selected areas with the rest of the Gambian territory. From this point of view, there were no essential differences; expectedly, the pattern of seasonal fluctuation is homogeneous for the whole country.

Advantage has been taken of older monitoring programmes, especially those performed by Howard Humphreys and Sons in 1973-74 and Gitec in 1980. Our measurements show that the water table has been sinking during the last decade to the extent we have marked out in Chapter II.C.5. This decline is not to be explained by high extraction of water from the aquifer by the population. The explanation is only to be found in changing climatic conditions. We refer to a well-known phenomenon observed by climatologists and agriculturalists, namely, a long-term trend (since 1968) toward lower rainfall in all Sahelian countries. Whether this be temporary or not, it exists and everybody working with water reserves must consider it.

We have calculated the quantity of water corresponding to a yearly rainfall of 960 mm as necessary to maintain the present level of the water table. If we go through records of Gambian meteorological stations, we find a simple explanation for the difference between ground-water

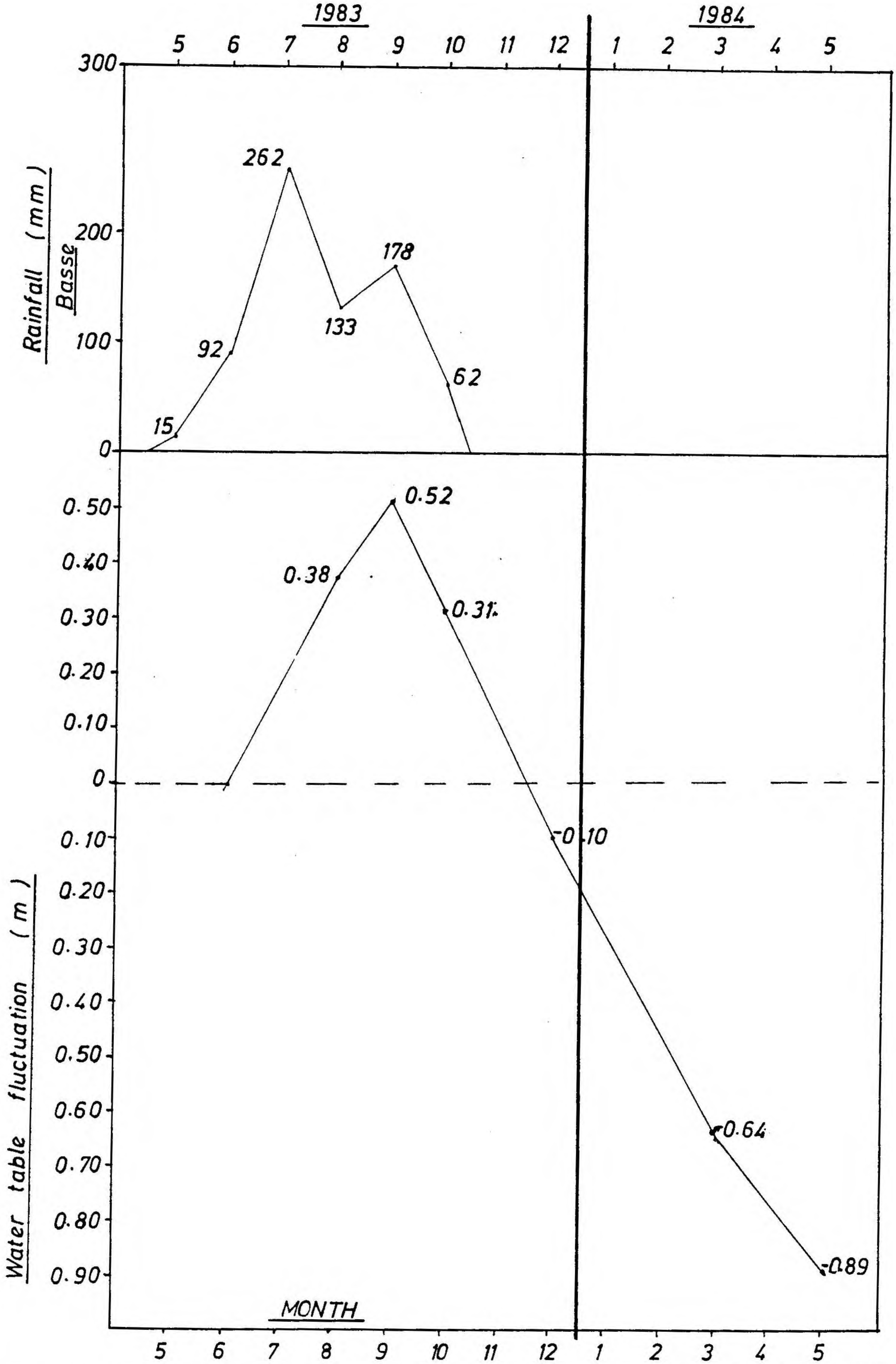


Figure 12. Rainfall and drawdown of water table, Sabi-Basse-Jar Kunda, 1983-1984
Rainfall: Meteorological station Basse
Drawdown: Average from 24 wells in Basse-Jar Kunda area.

levels several years ago and the ground water level of today.

In Yundum meteorological station (figure 13), which is representative for the Kombo Peninsula, the mean rainfall for the period 1952-1967 (16 years) was 1,339 mm; in none of these years was it less than 960 mm. For the period 1968- 1983 (16 years), the mean rainfall was 854 mm and 11 out of 16 years had rainfall less than 960 mm.

In Georgetown meteorological station, which may represent the eastern half of the country, the average rainfall for the period 1952-1967 was 1,040 mm and in only 4 cases out of 16 was it lower than 960 mm; of the next 16 years (1968-1983), 15 were under 960 mm and the average was 703 mm.

Thanks to generous reserves of ground water in the Gambia, the decline of the water table is not yet serious. But the trend toward lower rainfall is continuing, and all projects dealing with ground water must take it into consideration.

## D. Windmill pumping systems

### 1. Background

The problem of sources of energy is as sharp in the Gambia as in most other Sahelian countries. Lacking resources of petroleum, coal and hydroelectric potential, the Gambia has relied on imports of petroleum products which are costly and, as frequent gaps in electricity and petrol supply prove, unreliable.

Pumping water from boreholes and wells by means of generators and motor pumps is a luxury reserved for only a few of the biggest conurbations, and on a limited scale for irrigation and cattle watering. Not only proper supply but also transport and storage of fuel, as well as maintenance of equipment, are problematic in the case of these small pumping stations. In fact, to build a fuel-powered station for rural electricity supply is an enterprise with an uncertain future in the

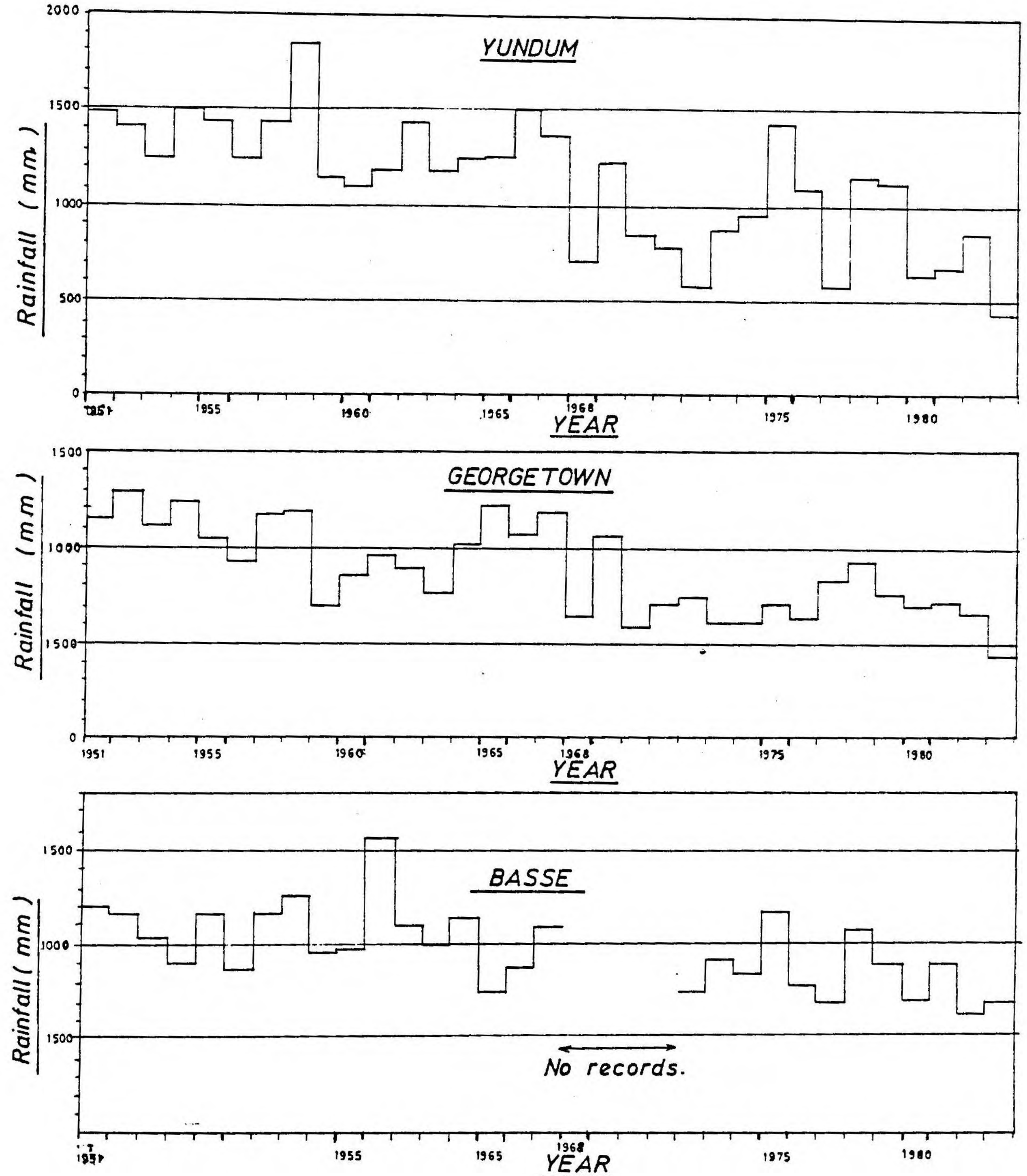


Figure 13. Rainfall 1951-1983 at Yundum, Georgetown and Basse 1951-1983.

Gambia; there are examples to be cited all over the country.

There is still, naturally, human energy as a source of power. A bucket on a rope and a person operating this primitive system is by far the most usual pumping unit in the Gambia. As mentioned earlier, the efficiency of this system is low, and health hazards considerable.

Hand pumps on closed wells represent clear progress, but they do not save human energy; moreover, their service life appears to be much shorter than the manufacturers suggest - undoubtedly partly because of an insufficient level of technical education of the people who use them.

A search for an alternative source of power for drawing water out of boreholes and wells is only natural in this situation. It is also natural for the project (part of which was devoted to this search) to test first the possibilities of using wind energy. It is the oldest and still the most reliable renewable source of power for pumping water. A basic necessity, however, is that there be enough wind during the whole year.

## 2. Wind speed maps and records

In West Africa, the speed of wind generally diminishes from north to south: regions neighbouring the Sahara are windy whereas regions on the Gulf of Guinea normally have little wind.

The Gambia is between these two extremes. Thus, it may be one reason for the relatively large differences in data published in various sources. Extremely high wind speeds are for example marked in a map "World Wide Wind Energy Resources Estimates" published by WHO in 1981: the Gambia should have, according to this map, a mean annual wind speed of between 5.1 and 5.6 m/s. One must wonder whether these figures were not erroneously cited as "m/s" instead of "knots" which would be more credible.

Another probable over-estimate appears in a study entitled "The

World Market for Medium Sized Wind Generators" (London, 1981) where the mean wind speed in the Gambia is said to be under 3.5 m/s in the eastern and over 3.5 m/s in the western part of the country.

Considerably lower mean wind speeds are marked in the map of wind isotachs of West Africa published in the C.R.E.S. Feasibility Study (1981). The eastern part of the Gambia has a mean wind speed of less than 2 m/s, while the western part lies in the area with winds of 2 to 3 m/s.

Finally, there is a "Map of Wind in Senegal" compiled by the Meteorological Services of Senegal (figure 14). There, the average wind speed in the eastern part of the Gambia is between 1 and 2 m/s, in the central and western part of the Gambia between 2 and 3 m/s, and in the Kombo Peninsula more than 3 m/s.

A decrease of wind speed from west to east is documented also by records of Gambian meteorological stations. These records should be the principal source of information for anybody dealing with wind energy in the country, but, although some of them are useful, there is still much to be desired in wind speed recording in the Gambia.

There are seven working meteorological stations in the Gambia. From west to east they are: Yundum, Banjul, Kerewan, Jenoi, Sapu, Georgetown and Basse. The speed of wind is measured in all these stations by cup anemometers mounted at the height of 6 ft. (1.8 m). No anemometer is mounted at the internationally recommended height of 10 m. (There is one on the roof of Yundum station but records are taken from another one). Moreover, two stations (Banjul, Georgetown) are closely surrounded by trees and houses and their records of wind cannot be considered reliable.

Table 1 shows the average monthly wind speeds recorded in the Gambia from 1978 to 1983. In the case of Kerewan, only records of 1979 and 1981 are available.

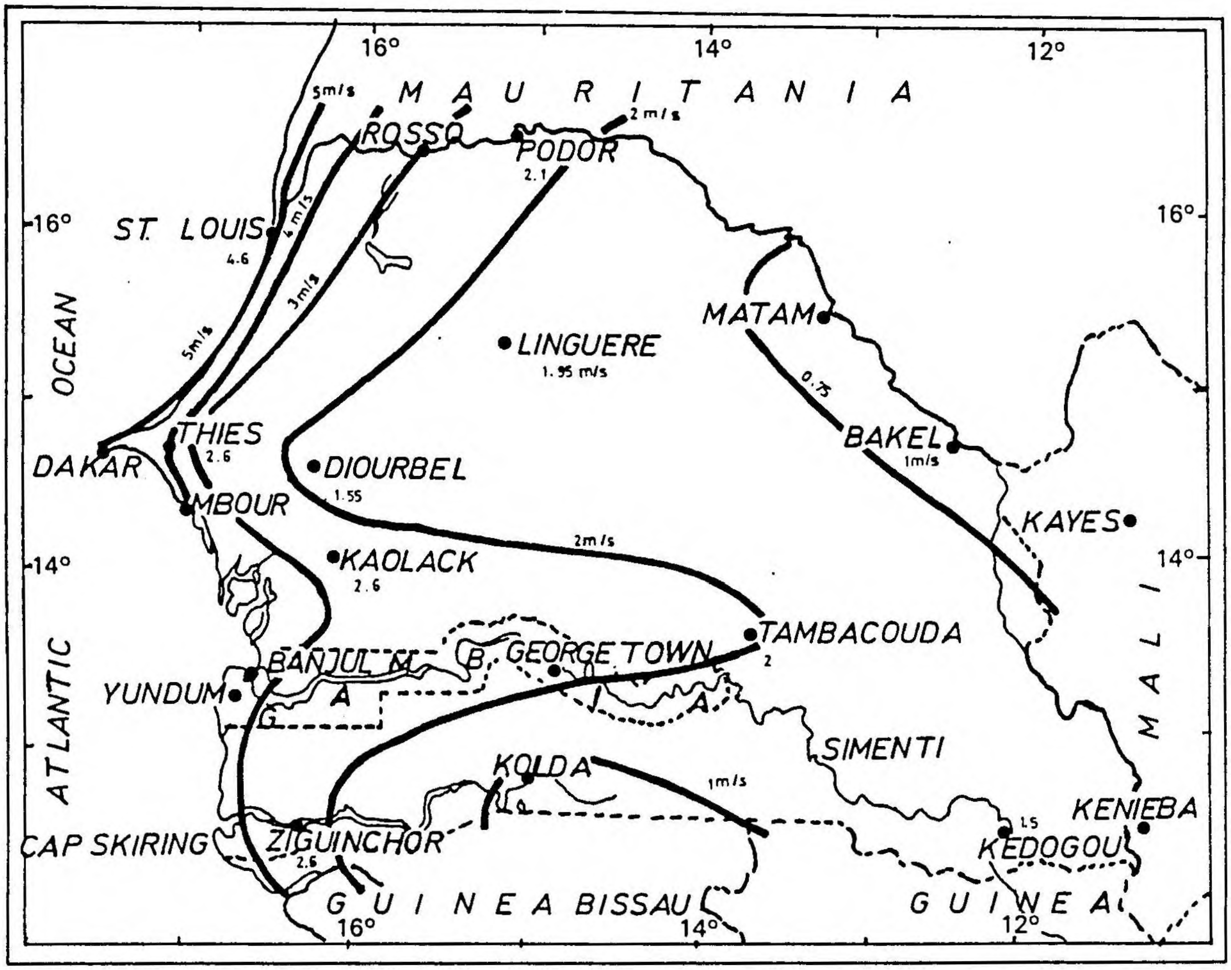


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FIGURE 14. Map of wind speed in Senegal and the Gambia

Table 1. Average monthly wind speeds, the Gambia, 1978-1983

| Station | Yundum | Jenoi | Sapu | Basse | Kerewan |
|---|---|---|---|---|---|
| Month | Wind speed in m/s | | | | |
| I | 3.08 | 1.99 | 1.91 | 1.17 | 2.47 |
| II | 3.13 | 2.22 | 2.10 | 1.26 | 3.16 |
| III | 3.22 | 2.21 | 2.07 | 1.50 | 3.13 |
| IV | 3.76 | 2.29 | 2.26 | 2.08 | 2.95 |
| V | 3.59 | 2.24 | 2.72 | 2.23 | 2.80 |
| VI | 3.43 | 2.29 | 2.72 | 1.36 | 2.67 |
| VII | 2.78 | 2.07 | 2.39 | 1.76 | 2.11 |
| VIII | 2.93 | 1.95 | 1.96 | 1.40 | 1.73 |
| IX | 2.28 | 1.75 | 1.69 | 1.12 | 1.88 |
| X | 1.91 | 1.71 | 1.13 | 1.00 | 1.42 |
| XI | 1.91 | 1.48 | 1.36 | 0.58 | 1.73 |
| XII | 2.22 | 2.29 | 1.92 | 0.80 | 1.81 |
| Year | 2.81 | 1.98 | 2.04 | 1.35 | 2.32 |

The months with most wind in the Gambia are April, May and June, while in October and November the winds are minimal. This corresponds to the change of their direction: in October, the influence of tropical maritime air mass coming from the south-west is finishing, the area of low pressure moves southward and behind it, tropical continental air mass comes from the north-east.

