DEMOCRATIC REPUBLIC

OF

SOMALIA

# MOGANBO IRRIGATION PROJECT

## FEASIBILITY STUDY

**APPENDICES VOLUME I**

**PART I: CLIMATE AND WATER RESOURCES**

**PART II: SOILS SURVEY**

Prepared for the

State Planning Commission
and
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Tippetts-Abbett-McCarthy-Stratton - New York

Financial and Technical Services - Cairo

# SOMALIA

# MOGANBO IRRIGATION PROJECT

## APPENDICES, VOLUME 1

## PART I

## CLIMATE AND WATER RESOURCES

# SOMALIA

## MOGANBO IRRIGATION PROJECT

APPENDICES, VOLUME 1 PART I

## CLIMATE AND WATER RESOURCES

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APPENDICES, VOLUME 1

# PART I: CLIMATE AND WATER RESOURCES

## A - CLIMATE

### Sources of Information

1 The two main sources of published information on climate in the Somali Democratic Republic are:

1) The Somali Republic and French Somaliland, Climatological Report No. 61, Investigations Division, Meteorological Office, Air Ministry, 1962. This report gives mean monthly and annual data for Kismayu from March 1943 to February 1950.

2) Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963. This book gives mean monthly and annual data collected to 1958, 1959 or 1960, dpending on the station. Daily rainfall is compiled for the main climatological stations -- Mogadishu, Kismayu, Alessandra, Villabrozze, Bardera and Baidoa -- excepting that only for Mogadishu are data available for the 1940's. Although published, some station-years of data appear to be incompletely observed.

2 A copy of both documents is available in the Climatological Section of the Meteorological Service, Department of Civil Aviation, Ministry of Transport. Observer's notebooks of monthly data since about 1963 are also on file in the Climatological Section, together with information that the office has compiled and processed therefrom. All of these are accessible to anyone with proper authority upon request from the Civil Aviation Department.

Climate Data Collection for Agriculture

3 The meteorological service was transferred from the Ministry of Agriculture to the Department of Civil Aviation in 1964. Since then, the program has been maintained primarily for aviation and many stations, previously operated in the interests of agriculture, were discontinued. Fantoli published records for intermittent periods from 1915 to 1960. Many of the records of early periods were for agricultural uses, collected on privately owned plantations. The programs were disrupted during World War II. In the 1950-1960 decade new interest in the collection of climatological data for agricultural purposes was spurred by the Food and Agriculture Organization of the United Nations, then activity

declined when the program was transferred to the Civil Aviation Department. A new program for data gathering in the interests of agriculture has since been promoted by the FAO/UNDP.

## Network of Stations and Extent of Data

4 Climatological stations in the Juba River basin or in nearby areas are listed in the following Table I-1, showing elevation, location, general classification and period of records:

Climatic Zones

5 The area of the proposed Moganbo Irrigation Project is on the southern edge of the "littoral steppe" (Fantoli) near the maritime climatic zone where Giumbo, Kismayu and Mogadishu are located. The littoral steppe extends upstream along the Juba River to Gelib and Alessandra. Further upstream is the continental steppe to and including Bardera and Baidoa. Lugh and Dolo lie in an arid steppe zone near the Ethiopian border.

Seasonal Climate

6 The monsoons, from the northeast during December through March and from the southeast and southwest from May through October, seem to control the climate. These windy periods are separated by periods of calm, called "Tanga Mbili," each about one to two months long, the duration and time varying from year to year. The first and usually the heaviest rainy period in the lower Juba River area, called Gu, is from April through June. The subsidiary rainy period from about mid-September through November is called Der. A third rainy period, called Hagai, occurs along and near the coast of the Indian Ocean, disrupting the dry season between Gu and Der. The

great dry season of Gilal occurs from December through March, with zero rainfall in all but a few years.

Precipitation

7 Mean annual precipitation in Somalia along the Juba River increases from the coast inland to Alessandra, then diminishes toward the border with Ethiopia. At Kismayu, the average annual precipitation for the continuous period from 1943 to 1976 was 367.7 mm. At Alessandra the long time average was 598 mm. The short time records (10 years) at Giamama indicate an average of 414.2 mm.

Kismayu

Table I-3 shows that the heaviest rains at Kismayu during the available record period -- which does not include those of the 1940 decade -- are of the Gu season, except in 1957, 1959, 1974 and 1975, when the greatest yearly rainfall occurred in the Hagai season, and 1961 when it occurred in the Der season. Note particularly the great variation in 1960 and 1961 for which, respectively, the Gu, Hagai and Der rainfalls were 379.9, 64.9 and 18.4 mm (1960) and

36.7, 369.4 and 563.9 mm (1961). A great amount of rainfall was experienced at Kismayu in the years 1961, 1964 and 1967 (over 700 mm in each case). The dry years are indicated by the records to have been 1950, 1957 and 1969; however, in some of these years at least, the rainfall was poorly observed.

8 The probability that rainfall levels will be exceeded in any year, based on the Kismayu and Alessandra records, is shown in Figure I-1. From this figure, precipitation for return periods -- the reciprocals of probabilities -- have been summarized as follows:

Table I-2

Probability of Annual Precipitation (mm)

| Return Period, Years | Station | |
| --- | --- | --- |
| | Kismayu | Alessandra |
| 50 | 1000 | 860 |
| 20 | 800 | 800 |
| 10 | 650 | 740 |
| 2 | 320 | 580 |

The great divergence in trends of probability of annual rainfall, as shown in Figure I-1, is quite realistic despite the fact that the period of record adopted for Alessandra was short and that there were instances of poor observation in the Kismayu records.

TABLE NO. I - 3

SOMALIA

MOGANBO IRRIGATION PROJECT

Monthly & Annual Precipitation & No. of Days with Rain at Kismayu

← GALIL → ← GU → ← HAGAI → ← DER → ←GALIL→

| YR | JAN | | FEB | | MAR | | APR | | MAY | | JUN | | JUL | | AUG | | SEP | | OCT | | NOV | | DEC | | Total Prec. | Total Days w/ Rain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | d | mm | |
| 1943 | 0 | 0 | 0 | 0 | 0 | 0 | 33.7 | — | 18.0 | — | 124.7 | — | 29.9 | — | 2.0 | — | 0 | — | 0.7 | — | 1.5 | - | 0 | - | 210.5 | — |
| 44 | 0 | | 0 | | 0 | | 12.4 | — | 156.2 | — | 46.7 | — | 27.4 | — | 10.4 | — | 11.4 | — | 106.1 | — | 5.5 | - | 3.2 | - | 379.3 | — |
| 45 | 0 | | 0 | | 0 | | 0 | | 336.0 | — | 63.7 | — | 29.9 | — | 19.3 | — | 2.3 | — | 0 | | 0 | | 0 | | 451.2 | — |
| 46 | 0 | | 0 | | 0 | | 3.2 | — | 121.9 | — | 224.8 | — | 34.0 | — | 14.4 | — | 24.3 | — | 8.6 | 3 | 1.0 | 2 | 0 | | 432.2 | — |
| 47 | 0 | | 0 | | 0 | | 92.4 | 8 | 155.1 | 21 | 152.4 | 14 | 17.3 | 10 | 71.1 | 11 | 9.3 | 5 | 14.4 | 5 | 16.5 | 3 | 0 | | 528.5 | 77 |
| 48 | 0 | | 0 | | 6.4 | - | 0 | | 25.8 | — | 71.5 | 18 | 24.8 | 8 | 18.6 | 10 | 1.5 | — | 16.8 | 2 | 0 | — | 22.1 | 5 | 187.5 | — |
| 49 | 0 | | 0 | | 0 | | 9.9 | — | 9.7 | 3 | 26.4 | 8 | 28.6 | — | 12.4 | — | 13.7 | — | 166.1 | — | 0 | | 3.3 | 2 | 270.1 | — |
| 50 | 0 | | 0 | | 0 | | 3.8 | 2 | 35.3 | 8 | 16.3 | 10 | 12.0 | 5 | 0 | 0 | 4.0 | 2 | 18.3 | 4 | 0 | 0 | 0 | 0 | 89.7 | 31 |
| 51 | 0 | | 0 | | 0 | | 15.8 | 3 | 323.0 | 9 | 38.0 | 5 | 54.0 | 6 | 10.0 | 2 | 0 | 0 | 16.0 | 6 | 9.0 | 4 | 31.0 | 6 | 496.8 | 41 |
| 52 | 0 | | 0 | | 0 | | 0.7 | 1 | 1.5 | 3 | 132.6 | 23 | 23.3 | 17 | 14.7 | 8 | 50.6 | 3 | 18.6 | 4 | 38.0 | 5 | 0 | 0 | 280.0 | 64 |
| 53 | 4.4 | 2 | 0 | | 0 | | 2.3 | 3 | 103.8 | 7 | 72.4 | 10 | 93.6 | 18 | 17.4 | 8 | 8.0 | 4 | 26.8 | 2 | 11.0 | 4 | 0 | 0 | 339.7 | 58 |
| 54 | 0 | | 0 | | 0 | | 31.3 | 7 | 28.4 | 8 | 79.8 | 9 | 24.6 | 12 | 18.1 | 10 | 3.4 | 6 | 0.5 | 3 | 22.1 | 3 | 0 | 0 | 208.2 | 58 |
| 55 | 0 | | 0 | | 0 | | 8.6 | 4 | 201.3 | 17 | 40.4 | 13 | 73.4 | 14 | 7.4 | 7 | 0 | 0 | 7.4 | 1 | 0 | 0 | 0 | 0 | 338.5 | 56 |
| 56 | 0 | | 0 | | 0.2 | 1 | 14.2 | 6 | 83.5 | 18 | 139.1 | 7 | 8.1 | 11 | 0 | 0 | 0.4 | 1 | 0 | 0 | 0 | 0 | 8.0 | 1 | 253.5 | 45 |
| 57 | 0 | | 0 | | 0 | | 1.5 | 1 | 0 | 0 | 0.8 | 1 | 51.5 | 2 | 0 | 0 | 0 | 0 | .0 | 0 | - | 4 | 0 | 0 | 59.8 | 8 |
| 58 | 0 | | 0 | | 0 | | 39.4 | 4 | 68.9 | 11 | 64.5 | 15 | 1.6 | 4 | 5.3 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 179.7 | 41 |
| 59 | 0.2 | 1 | 0 | | 0 | | 48.1 | 7 | 56.5 | 6 | 61.5 | 15 | 254.8 | 16 | 15.0 | 7 | 10.4 | 4 | 1.0 | 1 | 5.0 | 1 | 0 | 0 | 452.5 | 58 |
| 60 | 0 | | 0 | | 2.3 | 1 | 61.2 | 5 | 150.4 | 10 | 168.3 | 13 | 43.5 | 4 | 21.4 | 3 | 8.3 | 1 | 10.0 | 2 | 0 | 0 | 0 | 0 | 465.4 | 39 |
| 61 | 0 | | 0 | | 0 | | 0 | 0 | 8.2 | 1 | 28.5 | 3 | 255.0 | 23 | 114.4 | 10 | 259.4 | 15 | 85.6 | 8 | 212.7 | 8 | 6.2 | 2 | 970.0 | 70 |
| 62 | 0 | | 0 | | 0 | | 88.2 | 8 | 122.9 | 14 | 47.6 | 12 | 39.0 | 11 | 48.1 | 9 | 14.4 | 6 | 2.2 | 2 | 0 | 0 | 0 | 0 | 362.4 | 62 |
| 63 | 0 | | 0 | | 0 | | 182.9 | 11 | 125.0 | 10 | 51.8 | 11 | 62.8 | 13 | 13.6 | 11 | 81.6 | 15 | 0 | 0 | 6.8 | 2 | 9.9 | 5 | 534.4 | 78 |
| 64 | 0.8 | 2 | 12.8 | 1 | 0 | 0 | 182.8 | 11 | 328.6 | 17 | 90.5 | 11 | 55.3 | 12 | 71.8 | 7 | 6.6 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 749.2 | 64 |
| 65 | 0 | | 0 | | 0 | | 0 | 0 | 33.2 | 5 | 116.2 | 13 | 35.0 | 10 | 23.4 | 4 | - | - | 102.9 | 10 | 0 | 0 | - | - | 310.7 | 42 |
| 66 | 0 | | 0 | | 0 | | 100.0 | 9 | 5.7 | 5 | 124.6 | 12 | 26.4 | 7 | 24.8 | 10 | 8.1 | 7 | 16.8 | 4 | 34.4 | 3 | 0 | 0 | 340.8 | 57 |
| 67 | 0 | | 0 | | 0 | | 27.0 | 3 | 211.4 | 11 | 206.0 | 13 | 58.8 | 15 | 73.2 | 14 | 44.0 | 8 | 45.6 | 4 | 51.2 | 7 | 0 | 0 | 717.2 | 75 |
| 68 | 0 | | 0 | | 0.4 | 1 | 73.3 | 6 | 108.0 | 11 | 109.4 | 10 | 22.4 | 7 | 0 | 0 | 5.0 | 1 | - | - | - | - | 0 | 0 | 318.5 | 36 |
| 69 | 0 | | 0 | | 0 | | 0 | 0 | 21.0 | 5 | 37.8 | 7 | 6.8 | 4 | 8.6 | 3 | 4.0 | 2 | 0 | 0 | 6.6 | 2 | 0 | 0 | 84.8 | 23 |
| 70 | 0 | | 0 | | 4.8 | 2 | 48.9 | 6 | 86.8 | 11 | 153.8 | 13 | 72.6 | 8 | 4.4 | 6 | 16.8 | 3 | 4.2 | 1 | 0 | 0 | 0 | 0 | 392.3 | 50 |
| 71 | 0 | | 0 | | 0 | | 46.8 | 3 | 112.0 | 9 | 156.0 | 17 | 2.6 | 2 | 2.0 | 1 | 9.0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 328.4 | 36 |
| 72 | 0 | | 0 | | 0 | | 0 | 0 | 215.8 | 11 | 111.0 | 7 | 73.4 | 11 | 5.0 | 3 | 4.2 | 1 | 96.0 | 2 | 11.6 | 3 | 0 | 0 | 517.0 | 38 |
| 73 | 0 | | 0 | | 0 | | 12.0 | 1 | 21.8 | 6 | 134.2 | 9 | 41.8 | 6 | 1.6 | 1 | 0 | 0 | 0 | 0 | 4.0 | 1 | 0 | 0 | 215.4 | 24 |
| 74 | 0 | | 0 | | 6.0 | 2 | 12.0 | 3 | 44.4 | 5 | 41.6 | 5 | 68.8 | 11 | 3.4 | 2 | 3.4 | 2 | 0 | 0 | 0 | 0 | 8.4 | 1 | 188.0 | 31 |
| 75 | 0 | | 0 | | 0 | | 99.8 | 4 | - | - | 222.6 | 18 | 143.2 | 9 | 10.4 | 5 | 6.8 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 482.8 | 40 |
| 76 | 0 | | 0 | | 0 | | 24.0 | 2 | 10.5 | 3 | | | | | | | | | | | | | | | | |
| AVE. | 0.16 | | 0.38 | | 0.57 | | 37.5 | | 98.0 | | 95.6 | | 54.4 | | 20.1 | | 18.5 | | 23.2 | | 13.2 | | 2.8 | | 367.7 (364.5) | 48 |

Data Sources for Table I-3, Monthly and Annual Precipitation and Days of Rainfall:

(1) For the period 1943 through 1959, data were taken from Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

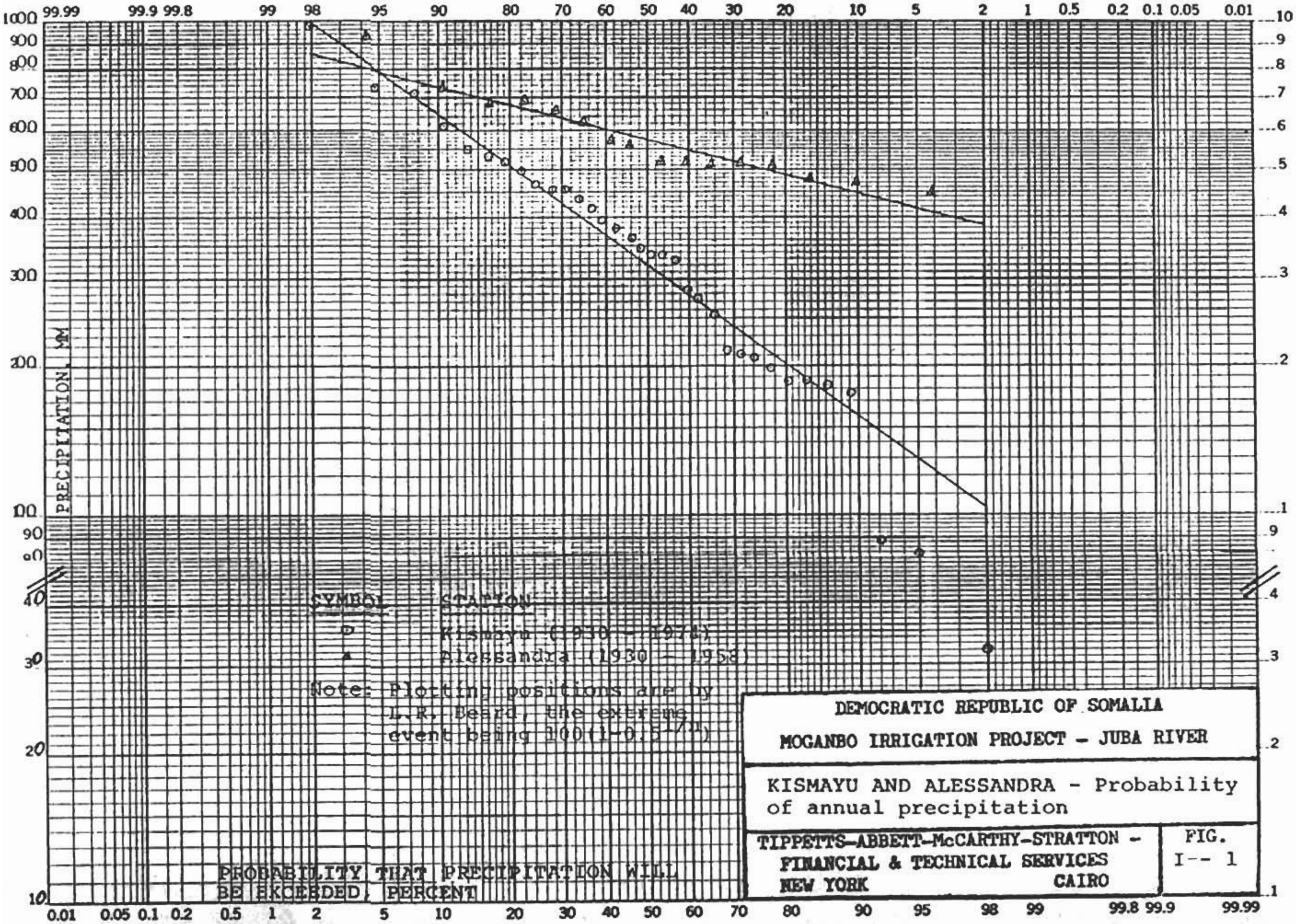
(2) Data for the years 1963, 1964 and 1967 were compiled from station observers' notebooks.

