DEMOCRATIC REPUBLIC OF SOMALIA

JUBA RIVER VALLEY DEVELOPMENT STUDY

VOL. III

GEOLOGY, HYDROLOGY AND HYDRAULIC ENGINEERING

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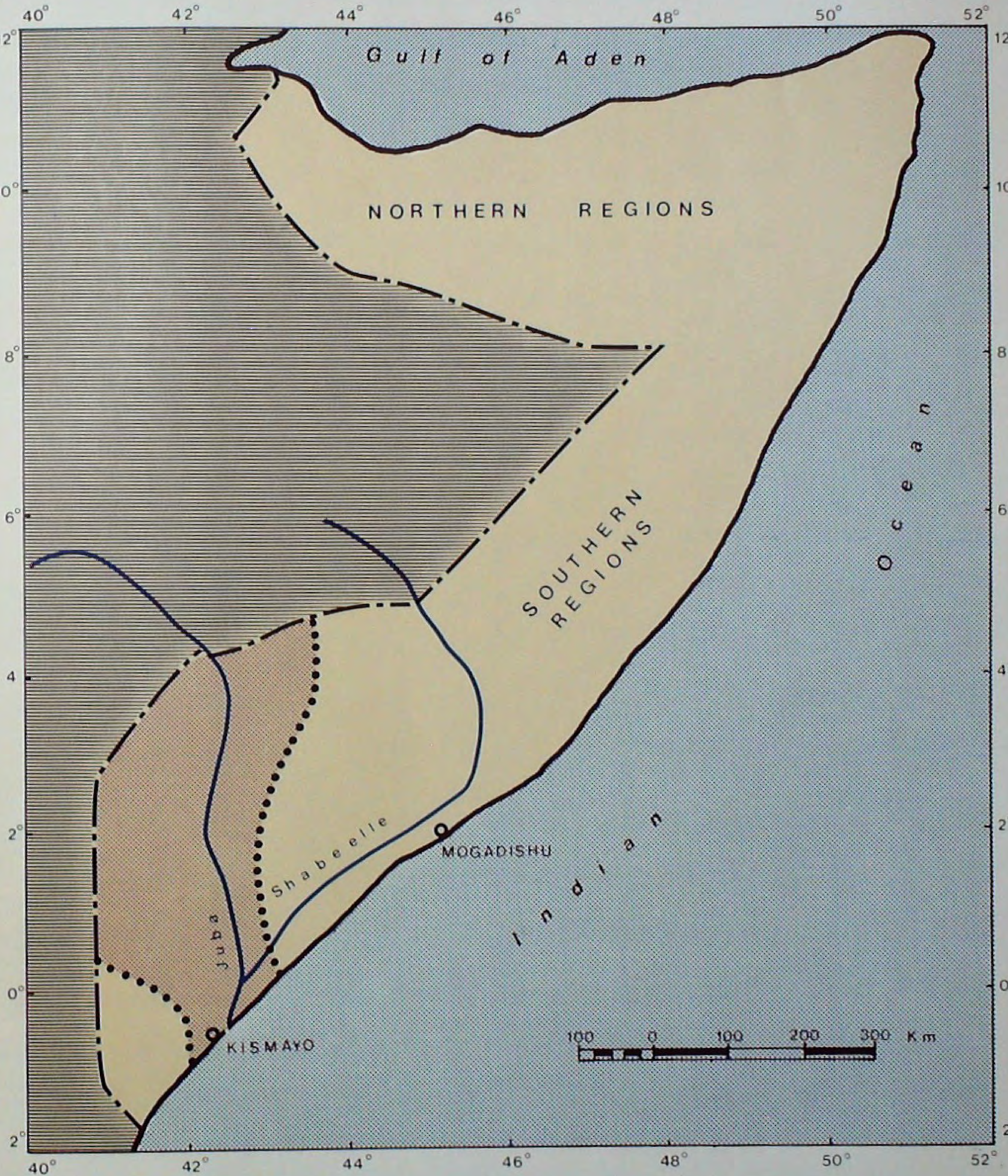

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GEOLOGY

CHAPTER 1.

REGIONAL GEOLOGY

1.1 INTRODUCTION

In the following pages a summary is given of the geological and hydrogeological situation in the Juba River Basin and of the availability of raw materials.

The information set forth was collected by a review of the literature available on these subjects and by field reconnaissances in the area. Where possible, the outline of the present position is followed by comments and observations on whether knowledge can be improved and on how to use that available to the best advantage.

1.2 GEOMORPHOLOGICAL OUTLINE

The Juba runs north-south through western Somalia, coming from Ethiopia. The Somali part of the basin is bounded to the west by the Kenya border, to the north by the Ethiopian border, to the east by the watershed with the Shabeellada River and to the south east again by the Shebeli watershed to the point where this river becomes lost in the swamps or enters the Juba. To the south-west of this area, from Kismayo to the Kenya border, the land is bounded by the Indian Ocean.

The climate of the Juba Basin is typically arid with four seasons: two monsoons separated by two short dry transition periods. Annual rainfall varies from about 200 mm in the north towards Dolow to a little over 500 mm in the southernmost part.

From the morphological aspect, four regions can be distinguished in the Somali part of the Juba Basin: the Calcareous-Gypsiferous Plateaux to the North, the Buur Area to the SE, the Lower Juba Plain to the south and the Coastal Dune Area.

1.2.1 The Calcareous-Gypsiferous Plateaux

These plateaux occupy the upper part of the Juba Basin to the north of Baardheere where extensive outcrops of Jurassic limestones and Jurassic-Cretaceous limestones and gypsums with sub-horizontal bedding are to be found. The typical feature of the region is the series of virtually flat, parallel plains stepping down from 500 m to about 100 m. These terraces or orographic flats were formed during diverse periods of intensive erosive activity which varied depending on the position of the base level coinciding with the Juba River and with sea level. Indeed, the terraces and flats grade towards the Juba and its tributaries. The phenomenon is evident in both the calcareous and the gypsiferous areas, though the landform in the latter is slightly gentler because the rock is more steadily eroded.

Inselbergs, formed of a succession of horizontal layers of rock capped by a harder horizon, rise from the flat areas, especially those with gypsiferous strata. The profiles of the inselbergs are concave, indicating a decrease in the intensity of erosion, typical of the peneplanation stage.

The surface drainage network is generally sub-parallel, though locally it tends to be rectangular where the tectonic structure has controlled the carving out of river and stream beds. Many of the water courses, the Juba included, have incised meanders in some places, providing further proof of the abrupt variations in base level which occurred in the past. The bottom of the Juba Valley is covered by a thick layer of unconsolidated deposits (exact thickness unknown) laid down during the recessive phases of floods.

A distinguishing feature of the areas where calcareous-gypsiferous rocks are in outcrop is the occurrence of oval-shaped depressions, the one to the west of El Mao being typical, into which run streams carrying detrital materials, forming seasonal swamps where water is lost by evaporation and by seepage into the gypsiferous ground.

1.2.2 The Buur Area

The Buur Area occupies the south-eastern part of the Juba Basin. It is distinguished by outcrops of Precambrian metamorphic and igneous rocks. The morphology here is typical of the African Basement Complex areas, peneplaned and subject to erosion from Precambrian to the start of the Jurassic and from the Cretaceous to recent times. It would appear that it was partly covered by marine sediments during the Jurassic.

The terrain is flat or virtually so, with groups of inselbergs (Buur in Somali) emerging here and there. These are formed of granites or quartz gneisses that are harder and more resistant than the remainder of the Basement, which is often covered by up to 20-30 m of eluvium or alluvium. Here too, the sides of the inselbergs are concave, indicating a decreasing trend in erosive force.

The surface drainage network is sub-parallel, tending to rectangular locally, often with meanders. The watercourses, all seasonal, frequently originate at the base of the inselbergs.

1.2.3 The Lower Juba Plain

This morphological area occupies the most southwesterly part of Somalia. It is bounded to the north by the calcareous-gypsiferous plateaux, to the east by the Shabeellada Basin, to the south by the Indian Ocean and to the west by the Kenya border.

This is flat terrain, sloping gently towards the sea and crossed by the Juba and its tributaries and, to the west of Kismayo by watercourses running from the Kenya border towards the Ocean. The plain is formed of alluvial material of various particle-size distributions, brought down by the rivers and streams since the late Tertiary, when the marine cycle closed. The alluvium, which may be several hundred metres thick, overlies Jurassic limestones to the north and Tertiary marine sediments towards the coast.

The surface drainage network is sub-parallel and empties into the Juba or directly into the sea. Because of the very flat lie of the land, the rivers are often meandering, and water tends to stagnate in the lower parts, forming swamps.

It is possible to divide the alluvium of the Lower Juba Plain into Tertiary-Quaternary and Recent. The former occupies most of the territory. Pedogenesis has occurred on the surface and so this material must be considered older than that found along the watercourses, which geologically speaking, belongs to the present day and age. This distinction is very evident

along the Juba which, with its distinguishing meanders, runs in its own flood plain, set slightly below the level of the surrounding alluvials, thereby indicating a recent variation in base level.

1.2.4 The Coastal Dune Area

This morphological unit is readily apparent along the shore and running inland for up to about 15 km. The strip is characterized by marine and eolian sediments with dunes, sand bars and beds of coral limestone. The dunes are particularly evident north-east of Kismayo where they may be several dozen metres high. They may be fixed or wandering, depending on the local morphology and vegetation. They form ridges. They also create depressions (Vadda being typical) with flat, swampy bottoms, surrounded by dunes of varying degrees of stability.

1.3 STRATIGRAPHIC AND STRUCTURAL SITUATION

The following résumé of the stratigraphy and structure of the Juba Basin is based on perusal of studies covering more or less extensive areas and on direct field investigations.

Earlier studies may be classed in three groups. There are the regional geology descriptions by Italians (Dainelli 1943, Stefanini 1959, Azzaroli and Merla 1960, and Azzaroli and Passerini 1965). Then there are the more detailed studies performed by various firms (Gulf, Hammar, Burmah, Sinclair, Dea and Frobisher) searching for oil in the middle and upper part of the basin, where the morphological situation permits direct sight of the Basement Complex and of the overlying Mesozoic carbonate rocks. Geological knowledge of the lower part of the basin is also available, thanks to oil exploration work. Here the Quaternary alluvial cover, with its vast level surface, has been penetrated by a number of deep holes, which have probed into the underlying Tertiary sediments. Some information on regional geology and detailed investigations of areas of limited extent can also be found in United Nations Reports (FAO 1958, UNDP 1970, 1973).

Various types of rock occur in the study area. These can be grouped into the following families:

A. Crystalline rock of the Basement Complex outcropping in the Buur Area;
B. Jurassic and Cretaceous limestones and gypsums outcropping in the upper part of the basin, north of Baardheere;
C. Tertiary consolidated marine sedimentary rocks, mainly detrital, encountered under the Quaternary cover by some exploratory oil wells drilled in the lower part of the basin;
D. Tertiary volcanic basalts, associated with the Rift Valley tectonic activity, outcropping especially in the upper part of the basin along the Ethiopian border;
E. Late Tertiary and Quaternary unconsolidated continental sedimentary rocks, detrital and chemical. The former outcrop extensively in the lower part of the basin south of Baardheere and along various valley

bottoms, while the recent chemical deposits (caliche) outcrop less frequently and occur on the sedimentary carbonate rocks in the upper part of the basin.

The description given of the various groups of rocks below follows the above order, thus ensuring lithological and chronological conformity.

A. Crystalline Basement Complex Rocks

The Basement Complex outcrops in the Buur region. As explained elsewhere, Buur is the Somali word used to indicate isolated mountains (inselbergs) rising from a more or less flat, peneplaned surface of crystalline rock covered by Quaternary alluvial and eluvial deposits. The Basement runs NE-SW for about 250 km; and NW-SE for around 100 km, between the Juba and Shabeellada to the south-eastern extremity of the Juba Basin.

It is possible to distinguish a lower and an upper metamorphic series and a series of igneous rocks of various types in the Basement Complex.

The lower series consists mainly of gneiss containing variable amounts of biotite, potash felspar and quartz, with various accessory minerals. There are also granite and amphibolite gneisses.

The upper series is not as well developed as the lower one. It consists of various types of metamorphics, the commonest being quartzites, often with concentrations of iron minerals, while variously silicified limestone-dolomite marbles also occur.

The commonest igneous rocks are granitic. These are encountered both as extensive intrusive masses and as injected masses concordant with the schistosity of the metamorphics. Granites are particularly frequent in the western part of the Buur area, east of Dhinsoor. There are two types of granite, one a massive medium and fine grained variety and the other having a porphyritic structure with large crystals of microcline. Syenites occur to a subordinate extent, as do basic intrusions whose composition ranges from diorite to gabbro.

Pegmatite and aplite dykes are frequent in both the metamorphics and the granites. They are usually lens-shaped and consist of quartz and felspar. Their thickness is of the order of the few metres.

The tectonic structure takes the form of a succession of anticlines and synclines, whose axes most frequently strike ESE-WNW or SE-NW.

The Basement was the product of intense regional metamorphism, which acted on detrital and carbonate sediments, followed by one or more phases when rocks of a predominantly acid magma were emplaced. It is considered that the metamorphism was Precambrian, while the igneous rocks are Late Precambrian or Cambrian.

The crystalline rocks of the upper Buur structure are covered to the north, west and east by onlapping Jurassic sedimentaries, while to the SE a regional fault brings the Basement into contact with the detrital Tertiary sedimentaries.

B. Jurassic and Cretaceous Limestones and Gypsums

These sedimentary rocks occupy the upper part of the Juba Basin between the Quaternary alluvial plain and the Kenya and Ethiopian borders. The Juba River has incised its bed in these rocks from Solaangi to the Ethiopian

border, i.e. for more than half its length in Somalia.

Exploration in this area, especially by the oil companies, has resulted in a number of formations and members being identified within the carbonate complex, which differ in lithology and age.

These are dealt with schematically in the following pages, particular attention being paid to the lithological situation existing along the course of the Juba, where dams and reservoirs might possibly be built.

The stratigraphic succession, from oldest to youngest, is as follows, in this area:

B.1 Isha Baydhaba Formation

This formation can be divided into four members: Deleb, Uanei, Baydhaba and Golado.

a. Deleb Member

This is formed of quartzy, sandy conglomerates which lie unconformably on the Basement, at the bottom of the Jurassic carbonate series. The maximum thickness encountered is 33 m. The most extensive outcrops occur on the edge of the Basement where this is covered by the sedimentary succession. The member is considered to be Upper Jurassic (Callovian).

b. Uuney Member

This lies conformably on the Deleb Member. From the bottom upwards, it consists of: 1) dark shales with pyrite; 2) lithographic limestones; 3) varicoloured shales with ammonites; 4) marly limestones and marls. The maximum thickness encountered is 120 m. This member outcrops on the edge of the Basement, where the Deleb Member is to be seen. It is considered to be Upper Jurassic (Callovian).

c. Baydhaba Member

The Baydhaba Member overlies the Uuney Member, the transition between the two being gradual. However, this lithological change is quite evident at Isha Baydhaba, after which the member is named. From the bottom upwards it consists of the following lithotypes: detrital limestones with pseudobreccia, bioclastic limestones and coquina, lithographic limestones locally detrital and oolitic with occasional brachiopods. The total thickness of the member is 90 m. The most extensive outcrops are at Baydhaba. The age is Callovian-Oxfordian.

d. Golado Member

The Golado Member consists of a thick succession of organogenic, detrital and oolitic limestones which lie conformably on the Baydhaba Member. The most characteristic lithological succession, from the bottom upwards, is as follows: algal and bioclastic limestones, coquina, calcirudites, calcarenite, lithographic limestones with marl interbeds, bioclastic and pisolitic limestones, bedded lithographic limestones, oolitic and pseudo-oolitic limestones with thin interbeds of fossiliferous marls, fossiliferous oolitic limestones, coquina and calcirudites, and oolitic limestones. Lateral variations in lithology can occur readily, as is to be expected with the sedimentation environment involved. For instance, it is apparent that in the Baardheere area the Golado Member is characterized by compact fossiliferous lithographic limestones with a few oolitic levels. The Golado Member is 600-700 m thick, where it has been measured so far. It outcrops to the east of the Juba and along its course. It is Callovian-Oxfordian in age.

B.2 Coanode Formation

The Coanode Formation consists of marls and marly limestones. It is clearly different lithologically and morphologically from the underlying and overlying limestone formations. The contact with the Goloda Member below is clear-cut. The most typical lithological succession, encountered between Baardheere and Buur Coanode, to the following from the bottom upwards: dark shales rich in brachiopods and belemnites, oolitic calcarenites and coquina, marls and shales with lithographic limestone interbeds, lithographic limestones with marl interbeds, calcirudites, dark limestones, pisolitic limestones, marly limestones, marls and shales with ammonites, belemnites and brachiopods. The formation is about 300 m thick. The best outcrop is along the course of the Juba between Baardheere and Coanode. To the west of the Juba the Coanode Formation passes heteropically to the mainly calcareous Uella Formation. According to the ammonites present, the age is Rimmeridgian.

B.3 Waajid Formation

This consists of a succession of fossiliferous and oolitic limestone strata, sometimes with marly interbeds. It is distinguished by the abundance of coral colonies. The total thickness varies from 300 to 350 m. Age is Upper Jurassic (Portlandian-Purbekian). It outcrops to the east and west of the Juba north of Baardheere, to the east it is mapped as an undivided formation, while to the west it has been divided into three members.

a. Colaliyo Member

At the bottom of this member is a 5 m bed of sandstone and mudstone which lies with marked morphological contrast on the Coanode marls. Then follow coral limestones, calcirudites, coquina and oolitic limestones.

b. Carow Member

This is characterized by dark grey calcareous marls and shales.

c. Mareesta Member

This member is distinguished by oolitic and algal limestones, sometimes dolomitized. The Mareesta Member to the west is heteropic with the Magdjile Member in which, mixed with the carbonate sediments, there is a detrital sandy fraction visible in some sandstone beds.

B.4 Garbahaaray Formation

This formation is named after a place some 30 km west of the Juba in the central part of the mountainous zone. From the sedimentological aspect it indicates the start of the regressive phase of the Jurassic-Cretaceous sedimentary cycle. It has been divided into the Busul and Mao Members, named after places which are located in this area.

a. Busul Member

This member overlies the Mareesta Member regularly. It is distinguished by beds of quartzy sandstone interbedded by marly and carbonate deposits. The lithological succession from the bottom upwards is: laminated coquina, shales, quartzy sandstones, marl, coquina, marl, dolomitic limestones and calcarenite, quartzy sandstones with interbeds of shale, calcirudites, oolitic and dolomitic limestones. The member is around 280 m thick. It outcrops extensively to the east and west of the Juba to the south of Luuq. Age must be about Lower Cretaceous.

b. Mao Member

The typical feature of the Mao Member is the abundance of gypsum and anhydrite, the last marine deposits of the regressive phase. It lies concordantly on the Busul Member and consists of alternations of gypsum, anhydrite, dolomitic limestones, shales, marls and sandy and marly limestones. Total thickness is around 420 m. The Mao Member outcrops extensively in the Upper Juba Basin, to the east and west of the river, starting from El Mao and continuing to Luuq and Dolow. Age is probably Lower Cretaceous.

B.5 Structural Characteristics of the Jurassic Rocks

The structure of the sedimentary Jurassic rocks, which outcrop to the west and east of the Juba north of Solaangi, is governed by the upswing of the Basement Complex in the Buur area. Indeed, the beds strike NE-SW and dip NW at 1-3° to the west of the crystalline rocks, while going eastwards the strike swings E-W and then NW-SE, arching around the raised Basement Complex.

Between Garbahaaray and Luuq, there is a succession of anticlines and synclines having a large radius of curvature and striking approximately NE-SW following the direction of the Ceel Waaq Mandheera sedimentation basin.

The best developed faults strike NE-SW, while minor fractures and fault planes strike NW-SE, N-S and E-W.

The start of the deformation which led to the present tectonic structure dates from late Jurassic - early Cretaceous, when the Basement in the Buur area began to rise. It continued on and off to the late Tertiary and Quaternary, in connection with the Kenya and Ethiopian Rift Valley tectonics. Associated with these tectonics are the basalt lava flows that occur in the Juba Basin and the main NE-SW regional fault with a throw of thousands of metres, which brings the southern side of the Buur crystallines in contact with the Tertiaries which form the substratum of the Lower Shabeellada and Juba Valleys. This fault is very evident where the Basement Complex island is in outcrop, but its position is doubtful at the point on the Juba where Quaternary sediments cover the faulted contact between Jurassic carbonates and the Tertiary detrital sediments.

C. Tertiary Sedimentary Rocks

Four exploratory oil wells, drilled in 1964 and 1965 in the lower part of the Juba Basin, show that beneath the alluvial cover there are Tertiary sedimentaries of marine origin. The Tertiary marine sediments, not less than 3,000-4,000 m thick, occur under several hundred metres of alluvium, starting a few dozen kilometres south of Dujuuma. It is here that the western continuation of the NE-SW regional fault should be found. This is the fault which, at Buur, brings the Basement Complex into contact with the Tertiaries and which, at the Juba River, brings the Tertiary detritals into contact with the Jurassic carbonates encountered at Dujuuma by two of the oil holes. These holes are a little north of those which penetrated thousands of metres of Tertiary ground.

The Tertiaries consist of sandstones and shales with subordinate limestones, gypsum and beds of lignite. The oldest formations reached are Paleocene, while the age of the most recent, consisting of clayey deposits with interbeds of limestone, gypsum and lignite (indicating a markedly regressive phase, as a prelude to emergence), is not known with certainty.

D. Tertiary Volcanic Rocks

Remnants of Tertiary or Quaternary basalt flows, the southernmost representatives of the huge outpourings in the nearby Ethiopian Rift Valley, are to be found in some parts of the Juba Valley. The most southerly outcrop occurs on the left of the Juba some 15 km south of Solaangi. The basalts are encountered with increasing frequency as one goes upstream, reaching a maximum in the Luuq and Dolow area, where the lavas cover several hundred square kilometres.

E. Late Tertiary and Quaternary Detrital and Chemical Sedimentary Rocks

In the Juba Basin there are extensive deposits of late Tertiary and Quaternary unconsolidated detrital rocks and to a subordinate extent, superficial chemical deposits. The first type of rock, of continental and alluvial origin, covers the lower part of the basin from Baardheere to the mouth with a thickness of up to 300-400 m. The sediments consist of sands, silts and clays deposited by the waters of the Juba. Similar rocks were also laid down by tributaries of the Juba, where these run through limestone and gypsum formations, in the upper part of the basin.

In the Juba Basin it is possible to distinguish between recent detrital sediments, which occur only in the beds of rivers, and loose sediments, covered by an eluvial soil, which are relatively older and lie some distance away from the present watercourses. In the lower part of the basin, along the coast, are lines of dunes running parallel to the shore. These dunes are often mobile owing to wind action and the lack of plant cover.

The carbonate and gypsiferous rocks outcropping in the upper part of the basin have an eluvial capping only where the landform is gentle, thus ensuring that the soil is not washed away. Where this is not the case, the carbonate rocks are covered by an irregular scattering of detritus. Eluvial cover in the Buur area is very thick (up to 20-30 m) and widespread over the peneplaned Basement rocks.

Locally the Jurassic carbonates may be covered by a brecciated carbonate crust of chemical origin, deposited from circulating waters, as a result of solution and deposition processes typical of this climatic belt.

1.4 THE HYDROGEOLOGICAL SITUATION

Information on the hydrogeological situation of western Somalia, including the Juba Basin is to be found mainly in the works of Abrens and Azzaroli (1951), in FAO reports (1958), UNDP reports (1970 and 1973), in the works of Dijon (1967) and in reports by the Agrar-und-Hydrotechnik group (1972) and Hendrikson (1973).

These papers and reports describe the regional hydrological situation on the basis of stratigraphic-structural knowledge and inventory data. They also contain programmes for further investigations for the promotion of agricultural and industrial development. The need to perform these investigations to locate other sources of supply has become urgent recently because of the persistent drought that has so harmed the economy of the country and the lives of the people.

1.4.1 Hydrogeological Provinces

The following hydrogeological provinces, within which the aquifers have uniform characteristics, may be distinguished in the Juba Basin:

A. Limestone-gypsum-basalt plateaux where there are three environments, bound up with the lithology: limestone-gypsum, limestone and basalt;
B. Buur Basement Complex;
C. Lower Juba Plain;
D. Beds of Juba, Madagoi and Shabeellada Rivers;
E. Coastal Strip.

The features of each of these hydrogeological environments are outlined below.

A. Limestone-gypsum-Basalt Plateaux

This area coincides with the most northernly part of the Juba Basin in Somalia, the distinguishing feature being the outcrops of limestone-gypsum rocks, limestones, and basalts of Jurassic, Cretaceous and late Tertiary age.

A.1 Hydrological Situation in the Limestone-gypsum Rocks

These rocks outcrop in the northernmost part along the border with Kenya and Ethiopia. Gypsums, anhydrites, limestones, marls, gypsiferous marls and sandstones of Jurassic-Cretaceous age predominate. There are ground-waters and karst springs. When water is present in the subsurface it can be tapped by wells ranging from 5 to 40 m in depth. It is nearly always highly mineralized (from 3 to 5 g/l residue).

A.2 Hydrological Situation in the Limestone

The limestones outcrop in the southern part of the plateaux traversed by the Juba and its tributaries. The main lithological types are Jurassic limestones of various origins, which in certain horizons contain beds of marl and sandstone. There are springs - often karst - and groundwaters can be reached by wells ranging from 3 to 10 and from about 20 to 50 m deep. Water quality is better than in the gypsum areas, the most frequent residue figures being between 1 and 2.5 g/l.

A.3 Hydrological Situation in the Basalts

In the limestone-gypsum plateaux there are outcrops of basalt lavas. These are especially common along the Ethiopian border. Tertiary basalts and tuffs are predominant. Where water occurs, it is found at depths of 5 to 8 m and between 40 and 60 m. The salt content is variable, the residue ranging from 1.5 to 4.5 g/l.

B. Buur Basement Complex

The Buur Basement Complex occurs in the south-eastern part of the Juba Basin. Here there are gneisses, quartzites and marbles with intrusions of granite and pyroxenites.

In the flat-lying areas the metamorphics are covered by a weather capping that may be as much as 20-30 m thick or by alluvials. Inselbergs, generally of granite or quartzite, without any weathered cover but surrounded at the base by coarse talus, arise here and there from the plain.

Springs are rare and their importance is negligible. Where groundwaters do exist they are found at between 8 and 20 m. The salt content is variable, there being good and bad waters (from 1-2 g/l to 18-36 g/l). The water occurs in the fractured Basement rocks and in the unconsolidated cover.

C. Lower Juba Plain

The Lower Juba Plain occupies the southwestern edge of Somalia. It is formed of late Tertiary and Quaternary alluvial deposits varying in particle size from gravels to clays. From the morphological and geological aspects, it also embraces the Juba, Madagoi and the lower reaches of the Shabeellada. From the hydrogeological viewpoint, the area immediately along these watercourses is considered as a hydrogeological province in its own right, differing from that of the Lower Juba province in as much as this lacks the influence of recharge to the aquifers from permanent watercourses or at least those that have surface flow for many months of the year. In the Lower Juba Plain (excluding the immediate courses of the rivers) the waters of the shallow aquifer, no deeper than about 50 m, are generally very hard (from 6 to 35 g/l residue). The waters encountered in a deeper aquifer (120-180 m) are of much better quality, with a residue of 2.5 to 5.5 g/l. This lower aquifer is under confined conditions and is probably formed of older Quaternary and probably Miocene sediments.

D. Beds of Juba, Madagoi and Shabeellada Rivers

This hydrogeological provice fringes the Juba, Madagoi and Shabeellada Rivers. It is characterized by the influence the surface flows of these watercourses have on the aquifers. The strip of influence varies in width from a few kilometres in the upper part of the basin, where the river flows in limestone formations to a few dozen kilometres in the lower plain, being particularly well developed at the confluence of the Juba, Madagoi and Webi Shabeellada. This aquifer occurs in late-Tertiary, Quaternary and Recent sediments, whose particle size varies from gravel to clay. It is only in the upper part of the basin that the aquifer may be formed of limestones. Water is generally found at depths of 3 to 8 m. Its quality is variable, but in can generally be used to water stock and even humans can utilize it marginally (from 1.5 to 3 g/l residue).

E. Coastal Strip

This provice occurs along the Indian Ocean coast, where it occupies a strip anything up to 10-15 km wide. Here there are eolian and sea sands and coral limestones of late-Tertiary and Quaternary age. Wells a few metres deep can tap water of variable quality, suitable for use by man and beast (from less than 1 to 3-4 g/l residue). The salt content naturally increases in depth, i.e. passing from the cone of fresh water to the saline waters below.

1.4.2 Water Resource Development

As far back as the 1958 FAO Report, the need was recognised to perform detailed hydrogeological investigations based on stratigraphic and structural information, backed up by data from geophysical prospecting and the drilling of pilot wells, so as to develop the aquifers in the various hydrogeological provinces in a rational manner. This fact is brought out even more clearly in the reports by Agrar-und-Hydrotechnik (1972), UNDP (1973) and Hendrikson (1973), which analyse the present situations and future needs.

Few of the wells sunk to date were preceded by proper hydrogeological studies; this is a serious omission, especially in regions such as the Juba Basin where rainfall is scarce, evaporation is high, morphological situations favourable to the collection of water are few and the stratigraphic and structural environment is frequently unsuitable for collecting and storing water in depth.

As the climatic conditions cannot be altered, investigations must hinge around the search for favourable morphological and geological conditions.

Favourable morphological situations can be found fairly easily, but it is more difficult to recognize stratigraphic and structural environments that may contain aquifers.

A broad outline of the investigatory themes in the various hydrogeological provinces is as follows:

- In the limestone-gypsum areas the most calcareous and arenaceous parts must be found.
- In the basalt areas it is advisable to seek out fissured masses underlain by marls and clays.
- In the limestone areas, fissured limestone masses with few or no marl interbeds should be sought, as should faulted zones.
- In the Buur Basement Complex area, the fractured and faulted parts of the basement and the coarse alluvials and eluvials are favourable for the storage of water.
- In the Juba Plain, areas must be identified where there are coarser deposits underlain by an impervious bed.
- Along the Juba, Madagoi and Shabeellada Rivers the objective should be to identify the deposits whose particle size is most favourable for the flow and storage of water.
- In the coastal strip it is necessary to know the spatial position of the saltwater-freshwater interface.

A properly organized programme of hydrogeological investigations is a multidisciplinary matter which must be discussed and agreed with the crop and livestock development planners, taking due account of the human resources and the social infrastructure. Thus, agreement must be reached between the various planners before any hydrogeological investigations are undertaken. In Chapter 3 of this Part I a complete programme has been drawn up.

CHAPTER 2.

GEOLOGICAL SITUATION BETWEEN LUUQ AND DOLOW

2.1 INTRODUCTION

This Report sets forth the results of the photogeological study with field control in the Juba River basin between Luuq and Dolow in western Somalia near the Ethiopian border. The study led to the preparation of the geological map given in Drawing III, I, 2, 1.

2.2 MORPHOLOGY

The landform is mainly flat with slight undulations and plateaux with escarpments and cuestas that are sometimes well developed.

2.3 REGIONAL GEOLOGY OUTLINE

The crystalline basement outcropping in the Buur area consists of Precambrian gneisses, quartzites and marbles with granitic intrusions. Above the peneplained surface of the Basement Complex lie transgressive conglomerates and sandstones followed by a Mesozoic succession in which predominate organogenic limestone facies, with levels of marls and oolitic limestones (Stefanini's "Baardheere Series", 1925) passing upwards to sandstones, dolomitic limestones and gypsums (Stefanini's "Luuq Series", 1925).

These Mesozoic sediments are constituted of the following formations:

1. Isha Baydhaba Formation. This lies unconformably on the Basement Complex. At the bottom are sandstones and shales (Deleb Member) and shales (Uuney Member) and then limestones of the Baydhaba Member and oolitic limestones of the Golado Member for a total thickness of 750 m. Age: Callovian.

2. Anole Formation. This consists of marls and shales with limestone intercalations. It lies conformably on the Isha Baydhaba Formation and is about 400 m thick. Age: Oxfordian.

3. Waajid Formation. This consists of limestones, partly algal and partly oolitic, with sandstone and shale intercalations. It lies conformably on the Anole Formation and can be divided into three members which, from the bottom upwards are: the Colaliyo (limestones, marly limestones, locally oolitic and arenaceous), the Carow (marls), Magdiile (sandstones and limestone). The total thickness is 350 m. Age: Kimmeridgian.

4. Garbahaaray Formation. This outcrops in the Luuq-Dolow area. Age: Portlandian-Lower Cretaceous.

5. Ambar Formation. This consists of sandstones with shale, siltite and marl intercalations and is heteropic with the Waajid and Garbahaaray Formations. Its thickness is about 450 m. Age: Kimmeridgian-Lower Cretaceous.

2.4 GEOLOGICAL SITUATION BETWEEN LUUQ AND DOLOW

The Garbahaaray Formation consists of sandstones with coquinas and evaporites (Gypsum Series). It lies conformably on the Waajid Formation and has two members, the Busul and the Mao, with a total thickness of a hundred or so metres.

There is no unconformity between the Busul Member and the Waajid Formation, but the contact between the two is marked by a key bed of algal limestone. The distinguishing feature of this member is the presence of clastic detritus with abundant quartz, indicating the start of the regressive phase of the Jurassic sedimentary cycle. The main lithological intervals in this member are as follows, from the bottom upwards: a) calcisiltites, laminated calcarenites, oolitic and dolomitic limestones with occasional clayey interbeds; b) hard, well-cemented quartzose sandstones with greenish clay interbeds; c) brownish and pinkish calcarenites and dolomitic limestones; d) whitish nodular marls with no fossils and greenish-grey marls; e) bluish-grey, very hard, poorly classified but well cemented quartzose sandstones; f) greenish clays. The succession of lithotypes indicates that the sedimentation environment was lagoonal with littoral or supraneritic phases. The total thickness of the Busul Member is around 280 m and its age is Jurassic-Cretaceous.

The Mao Member is constituted by terminal sediments of the regressive phase of the marine cycle. It lies on the Busul Member with no break in sedimentation. The main lithological types are gypsums and anhydrites (bluish-grey in colour), often lenticular, dolomitic limestones, clays, marls and marly and sandy limestones. The succession is indicative of a lagoonal environment with typical evaporitic facies. The total thickness of the member is around 420 m and its age is Portlandian-Lower Cretaceous.

During the Tertiary and Quaternary the area was affected by faults connected with the Rift Valley tectonism, and by basalt flows which probably came down from the Ethiopian Plateau, and appear in the Luuq area, too, as small stratoidal effusions. Among the recent formations, in addition to the alluvium, river terraces, talus cones and dunes, there are continental deposits in the Luuq area, namely gypsiferous marls and pebbles with huge gasteropods, lying in form of terraces along the Juba River.

2.5 STRUCTURES

The main structural feature in southern Somalia is the broad shield rising as an anticline in the Buur region, joining up with the Luuq anticline to the north-west. The bedding is generally subhorizontal, though near Luuq dips of 10-15° are encountered.

The main strike of the faults and fractures is NE-SW. The displacements are small, typical of a block-faulted region where tension faulting has been predominant.

CHAPTER 3.

GROUNDWATER EXPLORATION PROGRAMME
FOR THE JUBA VALLEY

3.1 INTRODUCTION

Groundwater exploration should be performed in the areas which have the most favourable combination of factors from the geological, hydrogeological, human and agricultural aspects.

3.2 EXISTING DATA

Climatic, geological and hydrogeological data are given in the FAO Report of 1958 and the UNDP Reports of 1970 and 1973. These describe the regional hydrogeological situation (at 1:1,000,000) on the basis of knowledge of the stratigraphic and tectonic situation and a waterpoint inventory.

More detailed stratigraphic and structural information (1:100,000) is provided by the surveys made by the oil companies, especially in the upper part of the Somali basin of the Juba.

Geological and hydrogeological information can also be obtained by interpreting the 1:60,000 black and white air photos flown by the RAF in 1960.

There is sufficient geological and hydrogeological information available for a general understanding of the regional problems, but not enough to perform a profitable investigatory campaign in the Juba Valley, including the drilling of exploratory wells.

3.3 EXISTING PROGRAMMES

The 1958 FAO and the 1973 UNDP Reports are the best sources of hydrogeological information. They divide Somalia into hydrogeological provinces within each of which the aquifers have uniform characteristics. Once having defined the hydrogeological province, the points for investigation are given, at regional level, of course. The same points are to be found in the Agrar-und-Hydrotechnik Report of 1972 (Study of Water Resources and Planning of Water Supply) and the Hendrikson Report of 1973 (A programme for the Allocation of Deep Wells to the Rural Areas), for which no new geological or hydrogeological investigations were performed. All these reports suggest that appropriate investigations be performed but do not give detailed programmes.

A detailed programme to be completed in 54 months is, however, given in the 1973 Groundwater Exploration Project performed jointly by the Government and the UNDP (SOM/73/A/01/01). It would appear that the programme is now being finalized. It covers the whole of Somalia and envisages the drilling of 144 exploratory wells ranging from 50-60 to 550-600 m in depth, pumping tests, chemical analyses, etc. on wells; investigations on springs; geophysical investigations of areas selected for boreholes and down the holes too; laboratory investigations and training of Somali personnel. It is not clear, however, where the 144 exploratory wells (convertible to production wells, if successful) are to be drilled. This could be because detailed geological and hydrogeological information required to site the wells with a good probability of success is not as yet available, at least in the Juba area.

3.4 HYDROGEOLOGICAL PROVINCES IN THE JUBA BASIN

There are the following hydrogeological provinces in the Juba basin (See Chapter 1, Para 1.4.1):

a. Limestone-gypsum-basalt plateaux where there are three environments, bound up with the lithology: limestone-gypsum, limestone and basalt. There are groundwaters and springs. The points to be explored are as follows: in the limestone-gypsum areas the least gypsiferous zones with structures favourable to the collection and storage of waters must be found; in the limestone areas the investigations should be directed to locating fissured masses with no marl interbeds (or very few), fault zones and structures favourable to the collection and storage of water (anticlines and synclines); in the basalt areas, it will be advisable to seek out fissured masses underlain by marls and clays.

Before performing direct exploration, using also wells, in the limestone-gypsum-basalt plateaux region, photogeological studies should be carried out using the existing black and white photos and there must be field geological surveys and geoelectrical surveys to pinpoint the most favourable situations with a degree of precision that is not possible at the present time.

b. Buur Basement Complex, where there are goundwaters and springs of little importance. The items to be investigated here are the fractured and faulted parts of the Basement and the unconsolidated alluvials and eluvials which are sufficiently coarse-grained to allow water to enter and circulate.

Direct investigations by means of exploratory wells must be preceded by geological interpretation of the existing black and white photos (to pinpoint the most highly fractured zones), by geoelectrical and geoseismic surveys (to identify the thickness of the fractured cap and the loose deposits), by field geological surveys, and by such techniques as remote sensing by satellite, which will indicate porosity, infiltration, recharge and outflow areas and also the permeability of the unconsolidated materials. All this must be done to improve on the present state of knowledge.

c. Lower Juba Plain, where there are groundwaters at various depths in the unconsolidated late Tertiary and Quaternary alluvials. Here the basic requirement is to identify the lateral extent and vertical thickness of the sediments, especially the coarser ones in which the water can enter and circulate more freely than in the finer ones. Another task is to ascertain the hydrogeological relationships and the hydrodynamic and chemical properties of the groundwaters. Little or nothing is known on these matters at the moment.

Before performing direct investigations, including the drilling of exploratory wells, the existing black and white photos must be interpreted from the geological aspect, remote sensing must be used to obtain information on the porosity, recharge and outflow areas and the permeability of unconsolidated materials, and geoelectrical prospecting must be used to follow the trend of the various deep water-bearing levels that may or may not have been identified on the surface or in boreholes.

d. Beds of Juba, Madagoi and Shabeellada Rivers. This hydrogeological province fringes the rivers concerned and is distinguished by the influence the surface flows have on the aquifers. The main point to be investigated is

the relationship between the surface waters and the lateral aquifers, studying the extent, regime, chemical and hydrodynamic properties thereof.

This hydrogeological province should be studied at the same time as that of the Lower Juba Plain, as it is included therein. There are thus close lithological and hydrogeological links between the two. It is to be recommended that the existing black and white air photos be interpreted from the geological aspect and that remote sensing and geoelectrical surveys be performed, so as to ascertain the trends of the alluvial deposits of different particle size and of the aquifers, because the coarser the deposit the more readily it will drain water from the river. When these investigations have been performed, it will then be possible to sink exploratory boreholes to check on the regime and the hydrodynamic and chemical properties of the groundwaters.

e. Coastal plain, where there are fresh groundwaters floating on seawaters. The investigations must be tailored to ascertain the spatial trend of the freshwater/saltwater interface; this is a typical problem to be tackled by geoelectrical means. The coastal area is included in the Lower Juba Plain and so the investigations on the black and white and satellite photos for the two hydrogeological provinces can be combined. When this has been done, the next step will be to sink exploratory wells or production wells.

3.5 PROGRAMME

In view of the situation and the present state of knowledge, it is recommended that more detailed geological and hydrogeological investigations be performed before sinking exploratory or production wells. Indeed, though the state of knowledge is adequate for a regional outline, it is too scanty for siting even exploratory holes with a good chance of success, except perhaps along the fringes of the Juba.

A programme of exploratory and production wells performed either by the Somali WDA or the UNDP, should be preceded or accompanied by the following investigations in the Juba basin.

a. Geological interpretation of the existing 1:60,000 black and white airphotos, to pinpoint the areas hydrogeologically most favourable for groundwaters and also to ascertain those best suited for the creation of surface reservoirs.

b. Acquisition and evaluation of satellite photos to reveal the lithological differences in the alluvial soils and the different evaporation intensities.

c. Electrical and seismic geophysical investigations performed by a number of teams who would run resistivity surveys with AB up to 3,000 m and refraction surveys with bases up to 50-100 m.

d. Field reconnaissances by hydrogeologists in the most interesting areas.

e. Exploratory and production boreholes in the most favourable areas.

f. The investigations will serve to instruct Somali personnel in hydrogeological exploration work.

CHAPTER 4.

GEOLOGICAL INVESTIGATIONS
FOR BAARDHEERE DAM AND RESERVOIR

4.1 INTRODUCTION

During the course of the studies for developing the Juba Valley, geological investigations have been performed in the reach north of Baardheere to identify the site most suitable for building a dam to eliminate flooding, and to store water for irrigation and perhaps to generate electricity too. The geological situations in the reservoir basin have been assessed to form an opinion on the watertightness thereof.

The results of these investigations are reported on a 1:100,000 photogeological map of the reservoir basin (Drg.III.I.4.1) and on nine topographic and geological cross sections studied to ascertain the most suitable dam site (Drg. III.I.4.2).

The nine sections are plotted on the 1:100,000 map along with the section proposed for damming in the 1965 Selchoz-promexport Project, which falls between Sections 1 and 2 of the present study. (See Fig. 1.I)

Also included in this Report are eight colour photographs taken from a low-flying aircraft to illustrate the landform at the nine cross sections concerned.

4.2 DAM SITE INVESTIGATIONS

It is apparent from the air-photo study, plus observations from low-flying aircraft and on the ground, that the site best suited for damming lies to the north of Baardheere in the northernmost part of the limestone plateaux.

The stretch with the best morphological and geological features starts some 20 km north of Baardheere, in a direct line (26 km by river) where the Juba passes from the alluvial plain to the valley entrenched in the limestones. This reach runs north for about 37 km. Farther north still, although the river is still in limestones, the valley broadens and the situations are not so favourable.

As mentioned in the introduction, nine possible dam sites were selected in this more favourable reach, the first two of which lie upstream and downstream of the site selected in the Selchozpromexport 1965 Juba River Scheme.

4.3 GENERAL GEOLOGICAL SITUATION

The general geological and morphological features of the reach of valley that is suitable for damming are as follows. The valley is entrenched in limestone formations which lie virtually level or dip slightly to the north-west. This is a terraced valley with the rocky terraces stepping down towards the Juba river, which constitutes the local base level. The walls of the valley rise fairly symmetrically from the river, the top of the lowest rock terrace being between 100 m and 70 m above the bed, going from south to north.

The general trend of the valley is north-south, though it tends to meander markedly in the central part of the stretch useful for damming.

The river itself meanders slightly in the valley bottom occupied by loose alluvial deposits, there being sedimentation in the inner part of the bends.

The rock formations in outcrop in the reach most suitable for damming are the Anole and the Waajid, the latter being the most common.

The Anole Formation, consisting of limestones with marly intercalations, would appear to occupy the lower part of Section 1. The Colalio Member of the Waajid Formation occupies the reach where the dam site is to be selected. It consists of limestones and coral limestones, calcirudites, oolitic limestone and coquina.

Basalts also exist in this area, among the limestones, but they do not affect the dam site and the reservoir basin.

The main faults strike NE-SW. They are not common. Subordinate faults strike N-S and NW-SE, often coinciding with the morphological features. The fault planes are usually close to the vertical. The strikes coincide with those of the jointing and of the morphological trends and watercourses that have cut into the limestones, following the path of least resistence. However, the jointing and the streams also have an E-W trend, which is not present in the fault systems.

The nine possible dam sites in the most suitable reach of the river have been topographically surveyed in detail so as to plot profiles at 1:2,000 horizontal scale and 1:500 vertical scale. Detailed geological surveys and seismic prospecting were then performed on each section; the individual results are reported below. (See Fig. 2.I)

Section 1

This is the most southerly section. It runs east-west at a point where the valley bottom is occupied by recent river alluvium consisting of silty and clayey sands. Though these deposits are quite extensive they are not very deep; a seismic survey run 75 m from the river on the right bank revealed the presence of bedrock at a maximum depth of 6.3 m. Where the alluvial plain finishes and the rock slopes of the valley sides begin, there is a considerable amount of talus; this is mixed with alluvial sands in the lower part.

There is some degree of symmetry in the position of the rocks on the two banks, as a result of the relatively horizontal attitude of the strata. From the bottom upwards there are grey fossiliferous limestones (gasteropods and lamellibranchs) with levels of coquina, then half way up there are very dark bituminous limestones, followed by oolitic limestones and light brown and yellowish calcarenites with grey marly limestone intercalations.

Section 2

This section runs NW-SE and the profile is symmetrical. There are no alluvial deposits on the left bank and the river washes the foot of the rocky slope. On the right bank there are silty and clayey sands, but bedrock must lie at a fairly shallow depth, in view of the situation on the other bank.

Here again there is some degree of symmetry in the rock outcrops on the two banks, especially in the lower, steeper parts where oolitic limestones and light brown and yellowish calcarenites outcrop in well-marked beds

fig. 1.1

BAARDHEERE AREA: PHOTOGEOLOGIC MAP

ZONA DI BAARDHEERE: CARTA FOTOGEOLOGICA

LEGEND Fig.2a,b.l *LEGENDA*

Alluvial sand with clayey lenses
Sabbie alluvionali con lenti argillose

Marly limestone
Calcare marnoso

Fallen block debris
Detriti di falda

Fossiliferous limestone
Calcare fossilifero

Calcarenite
Calcarenite

Coral limestone
Calcare corallino

Oolitic calcarenite
Calcarenite oolitica

Pisolitic limestone
Calcare pisolitico

Oolitic limestone
Calcare oolitico

Coral & pisolitic limestones
Calcari corallini e pisolitici

Bituminous limestone
Calcare bituminoso

Pisolitic & fossiliferous limestones
Calcari pisolitici e fossiliferi

T1 Seismic traverse
Traversa sismica

4,000 m/s Velocity of compressional waves
Velocità delle onde di compressione

S1 Soil sample
Campione di terreno

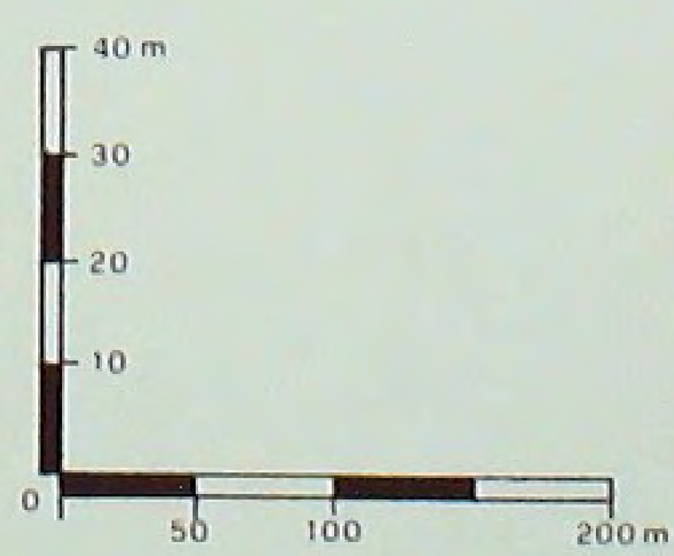


fig. 2 a.I

BAARDHEERE : GEOLOGICAL SECTIONS

BAARDHEERE : SEZIONI GEOLOGICHE

fig.2b.1

BAARDHEERE : GEOLOGICAL SECTIONS

BAARDHEERE : SEZIONI GEOLOGICHE

some tens of centimetres thick, showing signs of karst erosion on the exposed surfaces. These beds have a virtually horizontal attitude, though they tend to dip slightly towards the river on both banks owing to slight descent movements connected with the morphology. Overlying these lithotypes are dark fossiliferous limestones with a wealth of corals and a few rare lamellibranchs and large gasteropods. Oolitic levels are also encountered in places. Owing to the more gentle ground slopes here, occasional pockets of terra rossa are to be found too.

Section 3

This trends NNW-SSE and is fairly symmetrical. The valley bottom is covered by sandy materials laid down in the immediate past. To clarify the situation from the geotechnical aspect these materials were sampled and analysed: the results show them to be silty sands.

As with the other sections, there is talus deposition at the foot of the side slopes. This also onlaps the alluvium for a few metres.

A difference in the elevation of the lithotypes outcropping in the two banks points to the presence of a fault in the river bed, because the attitude of the strata is subhorizontal; however, the fault cannot be observed owing to the alluvial cover.

On the left bank the sequence from the bottom upwards is yellow oolitic limestones and calcarenites, well bedded at the height of the first terrace. Then follow grey pisolitic limestones and thinnish pink calcarenites. Above these come the grey fossiliferous (coral) limestones with intercalations of marly limestones, while terra rossa occurs on the left end of the profile where the slopes are not so marked.

On the right bank there are grey fossiliferous limestones at the bottom, followed immediately by oolitic limestones and yellowish-grey calcarenites, sometimes pinkish with a few intercalations of grey marly limestone.

Section 4

The section runs WNW-ESE and is asymmetrical, the river being decidedly over towards the right bank. There is a small alluvial plain on the left-hand side, formed of sands, though near the rock wall these are also mixed with talus deposits.

From the bottom upwards the side walls consist of oolitic limestones and yellowish grey calcarenites in thick beds, followed by grey fossiliferous (coral) limestone containing intercalations of marlier limestones with no obvious fossils.

In the outer parts of the section where the side slopes are gentler occurrences of terra rossa are to be observed.

Section 5

This runs NW-SE and is asymmetrical. The valley bottom is not very wide and is virtually all occupied by the river waters. It is only at the very edges that there is a small stretch of sandy alluvium and talus deposits. Owing to the alluvial cover it is not possible to see a fault with a small throw which certainly exists in the valley, as attested to by the lack of correspondence between the outcrops on both banks. Indeed, virtually the only rock in outcrop on the right side is grey fossiliferous limestone (corals, gasteropods and lamellibranchs) with intercalations of limestones apparently without any fossils, there being only a thin outcrop of yellowish oolitic limestones above the talus, while on the left bank the yellowish oolitic limestones reach the elevation of the first terrace and are then followed by the grey fossiliferous limestones.

Section 6

The section runs WSW-ENE and is fairly symmetrical as regards the rock walls, while the valley bottom is an alluvial plain only on the right hand side.

The outcropping rock consists exclusively of grey fossiliferous limestones (corals, gasteropods and lamellibranchs) with intercalations of grey limestones apparently without fossils.

On both flanks, above the first terrace where the slopes are gentler, the rock is covered in places by a residual soil deriving from the in-situ weathering of the limestones.

Section 7

This trends E-W and is decidedly asymmetrical. There are practically no alluvial deposits, on the right bank but they are fairly widespread on the left, where they consist of silty and clayey sands. The seismic survey shows their depth to be a little over six metres.

The survey of outcrops on the two banks has brought to light the existence of a fault running along the valley bottom, because while there are marly limestones on the right bank overlain by fossiliferous grey limestones, on the opposite bank the rocks are pisolitic limestones overlain by light grey marly limestones.

Section 8

This section runs WSW-ENE and is fairly symmetrical. The valley bottom is formed of sandy alluvials and as in Section 7, there is a fault present, since the rocks on the two banks do not match.

Indeed, on the right bank, after the marly limestones which run up to the height of the first terrace there are grey fossiliferous limestones, while on the other side there are no marly limestones, all the outcrops consisting of grey fossiliferous limestones with intercalations of apparently non-fossiliferous limestones.