## 3. Wind observations

The network of the meteorological stations in the Gambia is relatively dense, especially on the southern bank of the river. Yet two stations (Yundum, Banjul) do not give credible data and one (Kerewan) has an insufficiently long series of records. Kerewan happens to be, however, the only station on the northern bank of the Gambia River.

To get more data on wind speed, the staff of the project took advantage of every field trip to measure wind speed in different places by hand anemometer. Thus, a collection of more or less randomly obtained data came into existence. The data were then compared with the records of meteorological stations for the same time.

The conclusions made from these frequent measurings combined with the records of five stations can be summarized as follows:

- The average wind speed in the Gambia as measured at 2 m height ranges from 1.3 m/s in the most eastern part to 4 m/s at the seashore of the Atlantic (figure 15).

- Decrease of the wind speed has generally a NW-SE direction. Only on the seashore does this direction change to W-E, while in the central part of the Gambia it tends to be N-S.

- For most of the Gambian territory a rule can be applied: in the same geographical longitude and in the same time, the wind speed is usually higher on the northern bank than on the southern bank of the river.

To test the increase of the wind speed with the height, and to find correlations, the following measurements were organized:

An anemometer was mounted on the tower of the first wind mill constructed in Tanji to the height of 11 m. From 6 March 1984 to 31 May 1984, daily records were taken and compared with records of the nearest meteorological station in Yundum. Table 2 shows the results in one month.

Figure 15. Map of wind speed at 2m above ground in the Gambia.

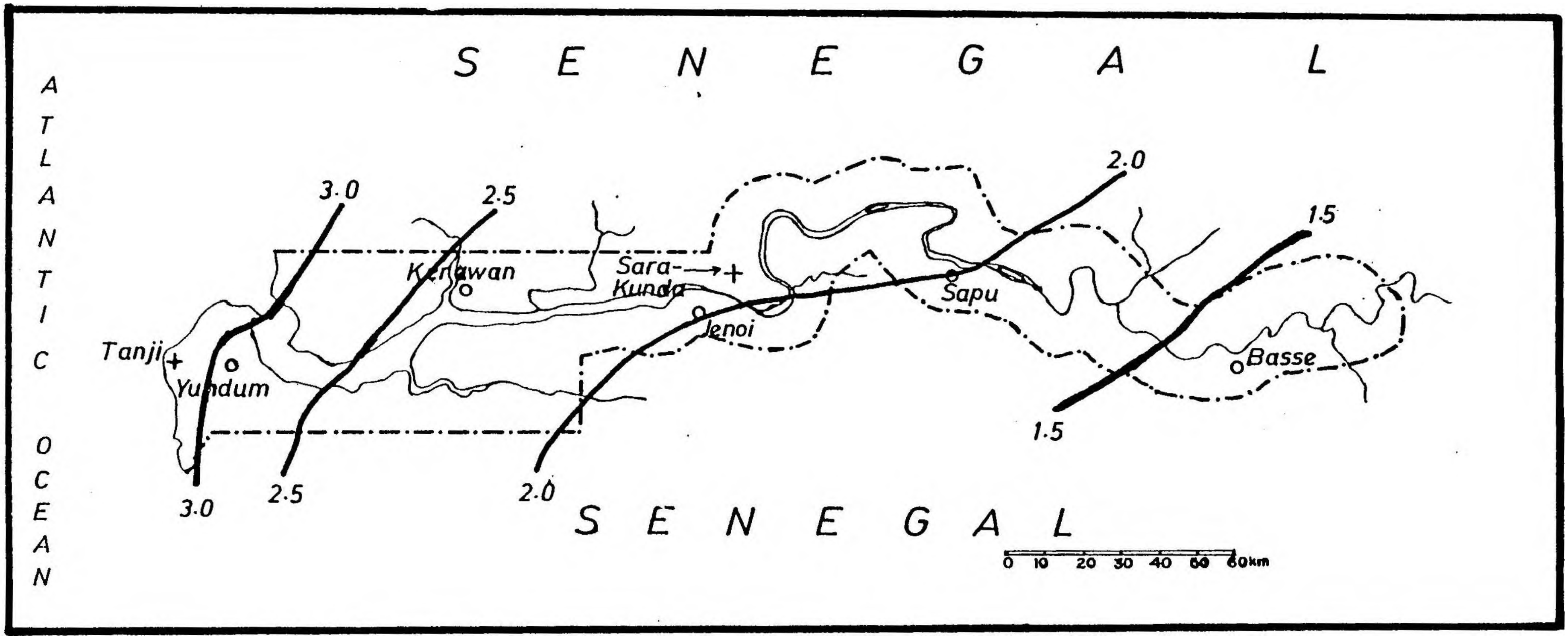


Table 2. <u>Comparison of wind speed in Yundum (at 2 m) and Tanji (at 11 m) May 1984</u>

| Day (May 1984) | Yundum | Tanji | Day (May 1984) | Yundum | Tanji |
|---|---|---|---|---|---|
| | Wind speed in m/s | | | Wind speed in m/s | |
| 1 | 1.73 | 3.90 | 17 | 3.27 | 3.67 |
| 2 | 1.72 | 2.96 | 18 | 2.31 | 3.07 |
| 3 | 1.99 | 3.93 | 19 | 1.49 | 3.87 |
| 4 | 2.11 | 3.81 | 20 | 1.88 | 2.57 |
| 5 | 1.58 | 3.69 | 21 | 2.10 | 3.51 |
| 6 | 1.74 | 2.41 | 22 | 1.99 | 2.81 |
| 7 | 1.59 | 3.42 | 23 | 1.74 | 3.54 |
| 8 | 1.72 | 2.53 | 24 | 2.18 | 3.28 |
| 9 | 1.56 | 3.11 | 25 | 2.30 | 3.42 |
| 10 | 1.44 | 3.82 | 26 | 1.80 | 2.18 |
| 11 | 1.26 | 2.96 | 27 | 2.08 | 2.87 |
| 12 | 1.85 | 2.47 | 28 | 2.34 | 2.75 |
| 13 | 2.11 | 3.90 | 29 | 2.61 | 2.88 |
| 14 | 2.36 | 2.47 | 30 | 2.07 | 3.50 |
| 15 | 2.65 | 2.91 | 31 | 1.59 | 3.49 |
| 16 | 1.79 | 3.07 | Average | 1.97 | 3.18 |

It can be seen from daily measurements as well as from monthly averages that:

1. The wind speed is considerally higher in Tanji (situated 1 km from the sea; measuring at 11 m) than in Yundum (situated 14 m from the sea; measuring at 2 m). The difference was 72 per cent

in the recorded period.

2. The wind regime (especially maxima and minima of wind speed) is different between the two sites.

To avoid the difference given by the positions of the two sites, a series of measurements was organized in Tanji. The wind speed at 2 m and at 11 m was measured in the same time at intervals of 10 minutes. The results are shown in table 3.

Table 3. Wind speed at 2 m and at 11 m in Tanji

| Date (1984) | Hour | Wind speed at 2m m/s | Wind speed at 11m m/s | difference % |
|---|---|---|---|---|
| 13.3 | 11.00-11.10 | 3.16 | 4.40 | 39 |
| 30.3 | 14.20-14.30 | 2.33 | 3.88 | 66 |
| 9.4 | 12.15-12.25 | 1.91 | 2.83 | 48 |
| 20.4 | 12.30-12.40 | 1.86 | 3.40 | 82 |
| 27.4 | 9.30- 9.40 | 1.92 | 3.20 | 66 |
| 30.4 | 15.10-15.20 | 3.37 | 5.13 | 52 |
| 14.5 | 9.50-10.00 | 1.88 | 3.66 | 94 |

In theory, the difference between wind speed at 2 m and 11 m should be 40 per cent. Our case only indicates that the houses, trees and fences surrounding the well brake the wind considerably.

The same programme of measuring was organized in Sara Kunda in North Bank Division, 130 km (straight line) from the seashore. Table 4 compares the wind speeds in Sara Kunda (measured at 11 m) with nearest stations Jenoi (measured at 2 m).

Table 4. Comparison of wind speed in Jenoi (at 2 m) and Sara Kunda (at 11 m), June 1984

| Day (June 1984) | Jenoi | Sara Kunda | Day (June 1984) | Jenoi | Sara Kunda |
|---|---|---|---|---|---|
| | m/s | | | m/s | |
| 7 | 1.20 | 2.18 | 19 | 1.64 | 1.74 |
| 8 | 1.55 | 1.96 | 20 | 1.27 | 2.57 |
| 9 | 1.38 | 2.54 | 21 | 1.29 | 2.32 |
| 10 | 1.42 | 2.21 | 22 | 1.74 | 2.29 |
| 11 | 1.43 | 2.18 | 23 | 1.13 | 2.72 |
| 12 | 1.56 | 2.59 | 24 | 0.93 | 1.59 |
| 13 | 1.57 | 3.07 | 25 | 1.50 | 1.30 |
| 14 | 1.74 | 2.68 | 26 | 1.34 | 2.47 |
| 15 | 1.45 | 2.97 | 27 | 1.35 | 2.03 |
| 16 | 1.94 | 2.52 | 28 | 0.85 | 2.00 |
| 17 | 1.63 | 2.58 | 29 | 1.57 | 2.46 |
| 18 | 1.30 | 2.24 | 30 | 1.28 | 1.35 |
| | | | Average | 1.42 | 2.27 |

The comparison of measurements (table 5) in site:

Table 5. Wind speed at 2 m and 11 m in Sara Kunda

| Date (1984) | Hour | Wind speed at 2 m m/s | Wind speed at 11 m m/s | difference % |
|---|---|---|---|---|
| 6.6 | 14.20-14.30 | 1.08 | 1.53 | 42 |
| 14.6 | 11.30-11.40 | 1.85 | 2.62 | 41 |
| 20.6 | 11.30-11.40 | 1.60 | 2.33 | 45 |

The difference between wind speed at 2 m and 11 m is very near the theoretical value of 40 per cent in Sara Kunda; there are no houses surrounding the well.

## 4. Site investigation

The site investigation for the first windmill took place at a time when only part of what is set forth in the previous two chapters was known. In that time, no windmill was working in the Gambia. A windmill in Serrekunda (UK manufactured "Clima" with 18 m tower and rotor of 1.8 m diameter) had not been working for at least 25 years. Another of the same type was allegedly mounted in Genieri (150 km east of Ganjul) and worked from 1951 to 1958, but nothing remained of it.

The third attempt to use wind energy in the Gambia was made by the Gambia Christian Council as a project by Mr. R. Mann, who mounted a small cretansail type windpump in Lamin (20 km from Banjul). Although Mr. Mann published his results in 1979 as hopeful, lack of subsequent development showed that he was perhaps too optimistic. In fact, his small windmill has not been used since the first or second year of its existence; then it was dismantled and moved to Brikama but was not used there.

Another attempt to use wind energy for water pumping was made by Rev. Melvin R. Pittman in Ndungu Kebbe on the northern bank of the Gambia River. This small Bowjon windpump, however, never actually worked.

It would appear, thus, that the Gambia is less than an ideal country for windmills. Both the team leader of the project and the consultant for wind energy were aware of the somewhat marginal position of the country, nevertheless they believed that there are at least parts of the Gambian territory quite suitable for windmills - on condition that an adequate type of construction be chosen.

Two regions were considered hopeful: the western part of Kombo

Peninsula and the western part of North Bank Division. A search for the best place to locate a well in these regions led to the choice of the village of Tanji (Western Division, South Kombo District) not far from the Atlantic shore. With this choice, there was some certainty that the windmill would work adequately (the aspect of practical use was considered as important as the proper experimentation). Successful operation could serve minimally as a proof of feasibility of windmills in about 50 Gambian villages which have similar geographical positions to Tanji. The proximity of Banjul and thus the possibility of frequent visits to Tanji was another advantage.

A second stage of site investigation for windmills took part after the suitability of Kombo Peninsula, as proven by success in Tanji, was clear. Taking into consideration the results of the observations carried out in Tanji, a conclusion was made that if an appropriate system is used, windmills may be successful even in the interior of the country.

The northern bank of the river was considered best for further experimentation (for reasons, see Chapter II. D. 3.). After a search for a suitable well in the central part of the country, six alternative sites were suggested to the Department of Water Resources in March 1984. From them, priority was given to the village of Sara Kunda (North Bank Division, Upper Baddibu District).

5. Selection of windmill

The search for the most suitable type of windmill was conducted on the following premises:

1. The windmill should be efficient even in not quite ideal wind conditions. It should have as low a cut-in windspeed as possible.

2. The system of transmission (rotor-pump) should be as simple as possible to avoid eventual difficulties with repair and to enable easy maintenance (provided no experienced or trained

person or team is recently in the Gambia).

3. Spare parts should be easily available.

An Italian system, Tozzi and Bardi, was selected as having several advantages:

1. The chosen size of tower is high enough (16 m) to take advantage of the increase of wind speeds with height.

2. The rotor of 6 m diameter with multiple blades (18 in total) has high solidity which gives high starting torque in light wind.

3. Transmission is not complicated: reciprocating motion is obtained by means of gears and crank.

4. Piston pumps are supplied in a wide range of diameters enabling the best choice to be made for the prevailing wind speed and hydraulic head.

5. Service and spare parts are relatively easily available in Senegal by LVIA-Communauté des Laics Volontaires in Thies.

This last fact proved to be very important. A group of Italian volunteers - engineers and fitters working with skilled Senegalese labourers, was contacted by the Team Leader of the project and all further work on windmill installations in the Gambia was carried out in close collaboration with LVIA.

(It is worth noting that LVIA is not the only organization constructing water lifting windmills in Senegal. The most productive - at least as the number of windmills is concerned - is the governmental DHUR (Département d'Hydraulique Urbaine et Rurale). It has at its disposal 200 windmills obtained from an Argentinian firm, FIASA. Of them, 137 have been erected since the beginning of 1983 to May 1984 in various sites of Senegal (mostly in the northern part). FIASA windmills are lower than those built by LVIA, they need a higher cut-in wind speed and they have lower capacity. Nevertheless, they are cheaper and easier to mount. But their precipitous installation in Senegal is far from being without problems. In fact, a large percentage of them do not work for such reasons as insufficient maintenance, badly chosen site or even lack of water in the well.