(3) Data for the years 1962, 1965, 1966 and 1968 were compiled from daily station summaries of the Civil Aviation Department (Mogadishu).

(4) Data for years 1960 and 1961 were compiled from monthly station summaries of the Civil Aviation Department at Mogadishu.

(5) For periods 1969 and 1970; May through December 1971; and 1974 through May 1976, data were compiled from station observers' monthly notebooks.

(6) For the periods January through April 1971; October through December 1971; and all of 1972 and 1973, data were taken from the daily station summaries of the Civil Aviation Department at Mogadishu.

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MOGANBO IRRIGATION PROJECT - JUBA RIVER

KISMAYU AND ALESSANDRA - Probability of annual precipitation

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NEW YORK CAIRO

FIG. I -- 1

Margherita (Giamama)

9 Numerous stations were operated near the project area, each for relatively short time periods. Recordings at Margherita (Giamama) were the longest of these. A comparison with the records at Kismayu for concurrent years (Table I-4) shows that precipitation at Giamama is higher than at Kismayu. An estimation of the long-time average precipitation at Giamama, based on direct proportion with Kismayu, would indicate about 516 mm annually. This is compatible with the precipitation recorded at Alessandra. Since Giamama is across the river from the project area, it is reasonable to assume that project long-time precipitation would be similar.

10 A characteristic of rainfall in the lower Juba River area is that amounts on many days are very small. For Alessandra, Fantoli shows that 54 per cent of the daily rainfall events were at or less than 5 mm and 93 per cent were at or less than 30 mm. Even though the Moganbo area may experience a mean annual rainfall of more than 500 mm, the rains are not wholly usable. Usable precipitation has been estimated and shown in Table III-3, Working Document III - Irrigation and Drainage Plans.

**TABLE NO. I - 4**

**SOMALIA**

**MOGAMBO IRRIGATION PROJECT**

**Comparison of Concurrent Rainfall Records at Giamama & Kismayu**

| | JAN | | FEB | | MAR | | APR | | MAY | | JUN | | JUL | | AUG | | SEP | | OCT | | NOV | | DEC | | TOTAL | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | K | G | K | G | K | G | K | G | K | G | K | G | K | G | K | G | K | G | K | G | K | G | K | G | K |
| YEAR | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| 1929 | | | | | | | | | | | | | 111.0 | 41.0 | 15.0 | 33.5 | 95.0 | 66.0 | 72.0 | 0 | 49.0 | 0 | 91.0 | 20.0 | | |
| 1930 | 0 | 0 | 0 | 0 | 57.5 | 17.0 | 82.0 | 18.0 | 362.0 | 85.0 | 88.0 | 40.0 | 87.0 | 0 | - | 0 | 27.0 | 0 | 191.0 | 0 | 70.0 | 22.0 | 6.0 | 0 | 970.5 | 182.0 |
| 1931 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 | 0 | 215.0 | 117.0 | 41.0 | 50.0 | - | - | - | - | - | - | 21.0 | 0 | 3.0 | - | 0 | - | | |
| 1932 | 0 | - | 0 | - | - | - | 37.5 | - | 60.5 | - | 32.0 | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| 1933 | 12.0 | 5.8 | 0 | 0 | 0 | 0 | 70.0 | 93.0 | 26.0 | 58.0 | 62.0 | 189.0 | 94.0 | 138.0 | 26.0 | 68.0 | 23.0 | 58.0 | 0 | 11.0 | 0 | - | 0 | - | 313.0 | 620.8 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 69.0 | 29.0 | 99.0 | 83.0 | 86.0 | 206.0 | 48.0 | 59.0 | 89.0 | 19.1 | 7.0 | 5.1 | 4.0 | 0.5 | 0 | 0 | 0 | 1.0 | 402.0 | 402.7 |
| 1935 | 0 | 0 | 0 | 15.0 | 0 | 0.5 | 34.0 | 5.0 | 23.0 | 24.0 | 141.0 | 58.0 | 41.0 | 31.0 | 24.5 | 40.0 | 8.0 | 13.0 | 3.5 | 23.5 | 16.0 | .0 | 32.0 | 1.0 | 323.0 | 211.0 |
| 1936 | 0 | 1.5 | 33.0 | 0 | 0 | 0 | 91.0 | 31.0 | 4.0 | 43.0 | 140.0 | 243.0 | 31.0 | 134.0 | 15.0 | - | 188.0 | - | - | - | 0 | - | 42.0 | - | 544.0 | 452.5 |
| 1937 | 0 | - | 0 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 1953 | - | 4.4 | - | 0 | - | 0 | - | 2.3 | 8.0 | 103.8 | 111.0 | 72.4 | 145.5 | 93.6 | 41.0 | 17.4 | 0 | 8.0 | 0 | 26.8 | 0 | 11.0 | 0 | 0 | 305.5 | 339.7 |
| 1954 | 0 | 0 | 0 | 0 | 0 | 0 | 44.0 | 31.3 | 37.0 | 28.4 | 112.0 | 79.8 | 41.0 | 24.6 | 19.0 | 18.1 | 0 | 3.4 | 0 | 0.5 | 5.0 | 22.1 | 10.0 | 0 | 268.0 | 208.2 |
| 1955 | 0 | 0 | 0 | 0 | 0 | 0 | 86.0 | 8.6 | 224.0 | 201.3 | 50.0 | 40.0 | 76.5 | 73.4 | 0 | 7.4 | 0 | 0 | 0 | 7.4 | 0 | 0 | 0 | 0 | 436.5 | 338.5 |
| 1956 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 14.2 | 60.0 | 83.5 | 42.0 | 139.1 | 0 | 8.1 | 0 | 0 | 0 | 0.4 | 0 | 0 | 40.0 | 0 | 0 | 8.0 | 142.0 | 253.5 |
| 1957 | 0 | 0 | 0 | 0 | 0 | 0 | 82.0 | 1.5 | 116.0 | 0 | 74.0 | 0.8 | 72.0 | 51.5 | 11.0 | 0 | 0 | 0 | 0 | 0 | 43.0 | 0 | 39.0 | 0 | 437.0 | 53.8 |
| 1958 | 14.0 | 0 | 0 | 0 | 0 | 0 | 121.0 | 39.4 | 57.0 | 68.9 | 41.0 | 64.5 | - | 1.6 | - | 5.3 | - | 0 | - | 0 | - | 0 | - | 0 | - | 179.7 |
| AV | 2.0 | 1.0 | 2.5 | 1.3 | 5.3 | 1.5 | 59.7 | 22.8 | 99.3 | 74.7 | 78.5 | 98.6 | 67.9 | 54.7 | 24.1 | 19.0 | 31.6 | 14.0 | 26.5 | 6.3 | 18.8 | 5.5 | 18.3 | 3.0 | 414.2 | 294.8 |
| #YRS | 13 | 12 | 13 | 12 | 11 | 12 | 12 | 12 | 13 | 12 | 13 | 12 | 11 | 12 | 10 | 11 | 11 | 11 | 11 | 11 | 12 | 10 | 12 | 10 | 10 | 11 |

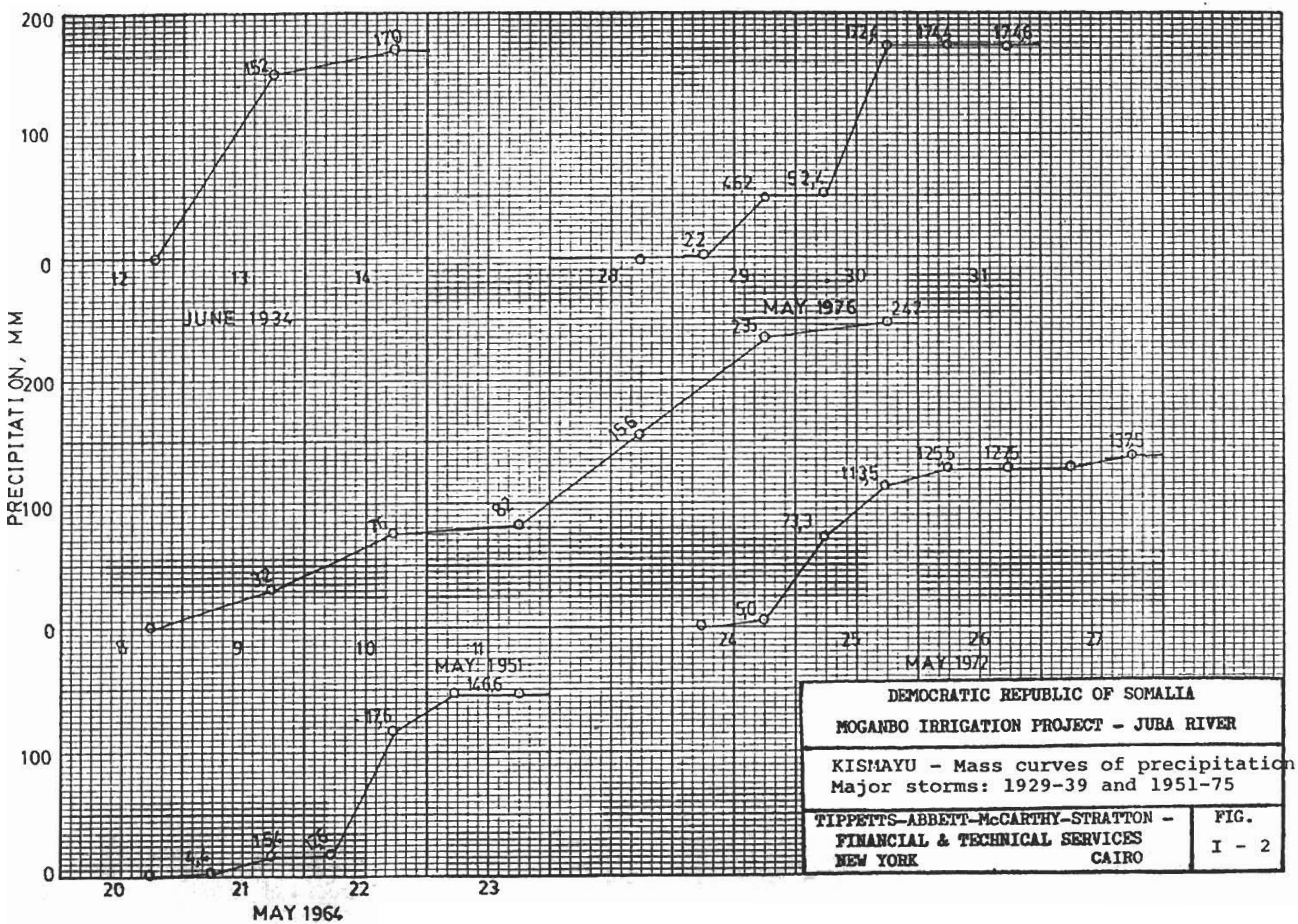
## Storm Rainfall

11 Daily rainfalls exceeding 50 mm were experienced in about half the years on record at Kismayu. The heaviest daily rain on record (June 14, 1934) was 152 mm, an amount equivalent to 38 per cent of the average rainfall for this station. In some years, one, two, three or even more periods of moderate to fairly heavy rains may occur, in which case the annual rainfall will be above normal. When such rainy periods do not occur, annual rainfall is small. The heavy rains are associated with the movement of the inter-tropical convergence zone across Somalia, particularly in the Gu season. There is no record of tropical cyclones occurring in the lower Juba area. Tropical cyclones have happened in the more northerly latitudes of Somalia. According to the Air Ministry report the Gulf of Aden has experienced three or four such storms in the period 1879 to 1944.

12 Mass curves of rainfall of major storms at Kismayu are shown in Figure I-2. For the period 1963 to date, data from twice-daily observations are available in office files of the Civil Aviation Department, sometimes with notations of beginning

and ending of rain and with three-hourly observations of the status of clouds, rains, etc. Although a recording raingage has been installed, recorder sheets of rainfall are generally not available, hence the mass curves of rainfall are not detailed with regard to hourly amounts.

13 Probabilities that amounts of storm rainfall for periods from one to three days will be exceeded are shown in Figures I-3 and I-4 for Kismayu and Alessandra, respectively. The basis for these figures is the "annual series," and not those for the individual Gu, Hagai and Der seasons, nor the series of n-period greatest events.

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MOGANBO IRRIGATION PROJECT - JUBA RIVER

KISMAYU - Mass curves of precipitation
Major storms: 1929-39 and 1951-75

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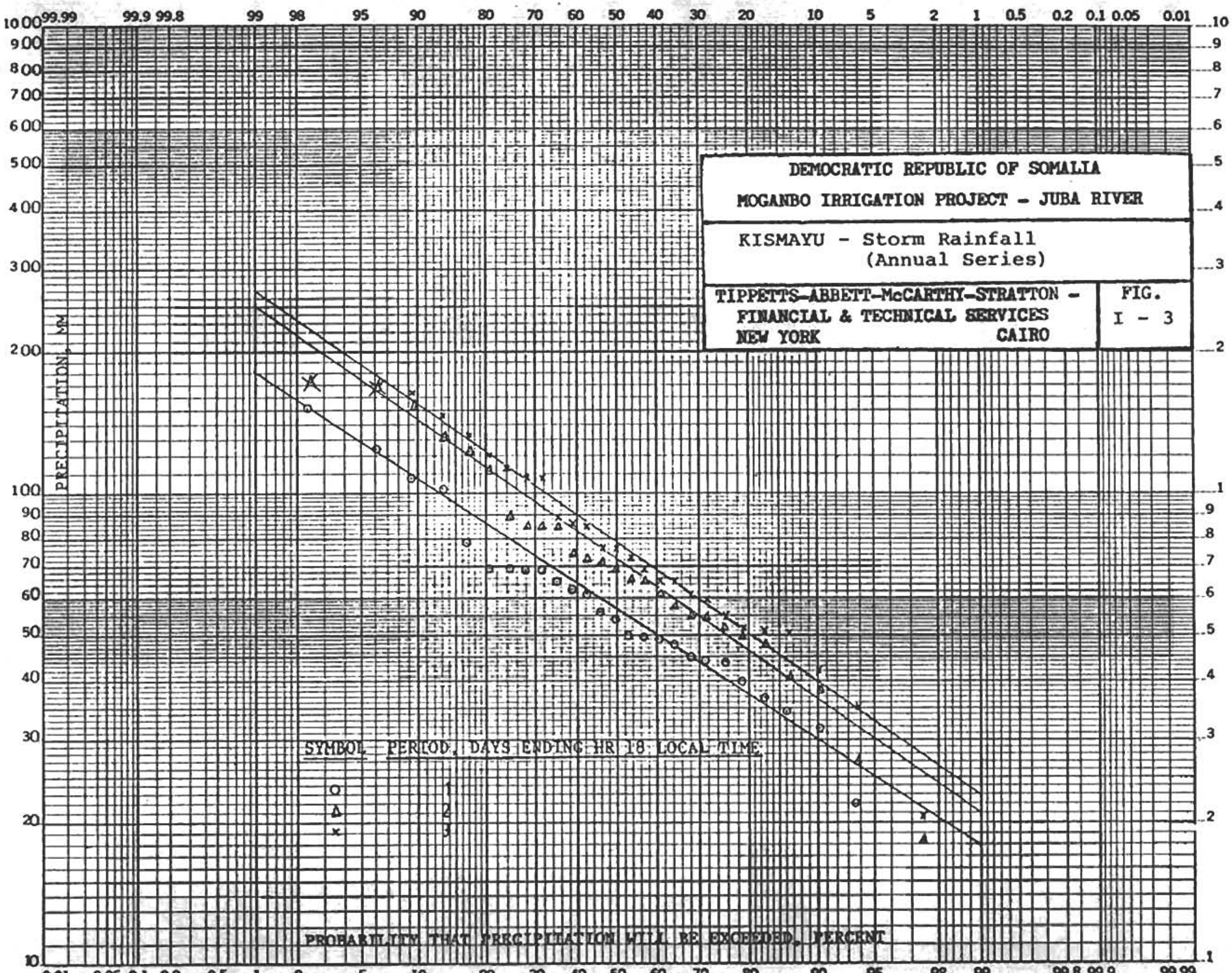
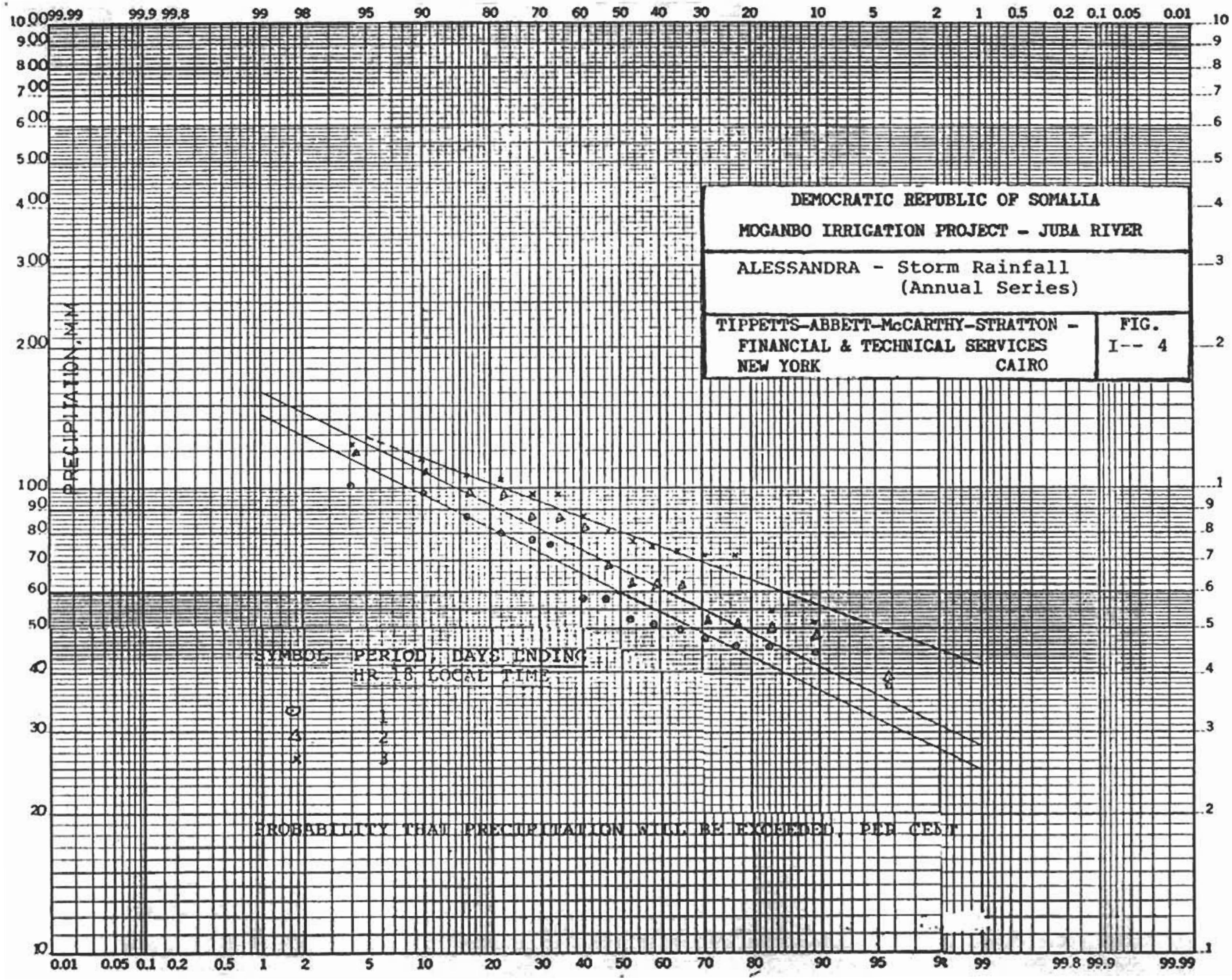
FIG. I - 2