Section 9

This is the northernmost section. It runs NW-SE and is extremely asymmetrical. Alluvial deposits are present virtually only on the right bank and after a short stretch of talus these give way to calcarenites. The stratigraphic situation is similar on the two banks, being as follows from the top to the bottom: calcarenites followed by fossiliferous limestones with pisolitic levels and then calcarenites again.

4.4 POSSIBLE DAM SITES

The widths and forms of the nine possible dam sites vary. Should it be wished to build a dam about 50 m high, then the crest lengths of the individual sections would be as follows:

Section 1	1,100 m approx.
Section 2	480 m "
Section 3	550 m "
Section 4	550 m "
Section 5	600 m "
Section 6	700 m "
Section 7	700 m "
Section 8	720 m "
Section 9	600 m "

The 1965 Selchozpromexport study suggested that the dam be sited between Sections 1 and 2, giving a crest length of about 800 m. From the morphological and geological point of view, however, Section 2 is the best for damming, being the narrowest and the most symmetrical.

Yet this does result in the loss of the waters that are brought down by a tributary draining an 800 km^2 basin, which would be controlled and stored by the 1965 Section. Even so, the Section 2 dam site would still appear preferable, at the present state of knowledge, because it lies upstream of a NE-SW fault which runs across the valley about two kilometres upstream of the 1965 Section.

4.5 RESERVOIR BASIN

The morphological and geological situation of the Baardheere Reservoir is shown on the 1:100,000 photogeological map in Drg. III.I.4.1. This map covers the area between Baardheere and Luuq and thus covers that involved with the dam site at Section 2. The position of the Juba and its tributaries can be seen from the map. It will be noted that the Juba flows generally N-S, though there are meanders and secondary bends generated during earlier erosive phases preceding the present one during which the meanders have been deepened. Erosion of the thalweg and of the meanders is particularly evident on the tributaries of the Juba, which constitutes the local base level.

There are also local deposits of unconsolidated silty-sandy sediments in the bed of the Juba; these are laid down particularly during the waning phases of floods. The main lines of the affluents run NW-SE, NE-SW and E-W, while the secondaries have a typical dendritic pattern. The Juba and its tributaries run across and are entrenched in a terraced limestone plateau, the Juba being the deepest of the watercourses and hence the one which collects the flows of all the tributaries.

The rocks outcropping along the Juba and in neighbouring areas belong to the Anole, Waajid and Garbahaaray Formations of the Upper Jurassic. They are mainly carbonates, though they are traversed by basalts locally. Alluvials and calcareous encrustations (caliche) cover all the previous formations.

The Anole Formation consists of limestones and marls, mainly blackish. This outcrops between Baardheere and Section 1, where it probably forms the lower part of the valley. Proceeding northwards the Waajid Formation is found in outcrop. This consists of beds of fossiliferous and oolitic limestones, sometimes with thin marly intercalations. It is characterized by abundant coral colonies. The Waajid Formation is visible for about 90 km on the sides of the Juba Valley going northwards from Section 1. From the bottom upwards it is sometimes possible to distinguish three members in the Waajid: the Colaliyo, the Curao and the Mareesta. The Colaliyo Member consists of limestones and coral, calcirudites, coquina and oolitic limestones; the Curao Member consists of dark calcareous marls and the Mareesta Member of oolitic and algal limestones, sometimes dolomitized.

All nine sections appear to lie in the Colaliyo Member.

Farther north again along the Juba, the Garbahaaray Formation which lies higher up the stratigraphic column is in outcrop up to Luuq and beyond. This formation has two members: the Busul and the Mao. The Busul Member consists of limestones and marls with sandstone intercalations. It outcrops along the Juba Valley for some 40 km north of the last outcrops of the Waajid Formation. The Mao Member consists of dolomites, limestones, marls, gypsums and anhydrites. It outcrops to the north of the Busul Member up to Luuq and beyond. The strata tend to strike NE-SW and dip very slightly to the NW. There are few very obvious structures or folds and these occur only in the northern part of the area towards Luuq. The best known are the Busul anticline and the Tamalo syncline.

The faults also strike mainly NE-SW, though there is also a secondary NW-SE strike to be seen.

Though there has been no detailed geological and morphological survey of the reservoir basin, the morphological situation, the stratigraphic succession and the climatic situation would all appear to indicate that the reservoir will be watertight, when the matter is viewed in the light of the volumes of water involved.

CHAPTER 5.

GEOLOGICAL INVESTIGATIONS IN THE SAAKOW BASIN

5.1 INTRODUCTION

Geological investigations have been performed in the stretch of the Juba to the north of Saakow to assess the possibility of constructing a dam to create a reservoir to be used for irrigation. Special attention has been given to appraising the watertightness of the basin.

The results are plotted on the 1:60,000 geological map of the area affected by the reservoir (Drg. III.I.5.1) and on a geological profile which was run across the most interesting area of the basin and surveyed on the ground. Drg. III.I.5.2 shows the location of the section at a scale of 1:5,000 in relation to the Juba and the village of Buulo Batuula; the points investigated by test pits and refraction surveying are indicated. Drg. III.I.5.3 gives the geological section at a horizontal scale of 1:2,000 and a vertical scale of 1:500; it also illustrates the points investigated and indicates the stratigraphy at depth.

Ten colour photographs accompany this Report to illustrate the geological situation and the amount of karst phenomena existing in this area.

5.2 GEOLOGICAL SITUATION

The geological situation in the area which may be occupied by the Saakow Reservoir is illustrated on the map in Drg. III.I.4.3. This was obtained from a photogeological study and ground surveys made in August, September and October 1975. (See Fig. 3.I)

The general trend of the valley here is NNW-SSE and there are two broad meanders. The valley is wide and the banks gently sloping. Locally there are limestone terraces, the remnants of earlier fluvial erosion.

There is a limestone bedrock covered by residual soils of variable thickness, while basalts, talus and river alluvials are also present. The bedrock belongs to the Anole Formation (Jurassic), the most frequent lithotypes being grey limestones, dark bituminous limestones, fossiliferous limestones and oolitic limestones. The beds vary in thickness from a few centimetres to about one metre, and are separated by thin interbeds of marl often no more than a few millimetres or centimetres thick. The beds dip slightly to the west or are virtually horizontal. They are jointed vertically and thus tend to form blocks which vary in size from a few cubic centimetres to getting on for a cubic metre. There are few faults; those encountered have a NW-SE strike.

In view of the geological and morphological situation, it has been thought advisable to represent the distribution of the limestone bedrock together with and in relation to the cover of terra rossa, the residual soil deriving from the solution and removal of the most calcareous parts of the Anole in geological time. The terra rossa deposits are very extensive and their thickness is extremely variable.

Two lithomorphological units have been distinguished in the Anole Formation by means of the photogeological study, the field surveys, the test pits and the seismic prospecting. One of these is a very shallow limestone, locally outcropping, mantled by residual soil, and the other is a deep limestone mantled by residual soil. The first is distinguished by limestones in outcrop and depths of residual soil not exceeding about 4 m, the second by limestone units that do not outcrop and more than 4 m of residual soil (sometimes as much as 10 m and over). The field observations, test pittings and laboratory analyses indicate that the residual soils consist of a matrix of variable particle size ranging from silty sands to clayey silts, plus fragments of limestones and calcitic concretions. In the test pits it is possible to distinguish an upper brown horizon, sometimes with organic matter, and a lower grey horizon with more limestone fragments. In the former the residual soil is older and more oxidized than in the latter.

Basalts are in outcrops on the left hand side of the Juba. These are dark rocks covered by isolated fragments set in a dark residual soil. These are the southernmost occurrences of the Tertiary and Quaternary volcanic activity associated with the Rift Valley. Owing to the extensive soil cover, the attitudinal relationship between the limestones and basalts is not yet clear.

The geological map reports talus areas at the bottom of limestone cliffs. These deposits are formed of loose sharp-edged limestone fragments varying in size from a few cubic centimetres to fractions of a cubic metre.

Along the river there are alluvial deposits ranging in particle size from sands to silts. Alluvials also occur near the river bed in local, shallow depressions known as desceck where the floodwaters pond. Alluvium is found too along the course of tributary streams; this is coarser, ranging from gravels to sands. The thickness of the Juba alluvials, determined along the geological profile by seismic refraction surveying, should not exceed 10 m or so.

The geological map also illustrates the morphological features as derived from the photointerpretation and field surveys. Connected with the morphological evolution of the valley are the cuestas in limestone terrain, the scarps in loose terrain, the outcrops of the top parts of the beds and the drainage system. The distribution of these features confirms the regional evolutionary situation, with the terraces grading down towards the Juba, the regional base level.

Karst phenomena are variously developed in the area. The geological map shows the position of the sinks in the limestone. These sinks are visible in the air photos and have been checked in the field. They are rounded or oval depressions with a maximum diameter of 100-150 m in the residual soils overlying the limestones. These depressions in the loose, residual soils are almost certainly attributable to the presence of cavities, probably of karst origin, in the underlying limestones.

Karst phenomena are also visible in various outcrops; these consist of clints and microcavities caused by solution (the photos show some typical examples). The area affected by karst phenomena is quite small compared with the situation in the Karst Alps. As regards basin watertightness, surface indications can be considered negligible. The limestone sinks are covered by finegrained residual soils having quite low permeability.

fig. 3.1

SAAKOW AREA : GEOLOGICAL MAP

ZONA DI SAAKOW : CARTA GEOLOGICA

5.3 INVESTIGATIONS ALONG THE BUULO BATUULA GEOLOGICAL PROFILE

To obtain a more detailed picture of the relationships between the limestone bedrock and the loose cover of residual and alluvial origin, pits have been sunk, geophysical surveys run and laboratory analyses of samples performed. The work was concentrated on a section, shown on the geological map, which passes near the village of Buulo Batuula and runs virtually at right angles to the course of the Juba.

This may be considered as a typical section, as it extends for many kilometres across country to be submerged. As the geological situation here is so even, the section reveals the problems that will be encountered in creating a reservoir, whether the dam is at Buulo Batuula or elsewhere in the vicinity. The profile was surveyed topographically at 1:5,000 (Drg. III. I.5.2). The elevations and location of the seismic surveying and pits are shown on the drawing.

Drg. III.I.5.3 shows the profile at a horizontal scale of 1:2,000 and a vertical scale of 1:500. The trend of the limestone bedrock and the thickness of the residual soil are plotted on the basis of the field surveys, the seismic prospecting, the test pits and the laboratory tests. Some of the information shown is certain while some is interpolated, lacking equipment for direct exploration (such as drill rigs) at this stage of the study.

5.3.1 Geophysical Investigations

Geoseismic surveying is based on the fact that the speed of propagation of longitudinal elastic waves or refracted compression waves increases with the degree of compaction of the rock. Thus, knowing the length of the base, it is possible to calculate both the speed of propagation of the waves in the various rock horizons in the subsurface and the thickness thereof. This method is particularly suitable when there are known differences of elastic properties between the rock types concerned (in the case in point: loose ground and compact limestone).

A "Bison Signal Enhancement Seismograph, Model 1570" was used for the investigation. This enables the subsurface to be probed to a depth of about 100 m. The survey depth varies depending on the geological condition, ranging from one third to one half the length of the Seismic Base.

As is apparent from the accompanying figures, a profile was run from both ends of the Base so as to reveal any non-horizontal contacts. The seismic diagrams also show the stratigraphic section expressed in metres, derived during the survey. This indicates the thickness of the various horizons distinguished on the basis of the velocity expressed in metres/second. The velocity data and the position of the traverses are shown on the geological profile. (See Fig. 4.I)

Seismic traverse 1

This was run parallel to the profile at Test Pit 2 on the left bank of the Juba. The Seismic Base was about 48 m long and probed to a depth of around 20 m. The investigation reveals a loose soil cover (velocity 350 m/s) ranging from 6 m thick at End A to 5 m at End B. Below this is the compact rock with a velocity of 4,000 m/s.

Seismic traverse 2

This was run on the left bank parallel to the dam centreline, with End A some 200 m from Test Pit 4 towards the river. The Base was 48 m long and probed to a depth of about 20 m. There is a surface layer with a velocity of 360 m/s that ranges from 1.7 m thick at End A to 3.7 m at End B, beneath which, down to a depth of 12 m at End A and 11 m at End B there is more compact material with a velocity of 900 m/s. This gives way to rock with a velocity of 2,800 m/s.

Seismic traverse 3

This lies on the left bank some 20 m from the present water level. The Base, perpendicular to the profile, was 48 m long and probed to a depth of about 20 m. There is an upper layer of 380 m/s material 6.5 m deep at End A and 6 m deep at End B, covering compact rock with a velocity of 2,550 m/s.

Seismic traverse 4

This was run on the right bank parallel to the dam centreline and End A was some 170 m from the river. It was about 48 m long and probed to a depth of some 20 m. There is an upper layer of 350 m/s ground 4.5 m thick at End A and 4 m thick at End B, overlying compact rock with a velocity of 1,650 m/s.

Seismic traverse 5

This is located on the right bank of the Juba between Test Pits 6 and 7. The Base was about 90 m long and probed to a depth of around 40 m. There is an upper layer of 350 m/s material 4.5 m thick at End A and 4 metres at End B, overlying compact rock with a velocity of 1,700 m/s.

5.3.2 Geotechnical Investigations

To obtain direct knowledge of the cover soils and to take samples for analysis, ten test pits were dug along the Buulo Batuulo profile. The location of these is shown in Drg. III.I.5.2. The pits are 4 m deep, on average, but some are shallower, where the limestone bedrock is found nearer the surface.

A detailed profile was surveyed in each pit and typical samples taken. Penetrometric and vane tests were also performed using pocket equipment so as to obtain an initial idea on the mechanical properties of the soils; by processing the results it is possible to obtain penetration and cohesion in kg/cm^2. Laboratory tests were also run on the test-pit samples to ascertain the particle size distribution; the resulting curves are reported herein.

The profiles of the test pits are given in Drg. III.I.5.3, from which the following may be observed. Test Pits 1, 2, 3, 4, 5, 7, 8, 9 and 10 are in residual soils which cover the limestone bedrock reached in Test Pits 1, 3, 8 and 10. Test Pit 6 is sunk in Juba River alluvium.

In nearly all parts, the residual soil is divided into two horizons, the upper one is brown in colour and contains organic matter and fragments of limestone or calcite concretions, while the deeper one is grey and without

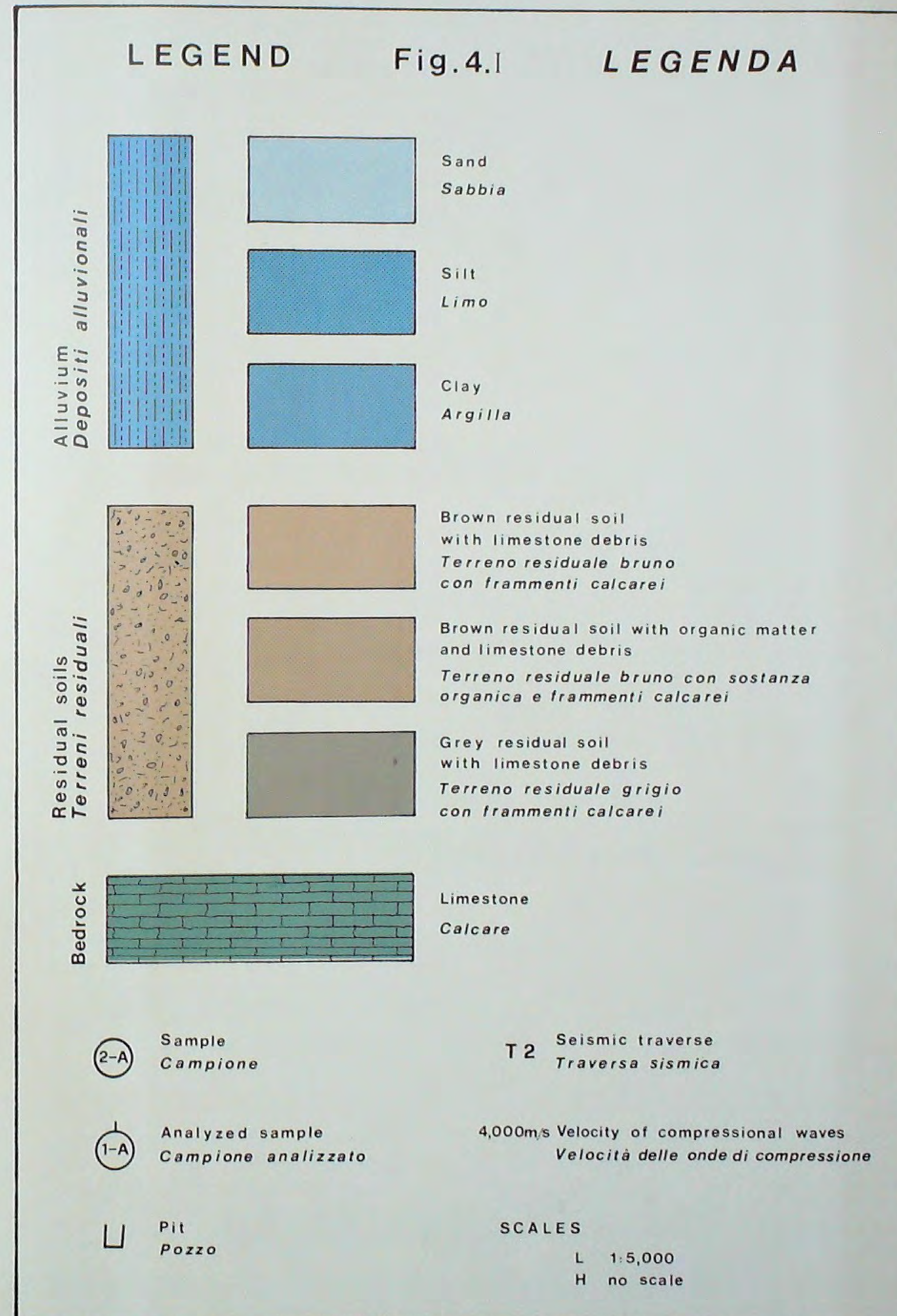


fig. 4.1

BUULO BATUULA GEOLOGICAL SECTION

SEZIONE GEOLOGICA DI BUULO BATUULA

any organic matter and the limestone fragements or calcite concretions are larger and more frequent. (See also Fig. 4.I)

In no case was penetration resistance of less than 3 kg/cm^2 measured, while cohesion varies from 0.3 to 0.8 kg/cm^2. The residual soil ranges in size from silty clay to silty and sandy gravel. The finest samples come from the dark-coloured upper horizon and the coarser ones from the grey lower one.

The profile of Test Pit 6 in the alluvium shows an alternation of sands and silts, with water at a depth of 2.6 m. As is apparent from the geological profile, this fact indicates that the alluvials are permeable and are fed from the Juba. The alluvials are more permeable than the residual soils, because the water table was not found in Test Pit 5. The particle-size distribution of the three samples of alluvium show them to consist of alternations of silty sand and silty clay. Penetration resistance is greatest in the silty horizons (over 5 kg/cm^2) and lowest in the sandy ones (over 2.2 kg/cm^2); cohesion is also greater in the silty horizons (0.5 kg/cm^2), being negligible in the sandy ones (0.05 kg/cm^2).

ANNEX 1

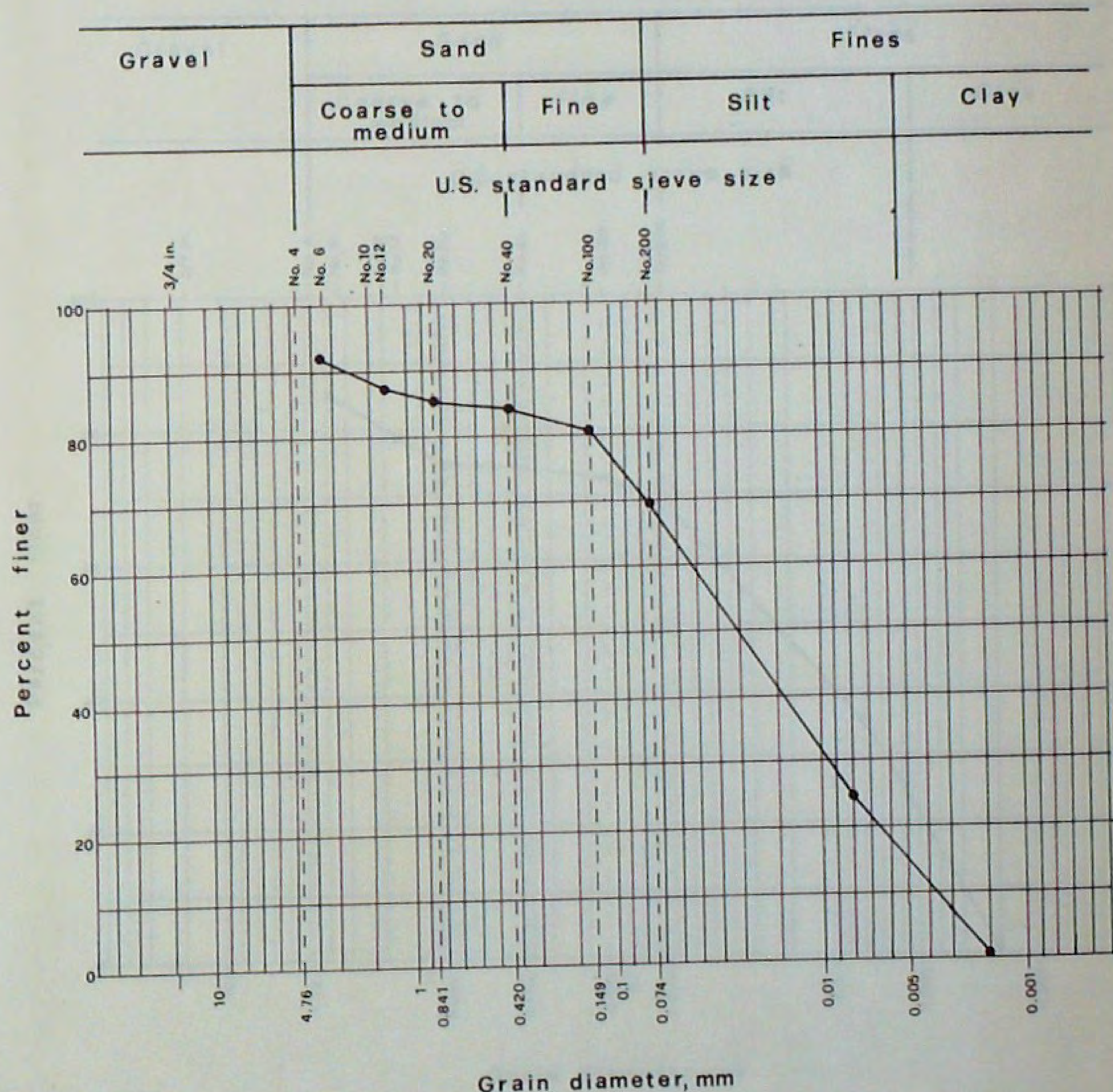
LABORATORY TESTS

Boring N° 1 Sample N° A

Description of soil RESIDUAL SOIL Depth of sample m 1.00

Date of testing JAN. 15th 1976

TECHNITAL S.p.A.



Visual soil description GREY RESIDUAL SILTY SAND SOIL WITH LIMESTONE DEBRIS

Soil clssification SANDY SILT

SAAKOW AREA – PIT SAMPLE TEST
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

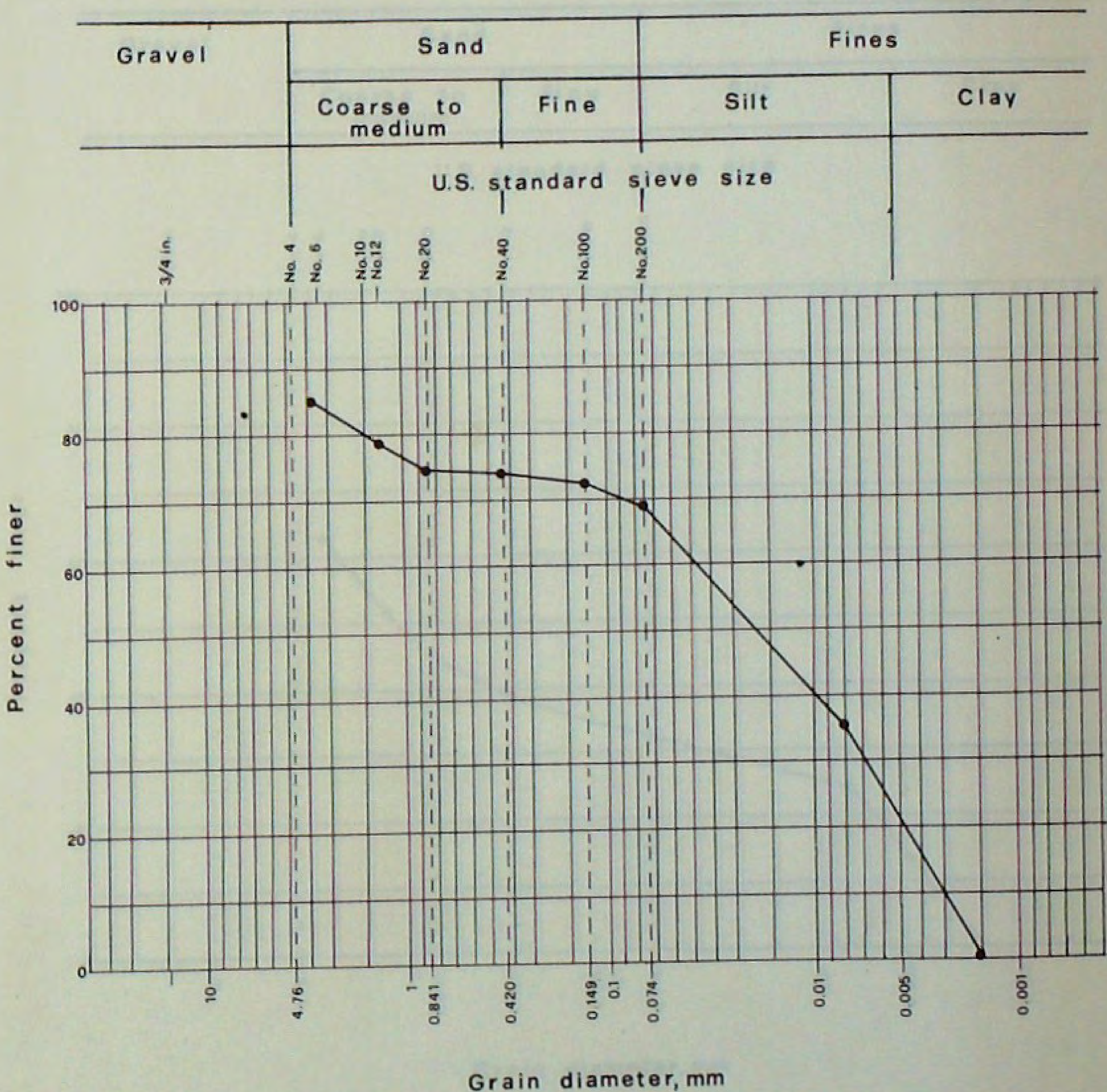
fig. 1.A1

Boring N° 2 Sample N° B

Description of soil BROWN RESIDUAL SOIL Depth of sample m 4.00

Date of testing JAN. 15th 1976

TECHNITAL S.p.A.



Visual soil description BROWN SILTY SOIL LIMESTONE DEBRIS

Soil clssification SANDY SILT

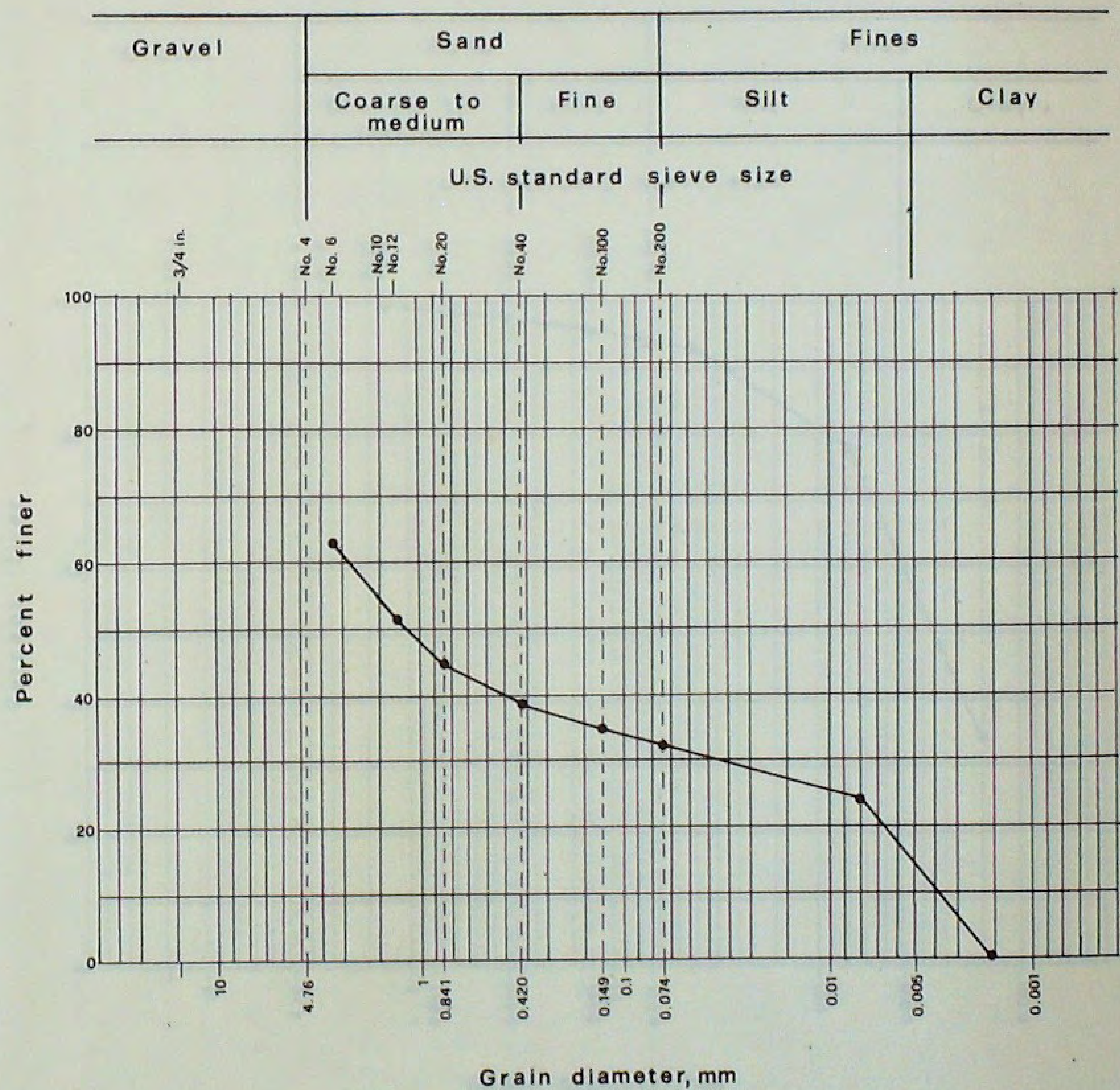
SAAKOW AREA – PIT SAMPLE TEST
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. 2.A1

Boring N° 3 Sample N° B

Description of soil RESIDUAL SOIL Depth of sample m 1.80

Date of testing JAN. 9th 1976



Visual soil description GRAY RESIDUAL SILTY SAND SOIL WITH LIMESTONE DEBRIS

Soil clssification SILTY & SANDY GRAVEL

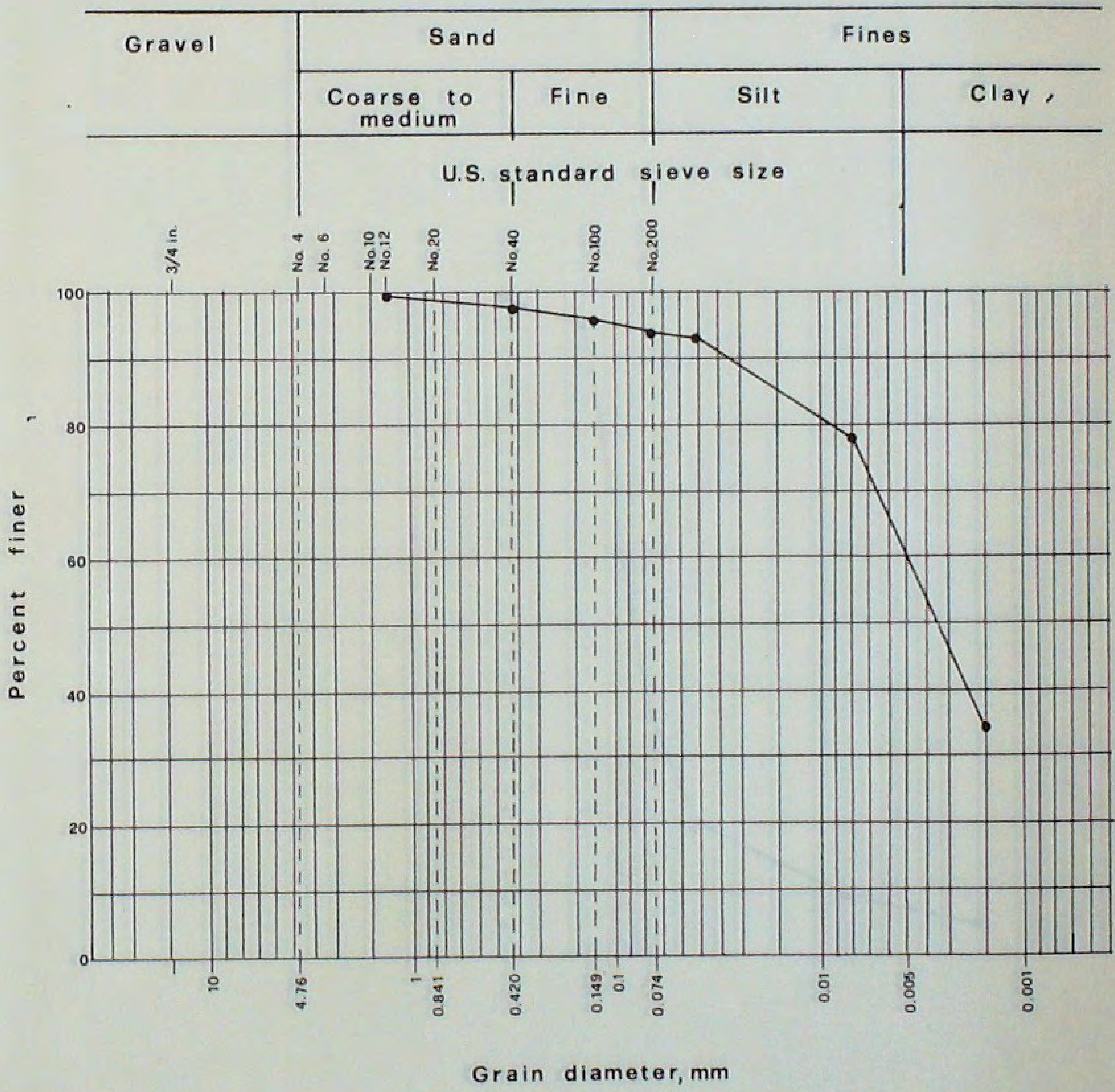
SAAKOW AREA – PIT SAMPLE TEST
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. 3.A1

Boring N° 4 Sample N° B

Description of soil RESIDUAL SOIL Depth of sample m 4.00

Date of testing JAN. 9th 1976



Visual soil description GREY SILTY SOIL WITH LIMESTONE DEBRIS

Soil clssification SILTY CLAY

SAAKOW AREA – PIT SAMPLE TEST

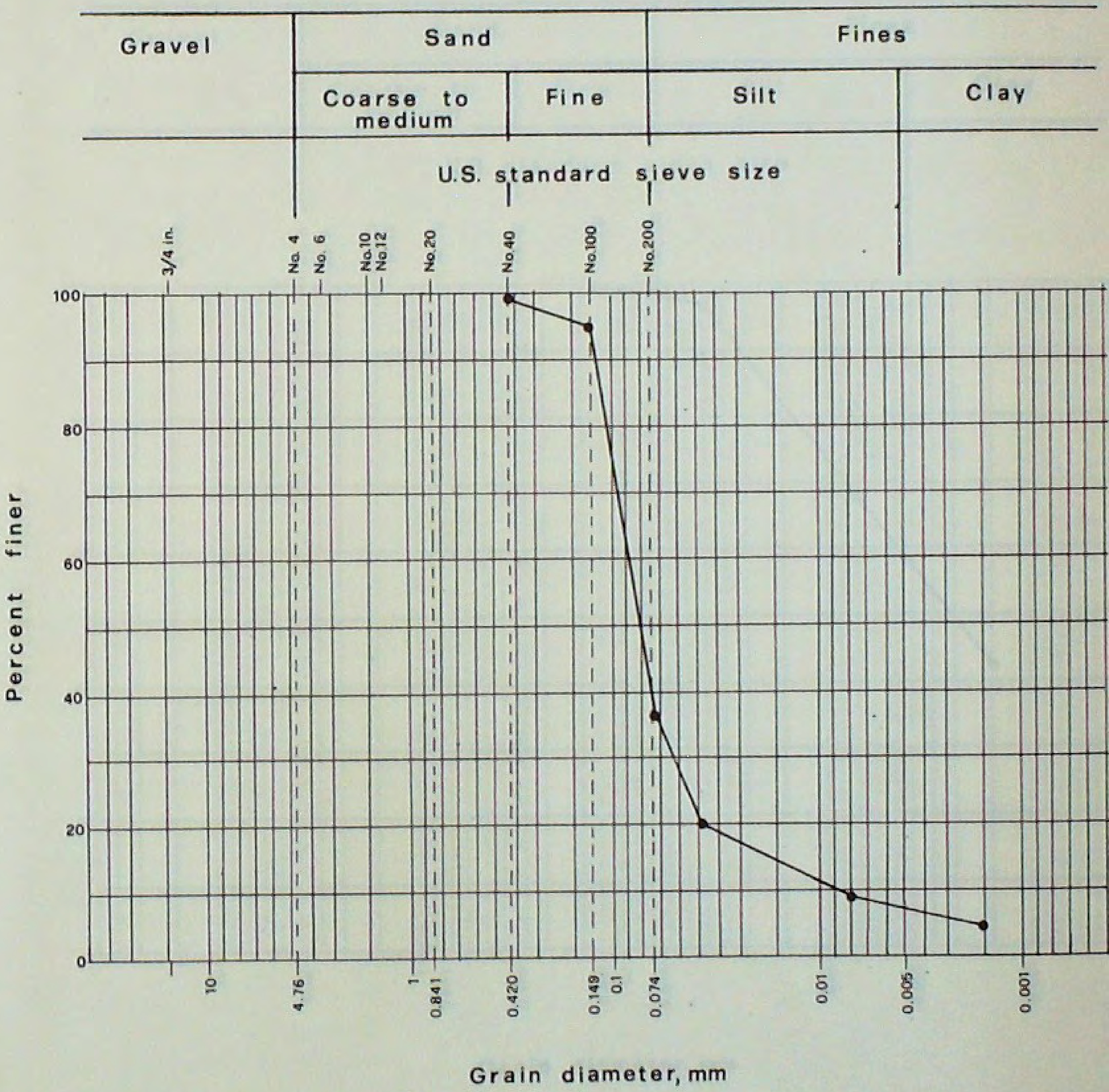
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. 4.A1

Boring N° 6 Sample N° A

Description of soil FLUVIAL SAND Depth of sample m 0.50

Date of testing JAN 14th 1976



Visual soil description FLUVIAL SAND

Soil clssification SILTY SAND

SAAKOW AREA – PIT SAMPLE TEST

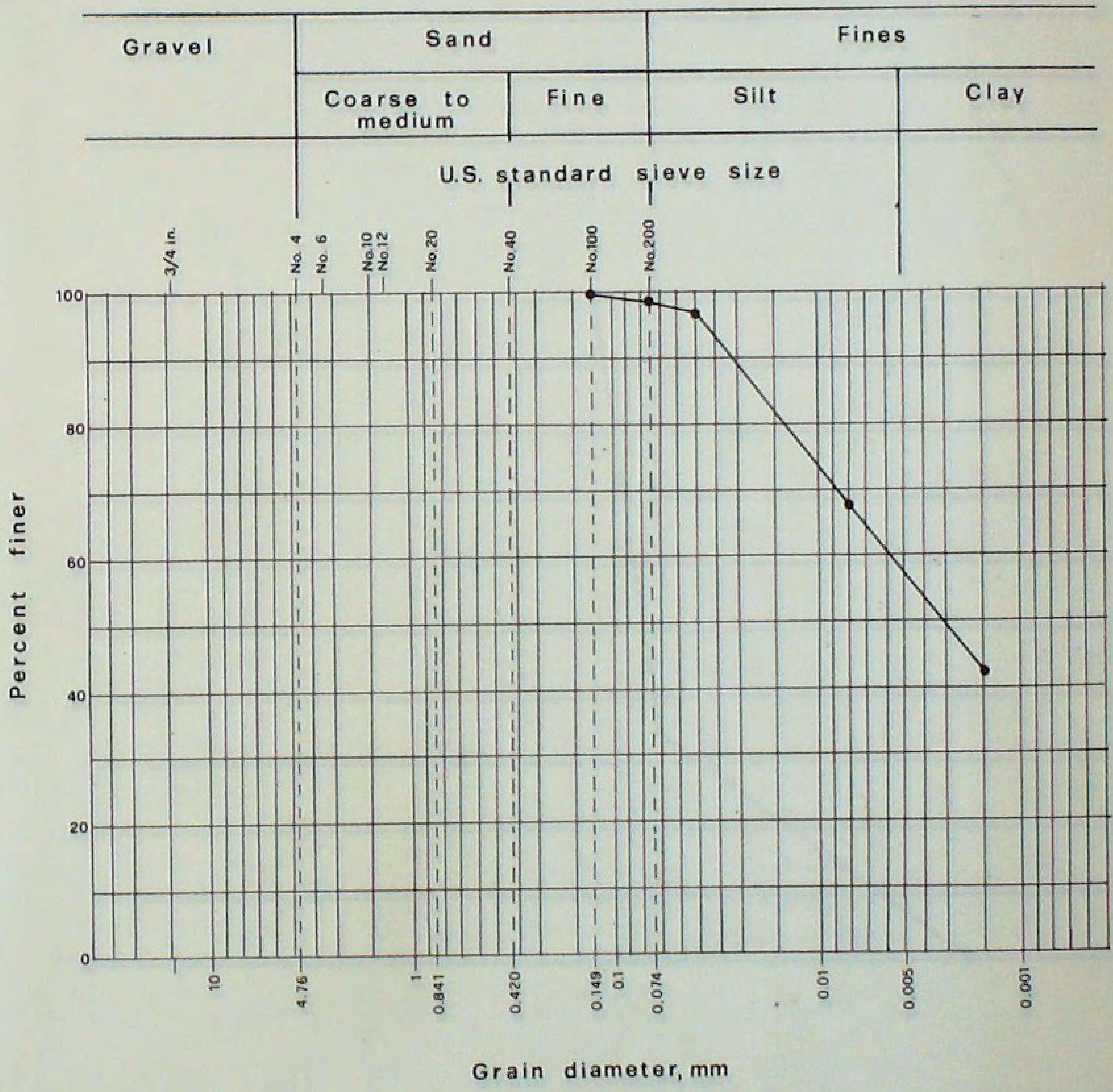
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. **5.A1**

Boring N° 6 Sample N° B

Description of soil FLUVIAL SILT Depth of sample m 0.90

Date of testing JAN. 13th 1976



Visual soil description FLUVIAL SILT

Soil clssification SILTY CLAY

TECHNITAL SpA

SAAKOW AREA – PIT SAMPLE TEST

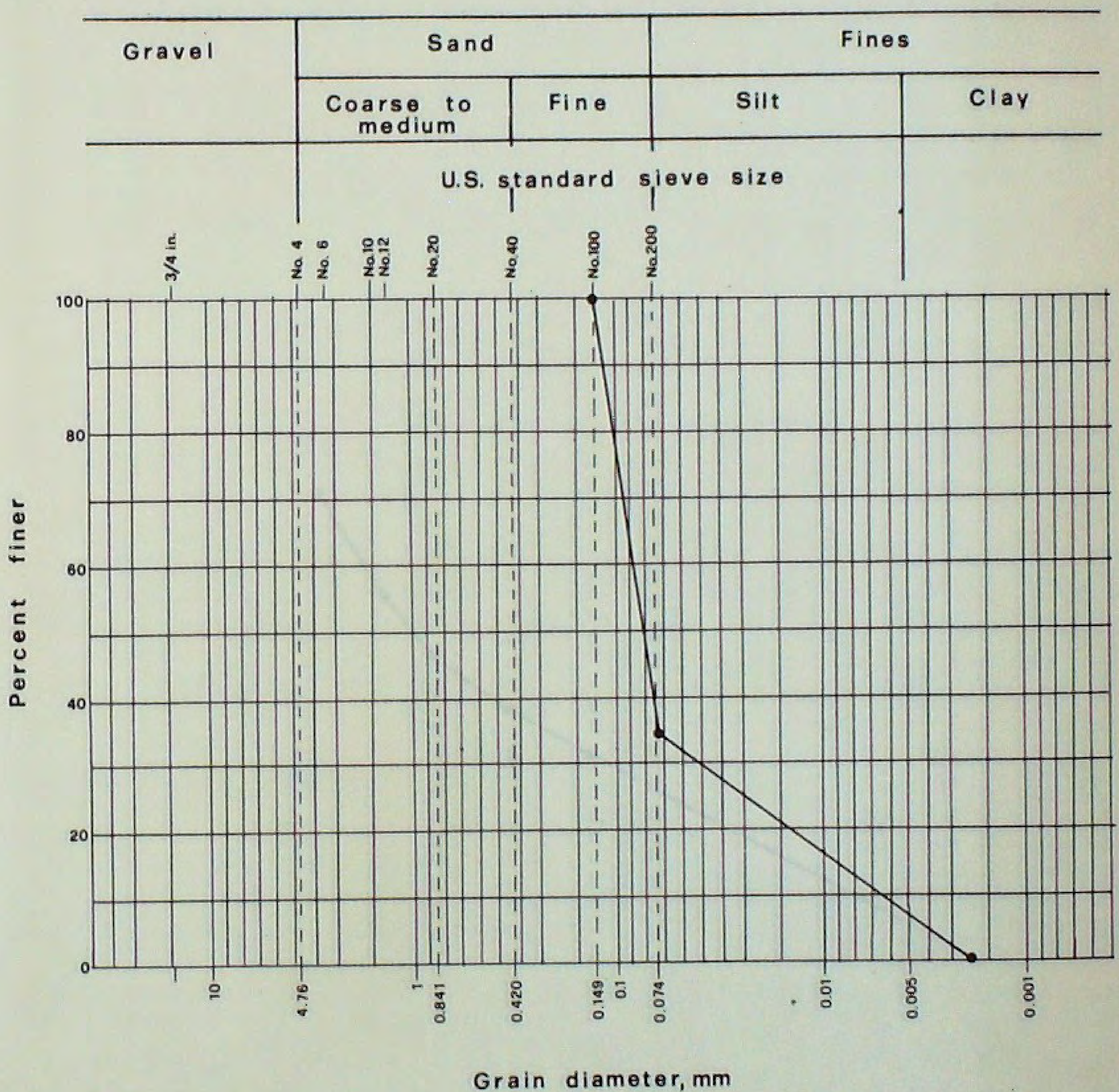
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. 6.A1

Boring N° 6 Sample N° C

Description of soil FLUVIAL SAND Depth of sample m 2.50

Date of testing JAN. 9th 1976



Visual soil description FLUVIAL SAND

Soil clssification SILTY SAND

SAAKOW AREA – PIT SAMPLE TEST

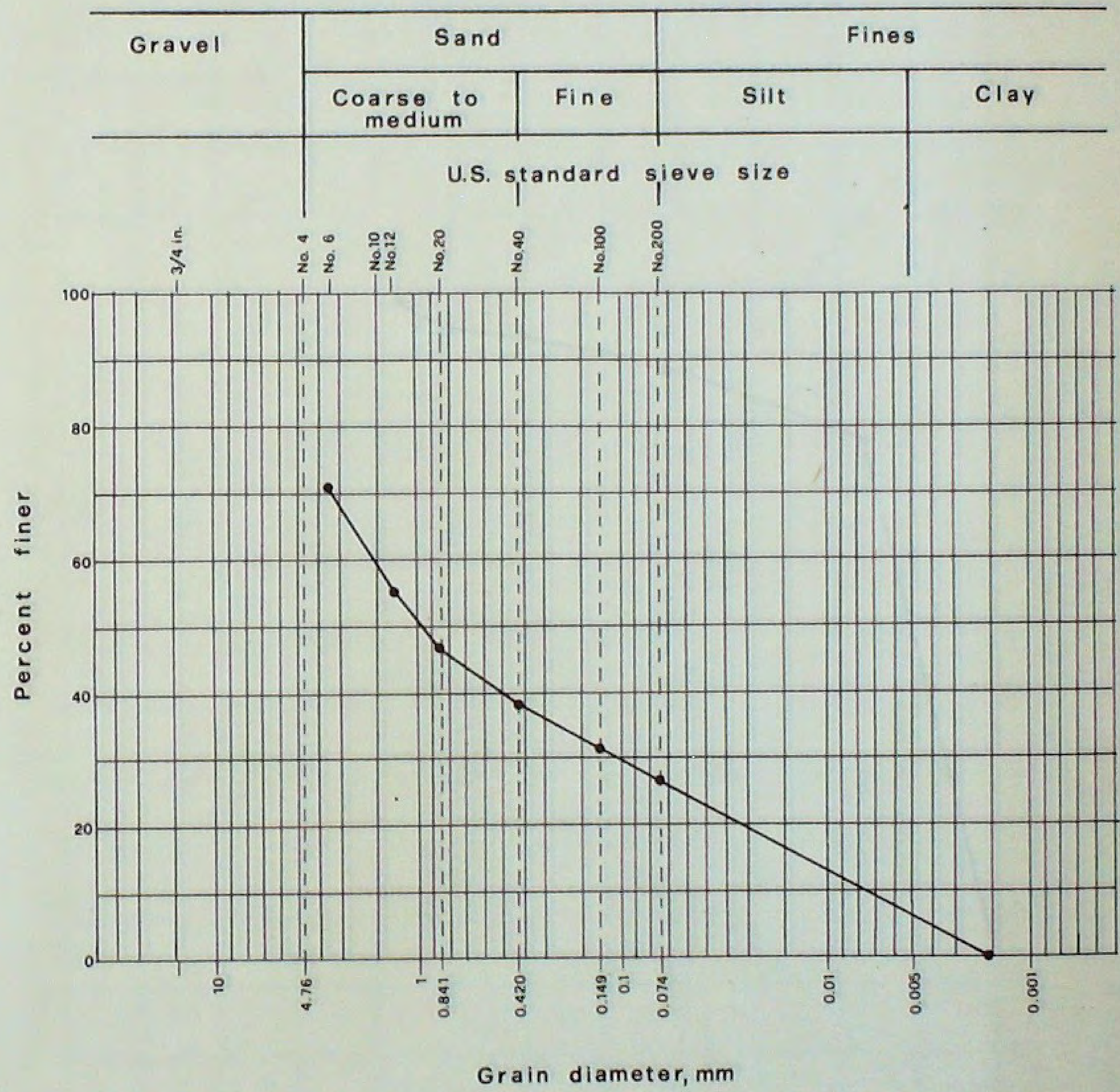
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. 7.A1