## 6. Experimental sites

The work on experimental sites included: deepening of wells so that they have at least 6 m of water column, production tests, construction of a water storage tank, construction of the windmill-pump system, instrumentation and such additional work as fencing and construction of washing platform. The windmill in Tanji was installed in November 1983, the windmill in Sara Kunda in May 1984.

The well in Tanji (Western Division, Kombo South District) is 18.5 m deep, the water level before the start of pumping was at 12.4 m. Transmissivity of the phreatic aquifer at the site, calculated on the basis of a recovery test, is 30 $m^2$/day.

The water storage tank is brick, round, with an inner diameter of 3.05 m. Its height is 3.5 m of which 2.5 m is the space for water. Maximal storage is 18.25 $m^3$. An overflow pipe connects the top of tank with the well. The tower of the windmill (photograph 1) is 16m high, the diameter of the rotor is 6 m. A piston pump of 120 mm diameter is connected with the tank by a system of 2-inch pipes. Hydraulic head is 17-18 m. One pump stroke (corresponding to one rotation of rotor) gives 1.58 liters of water. The instrumentation (figure 16) included: two flowmeters - one on the pipe going from the pump to the tank and one on the overflow pipe; one water-level meter of the level in the tank; and one cup-counter anemometer mounted on the tower at a height of 11 m.

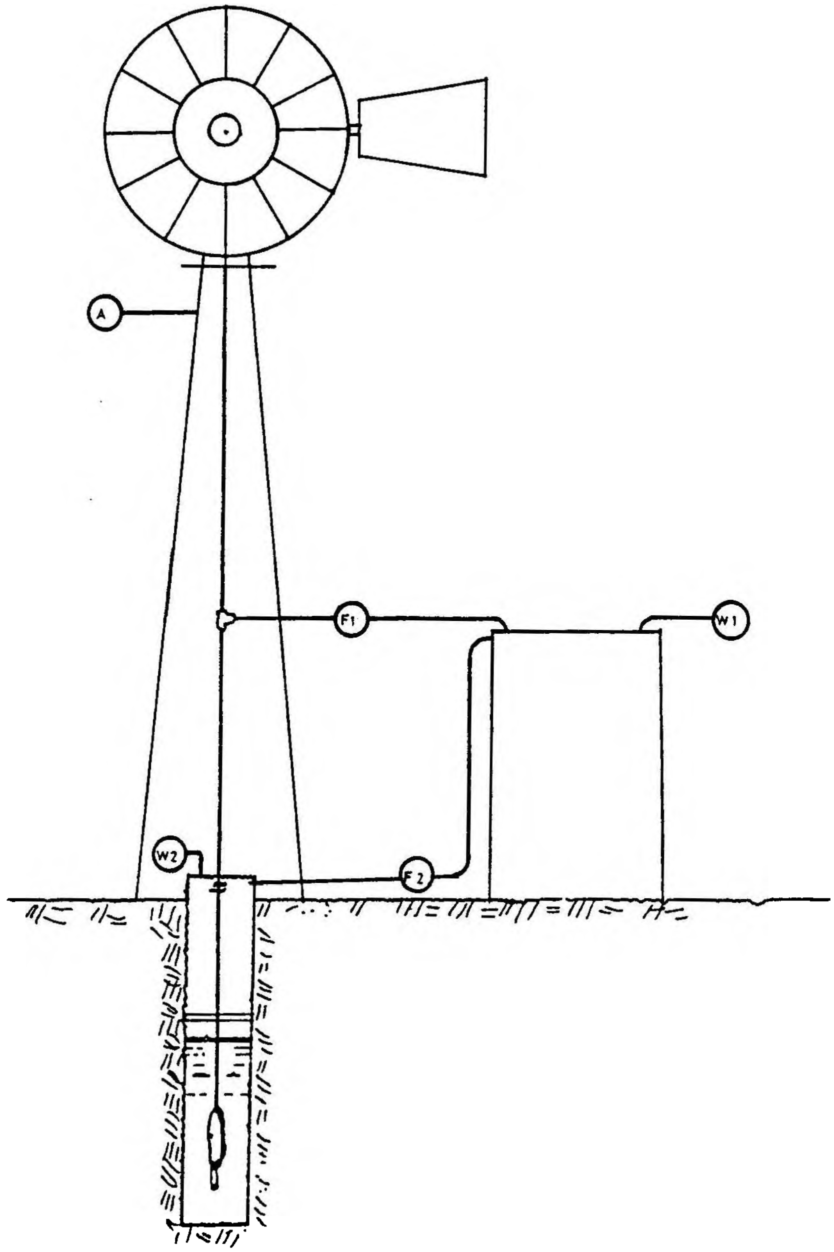
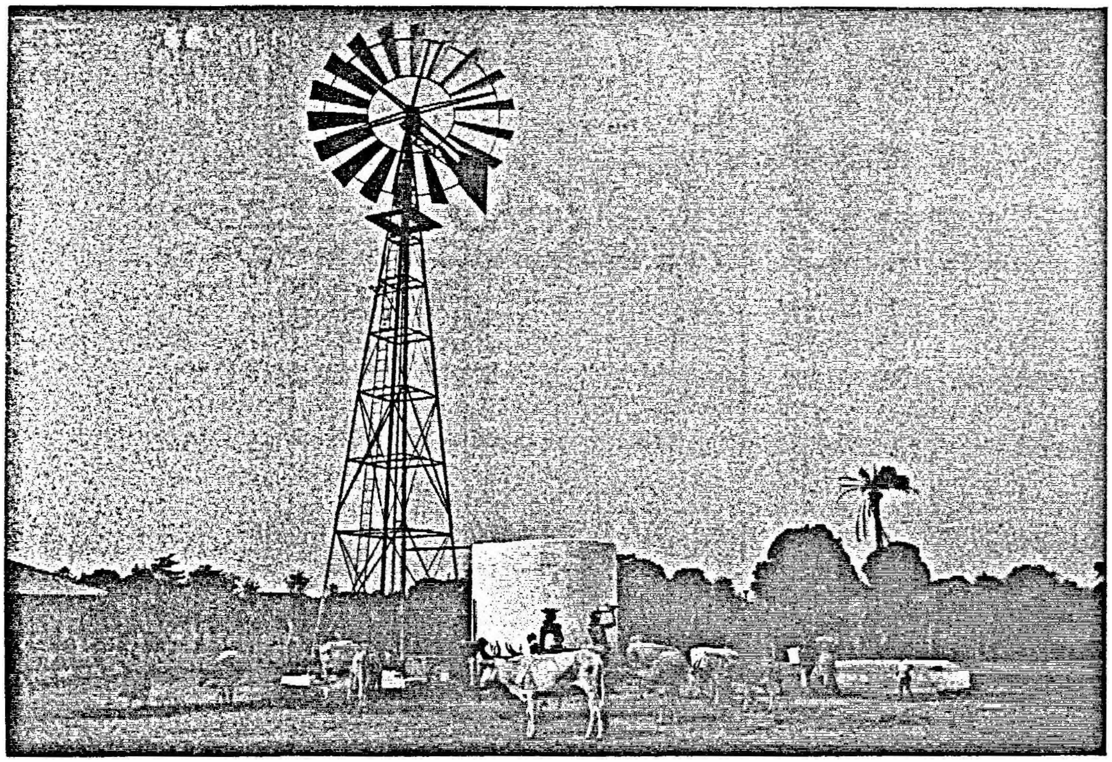



Figure 16. Instrumentation, windmill pumping system, Tanji
F1, F2 - flowmeters
W1 - water level meter (tank)
W2 - water level meter (well)
A - anemometer



Photograph 1. Windmill pumping installation, Tanji

In the observation period (January-May 1984), the data had been collected twice a day by an observer. A cut-in speed of the windmill as well as conditions of steady work were studied during frequent stays of the staff of the project in Tanji.

<u>The well in Sara Kunda</u> (North Bank Division, Upper Baddibu District) is 21.5 m deep, the water level before the start of pumping was at 15.25 m. Transmissivity of the phreatic aquifer at the site is 20 $m^2$/day.

The water storage tank (photograph 2) as well as tower and rotor have the same parameters as those in Tanji. A piston pump of 100 mm diameter gives 1.1 liters per stroke. Hydraulic head is 19-20 m. One flowmeter is installed on the pipe going to the tank. A cup-counter anemometer was mounted at 11 m height. The observations started on 24 May 1984, performed by an observer collecting records once a day.

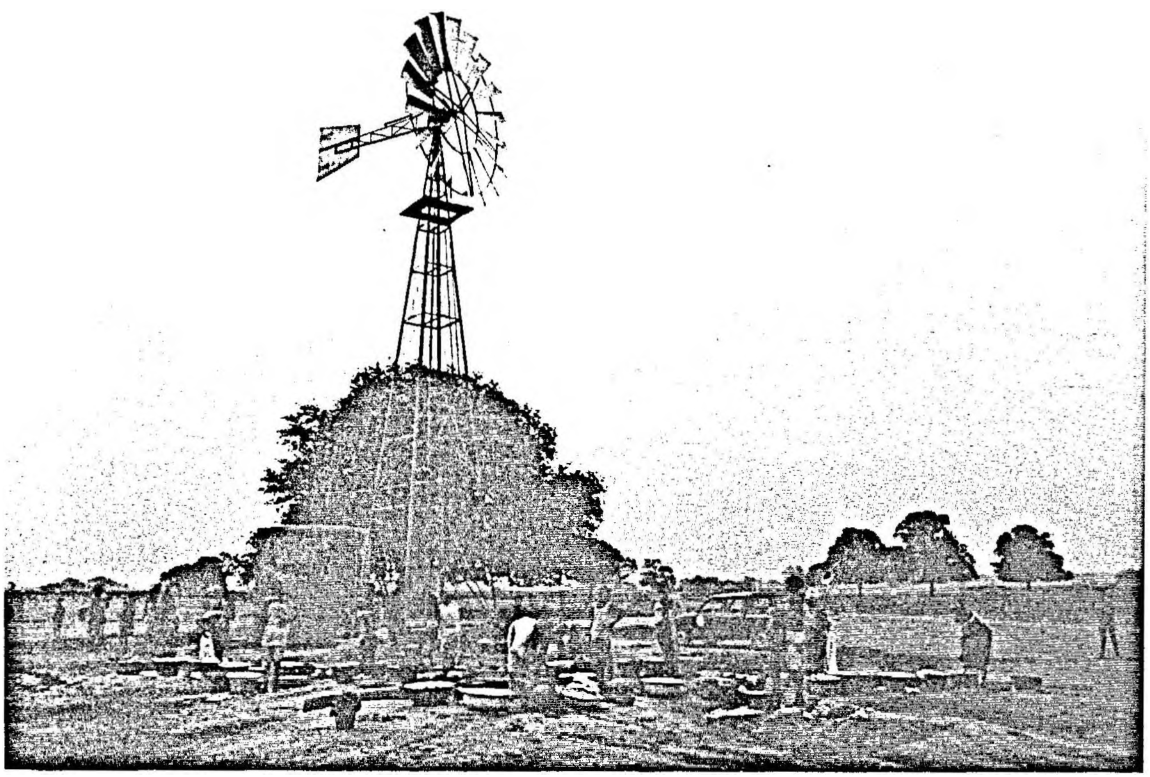
7. <u>Tanji</u>

The total amount of water pumped from the well in Tanji between 6 January and 30 April 1984 (116 days) was 2,920 $m^3$. The average daily amount for this period was 25.17 $m^3$. Maximal production for one day was 44 $m^3$ of water. This was reached on 23 April, while on 13 March and 5 April (in both cases) 42 $m^3$ were pumped. There were 2 days out of 116 recorded when the windmill did not work at all for lack of wind.

On the days of maximal yield, the average wind speed measured at 11 m was always more than 3 m/s while on the days when there was no production, the average wind speed was less than 1.5 m/s.

The cut-in wind speed of the windmill is about 2 m/s (measured at 11 m). The wind must, however, be steady for 20-30 seconds. Sudden gusts followed by calm are not sufficient, even if they are strong. Once the rotor is set into motion, wind speeds 1.8 m/s (measured at 11 m) are sufficient to keep it moving.

The correlation between daily average wind speed and production is unreliable. If the wind speed is 3 m/s for 12 hours, and 0 m/s for another



Photograph 2. Windmill pumping installation, Sara Kunda

12 hours, the daily average is 1.5 m/s but production can be 20 $m^3$. If the wind speed is really 1.5 m/s for 24 hours, then production is nil. But even considering this factor, we cannot neglect the fact that in all the months in question (January-May 1984) wind speeds were recorded as being significantly under the long-term average at Yundum meteorological station. If the windmill in Tanji worked well during this period, there should be little argument against similar installations anywhere in the Kombo Peninsula.

### 8. Sara Kunda

Although only few observations could be collected, the results are nevertheless instructive. A smaller diameter of the piston pump (100 mm) than that used in Tanji (120 mm) seems to be adequate for the wind conditions in Sara Kunda: the wind speeds here are considerably lower yet the windmill works almost with the same capacity.

From 24 May to 3 July 1984 (40 days), there was actually no day when the windmill did not work at all. The average output for the quoted period was 22 $m^3$/day. The average wind speed in the same period was 2.27 m/s. Maximal daily performance was 33 $m^3$/ day (figure 17). This was measured on 14 June 1984 when the wind speed averaged 2.97 m/s. Minimal daily performance was 6 $m^3$, measured 25 June 1984, when the wind speed averaged 1.30 m/s.

## E. Photovoltaic pumping system

### 1. Background

The idea of utilizing solar energy for pumping water in the Gambia seems to be attractive, owing to the geographical position of the country. There has never been any doubt that such conditions as intensity of irradiation or a daily length of sunshine are favourable in the Gambia.

While it is easy to show that there is ample solar energy for power pumping systems, important questions are still left to be answered. The suitability of existing systems for specific Gambian conditions must be tested from the point of view of their eventual future extension. The idea of installing small-scale solar pumping systems in all villages of the Gambia is not realistic today owing to the present high cost of equipment. But prospects of a radical decline of prices of photovoltaic cells may cause a change in the near future. Then, the experience and the data of output, durability and reliability of a small-scale solar system, collected in a pilot installation, may be useful. This was the philosophy of this part of the project.

## 2. Insolation

Information about solar conditions is not consistent in the Gambia. The irradiation data are recorded at the seven previously mentioned meteorological stations using Gun-Bellani radiometers. The accuracy of these measurements is not high and the data obtained should be regarded as indicative rather than precise.

More pyranometers were installed in the stations of Yundum, Sapu and Basse in 1979, yet for various reasons they had not served more than two years in Sapu and Basse and several months in Yundum. Nevertheless, the data obtained are similar to those known from Senegal and appear reliable. A new pyranometer was installed in Kaiaf in connection with the photovoltaic installation; the length of the records is not yet sufficient to be useful.

Table 6 compares the measurements collected in Sapu and Basse in 1980 with a long-term average for Dakar (Senegal).

It can be seen that in the first half of the dry season (November-January) the irradiation is at its lowest, while at the end of the dry season (March-May) it is highest.