DEMOCRATIC REPUBLIC OF SOMALIA
MOGANBO IRRIGATION PROJECT - JUBA RIVER
KISMAYU - Storm Rainfall
(Annual Series)
TIPPETTS-ABBETT-McCARTHY-STRATTON - FINANCIAL & TECHNICAL SERVICES
NEW YORK CAIRO
FIG. I - 3
SYMBOL PERIOD, DAYS ENDING HR 18 LOCAL TIME
○ 1
Δ 2
× 3
PRECIPITATION, MM
PROBABILITY THAT PRECIPITATION WILL BE EXCEEDED, PERCENT



DEMOCRATIC REPUBLIC OF SOMALIA
MOGANBO IRRIGATION PROJECT - JUBA RIVER
ALESSANDRA - Storm Rainfall
(Annual Series)
TIPPETTS-ABBETT-McCARTHY-STRATTON -
FINANCIAL & TECHNICAL SERVICES
NEW YORK
CAIRO
FIG.
I-- 4
PRECIPITATION, MM
SYMBOL PERIOD, DAYS ENDING
HR 18 LOCAL TIME
1
2
3
PROBABILITY THAT PRECIPITATION WILL BE EXCEEDED, PER CENT

14 From these figures, rainfall amounts for certain return periods are summarized in Table I-5 as follows:

Table I-5

Probability of Storm Rainfall (mm)

| Return Period, Years | Kismayu Days ending 1800 LT* 1 Day | Kismayu 2 Days | Kismayu 3 Days | Alessandra Days ending 1800 LT* 1 Day | Alessandra 2 Days | Alessandra 3 Days |
|---|---|---|---|---|---|---|
| 50 | 160 | 216 | 235 | 130 | 145 | (145) |
| 20 | 130 | 175 | 190 | 111 | 125 | 130 |
| 10 | 110 | 144 | 156 | 98 | 110 | 116 |
| 2 | 57 | 72 | 79 | 60 | 67 | 80 |

*Local Time

Alessandra experiences less intense storms than Kismayu, particularly in the Gu season. For the project area, the storm intensity can be assumed to be more nearly that of Alessandra. In some cases, rainfall exceeds the infiltration capacity of the soils. Drainage should be designed to control surface runoff corresponding to the 10-year return period.

15 The above compilations confirm not only that normal precipitation levels cannot assure a dependable

water supply for year-round cropping, but also that variations, whether month to month, season to season, or year to year, are indeed great, making even seasonal rainfed cultivation a high-risk activity.

## Air Temperature

16 Data from maximum and minimum thermometers are published by Fantoli for Margherita (Giamama) for the period October to December 1931 and January 1933 to November 1936 -- excepting four months. The highest monthly temperatures occur in the Gilal season and the lowest in the Hagai season. The extreme range in the period covering four years was 18.2°C in August 1936 to 37.0°C, which occurred in November and December 1934 and February, April and November, 1935 (Table I-6).

17 Temperature levels and variations do not represent any constraint on the length of the growing season.

## Ground and Surface Temperatures

18 Fantoli published mean monthly ground temperatures for each month from September 1934 to November 1938, for depths of 30, 50 and 70 cm below the ground

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MOGANBO IRRIGATION PROJECT

Table I-6

Summary of Air Temperatures at Giamama
(Oct.-Dec. 1931; Jan. 1933 - Nov. 1936)

(°C)

| Month | Absolute Maximum | Mean Maximum | Mean | Mean Minimum | Absolute Minimum |
|---|---|---|---|---|---|
| Jan | 36.0 | 33.2 | 28.5 | 23.9 | 21.0 |
| Feb | 37.0 | 34.0 | 28.9 | 23.9 | 21.0 |
| Mar | 35.0 | 33.4 | 28.6 | 23.8 | 23.0 |
| Apr | 37.0 | 34.2 | 29.4 | 24.7 | 22.0 |
| May | 35.0 | 33.4 | 28.5 | 23.6 | 22.0 |
| Jun | 35.0 | 31.8 | 27.1 | 22.3 | 21.0 |
| Jul | 34.0 | 30.0 | 26.1 | 22.2 | 20.0 |
| Aug | 32.5 | 30.9 | 26.1 | 21.4 | 18.2 |
| Sep | 33.6 | 32.0 | 26.8 | 21.7 | 20.0 |
| Oct | 35.0 | 32.9 | 27.7 | 22.6 | 21.0 |
| Nov | 37.0 | 33.0 | 28.0 | 23.1 | 20.0 |
| Dec | 37.0 | 33.5 | 28.4 | 23.3 | 22.0 |
| Year | 37.0 | 32.7 | 27.8 | 23.0 | 18.2 |

Source: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

surface at Alessandra. These are given in Table I-7 along with mean monthly ground surface temperatures from February 1954 to December 1955.

## Solar Radiation, Sunshine and Cloudiness

19 The Fantoli report presents monthly and annual data on solar radiation, as measured by a primi modelli Robitzsch-Fuess pyrheliometer, for two locations in Somalia, i.e. Mogadishu, as representative of a maritime climate, and Borca (Baidoa), as representative of a continental steppe climate. Solar radiation for the project area may exceed those of these two stations, inasmuch as mean cloudiness at Alessandra is less than at either Mogadishu or Baidoa. The measurements of cloudiness stand in good relation with those of sunshine shown by Fantoli. Reported records of solar radiation, cloud cover and sunshine hours are shown in Table I-8 for Mogadishu, and in Table I-9 for Borca (Baidoa). Table I-10 compares the long term mean amounts of cloudiness and sunshine hours for Alessandra, Mogadishu and Baidoa.

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Table I-7

Ground and Surface Temperatures

at Alessandra

(ºC)

| Month | Ground (1934-38) Depth, cm | | | Surface (1954-55) | |
|---|---|---|---|---|---|
| | 30 | 50 | 70 | Max | Min |
| Jan | 29.2 | 29.6 | 29.6 | 32.8 | 24.5 |
| Feb | 29.8 | 30.6 | 30.6 | 36.2 | 22.9 |
| Mar | 30.8 | 31.3 | 31.3 | 37.3 | 23.6 |
| Apr | 29.2 | 30.1 | 30.8 | 35.4 | 23.7 |
| May | 28.2 | 29.4 | 29.9 | 33.9 | 22.8 |
| Jun | 27.3 | 28.6 | 29.3 | 33.0 | 21.3 |
| Jul | 25.7 | 26.8 | 27.6 | 31.0 | 20.2 |
| Aug | 28.5 | 27.6 | 27.7 | 31.8 | 20.3 |
| Sep | 27.5 | 28.2 | 28.6 | 32.5 | 22.3 |
| Oct | 27.7 | 28.5 | 28.8 | 32.3 | 22.5 |
| Nov | 27.0 | 27.8 | 28.1 | 31.0 | 23.3 |
| Dec | 27.5 | 28.0 | 28.0 | 31.6 | 23.0 |
| Year Average | 28.2 | 28.9 | 29.2 | 33.2 | 22.5 |

Source: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

Table I - 8

## SOMALIA. MOGANBO IRRIGATION PROJECT

Mogadishu, 1954 to 1958: Solar Radiation, Cloud Cover in Tenths of Sky Covered, Averaged for Observations at 9, 12, 15 and 18 Local Time; Sunshine Hours

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *1 9* | *5 4* | | | | | | |
| Sol. Rad. | (640.8) | ? | ? | 573.9 | 589.4 | 460.2 | 527.0 | 539.6 | 601.0 | 631.7 | 584.2 | 611.4 | (675.9) |
| Cld. Cov. | 3.9 | 3.7 | 3.8 | 5.8 | 5.5 | 6.8 | 6.3 | 6.4 | 5.4 | 4.7 | 5.5 | 3.8 | (5.1) |
| Sun. Hrs. | 210.8 | 261.6 | 294.6 | 253.0 | 290.6 | 212.4 | 256.4 | 249.7 | 268.7 | 296.0 | 256.8 | 290.5 | 3141.1 |
| | | | | | | *1 9* | *5 5* | | | | | | |
| Sol. Rad. | 638.2 | ? | ? | 636.0 | 618.2 | 596.5 | 585.2 | 621.9 | 675.6 | 674.4 | 683.4 | 634.5 | (636.4) |
| Cld. Cov. | 4.0 | 4.3 | 3.0 | 5.2 | 6.2 | 6.8 | 7.2 | 6.7 | 5.6 | 4.4 | 4.4 | 3.5 | 5.1 |
| Sun. Hrs. | 275.5 | 187.6 | 297.6 | 254.8 | 277.3 | 278.3 | 228.5 | 232.2 | 260.1 | 262.3 | 264.6 | 244.3 | 3063.1 |
| | | | | | | *1 9* | *5 6* | | | | | | |
| Sol. Rad. | 643.4 | 681.7 | 673.5 | 617.0 | 601.0 | 596.1 | 538.9 | 648.8 | 680.0 | 660.8 | 598.7 | 612.9 | 627.4 |
| Cld. Cov. | 3.3 | 2.6 | 4.5 | 6.1 | 5.4 | 5.8 | 6.5 | 4.8 | 4.0 | 4.3 | 4.7 | 3.2 | 4.6 |
| Sun. Hrs. | 256.9 | 257.8 | 268.1 | 247.6 | 258.6 | 241.9 | 209.5 | 274.6 | 257.0 | 267.0 | 250.5 | 275.9 | 3065.4 |
| | | | | | | *1 9* | *5 7* | | | | | | |
| Sol. Rad. | 613.1 | 671.1 | 645.9 | 581.9 | 532.4 | 440.6 | 438.1 | 525.7 | 580.9 | 592.0 | 543.2 | 489.6 | 554.5 |
| Cld. Cov. | 3.5 | 2.4 | 2.8 | 4.8 | 5.7 | 5.3 | 5.9 | 4.7 | 3.7 | 3.9 | 5.1 | 4.6 | 4.4 |
| Sun. Hrs. | 270.4 | 262.5 | 303.3 | 221.4 | 231.3 | 203.6 | 202.9 | 250.2 | 261.2 | 280.4 | 233.0 | 204.9 | 2925.1 |
| | | | | | | *1 9* | *5 8* | | | | | | |
| Sol. Rad. | 495.2 | 492.8 | 519.0 | 496.3 | 447.9 | 395.4 | 424.1 | 499.9 | 527.2 | 514.8 | 528.2 | 501.4 | 486.8 |
| Cld. Cov. | 3.3 | 2.4 | 2.9 | 4.1 | 5.1 | 6.2 | 5.8 | 4.3 | 3.3 | 4.2 | 3.3 | 3.5 | 4.0 |
| Sun. Hrs. | 259.3 | 252.0 | 271.7 | 233.9 | 239.5 | 196.6 | 216.3 | 276.3 | 283.2 | 264.2 | 288.4 | 286.8 | 3068.0 |

Note: Solar radiation observed with Robitzsch-Fuess pyrheliometer.

Source: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

TABLE I-9

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## MOGANBO IRRIGATION PROJECT

## BONCA (Iscia Baidoa) 1956

Solar Radiation; Cloud Cover in Tenths of Sky Covered,
Averaged for Observations at 9, 12, 15 and 18 Local Time; and Sunshine Hours

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *1 9 5 6* | | | | | | | |
| Sol. Rad | 529.0 | 569.0 | 518.0 | 417.0 | 414.0 | 430.0 | 354.0 | 434.0 | 496.0 | 469.0 | 529.0 | 554.0 | 571.3 |
| Cld. Cov | 0.8 | 0.9 | 2.9 | 5.2 | 5.1 | 5.2 | 6.1 | 5.6 | 4.2 | 5.6 | 3.0 | 1.8 | 3.8 |
| Sun. Hrs | 281.1 | 287.4 | 284.1 | 220.6 | 251.5 | 234.8 | 176.0 | 224.8 | 252.9 | 206.9 | 254.4 | 287.8 | 2962.3 |

Note: Solar radiation observed with Robitzsch-Fuess pyrheliometer

SOURCE: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

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TABLE I-10

Comparison of Cloudiness, Hours of Sunshine
Mogadishu, Alessandra and Baidoa

| | Cloudiness, % Time | | | Hours Sunshine, % Day | | |
|---|---|---|---|---|---|---|
| | Moga. | Aless. | Baidoa | Moga. | Aless. | Baidoa |
| Month | 1910-40<br>1947-53 | 1930-39<br>1953-58 | 1923-39<br>1953-58 | 1933-40<br>1952-58 | 1934-37<br>1939<br>1953-58 | 1934-37<br>1939<br>1953-58 |
| JAN | 32 | 22 | 21 | 72 | 76 | 77 |
| FEB | 33 | 20 | 20 | 74 | 75 | 80 |
| MAR | 37 | 25 | 36 | 75 | 82 | 73 |
| APR | 44 | 40 | 61 | 71 | 62 | 62 |
| MAY | 47 | 43 | 62 | 72 | 63 | 63 |
| JUN | 55 | 42 | 59 | 51 | 57 | 56 |
| JUL | 57 | 44 | 72 | 57 | 57 | 42 |
| AUG | 52 | 40 | 64 | 67 | 65 | 55 |
| SEP | 44 | 32 | 58 | 73 | 70 | 59 |
| OCT | 44 | 35 | 67 | 71 | 62 | 51 |
| NOV | 41 | 36 | 55 | 72 | 55 | 65 |
| DEC | 38 | 31 | 34 | 69 | 63 | 74 |
| YEAR | 44 | 34 | 51 | 69 | 66 | 63 |

Source: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

Dew Point Temperatures, Vapor Pressure and Relative Humidity

20 The nearest climatological stations to the project area having dew point, vapor pressure and relative humidity data are at Yonte to the southwest and Alessandra to the north. Mean monthly data from Fantoli are summarized in Table I-11.

21 The Air Ministry comments, "It is said that when wet bulb temperature rises to 26°C or more, all work in still air conditions, especially heavy manual work, should be reduced to a minimum." The report then shows the average number of such occurrences at Kismayu in an eight-year period to have been from 0 to 22 at hour 0830, and 5 to 28 at hour 1430 local time, from August to April. The period June through September is most conducive to work and the months of April and May are usually the most oppressive.

Wind Velocity and Direction

22 The nearest contact anemometer has been at Alessandra, where Fantoli indicates that measurements were made from March 1953 to December 1958. Wind direction was measured during the same period

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Table I-11

Mean Monthly Data of Dew Point Temperature,
Vapor Pressure and Relative Humidity
(Yonte and Alessandra)

| | Dew Point Temp.°C | | Vapor Press.mm | Relative Humidity,% | |
|---|---|---|---|---|---|
| | Yonte[1] | Aless.[2] | Aless.[2] | Yonte[1] | Aless.[2] |
| Month | 1954-58 | 1954-58 | 1932-39 1953 | 1953-58 | 1931-39 1953-58 |
| Jan | 23.8 | 21.6 | 18.7 | 75 | 68 |
| Feb | 23.5 | 21.4 | 18.6 | 75 | 67 |
| Mar | 24.5 | 21.9 | 19.2 | 76 | 66 |
| Apr | 25.4 | 23.4 | 20.6 | 77 | 72 |
| May | 24.7 | 23.3 | 20.9 | 79 | 78 |
| Jun | 23.5 | 21.9 | 19.4 | 81 | 78 |
| Jul | 22.9 | 20.9 | 18.2 | 81 | 77 |
| Aug | 22.7 | 20.7 | 17.7 | 79 | 75 |
| Sep | 23.2 | 20.7 | 17.9 | 78 | 72 |
| Oct | 23.8 | 21.7 | 18.7 | 77 | 73 |
| Nov | 24.1 | 22.5 | 20.4 | 75 | 76 |
| Dec | 22.0 | 22.4 | 19.6 | 76 | 74 |
| MEAN | 23.8 | 21.9 | 19.2 | 77 | 73 |

[1]Mean of observations at hours 9 and 18 local time

[2]Hours of observation not stated

Source: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

and also during 1932 to 1936. Fantoli fails to present data on maximum wind velocities, even for Mogadishu, where momentary velocities were observed. For Mogadishu, he shows values by classes, about half of the observations being in the range 2.1 to 4 meters per second and 0.17 per cent at velocities over 8 meters per second, mostly in January and June. Mean monthly wind velocity and the number of events, at three observations per day, from each of eight directions, are given in Table I-12.

Evaporation

23 Observations by use of Wild evaporimeters have been made, according to Fantoli, at Mogadishu, Genale, Villabrozze and Bonca (Baidoa). Average annual amounts varied from 949 mm at Genale to 2263 mm at Villabrozze, or amounts from 2.6 to 6.2 mm per day. What relations these bear to lake evaporation or to evapotranspiration rates is not known. The Wyoming Team, in a USAID project at Afgoi, measured pan evaporation from August 1968 to January 1969, these data being published by Hunting Technical Services in the Project for the Water Control and Management of the Shabelli River, Volumes IIA and IIIA, for FAO.