Boring N° 8 Sample N° B

Description of soil RESIDUAL SOIL Depth of sample m 3.00

Date of testing JAN. 14[th] 1976



Visual soil description GREY SANDY SOIL WITH LIMESTONE DEBRIS

Soil clssification GRAVELLY & SILTY SAND

SAAKOW AREA – PIT SAMPLE TEST

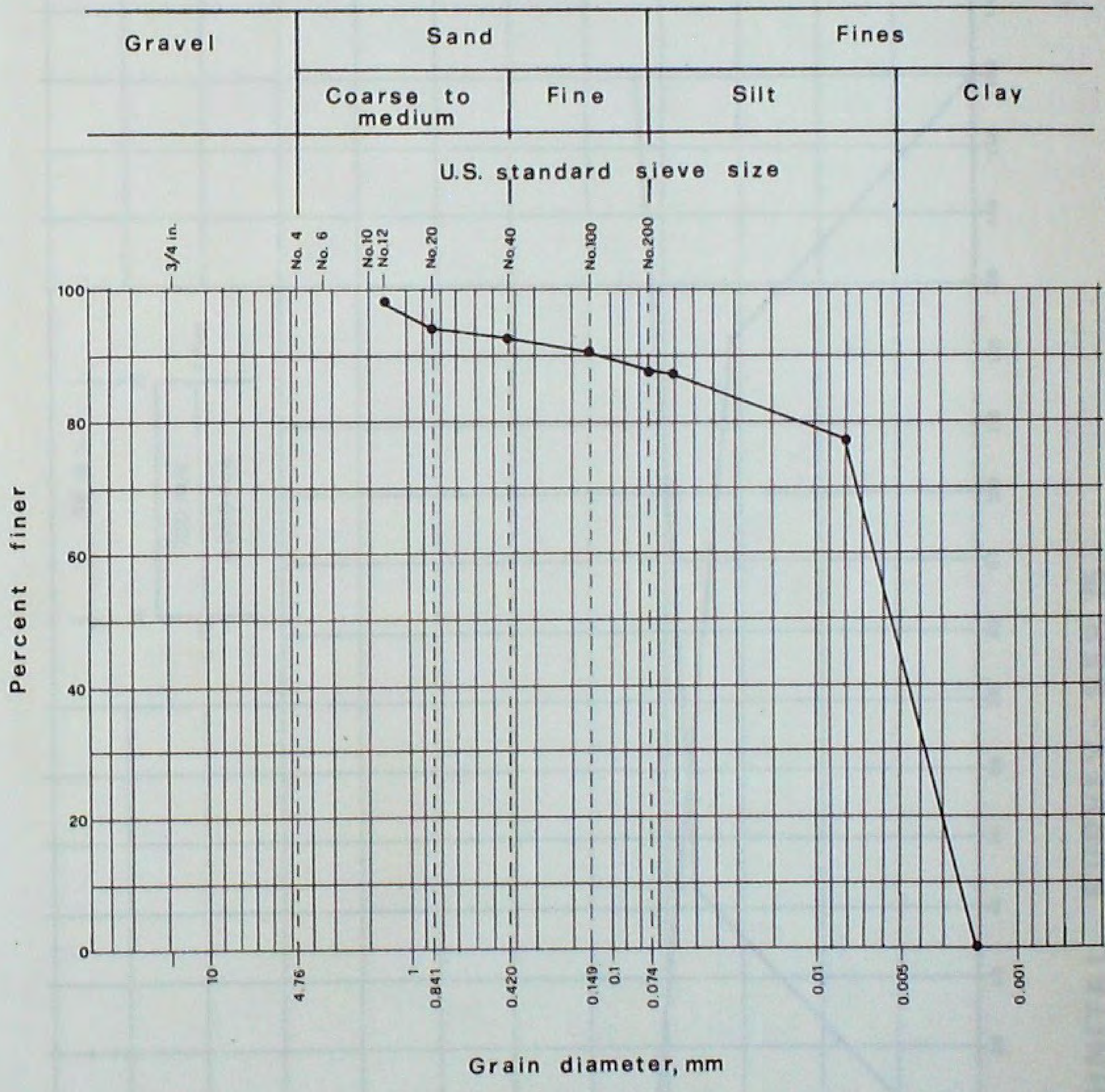
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. **8A1**

Boring N° 10 Sample N° A

Description of soil RESIDUAL SOIL Depth of sample m 1.00

Date of testing JAN. 9th 1976

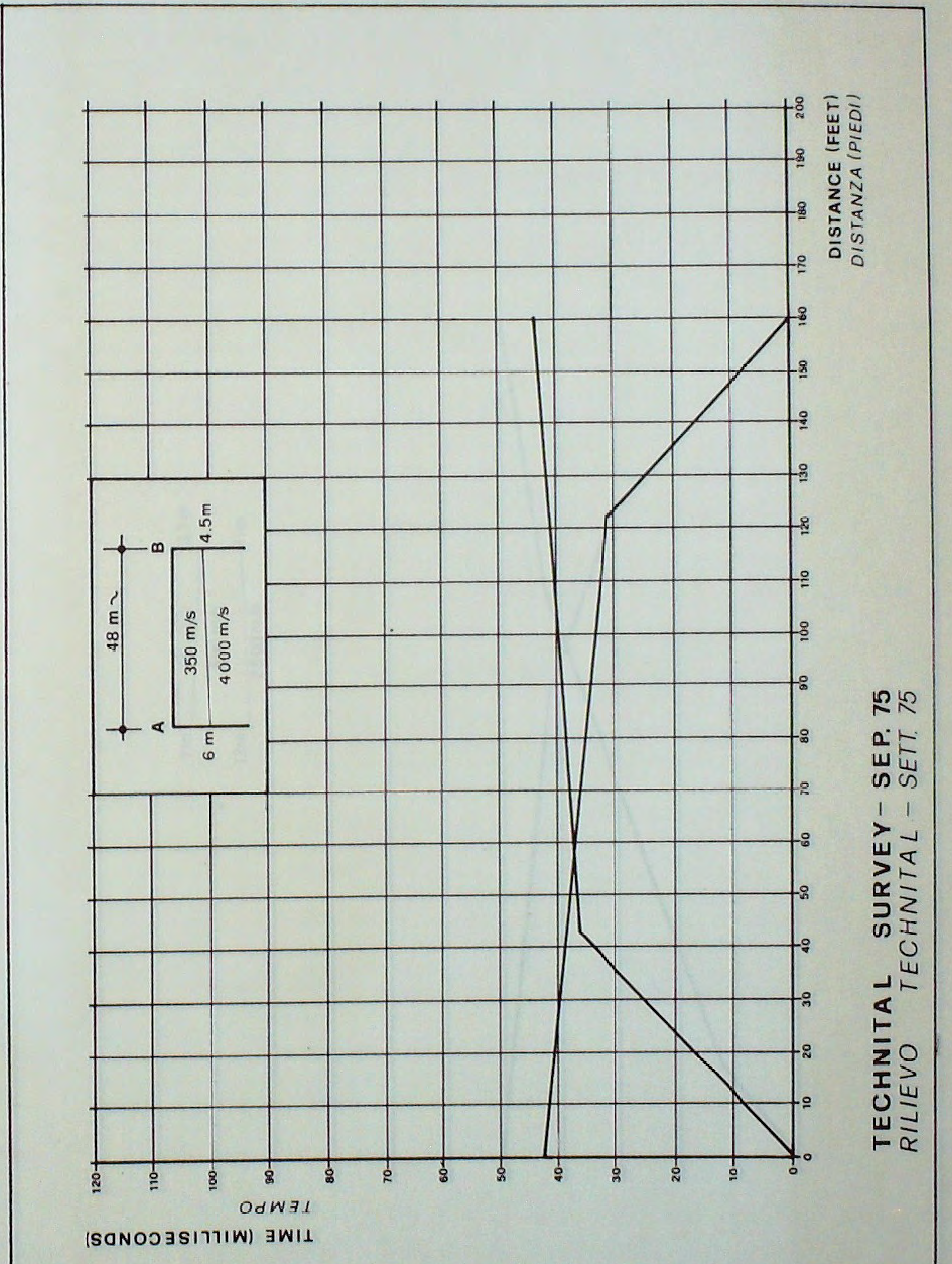


Visual soil description BROWN CLAYEY SOIL

Soil clssification SILTY CLAY

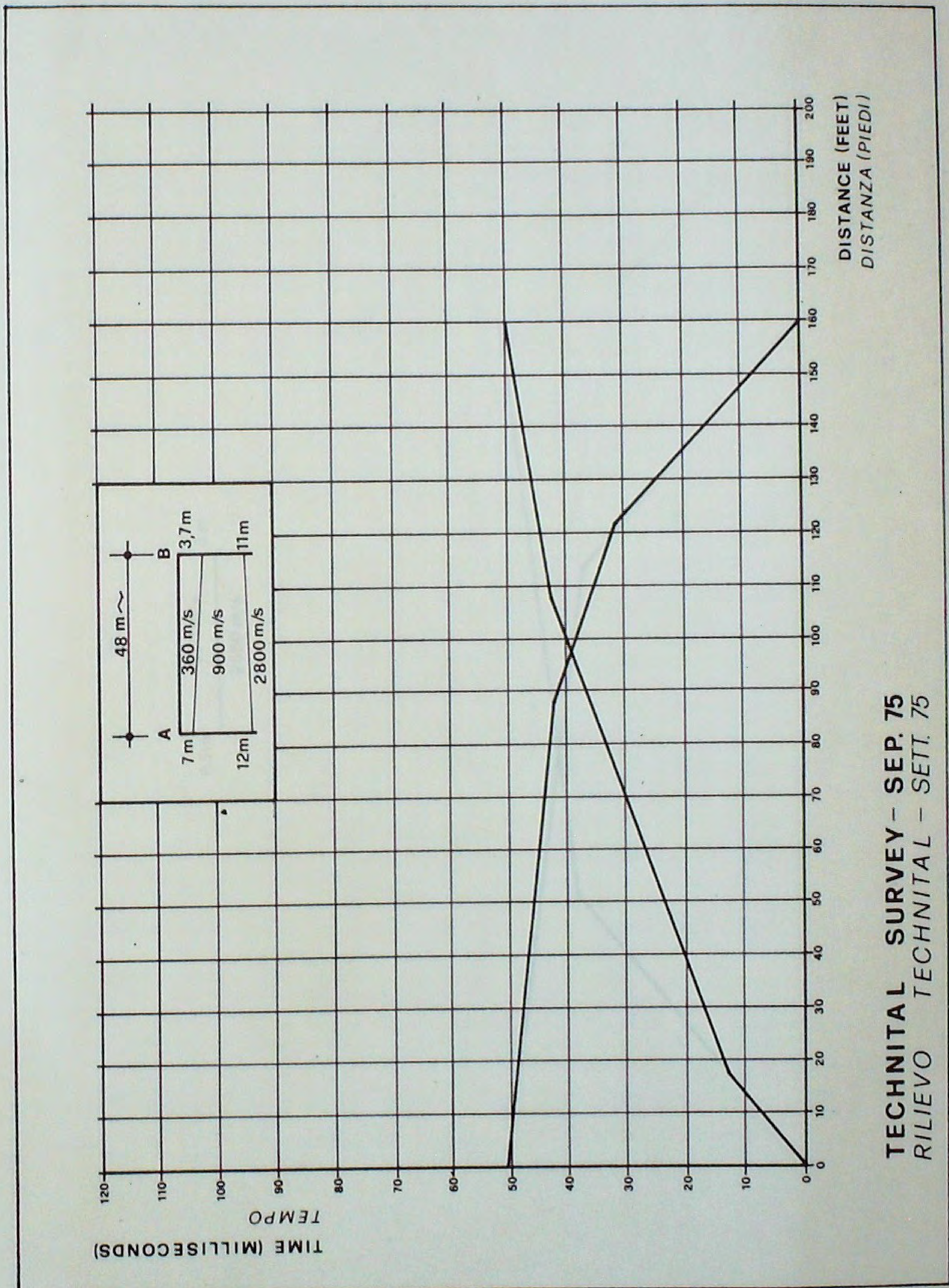
SAAKOW AREA – PIT SAMPLE TEST
ZONA DI SAAKOW – ANALISI GRANULOMETRICHE

fig. 9.A1



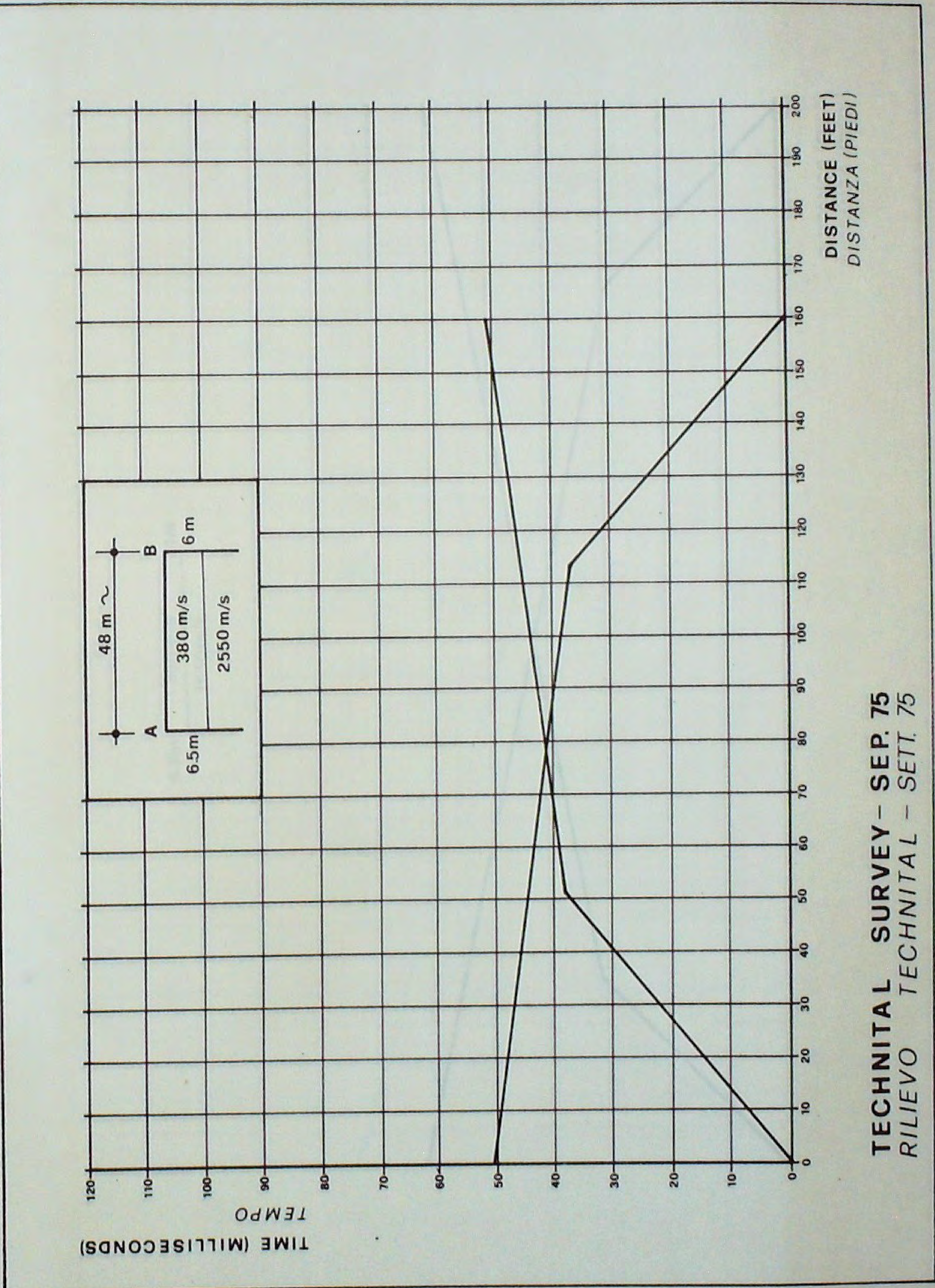
SAAKOW: SEISMIC TRAVERSE 1
SAAKOW: TRAVERSA SISMICA 1

fig.10.A1



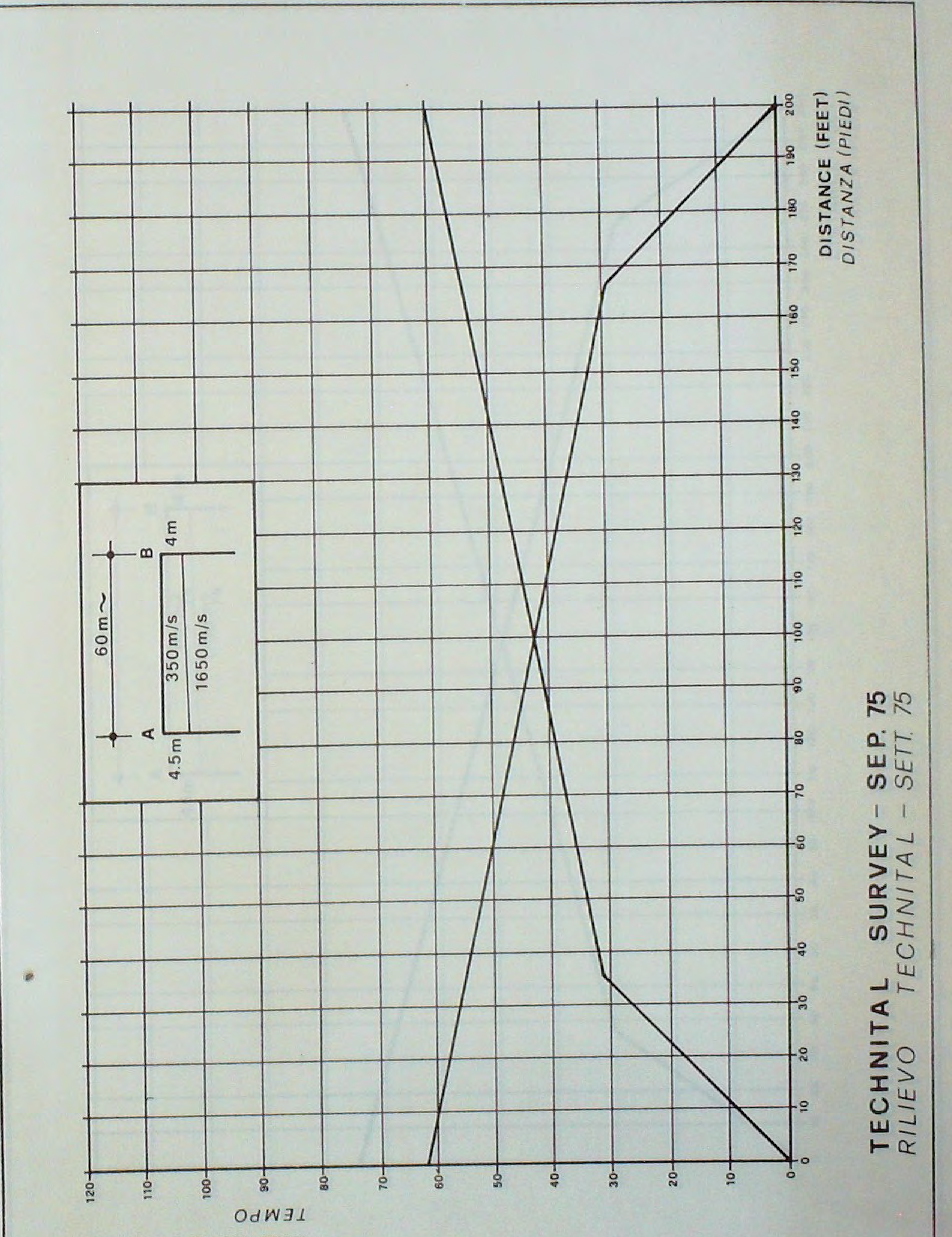
SAAKOW: SEISMIC TRAVERSE 2
SAAKOW: TRAVERSA SISMICA 2

fig.11.A1



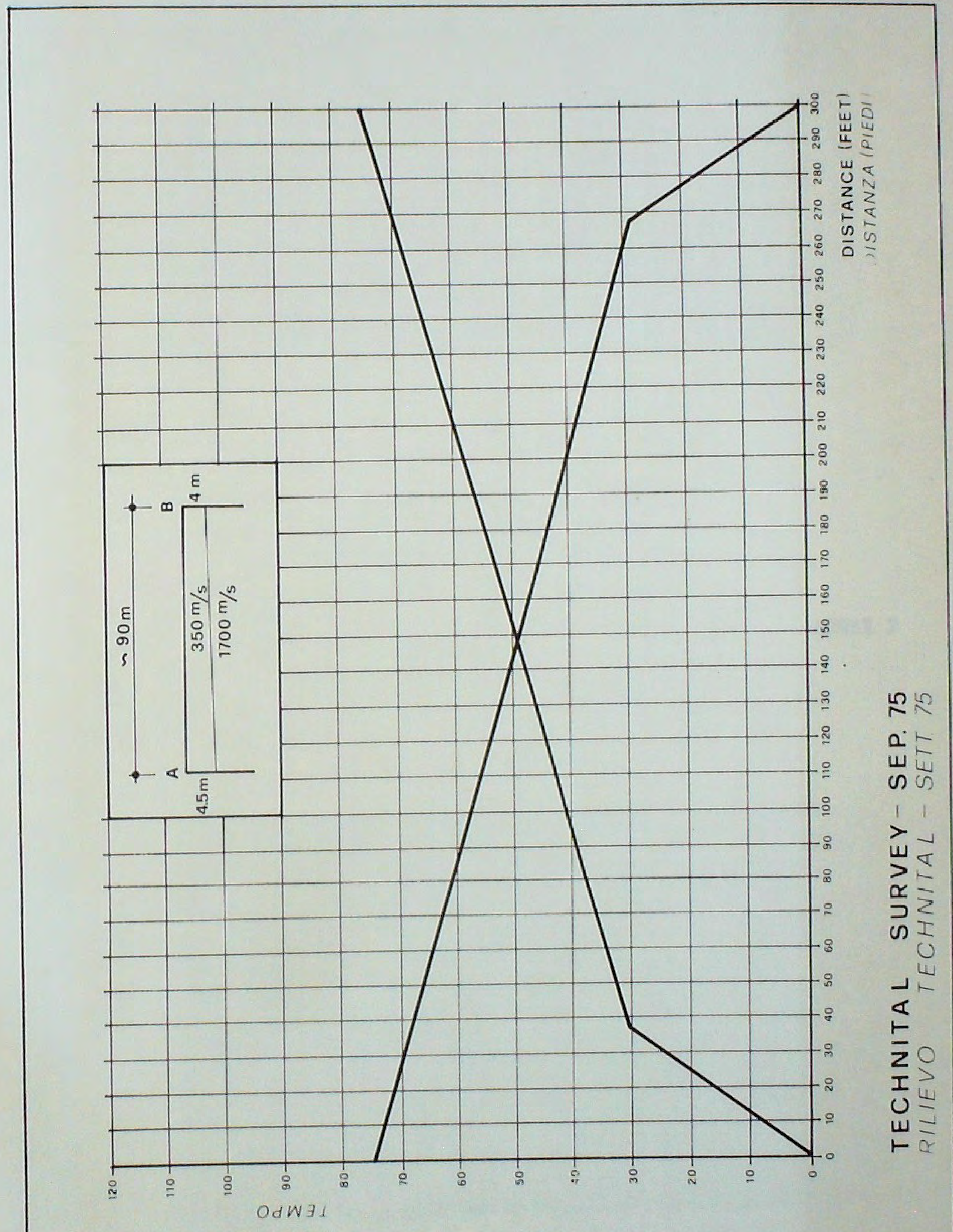
SAAKOW: SEISMIC TRAVERSE 3
SAAKOW: TRAVERSA SISMICA 3

fig. 12.A1



SAAKOW: SEISMIC TRAVERSE 4
SAAKOW: TRAVERSA SISMICA 4

fig.13.A1



SAAKOW: SEISMIC TRAVERSE 5

SAAKOW: TRAVERSA SISMICA 5

fig. **14.A1**

ANNEX 2

PICTURES OF TYPICAL MORPHOLOGICAL FEATURES

Photo 1 — Baardheere Reservoir — Southernmost part of the Juba Valley where the river runs between limestone terraces, seen from the south.
Foto 1 — Bacino di Baardheere — La parte più meridionale della Valle del F. Giuba che corre nei terrazzi calcarei, vista da sud.

Photo 4 — Baardheere Reservoir — Juba Valley at Technital Section 6, seen from the south.
Foto 4 — Bacino di Baardheere — La Valle del F. Giuba all'altezza della sezione Technital 6, vista da sud.

Photo 2 — Baardheere Reservoir — Juba Valley at Technital Section 1 (area in shade), seen from the south.
Foto 2 — Bacino di Baardheere — La Valle del F. Giuba all'altezza della sezione Technital 1 (zona in ombra) e della sezione russa (zona dell'ansa), vista da sud.

Photo 5 — Baardheere Reservoir — Juba Valley at Technital Section 8, showing part of reservoir area, seen from the south.
Foto 5 — Bacino di Baardheere — La Valle del F. Giuba all'altezza della sezione Technital 8 con visione parziale del bacino di invaso, vista da sud.

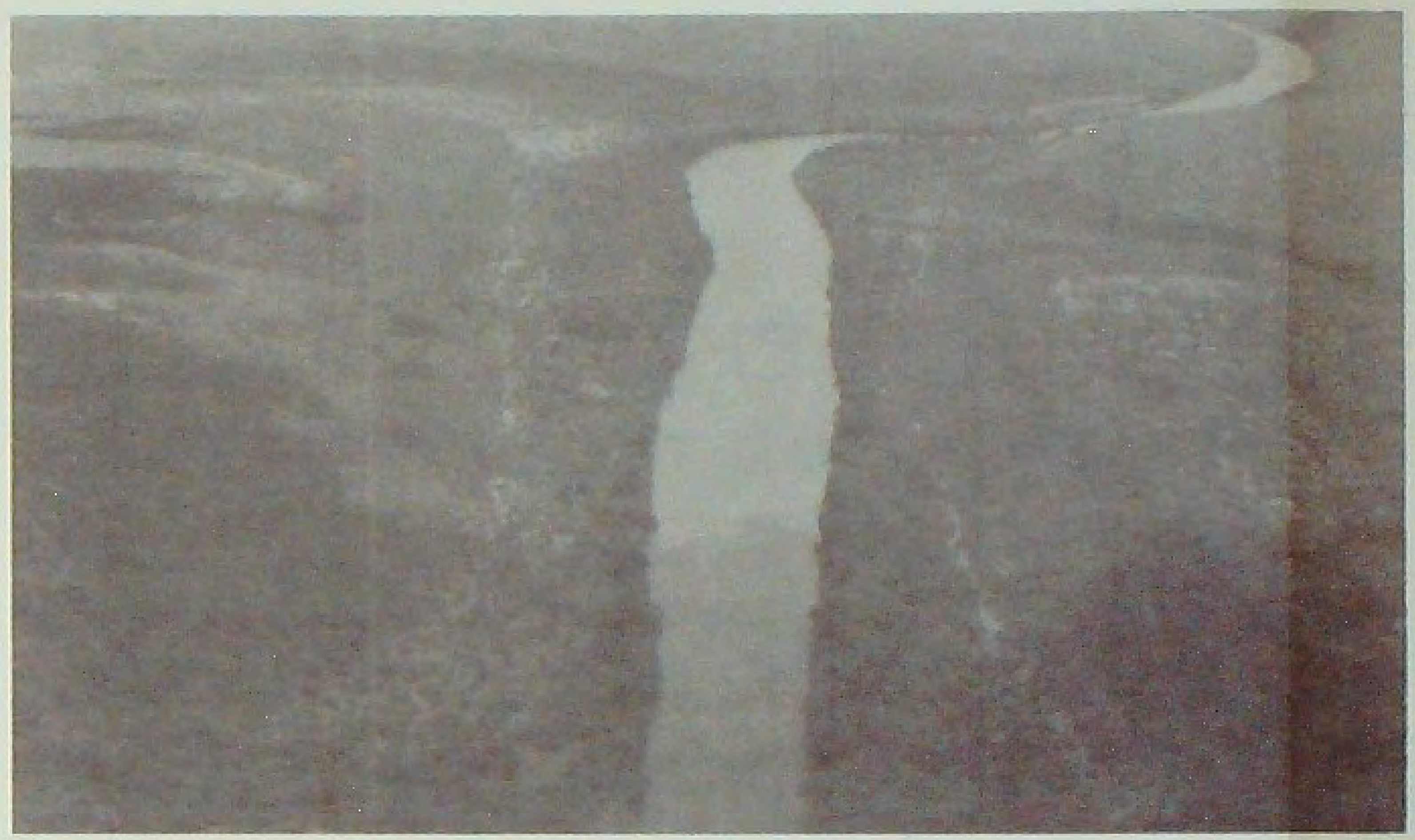


Photo 3 — Baardheere Reservoir — Juba Valley at Technital Section 2, seen from the south.
Foto 3 — Bacino di Baardheere — La valle del F. Giuba all'altezza della sezione Technital 2, vista da sud.

Photo 6 — Baardheere Reservoir — Juba Valley at Technital Section 8, seen from the north.
Foto 6 — Bacino di Baardheere — La Valle del F. Giuba all'altezza della sezione Technital 8, vista da nord.

Photo 7 — Saakow Reservoir — Right-hand side of reservoir at geological section studied.
Foto 7 — Bacino di Saakow — La sponda destra del bacino all'altezza della sezione geologica studiata.

Photo 8 — Saakow Reservoir — Left-hand side of reservoir at geological section studied.
Foto 8 — Bacino di Saakow — La sponda sinistra del bacino all'altezza della sezione geologica studiata.

Photo 9 — Saakow Reservoir — Outcrop of oolitic limestones.
Foto 9 — Bacino di Saakow — Affioramento di calcari oolitici.

Photo 10 — Saakow Reservoir — Strip of unconsolidated residual soil on compact limestones.
Foto 10 — Bacino di Saakow — Fascia di terreno sciolto residuale su calcari compatti.

Photo 11 — Saakow Reservoir — Concentrations of limestone fragments resulting from removal of residual soil matrix.
Foto 11 — Bacino di Saakow — Concentrazioni di frammenti calcarei per asportazione della matrice di terreni residuale.

Photo 12 — Saakow Reservoir — Microdepressions in limestones as a result of dissolution of calcium carbonate by rainwaters.
Foto 12 — Bacino di Saakow — Microdepressioni in calcari per scioglimento ad opera delle acque piovane.

Photo 13 — Saakow Reservoir — Microclints in limestones as a result of dissolution of calcium carbonate by rain-waters.
Foto 13 — Bacino di Saakow — Microcanali in calcari per scioglimento ad opera delle acque piovane.

Photo 16 — Saakow Reservoir — Pit in residual soil.
Foto 16 — Bacino di Saakow — Pozzo in suolo residuale.

Photo 14 — Saakow Reservoir — Alluvium on a tributary of the Juba.
Foto 14 — Bacino di Saakow — Alluvioni lungo un affluente del F. Giuba.

Photo 15 — Saakow Reservoir — Pit in residual soil with lime-stone fragments.
Foto 15 — Bacino di Saakow — Pozzo in suolo residuale con frammenti calcarei.

PART II

HYDROLOGY AND SURFACE WATER RESOURCES OF JUBA RIVER

INTRODUCTION

This Report sets forth the results of a fact-finding survey on the hydrology of the Juba Basin, performed at the planning level. The state of information on surface hydrology is examined first.

By critical analysis and the processing of data gleaned from the literature and from field investigations it has been possible to define certain hydrological characteristics of the river and to make an appraisal of the natural surface water resources.

Special hydrological investigations have been run with regard to the hydraulic projects proposed for development of the water resources.

The limits of water resources use can be defined at the design level by refining and deepening the analyses, but this does not mean that it will be possible to do without new data obtained by means of appropriate direct measurements.

CHAPTER 1.

PHYSIOGRAPHIC AND CLIMATIC FEATURES

1.1 MAIN PHYSIOGRAPHIC FEATURES

The Juba runs for some 800 km through Somali territory from Dolow to the Indian Ocean, maintaining virtually unaltered the hydrographic characteristics developed upstream on the southern slopes of the Ethiopian Plateau. It takes on a precise fluvial physiognomy starting from the confluence of three watercourses - the Webi Gestro, the Jaanale Doria and the Dawa Parma - above Dolow.

The Somali part of the Juba Basin accounts for about one third of the total catchment area. The drainage system here is poorly developed on the whole, the tributaries being seasonal streams. Indeed, these affluents contribute little to the total flow of the Juba, and then only during the flood season. Often the streams peter out in natural depressions, owing to infiltration and evaporation, before ever reaching the Juba.

The course of the Juba in Somalia can be considered in two parts, the more mountainous part from Dolow to about 40 km north of Dujuuma, where the river runs in a well-defined valley with organized drainage, and the alluvial plain part, which goes from there to the mouth, where the river generally runs between levees, forming numerous meanders.

The valley is broad with relatively stable sides and is bounded by hilly reliefs for the first 130 km from Dolow to beyond Luuq. There are two important intermittent tributaries, the Afmadow and the Circolote. Then the valley narrows and for over 170 km the river runs entrenched in rock; the tributaries here are short and their bed-slopes are steep.

The alluvial plain stretches for more than 200 km to the ocean. It is bounded to the west by terraced high ground which runs through the Soia and Afmadow regions, and to the south and east by dune ridges.

On the plain flanking the river are numerous natural depressions ("descecks") which fill with water during the rains and major floods. Some of the depressions return at least some of the water to the river when the levels recede, while others are too low-lying for this to happen. The interchange of water between the river and the descecks occurs either directly or via a kind of canal which follows the line of the main depressions ("far").

The Juba empties into the ocean a few kilometres east of Kismayo, breaching a big ridge of coastal dunes.

The profile of the Juba in Somalia is generally fairly uniform. The bed slope in the upstream part is around 0.3‰, while in the alluvial plain it ranges from 0.1 to 0.2‰.

In the upper course of the Juba there are numerous small islands that are submerged during the floods, while in the plain reach there are two large ones, Touta and Mombasa, the former being some 40 km long.

Towards its mouth the Juba is approached by the Webi Shebeli and the Bohol Magaday on the left-hand side and the Laag Dheere on the right. Normally the waters of the Shebeli are lost in the swampy area behind the coastal dune ridge, but when heavy flooding occurs they reach the Juba via a system of natural channels ("fartas").

Similarly the Bohol Magaday, a temporary river which drains an area of about 14,000 km^2 between the Juba and the Shebeli, runs to waste in system of pools and lakes (Harnaga and Tuculle Lakes), but on occasions the waters pass right through and flood vast areas, arriving in the Juba to the south of Camsuma via the Farta Tuculle.

On the right-hand side of the river, flood waters coming from Kenya are collected by the tributaries of the Laag Dheere and are discharged into the Uamo desceck, without reaching the Juba.

1.2 GENERAL NOTES ON CLIMATE

This is an arid tropical climate with four seasons: two wet (April-June and September-November) and two dry (December-March and June-August). In the mountainous part of the valley the two wet seasons are separated by a well-defined dry season (June-September), but this is not the case on the alluvial plain near the coast.

The seasonal trend of the rains is governed by the monsoon winds. In the first dry season or Gilal the wind blows steadily from north and north-east. Then the direction changes and more moderate winds blow from south and southwest bringing the Gu rains. The rain falls as short, sharp storms and the areal distribution of total precipitation is very uneven. In the following dry season or Hagi there are winds from the south-east and near the coast these bring light rains which connect those of the Gu to those of the Der. In the second wet season or Der, the monsoons again blow from the north-east, but the rains are not as intense as those of the Gu.

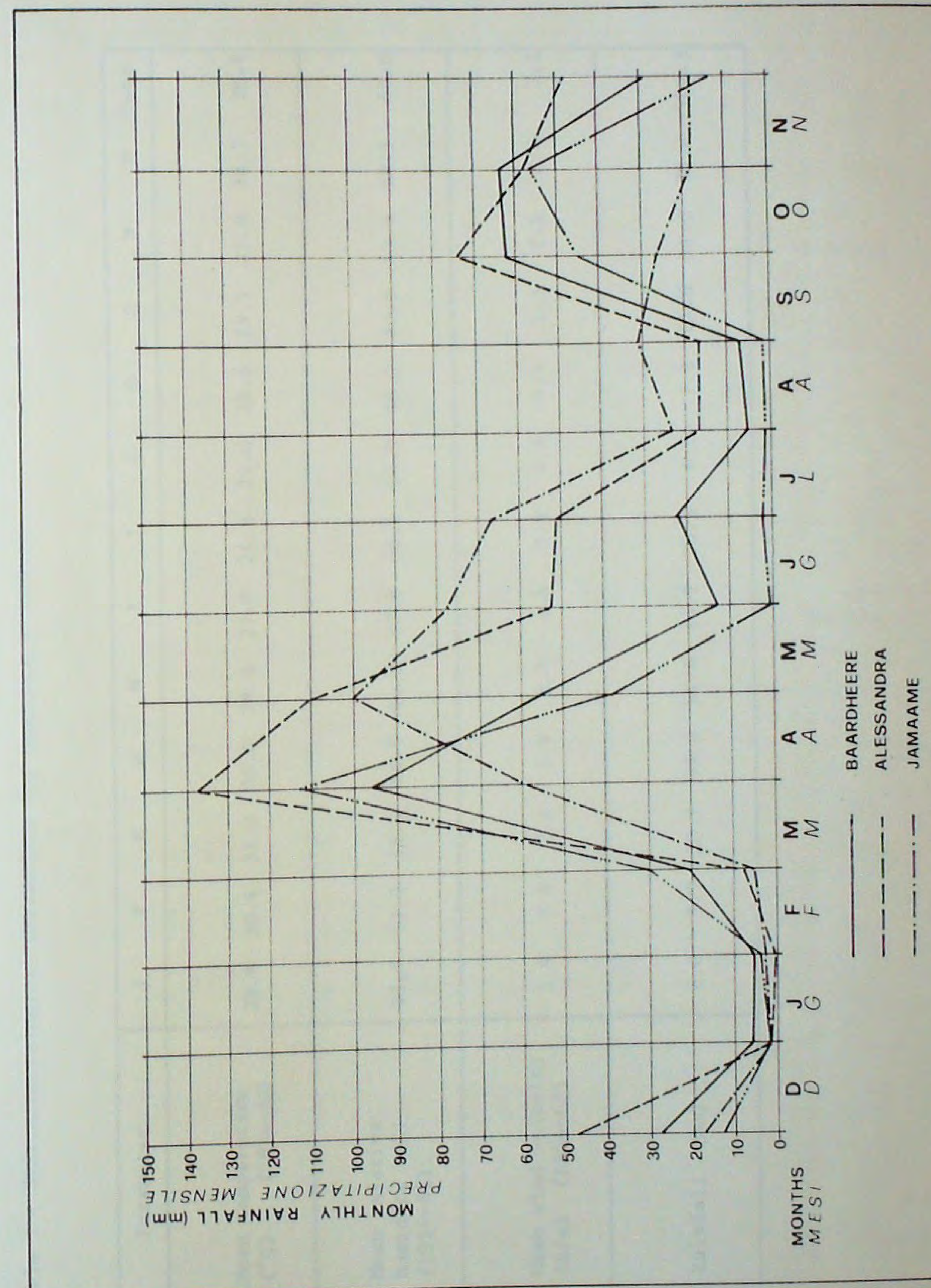
By way of illustration, Fig.1.II shows the rainfall trends at some reference stations considered for the irrigation districts singled out in the study. The stations are Luuq-Gannane, Baardheere, Alessandra and Jamaame.

The mean temperature is fairly constant in the various months of the year, with values fluctuating around 27-28 °C. April is the hottest month and August the coolest. The difference in the mean monthly temperatures does not usually exceed 4-5 °C. The highest temperatures and the biggest temperature ranges occur in the northern part of the basin.

Air humidity is always high, being greatest near the coast and lowest in the northern part of the basin.

Evaporation is also high, owing to the intense solar radiation and the ever-present winds. The few estimates available put the figure at over 2,000 mm/year.

Table 1 reports some hydrometeorological values for Baardheere Station, by way of example.



MONTHLY RAINFALL DIAGRAM
DIAGRAMMA DELLE PRECIPITAZIONI MENSILI

fig.1.II

Table 1 - Hydrometeorological parameters for Baardheere Station

Parameter	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mean temperature (°C) (1954-62)	29.9	30.4	31.3	30.0	28.6	27.8	26.8	27.0	28.6	29.1	27.9	28.7	28.8
Mean relative humidity (%) (1954-62)	53.5	53.3	55.3	61.5	64.8	62.8	66.5	64.0	60.0	60.0	63.5	58.5	60.0
Mean wind velocity (m/s) (1954-62)	3.9	2.8	2.4	1.8	3.2	4.8	3.9	4.6	4.1	2.5	2.5	2.2	3.2
Rainfall (mm)	6.0	5.7	20.7	95.0	54.6	14.2	20.3	6.0	7.1	62.9	64.0	28.4	384.5

CHAPTER 2.

BASIC HYDROGRAPHICAL DATA

2.1 SOURCES OF INFORMATION AND DATA AVAILABLE

Leaving aside new direct measurements, which did not come within the scope of the present study, all the basic hydrographical and hydrological data available were collected. This proved to be no easy task, because of the great dispersion of the sources of information and the recent removal and reorganization of the Hydrology and Flood Control Sections, which were previously under the Ministry of Public Works and now form part of the Ministry of Agriculture. It should also be mentioned that much of the hydrographical documentation mentioned in the literature and which should be on the Ministry of Agriculture or the Ministry of Public Works files, could not be found or was very incomplete.

A. An initial source of information is the FAO Report "Agricultural and Water Surveys in Somalia" (1968). The data of direct interest in this Report concern mainly the monthly streamflows at the Luuq Gannane, Baardheere, Kaitoi and Jamaame Stations (Fig.2.II) for the 1951-1965 period (Annex 1). The data for the 1963-1965 period refer to direct observations, while those for 1951-1962 were obtained indirectly.

Using the flow data collected in 1963-1965, the rating curves were plotted for the four stations and the experimental relationships linking flows at Luuq with those at Baardheere and Jamaame were worked out, as were the relationships linking Jamaame flows with those at Kaitoi.

Flows during the preceding period were derived by taking Luuq Gannane as the reference station, for which a broken period of record is available since 1951, and then transferring the hydrologic information to the other stations downstream by a correlation procedure.

The FAO Report does not give data on flood flows that can be used immediately, but it does indicate the results of short sampling campaigns to ascertain the chemical quality of the Juba waters and the amount of sediment transport.

B. The gauging stations installed during the FAO Project were practically abandoned from 1966 to 1969 and only sporadic discharge data are available for that period. Then at the end of 1969 the Luuq, Baardheere and Jamaame Stations were reactivated by a FAO expert (M.J. Morgan), and the Kaitoi Station was brought back into operation in 1972.

The Ministry of Agriculture's Hydrological Section has made available in manuscript form the daily discharge data covering fragmentary periods of observation from 1966 to 1974 at the Luuq and Baardheere Stations. These provide a second source of information (1).

C. A third source of information is the Selchozpromexport Report "The Juba River Scheme" (1965). This provides, particularly, mean monthly discharge data for the Luuq Gannane Station over the 1951-1964 period. Some of the figures (1963-1964) are from direct observations, while the remainder are derived. It should be noted that the original measurements were those performed by FAO, but in some cases the figures are slightly different from

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(1) It was not possible to obtain the data for the Kaitoi and Jamaame Stations.

those given in the FAO Report. This is because they were obtained by employing a flow scale used by Giprovodhoz for the "State Farms Project", plotted on the basis of a reduced number of FAO measurements; this scale is not identical with that adopted in the final FAO Report (1968).

The streamflow values for the 1951-1962 period were also derived from the series of stage readings available, using the Giprovodhoz flow scale. Hence these too are slightly different from the corresponding figures in the FAO Report.

The Soviet Report also gives some streamflow values for 1963-1964 at the Baardheere Station. As in the case of Luuq they originate from the FAO observations at Baardheere, and again they differ from the corresponding values in the FAO Report because a different flow scale was adopted.

The Soviet Report also presents a series of mean monthly discharges for 1963-1964 at the Kaitoi Station; these stem from stream gauging performed by Giprovodhoz for the State Farms Project.

Table 2 gives the monthly streamflows presented in the FAO and Selchozpromexport Reports for the three stations just mentioned and covering the 1963-1964 period of direct observations. Table 3, instead, compares some characteristics of the complete time series available for Luuq.

The experimental relationships which link flows at Luuq, taken as the reference station, with those observed at Baardheere and Kaitoi, are used for estimating the design values at the latter stations. The transfer of stream-gauging information has not been made for individual flows but simply for the annual values of diverse probability calculated for Luuq. In the procedure, the parameters of the probability distribution of annual streamflow and the seasonal breakdown of annual streamflow, calculated in both cases for Luuq, were held constant at the other stations.

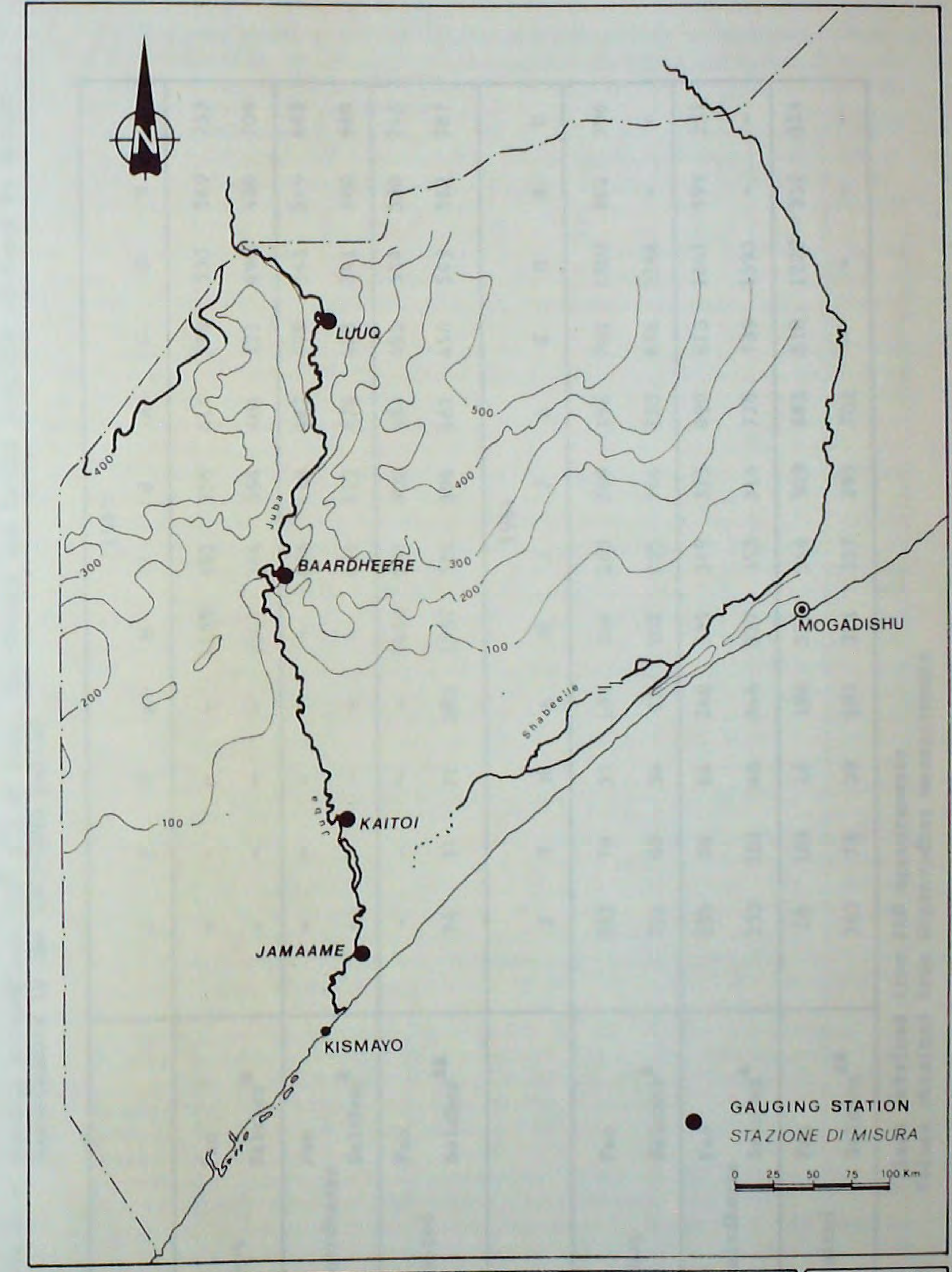
The Selchozpromexport Report also contains some numerical estimates of maximum daily discharges and flood volumes at Luuq Gannane. These data, too, were transferred to Baardheere and Kaitoi using procedures similar to those adopted for the annual streamflows.

As regards the tributaries of the Juba, the only information collected was some on the flood flows of the Bohol Magaday.

Finally, the Report presents the results of some short observations run by Giprovodhoz on the sediment transport situation at Kaitoi and the chemical quality of the waters at Kaitoi and Jamaame, with a few odd measurements at Luuq, Baardheere and Jilib too.

2.2 QUALITY OF DATA USED

The basic data used in this study are drawn from the FAO and Selchozpromexport Reports. It was felt that the data concerning more recent record are unsuitable for immediate use, as a preliminary critical review of their quality performed on cooperation with the Hydrology Section revealed that they may not be entirely representative and homogeneous, especially as far as the method of taking the measurements and processing the initial stage readings is concerned. Then again, these data are very scrappy and hence are unlikely to substantially increase the information content of the ensemble of basic data available from the FAO and Selchozpromexport Reports.



STREAMFLOW GAUGING STATIONS LOCATION
LOCALIZZAZIONE DELLE STAZIONI DI MISURA DEI DEFLUSSI

fig. 2. II

Table 2 - Monthly streamflows (10^6 m^3) at Luuq, Baardheere and Kaitoi Stations obtained by direct measurements in the 1963-1964 period

		1963											
		J	F	M	A	M	J	J	A	S	O	N	D
Luuq	Fao	-	-	-	-	1189	491	356	414	339	530	589	753
	Selchoz*	-	-	-	-	1347	384	354	404	321	496	490	704
Baardheere	Fao	-	-	-	-	-	456	418	482	478	545	549	669
	Selchoz*	-	-	-	-	-	454	412	474	428	541	560	688
Kaitoi	Fao	-	-	-	-	1456	501	400	454	453	514	550	743
	Selchoz**	74	31	31	583	1537	521	396	461	456	549	562	787
		1964											
		J	F	M	A	M	J	J	A	S	O	N	D
Luuq	Fao	221	78	37	103	206	269	269	796	701	1203	802	396
	Selchoz*	214	69	34	97	202	255	264	723	638	1366	-	-
Baardheere	Fao	255	99	64	246	325	349	315	699	615	1041	599	351
	Selchoz*	253	101	48	246	327	353	316	726	736	1393	-	-
Kaitoi	Fao	28	104	44	194	333	344	309	683	618	1229	932	324
	Selchoz**	265	73	39	187	321	337	295	702	-	-	-	-

* Values obtained from FAO measurements
** Values obtained from Giprovodhoz measurements

Table 3 - Characteristics of the time series of annual streamflow data available for Luuq

Parameter \ Variable	Annual streamflow		Minimum monthly streamflow		Maximum monthly streamflow	
	FAO series (°)	SELCHOZ. series (°°)	FAO series (°)	SELCHOZ. series (°°)	FAO series (°)	SELCHOZ. series (°°)
Mean	5.882	6.028	22	21	1.269	1.435
Standard deviation	1.374	1.740	14	14	228	352
Coefficient of variation	23	29	65	66	18	25
Maximum value	8.650	9.692	52	50	1.646	2.074
Minimum value	3.536	3.465	8	7	954	951

(°) 1951 - 1964

(°°) 1951 - 1963

The mean, the standard deviation and the maximum and minimum values are expressed in $m^3 \times 10^6$

For the Luuq Gannane Station there are two series of monthly streamflows for the 1951-1965 period, mostly obtained indirectly from the same original series of stage readings that are discontinuous and not too reliable, according to the bibliographic references.

The differences between the two series of data (Table 3) stem largely from the criteria adopted in interpreting the original stages, differences in the stage-discharge scales used, and differences in the processes for deriving missing data. In other words, there is a large element of subjectivity involved.

It is not possible to express an "a priori" opinion on the two series of figures for Luuq Gannane, because we do not have either the original stream-gauge data used for deriving them or supplementary data of proven reliability.

In the case of the other river gauging stations, except Jamaame for which only a single series of FAO streamflow values is available, the FAO data are presented in a less condensed form and are easier to process further than the Selchozpromexport data. However, the reliability of the reconstruction or synthesis of the flows in the Luuq-Kaitoi reach is limited by the fact that so little is known about the complex interrelationships between surface flows and ground-water circulation here.

Lacking checks and confirmation of an experimental nature, namely further simultaneous observations at the different measuring stations, we can do no more than express our opinion on the two procedures used for the space-wise transfer of hydrological information, basing our analysis on their individual characteristics and the fundamental hypotheses adopted. It is observed, in general, that both procedures are based on experimental relationships, namely on discharge scales and relations between the streamflows of different stations, derived from the results of short periods of observation, during which it has not been possible to explore a wide range of natural situations, especially as far as extreme events are concerned. Both procedures also assume that the hydromorphological features of each measuring section remain stationary for long periods, though this is a somewhat doubtful assumption for watercourses which have large, prolonged floods.

The procedure used in the FAO Project appears more flexible and better suited to represent the variability and dynamic nature of the hydrographic situation of the watercourse. However, in practical terms, the detail produced might well be illusory because of the degree of approximation involved in the initial data and the consequent propagation of errors.

The Selchozpromexport procedure makes wide use of probability concepts whose efficiency seems to be reduced by the small size of the observation samples available.

As regards use of the data in this study, it has been considered advisable to take maximum advantage of the capability of the two methods to produce information on the hydrological characteristics of the river, while bearing in mind the limitations inherent in the data. Thus, where possible, both the FAO and Selchozpromexport series of data have been used, so as to obtain comparative estimates.

The main data used to characterize the hydrological regime and the water resources of the Juba are the monthly streamflows. The month is the shortest period of time used because, for the moment, there were few figures providing a more detailed breakdown and it was not possible to perform such a breakdown with the monthly data available in the literature.

Yet considering the nature of the study and the quality of the data available, the monthly time scale can be taken to be quite adequate. When moving from the planning to the design level, however, it will be necessary to try to carry the investigation to a more detailed level. For instance, in view of the characteristics of the river, 7-day or 10-day data breakdowns would prove acceptable as regards significance and representativeness.

2.3 DEVELOPMENT OF THE STREAM GAUGE OBSERVATIONS

Discussion of the available data and the quality thereof would not be complete without mentioning the advisability of making a thorough revision of all the documentation bearing on river measurements, taking proper account of the actual conditions under which the measurements were made in the various observation periods. This is a job which could well be done by the Somali authorities who have first-hand knowledge of the past history of the gauging stations, duly helped, if necessary, by expatriate experts.