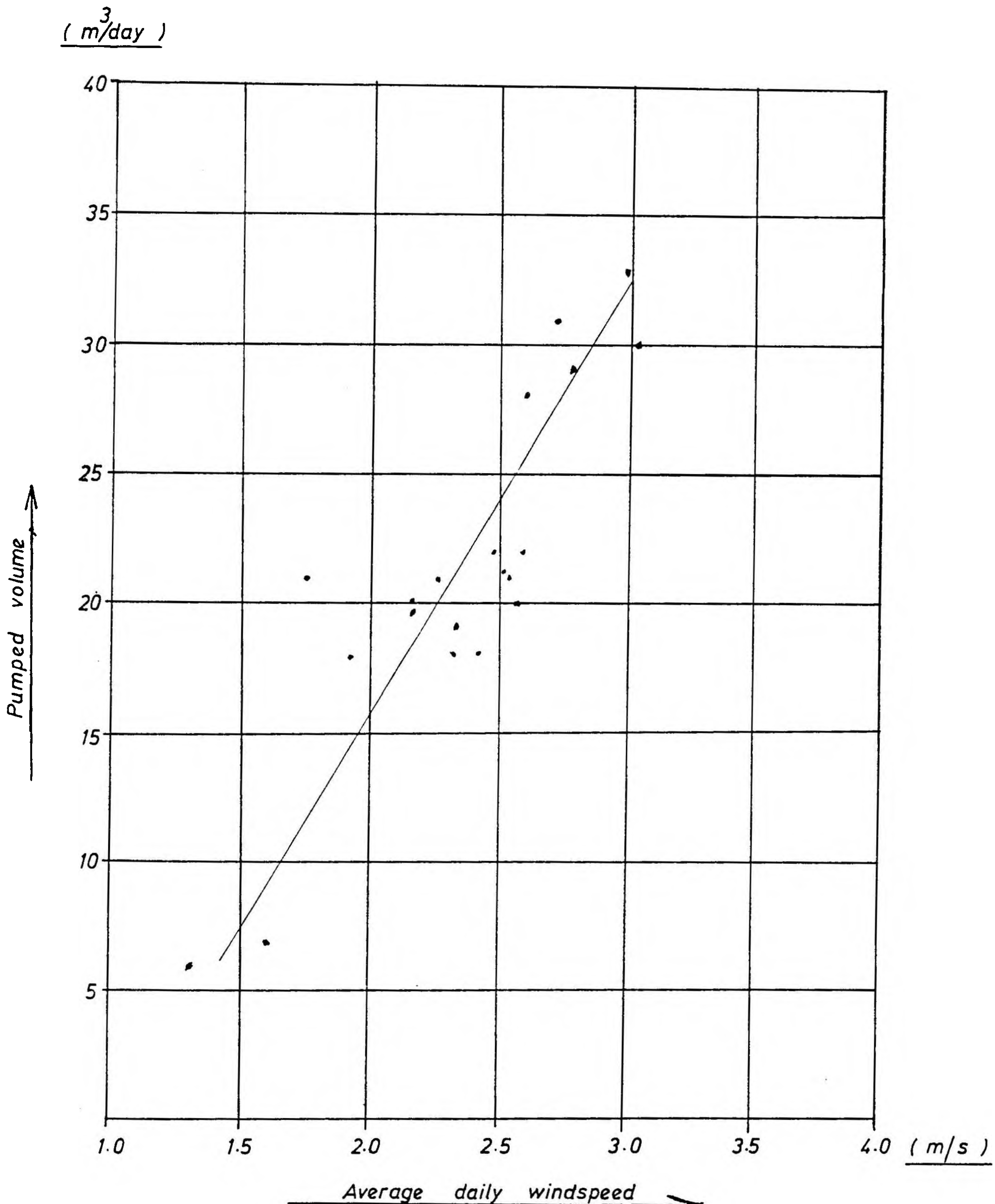



Figure 17. Daily production of windmill pumping system, Sara Kunda, June 1984

Table 6. Irradiation at Dakar (long-term average), Sapu and Basse (one-year records)

| Station | Dakar | Sapu | Basse |
|---|---|---|---|
| Month | Daily irradiation in langleys | | |
| January | 395 | 395 | 400 |
| February | 461 | 407 | 415 |
| March | 539 | 538 | 569 |
| April | 567 | 499 | 541 |
| May | 556 | 521 | 551 |
| June | 539 | 466 | 502 |
| July | 456 | 468 | 485 |
| August | 382 | 475 | 459 |
| September | 415 | 451 | 481 |
| October | 417 | 474 | 494 |
| November | 401 | 398 | 392 |
| December | 364 | 352 | 341 |

The sunshine time varies from 6 hours per day in rainy months (July, August) to 9 hours a day at the end of the dry season (March, April). If there is no direct correlation between the number of sunshine hours and irradiation, the reason is not only due to the position of the sun at different periods of the year, but also to the frequent high content of dust in the lower atmosphere. During the Harmattan (a dusty wind coming from the Sahara during the dry season), the irradiation may be considerably lower than normal even if there are no clouds. An expression "peak sun hours" sometimes appears in literature dealing with the use of solar energy, indicating hours when solar instruments are most efficient. The Gambia has 5.5 to 6 peak sun hours, which places this country among the most promising for the utilization of solar energy.

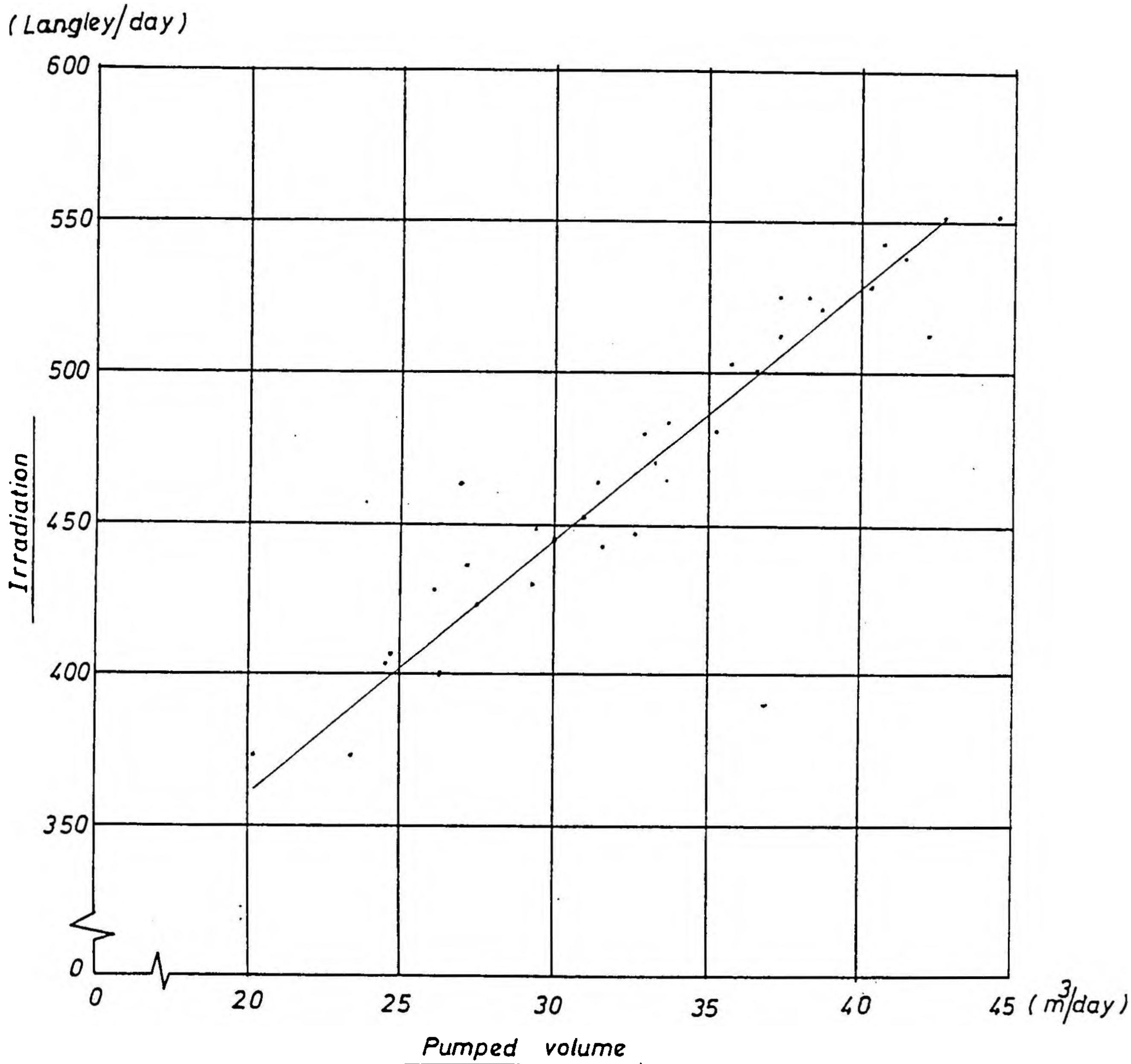
## 3. Site selection of pilot station

There was almost no limit given by solar conditions influencing the site investigation. A site was thus selected on the basis of such presumptions as: size of the village to be supplied by water, favourable hydrogeological conditions, and easy reach from the capital. The village of Mandina Ba (Western Division, Kombo Central District) with a population of about 1,000, had been selected by Mr. D. Starley, consultant for solar energy, in November 1982. Mandina Ba lies on the main road between Banjul and Soma some 35 km from the capital.

In September 1983, however, a decision by the Ministry of Water Resources and Environment came to change the site for another one outside the Western Division. A new site investigation was carried out and the village of Kaiaf (Lower River Division, Kiang East District) was selected (figure 18). The advantage of that choice was that the conditions, especially the depth of water table, were similar to Mandina Ba; so it was not necessary to change significantly the parameters of the system suggested for Mandina Ba. The greater distance from Banjul (180 km) and larger size of the village (population about 3,000) were less advantageous. If the whole village needs in future to be supplied by water from the photovoltaic installation, the system should be extended by more panels.

## 4. Selection of equipment

A photovoltaic system (e.g., system with direct conversion of light into electricity by means of silicon solar cells) has been considered as the most realistic choice. Storage of energy in batteries, presumed by the consultant Mr. D. Starley, was later dismissed, and a storage of water preferred. (The use of batteries for the substantial electrical storage would be more expensive and likely lead to major maintenance difficulties. The problem was analysed in "Supplementary Report on Solar Photovoltaic Water Pumps" by Mr. P. L. Fraenkel, consultant for renewable energy.)



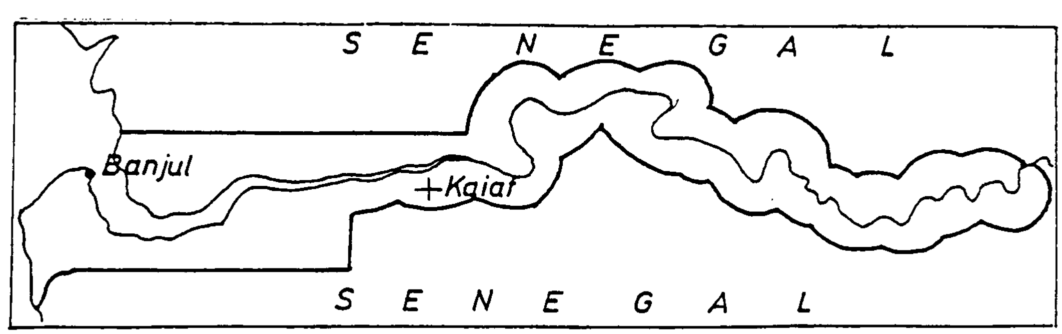




Figure 18. Irradiation and daily production of photovoltaic pumping system, Kaiaf (26 May-3 July 1984).
Geographical location of Kaiaf.

The system fitted for the conditions of the Gambia had to be:

1. fully automatic in operation;
2. free from features requiring regular maintenance or adjustment;
3. free from such hazardous features as lethally high voltages;
4. generally suitable for use in a rural village in a developing country;
5. economical, at the lower limit of the present market prices.

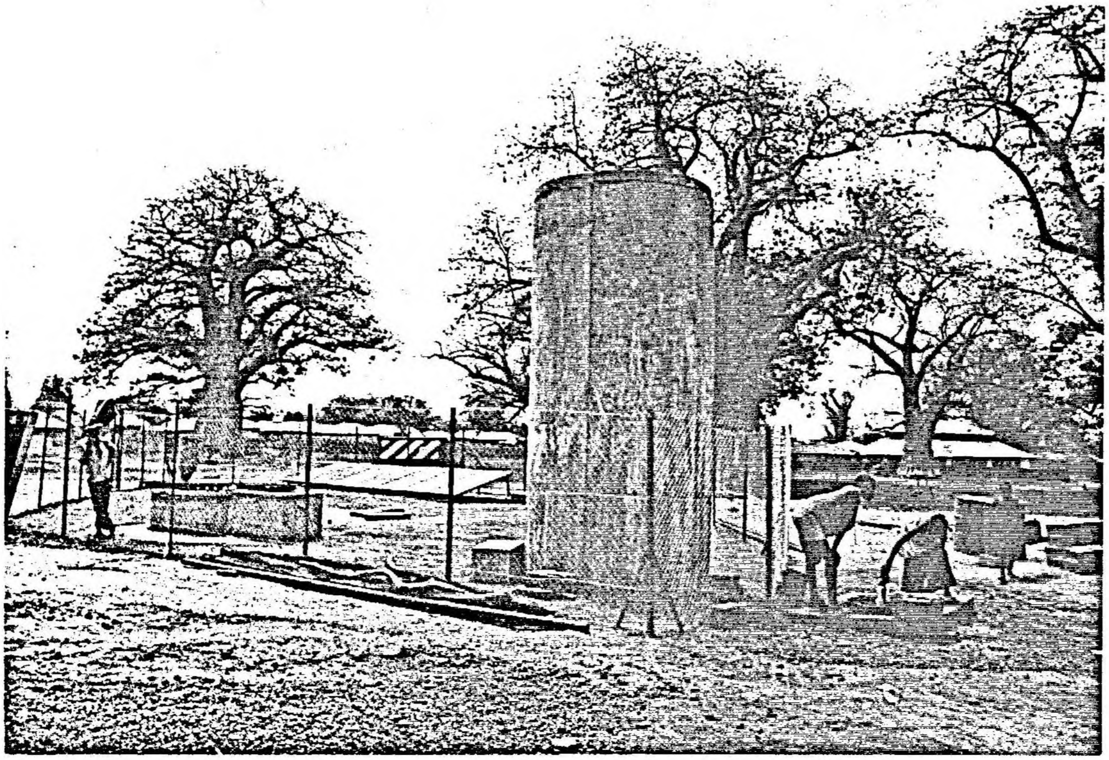
An average of 40 $m^3$/day was to be pumped through a static head of 19 m. This requirement for the yield had to be modified when the site of Mandina Ba was replaced by that of Kaiaf, where the static head was higher. A pumping rate of 30 $m^3$/day was then considered to be sufficient.

Bidding and selection of the supplier were directed from United Nations Headquarters. The Solarex Corporation (USA) was selected as a supplier whose technical and cost proposal was most convenient.

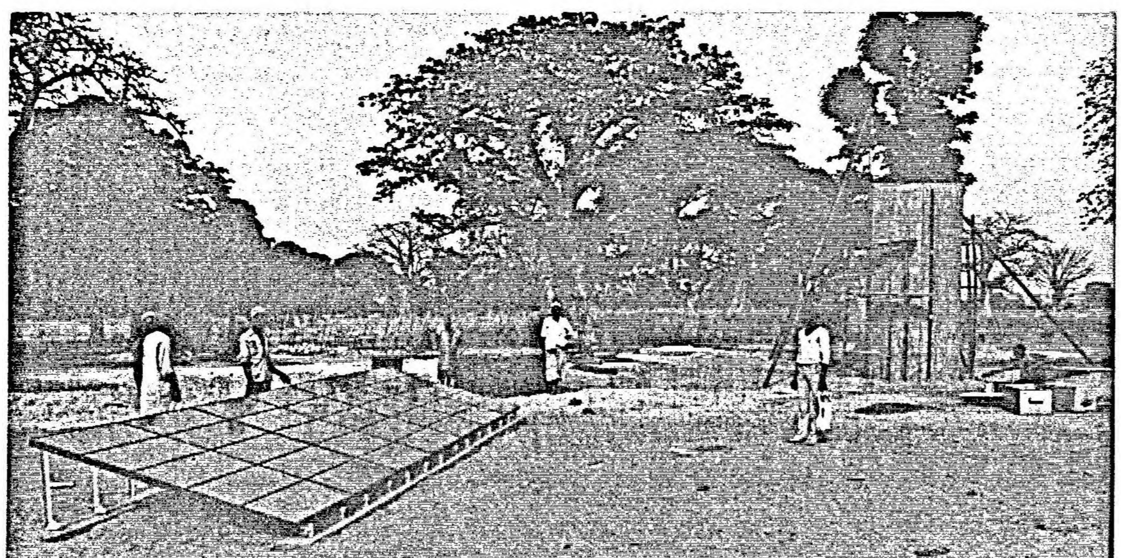
## 5. Installation at site

The work in the experimental site of Kaiaf included: construction of a new well, pumping test, construction of water storage tank, installation of array with photovoltaic cells and junction box, installation of pump and fencing. The installation of the photovoltaic equipment and pump took place between 18 and 22 May 1984. An acceptance test was carried out on 23 May 1984. Photographs 3 and 4 give two views of the installation.

The well in Kaiaf is 20 m deep, the water level before the start of pumping was 14.06 m under the surface. Transmissivity of the phreatic aquifer at the site is 60 $m^2$/ day. The water storage tank is built in concrete and has a diameter of 2 m; the height of it is 4.5 m, maximum water storage is 14.13 $m^3$. An overflow pipe connects the top of the tank with the well. The Solarex photovoltaic array consists of 35 type SX120 solar modules. The modules are arranged into seven panels, each containing five modules. The panels are formed by two vertical beams to which the modules are attached by mounting holes in their frames.