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### TABLE I-12

### Wind at Alessandra

| | Wind | Number of Events | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Vel. | W I N D D I R E C T I O N | | | | | | | | | |
| Month | m/s | N | NE | E | SE | S | SW | W | NW | Calm | Total |
| Jan | 1.7 | 5 | 338 | 299 | 87 | 28 | 0 | 0 | 0 | 173 | 930 |
| Feb | 2.0 | 1 | 131 | 346 | 109 | 29 | 0 | 0 | 0 | 215 | 831 |
| Mar | 1.9 | 1 | 92 | 432 | 216 | 14 | 0 | 0 | 0 | 255 | 1010 |
| Apr | 0.9 | 5 | 61 | 130 | 232 | 138 | 4 | 3 | 3 | 414 | 990 |
| May | 0.4 | 0 | 2 | 11 | 138 | 293 | 121 | 3 | 2 | 453 | 1023 |
| Jun | 0.6 | 1 | 0 | 0 | 97 | 343 | 193 | 14 | 0 | 342 | 990 |
| Jul | 0.6 | 0 | 0 | 0 | 19 | 377 | 289 | 13 | 0 | 325 | 1023 |
| Aug | 0.7 | 0 | 0 | 36 | 23 | 416 | 330 | 30 | 0 | 188 | 1023 |
| Sep | 1.0 | 0 | 0 | 0 | 133 | 502 | 149 | 0 | 0 | 206 | 990 |
| Oct | 1.1 | 0 | 2 | 14 | 305 | 246 | 81 | 0 | 0 | 372 | 1020 |
| Nov | 0.9 | 11 | 26 | 172 | 416 | 18 | 12 | 2 | 0 | 333 | 950 |
| Dec | 1.1 | 6 | 195 | 341 | 150 | 14 | 0 | 0 | 0 | 317 | 1023 |
| YEAR | 1.1 | 30 | 847 | 1781 | 1925 | 2418 | 1179 | 65 | 5 | 3593 | 11843 |

Source: Contributo alla Climatologia della Somalia, A. Fantoli, Rome, 1963.

24 Data for Afgoi are also available for the period July 1973 to December 1974 in an FAO report, Pilot Project for Irrigated Agricultural Development on the Shabelli River. At a mean rate of 7.1 mm, the annual pan evaporation is about 2600 mm. Taking the rough rule-of-thumb figure of 0.7 as the ratio of lake evaporation to Class-A pan evaporation, the annual lake evaporation would be about 1800 mm. Class-A pan evaporation at Afgoi for the years 1968, 1969, 1973 and 1974 is shown in Table I-13.

25 Wind speeds at Afgoi for the periods 1968-69 and 1973-74 exceeded considerably those shown in Table I-12 for Alessandra, while the maximum mean monthly air temperatures at Afgoi usually were less than the mean maximums shown in Table I-6 for Giamama. Annual evaporation at the Moganbo project area may therefore be assumed to be about equivalent to that at Afgoi.

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TABLE I-13

Class-A Pan Evaporation at Afgoi

(mm/day)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1968 | - | - | - | - | - | - | - | 6.0 | 6.8 | 6.7 | 4.4 | - | -- |
| 1969 | 5.7 | - | - | - | - | - | - | - | - | - | - | - | -- |
| 1973 | - | - | - | - | - | - | 6.8 | 8.5 | 9.1 | 7.4 | 5.5 | 7.8 | -- |
| 1974 | 8.4 | 9.3 | 9.1 | 5.9 | 5.8 | 6.6 | 6.7 | 6.5 | 8.3 | 6.0 | 6.2 | 7.3 | 7.2 |
| Mean | 7.0 | 9.3 | 9.1 | 5.9 | 5.8 | 6.6 | 6.8 | 7.0 | 8.1 | 6.7 | 5.4 | 7.6 | 7.1 |

Sources: Project for the Water Control and Management of the Shabelli River, Vol. IIA, IIIA, FAO; Pilot Project for Irrigated Agricultural Development on the Shabelli River, FAO.

## B - WATER RESOURCES

### Sources of Information

26 The main sources of information on the water resources of the Juba River are as follows:

1. The Juba River Scheme, Selchozpromexport, 1965: the first known compilation of discharges at Lugh which concern monthly mean discharges, 1925-1926 and 1951 to October 1964.

2. Agricultural and Water Survey of Somalia, FAO, 1966, Volumes I and II: Monthly runoff data for the Lugh, Bardera, Kaitoi and Giamama stations. The tabulated runoff differs from the previously mentioned report mainly because the discharge rating curve is based on more measurements. Some differences are too great to be accounted for by rating tables and probably result from the estimates for periods without gage-height data and from interpretations of uncertain and unreliable gage-height data.

3. The Department of Hydrology, Ministry of Agriculture, has unpublished data on daily, monthly and annual mean discharges, which at Lugh are processed from April 1951 to October 1967 (excepting periods of no gage-height data) and October 1969 to December 1975. For Giamama, processed records exist for January 1951 through February 1966. For the dry season or parts thereof, the "daily" records are for five-day periods, that is, days 1-5, 6-10, 26 to the end of the month.

These records, with the exception of a few months, are in close agreement with the monthly runoff data published by the FAO.

4. Planning and Design Study for the Juba Sugar Project, Appendix, June 1966, Booker-McConnell Ltd.: Daily mean discharges of recent years at Kaitoi and Kamsuma. Booker-McConnell Ltd. rate the quality of data for Lugh as fair, for Giamama as poor and for Kamsuma as good.

5. Juba River Valley Development Study, Vol. III, Technital S.p.A., April 17, 1976: Discounts Ministry data of recent years as unsuitable for use and reserves opinions on the FAO and USSR published data, choosing to use the FAO data as conservative in studies for a water supply for irrigation, etc., and the USSR flood-flow data as conservative in planning spillway capacities, etc. The USSR discharge rating table has greater discharges for stated gage-heights when the latter are in the flood-discharge range.

27 The data are incomplete and patchy, hardly justifying the efforts of statistical analysis. Nonetheless, they are better than nothing and the operation of some stations has been improved in recent years. The river reaches at the gages are said to be relatively stable from year to year, and on this basis, a discharge rating from measurements of 1963-1965 has been applied to gage readings

starting in 1951, and even to 1925-26, as was done by the USSR team for Lugh. The changes that occur from day to day or week to week must account in part for the many deviation points around a mean rating curve. The use of "shift adjustments" would be required to improve the record at Lugh. For Giamama, shift adjustments and/or river-slope or storage adjustments would have been required. The existing records may not be reliable even to ± 10 per cent on an annual basis and perhaps 50 per cent at minimum flows.

## The Juba River Basin

28 The Juba River is the greatest river of Somalia, with runoff about twice that of the Shabelli, the second largest river in the country. The Juba River basin as considered herein is independent of the Shabelli, even though the latter is a contributor during major floods. The stream system originates in the mountains of Ethiopia. Two streams, the Uebi Gestro and the Canale Doria, join near Dolo, and are joined at Dolo by the Dana Parma to form the Juba River, which flows generally in a southerly direction to the Indian Ocean near Kismayu. The drainage area is about 275,000 square kilometers

of which about 98,000 square kilometers are in Somalia. The river length in Somalia is about 900 kilometers in a valley length of 580 kilometers. The overall gradient from the proposed Bardera Dam down to the proposed project pumping plant near Bulo Yag is 20 cm per kilometer. The 33 river kilometers through the project area have an average slope of 11.7 cm per kilometer, with the gradient below the project becoming less than 10 cm per kilometer.

29 The Juba has few tributaries in its lower reach. The Bohol Madagoi enters from the left near Gelib and contributes to flood flows during the wet season. Lak Dera, another minor stream, connects with the Juba from the right, via Descek Wamo, near Yonte. When the Juba is in flood, the Descek Wamo acts as a flood relief area. During the 1961 flood, the Shabelli River also discharged into the Juba near the village of Bulo Naghib. This occurs about every 50 years.

River Gaging Stations

30 River gaging stations have been operated by several different agencies. The program was under

the Ministry of Public Works until it was transferred to the Ministry of Agriculture in 1970. The FAO Agricultural and Water Survey provided a major service from 1962 to 1965, while another FAO unit used the equipment and staff of its Shabelli River program at the Giamama station in 1969. The government agencies have been assisted by Italian and USSR staff. The Kamsuma station was started in the scope of the Fanole Project (USSR); in an exchange program the gage is being observed by staff of Booker-McConnell Ltd. while its records are being processed by the USSR staff.

31 Prior to 1967, the Juba River was gaged only at Lugh, Bardera, Kaitoi and Giamama. New stations were started in 1972 at Kamsuma (to replace Giamama where levels were becoming influenced by tides), in 1973 at Malenda, and in 1975 at Usman Moto, Bulo Merere and Misr, all in the lower basin. Lugh is the key station of the system in that it provides data on the runoff from Ethiopia and, having more reliable data than Bardera, it is basic to the planning of the Bardera storage project. The records at Giamama, and since 1972 at Kamsuma, are of greatest interest to the Moganbo project because of the proximity of these stations to the project area.

Lugh Station

32 Water levels were observed at Lugh in 1925 and 1926, then again from April 1951 to October 1967, though not continuously. The station was reactivated in October 1969. The Department of Hydrology of the Ministry of Agriculture has said that staff-gage observations were made twice daily. A water stage recorder was installed in 1963, but the period of use is not well defined. Discharge measurements were started May 30, 1963, with 8 measurements in 1963, 9 in 1964, 3 in 1965, 1 each in 1967 and 1969, 2 in 1971, 17 in 1972 and many in 1973, 1974 and 1975. Not all measurements have been processed. Measurements were made from a boat through 1969. A bridge was built in 1970 and measurements thereafter were usually made from its downstream side.

Giamama and Kamsuma Stations

33 Water levels at Giamama were observed from January 1951 to February 1966. The station is said to have been reactivated in October 1969, but records are not now available. Although a water stage recorder was installed in 1963, paper for it was not

always available. Discharge measurements were started in 1963. At Kamsuma, a station has been in operation since 21 August 1972. The staff gage is observed twice daily. Discharge measurements have been made at the highway bridge to define a rating curve.

Runoff of the Juba River

34 The Juba River basin (Upper and Lower) experiences two main wet and two dry seasons but the actual timing and amounts of rain and runoff are highly variable from year to year. Runoff is greatest usually in the Der season when rainfall in the Ethiopian highlands is heaviest. The river generally has its least flow in February or March, so that the hydrologic year of runoff could well be taken to start March 1. Differences in runoff between the calendar year and the hydrologic year are usually slight. Table I-14 gives annual runoff data as published by FAO for Lugh and Giamama, and as derived from Booker-McConnell data for Kamsuma.

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TABLE I-14

Juba River Annual Runoff

(Million cubic meters)

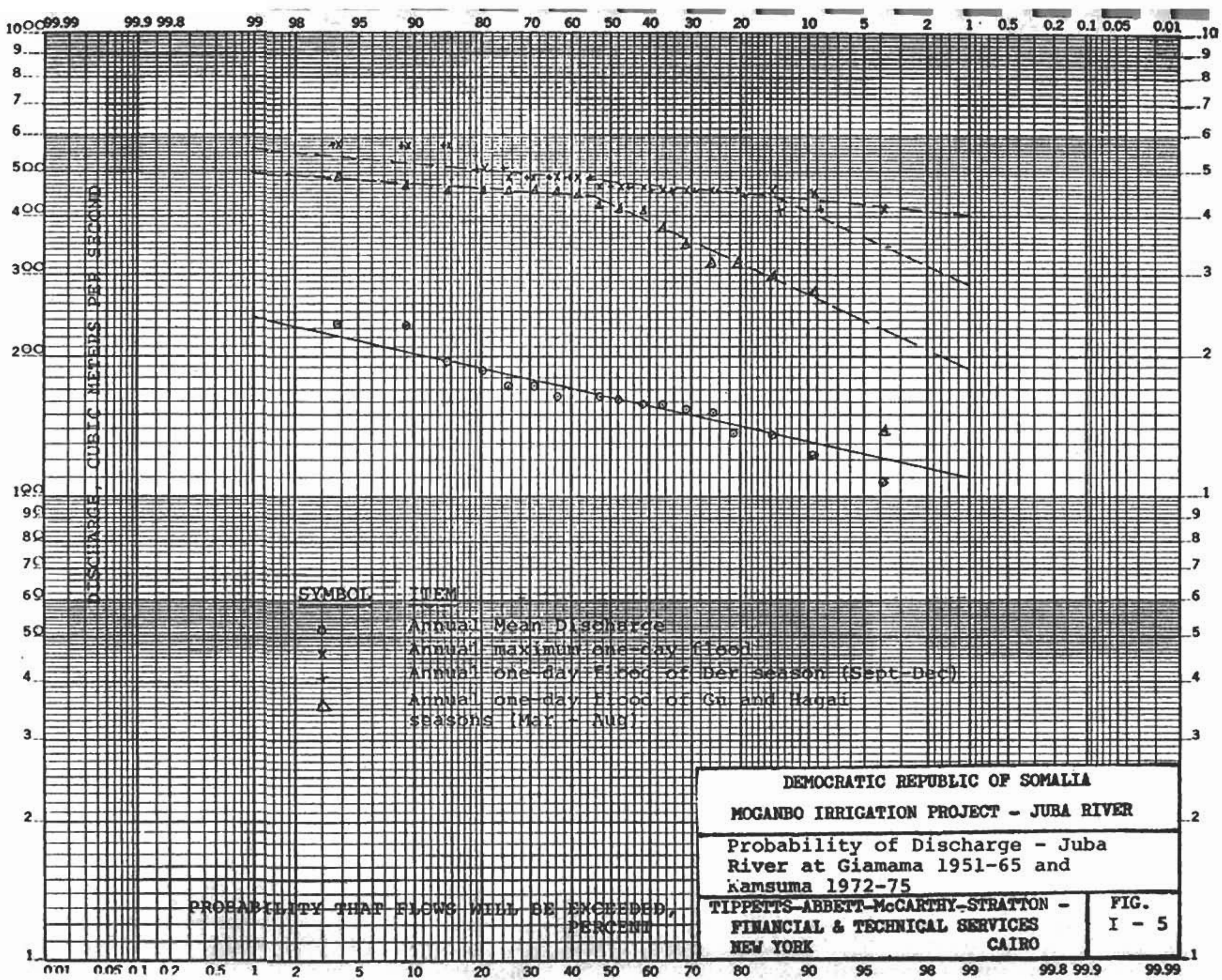
| Year | Lugh | Giamama | Kamsuma |
|---|---|---|---|
| 1951 | 8256 | 7416 | - |
| 1952 | 5349 | 5117 | - |
| 1953 | 4573 | 4351 | - |
| 1954 | 6611 | 6184 | - |
| 1955 | 3536 | 3424 | - |
| 1956 | 6000 | 5260 | - |
| 1957 | 5497 | 5431 | - |
| 1958 | 6217 | 5927 | - |
| 1959 | 6745 | 5408 | - |
| 1960 | 5714 | 5239 | - |
| 1961 | 8650 | 7293 | - |
| 1962 | 4764 | 4944 | - |
| 1963 | 5352 | 5140 | - |
| 1964 | 5081 | 4761 | - |
| 1965 | 3825[1] | 3885[2] | - |
| 1966 | 5246[1-2] | - | - |
| 1973 | - | - | 4780 |
| 1974 | - | - | 4330 |
| 1975 | - | - | 4950 |
| Mean, 1951-1965 | 5745 | 5319 | - |

[1]Includes rough estimates of runoff for parts of two months

[2]Data starting from July 1965 are from Ministry of Agriculture

35 For the common period of record, 1951-1965, the runoff is shown to decrease from Lugh to Giamama. This may be accepted, because the river overflows its banks and water is distributed via desceks, fartas and canals to lakes, swamps and irrigated agricultural lands. Kamsuma is a short distance upstream from Giamama. Yearly runoffs from 1973 to 1975 are shown to be less than the mean runoff of 1951 to 1965, reflecting the drought situation in Ethiopia.

36 Probability that annual runoff (experienced as annual mean discharge) would be exceeded in any year is shown in Figure I-5 (symbol "o") for the combined records of Giamama and Kamsuma. The average annual mean discharge is about 5240 million cubic meters. If the period of record were longer, it appears that the annual mean discharge of 1951 and 1961 (over 7000 million cubic meters) would represent about 50-year events of high runoff and that 1955 (less than 3500 million cubic meters) would represent about a 100-year event of drought. Monthly runoff of the Juba River at Giamama from January 1951 through February 1966, and September 1972 through




DEMOCRATIC REPUBLIC OF SOMALIA

MOGANBO IRRIGATION PROJECT - JUBA RIVER

Probability of Discharge - Juba River at Giamama 1951-65 and Kamsuma 1972-75

TIPPETTS-ABBETT-McCARTHY-STRATTON - FINANCIAL & TECHNICAL SERVICES
NEW YORK CAIRO

FIG. I - 5

December 1975 at Kamsuma, are shown in Table I-15. The mean annual runoff, based on all months of record, is 5239 million cubic meters or 166 cubic meters per second.

Floods

37 The maximum calendar-day floods at Giamama usually occur in the Der season. During the 15-year period 1951-1965, the annual floods occurred 12 times in the Der season (although in two of these years, floods in the Gu season were equally heavy), twice in the Gu season and once in the Hagai season. The probability that the annual maximum one-day flood and the maximum in the Der and Gu and Hagai seasons would be exceeded in any year are shown in Figure I-5. Representation of the floods by seasons is more significant than by an annual series because each season is associated with its particular monsoon. In the seasonal representation, each relationship has a break at a discharge of about 450 cubic meters per second, an indication that floods of lesser amount are contained quite well within the river banks and that floods of greater amount have caused overbank flooding.

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TABLE I-15

Monthly Runoff of Juba River at Giamama and Kamsuma

(million cubic meters)

GIAMAMA

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 308 | 96 | 30 | 679 | 1027 | 761 | 436 | 740 | 621 | 933 | 1005 | 780 | 7416 |
| 1952 | 225 | 24 | 8 | 75 | 566 | 362 | 241 | 569 | 845 | 1070 | 862 | 240 | 5117 |
| 1953 | 17 | 6 | 6 | 18 | 461 | 228 | 559 | 911 | 498 | 535 | 820 | 292 | 4351 |
| 1954 | 44 | 6 | 6 | 444 | 547 | 425 | 596 | 1057 | 993 | 1191 | 537 | 338 | 6184 |
| 1955 | 46 | 27 | 7 | 37 | 314 | 34 | 134 | 461 | 680 | 894 | 582 | 208 | 3424 |
| 1956 | 65 | 25 | 9 | 97 | 630 | 397 | 371 | 700 | 838 | 987 | 871 | 270 | 5260 |
| 1957 | 49 | 14 | 151 | 200 | 793 | 777 | 537 | 695 | 467 | 446 | 767 | 535 | 5431 |
| 1958 | 123 | 78 | 89 | 15 | 388 | 273 | 629 | 1087 | 972 | 978 | 899 | 396 | 5927 |
| 1959 | 270 | 19 | 7 | 7 | 454 | 500 | 551 | 601 | 693 | 836 | 1049 | 421 | 5408 |
| 1960 | 103 | 192 | 699 | 212 | 7 | 392 | 462 | 395 | 579 | 562 | 849 | 787 | 5239 |
| 1961 | 157 | 23 | 26 | 270 | 708 | 448 | 569 | 1022 | 937 | 864 | 1169 | 1100 | 7293 |
| 1962 | 365 | 111 | 18 | 136 | 535 | 151 | 271 | 428 | 663 | 985 | 878 | 403 | 4944 |
| 1963 | 34 | 6 | 13 | 393 | 1143 | 555 | 420 | 443 | 470 | 477 | 459 | 727 | 5140 |
| 1964 | 290 | 94 | 24 | 158 | 322 | 306 | 284 | 604 | 604 | 992 | 780 | 303 | 4761 |
| 1965 | 361 | 82 | 33 | 20 | 148 | 67 | 94 | 187 | 297 | 791 | 1146 | 659 | 3885 |
| 1966 | 174 | 57 | - | - | - | - | - | - | - | - | - | - | - |

KAMSUMA

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1972 | - | - | - | - | - | - | - | - | 726 | 845 | 1122 | 590 | - |
| 1973 | 197 | 81 | 37 | 21 | 145 | 275 | 312 | 735 | 873 | 1049 | 767 | 288 | 4780 |
| 1974 | 105 | 45 | 26 | 307 | 322 | 519 | 460 | 530 | 755 | 601 | 482 | 178 | 4330 |
| 1975 | 70 | 29 | 8 | 50 | 385 | 401 | 461 | 879 | 860 | 842 | 690 | 275 | 4950 |
| MEAN | 160 | 53 | 66 | 174 | 494 | 382 | 410 | 669 | 704 | 836 | 828 | 463 | 5239 |

Sources: 1951 to June 1965: Agricultural and Water Survey of Somalia, Vol. II, Lockwood Survey Corporation Ltd., for FAO, 1966.