At the same time, steps should be taken to check the operation of the existing gauging stations, rehabilitating them, if necessary, and strengthening the network by setting up new stations on the mainstream at points of special interest, as well as on the major tributaries, such as the Bohol Magaday.

Regarding collection of hydrological data, there appear to be the following shortcomings in the present situation:

1. The continuity of operation of the existing stations leaves something to be desired, as do the methods used; this may explain the inconsistencies encountered in the data collected.

2. The quality of the data is adversely affected by the lack of systematic checks on the hydromorphological and hydraulic characteristics of the measuring sections, e.g. stage-discharge scales established more than ten years ago are still being used at some stations without ever having been checked in the interim.

3. No measurements are made of sediment transport or bed-load or of water quality.

4. There is a lack of skilled staff to supervise operations in the field and to service the stations.

The possibility of improving knowledge on the hydrology and water resources of the Juba depends largely on the performance of new systematic measurements on a sufficiently extensive network of stations, which can benefit from the experience acquired to date. Consequently, the Hydrological Service will have to be strengthened from the organizational aspect (skilled staff, instruments and transport) and provided with more funds.

While on this subject it would not be out of place to say a word on the dispersion of responsibility for the measurement of hydrological elements: rainfall and other climatic factors are the responsibility of the Ministry of Communications; surface waters the responsibility of the Hydrological Section of the Ministry of Agriculture; groundwaters the responsibility

of the Ministry of Mineral Resources and the Water Board; abstraction of water for irrigation use the responsibility of the Irrigation Section of the Ministry of Agriculture; and so on. For planning the development of water resources it is obvious that close operational coordination must be ensured among the Services responsible for measuring hydrological elements, and perhaps it would be as well to reunify them under one single Administration.

CHAPTER 3.

CHARACTERISTICS OF JUBA STREAMFLOW

3.1 VARIABILITY OF ANNUAL STREAMFLOW

Turning now to the quantitative estimates, the time series of annual streamflow in the 1951-1965 period at the Luuq Gannane, Baardheere, Kaitoi and Jamaame Stations are given in Fig.3.II (a, b, c and d). The data are derived from the FAO Report. The same series of annual streamflows for Luuq, taken from the Selchozpromexport Report is shown in Fig.3e.II. The arithmetical mean is also indicated in the diagrams, while for the FAO series for Luuq, Baardheere and Kaitoi, the estimates of mean annual streamflow according to the Selchozpromexport Project are included as well.

The variability characteristics of annual streamflow are given in Table 4, which indicates the arithmetic mean, the standard deviation and the coefficient of variation, calculated on the available time series.

Judging from the FAO data the annual streamflow characteristics of the Juba are much the same throughout its length, the year-to-year variability being limited. In particular, it is observed that between Luuq and Baardheere there is a decrease in mean annual streamflow of over 6%, accompanied by a similar decrease in variability. This is attributable mainly to a reduction of the highest annual values in this reach. From Baardheere to Kaitoi the mean annual streamflow increases by 12%, while variability rises slightly. Analysis of the figures indicates a general increase in streamflow in all the wet years. Mean annual streamflow falls by about 14% between Kaitoi and Jamaame, while year-to-year variability reaches the lowest value encountered. The decrease in streamflow is general for all the years, be they dry or wet.

Comparison of the foregoing assessments with the estimates given in the Selchozpromexport Report reveals certain differences, some quite marked. Though the mean value of the series of annual streamflows at Luuq Gannane (Fig.3e.II; Table 4) is near that of the FAO data (2% higher), the year-to-year variability is much more marked, as can be seen also from the magnitude of the range of variation.

The procedure followed in the spatial extrapolation of the streamflow data hinges around the assumption that the mean annual streamflow increases gradually towards the mouth, while in point of fact, from Luuq to Baardheere it increases by 14% and from Baardheere to Kaitoi by over 2%. It thus ensues that for the Baardheere and Kaitoi the Russian mean annual streamflow estimates are 24% and 13% respectively higher than the FAO figures.

It is observed that, on the whole, in the Luuq and Kaitoi reach, where comparison is possible, the mean annual streamflow increases by about 5% according to FAO data and by about 16% according to Selchozpromexport data.

3.2 VARIABILITY OF MONTHLY STREAMFLOW

Taking the investigation now to the monthly level, using the FAO data, the variability characteristics of monthly streamflow have been calculated: the mean $\overline{m}$, the standard deviation $\overline{s}$, the coefficient of variation CV and the maximum and minimum values. The values of these parameters are set forth in Table 5, while the trend of the first three is indicated in Fig.4.II (a, b, c and d). The distribution of streamflow over the year is seen to be irregular. This is attributable to the feed conditions and the formation of runoff. The Juba is essentially fed by rainfalls on the southern slopes of the Ethiopian Plateau. There are two flood periods, which faithfully reflect the meteorological events in the area.

The first flood period is in April-May and is connected with the Gu rains. This is short and very variable. The second period is in August-November and is connected with the Der rains. This is longer and less variable than the first. Between the two flood periods, namely in June and July, the streamflow remains quite high, while the low-flow season is that which precedes the first flood period, minimum flows occurring in February-March.

The variability of streamflow values in each month is generally inversely related to the mean size of the streamflow. It attains exceptionally high values in March, because floods associated with premature Gu rains sometimes occur on the plateau in this normally dry month.

Further clarification on the distribution and variability of monthly streamflow is provided by Fig.5.II (a, b, c and d), where the range of variation of streamflow for each month is shown. It will be noted that the sequences of minimum and maximum values observed indicate two "artificial" years, one very wet, the other very dry, which constitute extreme cases because of the systematic way events of the same type occur in all the months. Of course, the annual streamflow values of the two artificial years are respectively much lower than the driest year observed and much greater than the wettest year on record.

It is interesting to note that the value of the streamflow for the artificially wet year decreases passing from Luuq to Baardheere and then increases between there and Kaitoi, after which it again decreases towards Jamaame, while the value of the streamflow for the artificially dry year increases progressively between Luuq and Kaitoi and then decreases from there to Jamaame.

A number of points on the trend of streamflow down the river (at the monthly level) and on the probable relations between the watercourse and groundwater circulation emerge from a comparative examination of the mean, maximum and minimum streamflow data.

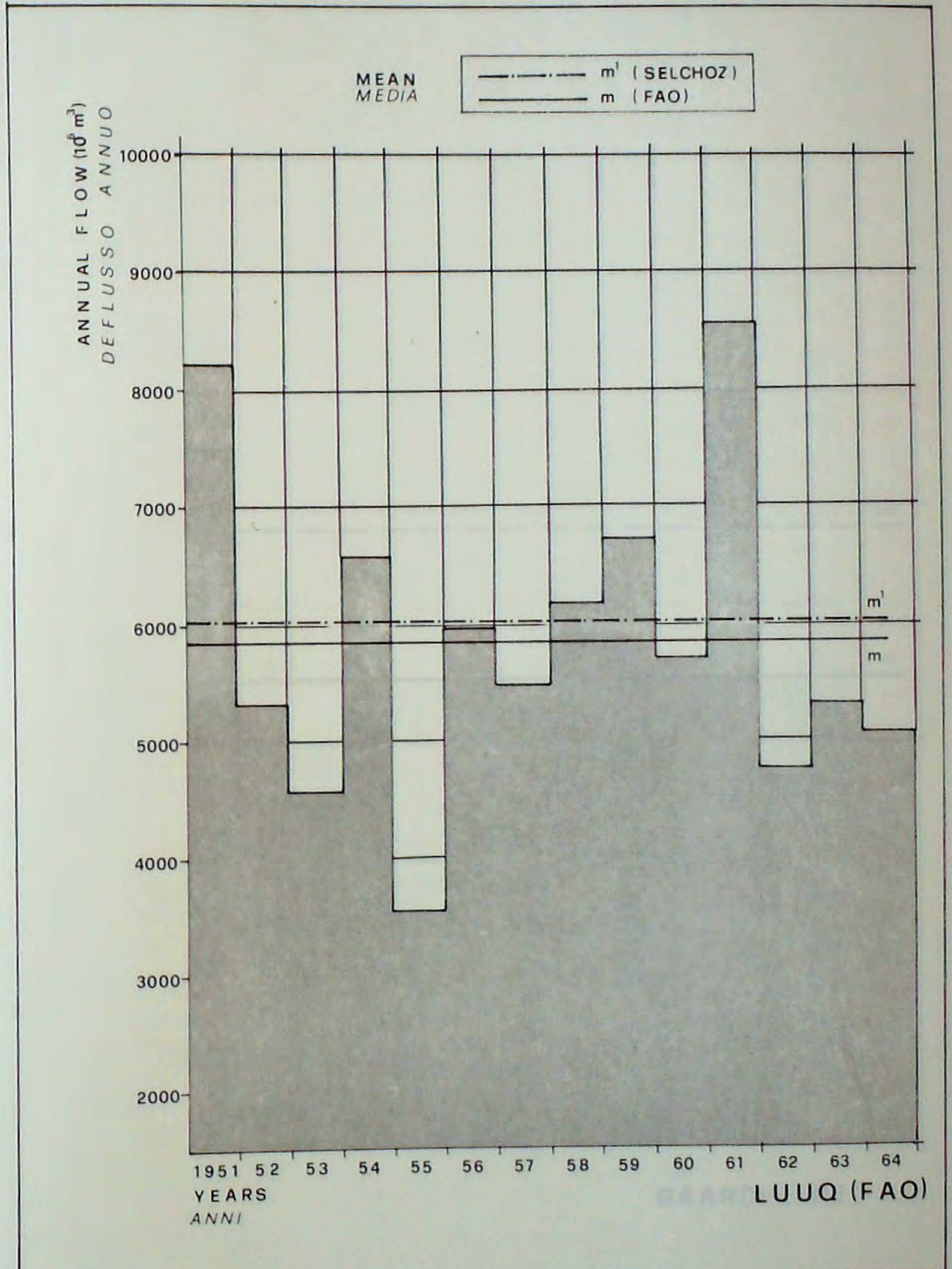
The typical bimodal diagram of the monthly flows is present along the whole course of the river, though it may be modified in various reaches depending on the proportion of surface and subsurface flow, the storage capacity of the channel and the inflows and outflows of water via tributaries and natural spillways, at various times of the year.

At the start of its Somali course the bimodal nature of the Juba flow is very marked, being closely linked to runoff from rainfall on the nearby heights. This character tends to become generally less pronounced towards the mouth under the influence of the river's natural regulating capabilities.

The Juba receives water from its Somali tributaries only during the flood seasons, and the quantity received even then is not great compared with the total streamflow.

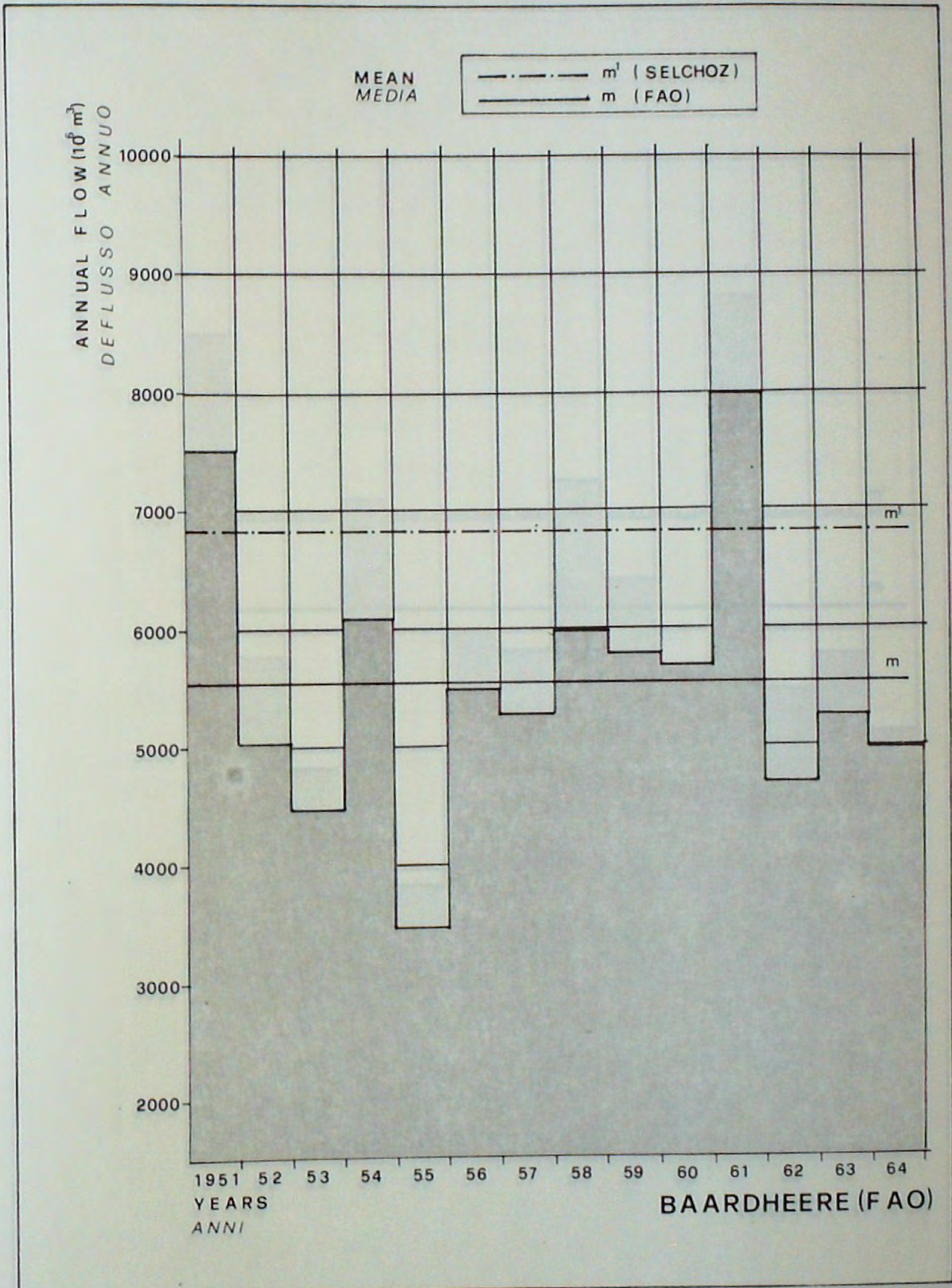
From the data available it is not always easy to assess what contribution groundwaters make to Juba flow.

Between Luuq and Baardheere, there are flow increases in the normal and low-flow periods and decreases during the floods, especially the Der floods. This is probably explained by water spilling out of the channel into the descecks during floods and to storage in porous riparian sediments, while the increase in streamflow is no doubt the result of groundwater returning to the channel and the slow restitution of water stored in the porous deposits.



ANNUAL FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI ANNUALI

fig.3a.II



ANNUAL FLOW HISTOGRAM
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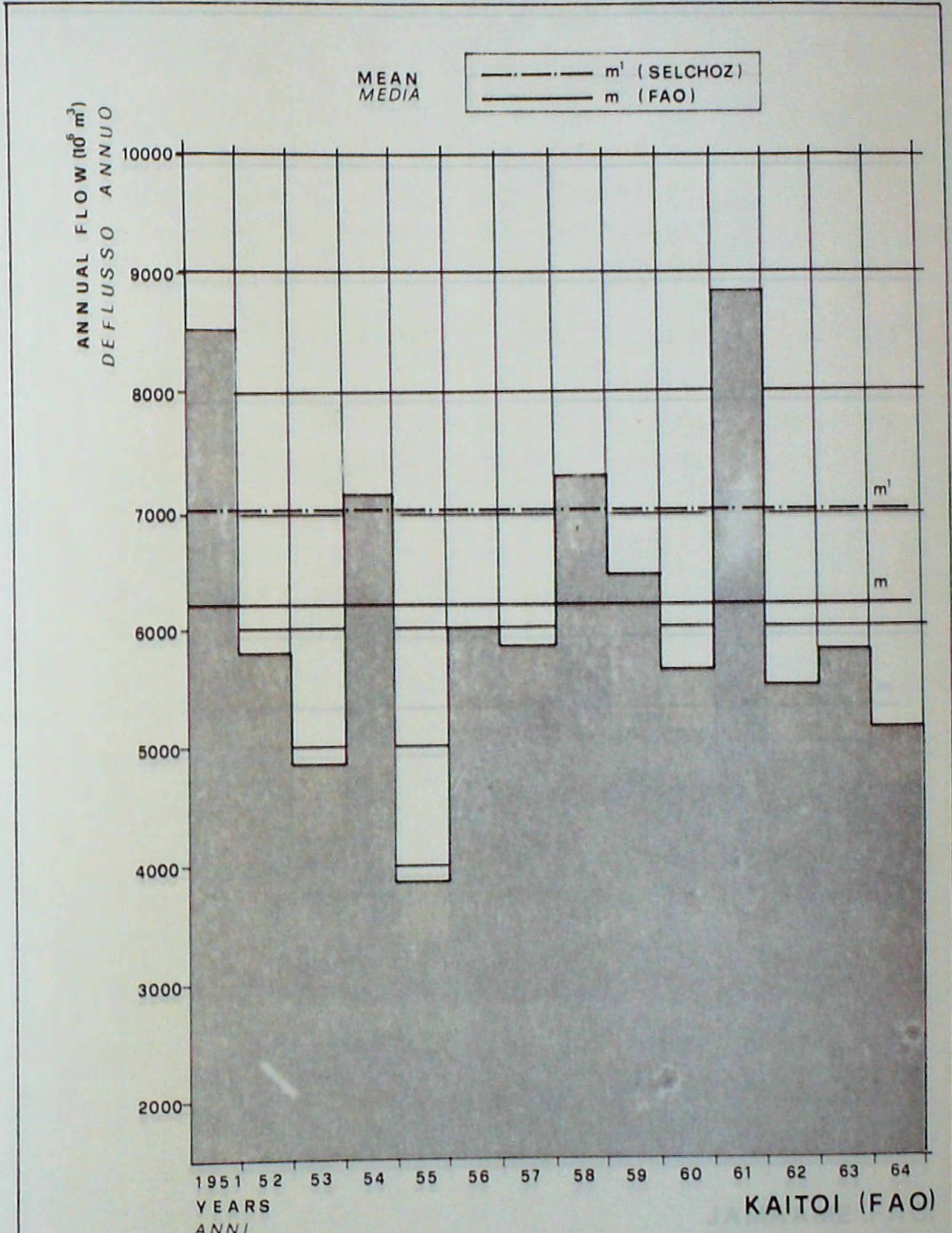
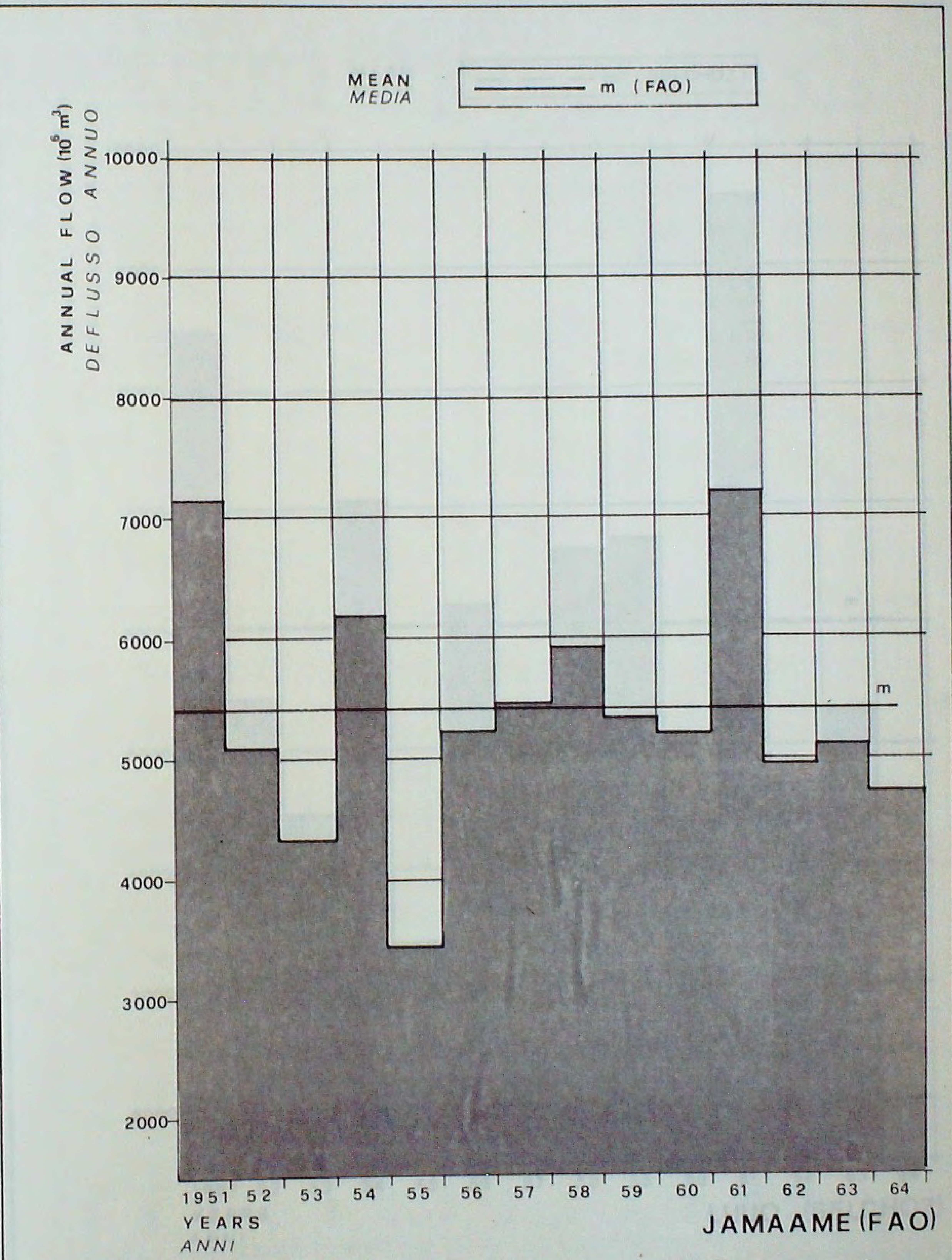
fig. 3b. II



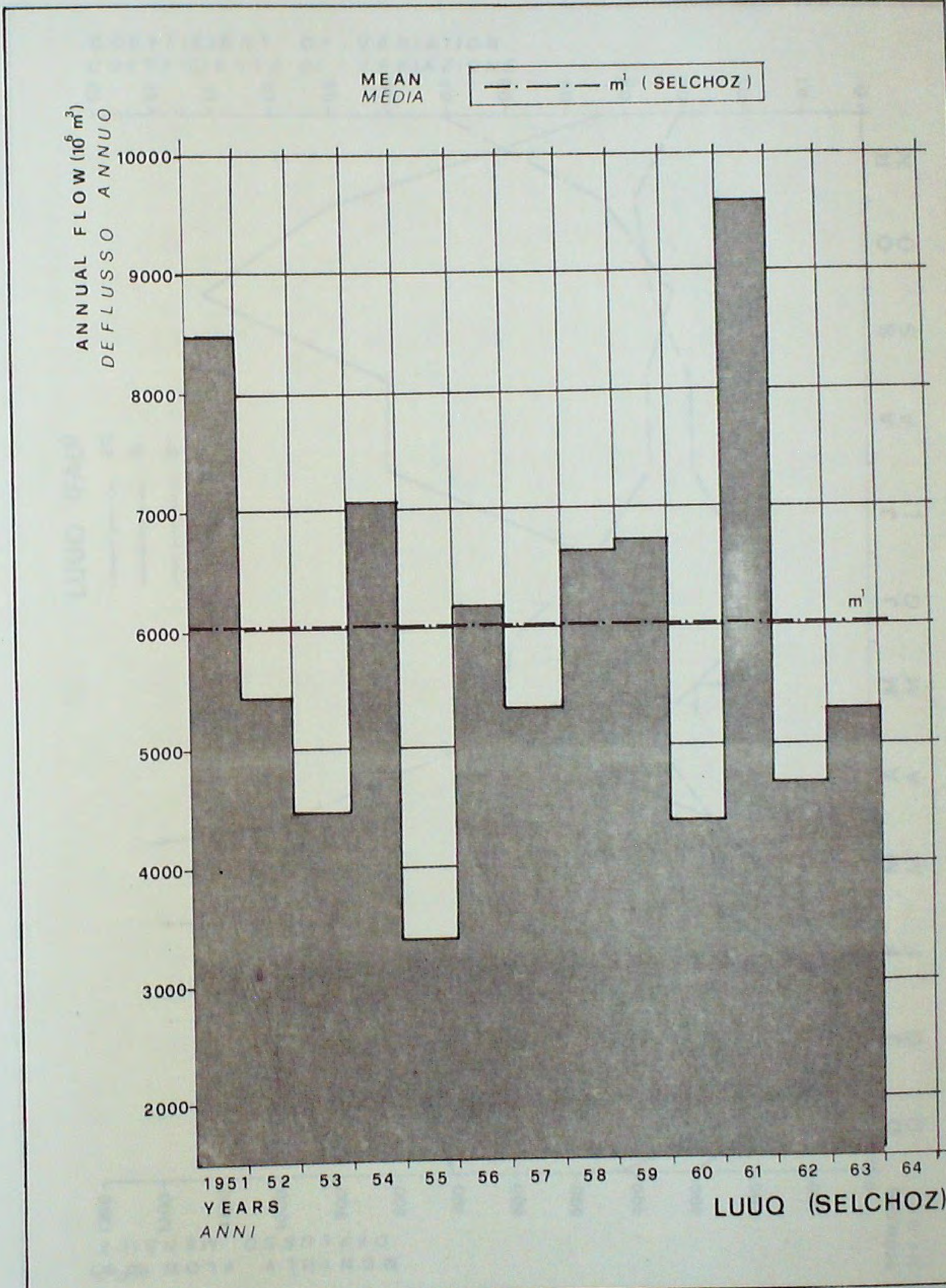
ANNUAL FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI ANNUALI

fig. 3c. II



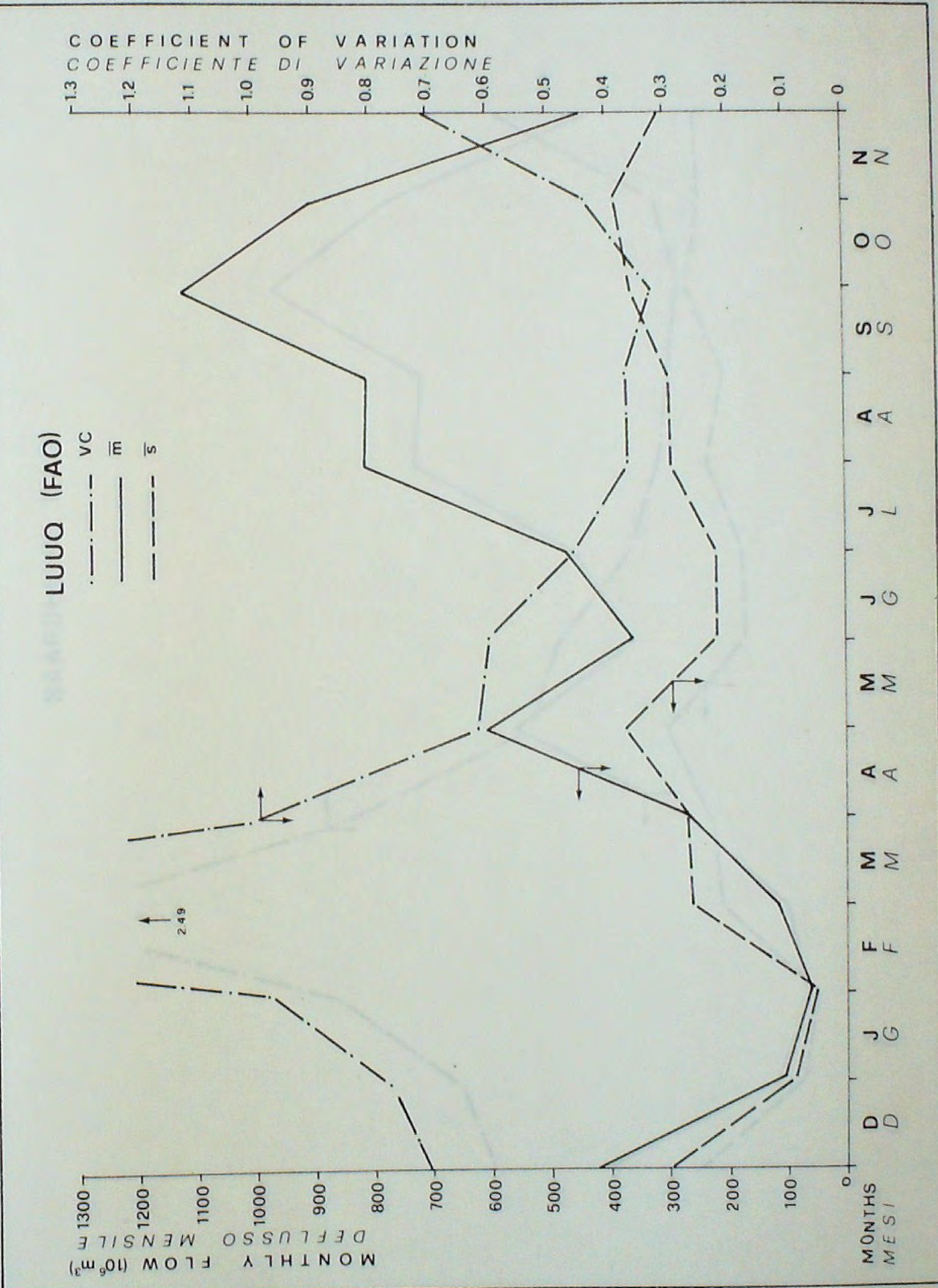
ANNUAL FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI ANNUALI

fig. 3d.II



ANNUAL FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI ANNUALI

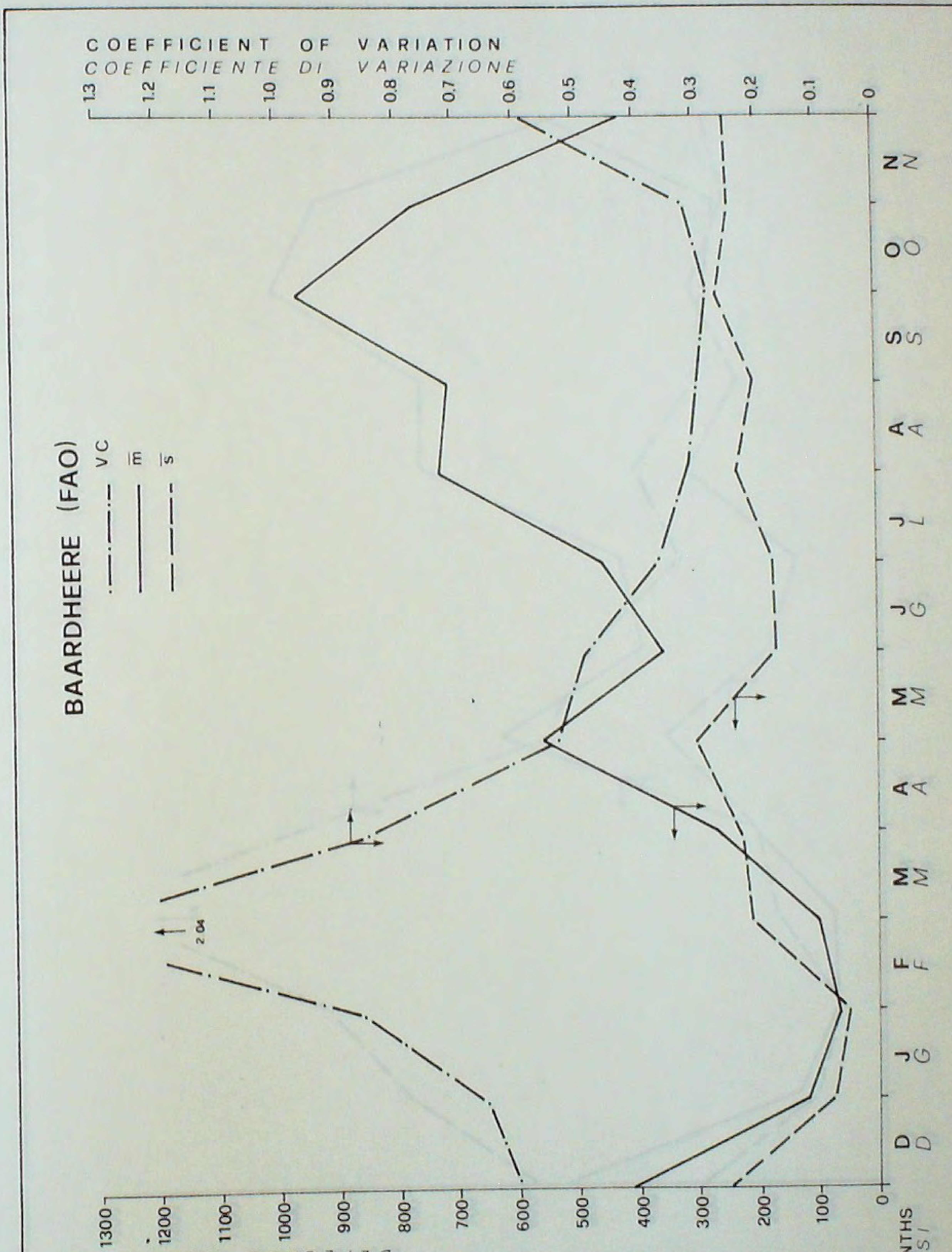
fig. 3e.II



MONTHLY FLOW VARIABILITY CHARACTERISTICS

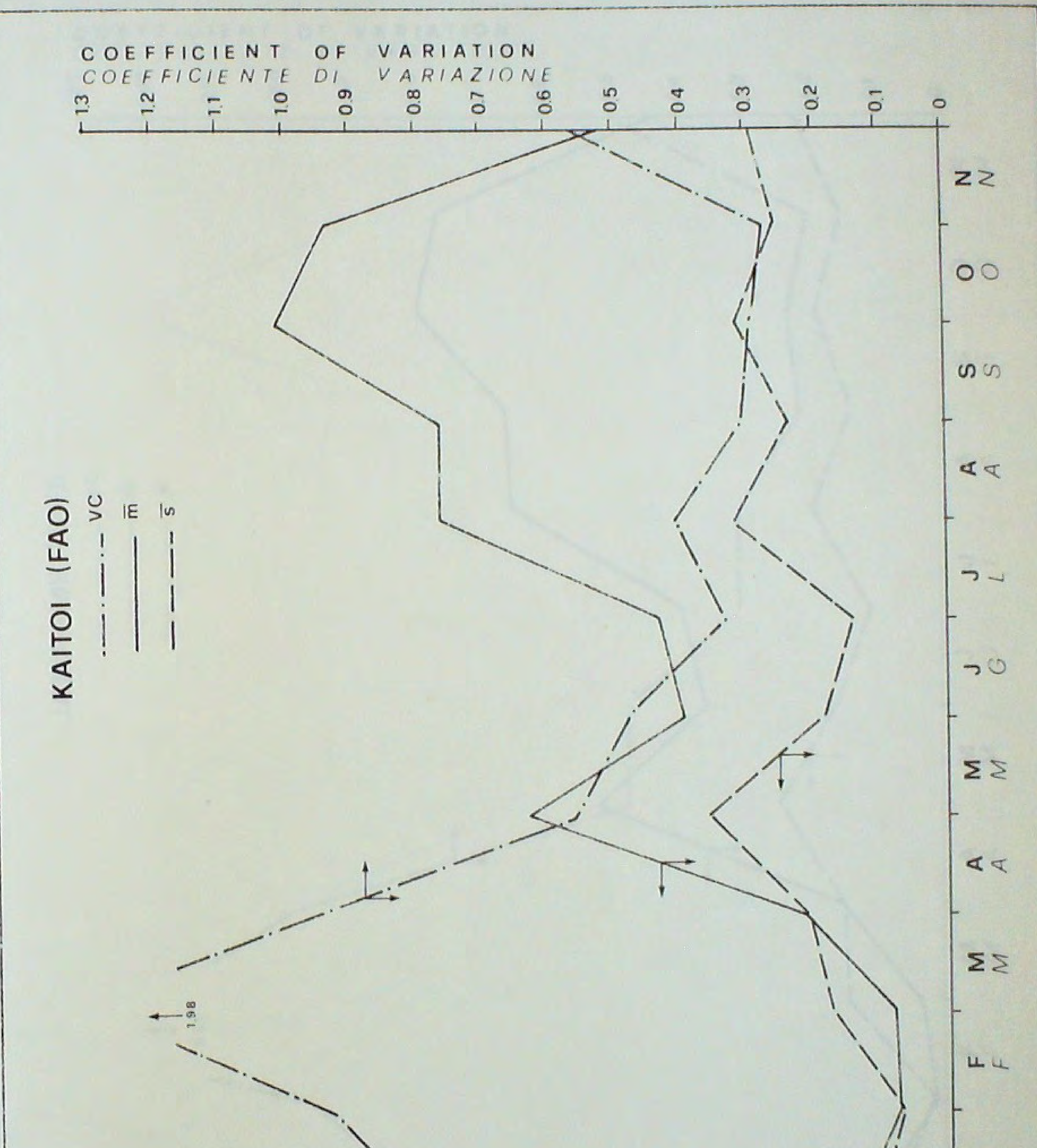
PARAMETRI CARATTERISTICI DELLA VARIABILITA DEI DEFLUSSI MENSILI

fig. 4 a. II



MONTHLY FLOW VARIABILITY CHARACTERISTICS
PARAMETRI CARATTERISTICI DELLA VARIABILITA DEI DEFLUSSI MENSILI

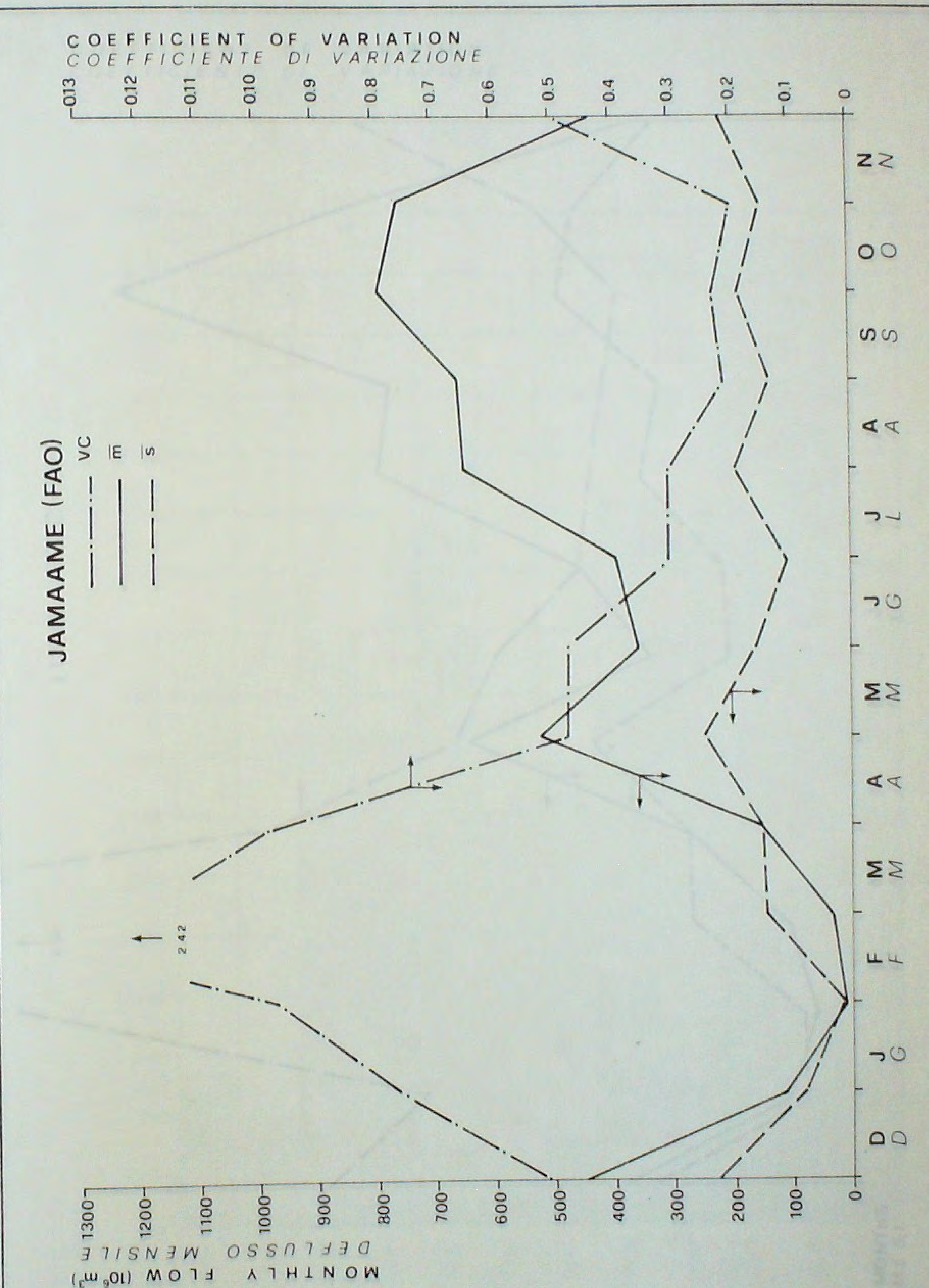
fig.4b.II



MONTHLY FLOW VARIABILITY CHARACTERISTICS

PARAMETRI CARATTERISTICI DELLA VARIABILITA DEI DEFLUSSI MENSILI

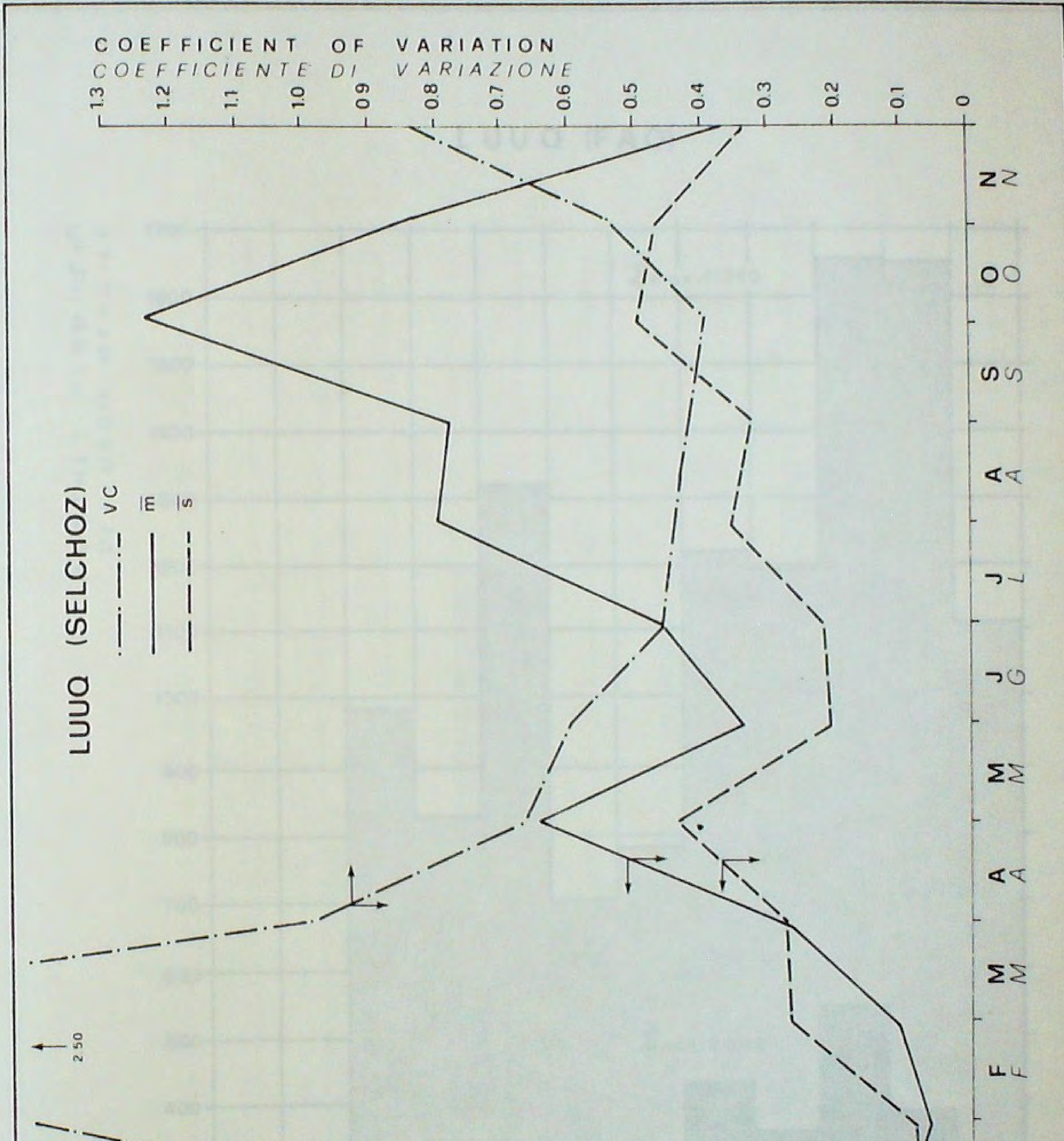
fig. 4c.II



MONTHLY FLOW VARIABILITY CHARACTERISTICS

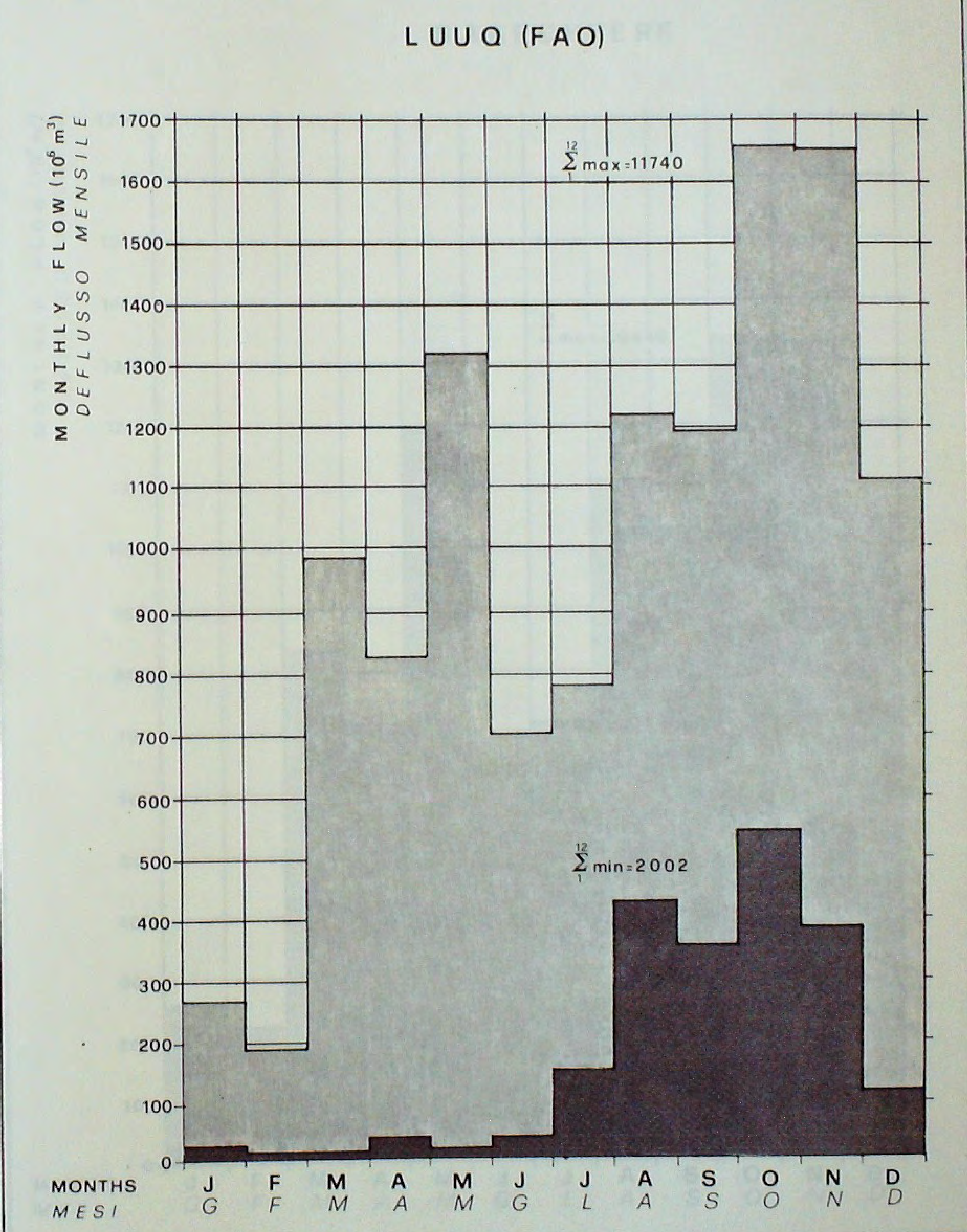
PARAMETRI CARATTERISTICI DELLA VARIABILITA DEI DEFLUSSI MENSILI

fig. 4d. II



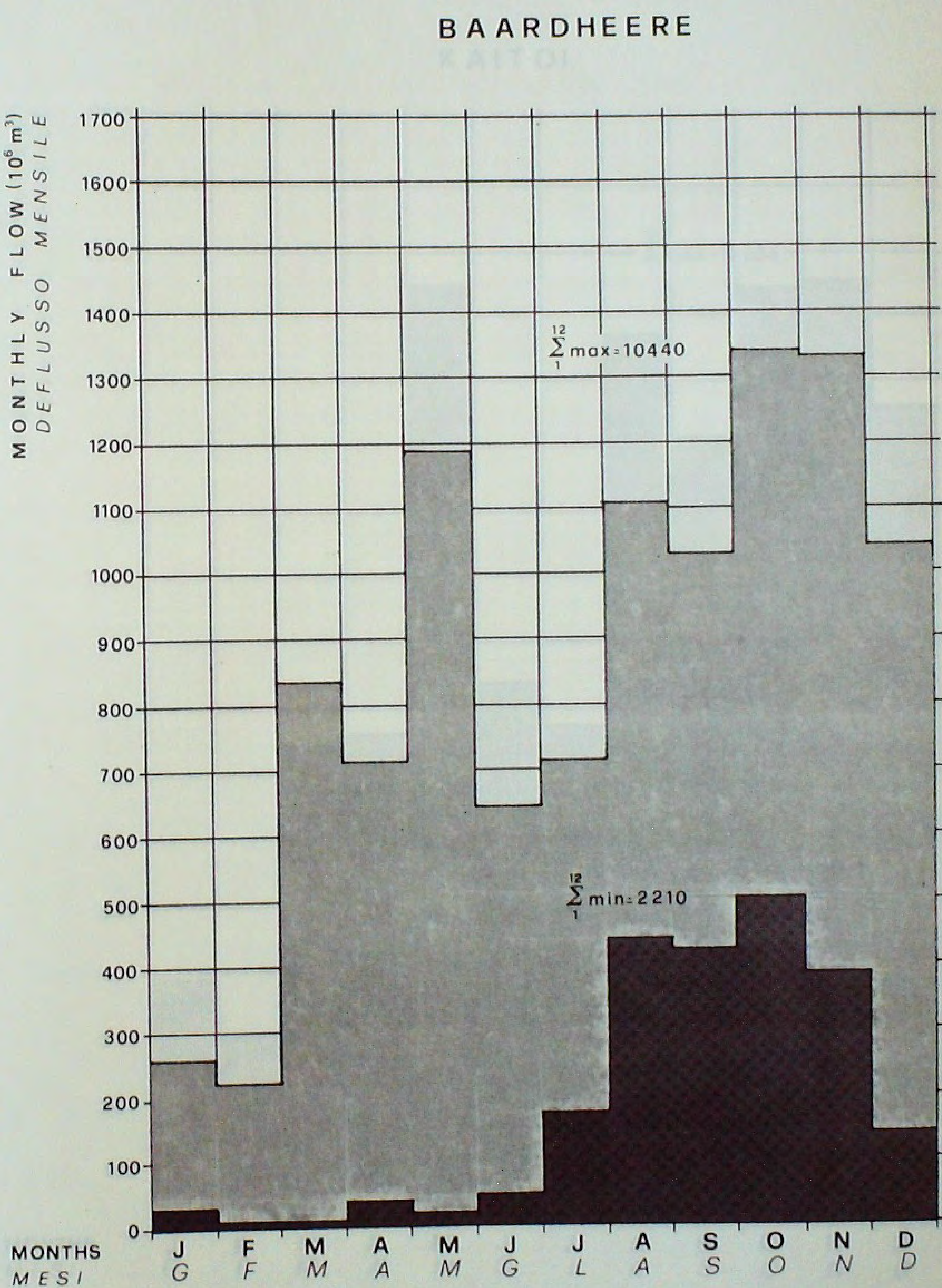
MONTHLY FLOW VARIABILITY CHARACTERISTICS
PARAMETRI CARATTERISTICI DELLA VARIABILITA DEI DEFLUSSI MENSILI