Photograph 3. Photovoltaic pumping installation, Kaiaf; pumps and storage tank in foreground, photovoltaic cell array left background.



Photograph 4. Photovoltaic pumping installation, Kaiaf; cell array at left, pumps in centre storage tank at right.

Further, the array consists of five strings of seven modules each. Each series string should develop approximately 120 V at peak power production, and total system current at peak power is approximately 11.5 amps.

At standard conditions (25°C, 1 kW/m²), the array peak power is 1,400 watts at 122.5 volts. Under operating conditions in the Gambia (28° - 30° daytime temperature), the temperature of the solar cells is increased above standard conditions (to approximately 60°C). At this temperature, array peak power should be about 1200 watts at 99 volts. The tilt of the array is adjusted according to the formula: local latitude plus 15°. In the Gambia, it equals 28°.

Output from the five series strings of the photovoltaic array are collected and combined at the junction box. The box also houses an inverter, watthour meter, pyranometer, array current meter (0-20 ADC), system voltmeter (0-150 VDC), and a run-time meter which measures and accumulates the time that the system is operating. The inverter (Grundfos type) accepts DC input from the photovoltaic array and yields variable frequency AC output. The pump Grundfos PS 8-4-(35-4) operates over a range of variable power produced by the motor. The inlet of the pump was placed 2 m above the bottom of the well.

## 6. Results at Kaiaf

The instrumentation of Kaiaf photovoltaic pumping station includes:

1. flowmeter (measuring the quantity of pumped water),
2. water-level meter (measuring the level of water in the well),
3. pyranometer (measuring irradiation),
4. watthour meter (measuring the energy consumed by the pump and integrating the instantaneous power over time),
5. current meter
6. system voltmeter, and
7. run-time meter (measuring and accumulating the time that the system is operating).

A programme of detailed observations took place immediately after the acceptancy test. Data from all instruments were collected at 30-minute intervals during daylight; 46 days of observations (26 May - 10 July) are available for this description. A period of the year corresponds to the beginning of the rainy season. However, only 5 days out of 46 were really rainy during daylight, while more frequently the amount of irradiation was influenced by clouds without rain.

In a normal day without dense clouds, the system in Kaiaf starts working between 9 and 9.30 a.m. At that time the array produces current of 2.5 - 2.6 amperes which is necessary for the pump to perform. The current then increases to reach top values (up to 11.2 amps) usually between noon and 2 p.m. The pumping cycle finishes at about 5 p.m. when the current is again under 2.5 amperes.

The volume of the pumped water is directly proportional to the irradiation, as can be seen in figure 19, showing one clear-day cycle in Kaiaf. Pumped volume is plotted against amount of irradiation on figure 18 to obtain a characteristic for the Kaiaf system. To get a volume of 30 $m^3$/ day, the irradiation of 430 langleys (5 kwh/$m^2$) per day is necessary.

The average daily pumped volume during 46 days was 30.52 $m^3$. Maximum volume was reached on 1 July 1984 (44.51 $m^3$), minimum on 16 June 1984 (3.37 $m^3$) when the system worked only two hours due to rain. The strongest current produced by the array was 11.2 amperes (15 June at 2 p.m. and 27 June at 1.30 p.m.). The irradiation varied from 172 langley/day (16 June) to 537 langley/day (1 July). The average for 46 days was 431.35 langleys per day.

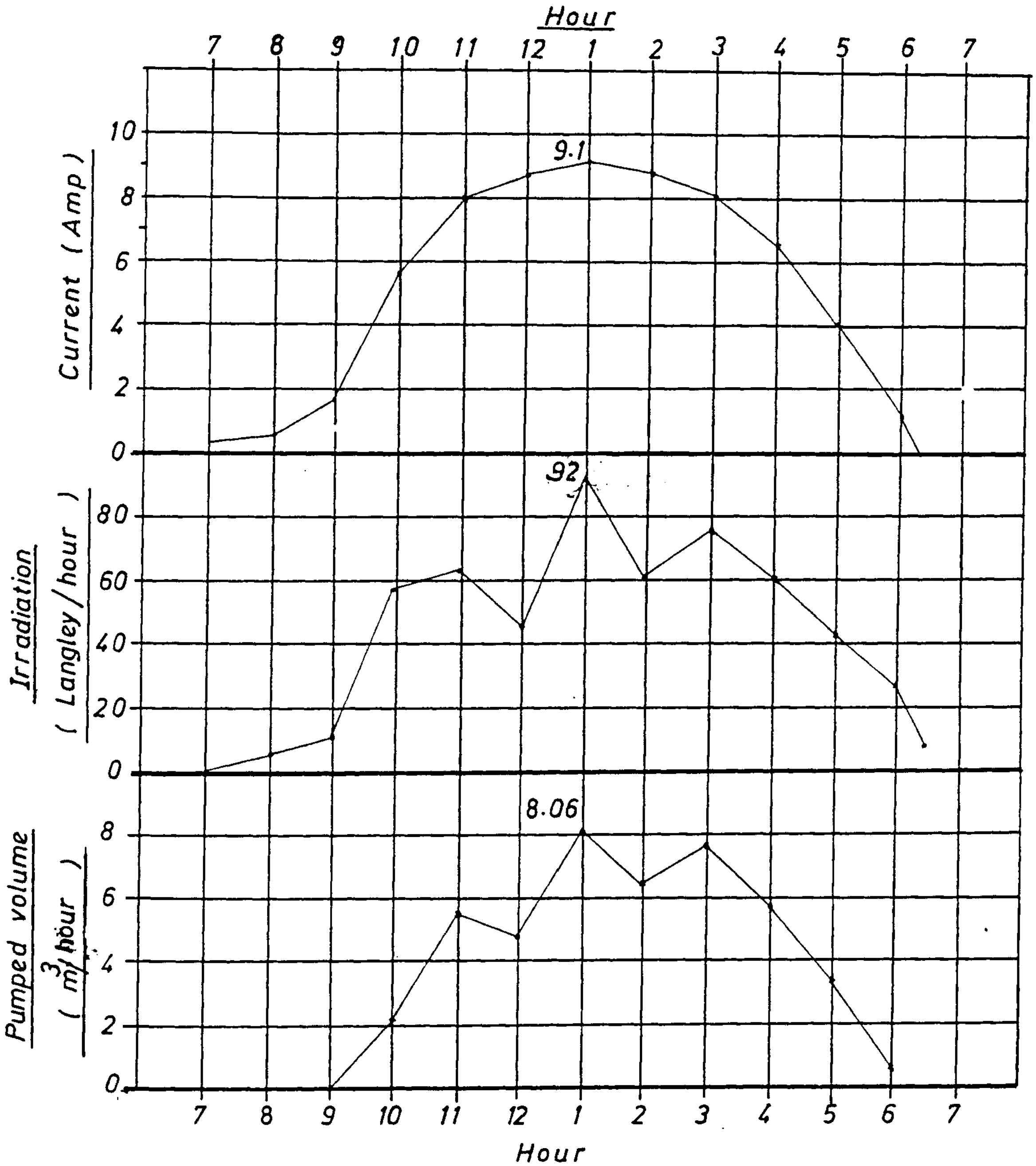



Figure 19. Daily cycle of photovoltaic pumping station, Kaiaf, 1 July 1984.

## III. UTILIZATION OF PROJECT RESULTS

### A. General note

A wide range of activities of the project provided various opportunities to make use of their results. A part of the activities, moreover, was directly predetermined to serve for immediate practical use at the same time as they served for collecting relevant data. It concerned primarily pilot pumping installations which have been supplying water for the population since they were installed.

The result of other activities is less visible, but significant nonetheless.

### B. Geophysics

A drilling programme was to start in the second half 1984 to continue during 1985. It was to be carried out within the Rural Water Supply Division of the Department of Water Resources. A proposal for the location of boreholes as well as for their technical parameters was prepared by the specialists of ~~the~~ project GAM-82-006 on the basis of the results of geophysical investigation. Were the programme put into practice, the main features recognized by geophysics, especially the composition of layers denominated as "DRU" (Deep Resistivity Unit) and "CEB" (Conductive Electrical Basement) could be verified. It could decide on the need for any further borehole drilling in the Gambia provided the pronounced frontier between two units also has hydrogeological significance.

## C. Monitoring programme

The records collected throughout a year were prepared to be at the disposal of any programme dealing with the phreatic aquifer in the Gambia. At present (1984), they can be useful especially for the UNSO project "National Strategy for the Environmentally Sound Management of Groundwater Resources" (GAM-82-004) which is aimed at an evaluation and management of ground-water reserves of Kombo Peninsula.

A number of levelled wells can be used for further observations and monitoring. If a modern observation network comes into existence, the results of monitoring in an extremely dry year would provide an important basis for comparison and correlation.

## D. Pilot pumping stations

After the windmill pumping systems were put into operation, both wells in Tanji and Sara Kunda became the main source of water for their respective villages.. The well in Tanji had been used before the windmill installation took place. Until then the only way to get water from the well was to draw it in buckets, and demand was rather low - 3.5 $m^3$ per day according to the recording in May 1983. After the water became available from taps, demand increased to 9 $m^3$ (in January 1984) and 10.5 $m^3$ (in April 1984).

As can be seen, only about half the water pumped out of the well is used in both cases; the rest goes back to the well. A distribution of water to several points of the village by a pipeline system is planned in Tanji. In Sara Kunda, it would be easy to lead the water from an overflow to a place suitable for gardening. The Department of Water Resources stipulated the right to decide on this.

For the well in Kaiaf, which has a solar pump, the distribution of the water is still more important. The tank is currently full shortly after mid-day but empty in the evenings and mornings at which times the villagers must rely on old traditional wells. There is no possibility to compare water demand before and after installing the photovoltaic system because the well did not exist.

## IV. FINDINGS

There are many positive results of the project. The fact that it was possible to fulfill all the tasks specified in the Project Document in reasonable time gives evidence about reserves and potentials existing in the country. The fruitful collaboration with the Senegalese partners, namely with LVIA Thies, showsthat even when resources in the Gambia are not sufficient, it is not always necessary to turn to developed countries for a solution. The purchase of the lifting windmills in Senegal is an example. It helped to solve one of the crucial problems of the project - the time shortage.

We can quote concretely the case of the windmill pumping station in Sara Kunda. It was only in the middle of February 1984 when the cost of the photovoltaic equipment became known. At that time it was clear that there were funds left, within the project budget, for purchase of a second windmill. It immediately took place and as early as 11 May 1984, the windmill, pump and water storage tank were ready to work. Only three months between the decision to purchase a windmill and its setting into motion may not seem to be a revolutionary achievement. It certainly is not, but specific conditions must be taken into account: a chronic lack of fuel, a long distance of Sara Kunda from Banjul (230 km) and the necessity to cross the river Gambia by ferry twice in each trip.

Another relevant fact, verified during implementation of the project, was not properly a finding but rather confirmation of what had been assumed: there are good and skilled workers in the Gambia, able to work on complicated and new tasks and to gain experience quickly. This human potential is somewhat hindered by a common lack of basic education of workers and by the little opportunity they have to assert themselves.

In contrast, however a certain lack of initiative among villagers was observed during installation of the pumps. Deeply rooted social customs result in many of the men being unproductive for long periods, while the women work most of the time. A fairer, more balanced and logical distribution of work and responsibilities among all villagers would contribute much to their general welfare.

## V. RECOMMENDATIONS

### 1. General note

Eighteen months of work on the project certainly give some idea about what is most needed in the field of ground-water investigation and utilization in the Gambia. The most important tasks are described in the Introduction. The recommendations traced in the following text concern directly the programme for the project and its activities.

Nevertheless, one general recommendation should be pointed out; no archives exist in the Department of Water Resources nor in any other institution of the Gambia for gathering documentation on ground water. Reports are stored in different divisions and with different persons and frequently the only way to find information is to locate the one person or institution responsible for the relevant document. This is time-consuming and unreliable; a central data bank or system of archives should be established to alleviate this problem.

### 2. Surface geophysical investigation

The recent geophysical survey provided new information about the geology and hydrogeology of the Gambia. Any future investigation must take these findings into consideration.

A geophysical survey of this type has a predominantly complementary character. Its aim is to complete findings obtained by drilled boreholes and wells, and to prepare premises for new boreholes and wells. Without documentation on any deep hydrogeological borehole in the Gambia, no interpreter of the geophysical investigation can avoid speculation on some important questions. Even if we repeat that surface geophysics, especially the electrical resistivity method, gave interesting results, we can hardly answer questions like: How is it possible that the division between "DRU" and "CEB" lies in more or less the same depth in the eastern and western parts of the country, while we assume that all complexes lie deeper and are considerably thicker in the western part? Or: How is it possible that a roof of Maestrichtian complex has not been detected to the south of Basse, where it most probably lies at about 200 m?

The answers to these and other questions are obviously to be found through drilling. Such is also the conclusion of the authors of the Final Report of CGG. They also suggest some modifications of both electrical and seismic methods to obtain results from deeper parts; but it would be unrealistic to carry out these rather expensive alternatives before drilling deep structural boreholes reaching the Eocene-Paleocene and Maestrichtian complexes.

The electrical resistivity method proved to be efficient in the field of salt water intrusion. The position of the interface dividing fresh and salt water can be detected quite safely to depths of approximately 100 m. Electrical soundings should be made before any well is drilled in the area adjacent to the sea and the lower part of the river Gambia. This might become one of the important activities of the Geophysical Unit, proposed to work within the Rural Water Supply Division of the Department of Water Resources.

## 3. Ground-water observation network

Even if we tried to avoid error in monitoring by including a rather high number of wells in a dense network, it is clear that the information obtained is not accurate. There are such factors as daily utilization of wells or their insufficient depth which influence the results both of observations of fluctuation of levels and chemistry of water.

Precise information about the phreatic aquifer is necessary and the period of measurement should not be limited to the time of duration of this or any other project. While continual collecting of meteorological data is considered normal, ground-water data are still collected more or less randomly. Most programmes dealing with ground-water include temporary monitoring of wells, but the information is not consistent and there are gaps between different programmes.

In a situation with an increasing stress on ground water it is of utmost importance that general plans for the use of water be developed in order to regulate future operations in an optimal way. The phreatic aquifer in the Gambia should be the first to be studied in detail because of its importance for rural water supply.

The establishment of a national ground-water observation network seems to be a natural stage in ground-water development. The network would consist of a number of drilled wells with piezometers equipped with screens to enable regular measurements and sampling. The depth of the piezometers should be at least 10 m below the water table, i.e., as deep as 40 m throughout most of the Gambia. The piezometers should be equipped with automatic water-level recorders. If they are not immediately available, the observation programme should be as shown in table 7.

Table 7. Ground-water observation network, frequency of observation

| Parameter | Number of observations per year |
|---|---|
| Ground-water level | 24 |
| Ground-water temperature | 24 |
| Ground water chemistry | 2 |

A minimum programme for the hydrochemical analyses should collect the following elements of data:

| | |
|---|---|
| temperature | sodium (Na) |
| electrical conductivity (Ec) | potassium (K) |
| oxygen ($O_2$) | magnesium (Mg) |
| pH | calcium (Ca) |
| alkalinity | iron (Fe) |
| chloride (Cl) | manganese (Mn) |

sulfate (SO)　　　　　　　　　nitrite (NO)

nitrate ($NO_3$)　　　　　　　ammonia ($NH_4$)

The existing meteorological stations or their surroundings could serve as bases for observation of ground water as well. From them, Kerewan, Sapu and Jenoi seem to be without problems for this purpose, in Yundum and Basse a suitable location should be found in the surroundings; Banjul and Georgetown are unsuitable.

With three observation points in each of five divisions, the area of the Gambia would be covered in a basic way; the establishing of 15 piezometers could be considered the first stage of setting a representative network. The cost of this first stage (establishment only, not observations) would be up to $US150,000.

Then, the collection of basic data on ground-water conditions could start, for the:

1. study of the interrelationship between ground water, climate and weather;
2. study of the influence of geology on ground water, including properties of the aquifer, topography, vegetation, unsaturated zone, etc;
3. study of the role of the phreatic aquifer in the hydrologic cycle; and
4. investigation of relationships between ground-water level chemistry and temperature in order to assess the implication of turnover and recharge.

The data so obtained would fill a gap in information about the phreatic aquifer and would be a valuable source for reference purposes, prediction measures, environmental control and estimation of resources.