July 1965 to February 1966: files of Department of Hydrology, Ministry of Agriculture, Somalia.

September 1972 to December 1975: Planning and Design Study for the Juba Sugar Project, Appendix XV, Booker-McConnell Ltd., June 1976.

38 Within the period of memory of a resident of the village of Moganbo, the 73-year-old Hadji Cimba Mokoma, there have been two great floods. The greatest flood of memory occurred when he was 14 years of age, thus in 1917. This flood lasted four months, starting, unusually, in the Gu season and extending to or into the Der season. His town was flooded. After this flood, crops were planted and yielded very good harvests. The second-ranked flood was that of 1961. Unlike the flood of 1917, the 1961 flood had its highest levels in late NOvember and early December. Moganbo was an island surrounded by water covering all the farm land. Precipitation data show that the 1961 seasonal rainfall pattern was reversed, with unusually heavy rains through the Hagai and Der seasons. Hadji Cimba could name no flood as third-ranked, in a class with those of 1917 and 1961. The impression upon him of these floods probably is, besides flood height, the duration of flooding.

39 At Giamama, three floods of the period of record had high stages. Daily mean gage-heights and discharges for these floods are presented in Table I-16. The table reveals as much of the quality of the record as of the individual floods. At least

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## MOGANBO IRRIGATION PROJECT

### TABLE I-16

### Three Greatest Floods of Record at Giamama

| Date | | Gage-Height, m | Discharge, $m^3$/sec |
|---|---|---|---|
| | | 1 9 5 6 | |
| Oct. | 31 | 6.73 | 462 |
| Nov. | 1 | - | - |
| | 2 | - | - |
| | 3 | - | - |
| | 4 | - | - |
| | 5 | 7.15 | 570 |
| | 6 | 6.76 | 485 |
| | | 1 9 5 9 | |
| Nov. | 3 | 7.11 | 485 |
| | 4 | 7.15 | 570 |
| | 5 | 7.21 | 570 |
| | 6 | 7.25 | 570 |
| | 7 | - | - |
| | 8 | - | - |
| | 9 | 7.15 | 570 |
| | 10 | 6.80 | 485 |
| | | 19 6 1 | |
| Nov. | 24 | 6.65 | 455 |
| | 25 | - | - |
| | 26 | 7.14 } | |
| | 27 | 7.15 } | |
| | 28 | 7.18 } | 570 |
| | 29 | 7.25 } | |
| | 30 | 7.25 } | |
| Dec. | 1 | 7.24 | 570 |
| | 2 | 6.82 | 485 |

Source: Ministry of Agriculture

these three floods seem to have been of about the same peak stage. In each case, the crest was reduced by overflow into desceks, fartas and lowlands. The Selchozpromexport report states that the greatest flood of record at Lugh occurred October 28, 1956, and at Giamama in 1961, with a level of 7.54 meters at the bridge below Giamama gage station; the report adds that the 1961 flood in this reach resulted from the combined floods of the Juba and Shabelli rivers, an event occurring about "once in 50 years."

Low Flows

40 The Selchozpromexport report states that the Gelib-Giamama reach of river had no surface water flow in 1941 and 1950. The Technital report mentioned previously indicates that the river at Giamama was dry in 1964. The Booker-McConnell report shows flow in 1974 but not for 1975 at Kamsuma. Numerous reports point out the unreliability of low-flow records that are derived from single-valued rating curves. This is most evident at discharges of less than 10 cubic meters per second. A tabulation of minimum flows is therefore omitted.

41 A discharge of about 27 cubic meters per second is significant with respect to the Moganbo project. The Technital report indicates that a dam is proposed at Saco. The project would be mainly a diversion dam, but its reservoir is planned to provide sufficient storage for a dependable supply of 27 cubic meters per second to downstream irrigation projects in the dry season. This would be sufficient to meet the requirements of projects now in operation or in a more advanced stage of implementation than the Moganbo project. The Moganbo project would have water supply in the dry season only when the inflow to Saco Reservoir would exceed 27 cubic meters per second. Periods when the discharge at Giamama and Kamsuma has been less than 27 cubic meters per second are shown in Table I-17.

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TABLE I-17

Periods of Discharge Less than 27 $m^3$/sec. in Juba River

| Year | GIAMAMA |
|---|---|
| 1951 | About Feb. 26 to about Mar. 31 |
| 1952 | Jan. 30 to Apr. 20 except one day |
| 1953 | Dec. 26 (1952) to Apr. 28 |
| 1954 | Dec. 30 (1953) to Jan. 6; Jan. 12 to ∿ Apr. 8 |
| 1955 | Jan. 6 to Apr. 23; June 3 to July 8 |
| 1956 | Jan. 8 to Apr. 23 except one day |
| 1957 | About Jan. 6 to Mar. 14 |
| 1958 | Jan. 17 to Feb. 23 except 8 days; Mar. 11 to Apr. 27 |
| 1959 | About Feb. 1 to May 3 |
| 1960 | About April 12-16; April 24 to ∿ June 14 |
| 1961 | About Jan. 11 to ∿ April 5 |
| 1962 | Feb. 14 to Apr. 1; Apr. 11-15; June 15-16 & 23-28 |
| 1963 | About Jan. 6 to ∿ April 15 |
| 1964 | Feb. 21 to April 15 |
| 1965 | Feb. 18 to May 10 except 4 days |
| 1966 | Starting Feb. 10 *(record discont. Feb. 28)* |
| | **KAMSUMA** |
| 1973 | Feb. 24 to April 30 |
| 1974 | Feb. 6 to April 7 |
| 1975 | Jan. 15 to April 24 |

MEAN: January 30 to April 29, i.e., three months

Regulated Irrigation Supply

42 Technital S.p.A., in its 1976 report to the EEC, recommends the construction of the Saco Dam and Reservoir Project and especially the Bardera Storage Reservoir Project, a multipurpose project for flood control, hydropower, irrigation supply, municipal supply, stream sanitation and other benefits. When the latter is completed, the Saco Project would revert to a re-regulating and diversion function. The Bardera Project, if developed to realize the potential of the Juba River runoff, would provide an ample supply for the Moganbo and many other irrigation projects. The most recent information published by the Government of Somalia (Juba Valley Development Programme, September 1976) estimates the time for implementation of Saco Dam at three years and Bardera Dam at eight years. The implementation of both projects has started, so Saco Dam should be completed by the end of 1979 and Bardera Dam by the end of 1984. It becomes apparent that a regulated water supply should be available to the Moganbo Irrigation Project about when it develops a full demand for water.

43 In order to test the adequacy of Bardera Reservoir to meet the water requirements for the Moganbo and other projects, a trial operation was made. Based on the hypothetical operation of Bardera reservoir for the period 1951 through 1966, there should be an average annual release of 5,412.6 x $10^6$ $m^3$. Table I-18 shows the estimated monthly releases. The unique climatological conditions of the lower Juba River basin make it possible to adopt a more intensive cropping pattern, so it was concluded that irrigation water supplies should be somewhat greater than shown in the EEC (Technital) report, Alternate D, Phase II. The irrigation water requirements were therefore increased as shown in Table I-19. Account was taken of the generation of dependable or firm power amounting to 56 megawatts and an equal installation for secondary or non-firm energy, for a total installed power capacity of 112 megawatts. Releases to meet demands for municipal water and sanitation were estimated at a constant 15 cubic meters per second. Total storage capacity at elevation 153 meters msl was estimated at 4,850 x $10^6$ $m^3$ after allowance had been made for 50 years of sedimentation.

44 Comparison of the estimated monthly releases (Table I-18) and the total estimated water requirements (Table I-19) verified that Bardera Reservoir should amply supply future water demands on the Juba River. There would have been one minor power shortage in September 1965. There would have been releases through the spillway of 887 x $10^6 m^3$ in 1951; 539 x $10^6 m^3$ in 1959, and 1740 x $10^6 m^3$ in 1961.

Table I - 18

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MOGANBO IRRIGATION PROJECT

Estimated Monthly Releases from Bardera Reservoir

Units - $10^6$ $m^3$

| Year | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 372 | 339 | 375 | 548 | 620 | 632 | 654 | 659 | 632 | 1065 | 1106 | 622 | 7674 |
| 52 | 372 | 351 | 375 | 332 | 372 | 456 | 415 | 394 | 674 | 633 | 407 | 404 | 5185 |
| 53 | 372 | 339 | 375 | 342 | 372 | 456 | 415 | 443 | 380 | 482 | 467 | 404 | 4847 |
| 54 | 372 | 339 | 375 | 360 | 372 | 456 | 415 | 718 | 669 | 675 | 482 | 404 | 5637 |
| 55 | 372 | 339 | 375 | 347 | 372 | 456 | 415 | 399 | 381 | 482 | 467 | 404 | 4809 |
| 56 | 372 | 358 | 399 | 412 | 442 | 456 | 445 | 453 | 402 | 482 | 467 | 404 | 5092 |
| 57 | 372 | 339 | 375 | 373 | 399 | 456 | 415 | 394 | 380 | 482 | 467 | 404 | 4856 |
| 58 | 372 | 339 | 375 | 365 | 391 | 456 | 415 | 394 | 380 | 482 | 467 | 404 | 4840 |
| 59 | 372 | 339 | 375 | 342 | 372 | 456 | 415 | 394 | 380 | 538 | 1177 | 404 | 5564 |
| 1960 | 372 | 351 | 653 | 324 | 372 | 456 | 415 | 410 | 380 | 482 | 467 | 404 | 5086 |
| 61 | 372 | 339 | 375 | 334 | 372 | 516 | 680 | 686 | 643 | 1046 | 1602 | 1022 | 7987 |
| 62 | 372 | 339 | 375 | 329 | 372 | 456 | 415 | 394 | 368 | 482 | 461 | 404 | 4773 |
| 63 | 372 | 339 | 375 | 347 | 524 | 618 | 480 | 538 | 368 | 482 | 467 | 404 | 5314 |
| 64 | 372 | 351 | 375 | 350 | 372 | 456 | 415 | 394 | 380 | 482 | 467 | 404 | 4818 |
| 65 | 372 | 339 | 375 | 353 | 375 | 456 | 415 | 431 | 463 | 496 | 467 | 404 | 4946 |
| 66 | 383 | 356 | 410 | 420 | 455 | 456 | 447 | 458 | 435 | 482 | 467 | 404 | 5173 |
| Total | 5963 | 5496 | 6337 | 5878 | 6604 | 7694 | 7271 | 7559 | 7315 | 9273 | 9911 | 7300 | 86,601 |
| Mean | 372.7 | 343.5 | 396.1 | 367.4 | 412.7 | 480.9 | 454.4 | 472.4 | 457.2 | 579.6 | 619.4 | 456.3 | 5,412.6 |
| Mean cms | 139.2 | 142.0 | 147.9 | 141.7 | 154.1 | 185.5 | 169.7 | 176.4 | 176.4 | 216.4 | 239.0 | 170.4 | 171.6 |

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TABLE I-19

Test of Adequacy of Bardera Reservoir to Meet Irrigation Water Requirements in Lower Juba Basin

$m^3/sec$

| Month | Technital Alternate D Phase II | Arbitrary Increase, This study | Total Requirements for This Study | Requirements in $10^6 m^3$ |
|---|---|---|---|---|
| Jan. | 74 | 50 | 124 | 332.1 |
| Feb. | 65 | 60 | 125 | 302.4 |
| Mar. | 75 | 50 | 125 | 334.8 |
| Apr. | 60 | 50 | 110 | 285.1 |
| May | 114 | 10 | 124 | 332.1 |
| Jun. | 161 | 0 | 161 | 417.3 |
| Jul. | 130 | 10 | 140 | 374.9 |
| Aug. | 112 | 20 | 132 | 353.5 |
| Sep. | 107 | 20 | 127 | 329.2 |
| Oct. | 165 | 0 | 165 | 441.9 |
| Nov. | 165 | 0 | 165 | 427.7 |
| Dec. | 136 | 0 | 136 | 364.2 |
| Mean | 114 | 22 | 136 | 357.9 |

Ground Water Supply for the Moganbo Project

45 No wells have been drilled in the area to supply irrigation water. Two sites, one near Giamama and one across the river from Kamsuma, have been investigated and found inadequate. In general, when water is found it is unsuitable in chemical content. Further investigation may prove the ground water supply to be adequate for limited domestic use.

Sediment Transport in the Juba River

46 Data are not available from any long-period program of sediment discharge measurements on the Juba River. The Selchozpromexport report, with reference to its analyses for the Bardera storage project, derived the suspended load for an annual runoff of 50 per cent probability as 13.8 million tons, an amount roughly equivalent to 2400 parts per million by weight. This amount was increased by 7 per cent to account for an estimate of bed load. The deposition in 50 years in the reservoir is given as 346.1 million cubic meters. (In Technital's report to the EEC, the 50-year deposition was estimated as 500 million cubic meters, but a storage allocation of 600 million cubic meters was made in project planning.)

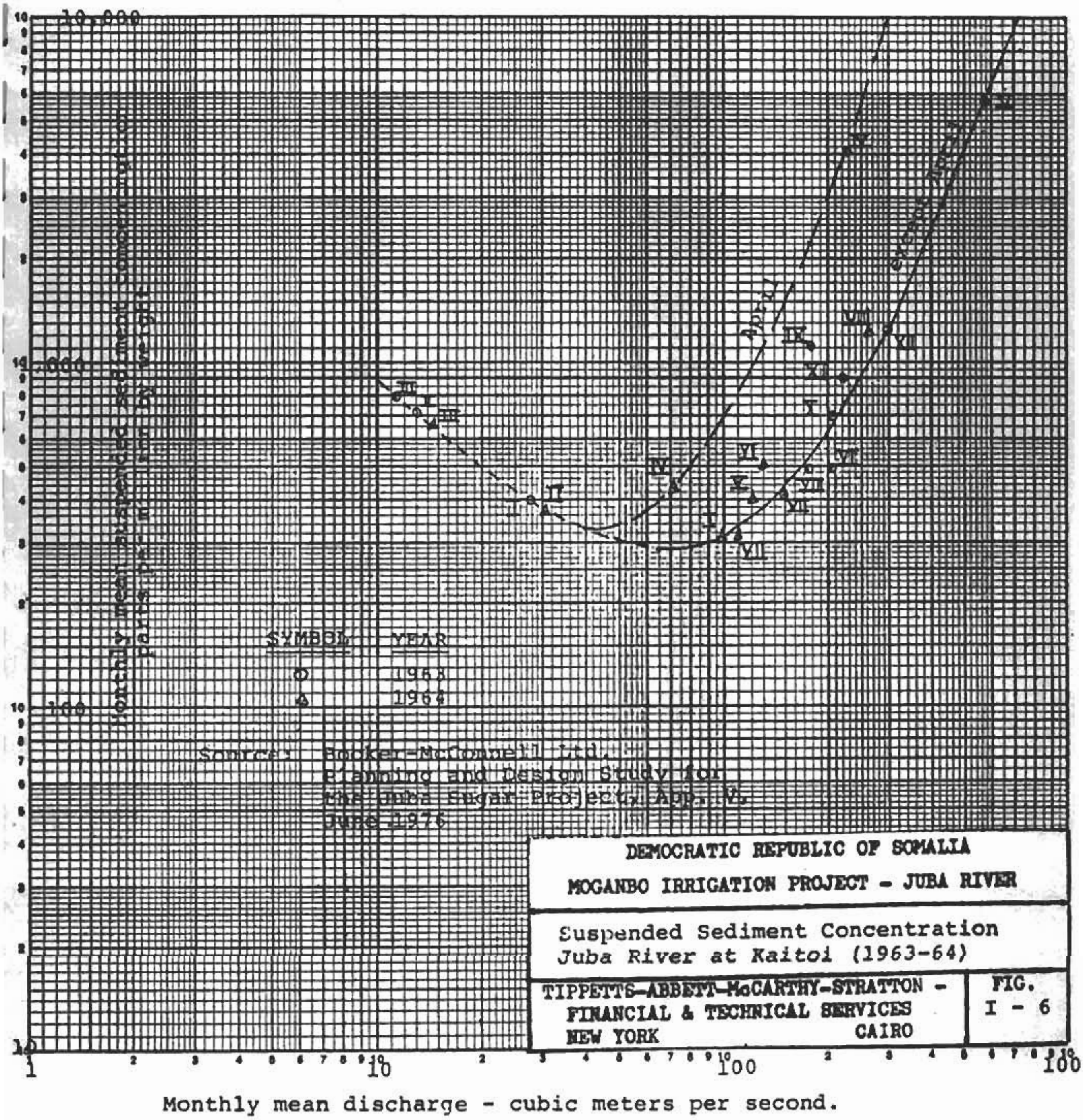
47 In the Booker-McConnell report, the mean suspended sediment concentration for the Juba River at Kaitoi for 1963 was derived as about 2300 parts per million, the mean water discharge being 189 cubic meters per second. For a water discharge with 20 per cent probability of occurrence (285 cubic meters per second), the mean suspended sediment concentration was computed as 3400 parts per million. Although the Moganbo Project area is far downstream from Kaitoi, the concentrations of suspended sediment at the canal intake would not be greatly different. Ratings of suspended sediment concentrations and discharges versus water discharge are shown in Figures I-6 and I-7 on a monthly basis. When the first rains of the Gu period begin to fall, the runoff washes the dry soil and flushes stream channels, so suspended-sediment concentrations are relatively high (perhaps as high as 10,000 parts per million by weight). A similar tendency may exist in September after the relatively dry Hagai period. With the building of Saco and Bardera Dams, there normally should be some reduction in sediment in the river. However, the release of clear water from these reservoirs may result in stream degradation below the dams

and no appreciable reduction in sediment at the Moganbo pumping site, at least until the river reaches a new stability, should be expected.