fig. **4**e. II



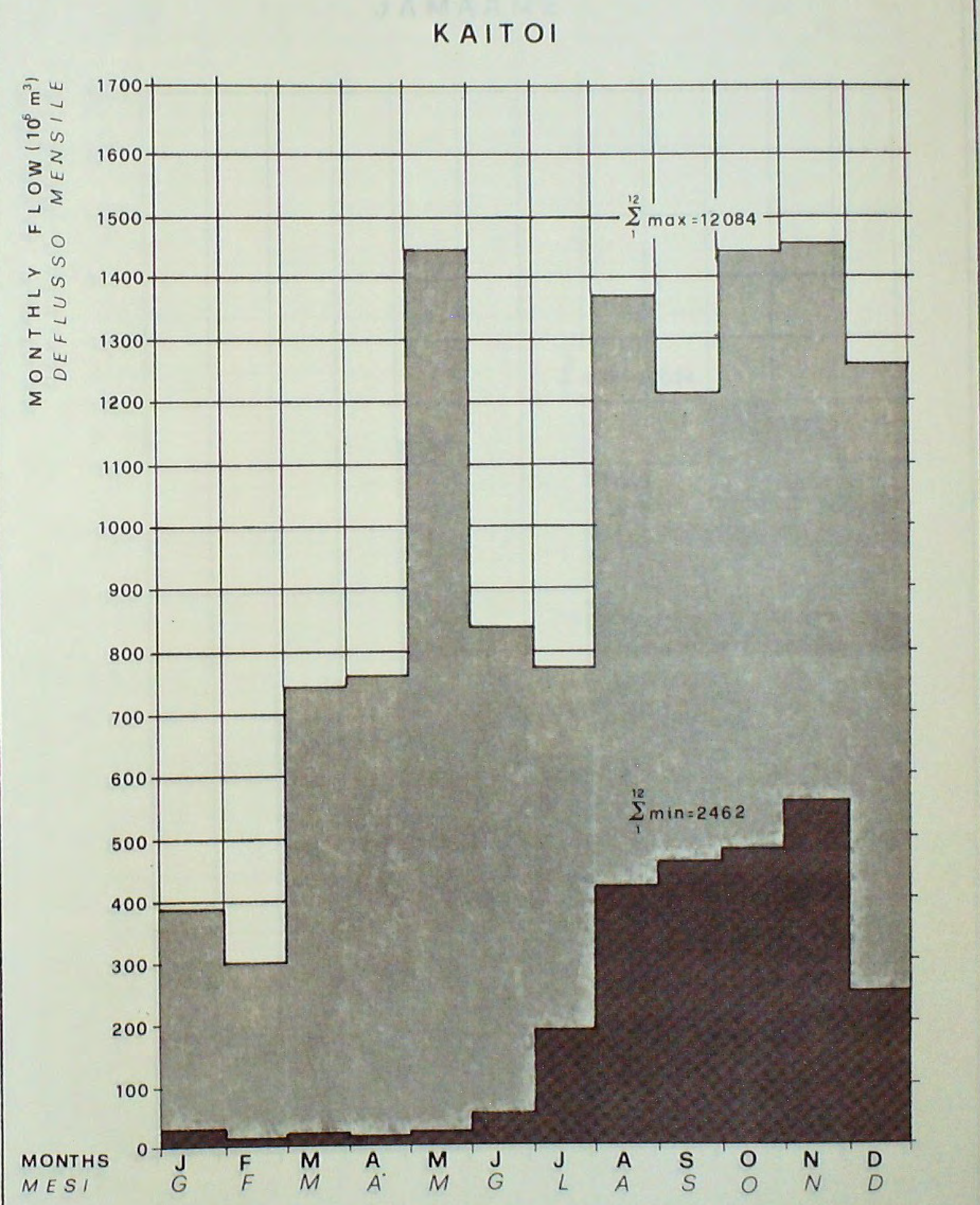
MAXIMUM AND MINIMUM MONTHLY FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI MENSILI MASSIMI E MINIMI

fig. 5a.II



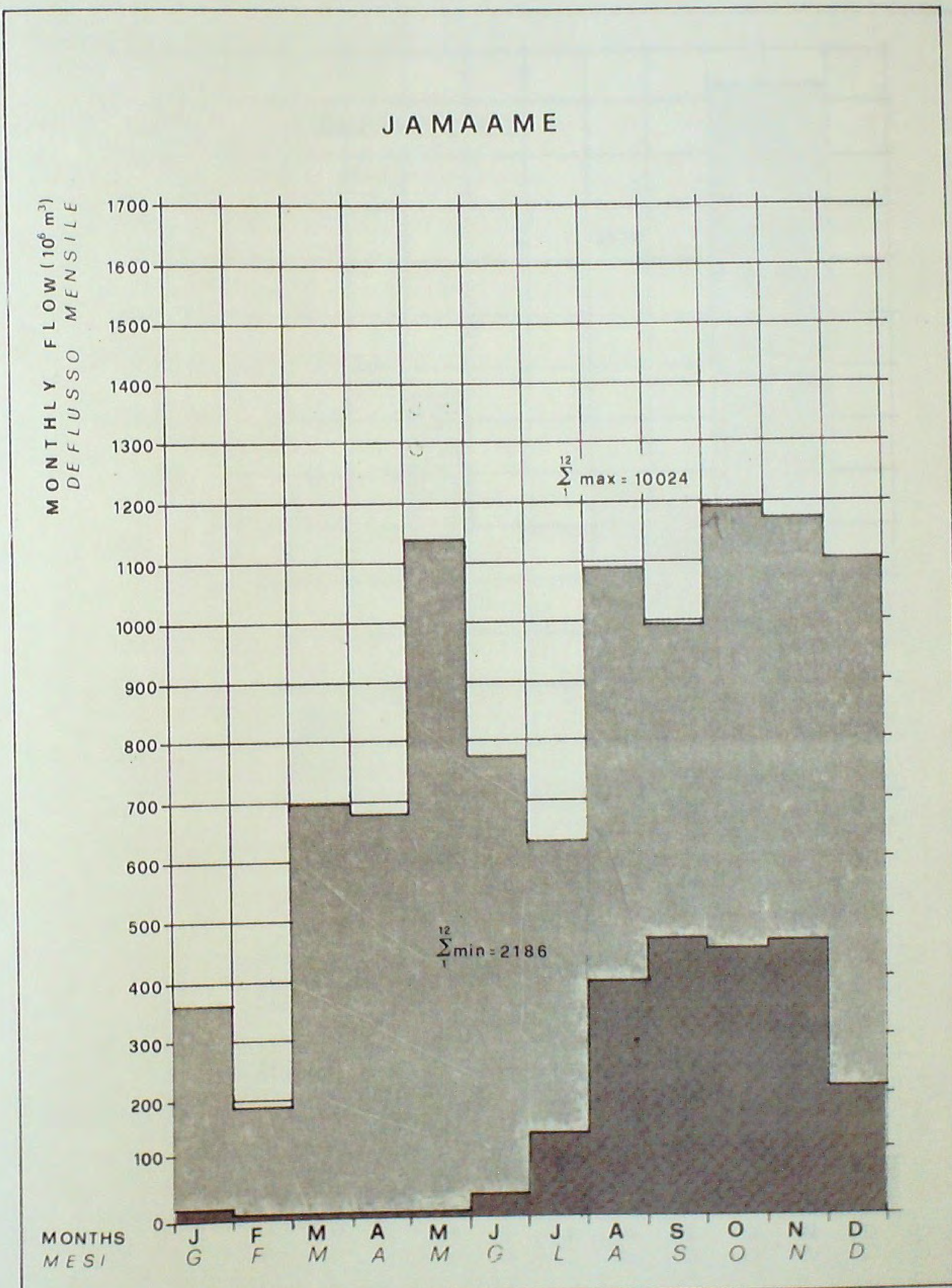
MAXIMUM AND MINIMUM MONTHLY FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI MENSILI MASSIMI E MINIMI

fig. 5b. II



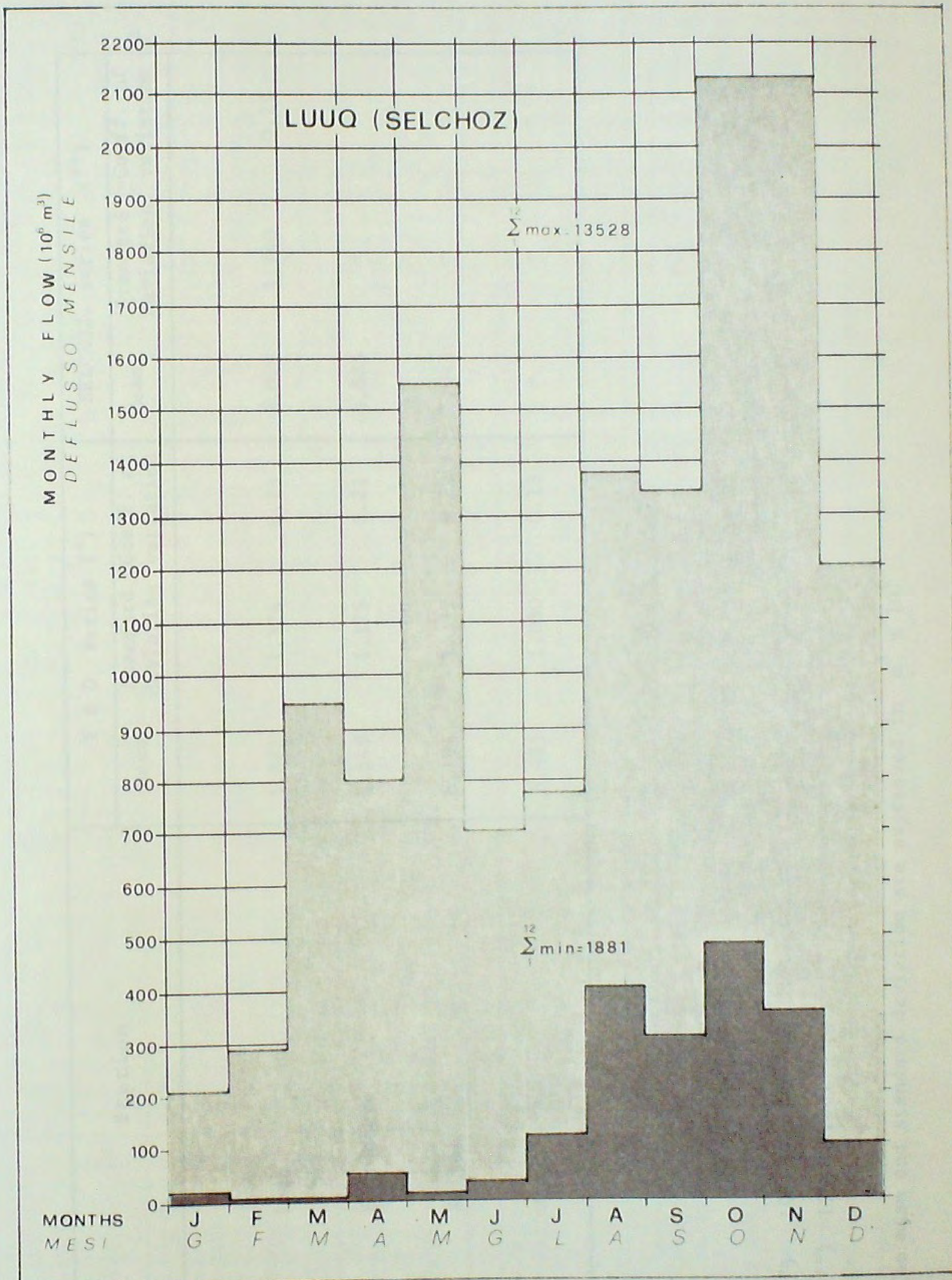
MAXIMUM AND MINIMUM MONTHLY FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI MENSILI MASSIMI E MINIMI

fig. 5c. II



MAXIMUM AND MINIMUM MONTHLY FLOW HISTOGRAM
ISTOGRAMMA DEI DEFLUSSI MENSILI MASSIMI E MINIMI

fig. 5d. II



MAXIMUM AND MINIMUM MONTHLY FLOW HISTOGRAM

ISTOGRAMMA DEI DEFLUSSI MENSILI MASSIMI E MINIMI

fig. 5e.II

Table 4 - Annual streamflow characteristics at various gauging stations

Station	F A O series (°)			SELCHOZ. series (°°)		
	Mean	Standard deviation	Coeff. of variation	Mean	Standard deviation	Coeff. of variation
Luuq	5,882	1,374	0.23	6,028	1,740	0.29
Baardheere	5,549	1,175	0.21	6,885	-	-
Kaitoi	6,194	1.377	0.22	7,043	-	-
Jamaame	5,421	1,050	0.19	-	-	-

(°) 1951 - 1964

(°°) 1951 - 1963

The mean and standard deviation are expressed in $m^3 \times 10^6$

Table 5 - Variability characteristics of monthly streamflow

Parameter	J	F	M	A	M	J	J	A	S	O	N	D
	MONTHS											
	LUUQ						(FAO) (*)					
mean	103	49	102	248	594	346	456	791	787	1106	879	420
standard deviation	76.6	47.2	249.1	254.7	361.6	204.8	202.9	275.2	279.1	338.3	365.3	290.7
c.v.	0.75	0.96	2.49	1.03	0.61	0.59	0.44	0.35	0.35	0.31	0.42	0.69
minimum value	22	8	8	28	13	29	139	414	339	530	368	104
maximum value	222	182	978	817	1313	695	772	1206	1171	1646	1640	1098
	BAARDHEERE						(FAO) (*)					
mean	125	67	106	270	562	362	459	728	715	964	774	418
standard deviation	82.8	57.8	216.0	230.5	304.3	176.4	171.4	235.1	211.6	268.1	248.9	251.8
c.v.	0.66	0.87	2.04	0.85	0.54	0.49	0.37	0.32	0.30	0.28	0.32	0.60
minimum value	34	9	9	38	19	51	174	438	421	502	382	133
maximum value	259	225	836	719	1189	644	716	1110	1031	1338	1329	1044
	KAITOI						(FAO) (*)					
mean	156	88	96	236	638	416	461	784	784	1033	965	536
standard deviation	126.6	83.7	190.8	228.2	382.6	206.5	161.3	338.8	259.0	335.5	265.8	315.9
c.v.	0.81	0.95	1.98	0.97	0.60	0.50	0.35	0.43	0.33	0.32	0.28	0.59
minimum value	28	17	19	18	19	51	184	417	453	468	550	238
maximum value	388	299	742	760	1456	837	769	1363	1213	1441	1461	1355
	JAMAAME						(FAO) (*)					
mean	151	51	78	196	564	401	432	694	704	839	823	486
standard deviation	120.8	55.0	183.3	195.0	292.6	207.8	152.8	240.1	183.1	237.0	195.0	264.7
c.v.	0.80	1.07	2.35	1.00	0.52	0.52	0.35	0.35	0.26	0.28	0.24	0.55
minimum value	17	6	6	7	7	34	134	395	467	446	459	208
maximum value	365	192	699	679	1143	777	629	1087	993	1191	1169	1100
	LUUQ						(SELCHOZ P.) (**)					
mean	94	55	102	269	646	339	466	800	781	1243	856	377
standard deviation	67.0	76.9	257.1	268.2	434.6	202.6	219.1	360.4	330.0	504.0	475.5	338.6
c.v.	0.71	1.41	2.52	1.00	0.67	0.60	0.47	0.45	0.42	0.41	0.56	0.90
minimum value	22	8	7	58	13	29	129	404	321	496	353	41
maximum value	214	298	951	809	1564	705	878	1382	1327	2073	2074	1253

Between Baardheere and Kaitoi the situation seems more complex from the geohydrological aspect. Streamflow increases for a good part of the year, because of inflows from tributaries in the area during the rains and because of the return to the channel of waters which spilled out upstream. There is a decrease in streamflow only in the driest season, perhaps because of infiltration.

In the Kaitoi-Jamaame stretch streamflow declines for the whole of the year because of evaporation and infiltration, as well as abstraction for irrigation use. The decrease in streamflow is particularly marked during the floods, when large volumes of water spill out onto the surrounding plain, because the channel is not large enough to cope.

The points to be drawn from the Selchozpromexport data on monthly streamflow distribution and the trends along the river are not so detailed as in the case of those just dealt with. This is because of the type of information available and because of the assumptions made when the data were processed.

Table 5 also gives the variability characteristics of monthly streamflow for Luuq, on the basis of the Soviet Report. The trends of these are illustrated in Fig.4e.II and Fig.5e.II. This series of monthly streamflows can be seen to be much more variable than that based on the FAO Report. This is because, while the minimum and mean values are quite similar to FAO's, the maximum values are decidedly higher, especially for the Der floods.

Similarly, the streamflow of the artificial dry year is 6% lower than that derived in the case of the processed FAO data, while that for the artificial wet year is about 15% higher.

As indicated earlier, all this variation would seem to stem from the different criteria adopted for evaluating the hydrometric data available and from differences in the stage-discharge scale - especially in the upper part - derived by extrapolation.

Owing to the procedure used in the Soviet Report, it is not possible to examine the variability of monthly streamflow at the other stations - Baardheere and Kaitoi - considered along the Juba. In fact, the streamflow distribution for these stations in the various months is taken to be the same as that observed at Luuq for each year of given probability.

3.3 FLOOD FLOWS

The flood flows of the Juba form mainly on the Ethiopian Plateau as a result of the Gu and Der rains. In its course through Somalia the increase in flows is limited to the contribution made by a few tributaries which, during the heaviest rains, convey some water as far as the mainstream. However, the amounts involved are small in comparison with those which descend from the Plateau.

Inundations as a result of flood flows in the Juba are common all along the river's Somali course, but they are of particular note in the alluvial plain downstream of Dujuuma, because of the volume of water that leaves the channel owing to its progressively smaller capacity, and also because of the extent of the areas that are flooded, owing to the flat lie of the land, as well as the damage caused to economic activities here. Flooding is especially bad when the Webi Shebeli and, particularly, the Bohol Magaday are in spate and their waters pour into the Juba.

The spring floods of the Juba are short and sharp, while the autumn floods are longer and the hydrograph has many peaks. The biggest flood of the year can occur in either of the two periods. It generally takes the flood wave four or five days to descend the Juba from Luuq to the Ocean.

The Selchozpromexport Report is the main source of quantitative data on the Juba floods. However, it should be mentioned that the information and evaluations concerning floods are decidedly less reliable than those for the normal regime, because of the singular nature of the events themselves, the difficulties involved in observation and measurement, and the need to have a long series of observations that includes numerous extreme cases.

The maximum daily discharge probability curve for Luuq Gannane has been plotted on the basis of the 1963-1964 direct observations and the 1951-1962 derived data. The maximum daily discharges at Baardheere and Kaitoi were then computed by correlation. The calculated maximum daily discharges of different probabilities are set forth in Table 6. Using a similar approach the 100 and 50-day floodflows at various levels of probability have been worked out too. The results are reported in Table 7.

According to the data processed from the Soviet Report, the flood discharges increase by some 5-10% between Luuq and Baardheere, and by about 2% between there and Kaitoi. The volume of the 50 and 100-day floods increases by about 12% between Luuq and Baardheere.

The only information on floodflows that can be obtained from the FAO Report is given in the form of 5-day average discharge for the 1951-1964 period. And even this is presented in graphic form.

It emerges that a Luuq, 5-day discharges exceeding 600 m^3/s only occurred on five occasions, and for periods not exceeding 20 days, all during the Der rains. The maximum value reported is 830 m^3/s in November 1961. The Gu flood values do not exceed 500 m^3/s.

A decrease of peak discharges of around 20% is noted at Baardheere station. Only on three occasions were there floods exceeding 600 m^3/s, with a maximum of 650 m^3/s in October-November 1956. The maximum Gu flood values were around 470 m^3/s.

At Kaitoi there are no discharges observed greater than 600 m^3/s, though this value occurs repeatedly in both the Gu and, especially, the Der floods. This would seem to be attributable to the reduced conveyance capacity of the channel, which results in natural flood abatement through lateral spreading.

The flows at Jamaame are even further attenuated, rarely exceeding 500 m^3/s. The general trend of the flood hydrograph is also smoother, owing to the lateral spreading upstream.

Though it is difficult to make a direct comparison between these data and those in the Selchozpromexport Report because of the different bases involved and because homogeneous procedures cannot be applied for both; it is, however, possible to discern a contrast between the increase in flood discharges (or at least the maintenance thereof) between Luuq and Kaitoi in the Selchozpromexport Report and the decrease - at least at the 5-day scale - indicated by the FAO data.

Thus, bearing in mind also the comparison of the two series of streamflow values at Luuq Station, it seems reasonable to except that the estimates of maximum discharges and flood volumes will be pitched on the

safe side, compared with what could be expected from processing FAO data in a similar manner.

The discharges and volumes that can actually flow along the channel in the flood plain are lower than those reported in the Tables, even for the highest frequencies. Indeed, it is calculated that the channel capacity at Faanoole is no more than 700-750 m^3/s, falling to 600 at Gannane. Thus the floods cause inundations in these areas practically every year.

The Bohol Magaday is the most interesting tributary of the Juba from the flood aspect, because of the inundations it causes directly and because of its interference with the Juba. The Farta Tuculle is also of interest in this regard. Only very approximate data are, however, available, derived on the basis of two particularly bad floods in 1961 and 1963. Assuming that the probability of the 1961 flood was 5%, the maximum discharge of the Magaday is estimated to be 290 m^3/s and that of the Farta Tuculle 230 m^3/s. The volume of this latter flood, for an 80-day duration, is estimated to be around 875 x 10^6 m^3.

3.4 LOW FLOWS

In the case of low flows, obtained from FAO data for the driest month, it is estimated that the mean value is of the order of 60 x 10^6 m^3 and the minimum value is 7 to 8 x 10^6 m^3, there being marked variations along the river, depending on the geohydrological conditions involved. The minimum monthly streamflow would appear to have been at Jamaame in February and March of 1953 and 1954, with a figure of 6 x 10^6 m^3.

The Selchozpromexport Report provides estimates for Luuq which are close to these figures (the variations being around 10%). The Report also provides information on the minimum daily streamflows, which are around 0.27 x 10^6 m^3, on average, and 0.13 x 10^6 m^3 at the lowest (1).

Information obtained from the literature and by direct means would seem to indicate that although the Juba is generally classed as a perennial river, it ran dry at Jamaame in the March-April period of 1941, 1950 and 1974.

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(1) Estimates made for the Faanoole Project are also available, the unpublished figures having been kindly provided by the Project Manager. These concern the minimum daily discharge and the minimum monthly discharge at Luuq Gannane. The processing done on data collected directly or derived for the 1951-1973 period gives higher figures than those indicated in the Selchozpromexport Report (1965).

Table 6 - Maximum daily discharge (m^3/s)

Station	Probability				
	1%	2%	5%	10%	50%
Luuq	2.150	1.940	1.620	1.391	830
Baardheere	2.380	2.060	1.760	1.505	870
Kaitoi	2.430	2.097	1.800	1.540	880
	100	50	20	10	2
	Return period (years)				

Source : Selchozpromexport Report

Table 7 - 100 - Day and 50 - Day duration floodflows ($m^3 \times 10^6$)

Flood duration	Station			
	Luuq		Baardheere	
	P = 1%	P = 5%	P = 1%	P = 5%
100 days	7.000	5.640	7.840	6.317
50 days	4.360	3.520	4.883	3.942

Source : Selchozpromexport Report

3.5 SEDIMENT TRANSPORT AND CHEMICAL PROPERTIES OF WATERS

There is little information available on sediment transport. What there is comes from a short campaign of measurements rum in 1963 at Kaitoi by Giprovodhoz, and to a lesser extent from a small number of observations at Luuq, Baardheere and Jamaame in 1965 for the FAO Project.

The specific sediment concentration at Kaitoi is reported to average 2.37 kg/m^3, with a peak of 11.3 kg/m^3 during the Gu floods.

Using the measurements that have been made, it has been possible to derive a rough experimental relationship between the mean monthly discharge and the amount of material transported.

The mean annual quantity of sediment transport at Kaitoi and Baardheere appears to be 18.5 and 20.3 x 10^6 tons of material, respectively. The sediment consists essentially of silt and clay with only around 8% of sand.

Information on the chemical composition of the Juba waters has been collected at various times, but never systematically. The most interesting data are those given in the Selchozpromexport Report, in the "Inter-river Economic Exploration Report" by the International Cooperation Administration, and in the FAO Report.

The salinity of the Juba waters is in the 200-500 mg/l range, in general, but it rises to 500-1,000 mg/l in the flood periods. The maximum concentration of over 1,400 mg/l occurs in the first days of the Gu floods and is attributable to the washing-out soils where salts accumulate during the dry season.

Other sources of salts in the Juba waters are the gypsiferous rocks which occur in the northern parts of the basin, and to a lesser extent, the salt-rich groundwaters which enter the channel during the dry season.

The higher salinity that accompanies the increase in streamflow is attributable mainly to a rise in the concentration of calcium and sulphate ions.

In the lower reaches of the river, there is a wedge of water with a salinity of around 1,600 mg/l, which runs for about 40 km inland from the mouth.

CHAPTER 4.

SURFACE WATER RESOURCES AND THE DEVELOPMENT THEREOF

4.1 NATURAL AVAILABILITY

Accurate evaluation of the water resources of the Juba is hindered by the paucity of the surface hydrology data and the poor reliability of the little information that is available.

From the data processing discussed earlier, it ensues that the Juba flows derive from the rain which falls on the Ethiopian Plateau and that the river receives little water on its way through Somalia.

Processing of the FAO data indicates that the natural surface water resources of the Juba amount to about 5.8 x 10^9 m^3, on average, with minor increases and decreases in the various reaches of the river, which do not generally exceed 7% (Table 4).

On the whole, along the observed course between Luuq Gannane and Jamaame (650 of the Juba's 800 km in Somalia) the surface water resources decrease by about 8%, with localized losses especially in the terminal reach.

The year-to-year variability of the resources is not marked, streamflow generally being in the 3.5 to 8.5 x 10^9 m^3 range; moreover, variability decreases notably in the lower part of the alluvial plain.

Fig.6.II (a, b, c, d and e) illustrates the duration curves of the natural annual stream flows (Da) at the various stations. From these it is possible to identify the flow that, on average, is equalled or exceeded for different durations (cumulative exceedence frequency), expressed as a percentage of the observation period. The arithmetic mean is always greater than that of the flow having a 50% duration, bringing out the asymmetrical nature of the annual streamflow frequency distribution: the annual volume of water available in 50% of the observation period averages about 5.5 x 10^9 m^3.

Some data characterizing that distribution are set forth in Table 8, where streamflows are also expressed as percentages of the mean of the period. On the basis of the data collected, it would seem that the streamflow ensured in all the years ("firm" water resources) amounts to a little more than 60% of the mean value, while surface water resources with a duration equal to 80% of the period - of specific interest for irrigation use - amount to around 4.8 x 10^9 m^3.

In the two extreme "artificial" years - dry and wet - constituted by the minimum and maximum values of the monthly streamflows, the flows would be 2 to 3 x 10^9 m^3 and 11 to 12 x 10^9 m^3 respectively, with marked variations along the course. It is apparent, however, that these values have probabilities approaching zero; they merely represent limiting values calculated for reference.

Estimates of natural surface water resources derived from Selchozpromexport data and hypotheses differ from the values given above by between 2 and 20% depending on the reach of river considered and the duration examined.

The seasonal distribution of resources is extremely uneven, as a direct consequence of the variability of rainfall.

Table 9 sets forth the characteristic data on seasonal distribution of natural water resources on the basis of FAO and Selchozpromexport data. The mean monthly streamflows $\overline{D}_m$, are expressed as a percentage of the mean annual flow, $\overline{D}_a$, and of the monthly flow averaged for the entire period ($\overline{D}_m$).

Most of the natural flow, around 60%, occurs in the August-November period, when rainfall is highest, while the remainder occurs mainly in the Gu flood period and the mean-flow period. There is marked variability of mean monthly streamflows, the fluctuations ranging from 10% to over 200% of the general monthly mean for the period.

Fig.7.II (a, b, c, d and e) shows monthly streamflow duration curves. These are of interest for quantifying possible use of resources without any important regulation structure. The curves indicate the frequency with which a given monthly streamflow was equalled or exceeded, on average, during the observation period.

Table 10 gives some values typifying the distribution of monthly availability. The marked lack of symmetry involves that the natural flow with a duration of real interest for water-use purposes amounts to no more than a small percentage of the general mean. For instance, the resources in the driest period, namely the three months from January to March, average 4 to 5% of the overall resources, the absolute minimum values being 6 to 8 x $10^6 m^3$ in the driest month.

Some further ideas on the distribution of resources in the various months can be derived from Fig.8.II (a, b, c and d), where the month-by-month trends of monthly streamflows with durations of 25%, 50% and 75% of the period are illustrated (derived from FAO data). The characteristic bimodality of the river regime is clearly apparent, albeit with different intensities and divisions.

The diagrams are also of interest because of what they indicate regarding the possibilities of using the waters without any regulation structures. On the basis of the data available they show the relationships between what appear to be firm flows in each month at different values of duration, in the various reaches of the river.

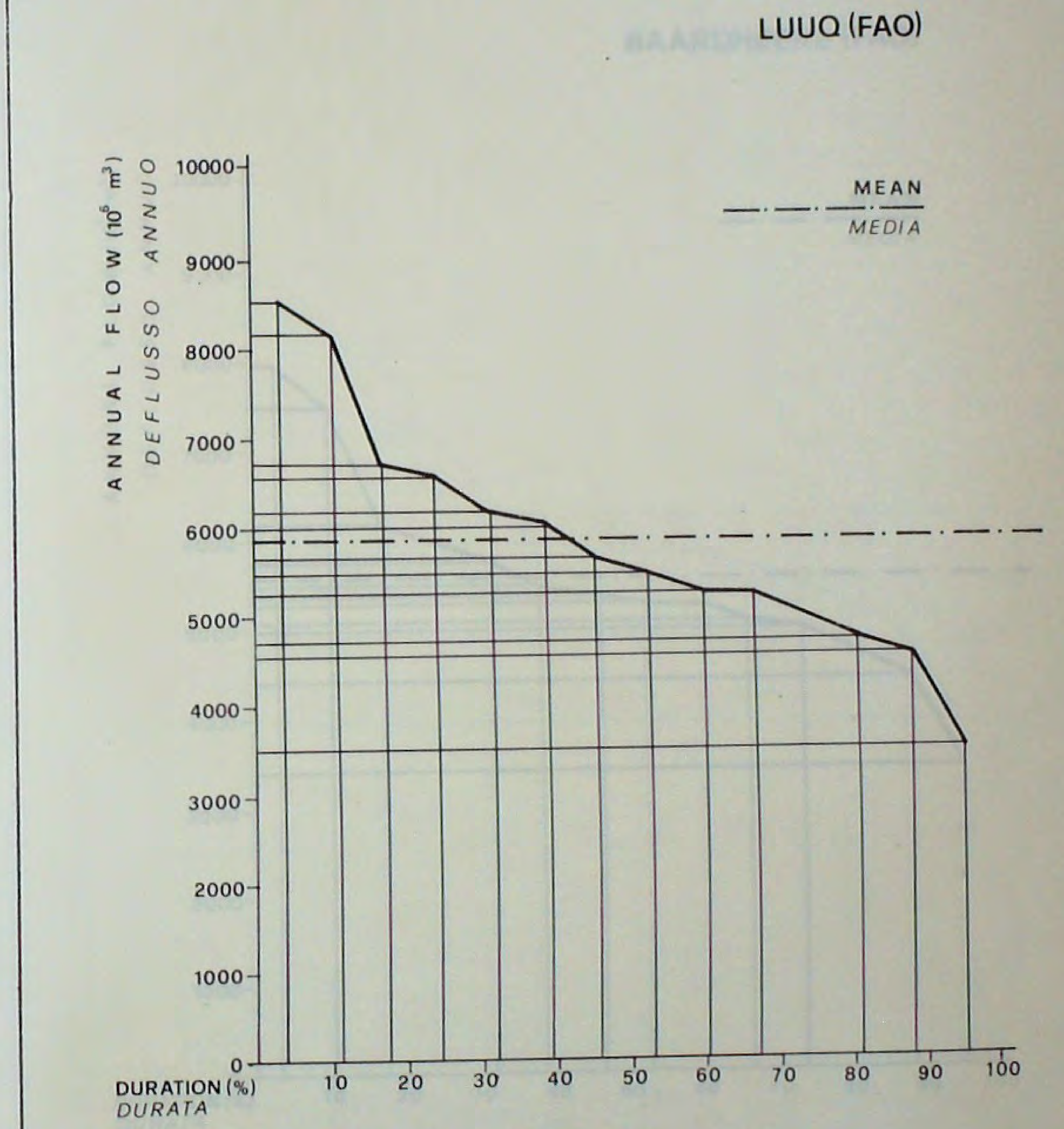
Comparison with the Soviet Project estimates, limited to the upper reaches of the river, is satisfactory on the whole, except for the extreme situations, where differences - some marked - are found.

The daily discharges of the Juba are decidedly variable, ranging from over 900 m^3/s to less than 5 m^3/s. In exceptional cases the bed may remain dry in reaches where evaporation and infiltration losses are high.

The mean flood discharges are actually in excess of the value just indicated, which only reflects the channel capacity in the plain reaches, that tends to decrease as the river approaches the sea. Because of the lack of balance between the volumes that flow during the floods and channel capacity, there are serious inundations every year, extensive areas being flooded and massive economic damage being caused.

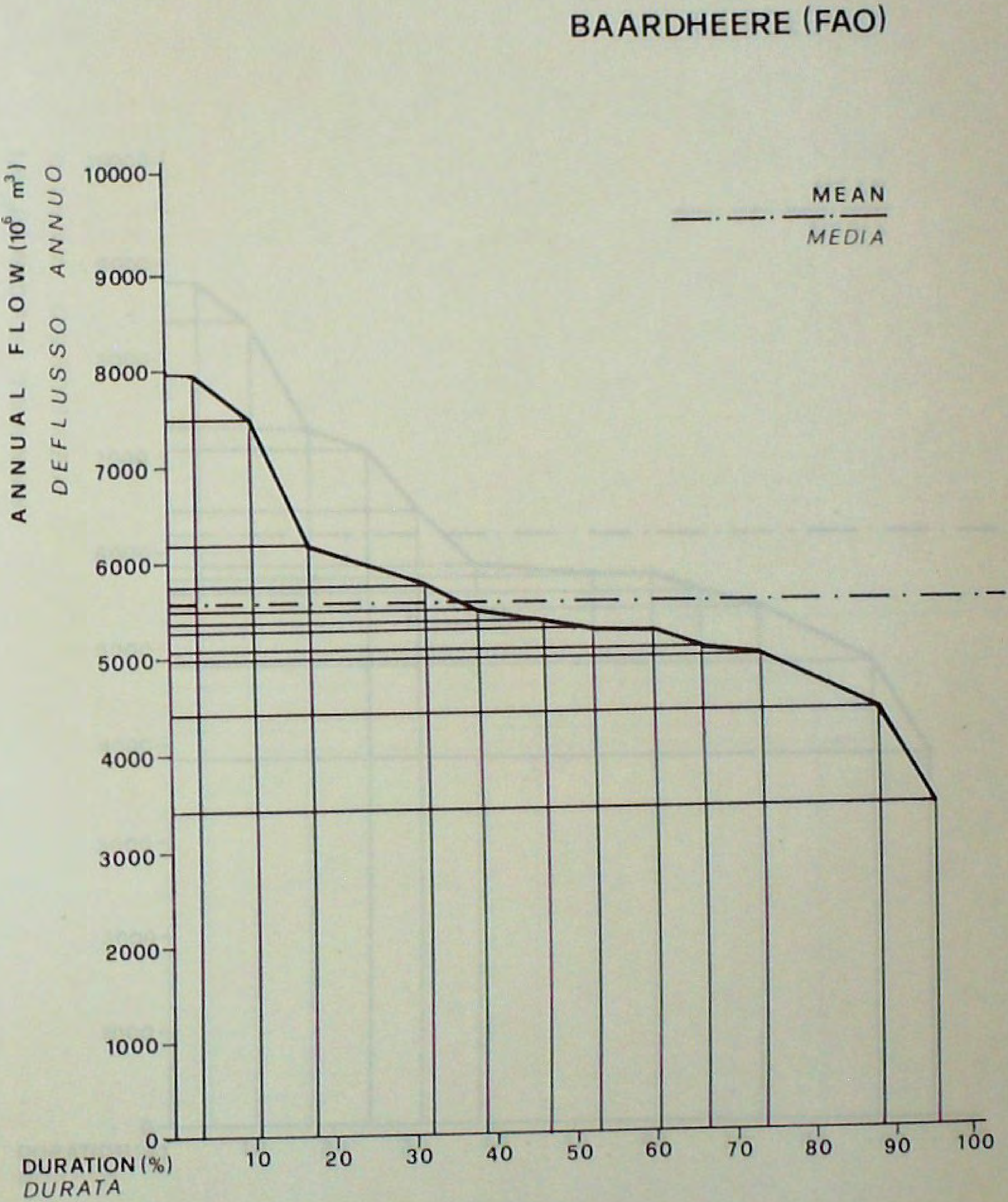
That part of the flows which exceeds the channel capacity must be considered as a negative resource, in a certain sense, and it is necessary to think in terms of protection rather than use, though there is no doubt that some of the water can be used by providing suitable storage capacity.

In general, the moderate mean salinity and chemical composition - with no ions in particularly high concentrations - signify that there are no restraints on the use of the Juba waters, except in the case of the first salt-laden flood flows and those near the mouth where the saline waters tend to wedge some way inland during the low-flow periods.



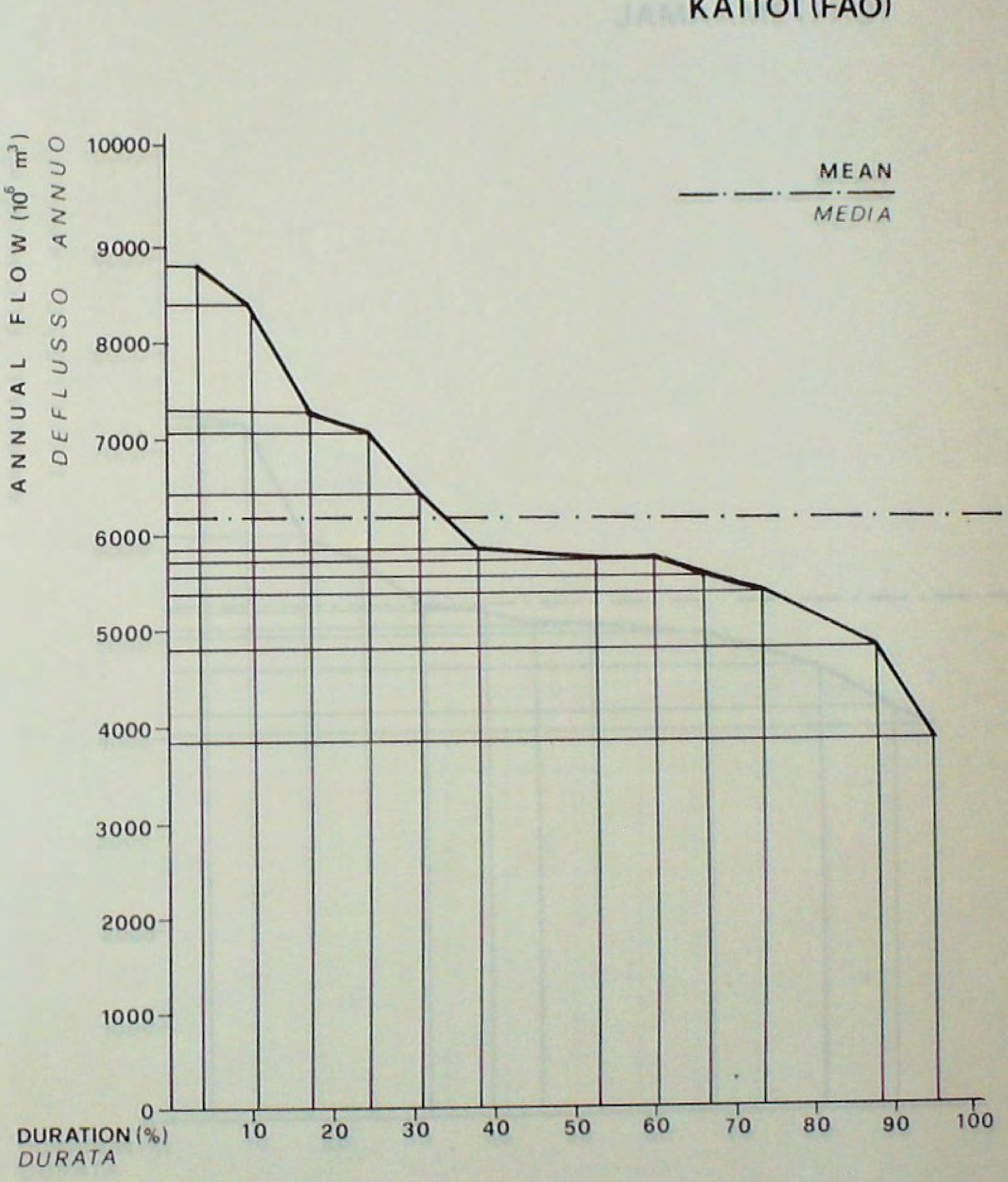
ANNUAL FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI ANNUI

fig. 6a. II



ANNUAL FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI ANNUI

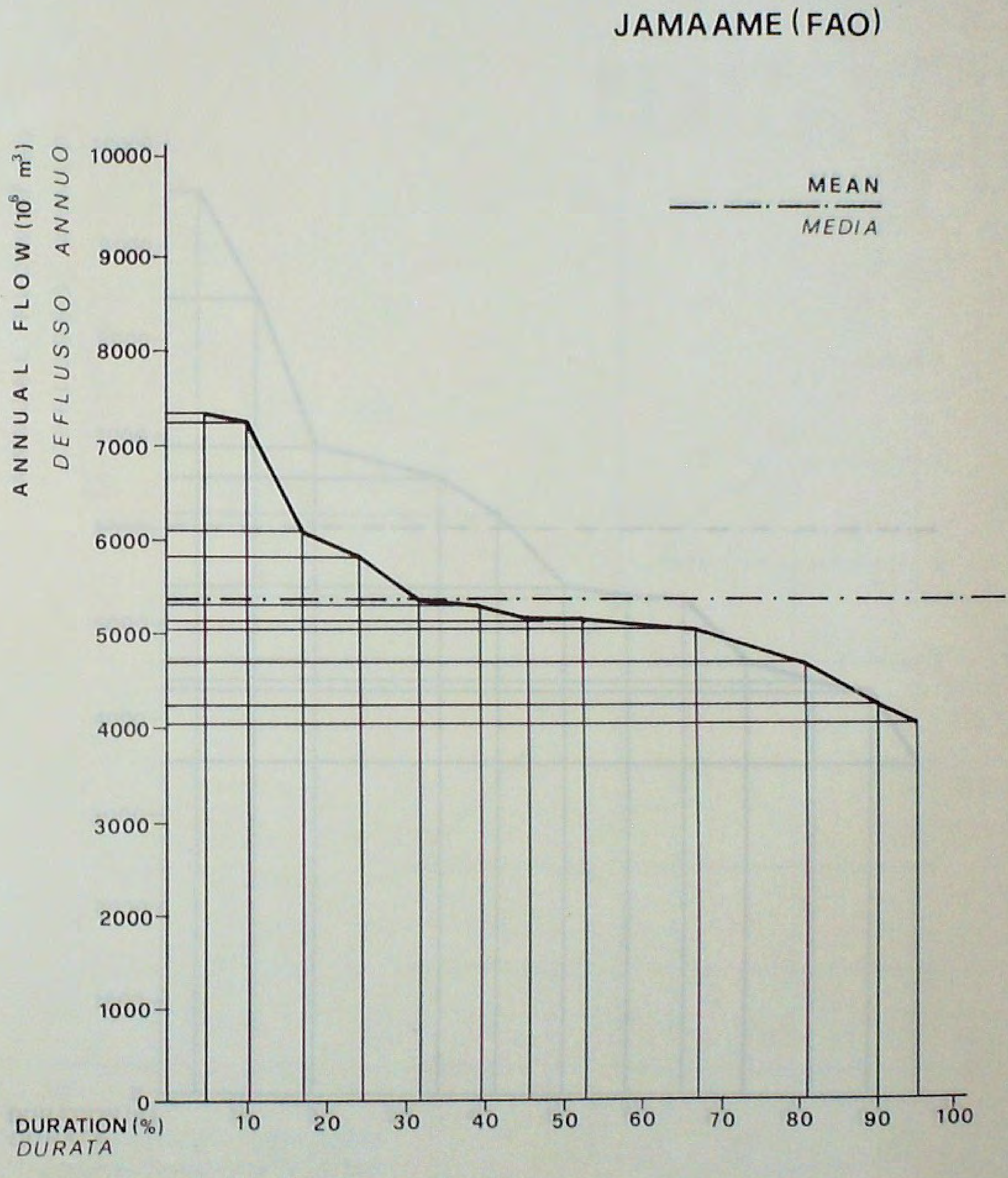
fig. 6b. II



ANNUAL FLOW DURATION CURVE

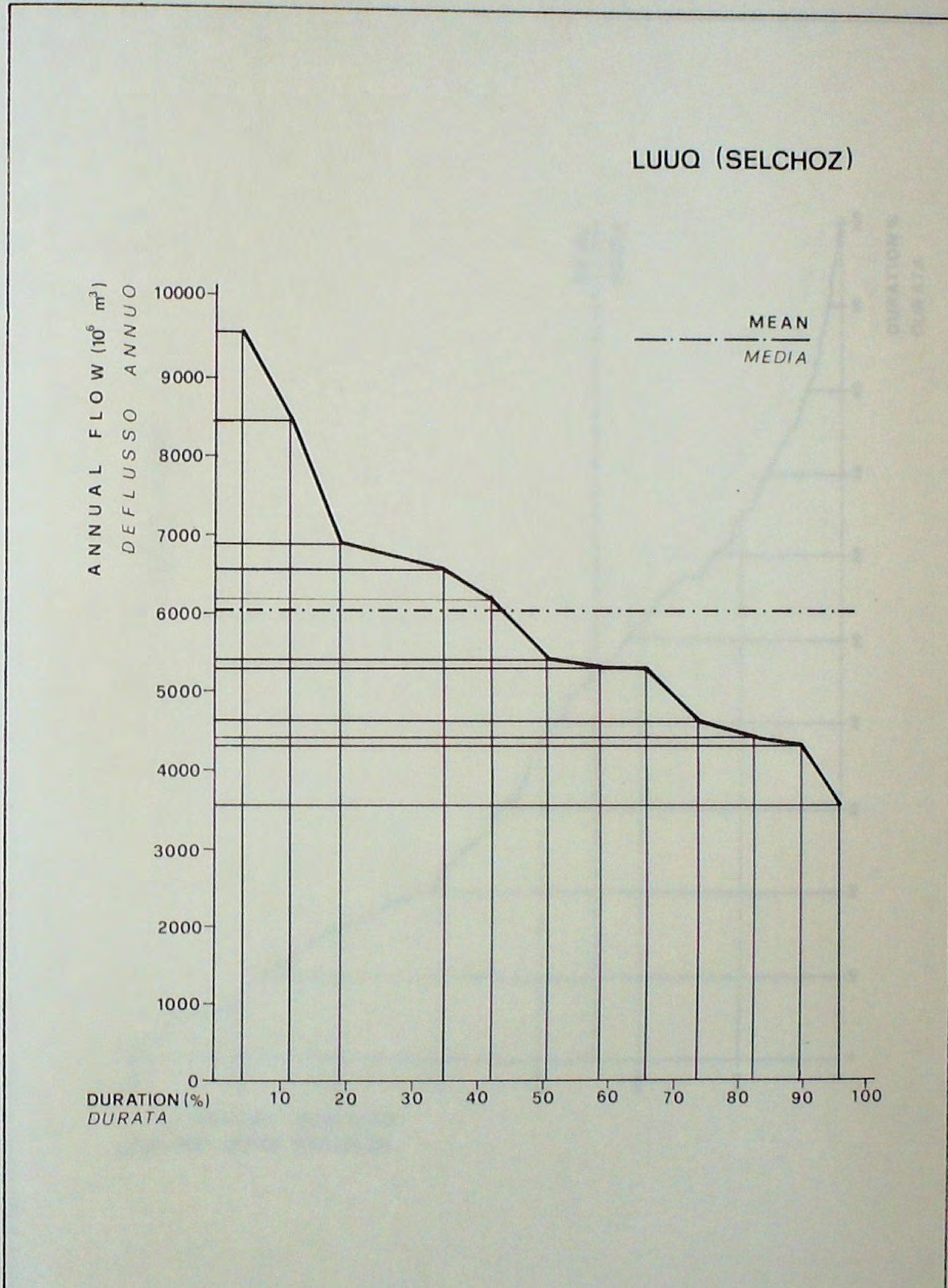
CURVA DI DURATA DEI DEFLUSSI ANNUI

fig. 6c. II



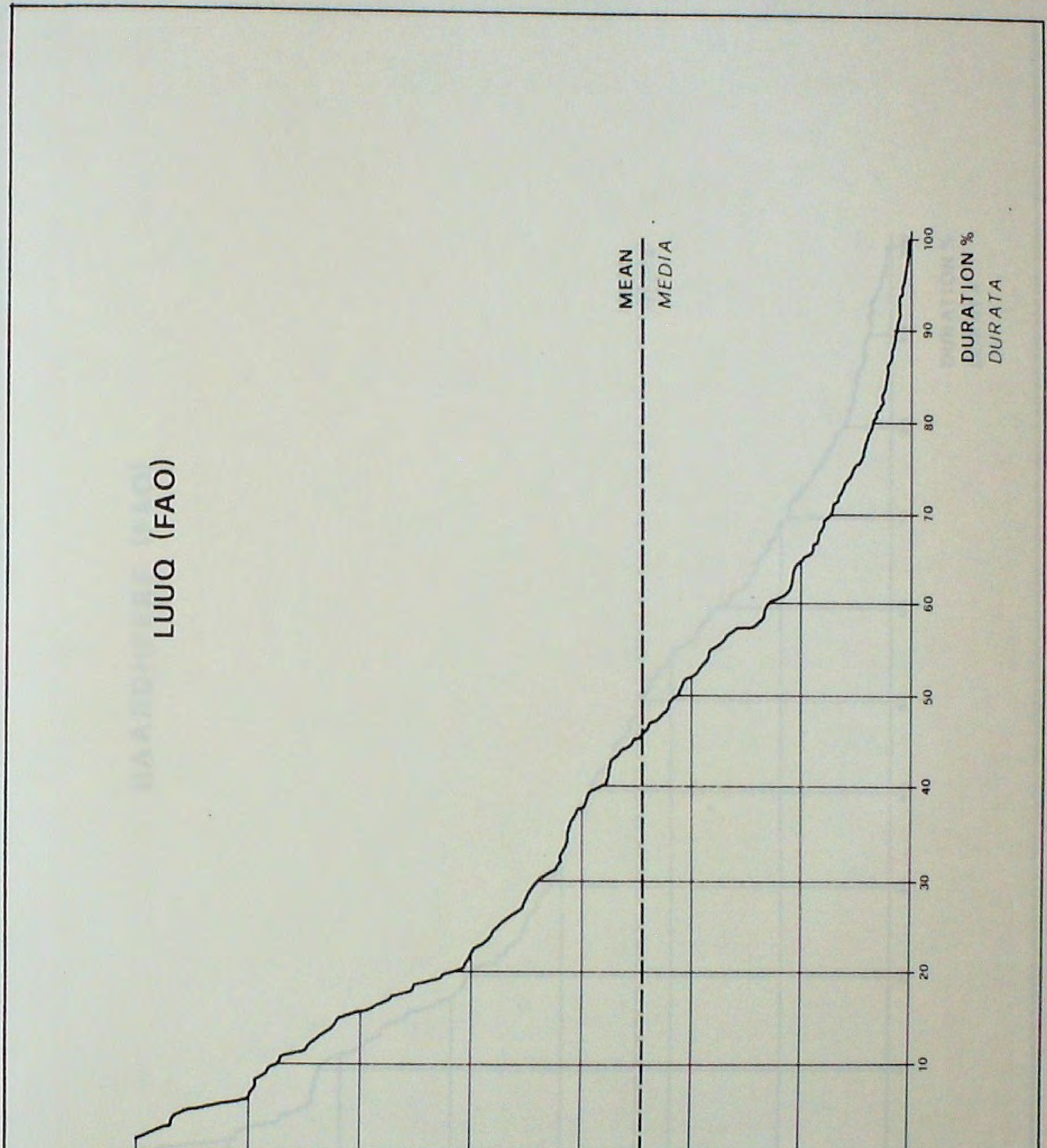
ANNUAL FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI ANNUI