4. <u>Installation of new windmill pumping units</u>

a. <u>Suitability of terrain</u>

We showed in Chapter II that at least half the territory of the Gambia is quite suitable for pumping water using wind energy. Provided the initial cost of the equipment is comparable with that for fuel-powered pumping installations, the advantage of windmills which need no fuel is obvious. The average daily production of a windmill may be 20 $m^3$ and more, as our experience shows. This quantity should secure a supply for a population of 600 if the daily consumption is calculated as 30 litres per head, but much more if the present consumption is taken into account.

In the villages of Kombo Peninsula as well as in the western part of North Bank Division, it seems that having a good well or borehole which is not surrounded by high trees is the only condition for mounting a windmill. The average windspeed of 3 m/s, necessary for good work of most systems, is available at 10 m.

In the eastern parts of Western Division, North Bank Division as well as in Lower River Division, a high tower and a rotor of large diameter are necessary. The average windspeed at 10 m does not reach 3 m/s. Only a system with a low cut-in windspeed can be successful.

The eastern Gambian divisions (MacCarthy Island Division, Upper River Division) are not recommended for windmill installations, with the possible exception of some open areas on the northern bank of the river.

b. Elements to be considered

Erection of a windmill and installation of its pump is not a long operation, if done by an experienced team. But any planning of windmill installations must allow for additional work on a water storage tank and water distribution system (which take more time than building a windmill). Problems of fuel, transport, supply of cement, reinforcement rods, lumber, rock, gravel and sand might considerably affect the work. The most important factor to be considered in planning windmill installations is, however, the human one. If there is not a team of at least 10 technicians and workers able to construct, repair and maintain windmills, it is not feasible to even consider a windmill programme. The training of such a team can take as much as half a year; in that time, participation of the trainees on concrete works of preparation, erection, repairs and maintenance of windmills is desirable. The training should be organized by the firm from which the windmills would be purchased. The presence in the Gambia of an engineer specialized in windmill installations, at least in the first stage of the programme, would be necessary as well.

c. Selection of supplier

In a recent Catalogue of windmachines" (CWD 84-2, February 1984), about 60 different firms supplying water-lifting windmills are cited. About a third of these firms offer windmills suitable for Gambian conditions. Some of them are relatively cheap: the prices range from $US3,000 to $US12,000. The cost of freight must be added; it is sometimes considerable if the suppliers are from Australia, New Zealand or Argentina for example.

Some suppliers have long years of experience and a good reputation and deserve preference if the selection is made from foreign firms. Such companies as Dempster Industries, Aermotor (both USA), Southern Cross or Varcoe (both Australia) offer a wide variety of products at reasonable prices. Numerous reasons can be given for continuing to keep contact with the products of Tozzi and Bardi and with LVIA Thies:

1. The windmills supplied and installed by LVIA proved to be adequate to Senegambian conditions (about 15 of them working now in Senegal, 2 in the Gambia).
2. The windmills are supplied together with brick storage tanks which fit to the daily production of windmill pump and enable easy distribution.
3. LVIA produces all parts except for pumps and heads (engines) on their own workshop in Thies. The distance from Thies to the Gambian frontier being 220 km on good roads, there is no problem to get whatever is needed in a reasonable time.
4. Training of Gambian personnel could be easily organized in the Thies workshop and on the sites of installations.

5. The price of a 16-m-high, 6-m-diameter windmill was $US 9,000 in 1983-1984. It included transport, installation and the construction of a water-storage tank. LVIA (Tozzi and Bardi) windmills are among those at moderate prices.
6. Preliminary, but non-binding, negotiation has already taken place between the chief engineer of LVIA and the team leader of GAM-82-T01. LVIA is ready to continue in collaboration if a new programme is started.

d. Outline of a programe

A two-year programme should continue after the pilot programme. This would include:

1. Training of Gambian personnel;
2. Selection of suitable sites;
3. Preparation of sites;
4. Continuing windspeed investigation; and
5. Construction of windmill pumping stations.

A realistic number of windmills would be 15 to 20. The construction of water storage tanks would be included as well as eventual later distribution network for some installations.

The programme should be financed separately or it could be a part of a bigger project including, tentatively, further development of photovoltaic installations and other activities.

As soon as the financing possibilities and conditions are known, it would be relatively easy to prepare a detailed Project Document on the basis of findings from this project. All documentation is available either in this report or in the Rural Water Supply Division.

5. Installation of new photovoltaic units

While it was necessary to find out the wind speed in different areas for windmill installations, this territorial problem does not exist for photovoltaic installations in the Gambia. But another problem exists: that of the high price of equipment.

If we compare the prices of windmill and photovoltaic equipment used in this project, then we find the photovoltaic installation to be three times as expensive as windmills. In conditions of approximately the same hydraulic head it pumped 20 per cent more water than the Tanji and 33 per cent more than the Sara Kunda windmills. While windmills can supply water at any time, day or night, the photovoltaic system provides it only for eight hours a day at best. With a relatively small tank it means that there is more water than needed for two or three hours of peak solar intensity ( in the early afternoon ) while in the mornings, the tank may be empty. So it is clear that a big storage tank or a sophisticated system of distribution is necessary for a photovoltaic system which further increases its cost.

Solarex Corporation happened to be the company whose system was accepted for a pilot installation. After the first months of work of the station it seemed reasonable to continue collaboration with the same company, if there are means to finance other photovoltaic stations.

As the initial costs are rather high, a thorough analysis should precede site selection. In the Gambian context, the places where windmill installation is not feasible should have priority. That means that MacCarthy Island Division and Upper River Division are the natural choices.

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## Annex 1

PROJECT STAFF

| Post Description | Name of incumbent | Full (F) or part time (PT) | Month assumed duty (1983) |
|---|---|---|---|
| | A. International staff | | |
| Team Leader | V. Plesinger (Czechoslovakia) | F | February |
| | B. National staff | | |
| Assistant | B. Njie | F | April |
| Assistant | G. Corr | F | June |
| Assistant | A. Jabbi | F | June |
| Driver | W. Sima | F | April |
| Driver | J. Gibba | F | April |
| Senior Surveyor | B. Lemon | PT | March |
| Surveyor Leveller | S.B.M. Njie | PT | March |
| Surveyor | T. Sebeh | PT | March |
| Surveyor | F. Camara | PT | March |

Annex 3

MONITORING PROGRAMME - LIST OF WELLS

| Number | Village | Co-ordinates | Map Sheet 1:50000, No. | Location |
|---|---|---|---|---|
| 1 | Berrending | 53 - 11 | 22 | Just past school from Gunjur |
| 2 | Bator Sateh | 54 - 08 | 22 | From Gunjur left side, about 200 m before beach. |
| 3 | Kulu Koch I | 56 - 09 | 22 | Demba Sanneh compound |
| 4 | Gunjur II | 57 - 10 | 22 | Opposite Bai Jobe's compound close to mosque |
| 5 | Gunjur III | 57 - 10 | 22 | Inside Health Centre |
| 6 | Kunkujang | 62 - 11 | 22 | Inside Alkali's compound |
| 7 | Nyofelleh | 61 - 14 | 22 | Butte Gibba's compound in the village |
| 8 | Nyofelleh Madina I | 62 - 15 | 22 | Only A/C well in village,first well in village from Brikama. |
| 9 | Nyofelleh Madina II | 62 - 15 | 22 | Opposite Bakery Badgie's compound. |
| 10 | Kassa Kunda | 64 - 17 | 22 | Opposite Landing Sanyang compound |
| 11 | Sala | 57 - 13 | 22 | Inside big garden owned by Modou Salifu Jallow;on way from Gunjur to Brikama |
| 12 | Sifoe I A/C | 58 - 17 | 22 | Opposite Alhagi Njai compound |
| 13 | Sifoe II UN | 58 - 17 | 22 | Behind the market, directly opposite Bakary Darboe |

| Number | Village | Co-ordinates | Map Sheet 1:50000, No. | Location |
|---|---|---|---|---|
| 14 | Kiti | - | 22 | - |
| 15 | Kiti Manjago | 64 - 20 | 22 | Inside Bernard Mendy's compound |
| 16 | Kabekel | 60 - 21 | 22 | Inside Salieu Sanyang's compound |
| 17 | Marakissa I | 61 - 21 | 22 | Between Seedy Tournay and Burama Jallow's compounds |
| 18 | Marakissa II UN | 61 - 21 | 22 | Opposite Pa Fadera in an open place |
| 19 | Manduar | 64 - 23 | 22 | Only well with motor pump in village,before Saikouba Bojang's |
| 20 | Djalabango | 63 - 18 | 10 | Opposite Yoro Jallow's compound |
| 21 | Brikama I | 66 - 22 | 10 | Inside Lamin Gibba's compound,near mosque and market |
| 22 | Brikama II | 67 - 22 | 10 | Inside Methodist Mission Workshop Centre(G.C.C. Programme Centre) |
| 23 | Kaimbujae | 69 - 25 | 10 | Inside Nyambi Saho's compound(N.Saho Kunda) |
| 24 | Bako | 68 - 27 | 10 | Opposite Salifu Jarju's compound,south main road |
| 25 | Madina Ba I | 68 - 28 | 10 | Near Lang Filly Sammu behind village |
| 26 | Madina Ba II UN | 68 - 28 | 10 | At curve to Tubakuta on right hand side |
| 27 | Tubakuta | 66 - 27 | 10 | Opposite Foday Conteh's compound |
| 28 | Kuloro | 68 - 29 | 10 | Inside School compound |
| 29 | Kuloro | 68 - 29 | 10 | After Dembo Touray's compound |

| Number | Village | Co-ordinates | Sheet of Map 1:50000 No. | Location |
|---|---|---|---|---|
| 30 | Dumbutu | 75 - 10 | 13 | East from road, back of Alkali's compound |
| 31 | Wurokang | 79 - 12 | 13 | East from road, Ousman Camara's and Omar Camara's compound |
| 32 | Kwinella | 80 - 14 | 13 | Road to Tendaba, before Lanyarr Sanyang's comp. |
| 33 | Bumari | 81 - 15 | 13 | In front of Alkali's compound |
| 34 | Bambako | 82 - 17 | 13 | 50 m from main road left side from Banjul, before Kebba Darboe's compound |
| 35 | Nema | 82 - 18 | 13 | Inside school compound |
| 36 | Kunong Mansa-Sansang | 83 - 20 | 14 | First comp. in village 20 m from main road, behind Alkali's compound |
| 37 | Kunong Fula Kunda | 83 - 21 | 14 | Inside Alkali's comp. centre of village |
| 38 | Kunong Numu Kunda | 83 - 22 | 14 | 50 m from main road, opposite Momodou Sarr's compound |
| 39 | Jirroff | 84 - 23 | 14 | North-west edge of village past Cherno Sabally's compound |
| 40 | Nema Kuta | 83 - 25 | 14 | 20 m from main road, front of landing Sanyang's compound |
| 41 | Jatta Kunda | 80 - 25 | 14 | Behind Samba Colley's compound |
| 42 | Sare Sarjo | 78 - 26 | 14 | Back of village from Soma, behind Demba Ceesay's compound |

| Number | Village | Co-ordinates | Sheet of Map 1:5000 No | Location |
|---|---|---|---|---|
| 43 | Njolfen | 77 - 29 | 14 | Surrounded by two compounds owned by Burama Jallow and Omar Colley |
| 44 | Munkutalla | 79 - 35 | 14 | Back of Alkali's comp.,the only Gov't. well in village. |
| 45 | Sare Fonkoi (Kohel) | 82 - 40 | 14 | Surrounded by 3 compounds owned by Amadou Touray, Yoro Jallow and Momodou Salifu Jallow |
| 46 | Sare Saide | 78 - 38 | 14 | Behind Kebba Ceesay's comp.,only and first UN well in village |
| 47 | Kolior | 82 - 28 | 14 | Near main road directly opposite Kebba Camara's compound |
| 48 | Kolior | 84 - 27 | 14 | Centre of village, opposite mosque |
| 49 | Jomarr | 85 - 27 | 14 | Near road to Jasobo,owned by Alh.Kawsu Camara the village alkali |
| 50 | Jasobo | 88 - 27 | 14 | Centre of village, inside Sarjo Colley's compound |
| 51 | Yoro Jula | 82 - 29 | 14 | Behind village fr. Banjul,about 125 m fr. main road. |
| 52 | Massembe | 83 - 31 | 14 | Inside village, beside Karambi Jarbi's comp. |
| 53 | Genieri | 83 - 33 | 14 | Centre of village opposite mosque. |
| 54 | Kaiaf | 82 - 34 | 14 | Close to main rd. (north) |

| Number | Village | Co-ordinates | Sheet of Map 1:50000 No. | Location |
|---|---|---|---|---|
| 55 | Jiffin | 83 - 36 | 14 | Centre of village behind Lamin-Fadera compound |
| 56 | Toniataba | 85 - 37 | 14 | Centre of village near Bantaba before mosque |
| 57 | Si-Kunda | 85 - 39 | 14 | Centre of village first well from Toniataba by back road,opposite Bantaba owned by Alkali |
| 58 | Soma | 85 - 42 | 14 | Road to Cassamance, in front of Kebba Demba's compound |
| 59 | Jenoi | 90 - 39 | 14 | 2nd to last compound before Agricultural Centre |
| 60 | Jenoi | 90 - 39 | 14 | At Agricultural Centre (M.F.C.) |
| 61 | Mansakonko | 87 - 42 | 14 | At Health Centre |
| 62 | Sankwia | 88 - 43 | 14 | In open place north-west edge of village opposite Talabeh Sanyang's compound |
| 63 | Kanikunda | 86 - 44 | 14 | Inside school compound |
| 64 | Karantaba | 85 - 44 | 14 | Back of Mbosey Fofana's compound under mango tree |
| 65 | Biranoya | 82 - 42 | 14 | First well before entering village from Soma |
| 66 | Misira | 79 - 42 | 14 | Inside school compound |
| 67 | Sabi | 63 - 87 | 20 | Near Bantaba |
| 68 | Sare Yoro Cheke | 64 - 88 | 20 | Edge of village |
| 69 | Kumbija | 66 - 89 | 20 | Opposite mosque |
| 70 | Kumbija II UN | 66 - 84 | 20 | After village to Sare Bona |
| 71 | Sare Bona | 68 - 91 | 20 | Next to Dampha Baldeh's compound |

| Number | Village | Co-ordinates | Sheet of Map 1:5000 No. | Location |
|---|---|---|---|---|
| 72 | Basse | 71 - 85 | 20 | About 100 m past Basse from Banjul at fence of compound |
| 73 | Kabakama | 70 - 86 | 20 | West edge of village |
| 74 | Giroba Kunda | 70 - 88 | 20 | Near and south of laterite road |
| 75 | Bassending | 71 - 85 | 20 | Inside Samo's compound |
| 76 | Alohungari | 72 - 82 | 20 | Left side from Banjul - 100 m from main road |
| 77 | Kerewan | 78 - 84 | 20 | South-west edge of village |
| 78 | Taibatu | 78 - 84 | 20 | East edge of village,before branch to Madina Koto |
| 79 | Bani | 79 - 82 | 20 | West edge of village |
| 80 | Sutukonding | 79 - 85 | 20 | East edge of village |
| 81 | Yorobawal | 84 - 86 | 20 | West edge of village |
| 82 | Koli Bantang | 85 - 87 | 20 | Out of village,near benchmark |
| 83 | Samba Kabude | 85 - 87 | 20 | West edge of village |
| 84 | Sare Dadi | 86 - 88 | 20 | Between Sare Dadi and Sare Pateh |
| 85 | Kuonkunding | 88 - 87 | 20 | West edge of village |
| 86 | Tuba Wappa | 88 - 83 | 20 | Before the village from Basse (N) |
| 87 | Sare Ngaba | 89 - 84 | 20 | Behind village |
| 88 | Sare Hamadi | 90 - 86 | 20 | North-west edge of village |
| 89 | Jar Kunda | 90 - 87 | 20 | Inside camp |
| 90 | Dampha Kunda | 73 - 89 | 20 | When entering village fr. Basse,among 1st wells on road |