Chemical Quality of the Juba River

48 Samples of the Juba River at Margherita (Giamama) were collected in 1960 by the International Cooperative Administration (ICA) and data were published in Inter-River Economic Exploration, 1961. The electrical conductivities, in millimhos per centimeter, are shown in Figure I-8, which also gives the discharges of the river for the same period of time (from tables in the files of the Department of Hydrology, Ministry of Agriculture). Not much can be concluded from the visual comparison of conductivity and discharge, mainly because the discharges are quite unrealistic.

49 Fortunately, the ICA reported the "depth of river" at the bridge when collecting the water samples and if these represented gage heights, some comparisons are possible. During the first rise, with peak on March 31, 1960, the conductivities are in phase with the rise of the river. In some at least of the remaining rises of the river, the

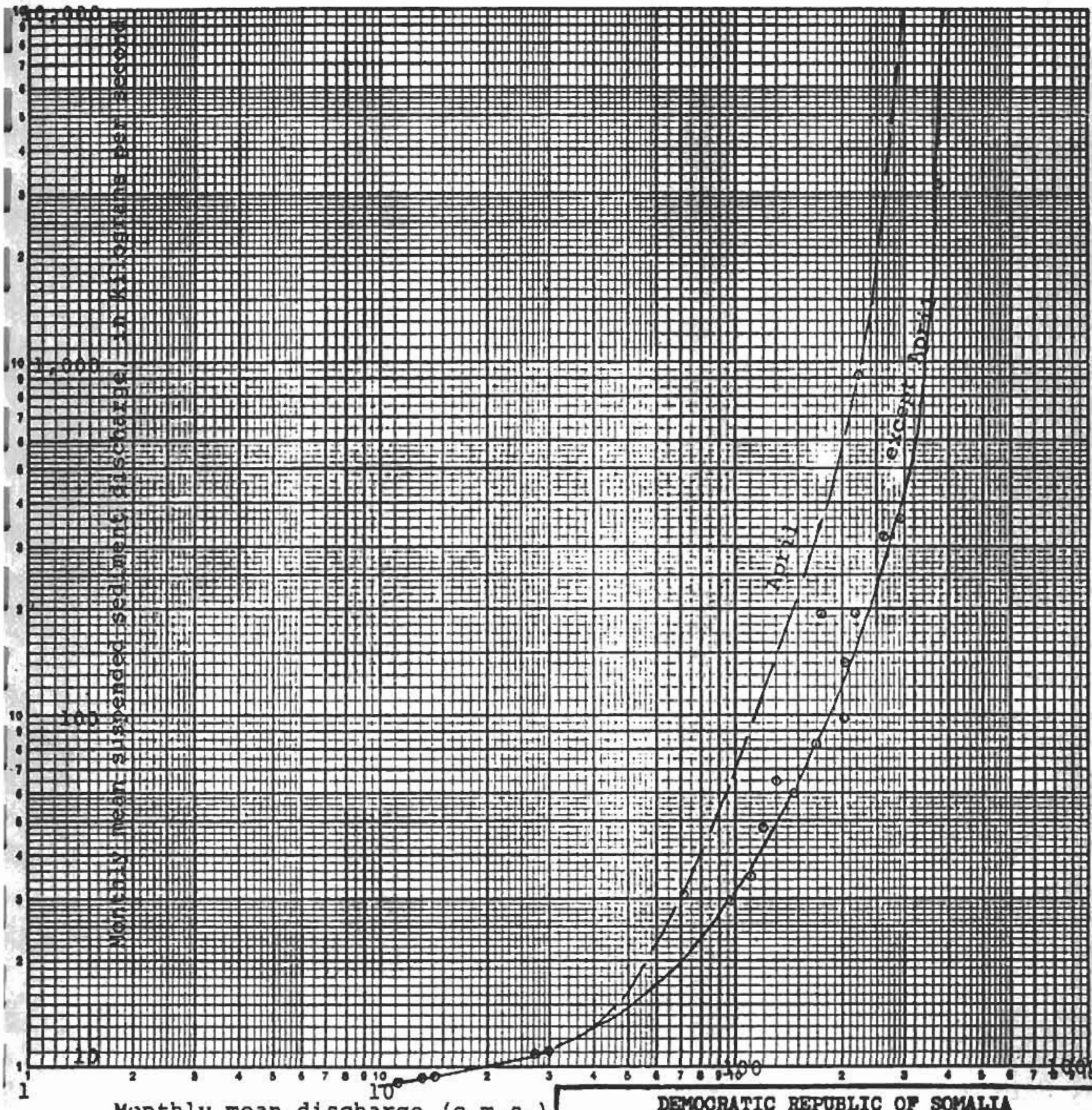



DEMOCRATIC REPUBLIC OF SOMALIA

MOGANBO IRRIGATION PROJECT - JUBA RIVER

Suspended Sediment Concentration
*Juba River at Kaitoi (1963-64)*

| TIPPETTS-ABBETT-McCARTHY-STRATTON - FINANCIAL & TECHNICAL SERVICES NEW YORK CAIRO | FIG. I - 6 |
|---|---|




**DEMOCRATIC REPUBLIC OF SOMALIA**

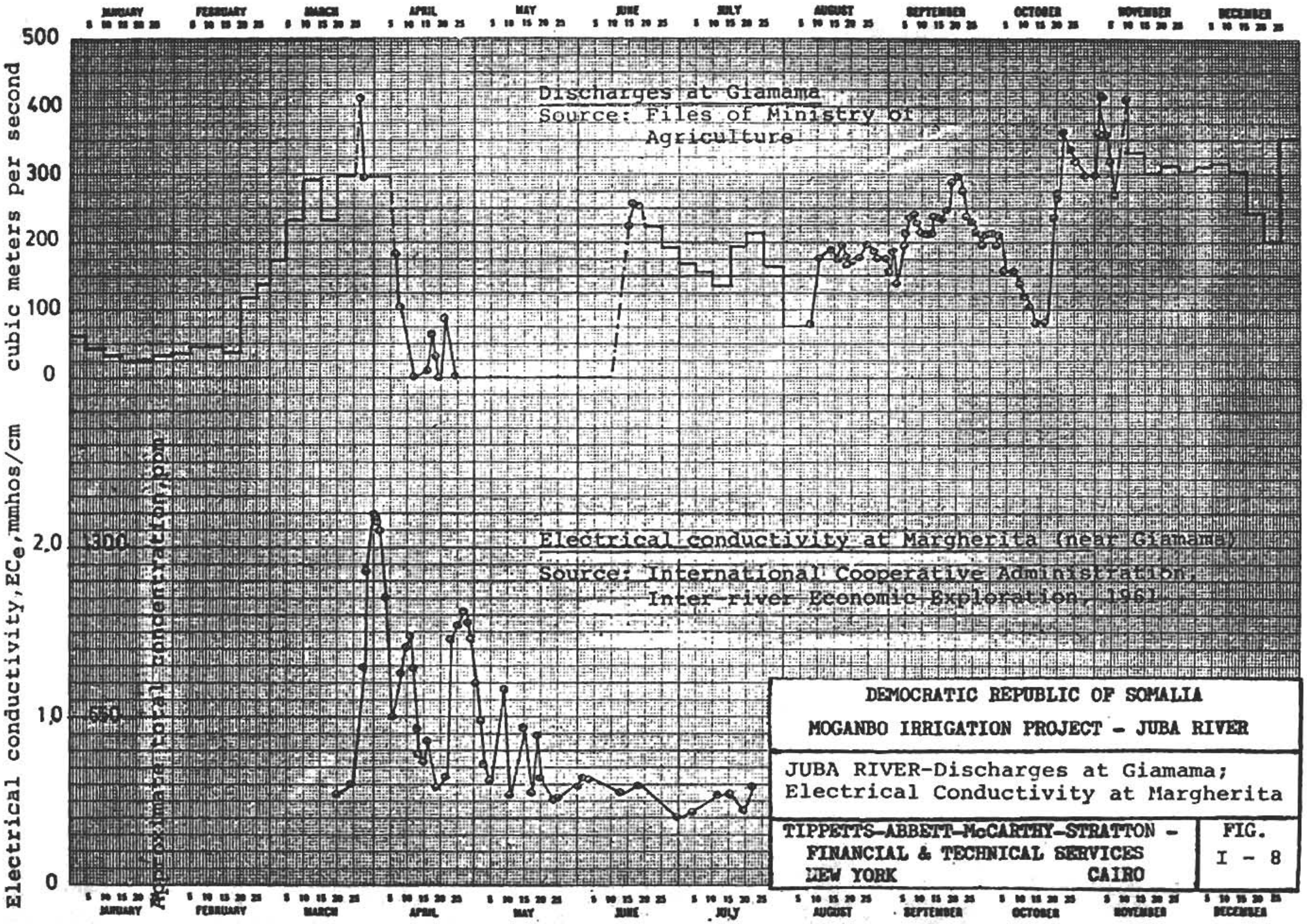
**MOGANBO IRRIGATION PROJECT - JUBA RIVER**

Suspended Sediment Discharge - Juba River at Kaitoi (1963-64)

**TIPPETTS-ABBETT-McCARTHY-STRATTON - FINANCIAL & TECHNICAL SERVICES**
**NEW YORK CAIRO**

**FIG. 1 - 7**

Source: Booker-McConnel Ltd., Planning and Design Study for the Juba Sugar Project, App. V June 1976




DEMOCRATIC REPUBLIC OF SOMALIA

MOGANBO IRRIGATION PROJECT - JUBA RIVER

JUBA RIVER-Discharges at Giamama; Electrical Conductivity at Margherita

TIPPETTS-ABBETT-McCARTHY-STRATTON - FINANCIAL & TECHNICAL SERVICES
NEW YORK CAIRO

FIG. I - 8

conductivities lag, an indication probably that the ions are contributed at reaches farther upstream. Total concentrations in parts per million have been computed as about 10 times conductivity in mmhos/cm less the milliequivalents per liter of the calcium and magnesium ions. The results may be expressed fairly well also by the proudct of 650 times the conductivity. The greatest concentration is about 1400 ppm. During this flood and the one of April 27, conductivities and concentrations are sufficiently high to rank as high in salinity hazard for irrigation of crops. During the remaining period of the testing program the water rated as medium, low and very low in salinity hazard.

50 Some of the ICA samples were tested for ion concentrations during the Gu and part of the Hagai season in 1960 (Table I-20). The calcium plus magnesium concentration is high relative to sodium concentration, a characteristic favorable for the maintenance of adequate soil permeability and soil tilth. The conductivity when expressed in mmhos per cm is approximately equal to the sum of the cations or the sum of the anions. A characteristic

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TABLE I-20

Chemical Quality of Juba River at Margherita (Giamama)

| Date of Sample 1960 | Depth of Water, (meters) | Computed Sediment Concen. ppm | $EC_e$ mmhos per cm | Milliequivalents per liter Na (est.) | Ca + Mg | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|
| Mar 31 | 7.63 | 1414 | 2.20 | 3.2 | 19.8 | 1.0 | 7.0 | 14.0 |
| Apr 4 | 7.29 | 1039 | 1.60 | 3.1 | 13.5 | 1.0 | 4.5 | 10.5 |
| Apr 6 | 6.35 | 659 | 1.00 | 2.0 | 8.0 | 2.0 | 3.0 | 5.0 |
| Apr 11 | 6.96 | 1065 | 1.48 | 2.5 | 13.0 | 2.0 | 5.0 | 9.8 |
| Apr 13 | 6.21 | 605 | 0.93 | 2.1 | 7.2 | 2.0 | 2.5 | 4.8 |
| Apr 15 | 5.98 | 500 | 0.75 | 2.3 | 5.2 | 2.0 | 2.8 | 2.7 |
| Apr 19 | 6.96 | 386 | 0.59 | 1.9 | 4.0 | 1.0 | 2.1 | 2.8 |
| Apr 23 | 7.64 | 903 | 1.45 | 3.6 | 11.2 | 1.0 | 4.5 | 9.0 |
| Apr 27 | 7.66 | 1070 | 1.63 | 1.6 | 15.5 | 1.0 | 3.5 | 11.8 |
| May 1 | 6.20 | 781 | 1.20 | 3.5 | 8.7 | 1.0 | 4.0 | 7.0 |
| May 5 | 7.39 | 403 | 0.63 | 1.8 | 4.5 | 2.0 | 2.5 | 1.8 |
| May 9 | 7.31 | 758 | 1.17 | 3.6 | 8.1 | 1.8 | 5.9 | 4.0 |
| May 15 | - | 617 | 0.95 | - | - | 2.0 | 5.0 | 3.0 |
| May 20 | - | 422 | 0.65 | - | - | 1.5 | 3.5 | 1.5 |
| Jul 23 | 5.25 | 390 | 0.60 | - | - | 1.5 | 2.0 | 2.5 |

Source: International Cooperative Administration of Juba River water is that, as the conductivity increases, the concentrations of calcium plus magnesium ions and of the sulphate ions tend to increase relative to the other ions.

51 In recent years, the Juba River at Alessandra has been sampled for chemical quality by Booker-McConnell Ltd. The results are quite consistent with the data of the ICA program. No information has been found regarding concentrations of boron and other trace elements.

52 The higher concentrations of salts at the beginning of the wet seasons appear due to the fact that the early floods flush the evaporated salts of the channel and countryside. Water should not be drawn off from the river during the early floods, but this is mainly because of the high silt content, i.e. to conserve on maintenance costs, rather than because of high chemical content. It is possible that regulation of river flows by Bardera Dam will stabilize chemical concentrations by eliminating the flushing phenomenon.

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# MOGANBO IRRIGATION PROJECT

## APPENDICES, VOLUME 1

## PART II

## SOILS SURVEY

# SOMALIA

## MOGANBO IRRIGATION PROJECT

## APPENDICES, VOLUME 1 PART II

## SOILS SURVEY

CONTENTS

## TABLES



## FIGURE

# SOMALIA

# MOGANBO IRRIGATION PROJECT

## APPENDICES, VOLUME I

## PART II: SOILS SURVEY

### A - DESCRIPTION OF PROJECT AREA

1 The project area is located in the southwest part of the Democratic Republic of Somalia, at 0°4' to 0°14' N latitude and 42°40' to 42°45' E longitude. It is part of the Lower Juba-Shabelli flood plain, just west of the present course of the Juba River. Polo (village) Moganbo is located to the north on the paved Kismayu to Gelib road and Polo Kobon is to the south. Several banana plantations are located west of the paved road, i.e. to the east of the project area.

2 The flood plain is formed of alluvium material of variable particle-size distribution.

brought down by the Juba and Shabelli rivers and tributaries since the late Tertiary period. Several hundred meters depth of alluvium layers are of Tertiary-Quaternary period and recent deposits have overlain Jurassic limestone to the north. Tertiary marine sediments toward the coast have been reported (Selchozpromexport).

3 The Juba River is set slightly below the surrounding flood plain, indicating a recent change in base level. The flood plain is flat with a sub-parallel surface drainage network towards the Juba or the Indian Ocean. The Juba flows into very flat, meandering swamps situated at lower levels, where stagnant-water pools and depressions (desceks) form. Several landform features can be recongized in this flood plain region. Terraces, channel remnants, levees, meanders, oxbows and slackwater depressions (desceks) are the most common features.

## Vegetation

4 In general, the project area is covered by shrubs and grass. Bush density varies with rainfall intensity, slope or topography and soil moisture-holding capacity. Acacia species and grass cover of different densities are the most abundant natural vegetation in the area. The natural vegetation is more dense in the vicinity of water courses or bodies and lowland forms or depressions, wherever available moisture is long lasting.

5 The surveyors found scattered corn and sesame fields in the project area. These crops, as well as tobacco and some vegetables, were grown by shifting farmers who follow the water receding from the lower land forms after the Gu rainy season. Their crops may or may not complete their life cycles, as the availability of moisture during the growing season depends upon the intensity of precipitation during the last wet season as well as the amount of rainfall during the growth season. Wilting signs were observed during August, especially at midday. Permanent wilting occurred while corn and sesame were at blooming or early maturity stages

at the end of August and in early September, 1976. Damaged crops were common on high, relatively steep areas, on medium to coarse-textured soils, especially those with saline subsoils.

## B - FIELD SURVEY

6 The soil field survey commenced on July 12th, 1976, and field work ended September 8th, 1976. Several meetings with government officials and soil specialists at the Afgoi soil-testing laboratory were held from the 8th to the 17th of September and the Soils Scientist made short field trips to the Mogadishu region.

7 The mapping of different land forms and soil types was based on interpretations of air photographs, supported by field traverses and site investigations. The soil map "Gelib 14," and aerial photographs and mosaics, in scales 1:100,000 and 1:30,000, respectively, were available. The preliminary landform map (Figure II-1) prepared on the basis of examination of the mosaic in the scale of 1:30,000, then by stereoscopic

examination of pairs of aerial photographs (1:30,000) taken in 1962. The field traverses utilized every available type of trails, dikes (man-made levees) and cut-lines of previous survey works. Seventeen new cut-lines were also made during this field work.. They included some 150 km of east-west cut-lines (at intervals of 750 to 1000 meters) and a few north-south lines.

8 Soil observations and examinations were made using auger bores to a depth of 130 cm. A total of 81 bores were examined and soil samples were collected for laboratory analysis. Twenty-five soil pits were also dug two meters deep in selected localities. The location of all bores and soil pits were marked on tracing paper matched to the aerial photographs, then marekd on the soil map of the project area (1:15,000). A small circle on the map indicates an auger bore site and a rectangle indicates a soil pit site.

9 At each profile site, comprehensive descriptions were made of surface relief, vegetation, depth of horizons or layers, hand texture, structure, color according to the Munsell color charts, consistency, salts, carbonates, gypsum, mottles, root and

pore size and distribution, reaction with dilute HCl, and the pH using field kit reagents and a color chart.

Soil Sampling and Analysis

10 Soil samples were collected from the soil surface and at different depths in the soil profile to determine variations in texture, color, structure and/or salt content. A total of 483 samples were collected, labelled and sent to the Afgoi soil laboratory for analyses. The following tests and methods were used:

(a) Particle-size distribution was determined using the hydrometer method. The texture class was determined using the texture triangle, and the saturation percentages were used to identify soil textural classes.

(b) $CaCO_3$ equivalent percentages: The samples were reacted with excess HCl and back titrated with NaOH.

(c) Organic matter percentages, by measuring organic carbon content: The samples were treated with excess potassium dichromate and sulphuric acid, digested with heat and back titrated with ferrous sulphate (% organic matter = % organic carbon x 1.72).

(d) Available potassium (ammonium acetate extractable potassium = soluble plus exchangable potassium): A 10-gram sample was shaken with a 100-ml ammonium acetate solution. The extracted potassium was determined by the flame method.

(e) Available phosphorus (sodium bicarbonate extractable phosphorus): A 5-gram sample was shaken with sodium bicarbonate solution. Phosphorus was determined colorimetrically in the filtrate.

(f) pH was determined in a saturated soil paste extract using a pH meter with glass electrode.