fig. 6d. II



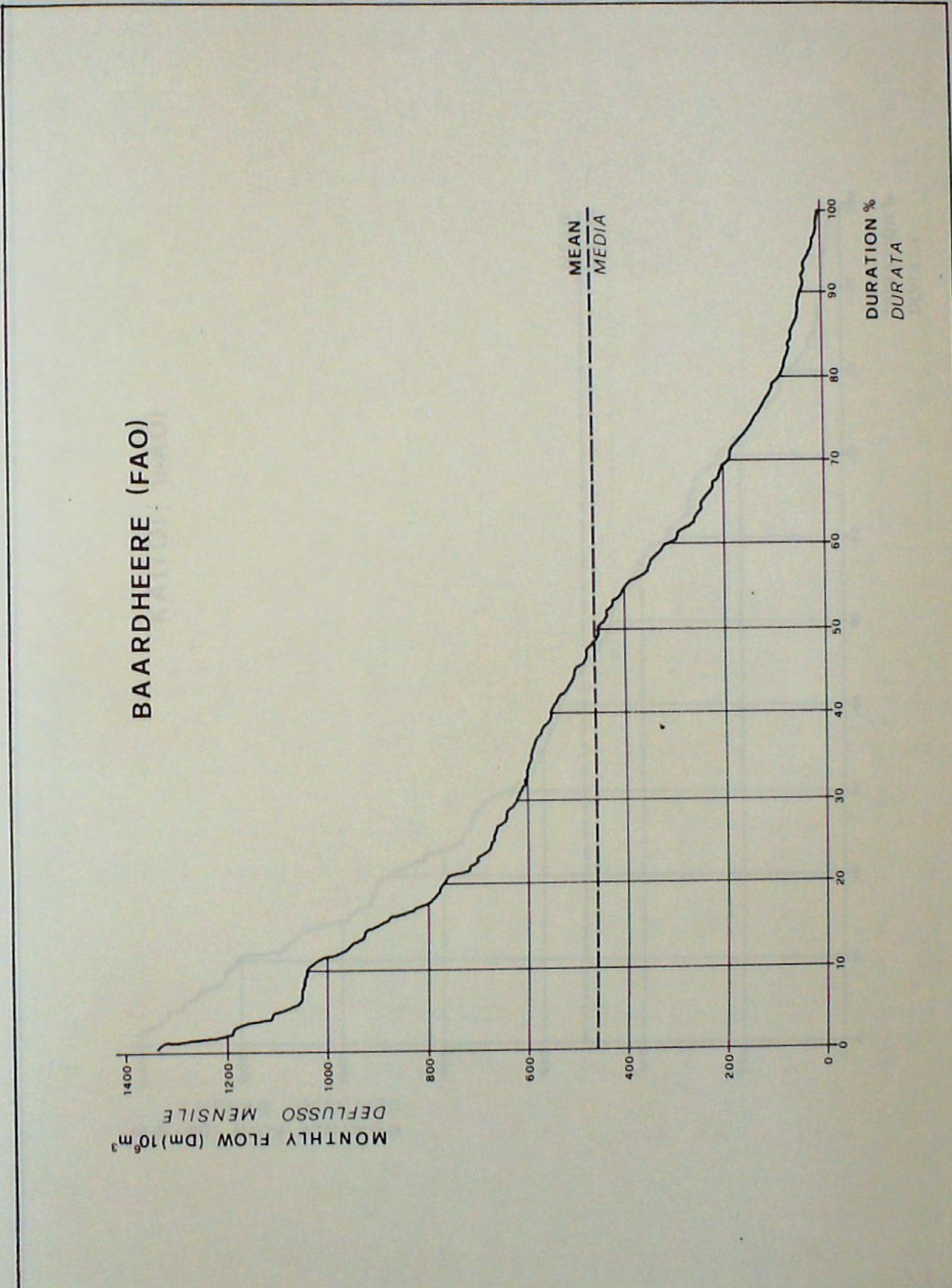
ANNUAL FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI ANNUI

fig. 6e. II



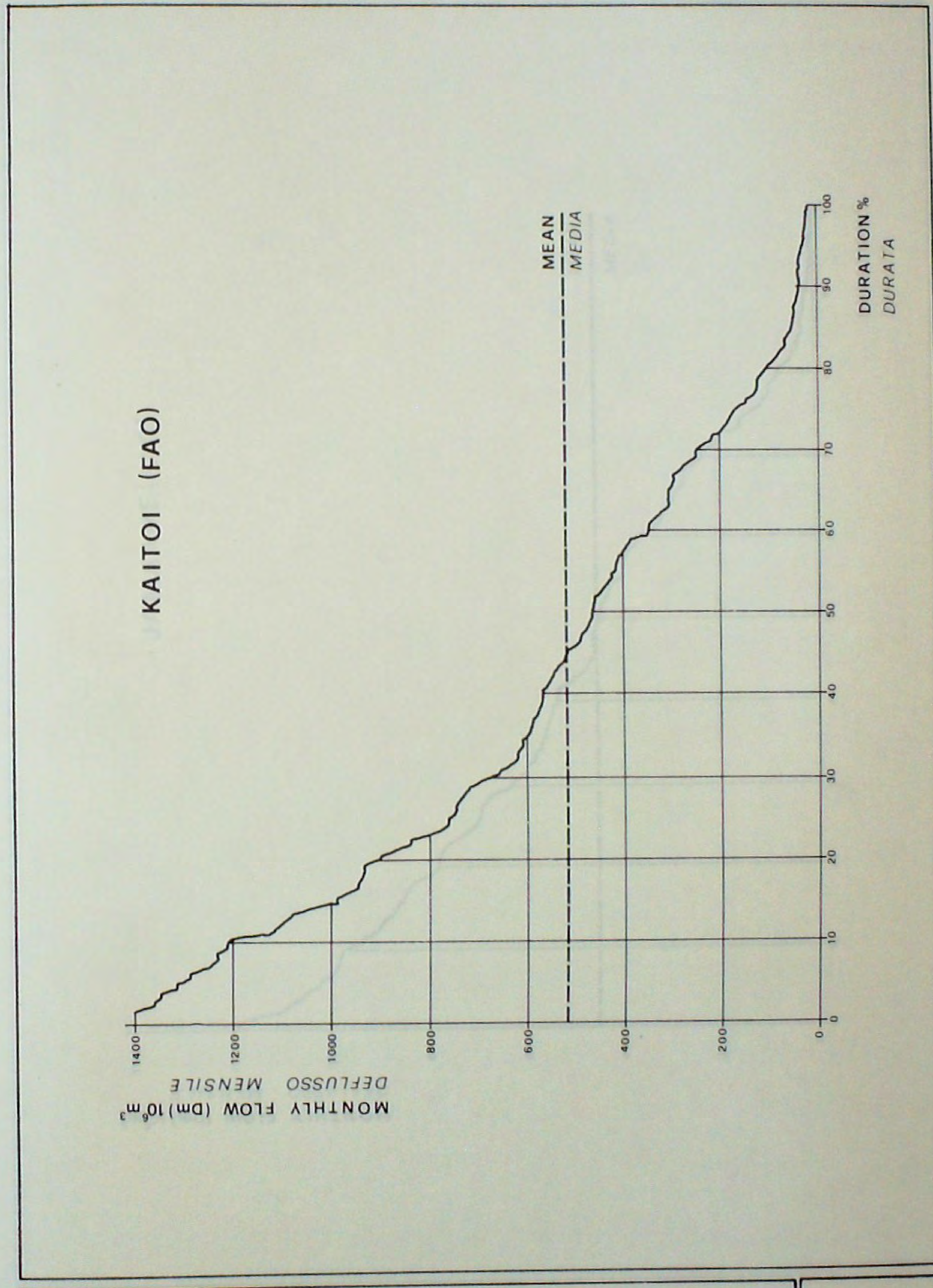
MONTHLY FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI MENSILI

fig. 7a. II



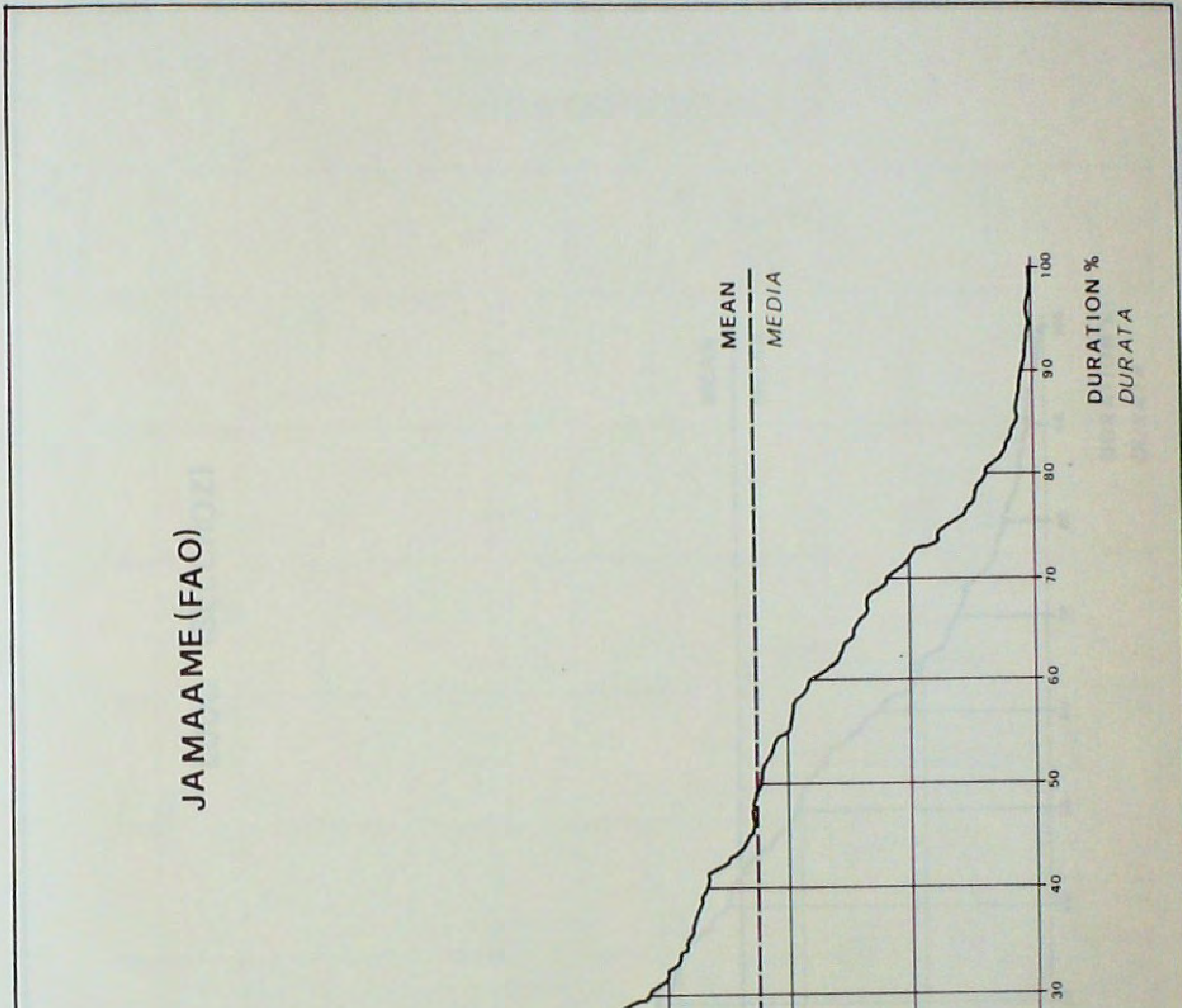
MONTHLY FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI MENSILI

fig. 7b. II



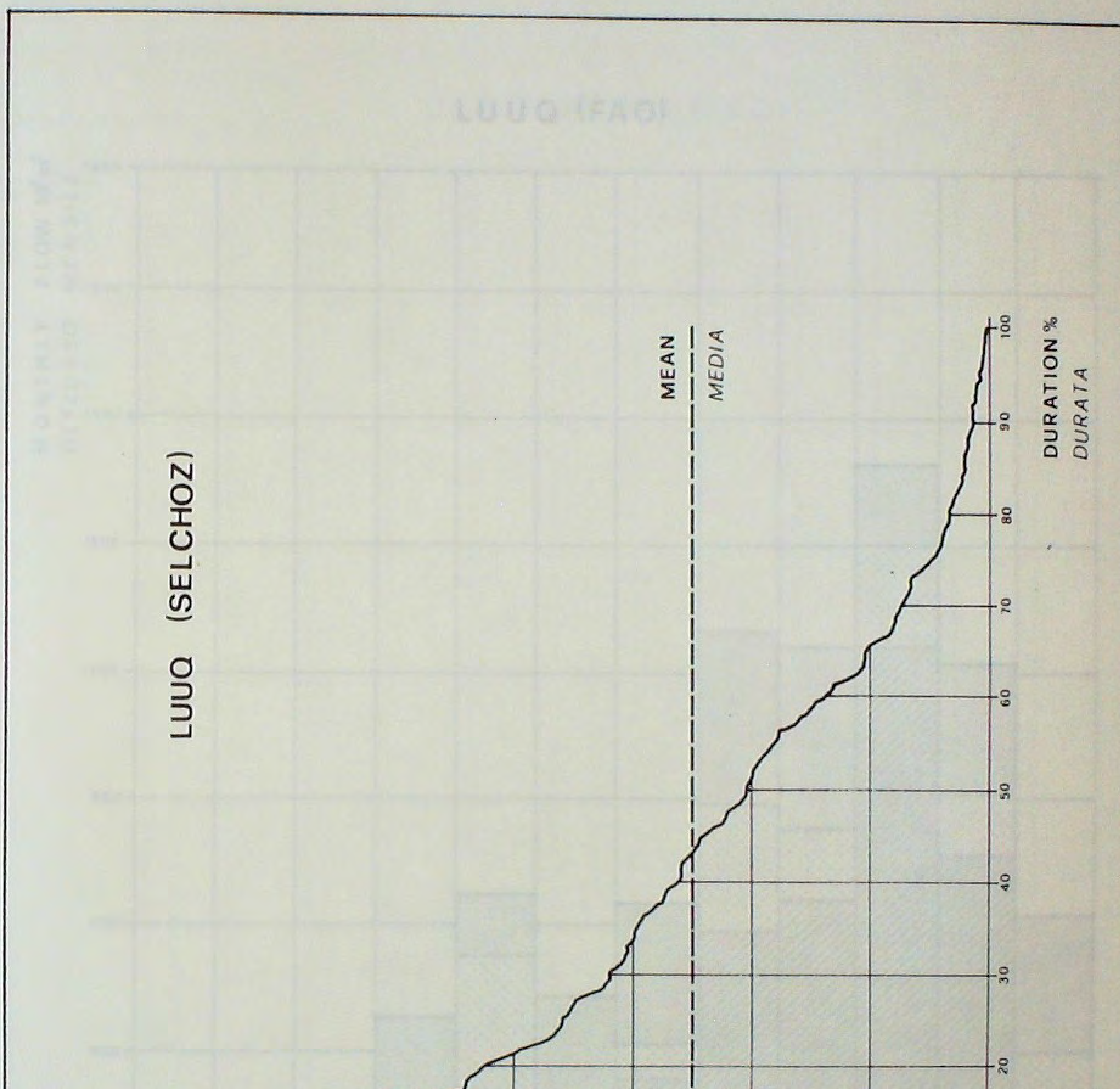
MONTHLY FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI MENSILI

fig. 7c. II



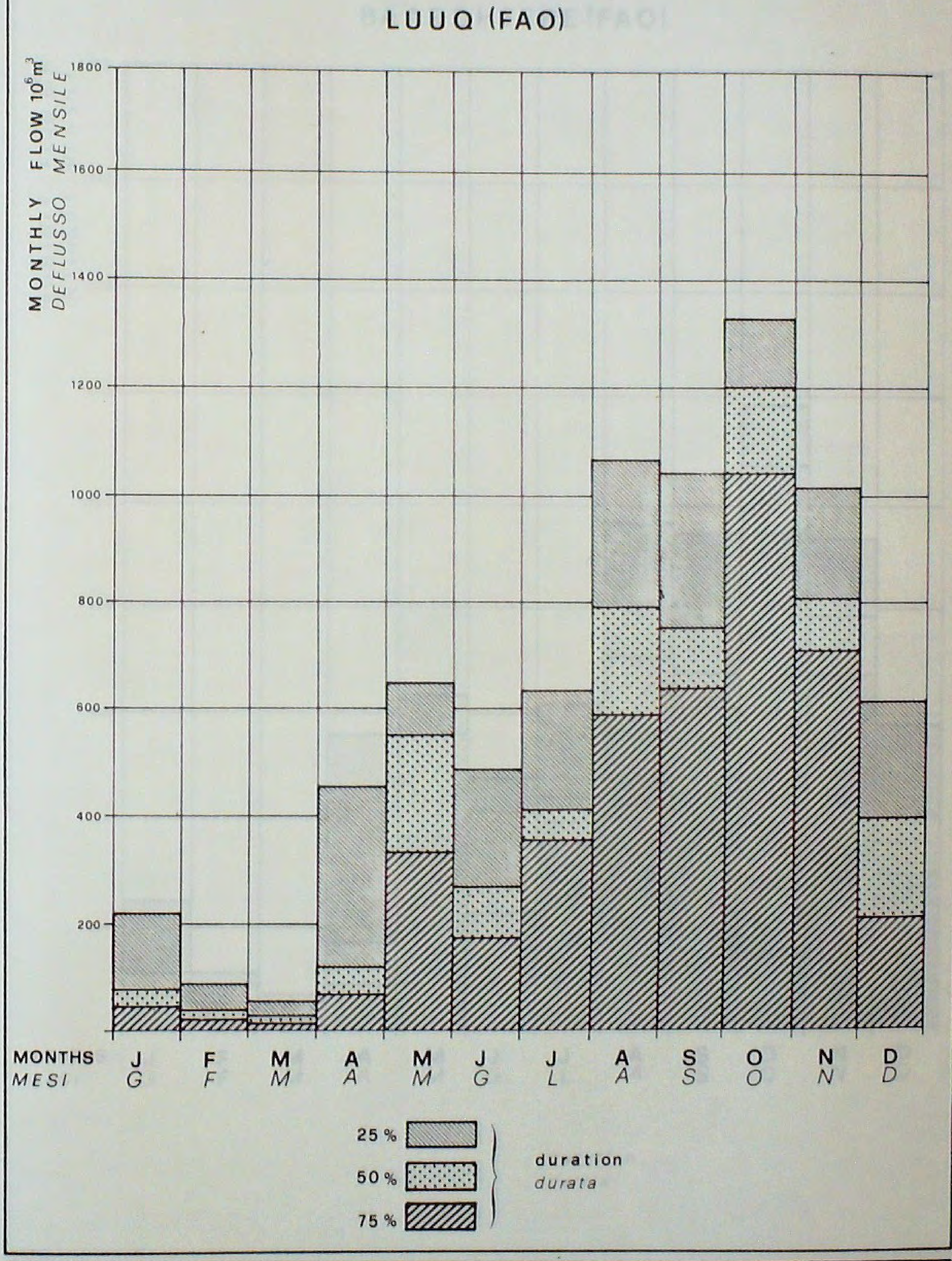
MONTHLY FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI MENSILI

fig.7d.II



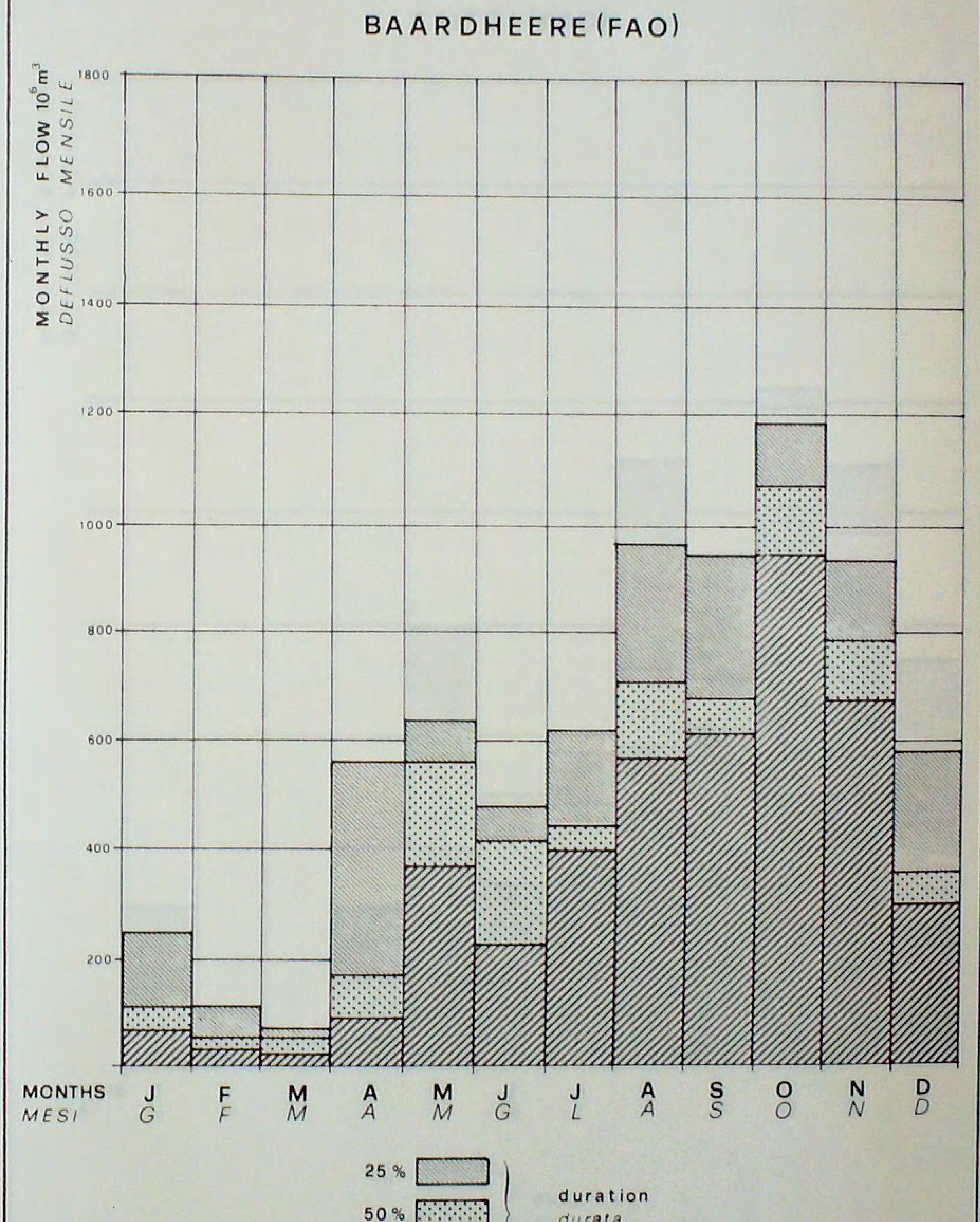
MONTHLY FLOW DURATION CURVE
CURVA DI DURATA DEI DEFLUSSI MENSILI

fig. 7e.II



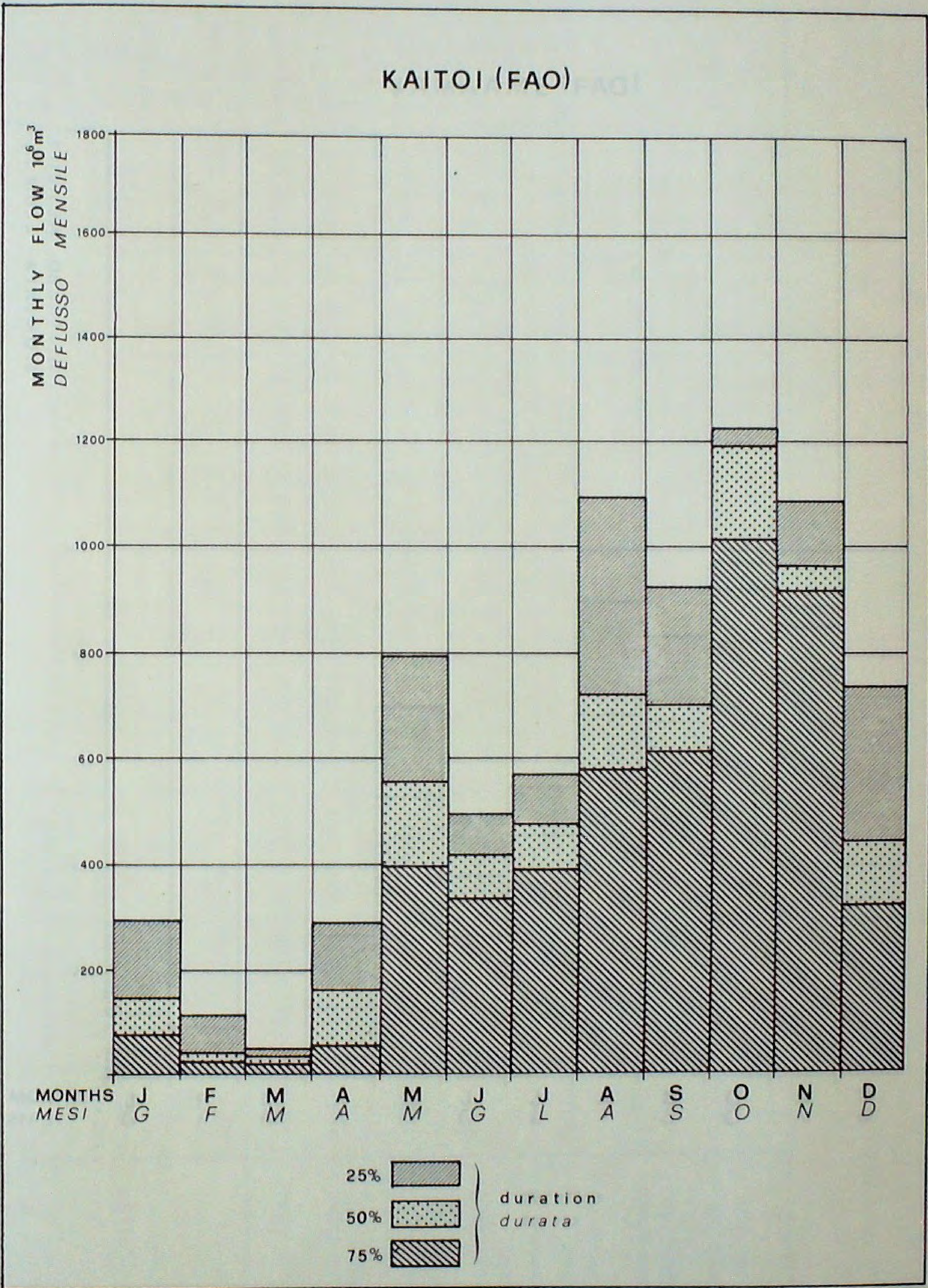
MONTHLY FLOWS (25%, 50%, 75% DURATIONS)
DEFLUSSI MENSILI (DURATA DEL 25, 50 E 75 %)

fig. 8a.II



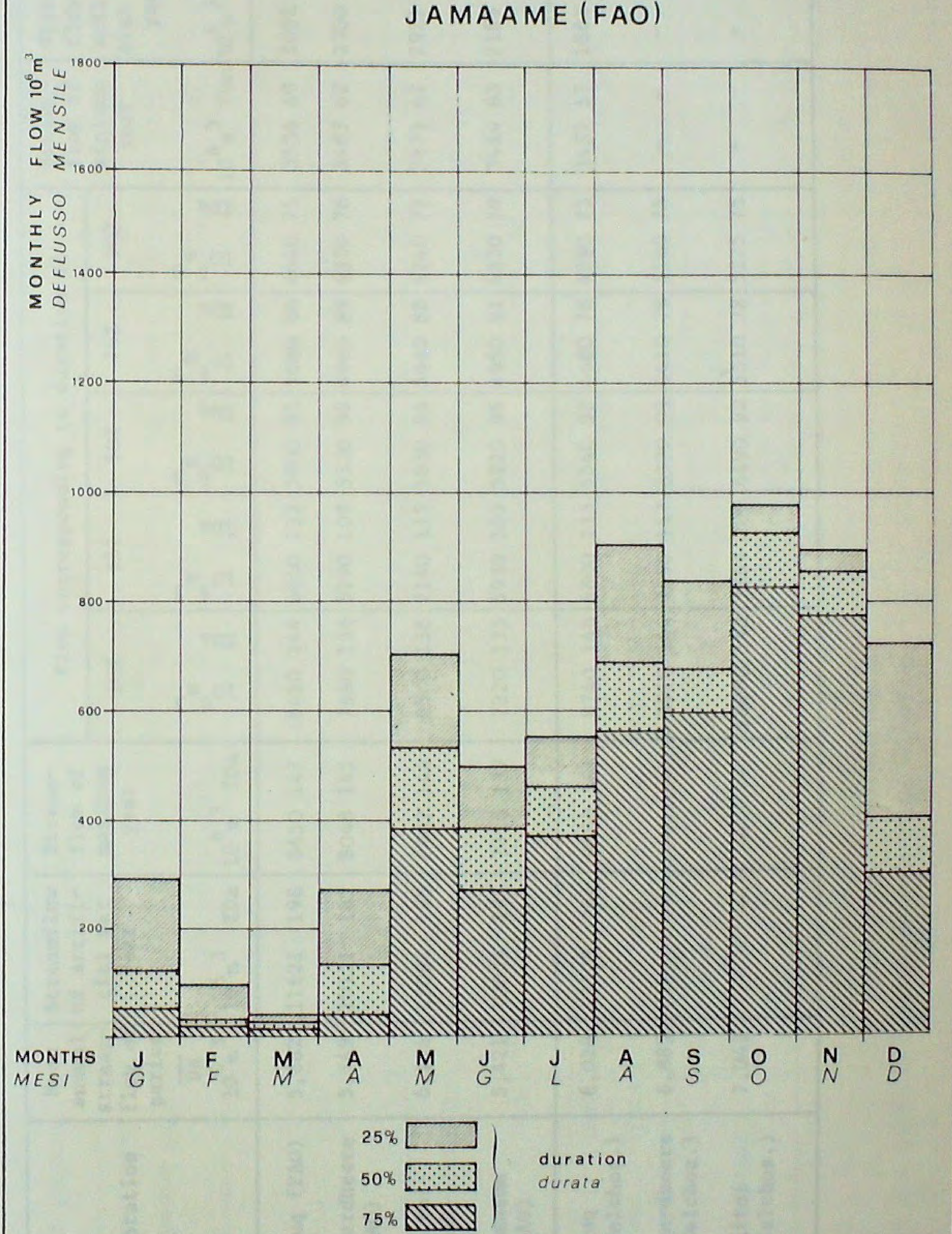
MONTHLY FLOWS (25 %, 50 %, 75 % DURATIONS)
DEFLUSSI MENSILI (DURATA DEL 25, 50 E 75 %)

fig. 8b. II



MONTHLY FLOWS (25%, 50%, 75% DURATIONS)
DEFLUSSI MENSILI (DURATA DEL 25, 50 E 75%)

fig. 8c.II



MONTHLY FLOWS (25%, 50%, 75% DURATIONS)
DEFLUSSI MENSILI (DURATA DEL 25, 50 E 75 %)

fig. 8d. II

Table 8 - Characteristics of distribution of water resources

Station	Mean annual streamflow of period Da	Streamflow of artificial wet year		Streamflow of maximum year		Flow corresponding to duration of										Streamflow of minimum year		Streamflow of artificial dry year	
						10%		25%		50%		75%		90%					
	$10^6 m^3$	$10^6 m^3$	%Da	$10^6 m^3$	%Da	$10^6 m^3$	%Da	$10^6 m^3$	%Da	$10^6 m^3$	%Da	$10^6 m^3$	%Da	$10^6 m^3$	%Da	$10^6 m^3$	%Dm	$10^6 m^3$	%Da
Luuq (FAO)	5,882	11621	198	8650	147	8480	144	6610	112	5600	95	5080	86	4440	75	3536	60	2002	34
Baardheere (FAO)	5,549	10121	182	8048	145	7560	136	5990	108	5320	96	4960	89	4320	78	3463	62	2300	41
Kaitoi (FAO)	6,194	12084	195	8902	144	8540	138	7140	115	5830	94	5440	88	4740	77	3871	62	2921	47
Jamaame (FAO)	5,421	10024	185	7416	137	7320	135	5930	109	5220	96	4950	91	4320	79	3424	63	2186	40
Luuq (Selchoz.)	6,028	13528	244	9650	161	8740	146	6800	113	5540	92	4680	78	4390	73	3437	57	1881	31
Baardheere (Selchoz.)	6,885	-	-	-	-	9910	144	7690	117	6370	93	5410	79	5160	75	-	-	-	-
Kaitoi (Selchoz.)	7,043	-	-	-	-	10090	142	7864	109	6490	92	5510	78	5275	75	-	-	-	-

Table 9 - Seasonal distribution of water resources

Station	Streamflow $10^6 m^3$ Annual mean $\bar{D}a$	Streamflow $10^6 m^3$ Monthly mean $\bar{D}m$	Mean monthly streamflow, D_m, as percentage of streamflow, D_a, and the monthly mean D_m, for the entire period: J	F	M	A	M	J	J	A	S	O	N	D
Luuq (FAO)	5882		1,8	0,8	1,7	4,2	10,1	5,9	7,8	13,9	13,4	18,8	14,9	7,1
		490	21	10	21	51	121	71	93	161	161	226	179	85
Baardheere (FAO)	5549		2,3	1,2	1,9	4,9	10,1	6,5	8,3	13,1	12,9	17,4	13,9	7,5
		462	27	15	23	58	121	78	99	158	155	209	168	20
Kaitoi (FAO)	6149		2,5	1,4	1,5	3,8	10,3	6,7	7,4	12,7	12,7	16,7	15,6	8,7
		516	30	17	19	46	124	81	89	152	152	200	187	104
Jamaame (FAO)	5421		2,8	0,9	1,4	3,6	10,4	7,4	8,0	12,8	13,0	15,5	15,2	9,0
		452	34	11	17	43	125	89	96	154	156	186	182	108
Luuq (Selchoz)	6028		1,6	0,9	1,7	4,5	10,7	5,6	7,8	13,3	13,0	20,6	14,2	6,3
		502	19	11	20	54	129	68	93	159	156	248	170	75

Table 10 - Characteristics of distribution of monthly availability

Station	Maximum monthly streamflow $10^6 m^3$	Maximum monthly streamflow %$\bar{D}m$	10% $10^6 m^3$	10% %$\bar{D}m$	25% $10^6 m^3$	25% %$\bar{D}m$	50% $10^6 m^3$	50% %$\bar{D}m$	75% $10^6 m^3$	75% %$\bar{D}m$	90% $10^6 m^3$	90% %$\bar{D}m$	Minimum monthly streamflow $10^6 m^3$	Minimum monthly streamflow %$\bar{D}m$	Mean monthly streamflow $10^6 m^3$
Luuq (FAO)	1646	336	1150	235	740	151	420	86	105	21	30	6	8	2	490
Baardheere (FAO)	1338	290	1040	225	670	145	455	98	140	30	45	10	9	2	462
Kaitoi (FAO)	1461	283	1210	234	760	147	460	89	160	31	30	6	17	3	516
Jamaame (FAO)	1191	263	975	216	700	155	450	100	140	31	15	3	6	1	452
Luuq (Selchoz)	2074	413	1270	253	720	143	410	82	100	20	30	6	7	1	502

4.2 INCREASED AVAILABILITY OF RESOURCES

The irregularity of the distribution of water resources - especially seasonally - means that measures must be taken to regularize streamflows in order to ensure water for various uses, particularly irrigation. The problem is how to increase the amount of water available in the dry season by harnessing the surpluses available at other times of the year, while providing adequate protection against the disastrous floods.

A preliminary investigation has been made of the streamflow - regulation characteristics along the river, leaving aside for the moment constraints of a geomorphological, geological and technical nature.

Table 11 indicates the water resources potentially available if certain regulation works were constructed. The investigation was run on the assumption of constant monthly water releases throughout the year, in the case of seasonal, annual and multiannual regulation.

It may be observed that, in general, conditions for the development of water resources are fairly uniform along the whole of the Juba.

By seasonal regulation, in other words by having sufficient capacity to shift part of the stream flow by a few months, it is possible to exploit around 17% of the resources, on average, thus making available minimum quantities of 70 to 90 x 10^6 m^3/month. By means of suitable storage to provide annual balance, instead, the water availability rises to over 60% of the natural resources, with volumes of around 280 to 300 x 10^6 m^3/month guaranteed. While by means of multiannual regulation it is possible to shift streamflows not only from one month to another but also from one year to another, thus making good the shortfalls in the dry years and avoiding possible failures in delivery. In the case of the Juba, regulation covering a two-year period would guarantee availability of around 80% of the water resources or something like 370 to 390 x 10^6 m^3/month. Beyond this point the increase in resource availability with increase in regulation capacity is not great.

There are no marked differences, in general, between estimates made on the basis of FAO data and those from the Soviet Report, at least for Luuq Gannane station, though the latter data do indicate a smaller proportion of the resource to be available as a result of annual compensation.

The foregoing results are for the most unfavourable case of streamflow (Critical Case 1) and they thus refer to the highest probable frequency of satisfying the assumed demand the exception being, of course, multiannual regulation extended to the whole period of observation.

Along with the general processing performed for the whole of the river, certain hydrological investigations of a more specific nature have been run for particular stations, in relation to given engineering construction projects envisaged for sites near those stations. The first of these hydrological investigations concerns the size of the reservoir to be created for streamflow regulation and flood control some 20-40 km north of Baardheere (see Part III of this Volume). The main aim was to obtain a rough estimate of the regulating capacity needed to ensure given water supplies for various uses and to appropriately moderate flood flows.

The streamflow data from Baardheere station contained in the FAO Report were selected for the investigation. As it is impossible at this stage to pass judgement on the correctness or otherwise of the FAO and Selchozpromexport data, it was decided to adopt the lowest figure for possible wa-

ter volumes, based on data available for Luuq and Baardheere stations.

In the first place, to obtain some general ideas on the subject, the investigation of the water resources potentially available at Baardheere if regulation is practised was extended to cover different levels of probability of satisfying the demand, namely admitting that there could be failures in a restricted number of years. The first three critical cases for annual and biennial regulation were considered, representing firm supplies on average in about 93%, 86% and 80% of the cases. This range of possible failures is of interest for the irrigation water users who can tolerate quite marked water deficits provided these are not too frequent. The results are given in Table 12.

It ensues that if failures in about 20% of the years are accepted in the case of annual regulation, the development level of the resource (percentage of general average of period) rises to around 85%. However, if all failures are excluded, three-year regulation is required to achieve this same percentage.

The analysis of the possibilities of regulating natural flows has been made in the light of the water demand growth assumptions framed in this development study, especially for irrigation use. Five alternatives or development solutions have been singled out for agricultural development and thus for irrigation. When these schemes are fully operational they will require fairly different water volumes at various times, depending on the crops grown and their distribution in the various irrigation districts along ghe valley. The schemes are:

A. No forage in Districts 2 and 5 and no rice
B. With forage in District 2 and no rice
C. With forage in Districts 2 and 5 and no rice
D. With forage in Districts 2 and 5 and with rice
E. Without forage but with rice

The water requirements for irrigation, at the monthly level, which correspond to the water demand at the head end of the district have been increased by 10% to cover conveyance losses.

In all five cases an identical allowance of 15 m^3/s has beed made to cover water supply needs and to ensure a minimum safe flow in the channel downstream of the dam. Breaking down these two items, 5 m^3/s should suffice for the former, leaving 10 m^3/s to permit proper dilution of pollutants, especially downstream of towns, and to keep the intrusion of the salt-water wedge at the mouth under control.

Table 13 sets forth the total monthly and annual water requirements. It will be observed that in the five alternatives considered the total annual demand lies in the 3,400-4,100 x 10^6 m^3 range, i.e. of the order of magnitude of the minimum annual streamflow values observed for the Juba. In particular, the minimum annual flow figure is exceeded by four of the five alternatives.

The average level of development of the water resource, expressed as a ratio between the mean monthly amount demanded for each alternative ($\overline{E}_m$) and the mean monthly streamflow of the period ($\overline{D}_m$), varies from 61.3% in Case A to 73.6% in Case D, with B, C and E at 68.5%, 70.2% and 67.9%, respectively. On the whole, the trend of demands over the course of the year is in line with the average trend of streamflow.

Table 11 - Water resources available in different periods

Period of min. flow in years	Luuq (FAO)		Baardheere		Kaitoi		Jamaame		Luuq (Selchoz)	
	Mean monthly streamflow $10^6 m^3$		Mean monthly streamflow $10^6 m^3$		Mean monthly streamflow $10^6 m^3$		Mean monthly streamflow $10^6 m^3$		Mean monthly streamflow $10^6 m^3$	
0,5	69,3	14,1	86,2	18,6	94,8	18,3	77,5	17,1	66,4	13,3
1	294,7	60,1	288,5	62,4	322,6	62,5	285,3	63,2	286,4	57,2
2 *	397,3	81,0	374,1	80,9	398,5	77,2	361,8	80,1	403,4	80,6
3 *	417,6	85,2	391,8	84,7	428,9	83,1	387,7	85,8	417,8	83,5
4 *	417,4	85,1	399,8	86,5	450,8	87,3	397,4	88,0	425,1	85,0
...	...	...	...	...	...	...	...	...	...	...
14 (a)	490,2	100,0	462,4	100,0	516,2	100,0	451,7	100,0	500,2	100,0

* Only successive years considered

(a) Thirteen years for the Selchozpromexport series at Luuq

Table 12 - Water resources available with different levels of probability

Critical case	Annual streamflow	Mean monthly streamflow	Level of development	Biennal streamflow	Mean monthly streamflow	Level of development
I	3,463 (1955)	288.6	62.5	8,978 (1955-56)	374.1	81.0
II	4,427 (1953)	368.9	79.8	9,516 (1952-53)	396.5	85.5
III	4,697 (1962)	391.4	84.7	9,677 (1954-55)	403.2	87.2

Table 13 - Total monthly and annual water requirements ($m^3 \times 10^6$)

Solution	J	F	M	A	M	J	J	A	S	O	N	D	Year
A	183.4	141.1	155.4	133.7	280.9	417.1	359.3	257.0	239.0	427.3	428.0	374.4	3397.4
B	242.1	197.1	218.3	156.9	297.1	430.0	387.1	307.8	283.2	439.2	438.3	402.5	3799.6
C	252.0	207.5	229.8	161.7	306.6	439.3	395.4	317.4	292.8	443.9	439.5	406.5	3892.4
D	237.5	195.1	241.0	195.6	345.2	455.6	388.4	351.8	317.0	481.1	466.2	404.3	4078.8
E	183.4	141.1	180.7	173.8	334.8	456.7	372.5	305.4	278.3	478.9	467.9	388.4	3761.9

The possibility of satisfying these requirements can be examined firstly simply by comparing availability and demand on a monthly basis, for the whole of the time series of streamflows to hand. This is equivalent to satisfying demand from the unregulated flows, without any relevant storage capacity. Table 14 gives some results of this comparison, the following being indicated for each alternative: level of development of the water resource; the annual deficits, namely the years (historical) when there was at least one month of deficit; monthly deficits, namely the months when the demand is not satisfied; and the statistical characteristics of the monthly deficits (mean, standard deviation and coefficient of variation).

The capacity of the reservoir needed to regulate streamflows to satisfy the different demands was then determined. The regulation calculations were run by means of numerical methods on the whole time series available, namely on the assumption that the reservoirs would be operated in such a way as to ensure multiannual regulation of the natural flows. The maximum capacity figure obtained by comparing availability and demand is the minimum storage needed to guarantee that the demand is completely satisfied on the basis of the time series examined. The calculation of the regulating capacity for Solution D is given in Annex 3, by way of example.

Table 15 sets forth the regulation capacities needed to guarantee the different drafts from the reservoir excluding all failures, for the observation period concerned. These values refer to the satisfaction of the whole of the irrigation demand, as well as the water supply and sanitary requirement, i.e. if a single reservoir sited near Baardheere had to satisfy the whole service.

The storages obtained depend on the level of development of the resource and on the demand diagram for each alternative. They vary from 2.3 to 3.3 times the mean monthly streamflow and from 3.8 to 4.6 times the average monthly draft. Regulation efficiency is fairly constant in the various solutions, except for C where it is slightly lower.

The analysis of regulation capacity was not pushed to different levels of probability of satisfying the demand, because at this stage it does not seem to be of any great interest to determine the probability and significance of failure. In actual fact this should be formulated on the basis of criteria which take account of numerous factors such as the reduction in water supply tolerated by various crops, the critical period of crop growth, cropping patterns, methods of running the irrigation districts, value-added of the various products, etc. It is no easy task to define these criteria and this would hardly seem justified at the initial planning level. However, it can be done at the design level within the context of a simulation study of the hydraulic system which would check on the response of the system to different hydrological inputs equally probable as the time series (synthetic hydrological sequences).

Purely by way of a guide we give the regulation capacities needed in the different alternatives to satisfy the total water demand thirteen years out of fourteen, namely excluding the first critical flow case. The values obtained are: $A_1 = 752 \times 10^6\ m^3$; $B_1 = 1{,}010 \times 10^6\ m^3$; $C_1 = 1{,}124 \times 10^6\ m^3$; $D = 1{,}140 \times 10^6\ m^3$; $E_1 = 925 \times 10^6\ m^3$.

Investigation of the possibility of satisfying the water demand for various uses was also extended to different levels of development of the water resource, for each alternative; in other words lower and higher levels than the real level of the alternative were analysed, while keeping the same demand rule over the various months of the year. The rule is expressed by the values of the ratio E_j/E_m relating demand E_j in the j-th month and the mean monthly demand $\overline{E}_m$. In this way the curves expressing regulation possibilities for each solution were plotted.

This approach enable information to be obtained on the relationship, for a given demand rule, between the necessary storage capacity and the average level of draft. Thus it is possible to determine what regulation would be necessary through the various stages of agricultural development, assuming that the demand rule remains roughly the same.

In addition to the different irrigation alternatives just referred to, a demand rule that is constant over the course of the year has also been examined. In addition to constituting a term of reference, this is also of direct interest as regards the use of flows for generating hydropower.

The investigation of each type of demand was performed parametrically for the following seven mean drafts: 65, 130, 195, 260, 325, 390 and 455 x 10^6 m^3/month.

It might well be indicated that the foregoing processing operations were performed without any reference to the actual morphology of the site and the possibility of finding the physical storage capacity to permit regulation at the demand rate considered.

Table 16 indicates the possibility of satisfying each type of demand at the above seven levels of development, without any regulation of the flows. It will be noted that for all the alternatives, except the case of constant draft in all months, the frequency with which the demand is satisfied is 90% or less only in the instance of the lowest level of development examined, namely equal to a "mean" draft of about 25 m^3/s. The increase of the deficit for some of the alternatives is illustrated in Fig.9.II(a and b).

Fig.10.II (a and b) shows the curves indicating the draft possibilities for the different types of demand, i.e. the curves which, for each type of alternative, indicate the relationship that exists between mean draft and the storage capacity needed to guarantee the monthly drafts. It is apparent that the more difficult solution at all levels of development is that involving constant draft, whatever be the state of the river and the demand diagram. The draft possibility curves of the other alternatives are fairly close to one another, especially at the lowest levels of draft.

As will be noticed, the capacities needed to ensure the satisfaction of demand in the five alternatives examined (actual situation of demand) fall in the biennial compensation zone (Alternatives B, C and D) or are at the lower limit thereof (E), except in the case of the alternative with the lowest demand (A), which falls in the annual compensation zone.

An investigation has also been run on the question of the size of a reservoir for Saakow, to be used to provide water for the irrigation districts downstream, especially in the short term. On the basis of the FAO data for the Baardheere and Kaitoi stations the time series of minimum flows for 1, 2, 3, 4, 5 and 6 month sequences were calculated for the first two critical cases (Table 17). These values were then stripped of losses due to evaporation from the pool surface (estimated indicatively as 200 mm/month, on average) and were used to calculate the capacities needed to ensure constant deliveries of 25-30 m^3/s over a 6-month period. The question of the dimensional design of the reservoir is discussed in Part III of this Volume.