Annex 4

## FLUCTUATION OF GROUND-WATER LEVEL

Dip under top of parapet

| No. | Village | Type of well | Elevation A.S.L. | 6/83 | 7/83 | 8/83 | 9/83 | 10/83 | 11/83 | 12/83 | 1/84 | 2/84 | 3/84 | 4/84 | 5/84 | pH | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Berending | UN | 14.25 | 14.17 | | 14.35 | 14.45 | 14.36 | 14.37 | 14.55 | 14.78 | 15.35 | 15.20 | 15.10 | 14.99 | 6.0 | 114.1 |
| 2. | Bator Sateh | TRAD | 9.54 | 10.26 | 10.34 | 10.34 | 10.34 | 10.40 | 10.42 | 10.48 | 10.74 | 10.78 | 10.80 | 10.65 | 10.68 | - | - |
| 3. | Kolu Koch | TRAD | 16.45 | 13.33 | 13.51 | 13.64 | 13.69 | 13.86 | 13.85 | 13.98 | 14.01 | 14.18 | 14.10 | 14.28 | 14.33 | 6.1 | 50.03 |
| 4. | Gunjur | A/C | 14.77 | 9.92 | 10.05 | 10.00 | 9.69 | 9.97 | 9.97 | 10.45 | 10.40 | 11.00 | 10.85 | 11.00 | 11.01 | 5.3 | 110 |
| 5. | Gunjur | UN | 16.69 | 11.25 | 11.50 | 11.51 | 11.91 | 11.60 | 11.55 | 12.05 | 11.98 | 11.98 | 11.90 | dry | dry | 5.5 | 78.6 |
| 6. | Kunkujang | PWD | 17.02 | 11.70 | 11.70 | 11.73 | 11.66 | 11.70 | 11.80 | dry | dry | 12.15 | 12.10 | 12.26 | 13.03 | - | - |
| 7. | Nyofelleh | TRAD | 21.22 | 14.42 | 14.56 | 14.60 | 14.76 | 14.85 | 15.15 | 15.46 | 15.18 | 15.23 | 15.20 | 15.23 | dry | 5.5 | 40 |
| 8. | Nyofelleh Madina I | TRAD | 23.22 | 15.55 | 16.02 | 15.75 | 16.00 | 16.10 | 16.20 | 16.92 | 16.38 | 16.52 | 16.40 | 16.50 | 16.30 | 5.5 | 56.6 |
| 9. | Nyofelleh Madina II | UN | 22.85 | 16.25 | 16.40 | 16.05 | 17.84 | 17.74 | 16.98 | 16.40 | 16.78 | 16.90 | 16.95 | 16.90 | 16.93 | 5.9 | 73 |
| 10. | Kassa Kunda | TRAD | 18.08 | - | 10.80 | - | 10.77 | 10.99 | 10.64 | 10.98 | 11.56 | 11.68 | 12.05 | 11.90 | 12.65 | 5.8 | 106 |
| 11. | Sala | TRAD | 9.60 | 9.45 | 9.10 | 9.48 | 9.71 | 9.22 | 9.16 | 8.10 | [illegible] | 10.06 | 10.02 | [illegible] | 10.30 | 5.7 | 85.5 |
| 12. | Sifoe | A/C | 11.13 | - | - | - | 9.32 | 9.39 | 9.64 | dry | 10.87 | 10.98 | 10.65 | 10.75 | 10.93 | 6.5 | 120 |
| 13. | Sifoe | UN | 12.88 | 11.05 | 11.20 | 11.10 | 10.74 | 11.30 | 10.97 | 11.45 | 11.40 | 11.50 | 11.45 | 11.80 | 12.49 | 6.2 | 80 |
| 14. | Kiti | UN | 19.72 | 12.77 | 13.02 | 12.98 | 13.03 | 12.96 | 13.00 | - | - | closed | - | - | - | - | 94.5 |
| 15. | Kiti Manjago | TRAD | 22.80 | 15.05 | 15.33 | 15.33 | 15.25 | 15.31 | 15.34 | 15.40 | 15.52 | 15.58 | 15.45 | 15.55 | 15.94 | 5.1 | 58.4 |
| 16. | Kebekel | TRAD | 15.87 | 11.55 | 11.81 | 11.76 | 11.81 | 12.57 | 12.06 | 12.10 | 12.12 | 12.37 | 12.50 | 12.42 | 12.56 | 6.2 | 46.4 |
| 17. | Marakisa I | A/C | 16.98 | 11.62 | 11.97 | 11.84 | 12.08 | dry | dry | dry | dry | dry | dry | 12.30 | 12.39 | - | - |
| 18. | Marakisa II | UN | 17.76 | 12.25 | 12.36 | 12.39 | 12.46 | 12.55 | 12.55 | 12.70 | 12.75 | 12.93 | 12.86 | 13.00 | 13.06 | 5.8 | 46.3 |
| 19. | Mandur | UN | 21.44 | 12.80 | 12.92 | 12.88 | 12.92 | 13.04 | 13.23 | - | - | closed | - | - | - | - | - |
| 20. | Djalaban Go | TRAD | 26.34 | 17.25 | 17.34 | 17.31 | 17.58 | 17.40 | 17.58 | 17.83 | 17.75 | 18.00 | 18.05 | 17.90 | 17.88 | 4.2 | 66.2 |
| 21. | Brikama | TRAD | 22.43 | 13.70 | 13.82 | 13.82 | 13.61 | 13.73 | 14.05 | 14.02 | 14.35 | 14.40 | 14.05 | 14.42 | 14.64 | 6.7 | 31.8 |
| 22. | Brikama | A/C | 18.47 | 9.87 | 9.81 | 9.86 | 9.60 | 9.66 | 9.85 | 10.00 | 10.40 | 12.21 | 10.28 | 10.50 | 10.56 | - | - |
| 23. | Kaimbujae | TRAD | 15.42 | 9.13 | 9.20 | 8.99 | 9.07 | 8.95 | 9.10 | 9.37 | 9.20 | 9.37 | 9.35 | 9.80 | 9.73 | 5.7 | 57 |
| 24. | Bako | A/C | 18.42 | 10.45 | 10.40 | 10.49 | 10.45 | 10.55 | 10.48 | 10.50 | 10.46 | 10.50 | 10.70 | wrong measurement | 10.60 | [illegible] | 48 |

NOTES: UN = United Nations, TRAD = traditional, A/C = Area Council, PWD = Public Works Department, pH = Alkalinity-acidity index, EC = electrical conductivity

| No. | Village | Type of well | Elevation A.S.L. | Dip under top of parapet 6/83 | 7/83 | 8/83 | 9/83 | 10/83 | 11/83 | 12/83 | 1/84 | 2/84 | 3/84 | 4/84 | 5/84 | PH | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Madina Ba | A/C | 19.93 | 9.45 | 9.42 | 9.46 | 9.42 | 9.50 | 9.55 | 9.70 | 9.80 | 9.68 | 9.75 | 9.73 | 9.76 | 5.6 | 171 |
| 26 | Madina Ba | UN | 17.36 | - | - | 12.16 | 12.17 | 12.27 | 12.22 | 12.32 | 12.48 | 12.38 | 12.45 | 12.56 | 12.58 | | |
| 27 | Tubakuta | TRAD | 23.64 | 15.78 | 15.82 | 15.95 | 15.90 | 15.47 | 16.05 | 17.12 | 16.33 | 16.35 | 16.30 | 16.75 | 16.48 | 5.1 | 33 |
| 28 | Kuloro I | A/C | 24.17 | 18.05 | 18.07 | 18.10 | 18.10 | 18.36 | 18.30 | 18.45 | 18.39 | 18.36 | 18.40 | dry | dry | 5.5 | 38 |
| 29 | Kuloro II | UN | 26.07 | 19.39 | 19.50 | 19.46 | 19.58 | 19.84 | 19.62 | 19.65 | 19.80 | 19.80 | 19.82 | 19.90 | 20.02 | 5.6 | 50 |
| 30 | Dumbutu | A/C | 27.12 | 26.05 | 25.68 | 25.33 | 25.47 | 26.50 | 26.40 | - | 25.80 | - | - | 26.20 | 25.70 | - | 53.1 |
| 31 | Wurokang | TRAD | 15.49 | 15.85 | 15.25 | 14.52 | 14.60 | 15.40 | 16.90 | - | 15.71 | - | - | 15.80 | 16.10 | - | 43 |
| 32 | Kwinella | TRAD | 15.46 | 13.90 | 14.05 | 14.10 | 14.12 | 14.10 | 14.20 | - | 14.40 | - | - | 14.33 | 14.50 | 5.6 | 100 |
| 33 | Bumari | TRAD | 17.48 | 16.72 | 15.53 | 16.48 | 16.60 | 16.87 | 16.60 | - | 16.90 | - | - | 16.90 | 17.10 | - | 43 |
| 34 | Bambako | TRAD | 11.06 | 11.34 | 10.29 | 10.10 | 10.16 | 10.82 | 10.70 | - | 11.16 | - | - | 11.30 | 11.55 | - | 43 |
| 35 | Nema | UN | | 19.88 | 19.91 | 19.95 | 19.96 | 20.10 | 20.12 | - | 20.15 | - | - | 20.20 | 20.10 | - | |
| 36 | Kunong Mansasan-sang | A/C | 11.23 | 9.38 | 9.20 | 9.15 | 9.11 | 9.20 | 9.10 | - | 9.50 | - | - | - | 9.50 | - | 53 |
| 37 | Kunong Fula Kunda | A/C | 16.91 | 15.59 | 15.70 | 15.50 | 15.50 | 15.50 | 15.55 | - | 15.70 | - | - | 16.15 | 16.10 | 5.1 | 67 |
| 38 | Kunong Numu Kunda | TRAD | 18.43 | 15.35 | 15.49 | 15.18 | 15.21 | 15.50 | 15.30 | - | 15.40 | - | - | 16.39 | 15.60 | 5.3 | 45.4 |
| 39 | Jiroff | TRAD | 20.51 | 13.34 | 17.05 | 16.76 | 17.28 | 17.30 | 17.00 | - | 17.14 | - | - | 17.32 | 17.20 | - | 100 |
| 40 | Nema Kuta | A/C | 19.89 | 15.80 | 15.62 | 15.60 | 15.57 | 15.84 | 15.80 | - | 16.06 | - | - | 16.50 | 16.40 | - | 57 |
| 41 | Jatta Kunda | A/C | - | 21.03 | - | 21.00 | - | 21.10 | - | - | 21.85 | - | - | 22.36 | 22.30 | 5.98 | 61 |
| 42 | Sare Sartu | TRAD | - | 25.87 | - | 25.69 | - | 25.68 | - | - | 26.62 | - | - | 26.12 | 26.10 | 6.06 | 65.6 |
| 43 | Njofen | A/C | - | - | - | 36.12 | - | 36.14 | - | - | 36.20 | - | - | 36.60 | 36.00 | 5.98 | 157.9 |
| 44 | Munku Talla | UN | 37.55 | - | - | 32.52 | 32.40 | 32.70 | - | - | 32.70 | - | - | 32.50 | 34.40 | 5.67 | 59.7 |
| 45 | Sare Fonkoi | TRAD | 24.58 | - | 22.31 | 22.21 | 22.20 | 22.40 | - | - | 22.40 | - | - | 24.03 | 22.50 | 5.59 | 35.8 |

Annex 4 (Continued)

| No | Village | Type of Well | Elevation A. S. L. | 6/83 | 7/83 | 8/83 | 9/83 | 10/83 | 11/83 | 12/83 | 1/84 | 2/84 | 3/84 | 4/84 | 5/84 | pH | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Dip under top of parapet | | | | | | | | | | | | | |
| 46 | Sare Saide | UN | 30.85 | | 26.25 | 26.22 | 26.24 | 26.50 | - | - | 26.45 | - | - | 26.82 | 26.85 | - | - |
| 47 | Kolior I | TRAD | 11.87 | 9.98 | 8.95 | 10.35 | 10.58 | 10.75 | 10.87 | - | 10.56 | - | - | 11.52 | 11.10 | 5.9 | 59 |
| 48 | Kolior II | TRAD | - | 9.98 | 10.15 | 10.34 | 9.85 | 9.43 | 10.85 | - | 11.30 | - | - | 12.35 | 12.20 | 6.3 | 78 |
| 49 | Jomarr | A/C | - | 12.50 | 12.15 | 11.85 | 12.00 | 11.94 | 12.00 | - | 12.19 | - | - | 12.54 | 12.60 | - | - |
| 50 | Jasobo | TRAD | - | 5.89 | 4.16 | 4.20 | 3.97 | 5.72 | 5,50 | - | 5.80 | - | - | 6.20 | 6.20 | - | 144.2 |
| 51 | Yoro Yula | TRAD | 16.33 | 15.22 | 15.18 | 15.08 | 15.10 | 15.15 | 15.20 | - | 15.78 | - | - | 15.76 | 15.35 | - | 84 |
| 52 | Messembe | TRAD | 21.85 | 19.71 | 19.78 | 19.67 | 19.75 | 20.25 | 19.75 | - | 19.90 | - | - | 19.95 | 20.95 | 5.3 | 64 |
| 53 | Genieri | TRAD | 10.69 | 13.43 | 13.39 | 13.33 | 13.38 | 13.63 | 13.78 | - | 13.61 | - | - | 14.20 | 13.90 | 4.9 | 58 |
| 54 | Kaiaf | TRAD | 12.92 | 9.65 | 9.48 | 9.62 | 9.57 | 9.59 | 9.75 | - | 9.77 | - | - | dry | dry | 5.5 | 300 |
| 55 | Jiffin | TRAD | 14.54 | 12.29 | 12.13 | 12.12 | 12.02 | 12.43 | 12.28 | - | 12.45 | - | - | 12.70 | 12.70 | - | 202 |
| 56 | Toniataba | TRAD | 8.93 | 8.70 | 8.95 | 7.75 | 7.52 | dry | - | - | - | - | - | 8.23 | - | - | - |
| 57 | Si-Kunda | A/C | 7.73 | 7.80 | 7.72 | 7.50 | 7.49 | 7.48 | 7.51 | | 6.85 | - | - | 8.30 | 7.60 | 5.8 | 86 |
| 58 | Soma | TRAD | 14.49 | 4.75 | 14.33 | 14.25 | 14.27 | 14.40 | 14.74 | - | 14.80 | - | - | 14.90 | 14.80 | - | 50 |
| 59 | Jenoi | A/C | 8.23 | 7.42 | 7.28 | 7.35 | 7.26 | 7.40 | - | - | 7.55 | - | - | 7.60 | 7.57 | - | 130 |
| 60 | Jenoi | TRAD | 7.69 | 8.65 | 6.79 | 6.79 | 6.75 | 6.70 | - | - | - | - | - | 7.08 | - | - | 353 |
| 61 | Mansakonko | UN | 25.61 | 25.05 | 24.18 | 24.22 | 24.14 | 24.40 | 24.26 | - | 24.35 | - | - | 24.45 | 24.60 | 5.0 | - |
| 62 | Sankwia | A/C | 12.73 | 10.00 | 9.97 | 9.85 | 9.80 | 9.80 | - | - | 10.10 | - | - | 10.60 | 10.60 | - | - |
| 63 | Kani Kunda | A/C | 15.78 | 12.25 | 12.25 | 12.19 | 12.20 | 12.55 | - | - | 12.33 | - | - | 12.58 | 12.55 | - | 160 |
| 64 | Karantaba | TRAD | 18.11 | 14.00 | 14.17 | 14.16 | 14.35 | 14.32 | - | - | 14.40 | - | - | 14.50 | 14.63 | 3.42 | 320 |
| 65 | Biranoya | TRAD | - | 16.45 | 16.64 | 16.53 | 16.41 | 16.40 | 16.20 | - | 16.75 | - | - | 16.90 | 17.05 | 6.30 | 57 |
| 66 | Misira | ACTION AID | 27.91 | 21.05 | 21.15 | 21.13 | 21.12 | 21.50 | 21.15 | - | 21.22 | - | - | 21.30 | 21.50 | - | 110 |
| 67 | Sabi | TRAD | - | 10.23 | - | 10.00 | 9.98 | 10.29 | - | 10.78 | - | - | 10.78 | - | 11.05 | 3.7 | 320 |
| 68 | Sare Yoro Cheke | TRAD | - | 10.35 | - | 10.05 | 10.10 | 10.09 | - | 10.60 | - | - | 10.60 | - | 10.90 | 3.9 | 42 |
| 69 | Kumbija I | TRAD | - | 10.37 | - | 10.52 | 9.11 | 10.70 | - | 11.40 | - | - | 11.41 | - | 11.45 | - | - |
| 70 | Kumbija II | UN | - | 7.60 | - | 7.62 | 7.81 | 7.62 | - | 8.16 | - | - | 8.20 | - | 8.26 | 4.3 | 44 |