(g) Electrical conductivity ($EC_e$): a saturated soil paste-extract was measured with a Solu-Bridge (conductivity cell).

(h) Soluble cations and anions were measured in the prepared extract as follows:

- Sodium and potassium, by flame photometry;
- Calcium and magnesium, titrated with versine (EDTA), using a buffer solution pH 9.5 and suitable indicators;
- Chlorine, titrated by silver nitrate solution;
- Carbonate and bicarbonate ions were neutralized by sulphuric acid;

- Sulphate ions: the difference between total cations and other determined ions;
- Sodium adsorption rate: calculated from concentrations of Na, Ca and Mg in the saturation extract ($SAR = Na/[Ca+Mg/2]^{1/2}$ ).

C - PROJECT SOILS ANALYSIS

11 The soils of the Moganbo project are developed in the very complex landforms of the southern region of the Lower Juba River flood plain. The old and recent deposition of Juba River sediments in this area were reworked during late stages of formation. The overflow during high flood seasons finds its way through and over some parts of the complicated landforms near Moganbo and Bulo Yag. The flood plain meander contains abandoned channel courses, levees and oxbows. Flood plain slackwater lowlands, known locally as "desceks," are commonly found adjacent to flood plain levee bodies. All these types of landforms are intermixed and vary in size in the project area.

12 Ant mounds are common in this project area, especially on medium textured soils (loams). These mounds, in many sizes and heights, up to 5 meters in height and 15 meters in diameter, are found in

relatively large parts of the surveyed project area and represent one of the obstacles to development. They must be levelled before irrigated agriculture development can proceed.

Soil Profiles

13 All soil profiles are deep and well drained except where ponded water stands for prolonged periods in the desceks. Investigations to a depth of two meters did not encounter any watertable in the project area. A dry well seven meters deep was encountered on the southern part of the project area (the N cut-line).

14 Stony subsoils were encountered in the southern part of the project area (Profiles of Pits 10, 23, and Bore 76). Gravels are commonly present even in fine-textured soil materials. These stony subsoils and the presence of gravel may indicate several flooding and erosional cycles during the land formation period in the Juba flood plain. These, along with the presence of large bodies of coarse-textured surface material as well as stratified soil material, reflect the large variation of the flood and flow pattern of the Juba River. This mode of formation

of different landforms and perhaps soil types is common in the basins of large river streams such as the Nile River and Juba-Shabelli Rivers.

Soil Characteristics

15 Sediments carried by the Juba River are calcareous. Table II-1 shows calcium carbonate equivalents for samples from a representative test pit (No. 1).

16 As shown in Table II-2, only four samples had pH values less than 7.0. Over one-half of the samples were neutral to base and 45 per cent were in the range of base to alkali. Only 1.5 per cent were above 8.3 and in the alkaline range. No surface alkali spots were observed.

17 The salt hazard in the project area is relatively low, as may be seen in Table II-3. Of a total of 480 samples tested, 65.2 per cent indicated no salt hazard and only 20.4 per cent showed a high to very high hazard.

18 Almost three-fourths of the 422 samples tested showed a sodium adsorption ratio of less than 10, which would indicate no sodium hazard. Table II-4 shows that 15.2 per cent of the samples had a very high hazard of over 25.

# SOMALIA

## MOGANBO IRRIGATION PROJECT

### Table II-1

### Calcium Carbonate Equivalents, Texture and Organic Matter[1]

| Sample Depth cm | $CaCO_3$ equiv % | Sat. % | Sand % | Silt % | Clay % | Tex-* ture | Org. MC % | Av. P ppm | Av.K meq/L 100gm |
|---|---|---|---|---|---|---|---|---|---|
| 2 - 20 | 23 | 40 | 22 | 56 | 22 | L | 1.1 | 3.0 | 0.4 |
| 70 | 24 | 48 | 22 | 60 | 18 | CL | 0.8 | 0.5 | 0.3 |
| 110 | 23 | 52 | 26 | 58 | 16 | C | 0.6 | 2.8 | 0.3 |
| 150 | 18 | 48 | 26 | 56 | 18 | CL | 0.1 | 2.0 | 0.2 |
| 175 | 15 | 52 | 24 | 65 | 14 | C | 0.3 | 2.0 | 0.2 |
| 200 | 15 | 40 | 22 | 60 | 18 | L | 0.3 | 1.8 | 0.2 |

[1] Total samples 106 (25 pits, 81 bores)

*See Table II-5.

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MOGANBO IRRIGATION PROJECT

Table II-2

The pH of Saturated Soil Paste Extracts,

Classes and Distribution

| pH | Class | Samples from Pits | Samples from Bores | Total | % |
|---|---|---|---|---|---|
| | | 138 | 344 | 482 | 100 |
| <7 | Slightly acid | 1 | 3 | 4 | 0.8* |
| 7-7.7 | Neutral to base | 61 | 193 | 254 | 52.7 |
| 7.8-8.3 | Base to alkali | 71 | 146 | 217 | 45.0** |
| >8.3 | Alkali | 5 | 2 | 7 | 1.5** |

* Surface samples

** Subsoil samples

# SOMALIA

## MOGANBO IRRIGATION PROJECT

### Table II-3

### Electrical Conductivity of Saturated Soil Paste Extracts, Classes and Distribution

| ECe mmhos/cm | Class | Samples from Pits | Samples from Bores | Total | % |
|---|---|---|---|---|---|
| | | 136 | 344 | 480 | 100 |
| < 2 | No salt hazard | 75* | 238* | 313 | 65.2* |
| 2-3.9 | Low salt hazard | 10 | 26 | 36 | 7.5 |
| 4-7.9 | Medium salt hazard | 8** | 25 | 33 | 6.9** |
| 8-16 | High salt hazard | 25** | 33 | 58 | 12.1** |
| > 16 | Very high salt hazard | 18** | 22 | 40 | 8.3** |

* Surface samples

** Subsoil samples

# SOMALIA

## MOGANBO IRRIGATION PROJECT

### Table II-4

### Calculated Sodium Adsorption Ratio Values, Classes and Distribution

| SAR | Class | Samples from Pits | Bores | Total | % |
|---|---|---|---|---|---|
| | | 138 | 284 | 422 | 100 |
| < 10 | No Na - hazard | 90 | 223 | 313 | 74.2 |
| 10-15 | Low Na - hazard | 7 | 14 | 31 | 4.9 |
| 15-25 | High Na - hazard | 11 | 13 | 24 | 5.7* |
| > 25 | Very high Na-hazard | 30 | 34 | 64 | 15.2* |

* Subsoil samples

19 Weathering of sandy materials releases enough free iron oxides to form cemented sandy material near the soil surface. The subsoils of these lands are usually cemented by leached (illuviated) secondary carbonates which make them calcareous and sometimes of medium salinity. This type of soil formation, along with the common saline or saline-alkali subsoils, especially of fine-textured material, reflects the leaching capacity of the semi-arid climate of the project area.

20 In some areas, as indicated in Table II-3, salt accumulations prevail in heavy, impermeable, clayey-textured material where water cycling is limited.

21 The relatively low organic matter content, as indicated by the low organic carbon percentages in Table II-1, reflects the effect of constant high temperatures. Organic matter normally decomposes during the dry season. The low content of organic matter suggests the need for the application of organic fertilizers (manure).

22 A sample of the chemical and physical characteristics of the soils of the project area is shown

in Tables II-1 and II-6. The soils generally fall in a textural class of silt loam to clay loam, with 41 per cent of the samples falling in the latter class (Table II-5).

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MOGANBO IRRIGATION PROJECT

Table II-5

Saturation Percentages and
Soil Textural Classes Distribution

| Sat. % | Texture | Samples from Pits | Bores | Total | % |
|---|---|---|---|---|---|
| | | 138 | 342 | 480 | 100 |
| < 28 | Loamy sand (LS) | 4 | 9 | 13 | 2.7 |
| 28-35 | Sandy loam (SL) | 14 | 9 | 23 | 4.8 |
| 36-42 | Loam (L) | 29 | 70 | 99 | 20.6 |
| 43-50 | Silt loam to clay loam (S+L to CL) | 65 | 132 | 197 | 41.0 |
| 51-60 | Clay (C) | 22 | 93 | 115 | 24.0 |
| > 60 | Heavy clay (HC) | 4 | 29 | 33 | 6.9 |

TABLE II - 6

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MOGANBO IRRIGATION PROJECT

CHEMICAL AND PHYSICAL ANALYSIS OF SAMPLES FROM PIT NO. 1[(1)]

| Sample depth cm | pH | ECe mmhos /cm | Soluble cations | | | | SAR | Soluble anions | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg meq/L | Na | K | | $CO_3$ | $HCO_3$ meq/L | Cl | $SO_4$ |
| 0-20 | 7.9 | 0.9 | 3.0 | 1.3 | 4 | 0.1 | 3 | - | 2.8 | 3 | 2 |
| 20-70 | 8.4 | 7.0 | 4.0 | 4.3 | 78 | 0.1 | 39 | 0.8 | 1.2 | 41 | 43 |
| 70-100 | 8.2 | 30.0 | 22.5 | 25.0 | 287 | 0.3 | 59 | - | 2.0 | 108 | 224 |
| 110-150 | 8.4 | 30.0 | 24.5 | 32.0 | 309 | 0.3 | 58 | 0.4 | 1.2 | 130 | 244 |
| 150-175 | 8.4 | 30.0 | 24.0 | 27.0 | 278 | 0.2 | 55 | - | 2.0 | 103 | 214 |
| 175-200 | 8.4 | 30.0 | 24.0 | 28.0 | 286 | 0.2 | 56 | - | 1.2 | 105 | 232 |

(1) Total samples 106 (25 pits, 81 bores)

## D - LAND CLASSIFICATION

### Classification Criteria

23 The standards developed for the purpose of classifying project lands with respect to relative productivity and economic costs are described in the following paragraphs. Typical profiles for the different land classes are shown at the end of this section. Soil infiltration rates, samples of which are shown in Table II-8, were also considered in making the land classification.

(a) Class I lands: Soils shall be fertile, with a high percentage of organic matter. Electrical conductivity ($EC_e$) shall be less than 2. The sodium absorption rate (SAR) should be under 10 and the pH 6.5-7.5.

Drainage: Soils should have excellent surface drainage, be moderately permeable, and have little or no requirement for subsurface drainage under irrigated consitions.

Topography: Level to gently sloping, with slopes of not more than one per cent and with no undulations.

(b) Class II lands:

Soils shall be moderately fertile, with greater than 1 per cent organic matter at the surface. Electrical conductivity ($EC_e$) shall fall in the range of 2.0 to 3.9. The sodium absorption ratio

(SAR) should be between 10 and 15 and pH should fall between 7.0 and 7.7.

Drainage: There should be good surface drainage. The soils should be moderately permeable. Subsurface drainage may be required but the estimated drain spacing should not be closer than 200 meters. The subsurface (below the root zone) should be well drained.

Topography: Land can be gently rolling, with land smoothing but no heavy land levelling required. Scattered ant hills would not change the basic cost of land smoothing.

(c) Class III Lands

Soils: May be deficient in organic matter. Electrical conductivity ($EC_e$) should be from 4 to 7.9, the sodium adsorption ratio (SAR) between 10 and 15 and the pH between 7.0 and 8.0.

Drainage: Moderate surface drainage. Relatively low permeability, with a requirement for drain spacing of from 50 to 100 meters. Soils below the root zone should be slightly permeable.

Topography: Moderately rolling and interlaced with small drainage channels. Some fairly heavy land levelling may be required in addition to land smoothing. Moderately high land development costs.

(d) Class IV Lands

Soils: May be deficient in organic matter. Electrical conductivity ($EC_e$) of from 8 to 16. Sodium adsorption ratio of from 15 to 25 and pH in the range 7.7 to 8.3.

Drainage: Adequate surface drainage. Low permeability with slow internal drainage. May require mole drains on 15 to 20 meter spacing. Drainage costs may be excessive at present.

Topography: Moderately rolling. Uniform slope exceeding 3 per cent. Irrigation would require special care and would be expensive. May be old river channels, difficult to develop for irrigation.

(e) Class V Lands

Coarse to very coarse textured soils, very difficult to serve by the planned irrigation system.

Project Lands Classification (See Figure II-1)

24 A total of almost 10,000 hectares were classified according to the foregoing standards. None of the soils would fall into the most favorable Class I, but all project lands could be classed as arable, with some restrictions. The combined findings of the soil survey, agronomic investigations, irrigation planning

and drain location resulted in the delineation of a gross area of 6943 hectares considered suitable for irrigation development. Soils of the various classifications are described in subsequent paragraphs, and the irrigable soils by class and area are shown in Table II-7 and Figure II-1.

Class II

25 Soil class II is composed of two types of soil profiles underlain by permeable substrata. One soil profile has clay loam texture for the surface material and loamy subsoil. The substrata under this type is usually of sand loam texture (Pits No. 6, 7, 8, 11, 14). This type of soil is well drained, and non-saline. Good crop stands were observed in July 1976 (end of Gu season). Wilted blooming corn and sesame were found during August and September (Hagai), showing that moisture stress during the dry season renders good production difficult.

26 Grass cover is dense and abundant on these soils but may suffer if prolonged dry season occurs. These soils are good for rice and cotton plus other crops if the moisture requirement is supplied. Irrigation, drainage and good management are essential to develop these soils. Salinity-alkalinity hazards must be kept to a minimum.

27 A second soil profile falling in this general classification has a loam material on the surface but its subsoil contains clay loam or silt loam, and sometimes a clay layer of variable thickness above the permeable substrata (Pits 5, 9, 12).

28 This stratified type was generally cropped with corn and sesame but scattered bush is the natural vegetation. Weak stands of grass also were noticed. Scattered ant mounds are common. The water-holding capacity depends very much on the depth, thickness and permeability of the middle heavy-textured layers. This kind of soil requires good water management. Drains may be required if the middle layer is very thick or impermeable.

29 As shown in Table II-7, there are about 2870 hectares of Class II land in the selected project area.

Class III

30 Soils with clay, clay loam to silt loam, or loam surface texture with clayey subsoils fall within the class III standard. The soil is deep, compacted and has only fair drainage. The surface is salt-free but calcareous in many areas. The subsoil is slightly to medium saline.

31 The soil profile may be undeveloped (recent), entisols and inceptisols when partially developed, or fairly developed groumosols or vertisols. This group could be subdivided according to the degree of development or the levels of salinity and akalinity of the subsoil. There are three degrees of profile development, namely Entisols, Inceptisols and vertisols, and two salinity subdivisions, slightly to medium saline alkali and highly saline alkali subsoils.

32 These soils have high moisture-holding capacity. Most of the rainfed crops are grown on these soil types. The farmers get fair crops if salinity stresses are kept low by providing suitable moisture throughout the growth season.

33 A review of Table II-7 shows that an estimated 3118 ha fall in class III and are capable of sustained production under irrigation.

Class IV

34 There are two general types of soils which come within the standards of class IV. One type is found in old river channels where the soils are of a deep clayey textured material with prevailing high moisture

content and moderately well drained. These soils would fall in a higher class except for the high cost of development. Since they represent less than 10 per cent of the project area and are interspersed with better soil classes, it is concluded that the inclusion of these soils within the irrigable acreage would be beneficial to the project.

35 Another group of soils in class IV consists of a loamy surface underlain by clay loam. These are highly calcareous and are saline and alkaline. These unleached soils are situated at a higher level than much of the project area and may be difficult to serve with the planned irrigation system. Some salt crystals and large concentrations of carbonates and gypsum were visible. This soil could be leached by application of irrigation water. This second category of the class IV soils was included in the project as irrigable land because of its small integrated area and because of its proximity to the main project drain.

36 In all, 824 ha of class IV lands have been included in the project.

Class V

37 Soils in class V are mostly outside the proposed project area. One small piece, 131 ha, is included

as a part of Block C. Although another area of class V is within the project boundary, it is too high to be reached by the project water supply systems and has not been included in area totals.

38 Class V includes the coarsest textured soils in the project area. The reddish brown and light brown colors are a general means of identification. The soils are deep with good permeability and are slightly acid to neutral. At depth, they are calcareous and occasionally slightly saline. They would fall in a general classification of sandy loam over loam and sandy clay.

## E - SUMMARY

39 The results of the soil survey lead to the conclusion that there are no serious salinity or alkalinity problems that would justify leaving certain soils out of the selected project area.

40 Texturally, the soils fall predominantly into the general classifications of loam, silt loam, and clay.

41 Surface drainage is adequate to control runoff from both rainfall and irrigation, after fields have been properly shaped by land development. Subsurface

drainage should not be considered until the project has been in operation for a number of years and such need has been demonstrated. Appropriate allowance for funding future subsurface drainage as and when needed should be included in the project cost estimate.

42 Surface soils are fairly fertile and contain organic matter and available potassium (K) and phosphate (P) Subsurface soils at depths of 40 cm in some areas contain some salts. This indicates that land grading should be held to a minimum to maintain soil fertility.

43 The overall project topography indicates there are no long steep slopes. With proper layout of canals and farm ditches, land development should be confined to a moderate amount of land smoothing, except for the small areas of class IV lands requiring rather heavy land grading.

44 After land grading, the chemical characteristics of surface soils should be analyzed and appropriate steps should be taken to replace "trace elements" such as magnesium or zinc, which may be removed from surface soils by grading. In any case the growing of green manure, application of animal manure and the use of chemical fertilizers will be necessary.

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MOGANBO IRRIGATION PROJECT

Table II-7

Project Land Classification

Irrigable Soils

(hectares)

| Block | Class I | II | III | IV | V | Total |
|---|---|---|---|---|---|---|
| A | - | - | 564 | 72 | - | 636 |
| B | - | 179 | 396 | 51 | - | 626 |
| C | - | 662 | 36 | 137 | 131 | 966 |
| D | - | 686 | 609 | 55 | - | 1350 |
| E | - | 154 | 471 | 260 | - | 885 |
| F | - | 598 | 112 | 70 | - | 780 |
| G | - | 94 | 628 | 136 | - | 858 |
| H | - | 497 | 302 | 43 | - | 842 |
| Total: | - | 2870 | 3118 | 824 | 131 | 6943* |

*Note: Estimated project cropped land (6260 ha) was determined by subtracting 683 hectares from the total irrigable area, as an allowance for roads and infrastructural rights of way, villages, etc. (see Working Document III - Irrigation and Drainage).