Table 14 - Characteristics of satisfaction of demand without regulation

Alternative	Mean monthly deliveries $10^6 m^3$	Level of development of water resource %	Annual deficit N	Annual deficit %	Monthly deficit N	Monthly deficit %	Characteristics of monthly deficit m	s	CV
A	283.1	61.3	14	100	62	36.9	113.5	68.4	60.3
B	316.6	68.5	14	100	67	39.8	146.2	73.7	50.4
C	324.2	70.2	14	100	71	42.2	153.8	84.1	54.7
D	339.9	73.6	14	100	69	41.1	154.5	76.4	49.4
E	313.5	67.9	14	100	67	39.8	122.7	77.3	63.0

Table 15 - Regulation capacity necessary for the various alternative development solutions

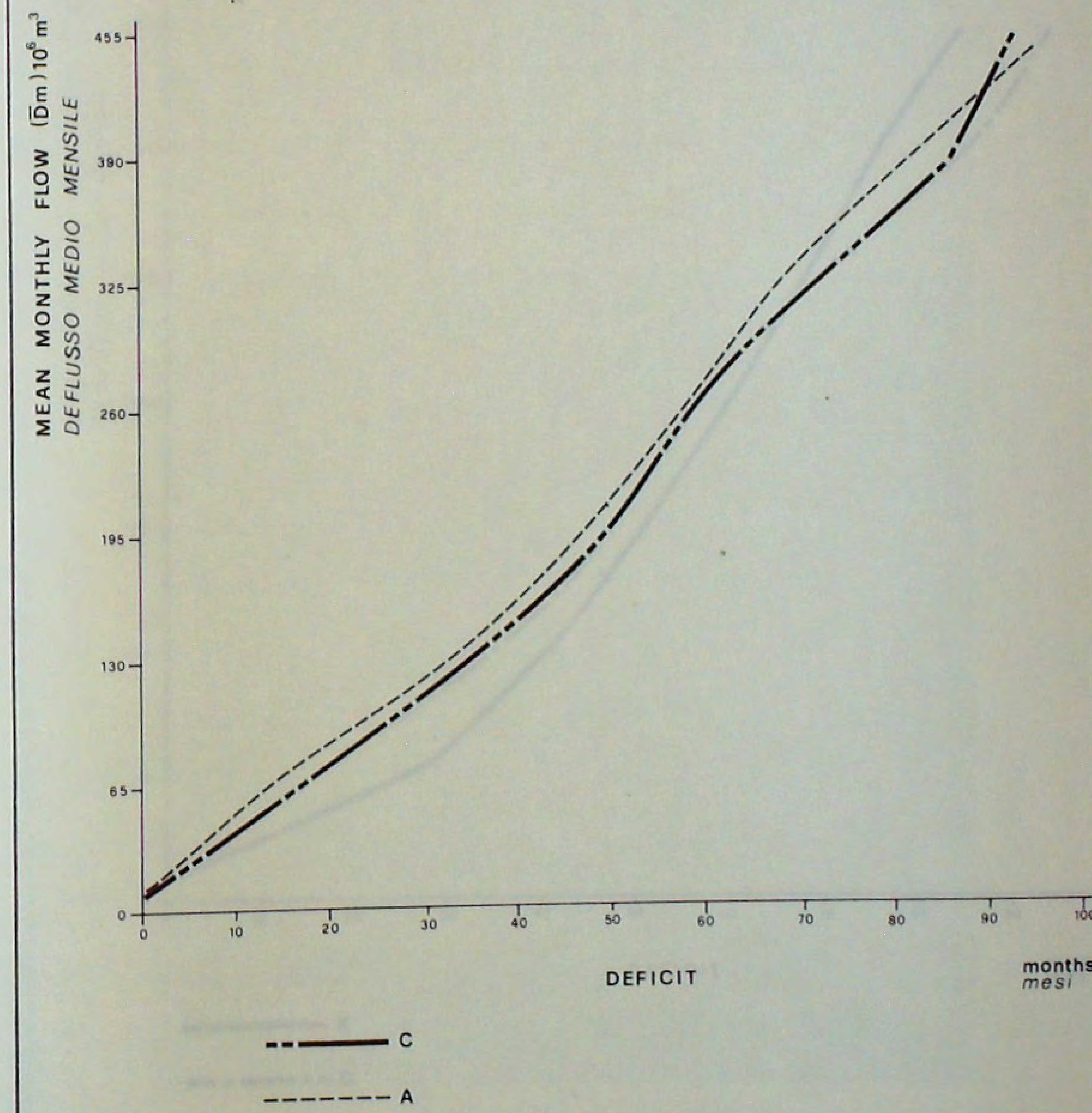
Solution	Annual deliveries 10^6 m^3	Mean monthly deliveries ($\overline{E}m$) 10^6 m^3	Level of development ($\overline{E}m/\overline{D}m$) %	Capacity needed (V) 10^6 m^3	$V/\overline{D}m$	$V/\overline{E}m$
A	3,397	283	61	1,062	2.3	3.8
B	3,800	317	69	1,358	2.9	4.3
C	3,892	324	70	1,482	3.2	4.6
D	4,079	340	74	1,518	3.3	4.5
E	3,762	313	68	1,288	2.8	4.1

Table 16 - Satisfaction of various types of demand without regulation of flows

	"Constant" Type		Type "A"		Type "B"		Type "C"		Type "D"		Type "E"	
Mean monthly deliver-ed ($10^6 m^3$)	Deficit (months)	Frequency of demand satisfaction (%)	Deficit (months)	Frequency of demand satisfaction (%)	Deficit (months)	Frequency of demand satisfaction (%)	Deficit (months)	Frequency of demand satisfaction (%)	Deficit (months)	Frequency of demand satisfaction (%)	Deficit (months)	Frequency of demand satisfaction (%)
65	28	83,3	13	91,7	17	89,9	17	89,3	16	89,9	12	92,9
130	41	75,1	33	79,9	35	79,2	35	78,7	36	78,1	34	79,8
195	51	69,2	47	71,6	49	70,8	50	69,8	48	71,0	42	75,0
260	60	63,9	58	65,1	58	65,5	58	65,1	58	65,1	56	66,7
325	68	59,2	67	59,8	68	59,5	71	57,4	68	49,2	71	57,7
390	75	55,0	81	51,5	85	49,4	86	48,5	83	50,3	83	50,6
455	84	49,7	97	42,0	95	43,5	93	44,4	97	42,0	98	41,7

Table 17 - Minimum streamflow observed for different periods of time (10^6 m^3)

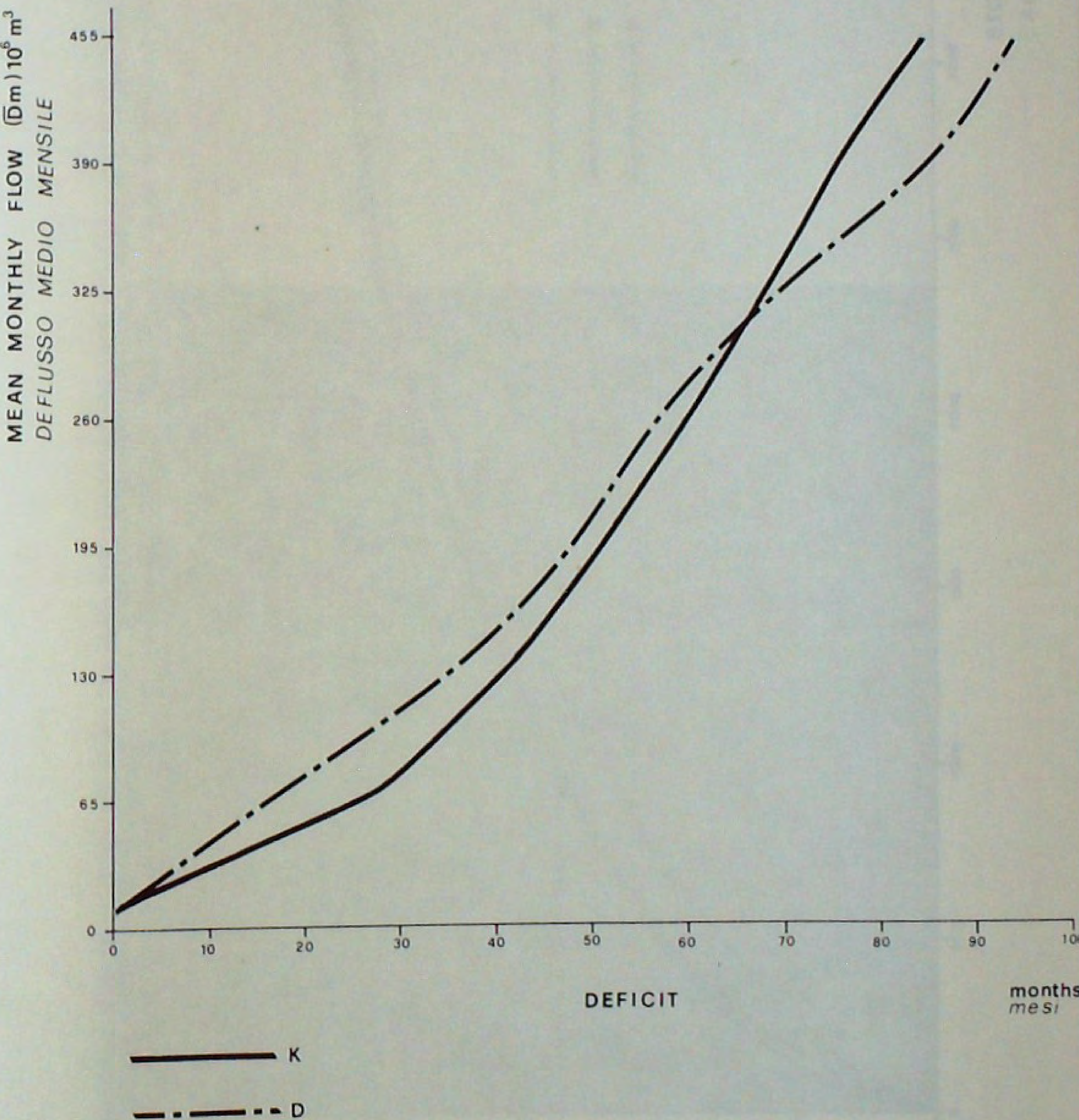
Period of minimum flow (consecutive months)	CRITICAL CASE		CRITICAL CASE	
	I	II	I	II
1	9	9	17	17
2	18	20	36	37
3	60	80	67	116
4	143	193	98	175
5	276	455	358	506
6	517	629	569	694
STATION	BAARDHEERE		KAITOI	



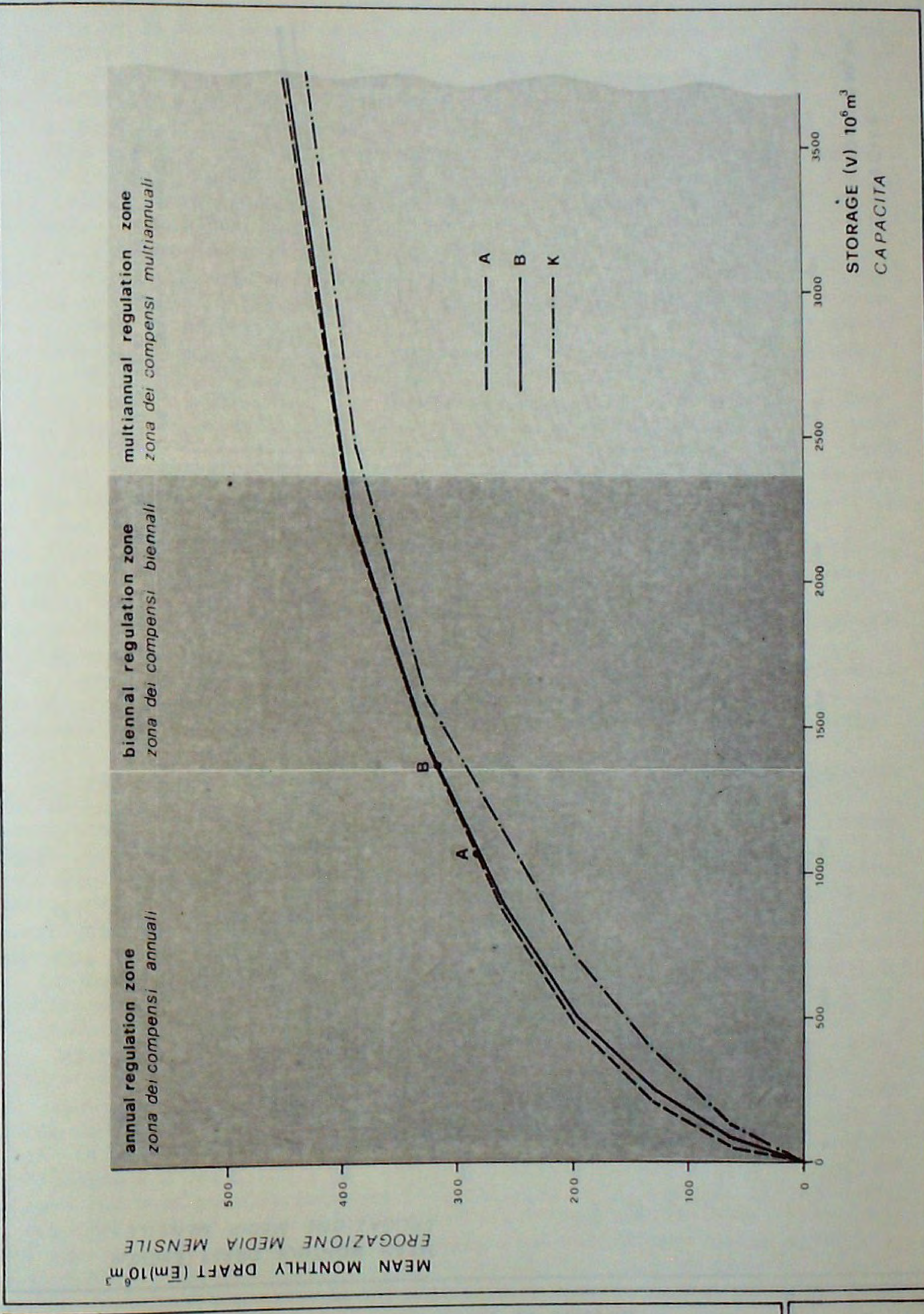
SATISFACTION OF DEMAND WITHOUT FLOW REGULATION

SODDISFACIMENTO DELLA DOMANDA A REGIME NATURALE

fig. 9 a.II



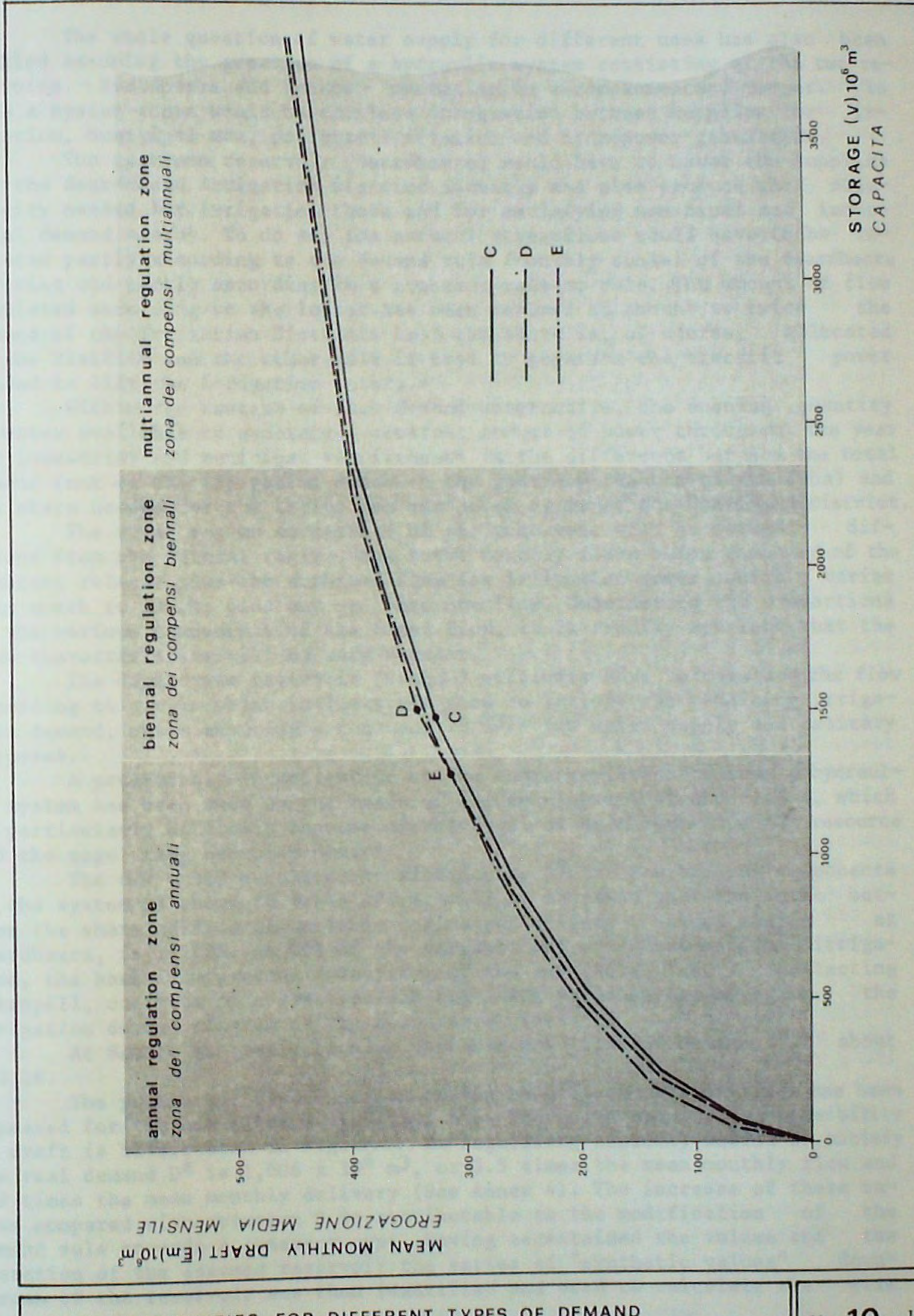
SATISFACTION OF DEMAND WITHOUT FLOW REGULATION *SODDISFACIMENTO DELLA DOMANDA A REGIME NATURALE*	fig. 9b.II



DRAFT POSSIBILITIES FOR DIFFERENT TYPES OF DEMAND

POSSIBILITÀ DI EROGAZIONE PER I DIVERSI TIPI DI DOMANDA

fig.10a.II



DRAFT POSSIBILITIES FOR DIFFERENT TYPES OF DEMAND

POSSIBILITA DI EROGAZIONE PER I DIVERSI TIPI DI DOMANDA

fig.10b.II

The whole question of water supply for different uses has also been tackled assuming the creation of a hydraulic system consisting of the two reservoirs - Baardheere and Saakow - operating in a complementary manner. In such a system there would be complete integration between supplies for irrigation, municipal use, pollutants dilution and hydropower generation.

The upstream reservoir (Baardheere) would have to cover the supplies for the Baardheere Irrigation District directly and also produce the electricity needed for irrigation there and for satisfying municipal and industrial demand nearby. To do so, the natural streamflows would have to be regulated partly according to the demand rule (monthly scale) of the Baardheere District and partly according to a constant release rule. The amount of flow regulated according to the latter has been assumed to amount to twice the demand of the Irrigation District: half the share is, of course, allocated to the District and the other half is used to generate the electric power needed to lift the irrigation waters.

Within the context of each demand alternative, the ensuing quantity of water available to generate a constant amount of power throughout the year for industrial and municipal requirements is the difference between the total demand (net of the irrigation areas in the upstream reaches of the Juba) and the share needed for the irrigation and power needs of the Baardheere District.

The river regime downstream of the reservoir will be markedly different from the natural regime, the total monthly flows being composed of the constant release plus the turbined flow for irrigation power, which varies from month to month, plus any spillage overflow. Considering the proportions of the various components of the total flow, it is readily apparent that the flow characteristics will be very regular.

The downstream reservoir (Saakow) will only have to regulate the flow according to a rule which includes the need to satisfy the remaining irrigation demand, while ensuring a constant 15 m^3/s for water supply and sanitary purposes.

A preliminary investigation of the characteristics of such a hydraulic system has been made on the basis of the development alternative D, which is particularly difficult because of the level of development of the resource and the regulation capacity needed.

The new water requirements alternative D^* for the various components of the system is shown in Table 18. It will be observed that the ratio between the share of flow at variable regime and that at constant regime at Baardheere, is 1:1.25. As 50% of the variable share is consumed for irrigation, the base flow present downstream of the reservoir, i.e. neglecting overspill, consists of a constant 60% and a 40% variable depending on the irrigation demand diagram of the Baardheere District.

At Saakow the ratio between variable and constant demand is about 1:0.18.

The parametric investigation of the regulation possibilities has been repeated for the new alternative (Type D^*). The curve showing the possibility of draft is illustrated in Fig.11.II. The regulating capacity needed to satisfy the real demand D^* is 1,606 x 10^6 m^3, or 3.5 times the mean monthly flow and 4.9 times the mean monthly delivery (See Annex 4). The increase of these ratios compared with solution D is attributable to the modification of the demand rule towards a constant type. Having ascertained the volume and the operation of the assumed reservoir the series of "synthetic values" downstream of the reservoir was then identified and used to calculate the size necessary for the reservoir at Saakow.

The results of the investigation on the draft possibilities of this latter reservoir are indicated as curve S* in Fig.11.II. The regulating capacity needed to satisfy the specific demand S* is 328 x 10^6 m^3. It will be noted that the value is relatively low, although the regulation is effected at the flow module, i.e. it is a direct consequence of the very even flow rates produced artificially in the reach between the two reservoirs.

A detailed discussion of the design of the integrated hydraulic system is given in Part III of this Volume.

If the whole of the Juba Valley is to be developed it is necessary to control and attenuate the floods. So special attention has been given to the possibility of the flood abatement possibilities of the Baardheere Reservoir. For this investigation reference has been made to the floodflow values given in the Selchozpromexport Report, as these are the only data immediately available that can be used for an assessment of this type. It should also be observed that, considering the assessment of streamflow data made here, these values should always be higher than those that would stem from the FAO data. Hence the resulting assessments should all be pitched on the safe side (without, however, going into the matter of the reliability of the data available).

In particular reference has been made to the type-hydrographs of the Autumn 1959 and Autumn 1961 floods of 100-day duration, calculated at Baardheere for probability levels of 1% and 5% (Annex 5). It should not be forgotten that these hydrographs were obtained from those actually observed at Luuq, taking account of the transfer of data from Luuq to Baardheere and of the probability distribution of the volumes of the 100-day floods (1).

The two hydrographs have probable peak discharges very close, being around 2,400 m^3/s and 1,800 m^3/s for the 100-year and the 20-year flood, respectively. The flood volumes calculated above the value of 350 m^3/s (the average of the mean monthly discharge of the Der period) are around 6,500 and 4,000 x 10^6 m^3 for the two probability levels.

From these diagrams the flood volumes that should be stored in the envisaged reservoir in the case of different maximum discharges released from the reservoir have been calculated graphically. As the flood hydrograph is typically bimodal, the volume calculation was repeated also taking account of the compensation possibilities offered by the natural trend of the flows, namely the period of lower flow between the two peaks.

Examination of the Fig.12a,b.II curves shows that in the case of a 100-year flood the greatest compensation efficiency is obtained for an 800 m^3/s outflow from the reservoir, with a reduction of about 400 x 10^6 m^3 in the capacity needed to moderate the flood with the 1959 hydrograph and about 200 x 10^6 m^3 with the 1961 hydrograph. In the case of a 20-year flood the best compensation is obtained with an outflow of 600-700 m^3/s, giving reductions of about 350 x 10^6 m^3 and 100 x 10^6 m^3, for the 1959 and 1961 hydrographs.

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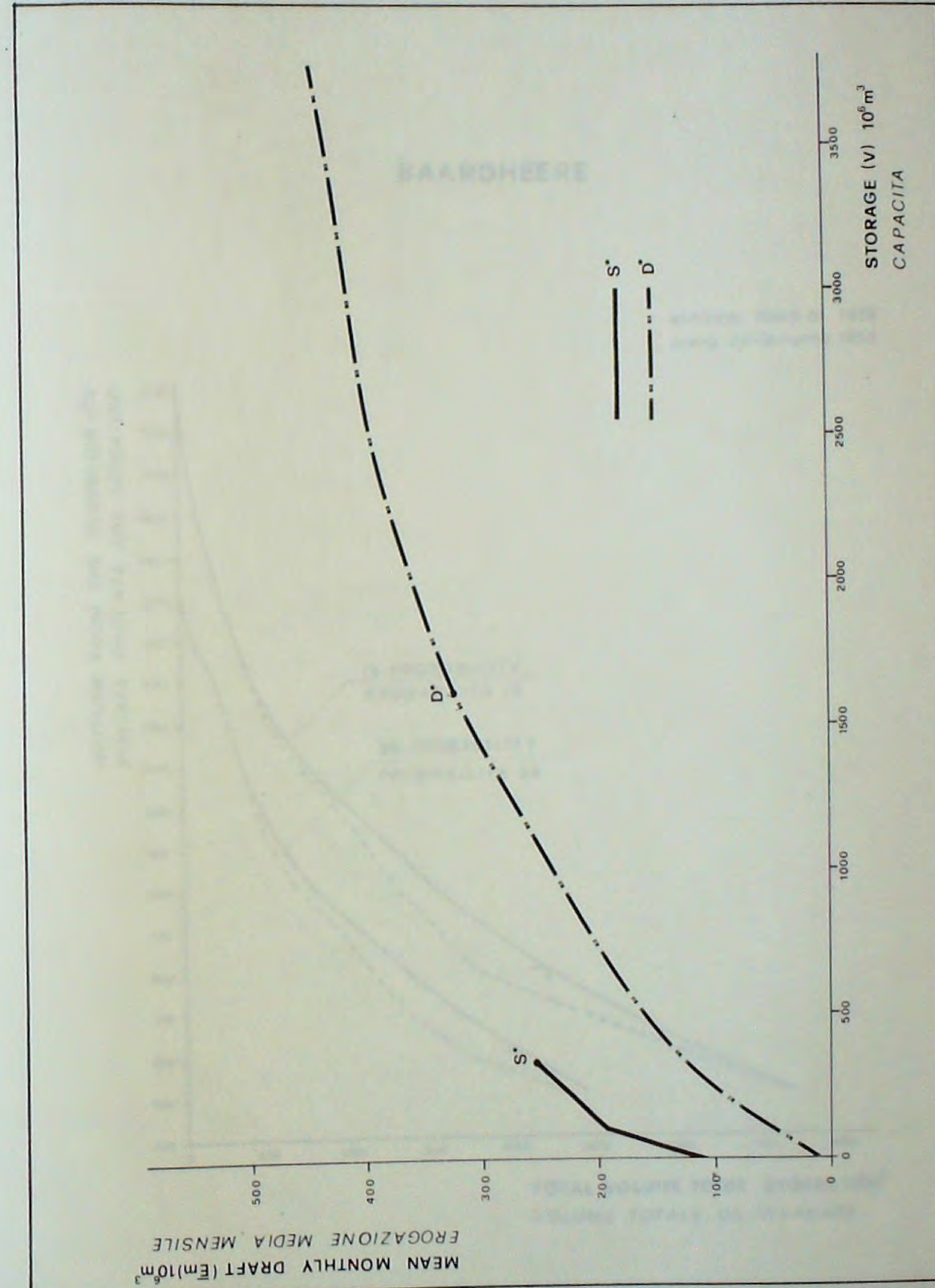
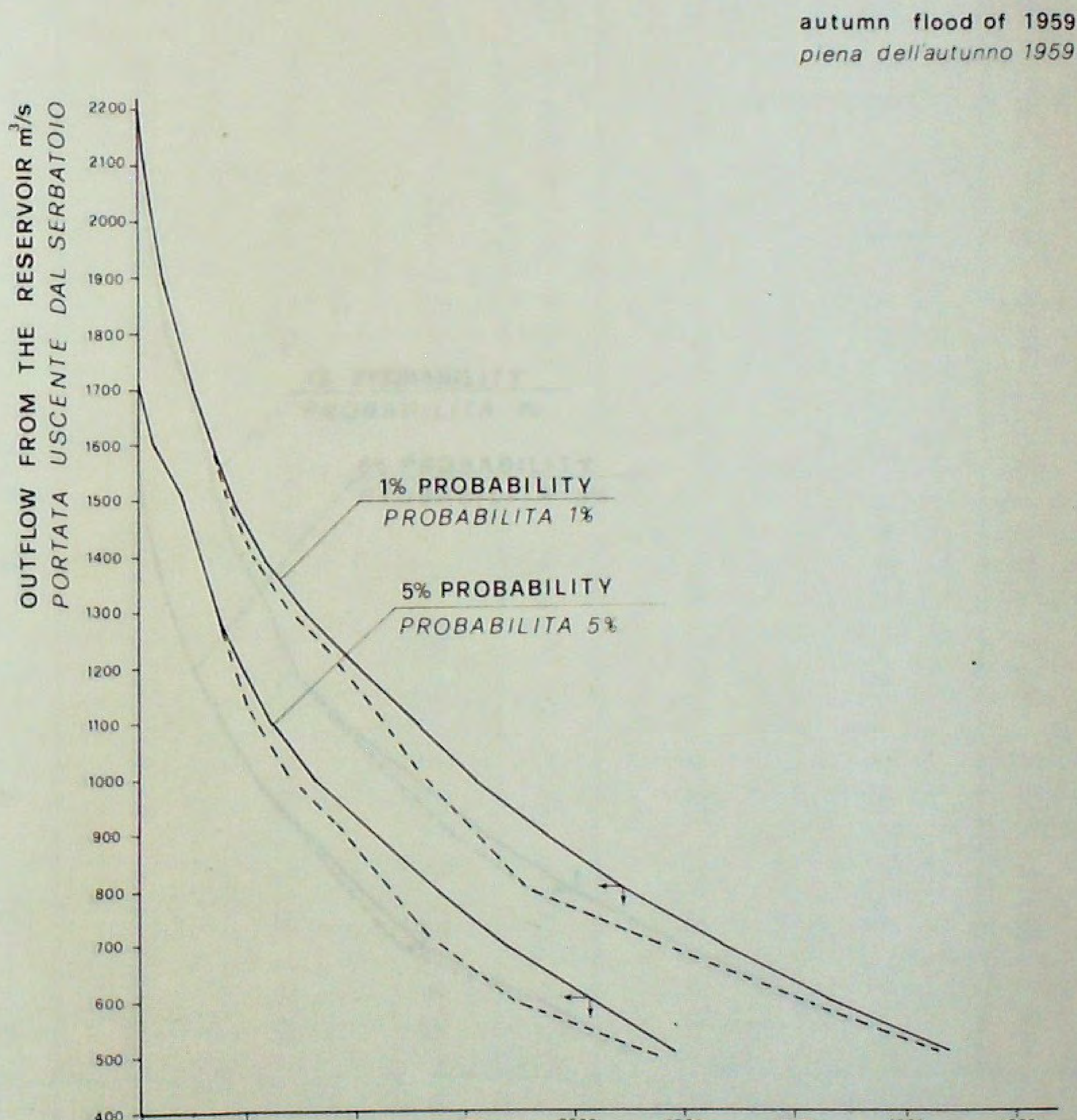
(1) The maximum discharge of the 1959 flood had a probability of 20% and the 100-day flood volume a probability of 21.4%, while the respective figures for the 1961 flood are 13.3% and 7.1% (1965 Selchozpromexport Report).



DRAFT POSSIBILITIES: BAARDHEERE-SAAKOW INTEGRATED SYSTEM
POSSIBILITA DI EROGAZIONE: SISTEMA INTEGRATO BAARDHEERE-SAAKOW
fig. 11. II

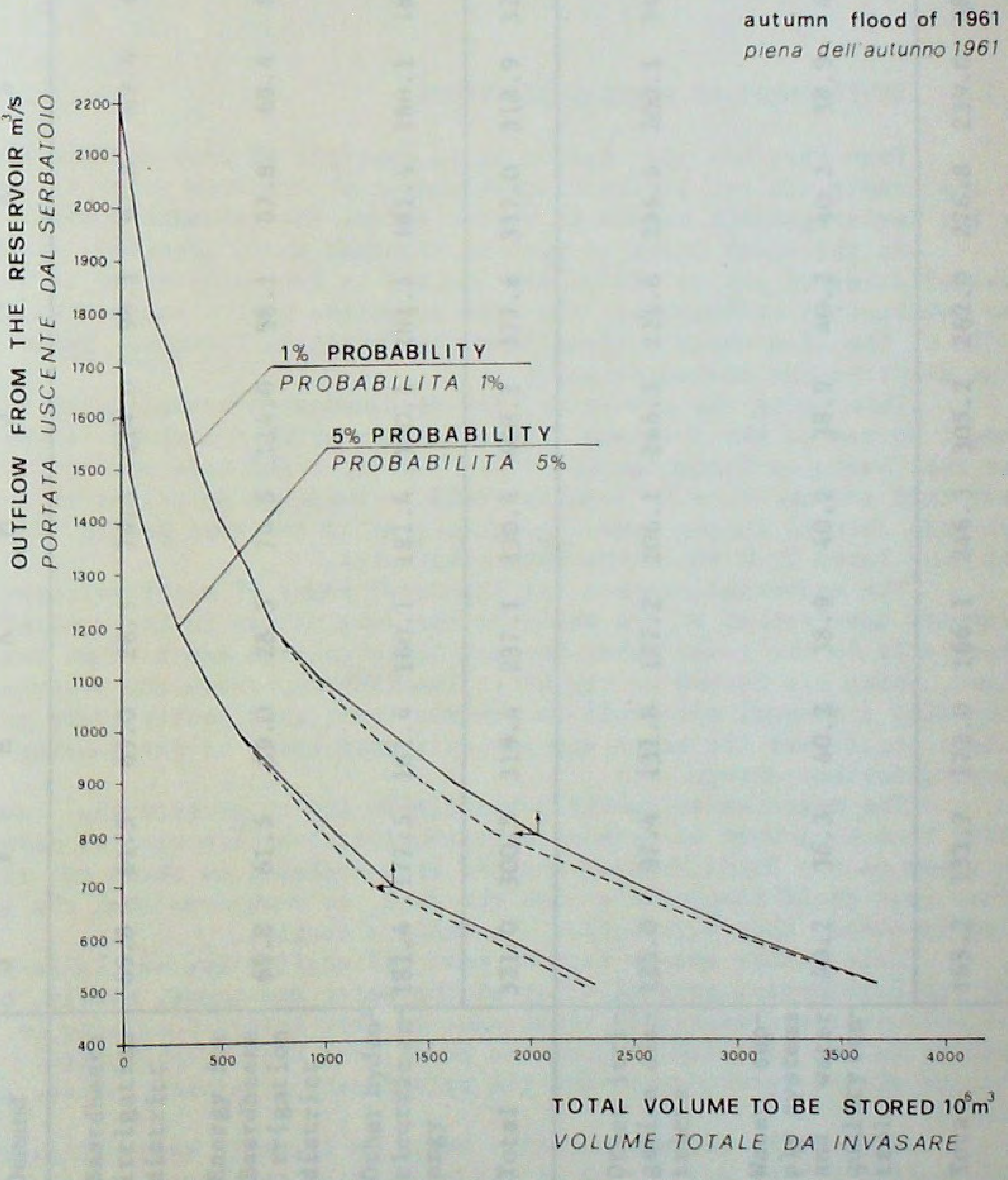
BAARDHEERE



VOLUMES TO BE STORED FOR FLOOD REGULATION
VOLUMI DA INVASARE PER LA LAMINAZIONE DELLE PIENE

fig.12a.II

BAARDHEERE



VOLUMES TO BE STORED FOR FLOOD REGULATION
VOLUMI DA INVASARE PER LA LAMINAZIONE DELLE PIENE

fig.12 b.II

Table 18 - Water requirements for different uses in the Baardheere-Saakow hydraulic system (Alternative D*)

Reservoir	Demand	J	F	M	A	M	J	J	A	S	O	N	D	Year
Baardheere	Baardheere irrigation district	69.8	61.5	69.0	28.5	74.5	114.0	98.1	67.8	69.4	69.7	64.8	79.6	866.7
Baardheere	Energy for Baardheere irrigation district	69.8	61.5	69.0	28.5	74.5	114.0	98.1	67.8	69.4	69.7	64.8	79.6	866.7
Baardheere	Other hydro-electric energy	181.4	177.5	181.4	180.1	181.4	180.1	181.4	181.4	180.1	181.4	181.1	181.4	2167.7
Baardheere	Total	321.0	300.5	319.4	237.1	330.4	408.1	377.6	317.0	318.9	320.8	309.7	340.6	3901.1
Saakow	Other irrigation districts	125.0	97.4	131.8	127.2	206.1	266.3	221.8	236.6	200.1	342.8	342.9	263.2	2561.2
Saakow	Water supply systems and water quality control	40.2	36.3	40.2	38.9	40.2	38.9	40.2	40.2	38.9	40.2	38.9	40.2	473.3
Saakow	Total	165.2	133.7	172.0	166.1	246.3	305.2	262.0	276.8	239.0	383.0	381.8	303.4	3034.5

Determination of the capacity of the proposed reservoir depends also on the storage possibilities of the selected site, the channel capacity downstream and the level of probability it is wished to assign to flood control. Assuming favourable morphological conditions at the dam site, in order to contain a maximum discharge of 700 m^3/s, corresponding to the estimated capacity of the channel in the lower Juba, something like 2,400 x 10^6 m^3 storage capacity would be needed for the 100-year flood and 1,300 x 10^6 m^3 for the 20-year flood.

The question of flood-storage capacity is discussed in greater detail in Part III of this Volume.

4.3 DEVELOPMENT OF NATURAL RESOURCES

From what has gone before it is possible to draw certain conclusions on the conditions and limits of development of the Juba water resources and on the investigations needed to better define the relevant context.

In the first place it must be remarked that, generally speaking, the possibilities of taking action are limited to the mainstream, as there are few substantial tributaries: the Juba transfers to the sea virtually the whole of the flow which arrives from the Ethiopian Plateau, with unvaried time distribution characteristics.

This being the situation, the development measures taken along the Somali course of the Juba are very dependent on what happens in the part of the Juba basin in Ethiopian territory. Hence, sight must not be lost of the fact that action taken in Somalia would be rendered pointless if there were man-made changes in the hydrological regime of the Webi Gestro, Canale Doria and Dawa Parma from which the Juba originates.

The essential premise for the development of water resources and the economic development of the whole of the Juba valley is the control of floods, especially in the lower Juba, between Jilib and the mouth. When the flood flows, which are formed on the Ethiopian Plateau, reach the alluvial plain, they find a channel too small to contain them; thus nearly every year the waters spill over the banks and inundate vast areas of surrounding lands, causing serious damage.

The measures to control Juba floods and to protect the surrounding lands from them must be developed in coordination with similar measures to be taken on the Bohol Magaday and the Webi Shebeli, as these two rivers sometimes pour their floodwaters into the Juba, on occasions when the latter is also in flood, thus aggravating the whole situation.

Only rather sparse data of poor reliability are available for assessing the development possibilities of the water resources, namely, to define the potential and available resources. In particular, knowledge is decidedly lacking on the geomorphology of the basin, the hydromorphological characteristics of the watercourse, and the relationships between surface and ground waters.

Thus it is recommended that steps be taken to systematically collect information on the unknown or poorly known sectors concerned, and to critically review, experimentally check and integrate the data presently available, so as to eliminate inconsistences and uncertainties.

The alternatives and technical solutions possible for flow regulation and flood control are limited as regards type and location by the physiographic, morphological, climatic and geological conditions in the valley. The relevant measures can be identified at the planning level on the basis of the hydrological documentation available, but their more precise definition at the final design and construction levels is hindered by the lack of precision mentioned above.

A N N E X E S
T O P A R T II

ANNEX 1.

HYDROLOGICAL DATA (FAO)

ANNEX 1.1 MONTHLY FLOWS (Hectare Meter - Thousands)

Years	LUUQ STATION												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
1951	22.2	8.5	4.2	81.7	131.3	61.2	41.9	90.3	62.5	137.6	114.4	69.8	825.6
1952	15.9	2.3	1.0	14.3	62.6	17.0	28.1	62.9	104.9	134.2	81.3	10.4	534.9
1953	2.4	0.9	0.9	6.4	48.9	17.2	61.8	107.0	44.4	66.8	85.9	14.7	457.3
1954	4.2	0.8	0.8	54.9	55.5	38.6	77.2	119.7	117.1	133.7	36.8	21.8	661.1
1955	4.3	3.4	1.0	6.1	23.9	2.9	13.9	54.9	75.8	104.4	50.8	12.2	353.6
1956	6.0	3.1	1.2	21.7	64.1	26.3	39.2	91.7	94.3	164.6	71.0	16.8	600.0
1957	4.9	2.2	13.1	11.8	95.4	69.5	64.9	73.8	42.1	53.7	70.5	47.8	549.7
1958	7.6	9.2	5.2	6.6	33.5	18.1	72.8	114.7	108.5	116.7	80.7	48.1	621.7
1959	15.8	2.3	1.3	2.8	59.5	57.8	55.6	59.1	109.5	125.7	158.3	26.8	674.5
1960	8.7	18.2	97.8	8.6	1.3	43.8	37.1	41.8	64.5	84.9	102.0	62.7	571.4
1961	5.3	3.2	6.7	46.0	61.4	44.7	64.0	120.6	105.4	133.9	164.0	109.8	865.0
1962	22.0	5.2	3.4	12.9	55.3	11.0	20.0	50.6	68.4	119.0	76.5	32.1	476.4
1963	2.2	1.6	2.6	62.7	118.9	49.1	35.6	41.4	33.9	53.0	58.9	75.3	535.2
1964	22.1	7.8	3.7	10.3	20.6	26.9	26.9	79.6	70.1	120.3	80.2	39.6	508.1
1965	26.2	9.9	2.2	2.8	8.1	4.1	-	-	-	-	-	-	-

Source : FAO Report

ANNEX 1.2

MONTHLY FLOWS (Hectare Meter - Thousands)

Years	BAARDHEERE STATION												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
1951	25.9	10.9	6.5	71.9	118.9	59.0	43.3	77.8	58.9	111.1	104.7	64.2	753.1
1952	16.0	3.8	1.2	18.0	58.9	24.5	29.5	59.7	88.4	118.7	76.9	13.3	508.9
1953	4.0	1.0	1.0	8.3	45.3	20.5	64.3	94.8	43.6	62.6	79.4	17.9	442.7
1954	6.2	0.9	0.9	55.2	51.1	40.4	67.5	107.7	103.1	116.4	38.2	33.8	621.4
1955	6.2	5.1	1.2	8.8	25.3	5.1	17.4	52.7	67.0	92.7	50.2	14.6	346.3
1956	7.8	4.7	2.0	20.9	62.3	28.8	40.1	78.7	82.1	133.8	70.2	20.1	551.5
1957	6.9	3.5	20.2	15.3	87.3	64.4	60.5	66.1	42.1	50.2	66.3	45.6	528.4
1958	10.3	12.6	7.3	7.0	36.2	22.2	71.6	104.3	97.2	105.4	76.5	48.6	599.2
1959	18.4	3.6	1.8	3.8	55.0	54.0	51.9	56.5	96.1	105.1	105.1	29.2	580.5
1960	11.4	22.5	83.6	12.3	1.9	47.0	39.3	43.8	60.0	67.9	91.2	56.7	537.6
1961	7.5	5.0	5.5	58.3	58.6	45.8	60.5	111.0	92.4	122.9	132.9	104.4	804.8
1962	25.8	7.4	6.0	16.6	51.6	13.9	23.5	47.7	61.1	103.8	77.6	34.7	469.7
1963	3.4	2.5	4.3	57.2	101.6	45.6	41.8	48.2	47.8	54.5	54.9	66.9	528.7
1964	25.5	9.9	6.4	24.6	32.5	34.9	31.5	69.9	61.5	104.1	59.9	35.1	495.8
1965	24.1	10.9	6.4	7.7	17.8	2.1	-	-	-	-	-	-	-

Source : FAO Report

ANNEX 1.3

MONTHLY FLOWS (Hectare Meter - Thousands)

Years	KAITOI STATION												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
1951	38.0	11.7	4.6	76.0	128.5	83.7	45.7	75.3	65.2	112.2	125.0	86.2	852.1
1952	27.7	3.3	1.9	9.5	58.7	38.4	27.0	58.5	93.9	134.5	98.8	26.0	578.2
1953	3.1	1.7	1.9	3.1	47.2	24.3	57.3	110.3	53.6	60.7	93.0	28.9	485.1
1954	5.8	1.7	2.2	52.4	56.5	43.2	62.1	131.4	120.8	144.1	59.1	34.4	713.7
1955	5.9	4.3	1.9	5.4	34.3	5.1	18.4	48.4	70.4	108.7	60.5	23.8	387.1
1956	8.5	3.8	2.6	11.9	71.6	41.2	39.4	73.7	93.6	122.9	97.2	30.0	596.4
1957	6.9	3.1	16.8	21.0	94.5	75.9	55.8	72.6	48.5	46.8	89.0	56.7	587.6
1958	14.6	11.2	11.8	3.3	41.0	30.0	76.9	136.3	121.3	123.2	109.9	52.3	731.8
1959	29.0	29.9	1.9	1.8	46.1	51.5	56.5	62.9	89.9	102.3	131.5	44.2	647.5
1960	12.4	21.4	74.2	24.5	1.9	40.4	47.8	41.7	59.6	61.5	94.5	83.6	563.5
1961	17.3	3.2	4.3	29.5	79.5	46.6	57.8	128.2	107.5	134.7	146.1	135.5	890.2
1962	38.8	13.7	3.2	16.1	54.6	17.8	29.8	44.9	65.6	120.3	99.0	41.8	545.6
1963	7.4	3.6	3.2	56.8	145.6	50.1	40.0	45.4	45.3	51.4	55.0	74.3	578.1
1964	2.8	10.4	4.4	19.4	33.3	34.4	30.9	68.3	61.8	122.9	93.2	32.4	514.2
1965	37.9	10.8	4.1	2.4	-	-	-	-	-	-	-	-	-

Source : FAO Report

ANNEX 1.4

MONTHLY FLOWS (Hectare Meter - Thousands)

Years	JAMAAME STATION												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
1951	30.8	9.6	3.0	67.9	102.7	76.1	43.6	74.0	62.1	93.3	100.5	78.0	741.6
1952	25.5	2.4	0.8	7.5	56.6	36.2	24.1	56.9	84.5	107.0	86.2	24.0	511.7
1953	1.7	0.6	0.6	1.8	46.1	22.8	55.9	91.1	49.8	53.5	82.0	29.2	435.1
1954	4.4	0.6	0.6	44.4	54.7	42.5	59.6	105.7	99.3	119.1	53.7	33.8	618.4
1955	4.6	2.7	0.7	3.7	31.4	3.4	13.4	46.1	68.0	89.4	58.2	20.8	342.4
1956	6.5	2.5	0.9	9.7	63.0	39.7	37.1	70.0	83.8	98.7	87.1	27.0	526.0
1957	4.9	1.4	15.1	20.0	79.3	77.7	53.7	69.5	46.7	44.6	76.7	53.5	543.1
1958	12.3	7.8	8.9	1.5	38.8	27.3	62.9	108.7	97.2	97.8	89.9	39.6	592.7
1959	27.0	1.9	0.7	0.7	45.4	50.0	55.1	60.1	69.3	83.6	104.9	42.1	540.8
1960	10.3	19.2	69.9	21.2	0.7	39.2	46.2	39.5	57.9	56.2	84.9	78.7	523.9
1961	15.7	2.3	2.6	27.0	70.8	44.8	56.9	102.2	93.7	86.4	116.9	110.0	729.3
1962	36.5	11.1	1.8	13.6	53.5	15.1	27.1	42.8	66.3	98.5	87.8	40.3	494.4
1963	3.4	0.6	1.3	39.3	114.3	55.5	42.0	44.3	47.0	47.7	45.9	72.7	514.0
1964	29.0	9.4	2.4	15.8	32.2	30.6	28.4	60.4	60.4	99.2	78.0	30.3	476.1
1965	36.1	8.2	3.3	2.0	14.8	6.7	-	-	-	-	-	-	-

Source: FAO Report

ANNEX 2.

HYDROLOGICAL DATA (SELCHOZPROMEXPORT)

MONTHLY FLOWS (m^3/s)

Years	TO LUQQ GANNANE												Annual
	J	F	M	A	M	J	J	A	S	O	N	D	
1951	(80.1)	(32.2)	(15.3)	312	584	229	150	328	221	581	477	242	271
1952	59.3	8.6	3.6	56.2	223	80.5	101	231	379	601	304	36.8	174
1953	8.3	3.4	3.1	26.0	163	64.1	241	438	160	228	334	52.8	143
1954	14.7	3.4	2.8	212	194	146	270	491	512	588	136	79.7	221
1955	14.7	13.3	(3.7)	25.8	84.9	11.2	48.2	194	268	418	186	42.8	109
1956	20.7	11.6	4.1	82.9	240	101	138	314	853	774	282	60.0	198
1957	16.7	8.3	48.6	52.8	388	272	225	225	152	196	265	165	170
1958	26.8	36.2	18.6	22.3	121	66.9	328	458	437	480	342	189	210
1959	(56.6)	(8.4)	(4.9)	26.1	211	210	194	208	456	567	539	97.5	215
1960	(30.0)	(123)	(355)	31.2	4.9	(159)	(134)	154	226	284	(157)	(15.2)	(139)
1961	(18.1)	(12.5)	(12.3)	(173)	228	171	229	516	407	635	800	468	306
1962	79.3	20.0	12.9	50.1	192	40.0	71.8	175	248	(495)	(283)	(117)	149
1963	(32.0)	(12.3)	(11.0)	(278)	503	148	132	151	124	185	189	263	(169)
1964	80.0	28.6	12.6	37.6	75.3	98.2	98.4	270	246	510	-	-	-

Source: Selchozpromexport Report

ANNEX 3.

RECKONING OF REGULATING CAPACITY D

*** OUTPUT ***

RESERVOIR STATE - R = RISING
F = FALLING
S = SPILLING
E = EMPTY

P-T = Regulation volume to compensate falling between the months marked with P and T

YEAR	MONTH	INFLOW-X	DRAFT-D	X-D	S(X-D)		STORAGE	WASTE	RESERVOIR STATE	
1951	1	259.0	237.6	21.4	21.4	P 1	262.1	.0	R	
	2	109.0	195.1	-86.1	-64.7		176.0	.0	F	
	3	65.0	241.0	-176.0	-240.7	T 1	-.0	.0	E	P-T = 262.1
	4	719.0	195.8	523.2	282.5		523.2	.0	R	
	5	1189.0	345.3	843.7	1126.2		1366.9	.0	R	
	6	590.0	455.5	134.5	1260.7		1501.4	.0	R	
	7	433.0	388.5	44.5	1305.2		1517.9	28.0	S	
	8	778.0	351.8	426.2	1731.4		1517.9	426.2	S	
	9	589.0	317.1	271.9	2003.3		1517.9	271.9	S	
	10	1111.0	481.0	630.0	2633.3		1517.9	630.0	S	
	11	1047.0	466.0	581.0	3214.3		1517.9	561.0	S	
	12	642.0	404.1	237.9	3452.2	P 2	1517.9	237.9	S	
1952	1	160.0	237.6	-77.6	3374.6		1440.3	.0	F	
	2	38.0	195.1	-157.1	3217.5		1283.2	.0	F	
	3	12.0	241.0	-229.0	2988.5		1054.2	.0	F	
	4	180.0	195.8	-15.8	2972.7		1038.5	.0	F	
	5	589.0	345.3	243.7	3216.4		1282.1	.0	R	
	6	245.0	455.5	-210.5	3005.9		1071.6	.0	F	
	7	295.0	388.5	-93.5	2912.4	T 2	978.1	.0	F	P-T = 539.8
	8	597.0	351.8	245.2	3157.6		1223.3	.0	R	
	9	884.0	317.1	566.9	3724.5		1517.9	272.3	S	
	10	1187.0	481.0	706.0	4430.5		1517.9	706.0	S	
	11	769.0	466.0	303.0	4733.5	P 3	1517.9	303.0	S	
	12	133.0	404.1	-271.1	4462.4		1246.8	.0	F	
1953	1	40.0	237.6	-197.6	4264.8		1049.2	.0	F	
	2	10.0	195.1	-185.1	4079.7		864.1	.0	F	
	3	10.0	241.0	-231.0	3848.7		633.1	.0	F	
	4	83.0	195.8	-112.8	3735.9		520.3	.0	F	
	5	453.0	345.3	107.7	3843.6		628.0	.0	R	
	6	205.0	455.5	-250.5	3593.1	T 3	377.5	.0	F	P-T = 1140.9
	7	643.0	388.5	254.5	3847.6		632.0	.0	R	
	8	948.0	351.8	596.2	4443.8		1228.2	.0	R	
	9	436.0	317.1	118.9	4562.7		1347.1	.0	R	
	10	626.0	481.0	145.0	4707.7		1492.1	.0	R	

(Cont.d) Annex 3

	12	456.0	404.1	51.9	8971.4	P 7	1517.9	51.9	S	
1958	1	103.0	237.6	-134.6	8836.8		1383.3	.0	F	
	2	126.0	195.1	-69.1	8767.7		1314.2	.0	F	
	3	73.0	241.0	-168.0	8599.7		1146.2	.0	F	
	4	70.0	195.8	-125.8	8473.9		1020.5	.0	F	
	5	362.0	345.3	16.7	8490.6		1037.1	.0	R	
	6	222.0	455.5	-233.5	8257.1	T 7	803.6	.0	F	P-T = 714.3
	7	716.0	388.5	327.5	8584.6		1131.1	.0	R	
	8	1043.0	351.8	691.2	9275.8		1517.9	304.4	S	
	9	972.0	317.1	654.9	9930.7		1517.9	654.9	S	
	10	1054.0	481.0	573.0	10503.7		1517.9	573.0	S	
	11	765.0	466.0	299.0	10802.7		1517.9	299.0	S	
	12	486.0	404.1	81.9	10884.6	P 8	1517.9	81.9	S	
1959	1	184.0	237.6	-53.6	10831.0		1464.3	.0	F	
	2	36.0	195.1	-159.1	10671.9		1305.2	.0	F	
	3	18.0	241.0	-223.0	10448.9		1082.2	.0	F	
	4	38.0	195.8	-157.8	10291.1	T 8	924.5	.0	F	P-T = 593.5
	5	550.0	345.3	204.7	10495.8		1129.1	.0	R	
	6	540.0	455.5	84.5	10580.3		1213.6	.0	R	
	7	519.0	388.5	130.5	10710.8		1344.1	.0	R	
	8	565.0	351.8	213.2	10924.0		1517.9	39.4	S	
	9	961.0	317.1	643.9	11567.9		1517.9	643.9	S	
	10	1051.0	481.0	570.0	12137.9		1517.9	570.0	S	
	11	1051.0	466.0	585.0	12722.9	P 9	1517.9	585.0	S	
	12	292.0	404.1	-112.1	12610.8		1405.8	.0	F	
1960	1	114.0	237.6	-123.6	12487.2	T 9	1282.2	.0	F	P-T = 235.7
	2	225.0	195.1	29.9	12517.1		1312.1	.0	R	
	3	836.0	241.0	595.0	13112.1	P 10	1517.9	389.2	S	
	4	123.0	195.8	-72.8	13039.3		1445.1	.0	F	
	5	19.0	345.3	-326.3	12713.0	T 10	1118.8	.0	F	P-T = 399.1
	6	470.0	455.5	14.5	12727.5		1133.3	.0	R	
	7	393.0	388.5	4.5	12732.0		1137.8	.0	R	
	8	438.0	351.8	86.2	12818.2		1224.0	.0	R	
	9	600.0	317.1	282.9	13101.1		1506.9	.0	R	
	10	679.0	481.0	198.0	13299.1		1517.9	187.0	S	
	11	912.0	466.0	446.0	13745.1		1517.9	446.0	S	
	12	567.0	404.1	162.9	13908.0	P 11	1517.9	162.9	S	
1961	1	75.0	237.6	-162.6	13745.4		1355.3	.0	F	
	2	50.0	195.1	-145.1	13600.3		1210.2	.0	F	
	3	55.0	241.0	-186.0	13414.3	T 11	1024.2	.0	F	P-T = 493.7
	4	583.0	195.8	387.2	13801.5		1411.5	.0	R	
	5	586.0	345.3	240.7	14042.2		1517.9	134.2	S	
	6	458.0	455.5	2.5	14044.7		1517.9	2.5	S	
	7	605.0	388.5	216.5	14261.2		1517.9	216.5	S	
	8	1110.0	351.8	758.2	15019.4		1517.9	758.2	S	
	9	924.0	317.1	606.9	15626.3		1517.9	606.9	S	
	10	1229.0	481.0	748.0	16374.3		1517.9	748.0	S	
	11	1329.0	466.0	863.0	17237.3		1517.9	863.0	S	
	12	1044.0	404.1	639.9	17877.2		1517.9	639.9	S	

(Cont.d) Annex

1962	1	258.0	237.6	20.4	17897.6	P 12	1517.9	20.4	S	
	2	74.0	195.1	-121.1	17776.5		1396.8	.0	F	
	3	60.0	241.0	-181.0	17595.5		1215.8	.0	F	
	4	166.0	195.8	-29.8	17565.7		1186.0	.0	F	
	5	516.0	345.3	170.7	17736.4		1356.7	.0	R	
	6	139.0	455.5	-316.5	17419.9		1040.2	.0	F	
	7	235.0	388.5	-153.5	17266.4	T 12	886.7	.0	F	P-T = 631.2
	8	477.0	351.8	125.2	17391.6		1011.9	.0	R	
	9	611.0	317.1	293.9	17685.5		1305.8	.0	R	
	10	1038.0	481.0	557.0	18242.5		1517.9	344.9	S	
	11	776.0	466.0	310.0	18552.5	P 13	1517.9	310.0	S	
	12	347.0	404.1	-57.1	18495.4		1460.8	.0	F	
1963	1	34.0	237.6	-203.6	18291.8		1257.2	.0	F	
	2	25.0	195.1	-170.1	18121.7		1087.1	.0	F	
	3	43.0	241.0	-198.0	17923.7	T 13	889.1	.0	F	P-T = 628.8
	4	572.0	195.8	376.2	18299.9		1265.3	.0	R	
	5	1016.0	345.3	670.7	18970.6		1517.9	418.1	S	
	6	456.0	455.5	.5	18971.1		1517.9	.5	S	
	7	418.0	388.5	29.5	19000.6		1517.9	29.5	S	
	8	482.0	351.8	130.2	19130.8		1517.9	130.2	S	
	9	478.0	317.1	160.9	19291.7		1517.9	160.9	S	
	10	545.0	481.0	64.0	19355.7		1517.9	64.0	S	
	11	549.0	466.0	83.0	19438.7		1517.9	83.0	S	
	12	669.0	404.1	264.9	19703.6		1517.9	264.9	S	
1964	1	255.0	237.6	17.4	19721.0	P 14	1517.9	17.4	S	
	2	99.0	195.1	-96.1	19624.9		1421.8	.0	F	
	3	64.0	241.0	-177.0	19447.9		1244.8	.0	F	
	4	246.0	195.8	50.2	19498.1		1295.0	.0	R	
	5	325.0	345.3	-20.3	19477.8		1274.7	.0	F	
	6	349.0	455.5	-106.5	19371.3		1168.2	.0	F	
	7	315.0	388.5	-73.5	19297.8	T 14	1094.7	.0	F	P-T = 423.2
	8	699.0	351.8	347.2	19645.0		1441.9	.0	R	
	9	615.0	317.1	297.9	19942.9		1517.9	221.9	S	
	10	1041.0	481.0	560.0	20502.9		1517.9	560.0	S	
	11	599.0	466.0	133.0	20635.9	P 15	1517.9	133.0	S	
	12	351.0	404.1	-53.1	20582.8		1464.8	.0	F	

MINIMUM STORAGE REQUIRED = 1517.918

(Cont.d) Annex 3

	11	794.0	466.0	328.0	5035.7	P 4	1517.9	302.2	S	
	12	179.0	404.1	-225.1	4610.6		1292.8	.0	F	
1954	1	62.0	237.6	-175.6	4635.0		1117.2	.0	F	
	2	9.0	195.1	-186.1	4448.9		931.1	.0	F	
	3	9.0	241.0	-232.0	4216.9	T 4	699.1	.0	F	P-T = 818.8
	4	552.0	195.8	356.2	4573.1		1055.3	.0	R	
	5	511.0	345.3	165.7	4738.8		1221.0	.0	R	
	6	404.0	455.5	-51.5	4687.3		1169.5	.0	F	
	7	675.0	388.5	286.5	4973.8		1456.0	.0	R	
	8	1077.0	351.8	725.2	5699.0		1517.9	663.3	S	
	9	1031.0	317.1	713.9	6412.9		1517.9	713.9	S	
	10	1164.0	481.0	683.0	7095.9	P 5	1517.9	683.0	S	
	11	382.0	466.0	-84.0	7011.9		1433.9	.0	F	
	12	338.0	404.1	-66.1	6945.8		1367.8	.0	F	
1955	1	62.0	237.6	-175.6	6770.2		1192.2	.0	F	
	2	51.0	195.1	-144.1	6626.1		1048.1	.0	F	
	3	12.0	241.0	-229.0	6397.1		819.1	.0	F	
	4	86.0	195.8	-107.8	6289.3		711.3	.0	F	
	5	253.0	345.3	-92.3	6197.0		619.0	.0	F	
	6	51.0	455.5	-404.5	5792.5		214.5	.0	F	
	7	174.0	388.5	-214.5	5578.0	T 5	-.0	.0	E	P-T = 1517.9
	8	527.0	351.8	175.2	5753.2		175.2	.0	R	
	9	670.0	317.1	352.9	6106.1		528.1	.0	R	
	10	927.0	481.0	446.0	6552.1		974.1	.0	R	
	11	502.0	466.0	36.0	6588.1		1010.1	.0	R	
	12	146.0	404.1	-258.1	6330.0		752.0	.0	F	
1956	1	78.0	237.6	-159.6	6170.4		592.4	.0	F	
	2	47.0	195.1	-148.1	6022.3		444.3	.0	F	
	3	20.0	241.0	-221.0	5801.3		223.3	.0	F	
	4	209.0	195.8	13.2	5814.5		236.5	.0	R	
	5	623.0	345.3	277.7	6092.2		514.2	.0	R	
	6	288.0	455.5	-167.5	5924.7		346.7	.0	F	
	7	401.0	388.5	12.5	5937.2		359.2	.0	R	
	8	787.0	351.8	435.2	6372.4		794.4	.0	R	
	9	821.0	317.1	503.9	6876.3		1298.3	.0	R	
	10	1338.0	481.0	857.0	7733.3		1517.9	637.4	S	
	11	702.0	466.0	236.0	7969.3	P 6	1517.9	236.0	S	
	12	201.0	404.1	-203.1	7766.2		1314.8	.0	F	
1957	1	69.0	237.6	-168.6	7597.6		1146.2	.0	F	
	2	35.0	195.1	-160.1	7437.5		986.1	.0	F	
	3	202.0	241.0	-39.0	7398.5		947.1	.0	F	
	4	153.0	195.8	-42.8	7355.7	T 6	904.3	.0	F	P-T = 613.6
	5	873.0	345.3	527.7	7883.4		1432.0	.0	R	
	6	644.0	455.5	188.5	8071.9		1517.9	102.6	S	
	7	605.0	388.5	216.5	8288.4		1517.9	216.5	S	
	8	661.0	351.8	309.2	8597.6		1517.9	309.2	S	
	9	421.0	317.1	103.9	8701.5		1517.9	103.9	S	
	10	502.0	481.0	21.0	8722.5		1517.9	21.0	S	
	11	663.0	466.0	197.0	8919.5		1517.9	197.0	S	

ANNEX 4.