Annex 4 (continued)

| No | Village | Type of well | Elevation A.S.L. | Dip under top of parapet 6/83 | 7/83 | 8/83 | 9/83 | 10/83 | Dip Under Top of Parapet 11/83 | 12/83 | 1/84 | 2/84 | 3/84 | 4/84 | 5/84 | pH | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | Sare Bona | TRAD | - | 6.15 | - | 5.97 | 5.94 | 5.90 | - | 6.33 | - | - | 6.60 | - | 6.45 | 4.2 | 32 |
| 72 | Basse | TRAD | - | 11.00 | - | 10.22 | 10.00 | 9.96 | - | 10.82 | - | - | 11.04 | - | 11.40 | - | 150 |
| 73 | Kabakama | TRAD | - | 3.05 | - | 2.50 | 2.51 | 2.32 | - | 3.08 | - | - | 3.60 | - | 3.55 | 5.4 | 55 |
| 74 | Giroba Kunda | A/C | - | 7.43 | - | 6.96 | 7.02 | 6.92 | - | 7.48 | - | - | 8.47 | - | 9.20 | 6.1 | 140 |
| 75 | Basse Ending | TRAD | - | 7.05 | - | 6.35 | 6.66 | 6.54 | - | 7.11 | - | - | 7.45 | - | 7.35 | 4.78 | 50 |
| 76 | Alohungari | UN | - | 16.40 | - | 16.30 | 16.19 | 15.94 | - | 16.53 | - | - | 16.91 | - | 17.45 | 4.8 | 54 |
| 77 | Kerewan | TRAD | - | 10.88 | - | 10.45 | 9.90 | 9.93 | - | 10.95 | - | - | 12.07 | - | 12.07 | 4.9 | 260 |
| 78 | Taibatu | A/C | - | 13.29 | - | 12.64 | 12.80 | 12.70 | - | 10.34 | - | - | 10.50 | - | 14.55 | 4.5 | 30.6 |
| 79 | Bani | TRAD | - | 9.67 | - | 9.81 | 9.68 | 9.81 | - | 9.70 | - | - | 9.90 | - | 9.60 | 4.2 | 44 |
| 80 | Sutukonding | TRAD | - | 13.05 | - | 12.66 | 12.70 | 12.75 | - | 13.20 | - | - | 13.15 | - | 14.10 | 4.3 | 160 |
| 81 | Yoro Bawal | TRAD | - | 21.48 | - | 21.00 | 21.48 | 21.26 | - | 21.00 | - | - | 21.20 | - | 22.58 | 4.5 | 70 |
| 82 | Kolibantang | UN | - | 27.31 | - | 25.00 | 24.26 | 25.40 | - | 25.43 | - | - | 29.70 | - | 26.20 | 5.2 | 36 |
| 83 | Samba Kabude | PWD | - | 29.00 | - | 27.59 | 26.51 | 27.55 | - | 27.95 | - | - | 26.68 | - | 29.00 | - | 60 |
| 84 | Sara Dadi | UN | - | 33.17 | - | 33.05 | 33.13 | 33.59 | - | 33.73 | - | - | 33.80 | - | 33.70 | 5.3 | 31 |
| 85 | Kuonkunding | A/C | - | 35.85 | - | 36.02 | 35.56 | 35.94 | - | 36.40 | - | - | 37.64 | - | 36.90 | 4.8 | 48 |
| 86 | Tuba Wappa | A/C | - | 18.05 | - | 18.05 | 18.20 | 18.11 | - | 18.85 | - | - | 21.38 | - | 19.60 | 4.5 | 41 |
| 87 | Sare Ngaba | UN | -- | 23.40 | - | 23.34 | 23.57 | 28.86 | - | 23.86 | - | - | 25.64 | - | 26.35 | 4.5 | 84 |
| 88 | Sare Hamadi | A/C | - | 28.55 | - | 28.85 | 28.70 | 28.77 | - | 29.00 | - | - | 29.30 | - | 29.40 | 4.9 | 28 |
| 89 | Jar Kunda | UN | - | 36.47 | - | 36.01 | 36.15 | 36.20 | - | 36.40 | - | - | 37.38 | - | 37.95 | 5.0 | 30 |
| 90 | Dampha Kunda | TRAD | - | 10.77 | - | 8.05 | 7.45 | 7.45 | - | 8.35 | - | - | 9.50 | - | 8.20 | 4.4 | 280 |

Annex 5

CHEMICAL ANALYSES OF WATER FROM WELLS

| No. | Village | Date of analysis | pH | EC nmhos | Colour(Unit) | Turbidity (FTU) | Susoended Solids $Mgl^{-1}$ | Total Alkalinity Mg $CaCo_3$ $l^{-1}$ | Total Hardness Mg $CaCo_3$ $L^{-1}$ | Ca | Mg | K | $NH_4$ | Fe | $NO_3$ | CL | F | $PO_4$ | $SO_4$ | $HCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Bator Sateh | 16/8/83 | 6.28 | 149.0 | 80 | 20 | 0.0 | 21.32 | 36.0 | 29.0 | 7.0 | 1.13 | 0.219 | 0.506 | 14.08 | 12.0 | 0.05 | 0.50 | 5.0 | 26.0 |
| 3 | Kolu Koch | 16/8/83 | 6.5 | 55.0 | 50 | 12 | 0.0 | 14.76 | 17.0 | 16.0 | 1.0 | 1.13 | 0.065 | 0.69 | 6.6 | 1.7 | 0.02 | 1.22 | 4.0 | 18.0 |
| 7 | Nyofelleh | 16/8/83 | 5.31 | 28.0 | 950 | 260 | 118.0 | 8.2 | 3.4 | 3.0 | 0.4 | 1.70 | 2.0 | 2.026 | 7.92 | 0.5 | 0.0 | 0.50 | 5.0 | 10.0 |
| 15 | Kiti Manjago | 16/8/83 | 5.4 | 55.0 | 110 | 22 | 0.0 | 4.92 | 8.0 | 5.0 | 3.0 | 1.68 | 0.219 | 0.31 | 16.72 | 6.0 | 0.0 | 0.70 | 3.0 | 6.0 |
| 17 | Marakissa I | 16/8/83 | 5.55 | 39.0 | 1000 | 270 | 140.0 | 18.04 | 12.40 | 4.0 | 8.4 | 1.14 | 0.052 | 0.228 | 3.52 | 0.4 | 0.05 | 0.14 | 5.0 | 22.0 |
| 26 | Mandina Ba | 16/8/83 | 6.0 | 161.0 | 70 | 15 | 5.0 | 34.44 | 18.0 | 8.0 | 10.0 | 16.0 | 0.36 | 0.19 | 7.48 | 6.3 | 0.15 | 0.50 | 4.0 | 42.0 |
| 30 | Dumbutu | 24/9/83 | 6.0 | 4.2 | 130 | 32 | 8.0 | 8.19 | 8.8 | 8.0 | 0.8 | - | 1.08 | 0.78 | 6.6 | 5.3 | - | 0.24 | 3.0 | 10.0 |
| 32 | Kwinella | 26/9/83 | 4.75 | 109 | 105 | 23 | - | 8.19 | 20.0 | 13.0 | 7.0 | 4.35 | 0.774 | 0.304 | 15.40 | 5.0 | 0.1 | 0.11 | 4.0 | 10.0 |
| 40 | Nema Kuta | 26/8/83 | 5.95 | 94 | 35 | 3 | - | 32.76 | 20.0 | 13.10 | 6.90 | 1.17 | 0.0 | 0.38 | 0.96 | 4.80 | 0.1 | 0.1 | 4.0 | 40.0 |
| 42 | Sare Sarjo | 26/8/83 | 5.95 | 60 | 105 | 23 | - | 16.38 | 10.50 | 7.70 | 2.80 | 1.00 | 0.671 | 0.633 | 7.92 | 3.8 | 0.1 | 0.12 | 4.0 | 20.0 |
| 47 | Kolior I | 26/8/83 | 5.7 | 99 | 10 | 2 | - | 16.38 | 30.0 | 16.0 | 14.0 | 2.8 | 0.968 | 0.19 | 7.48 | 4.8 | 0.122 | 0.18 | 6.0 | 20.0 |
| 65 | Biranoya | 26/8/83 | 5.25 | 60 | 50 | 8 | - | 8.19 | 4.4 | 2.50 | 1.90 | 1.0 | 1.06 | 0.253 | 3.52 | 6.4 | 0.1 | 0.13 | 3.0 | 10.0 |
| | Kalagi UN | 10/9/83 | 6.5 | 74 | 90 | 20 | 5 | 16.38 | 21.0 | 18.0 | 3.0 | - | 0.065 | 0.13 | 18.48 | 3.2 | - | - | 11.0 | 20.0 |
| | Somita UN | 10/9/83 | 7.55 | 132 | 40 | 10 | 0 | 8.19 | 45.36 | 94.0 | 1.36 | - | 0.1161 | 0.29 | 14.96 | 1.8 | - | - | 12.0 | 10.0 |
| 67 | Sabi | 7/10/83 | 3.9 | 280 | 255 | 63 | 0 | 0.0 | 40.0 | 18.64 | 31.36 | - | 4.51 | 0.15 | 36.08 | - | - | - | - | 0.0 |
| 70 | Kumbija II | 8/10/83 | 5.85 | 39 | 80 | 20 | 0 | 11.47 | 11.0 | 10.10 | 0.9 | - | 0.10 | 0.127 | 4.84 | 7.0 | - | - | - | 14.0 |
| 75 | Basse Nding | 10/10/83 | 5.12 | 39 | 190 | 54 | 0 | 1.64 | 7.08 | 4.04 | 3.04 | - | 0.232 | 0.88 | 7.92 | 2.8 | - | - | - | 2.0 |
| 81 | Yoro Bawol | 10/10/83 | 5.73 | 73 | 500 | 250 | 42 | 6.55 | 38.44 | 23.0 | 15.44 | - | 1.99 | 2.66 | 16.28 | 3.7 | - | - | - | 8.0 |
| 89 | Jar Kunda | 7/10/83 | 6.82 | 78 | 120 | 26 | 0 | 27.85 | 32.72 | 31.8 | 0.92 | - | 0.10 | 0.25 | 7.48 | 1.0 | - | - | - | 34.0 |
| 90 | Dampha Kunda | 10/10/83 | 6.1 | 280 | 80 | 27 | 0 | 16.38 | 56.9 | 32.10 | 24.80 | - | 0.28 | 0.88 | 23.32 | 2.0 | 2.0 | - | - | 20.0 |

Notes: pH - Alkalinity-acidity index, EC - electrical conductivity(in micromhos)

Annex 6

## PERFORMANCE OF WINDMILL PUMPING SYSTEM IN TANJI AND SARA KUNDA

### A. Tanji (7 March - 25 April 1984)

| Date in March 1984 | Daily production ($m^3$) | Average windspeed at 11 m (m/s) | Date in April 1984 | Daily production ($m^3$) | Average windspeed at 11 m (m/s) |
|---|---|---|---|---|---|
| 7 | 12 | 2.65 | 1 | 30 | 2.01 |
| 8 | 38 | 3.32 | 2 | 9 | 1.48 |
| 9 | 38 | 3.08 | 3 | 13 | 1.53 |
| 10 | 27 | 2.50 | 4 | 12 | 1.45 |
| 11 | 36 | 3.50 | 5 | 42 | 3.20 |
| 12 | 40 | 3.55 | 6 | 38 | 3.59 |
| 13 | 42 | 3.35 | 7 | 39 | 3.25 |
| 14 | 36 | 3.02 | 8 | 40 | 3.33 |
| 15 | 31 | 2.80 | 9 | 39 | 3.45 |
| 16 | 32 | 2.65 | 10 | 37 | 3.60 |
| 17 | 32 | 2.70 | 11 | 37 | 4.30 |
| 18 | 30 | 2.91 | 12 | 33 | 4.02 |
| 19 | 34 | 3.15 | 13 | 31 | 3.55 |
| 20 | 41 | 3.60 | 14 | 29 | 3.11 |
| 21 | 31 | 2.85 | 15 | 33 | 3.65 |
| 22 | 23 | 3.05 | 16 | 32 | 3.40 |
| 23 | 37 | 2.63 | 17 | 30 | 2.75 |
| 24 | 25 | 1.95 | 18 | 20 | 2.25 |
| 25 | 21 | 1.95 | 19 | 18 | 2.40 |
| 26 | 32 | 2.80 | 20 | 25 | 2.85 |
| 27 | 29 | 2.32 | 21 | 36 | 3.89 |
| 28 | 29 | 2.19 | 22 | 42 | 3.65 |
| 29 | 32 | 2.84 | 23 | 44 | 3.95 |
| 30 | 40 | 2.98 | 24 | 30 | 2.80 |
| 31 | 25 | 2.05 | 25 | 37 | 3.82 |

### B. Sara Kunda (7 - 28 June 1984)

| Date in June 1984 | Daily production ($m^3$) | Average windspeed at 11 m (m/s) | Date in June 1984 | Daily production ($m^3$) | Average windspeed at 11 m (m/s) |
|---|---|---|---|---|---|
| 7 | 19 | 2.18 | 18 | 29 | 2.24 |
| 8 | 18 | 1.96 | 19 | 21 | 1.74 |
| 9 | 21 | 2.54 | 20 | 20 | 2.57 |
| 10 | 18 | 2.21 | 21 | 18 | 2.32 |
| 11 | 20 | 2.18 | 22 | 19 | 2.29 |
| 12 | 28 | 2.59 | 23 | 31 | 2.72 |
| 13 | 30 | 3.07 | 24 | 7 | 1.59 |
| 14 | 29 | 2.68 | 25 | 6 | 1.30 |
| 15 | 33 | 2.97 | 26 | 22 | 2.47 |
| 16 | 21 | 2.52 | 27 | 11 | 1.62 |
| 17 | 22 | 2.58 | 28 | 15 | 1.47 |

Annexe · 7

PERFORMANCE OF PHOTOVOLTAIC PUMPING SYSTEM IN KAIAF

(26 May - 14 July 1984)

| Date 1984 | Daily production ($m^3$) | Daily irradiation (langley) | Energy consumed by pump (watt-hour) | Date 1984 | Daily production ($m^3$) | Daily irrad. (langley) | Energy consumed by pump (watthour) |
|---|---|---|---|---|---|---|---|
| 26.5 | 26.96 | 463 | 541 | 20.6 | 28.76 | 418 | 515 |
| 27.5 | 43.47 | 557 | 685 | 21.6 | 40.06 | 521 | 642 |
| 28.5 | 40.18 | 527 | 643 | 22.6 | 36.58 | 496 | 610 |
| 29.5 | 31.29 | 450 | 529 | 23.6 | 35.08 | 489 | 602 |
| 30.5 | 27.15 | 438 | 500 | 24.6 | 33.01 | 480 | 584 |
| 31.5 | 25.25 | 427 | 481 | 25.6 | 40.80 | 543 | 660 |
| 1.6 | 29.41 | 428 | 524 | 26.6 | 41.52 | 538 | 664 |
| 2.6 | 7.38 | 176 | 197 | 27.6 | 42.13 | 511 | 661 |
| 3.6 | 31.82 | 442 | 546 | 28.6 | 17.45 | 280 | 339 |
| 4.6 | 35.74 | 481 | 585 | 29.6 | 10.63 | 302 | 339 |
| 5.6 | 33.68 | 485 | 574 | 30.6 | 39.94 | 504 | 623 |
| 6.6 | 29.50 | 449 | 526 | 1.7 | 44.51 | 552 | 687 |
| 7.6 | 13.79 | 223 | 251 | 2.7 | 27.64 | 422 | 495 |
| 8.6 | 20.01 | 372 | 430 | 3.7 | 33.63 | 471 | 574 |
| 9.6 | 42.75 | 554 | 683 | 4.7 | 32.85 | 444 | 555 |
| 10.6 | 24.74 | 405 | 459 | 5.7 | 23.81 | 371 | 452 |
| 11.6 | 38.67 | 521 | 632 | 6.7 | 28.25 | 443 | 536 |
| 12.6 | 38.22 | 525 | 623 | 7.7 | 26.33 | 397 | 484 |
| 13.6 | 35.71 | 503 | 596 | 8.7 | 36.67 | 498 | 619 |
| 14.6 | 31.54 | 462 | 549 | 9.7 | 33.62 | 474 | 586 |
| 15.6 | 37.31 | 526 | 633 | 10.7 | 10.23 | 253 | 281 |
| 16.6 | 3.37 | 166 | 172 | 11.7 | 40.00 | not measured | |
| 17.6 | 24.57 | 402 | 461 | 12.7 | 34.58 | 492 | 604 |
| 18.6 | 37.29 | 511 | 610 | 13.7 | 31.87 | 440 | 548 |
| 19.6 | 30.01 | 444 | 527 | 14.7 | 44.03 | 543 | 686 |