## SOIL PROFILES

### Pit 7, Class IIa

I Just west of the dike. Undulating to level. Scattered shrubs on grass.

| | |
|---|---|
| 0-20 | Gray yellowish brown to brown (10YR4/2 to 7.5YR 4/3) clay loam. Coarse granules, hard, friable, sticky and plastic. Abundant fine and medium roots. Croacked to 70 cm. Calcareous. pH 8. |
| 20-50 | Grayish yellowish brown (10YR 4/2) to dull yellowish brown (10YR 4/3) silt loam to clay loam. Weak blocky, soft, friable, slightly sticky and slightly plastic. Calcareous. pH 8. |
| 50-70 | Dull yellowish brown (10YR 6/4, 5/4) silt loam to loam, massive. Soft, friable, slightly sticky, non plastic. A sand band of 2-5 cm is found at 65 cm. Calcareous. |
| 70-115 | Brown (7.5YR 4/3, 4/4) to dull yellowish brown (10YR 6/4) silt loam to loam. Coarse granules to sub angular blocky. Slightly hard to slightly sticky. Calcareous. pH 8. |
| 115-155 | Dull yellowish brown (10YR 6/4) fine sand loam to fine sand. Massive. Calcareous |
| 155-200 | Brownish block (10YR 3/2, 2/2) to dark brown (10YR 3/4) clay to clay boam. Compacted, very hard, sticky, plastic. Calcareous. pH 8. |
| | Stratified profile with impermeable substrata. |

## SOIL PROFILE

### Pit 7, Class IIa

| Sample Depth cm | pH | $EC_e$ mmhos /cm | SOLUBLE CATIONS, meq/L Ca | Mg | Na | K | SAR | SOLUBLE ANIONS, meq/L $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-20 | 7.7 | 0.70 | 3.8 | 1.3 | 2.0 | 0.2 | 1.3 | 1.2 | 0.8 | 3.5 | 2 |
| 50 | 7.8 | 0.80 | 2.3 | 2.0 | 4.0 | 0.02 | 2.7 | 0.8 | 1.2 | 2.7 | 4 |
| 75 | 7.8 | 1.70 | 5.5 | 3.0 | 10.4 | 0.1 | 5.0 | - | 2.0 | 7.2 | 11 |
| 125 | 7.7 | 2.80 | 14.5 | 5.5 | 13.0 | 0.2 | 4.1 | - | 1.8 | 10.7 | 20 |
| 160 | 7.6 | 1.90 | 10.0 | 3.0 | 7.4 | 0.2 | 2.9 | - | 1.6 | 10.0 | 8 |
| 200 | 7.8 | 3.50 | 16.5 | 6.0 | 16.5 | 0.1 | 4.9 | 0.4 | 1.2 | 22.0 | 15 |

| Sample Depth cm | Carbon-ate % | Sat. % | Sand % | Silt % | Clay % | Texture Class | Organic C % | Average P, ppm | Average K, meq/100g |
|---|---|---|---|---|---|---|---|---|---|
| 0-20 | 19.3 | 44 | 20 | 54 | 26 | Silt Cl | 1.8 | 2.3 | 1.0 |
| 50 | 19.5 | 40 | 18 | 48 | 34 | L | 0.9 | 1.8 | 0.2 |
| 75 | 17.8 | 33 | 28 | 30 | 42 | SL | 0.7 | 1.8 | 0.2 |
| 125 | 16.7 | 36 | 26 | 38 | 36 | L | 0.5 | 2.0 | 0.2 |
| 160 | 13.5 | 35 | 48 | 28 | 24 | SL | 0.3 | 4.0 | 1.0 |
| 200 | 18.0 | 44 | 26 | 58 | 16 | Silt Cl | 1.0 | 6.5 | 0.4 |

Pit 11, Class IIb

E 3W Rough to very rough channel complex sloping east. Dense bush over tall grass. Patches of corn and sesame.

| cm | |
|---|---|
| 0-10 | Brownish black (10YR 3/2) clay to clay loam, coarse, granular, slightly hard, friable, sticky and plastic. Few very fine roots. Non-calcareous surface, i.e. no effervescence with HCl. |
| 10-40 | Brownish black (10YR 2/3 or 7.5YR 2/2, 2/3) clay loam, coarse granular to weak blocky. Hard, sticky and plastic. Non-calcareous to 20 cm but slightly calcareous below. Cracked surface to 40 cm. |
| 40-70 | Brown (7.5YR 4/4) massive loam to clay loam, loose, slightly plastic and slightly stickly. Micaceous. Calcareous. pH 7.5+. |
| 70-100 | Brown (7.5YR 4/4) sandy clay loam, fine granular, loose, friable, slightly sticky and slightly plastic. Micaceous, calcareous material with salt nodules. pH 8. |
| 100-175 | Dark brown (7.5YR 3/4 ) sandy clay loam, massive to granular (stratified sand and clay). Calcareous. pH 8. |
| 175-200 | Brown (7.5YR 4/4) sandy loam. Massive, calcareous. pH 8. |

## SOIL PROFILE

### Pit 11, Class IIb

| Sample Depth cm | pH | $EC_e$ mmhos /cm | SOLUBLE CATIONS, meg/l Ca | Mg | Na | K | SAR | SOLUBLE ANIONS, meg/l $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 7.4 | 0.9 | 5.5 | 2.0 | 2.6 | 0.2 | 1.3 | 0.8 | 1.2 | 3.9 | 4.4 |
| 40 | 7.7 | 0.5 | 3.5 | 1.8 | 1.3 | 0.2 | 0.8 | 0.8 | 0.4 | 2.2 | 3.4 |
| 70 | 7.8 | 0.5 | 2.8 | 1.0 | 1.3 | 0.1 | 0.9 | 0.4 | 1.2 | 1.4 | 2.2 |
| 100 | 7.8 | 0.5 | 3.0 | 1.3 | 2.2 | 0.1 | 1.5 | 0.4 | 0.8 | 1.3 | 4.1 |
| 135 | 7.7 | 0.6 | 3.5 | 1.3 | 2.2 | 0.1 | 1.4 | - | 2.0 | 2.0 | 3.1 |
| 175 | 7.8 | 0.5 | 3.0 | 1.3 | 1.4 | 0.1 | 0.1 | - | 2.0 | 1.8 | 2.0 |
| 200 | 7.8 | 0.5 | 2.8 | 1.3 | 1.7 | 0.1 | 1.2 | - | 1.6 | 1.8 | 2.5 |

| Sample Depth cm | Carbon-ate % | Sat. % | Sand % | Silt % | Clay % | Texture Class | Organic C % | Average P, ppm | Average K, meg/100g |
|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 7.8 | 46 | 30 | 54 | 16 | Silt Cl | 2.4 | 27.0 | 0.4 |
| 40 | 9.0 | 46 | 38 | 32 | 30 | " | 1.4 | 24.0 | 0.4 |
| 70 | 9.8 | 40 | 28 | 54 | 18 | L | 0.6 | 23.0 | 0.2 |
| 100 | 12.3 | 42 | 42 | 28 | 30 | L | 0.5 | 8.0 | 0.2 |
| 135 | 13.0 | 35 | 42 | 30 | 28 | SL | 0.5 | 7.0 | 0.2 |
| 175 | 18.0 | 36 | 28 | 38 | 34 | L | 0.7 | 6.0 | 0.2 |
| 200 | 15.5 | 33 | 44 | 38 | 18 | SL | 0.1 | 4.0 | 0.1 |

Pit 3, Class IIIa

B1E (B 750 E) Undulating, gentle slope, bush and grass (medium to dense), scattered good corn and sesame.

| cm | |
|---|---|
| 0-10 | Brownish gray (7.5YR 4/1 D). Brownish black (19YR 3/2 m) loam to clay loam, granular to subangular blocky, loose, friable, slightly sticky, slightly plastic. Dense roots of fine size. |
| 10-25 | Brownish black (10YR 3/3) clay loam, subangular blocky, hard, sticky and plastic. Abundant coarse and medium roots. Some gravels and a few salt mottles with strong effervescence. pH 7.5+. |
| 25-40 | Brownish black (7.5YR 2/2) clay loam. Subangular blocky to blocky. Hard, friable, sticky and plastic, slightly compacted. Medium roots are common with a few coarse roots. pH 7.5+. |
| 40-70 | Brownish black (7.5YR 2/2) clay, blocky, compacted, hard, sticky and plastic. Salt mottles common. pH 8. |
| 70-105 | Dark brown (7.5 2/2) clay, blocky, to weak prismatic. Most compacted, hard very sticky and plastic. Slichensides are present. Salt nodules with gypsum crystals of sand size. |
| 105-155 | Dark brown (7.5YR 3/3) clay like above layer with dominance of slichensides and less of salt nodules. |
| 155-200 | Brownish black (7.5YR 3/2) clay, subangular blocky. Medium hardness, friable, sticky and plastic. Dominance of salt crystals and accumulation starts at 140 cm and increases downward, 20% or more of pedes are salt covered. Storng effervescence. pH 8. |

# SOIL PROFILE

## Pit 3, Class IIIa

| Sample Depth cm | pH | $EC_e$ mmhos /cm | SOLUBLE CATIONS, meg/l Ca | Mg | Na | K | SAR | SOLUBLE ANIONS, meg/l $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-25 | 7.7 | 1.9 | 14.5 | 4.0 | 4.4 | 0.6 | 1.4 | 0.8 | 0.4 | 4.0 | 18.1 |
| 40 | 7.7 | 2.5 | 19.3 | 8.0 | 8.0 | 0.1 | 2.2 | - | 1.6 | 3.7 | 30.0 |
| 70 | 7.8 | 5.5 | 24.5 | 17.0 | 34.8 | 0.1 | 7.7 | - | 1.8 | 17.9 | 56.7 |
| 105 | 7.9 | 15.0 | 31.0 | 48.8 | 143.5 | 0.2 | 22.7 | 0.4 | 1.9 | 59.9 | 161.8 |
| 155 | 7.9 | 24.0 | 34.3 | 65.8 | 191.3 | 0.2 | 27.0 | - | 2.0 | 171.0 | 118.0 |
| 200 | 7.9 | 32.5 | 36.0 | 70.0 | 191.3 | 0.2 | 26.3 | 0.4 | 1.2 | 190.0 | 100.0 |

| Sample Depth cm | Carbon-ate % | Sat. % | Sand % | Silt % | Clay % | Texture Class | Organic C % | Average P, ppm | Average K, meg/100g |
|---|---|---|---|---|---|---|---|---|---|
| 0-25 | 18.5 | 56 | 18 | 66 | 16 | C | 1.8 | 2.8 | 0.9 |
| 40 | 22.5 | 48 | 18 | 72 | 10 | CL | 0.3 | 1.8 | 0.3 |
| 70 | 21.8 | 52 | 18 | 76 | 6 | C | 0.8 | 0.5 | 0.3 |
| 105 | 21.0 | 52 | 20 | 78 | 2 | C | 0.4 | 2.3 | 0.3 |
| 155 | 22.0 | 52 | 24 | 76 | 0 | C | 0.3 | 0.5 | 0.2 |
| 200 | 24.5 | 48 | 18 | 58 | 24 | CL | 0.14 | 0.5 | 0.2 |

Pit 10, Class IIIb

O 1W Undulating with common ant mounds. Stony subsoil. Scattered shrubs on grass land. Dying corn field.

cm

| | |
|---|---|
| 0-15 | Brownish black (10YR 3/2) clay loam, granular to subangular blocky. Slightly hard, friable, slightly sticky, slightly plastic. Cracks to 35 cm, common fine and medium roots. Calcareous. pH 8. |
| 15-35 | Dark brown (10YR 3/3) clay boam with some gravels. Subangular blocky. Hard, friable, sticky and plastic. Strong effervescence. pH 8. Some salt nodules 25-35 cm. |
| 55-80 | Dark brown (7.5YR 3/3) compacted moist clay, subangular blocky to blocky, with gypsum crystals. Very sticky, very plastic. Calcareous. pH 8. |
| 80-105 | Brownish black (7.5YR 3/2) compacted clay, blocky to weak prismatic, very sticky and very plastic. Calcareous. pH 8. |
| 105-125 | Brownish black (7.5YR 3/2) stony clay, salt crystals, calcareous. pH 8. |
| 125-200 | Yellowish brown (10YR 5/6) to dull yellowish brown (10YR 5/4) stony loam (50-75% stones). Very calcareous. pH 8. |

## SOIL PROFILE

### Pit 10, Class IIIb

| Sample Depth cm | pH | $EC_e$ mmhos /cm | SOLUBLE CATIONS, meg/l Ca | Mg | Na | K | SAR | SOLUBLE ANIONS, meg/l $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-15 | 7.6 | 4.7 | 30.0 | 13.0 | 19.1 | 1.2 | 4.1 | 0.8 | 2.8 | 13.0 | 47.2 |
| 35 | 8.0 | 7.0 | 13.3 | 8.5 | 5.2 | 0.3 | 19.8 | - | 2.8 | 42.4 | 42.1 |
| 60 | 7.9 | 16.0 | 21.5 | 10.0 | 10.4 | 0.4 | 2.4 | - | 2.0 | 41.6 | 4.6 |
| 80 | 8.0 | 12.0 | 18.0 | 16.5 | 143.5 | 0.3 | 34.6 | - | 1.8 | 33.0 | 143.5 |
| 105 | 8.4 | 9.0 | 3.8 | 5.5 | 104.3 | 0.2 | 48.5 | - | 2.0 | 28.6 | 83.8 |
| 125 | 8.3 | 8.5 | 2.8 | 5.5 | 104.3 | 0.1 | 51.2 | - | 3.6 | 40.0 | 69.1 |

| Sample Depth cm | Carbon-ate % | Sat. % | Sand % | Silt % | Clay % | Texture Class | Organic C % | Average P, ppm | Average K,mg/100g |
|---|---|---|---|---|---|---|---|---|---|
| 0-15 | 7.5 | 47 | 26 | 60 | 14 | Silt-Cl | 1.8 | 12.5 | 0.6 |
| 35 | 14.0 | 46 | 30 | 56 | 14 | " | 0.8 | 2.0 | 1.0 |
| 60 | 15.0 | 50 | 32 | 58 | 10 | " | 0.9 | 2.0 | 0.8 |
| 80 | 13.0 | 60 | 32 | 56 | 12 | C | 0.75 | 1.0 | 0.6 |
| 105 | 13.3 | 80 | 24 | 60 | 16 | Silt-Cl | 0.5 | 4.0 | 0.6 |
| 125 | 15.0 | 64 | 24 | 56 | 20 | " | 0.6 | 2.8 | 0.4 |

Pit 22, Class IV

| | |
|---|---|
| N 6 W | Undulating to level, high land. Medium to dense bush. Acacia trees. |
| 0-10 | Dull yellowish brown (10YR 4/3) clay loam, gravelly, dusty, fine granular, fine and medium cracks to 30 cm. pH 7.5. |
| 10-30 | Dull yellowish brown (10YR 4/3) clay loam, gravelly, granular to subangular blocky, slightly hard, slightly sticky, plastic, salt mottles 15-30 cm. pH 7.5. |
| 30-65 | Dull yellowish brown (10YR 4/3) silty clay, subangular blocky. Hard, very sticky, very plastic, gravelly. Calcareous. Tree roots. |
| 65-100 | Dark brown (10YR 3/4) clay, subangular blocky, compacted, hard, sticky, plastic. Weak slichensides. Some salt mottles and salt nodules. pH 8. |
| 100-120 | Like above except it is a zone of salt accumulation; gypsum plus carbonate crystals. |
| 120-180 | Like above except that only salt mottles are present. Also, developed slichensides are common. |
| 180-200 | As above, more more accumulation of carbonate and cypsum crystals. |

## SOIL PROFILE

### Pit 22, Class IV

| Sample Depth cm | pH | $EC_e$ mmhos / cm | SOLUBLE CATIONS, meq/l Ca | Mg | Na | K | SAR | SOLUBLE ANIONS, meq/l $CO_3$ | $HCO_3$ | Cl | $SO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 7.7 | 0.9 | 4.0 | 2.0 | 3.5 | 0.2 | 2.0 | 0.8 | 0.2 | 4.0 | 4.7 |
| 30 | 7.9 | 3.2 | 4.0 | 3.8 | 24.3 | 0.1 | 12.3 | - | 0.8 | 25.3 | 6.1 |
| 65 | 7.9 | 14.0 | 9.0 | 20.0 | 147.8 | 0.1 | 38.8 | - | 1.0 | 116.0 | 59.9 |
| 100 | 7.9 | 30.0 | 25.0 | 41.5 | 243.5 | 0.2 | 42.2 | T | 1.2 | 126.0 | 183.0 |
| 120 | 7.9 | 24.0 | 24.5 | 27.5 | 191.3 | 0.2 | 37.7 | - | 1.0 | 82.0 | 160.0 |
| 180 | 7.9 | 13.0 | 12.0 | 15.9 | 130.4 | 0.1 | 35.2 | 0.4 | 0.2 | 59.0 | 98.4 |
| 200 | 8.0 | - | 8.5 | 13.5 | 130.4 | 0.1 | 39.3 | - | 1.0 | 72.0 | 79.5 |

| Sample Depth cm | Carbon-ate % | Sat. % | Sand % | Silt % | Clay % | Texture Class | Organic C % | Average P, ppm | Average K, meq/l |
|---|---|---|---|---|---|---|---|---|---|
| 0-10 | 13.5 | 40 | 40 | 44 | 16 | L | 9.1 | 5.4 | 0.8 |
| 30 | 18.5 | 40 | 38 | 50 | 12 | L | 0.7 | 1.8 | 0.6 |
| 65 | 20.3 | 44 | 36 | 50 | 14 | Silt-Cl | 0.6 | 0.5 | 0.8 |
| 100 | 16.0 | 52 | 36 | 64 | 0 | C | 0.4 | 1.0 | 1.0 |
| 120 | 18.0 | 56 | 22 | 62 | 16 | C | 0.4 | 1.0 | 0.6 |
| 180 | 16.5 | 72 | 24 | 70 | 6 | Silt | 0.3 | 1.0 | 0.6 |
| 200 | 18.5 | 72 | 28 | 54 | 18 | " | 0.6 | 1.0 | 0.8 |

## Table II-8

## Rates of Soil Infiltration.

The rates of soil infiltration are variable. The field measurements suggest that irrigation water should be added gradually. If water is added rapidly, swelling may occur, closing the cracks and reducing infiltration to very low rates. Appreciable movement of water through the soil profile can take place via the extensive network of cracks which appear as the soil dries out.

Soil infiltration tests were carried out at nine sites. Tests were also conducted on the subsoil at depths to 200 cm to give an impression of water movement. The infiltrometer consisted of an inner metal ring of about 25 cm diameter and 40 cm in height. The rings were inserted into the ground to depths more than 10 cm. A head of between 10 and 25 cm of Juba River water was maintained in the inner and outer rings. The intake of water was measured by reading the height of the water in the inner ring of the infiltrometer.

The rates of water movement were found to range between 0.01 and 30 cm per hour.

| Site | Depth cm | Texture | Infiltration Rate cm/day |
|---|---|---|---|
| C | Surface layer | Sil | 22.2 |
| | | | 13.2 |
| | | | 8.3 |
| | | | 6.8 |
| $E_{3W}$ | Surface layer | L or Sil | 0.86 |
| | 150-200 | Sil | 2.90 |
| $F_{1W}$ | Surface layer | Sil | 30.00 |
| $H_{1W}$ | Surface layer | L or Sil | 6.53 |
| | Surface layer | L or Sil | 4.23 |