RECKONING OF REGULATING CAPACITY D*

*** OUTPUT ***

RESERVOIR STATE - R = RISING
F = FALLING
S = SPILLING
E = EMPTY

P - T = Regulation volume to compensate falling between the months marked with P and T

YEAR	MONTH	INFLOW-X	DRAFT-D	X-D	S(X-D)		STORAGE	SPILL	RESERVOIR STATE	
1951	1	259.0	320.9	-61.9	-61.9		445.9	0.0	R	
	2	109.0	300.4	-191.4	-253.2		254.6	0.0	F	
	3	65.0	319.6	-254.6	-507.8		0.0	0.0	E	
	4	719.0	237.3	481.7	-26.1		481.7	0.0	R	
	5	1189.0	330.3	858.7	832.6		1340.4	0.0	R	
	6	590.0	408.0	182.0	1014.6		1522.4	0.0	R	
	7	433.0	377.8	55.2	1069.8		1577.7	0.0	R	
	8	778.0	317.0	461.0	1530.9		1605.9	432.8	S	
	9	589.0	318.9	270.1	1801.0		1605.9	270.1	S	
	10	1111.0	320.9	790.1	2591.1		1605.9	790.1	S	
	11	1047.0	309.8	737.2	3328.3		1605.9	737.2	S	
	12	642.0	340.7	301.3	3629.6	P 1	1605.9	301.3	S	
1952	1	160.0	320.9	-160.9	3468.7		1445.0	0.0	F	
	2	38.0	300.4	-262.4	3206.3		1182.6	0.0	F	
	3	12.0	319.6	-307.6	2898.8		875.1	0.0	F	
	4	180.0	237.3	-57.3	2841.5	T 1	817.7	0.0	F	P-T = 788.13
	5	589.0	330.3	258.7	3100.2		1076.5	0.0	R	
	6	245.0	408.0	-163.0	2937.2		913.5	0.0	F	
	7	295.0	377.8	-82.8	2854.4		830.7	0.0	F	
	8	597.0	317.0	280.0	3134.5		1110.7	0.0	R	
	9	884.0	318.9	565.1	3699.5		1605.9	70.0	S	
	10	1187.0	320.9	866.1	4565.7		1605.9	866.1	S	
	11	769.0	309.8	459.2	5024.9	P 2	1605.9	459.2	S	
	12	133.0	340.7	-207.7	4817.2		1398.2	0.0	F	
1953	1	40.0	320.9	-280.9	4536.3		1117.3	0.0	F	
	2	10.0	300.4	-290.4	4245.9		826.9	0.0	F	
	3	10.0	319.6	-309.6	3936.4		517.4	0.0	F	
	4	83.0	237.3	-154.3	3782.0		363.1	0.0	F	
	5	453.0	330.3	122.7	3904.7		485.8	0.0	R	
	6	205.0	408.0	-203.0	3701.8	T 2	282.8	0.0	F	P-T =1323.11
	7	643.0	377.8	265.2	3967.0		548.0	0.0	R	
	8	948.0	317.0	631.0	4598.0		1179.1	0.0	R	
	9	436.0	318.9	117.1	4715.1		1296.1	0.0	R	
	10	626.0	320.9	305.1	5020.2		1601.3	0.0	R	
	11	794.0	309.8	484.2	5504.4	P 3	1605.9	479.6	S	
	12	179.0	340.7	-161.7	5342.7		1444.2	0.0	F	

1954	1	62.0	320.9	-258.9	5083.9	1185.3	0.0	F	
	2	9.0	300.4	-291.4	4792.5	893.9	0.0	F	
	3	9.0	319.6	-310.6	4481.9 T 3	583.4	0.0	F	P-T =1022.52
	4	552.0	237.3	314.7	4796.6	898.1	0.0	R	
	5	511.0	330.3	180.7	4977.3	1078.8	0.0	R	
	6	404.0	408.0	-4.0	4973.3	1074.8	0.0	F	
	7	675.0	377.8	297.2	5270.6	1372.0	0.0	R	
	8	1077.0	317.0	760.0	6030.6	1605.9	526.2	S	
	9	1031.0	318.9	712.1	6742.7	1605.9	712.1	S	
	10	1164.0	320.9	843.1	7585.8	1605.9	843.1	S	
	11	382.0	309.8	72.2	7658.0 P 4	1605.9	72.2	S	
	12	338.0	340.7	-2.7	7655.3	1603.2	0.0	F	
1955	1	62.0	320.9	-258.9	7396.4	1344.3	0.0	F	
	2	51.0	300.4	-249.4	7147.1	1094.9	0.0	F	
	3	12.0	319.6	-307.6	6839.5	787.4	0.0	F	
	4	88.0	237.3	-149.3	6690.2	638.1	0.0	F	
	5	253.0	330.3	-77.3	6612.9	560.8	0.0	F	
	6	51.0	408.0	-357.0	6255.9	203.8	0.0	F	
	7	174.0	377.8	-203.8	6052.1 T 4	0.0	0.0	E	P-T =1605.87
	8	527.0	317.0	210.0	6262.2	210.1	0.0	R	
	9	670.0	318.9	351.1	6613.3	561.1	0.0	R	
	10	927.0	320.9	606.1	7219.4	1167.3	0.0	R	
	11	502.0	309.8	192.2	7411.6	1359.5	0.0	R	
	12	146.0	340.7	-194.7	7216.9	1164.8	0.0	F	
1956	1	78.0	320.9	-242.9	6974.0	921.9	0.0	F	
	2	47.0	300.4	-253.4	6720.6	668.5	0.0	F	
	3	20.0	319.6	-299.6	6421.1	369.0	0.0	F	
	4	209.0	237.3	-28.3	6392.7	340.6	0.0	F	
	5	623.0	330.3	292.7	6685.5	633.4	0.0	R	
	6	288.0	408.0	-120.0	6565.5	513.4	0.0	F	
	7	401.0	377.8	23.2	6588.7	536.6	0.0	R	
	8	787.0	317.0	470.0	7058.7	1006.6	0.0	R	
	9	821.0	318.9	502.1	7560.8	1508.7	0.0	R	
	10	1338.0	320.9	1017.1	8578.0	1605.9	920.0	S	
	11	702.0	309.8	392.2	8970.1 P 5	1605.9	392.2	S	
	12	201.0	340.7	-139.7	8830.5	1466.2	0.0	F	
1957	1	69.0	320.9	-251.9	8578.6	1214.3	0.0	F	
	2	35.0	300.4	-265.4	8313.2	948.9	0.0	F	
	3	202.0	319.6	-117.6	8195.6	831.4	0.0	F	
	4	153.0	237.3	-84.3	8111.3 T 5	747.1	0.0	F	P-T = 858.83
	5	873.0	330.3	542.7	8654.0	1289.8	0.0	R	
	6	644.0	408.0	236.0	8890.0	1525.8	0.0	R	
	7	605.0	377.8	227.2	9117.3	1605.9	147.1	S	
	8	661.0	317.0	344.0	9461.3	1605.9	344.0	S	
	9	421.0	318.9	102.1	9563.4	1605.9	102.1	S	
	10	502.0	320.9	181.1	9744.5	1605.9	181.1	S	
	11	663.0	309.8	353.2	10097.7	1605.9	353.2	S	
	12	456.0	340.7	115.3	10213.0 P 6	1605.9	115.3	S	
1958	1	103.0	320.9	-217.9	9995.2	1388.0	0.0	F	
	2	126.0	300.4	-174.4	9820.8	1213.6	0.0	F	
	3	73.0	319.6	-246.6	9574.2	967.1	0.0	F	
	4	70.0	237.3	-167.3	9406.9	799.7	0.0	F	
	5	362.0	330.3	31.7	9438.6	831.5	0.0	R	

	6	222.0	408.0	-186.0	9252.6 T 6	645.5	0.0	F	P-T = 960.42
	7	716.0	377.8	338.2	9590.8	983.7	0.0	R	
	8	1043.0	317.0	726.0	10316.9	1605.9	103.9	S	
	9	972.0	318.9	653.1	10970.0	1605.9	653.1	S	
	10	1054.0	320.9	733.1	11703.1	1605.9	733.1	S	
	11	765.0	309.8	455.2	12158.3	1605.9	455.2	S	
	12	486.0	340.7	145.3	12303.6 P 7	1605.9	145.3	S	
1959	1	184.0	320.9	-136.9	12166.7	1469.0	0.0	F	
	2	36.0	300.4	-264.4	11902.3	1204.6	0.0	F	
	3	18.0	319.6	-301.6	11600.8	903.1	0.0	F	P-T = 902.14
	4	38.0	237.3	-199.3	11401.5 T 7	703.7	0.0	F	
	5	550.0	330.3	219.7	11621.2	923.5	0.0	R	
	6	540.0	408.0	132.0	11753.2	1055.5	0.0	R	
	7	519.0	377.8	141.2	11894.4	1196.7	0.0	R	
	8	565.0	317.0	248.0	12142.5	1444.7	0.0	R	
	9	961.0	318.9	642.1	12784.5	1605.9	481.0	S	
	10	1051.0	320.9	730.1	13514.7	1605.9	730.1	S	
	11	1051.0	309.8	741.2	14255.9 P 8	1605.9	741.2	S	
	12	292.0	340.7	-48.7	14207.2	1557.2	0.0	F	
1960	1	114.0	320.9	-206.9	14000.3	1350.3	0.0	F	
	2	225.0	300.4	-75.4	13924.9 T 8	1274.9	0.0	F	P-T = 330.95
	3	836.0	319.6	516.4	14441.3 P 9	1605.9	185.5	S	
	4	123.0	237.3	-114.3	14327.0	1491.6	0.0	F	
	5	19.0	330.3	-311.3	14015.7 T 9	1180.3	0.0	F	P-T = 425.61
	6	470.0	408.0	62.0	14077.7	1242.3	0.0	R	
	7	393.0	377.8	15.2	14093.0	1257.5	0.0	R	
	8	438.0	317.0	121.0	14214.0	1378.6	0.0	R	
	9	600.0	318.9	281.1	14495.1	1605.9	53.8	S	
	10	679.0	320.9	358.1	14853.2	1605.9	358.1	S	
	11	912.0	309.8	602.2	15455.4	1605.9	602.2	S	
	12	567.0	340.7	226.3	15681.7 P 10	1605.9	226.3	S	
1961	1	75.0	320.9	-245.9	15435.9	1360.0	0.0	F	
	2	50.0	300.4	-250.4	15185.5	1109.6	0.0	F	
	3	55.0	319.6	-264.6	14920.9 T 10	845.1	0.0	F	P-T = 760.82
	4	583.0	237.3	345.7	15266.6	1190.7	0.0	R	
	5	586.0	330.3	255.7	15522.3	1446.5	0.0	R	
	6	458.0	408.0	50.0	15572.3	1496.5	0.0	R	
	7	605.0	377.8	227.2	15799.6	1605.9	117.8	S	
	8	1110.0	317.0	793.0	16592.6	1605.9	793.0	S	
	9	924.0	318.9	605.1	17197.7	1605.9	605.1	S	
	10	1229.0	320.9	908.1	18105.8	1605.9	908.1	S	
	11	1329.0	309.8	1019.2	19125.0	1605.9	1019.2	S	
	12	1044.0	340.7	703.3	19828.3 P 11	1605.9	703.3	S	
1962	1	258.0	320.9	-62.9	19765.4	1543.0	0.0	F	
	2	74.0	300.4	-226.4	19539.1	1316.6	0.0	F	
	3	60.0	319.6	-259.6	19279.5	1057.1	0.0	F	
	4	166.0	237.3	-71.3	19208.2	985.7	0.0	F	
	5	516.0	330.3	185.7	19393.9	1171.5	0.0	R	
	6	139.0	408.0	-269.0	19124.9	902.5	0.0	F	
	7	235.0	377.8	-142.8	18982.1 T 11	759.7	0.0	F	P-T = 846.18
	8	477.0	317.0	160.0	19142.2	919.7	0.0	R	
	9	611.0	318.9	292.1	19434.2	1211.8	0.0	R	
	10	1038.0	320.9	717.1	20151.4	1605.9	323.1	S	

(Cont.d) Annex 4

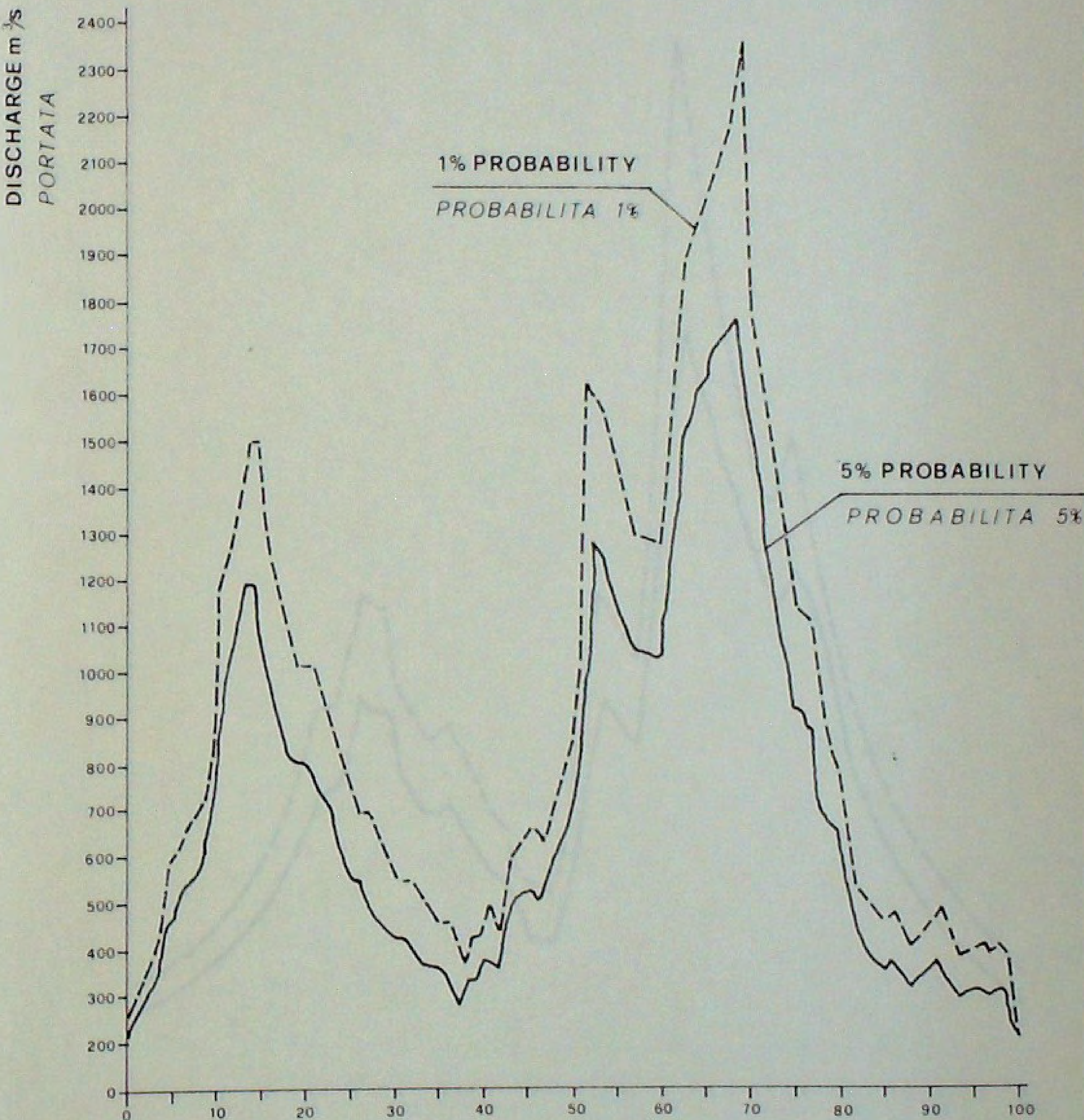
	11	776.0	309.8	466.2	20617.6	1605.9	466.2	S	
	12	347.0	340.7	6.3	20623.9 P 12	1605.9	6.3	S	
1963	1	34.0	320.9	-286.9	20337.0	1319.0	0.0	F	
	2	25.0	300.4	-275.4	20061.6	1043.6	0.0	F	
	3	43.0	319.6	-276.6	19785.1 T 12	767.1	0.0	F	P-T = 838.82
	4	572.0	237.3	334.7	20119.7	1101.7	0.0	R	
	5	1016.0	330.3	685.7	20805.4	1605.9	181.6	S	
	6	456.0	408.0	48.0	20853.5	1605.9	48.0	S	
	7	418.0	377.8	40.2	20893.7	1605.9	40.2	S	
	8	482.0	317.0	165.0	21058.7	1605.9	165.0	S	
	9	478.0	318.9	159.1	21217.8	1605.9	159.1	S	
	10	545.0	320.9	224.1	21442.0	1605.9	224.1	S	
	11	549.0	309.8	239.2	21681.1	1605.9	239.2	S	
	12	669.0	340.7	328.3	22009.4 P 13	1605.9	328.3	S	
1964	1	255.0	320.9	-65.9	21943.6	1540.0	0.0	F	
	2	99.0	300.4	-201.4	21742.2	1338.6	0.0	F	
	3	64.0	319.6	-255.6	21486.6	1083.1	0.0	F	
	4	246.0	237.3	8.7	21495.3	1091.7	0.0	R	
	5	325.0	330.3	-5.3	21490.0	1086.5	0.0	F	
	6	349.0	408.0	-59.0	21431.0	1027.5	0.0	F	
	7	315.0	377.8	-62.8	21368.3 T 13	964.7	0.0	F	P-T = 641.18
	8	699.0	317.0	382.0	21750.3	1346.7	0.0	R	
	9	615.0	318.9	296.1	22046.4	1605.9	37.0	S	
	10	1041.0	320.9	720.1	22766.5	1605.9	720.1	S	
	11	599.0	309.8	289.2	23055.7	1605.9	289.2	S	
	12	351.0	340.7	10.3	23066.0 P 14	1605.9	10.3	S	

MINIMUM STORAGE REQUIRED = 1605.87

ANNEX 5.

FLOOD HYDROGRAPHS

LUUQ (SELCHOZ)



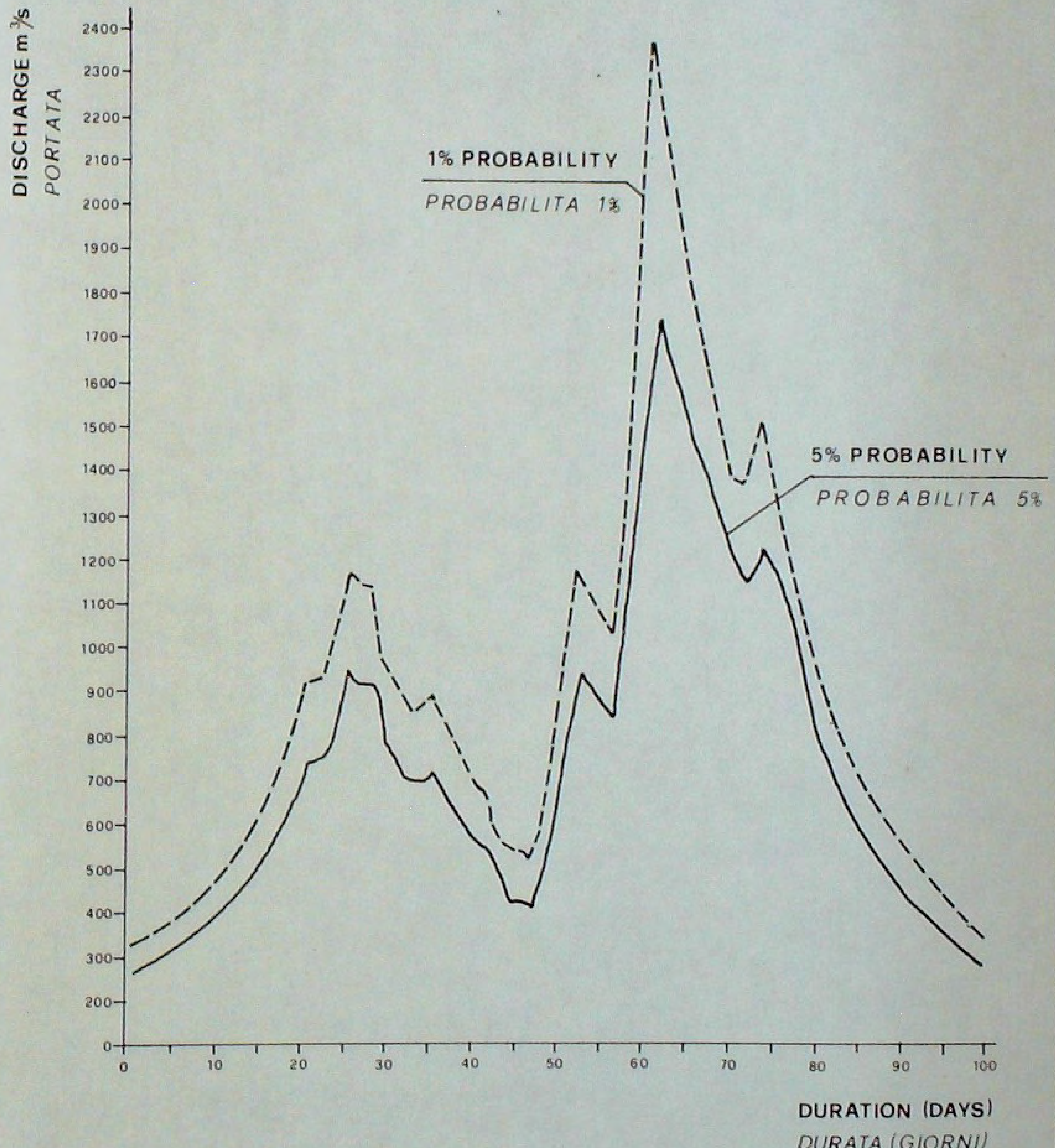
type of autumn flood of 1959

tipo di piena dell'autunno 1959

FLOOD HYDROGRAPHS
IDROGRAMMI DI PIENA

annex. 5 a.

LUUQ (SELCHOZ)



type of autumn flood of 1961

tipo di piena dell'autunno 1961

FLOOD HYDROGRAPHS

IDROGRAMMI DI PIENA

annex. 5 b.

PART III

HYDRAULIC PROBLEMS AND SOLUTIONS

SUMMARY AND RECOMMENDATIONS

SUMMARY

This part leads to a preliminary definition of the hydraulic works necessary to solve the two basic problems for development of the Valley: flood control and flow regulation.

The approach has been to consider firstly the two problems separately and then to combine their requirements.

The 1% and 5% probability floods have been considered as first and second critical case, characterized respectively by peak flows at Baardheere and Kaitoi of 1,800 cu.m/sec and 2,400 cu.m/sec.

As the capacity of the river channel is around 700 cu.m/sec a total storage volume of 2,450 and 1,250 million cu.m has been calculated in the two cases to control flood by reservoir.

For flow regulation requirements two phases of development of the Valley have been considered. The first one leads to the necessity to guarantee a minimum flow of 27 cu.m/sec in the driest months, i.e. water requirement for irrigation of 34,000 ha of pluriannual crops, foreseen by the 10th year of project life, meanwhile in the second phase a total annual water demand of 4,000 million cu.m has been calculated, i.e. water requirement at full development, the required flow varying throughout the year according to monthly water needs of various crops (see Table 13, Part II, Para 4.2).

Two critical cases have been considered as well for calculation of regulation storage required:

- in the first phase they are based respectively on the sequences of months with minimum streamflow over the period of record of observation of flows (14 years) and with flows immediately above, which have probability to occur of about 1% and 12%;
- in the second phase it has been considered the capacity required to cover completely water requirement in 100% of the years and in 93%, this second case being the maximum reliability obtainable providing for only annual regulation. This hypothesis could become compulsory if the salinity of the flood waters would result to be prohibitive for a pluriannual regulation, thus making necessary the complete drying of the reservoir every year. The regulation storage requirements, accounting also for infiltration losses in the canals, for water supply for human consumption and for sanitary considerations (see also para. 4.2, Part II), are as follows:

(in million cu.m)

	1st phase	2nd phase
1st critical case	250	1,518
2nd critical case	160	1,140

The morphological features of the river have then been examined to select possible works to provide for the above requirements, and it has been found that two barrages and reservoirs are feasible upstream of Saakow and upstream of Baardheere. To provide for flood control by construction of embankment or of floodway canals discharging in a reservoir at some distance from the river or in areas not draining to the river, should be discarded.

Preliminary evaluations (1) indicate that increasing the height of the barrage, the reservoir near Saakow could reasonably store up to 900×10^6 cu.m, meanwhile the one in Baardheere could go up to $4,000 \times 10^6$ cu.m.

Through economic and technical considerations two possible solutions have been defined and compared.

Solution A

The barrage near Saakow (whose implementation would take 3 years) would provide for regulation of flows as required in Phase 1 of development.

The Baardheere dam (whose implementation would take 8 years) would provide for regulation of flows as required in Phase 2 and for flood control. Once the Baardheere dam is put into operation the Saakow barrage would be used only as a diversion work for water intake for irrigation.

Solution B

The barrage near Saakow would provide for flow regulation as required in Phase 1 and would work for flow regulation also in Phase 2 in an integrated system with the Baardheere dam.

In Phase 2 the Baardheere dam would provide for flood control and would regulate flows so as:

- to discharge into the river channel throughout the year a constant flow of $100 \times m^3/s$. This flow would be utilized for hydropower production for civil and industrial use;
- to discharge into the irrigation canals leading to the irrigated areas between Baardheere and Saakow a total annual volume of 866 million cu.m regulated according to water needs of the areas;
- to discharge into the river channel the flows utilized for hydropower production to feed the pumping stations to irrigate the areas between Baardheere and Saakow: in the hypothesis that half of the areas need irrigation by pumping the volume of water for this purpose would be the same as the figure above and would be regulated in the same way.

Saakow barrage would de-modulate the rather constant flow discharged by the Baardheere dam to provide for water demand of irrigated areas downstream of Saakow, for water supply for human consumption, and to maintain a constantly minimum flow of $15 \times m^3/s$ in the river for hygienic purposes.

The required storage capacities for flows regulation in solution A are those indicated above, meanwhile in solution B they are slightly higher (see also para. 4.2, Part II), as follows:

(1) Based on uncontrolled contour maps in scale 1:20,000, with 10 m interval for contours, obtained by plotting the 1:60,000 RAF air photos.

	At Baardheere		At Saakow	
	Critical case I (100%)	Critical case II (93%)	Critical case I (100%)	Critical case II (93%)
	(million cu.m)			
Solution B	1,605	1,340	328	169

Combining the two functions of flow regulation and flood control in the Baardheere dam the total required storage volume is less than the sum of the volumes calculated separately because of the overlapping of the two functions. Through appropriate calculation the figures obtained are the following: (see Part III)

Critical case I for flood control

	Critical case I for flow regulation	Critical case II for flow regulation
	(million cu.m)	
Solution A	3,400	2,800
Solution B	3,100	2,600

Critical case II for flood control

	Critical case I for flow regulation	Critical case II for flow regulation
	(million cu.m)	
Solution A	2,200	1,650
Solution B	2,000	1,400

The figures above show that the total required storage capacity in the Baardheere reservoir is less in the case of the integrated system (Solution B). Because of this, because of increased reliability and because of the advantages of having a hydropower production for civil and industrial use, it has been decided to adopt Solution B.

For the final assessment of the storage volume required in the two reservoirs the most critical cases ("Case I") have been adopted, i.e. the 100-year flood for flood control and the regulation of flow in the 100% duration year.

RECOMMENDATIONS

It is finally recommended to adopt the hydraulic integrated system Baardheere-Saakow as the one which can assume flood control and flow regulation at the lowest cost and highest reliability.

The technical and economic feasibility of this system seems finally ascertained by examination of the technical data available to date. Further and detailed investigations, most of all on the geological and topographical features of the basins and on the salinity of the water of the river, could result in some adjustement of the length of the barrages, and of the volume of the reservoirs, and a final word could be said about annual or biannual regulation. But this is unlikely to change much in the overall recommended system.

At the present stage of the study the recommended volume for the two reservoirs of Saakow and Baardheere, accounting also for siltation, seepage losses and evaporation losses in the basin, are the following:

- Baardheere basin

	million cu.m
Cumulative volume for regulation and flood control	3,100
For silting	500
For evaporation	200
	3,800

- Saakow reservoir

	million cu.m
Regulation volume (including evaporation losses)	328
For silting	30
For seepage losses	15
	373

The recommended structures required are the following:

- Saakow barrage

Masonry weir (height 15 m) in the river bed with two earth dykes of maximum height 17.3 m and length around 1,700 m; the weir is 2.3 m lower than the earth dyke so as to let the 100% flood of 2,400 cu.m/sec to overflow without any damage to the works. Five 8 x 3.50 m water ways in the body of the weir would allow a total maximum discharge of 500 cu.m/sec without any increase of water level. These waterways are utilized also for hydropower production.

- Baardheere dam

Rockfill or concrete gravity dam; storage depth of 55 m with spillways 6 x 70 m to discharge the 2,400 cu.m/sec flood wave. Crest length of the dam: 600 m.

CHAPTER 1.

THE FLOOD PROBLEM

1.1 INTRODUCTION

It is quite evident from the field work which has been done that agriculture in the Juba Valley is conditioned wholly by what happens in the river itself. This is true in both a positive and negative sense, the floods being used for agriculture, especially in the 120 "desceck" covering an area of over 30,000 ha along the river, while the same floods can and do cause great damage when they invade (violently sometimes) the modern farm enterprises.

The river channel at the present time can carry about 700 m^3/s (1), but there is something like a 50% probability that the flood flows will exceed this figure. This cannot be allowed, even though damage is not serious until discharges of 850 to 900 m^3/s are reached (with a probability of 40%), while damage is disastrous when they exceed 1,200 m^3/s (probability of 20%).

During the short period when systematic stream gauging was performed on the river, peak discharges of 1,600 m^3/s were recorded at Luuq. The estimated probability of these is 5%, while the estimated 100-year flood is around 2,000 m^3/s.

Lacking any sufficient time series of flood-flow data, the Selchozpromexport hydrographs have been used in this study. The hydrographs were derived for the Baardheere Station by reference to the floods in the autumn of 1959 and 1961 at Luuq Station. The derivation operation concerned both the correlation of the events between the two gauging stations and the probability distribution of flood flows, especially the 100-year and 20-year floods.

To take the processing further in the present Report, the values for both probabilities are examined with a view to optimizing the choices for the relevant improvement measures. It should also be noted that, generally speaking, though the trend of the flows during the 1959 and 1961 floods was slightly different, the volumes involved were more or less the same.

In order to calculate the storage volume needed to control the floods, account was taken of the bicuspid nature of the event and it has been assumed that compensation can be provided in the concave part of the hydrograph.

The next stage was to calculate the storage values w assuming different spillway discharges, Q_{sf}, and flood probabilities, so as to ascertain the discharges to be topped, Q_{sc}, downstream of the flood-control structure, because they exceed the natural, 700 m^3/s, capacity of the channel.

	Probability 1%	Probability 5%	
Q_{sf} = 600 m^3/s	w = 3,000 x 10^6 m^3	w = 1,700 x 10^6 m^3	Q_{sc} = 0 m^3/s
= 700	w = 2,400	w = 1,250	= 0
= 800	w = 1,800	w = 1,100	= 100
= 900	w = 1,550	w = 850	= 200
= 1,000	w = 1,300	w = 600	= 300
= 1,100	w = 1,100	w = 450	= 400
= 1,200	w = 900	w = 350	= 500

---

(1) This figure may be slightly lower in a few reaches, but with very minor longitudinal protection works here and there, the discharge of 700 m^3/s can be ensured.

1.2 FLOOD CONTROL BY EMBANKMENTS

From the technical aspect it is possible to provide flood protection on the Juba by the construction of embankments or reservoirs. If embankments were built right on the very edge of the river, the "Gallery Forest" which is a basic factor in the conservation of the banks, would be destroyed. If, instead, the embankments were set farther away, a considerable amount of the most fertile bottom land would be lost for farming and a number of small settlements would have to be sacrificed.

Though it is evident even without calculation that the construction of embankments would be a costly undertaking, it has been considered advisable to attempt an order-of-magnitude estimate of the costs, to obtain more concrete ideas on the subject. The estimate is based on the assumption that protection has to be provided from a 20-year flood, it generally being considered that flooding of this frequency is acceptable in non urban areas. As indicated earlier, the 20-year flood at Luuq has a discharge of around 1,600 m^3/s, while at Baardheere it is 1,800 m^3/s. To cope with this by means of embankments, sited as postulated above, would involve the following (see Fig.1.III (a, b).

1. Regularization of the channel for a uniform width of 100 m and construction of continuous embankments along the banks rising to an average of 7 m above ground level.

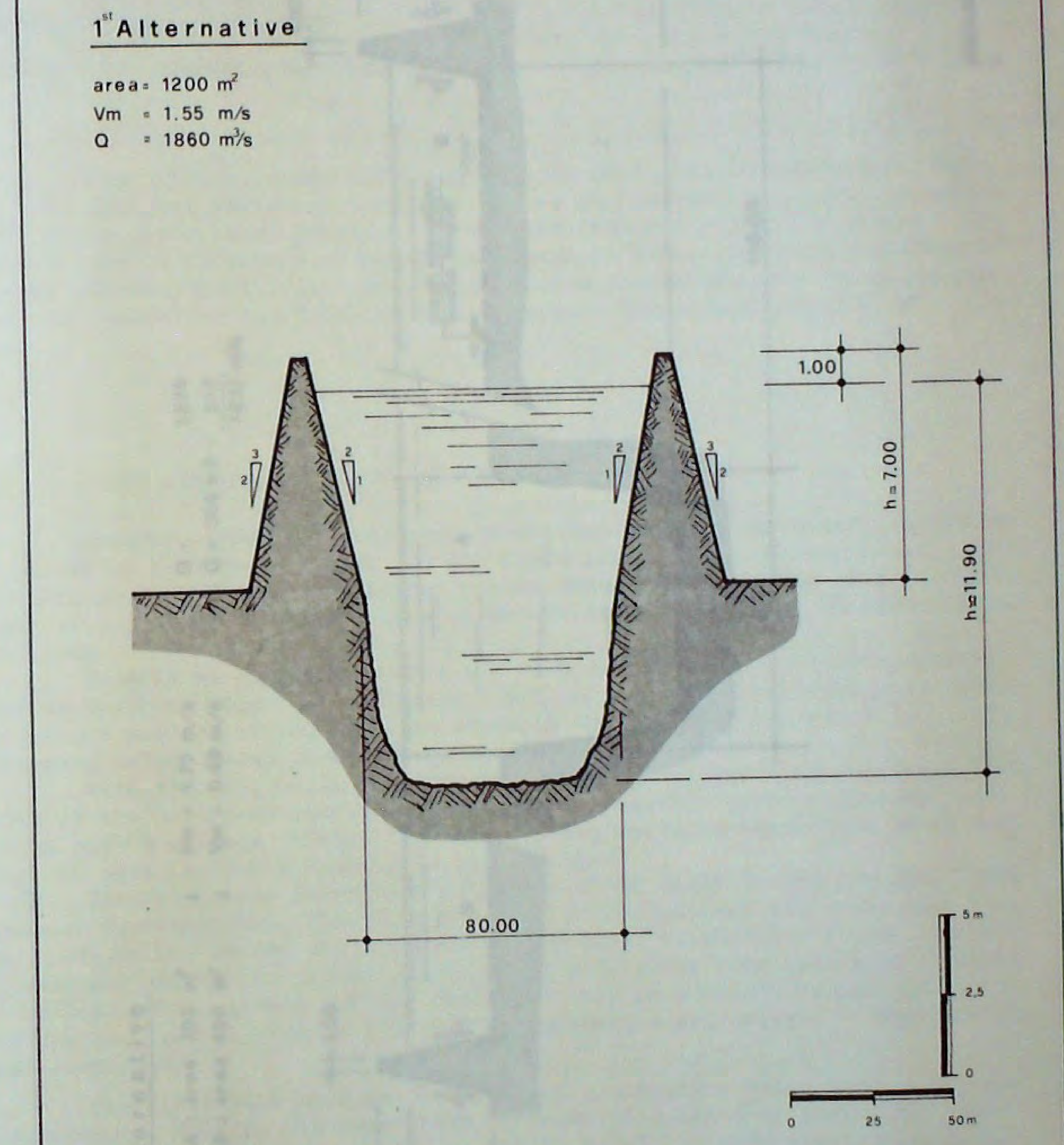
2. Leave the channel as it now is and build 4 m high embankments 400 m apart.

In both instances it is assumed that the works would be built in the lower Juba, south of Manane, where the most important agricultural developments will be located. Thus the last 150 km of river would be involved. There are already some embankment works here, but no account is taken of these, as they are not in keeping with modern thinking on this subject.

The cost of the first solution consists in the actual cost of construction, the loss of Class I agricultural land, the cost of planting and maintaining vegetation protection and the capitalized costs of supervision and maintenance.

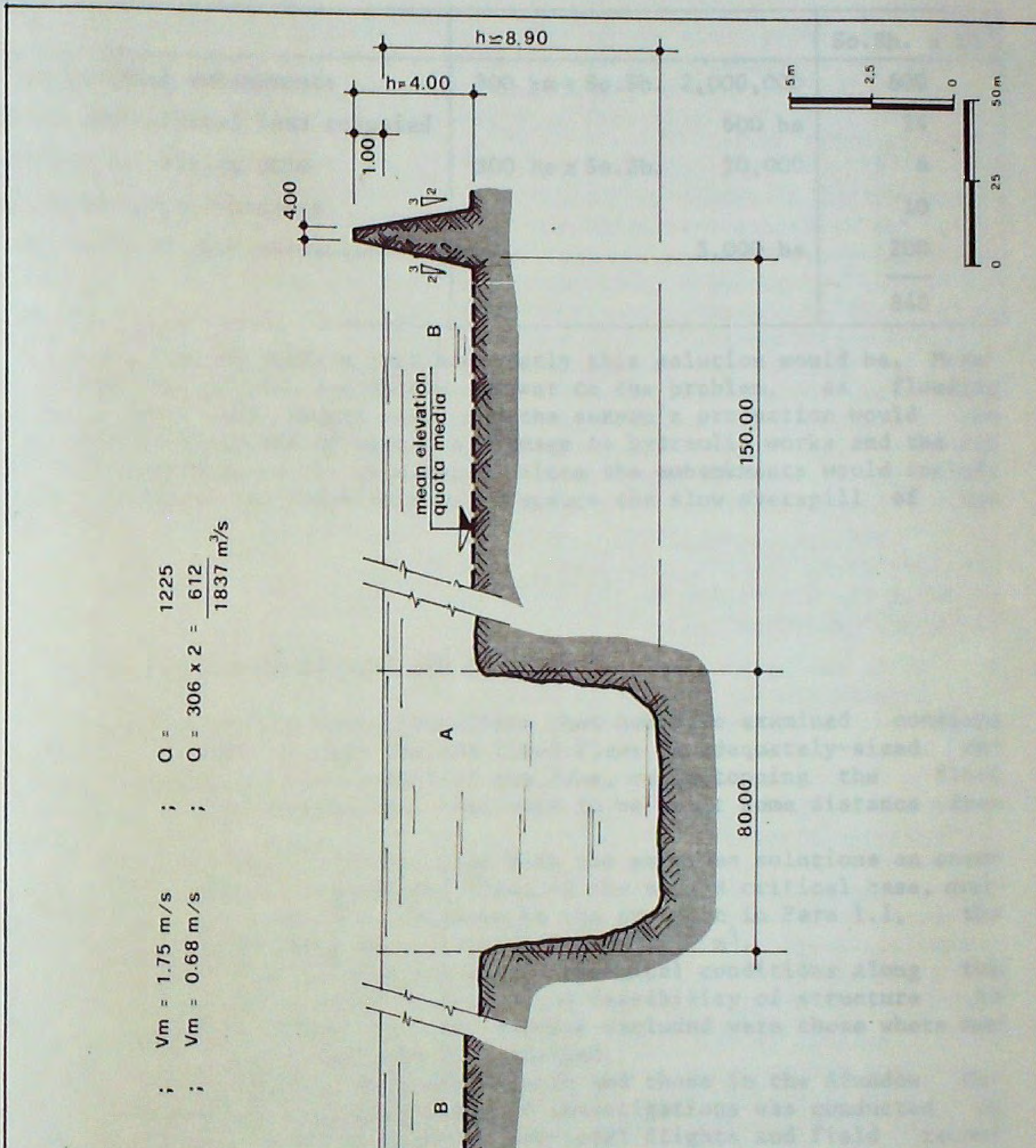
		So.Sh. x 10^6
Cost of building stabilized embankments and of shaping the channel	300 km x So.Sh. 3,000,000	900
Value of agricultural land occupied	1,500 ha	30
Vegetation for making good	500 ha x So.Sh. 20,000	10
Supervision and maintenance (lump sum)		40
		980

For the second solution the costs also include the loss of harvests from some 5,000 ha of bottom lands.



KAITOI: LEVEES SIZED FOR Qmax = 1,800 m³/s
KAITOI SEZIONE ARGINATA PER Qmax = 1800 m³/s

fig. 1a.III



KAITOI: LEVEES SIZED FOR Qmax = 1,800 m³/s
KAITOI: SEZIONE ARGINATA PER Qmax = 1800 m³/s

fig. 1b.III

		So.Sh. x 10^6
Cost of building embankments	300 km x So.Sh. 2,000,000	600
Value of agricultural land occupied	600 ha	24
Vegetation for making good	300 ha x So.Sh. 20,000	6
Supervision and maintenance		10
Capital value of lost production	5,000 ha	200
		840

These figures confirm just how costly this solution would be. Moreover, it does not provide a complete answer to the problem, as flooding would still occur every twenty years and the season's production would be lost on tens of thousands of hectares. Damage to hydraulic works and the riparian infrastructure is not considered, since the embankments would include properly controlled spillways that would ensure the slow overspill of the flood.

1.3 FLOOD CONTROL RESERVOIRS AND FLOODWAYS

Another system of flood protection that has been examined consists in providing temporary storage for the flood flows in adequately-sized reservoirs to be built in the channel of the Juba, or in topping the flood peaks with a floodway running to a reservoir to be built some distance from the river.

To make an immediate comparison with the previous solutions an examination has been made of the 20-year flood in the second critical case, overspilling a maximum of 700 m^3/s. As shown in the prospect in Para 1.1, the reference volume under these conditions is $1,250 \times 10^6$ m^3.

With this figure in mind the geomorphological conditions along the whole of the Juba were examined to assess the feasibility of structure to ensure such a storage volume. The only reaches excluded were those where vast areas of good irrigable land would be submerged.

Thus the areas downstream of Faanoole and those in the Afmadow depression were excluded. The first stage of investigations was conducted on the 1:60,000 air photos and by means of low-level flights and field reconnaissances. During the second phase, where conditions were generally deemed to be favourable, ground surveys were conducted on a widely-spaced grid, the air photos being plotted as 1:20,000 topographic maps, using appropriate ground control.

a. The first idea explored was that of a spreading basin between Dujuuma and Faanoole, holding the water back by means of a fixed or semi-fixed weir in the channel. A preliminary assessment of stability and watertightness indicates these to be satisfactory at the weir and in the storage basin.

The desired storage capacity could be obtained by building a dyke across the valley from the weir, the ends of the dyke swinging upstream to a point where the elevation of the crest is the same as that of the land surface.

The cross-slope of the valley is 0.1%, while the longitudinal slope is around 0.25‰. With a dyke rising to a maximum height of 10 m - which would not be particularly costly or difficult to build - the total length would be about 80 km.

Allowing a freeboard of 2 m on the sill of the weir, the pool area necessary for a storage volume of 1.5×10^9 m^3 (about 250×10^6 m^3 being allowed for siltation over a 50-year period (1)) would be around 550 km^2. With evaporation estimated at around 2 m per year, there would be a loss of over $1,000 \times 10^6$ m^3 or 30% of the streamflow which occurs with a probability of 80%, for which the water-use projects are designed. With such losses this solution is obviously not acceptable.

A variation on the same theme, using a higher dyke, is not viable because of the length of the dyke and the cost of the structure itself. By way of example, with a dyke 20 m high swinging back upstream closer to the channel so as to reduce the pool area to 250 km^2 and halve evaporation to 500×10^6 m^3, the dyke would be over 120 km long and the cost would exceed So.Sh. 1,000 million, so this solution was also discarded.

b. A decidedly more favourable situation is encountered to the north of Dujuuma, where the plain starts to narrow, forming a valley in the strict sense of the word below Saakow. Detailed studies have been performed here. These are described ahead.

c. In the reach to the north, from Anole to Baardheere, where the river cuts through the hills, the restraint is the elevation of the town of Baardheere and the gardens there, which would mean that the dam could be no more than a score or so metres in height.

With reference to the Baardheere benchmark it ensues that the elevation of the channel bed immediately upstream of Anole is 74.50 m, while 1,000 ha of intensively cultivated land in the Baardheere floodplain lie at El. 90.

With a 16.50-m dyke, which could also be built economically, it would be possible to avoid inundating these lands. This would make available a 50-km long strip of valley some 300 m wide, providing a maximum volume of 150×10^6 m^3. This falls far short of the storage volume required for the flood-control reservoir.

d. An area on the right of the river and some distance away, at the first bend one encounters coming from Baardheere, has been examined with particular attention. Some large-scale topographic maps indicate this area as being a "depression". Indeed, some distance away from the river there is a very broad depression but there is no possibility of using it because both the depression itself and the broad plateau between there and the river lie well above the elevation of the Juba channel. Thus, this possibility has also had to be eliminated, as will be appreciated, since the depression would be of no use as a flow-regulation structure for irrigation.

e. Going upstream towards the mountainous stretch north of Baardheere, the valley is still broad in the first few kilometres. Then geomorphological conditions are encountered which are certainly favourable for the construc-

(1) This volume is considered to be sufficient, in view of the limited time the waters will be backed up.

tion of a dam that would provide a reservoir of the size required. This stretch of river, which runs for some 150 km north of Baardheere, is examined in greater detail in the following paragraph.

f. Upstream again, between Marile and Dolow, there is a broad valley with an even lie and very tabular structure, where conditions are similar to those in the areas to the south of Dujuuma. Hence it would be difficult to build a proper flood-control reservoir.

g. A possibility, albeit marginal, of topping the floods, may exist on the Dawa Parma, whose waters could be diverted by a long, costly canal to the nearby depression of Ceel Macaw. There are no data available with which to assess the contribution this tributary may make to the Juba flood flows. However, the fact remains that the river drains about one quarter of the whole basin area upstream of Luuq. Even so it is not recommended that this possibility be investigated further at this stage. Some of the reasons for this are: the relevant flood-control structure would be very isolated and part of it would lie in Ethiopian territory; it would be a costly operation; suitable hydrological and topographical bases would be required, and these could certainly not be provided in a reasonably short space of time.

To sum up, the investigations have shown that only two stretches of river are suitable for building reservoirs of the volume needed to ensure flood control: one approximately between Saakow and Anole; the other upstream of Baardheere in a reach some 100 km in length.

1.4 CHOICE OF SOLUTIONS

A rough estimate has been made of the cost of a barrage upstream of Saakow to store $1,500 \times 10^6$ m^3, so as to control a 5% flood event. The dam would be 28.50 m high and some 5,500 m long, at the crest. The major cost items are:

		So.Sh. x 10^6
Road rerouting	30 km at So.Sh. 200,000	6
Reinforced concrete weir in river bed, including steel	80,000 m^3 at So.Sh. 1,200	96
Earth dyke	1,600,000 m^3 at So.Sh. 30	48
Slope protection and misc.	lump sum	10
		160

The cost of a concrete gravity dam upstream of Baardheere has also been calculated with a similar degree of approximation, for a point where a 400 m long 44.50-m high structure would appear feasible. The cost would be around So.Sh. 100×10^6.

Both these solutions for flood control by temporary storage of the waters are clearly more favourable than the others which involve the construction of longitudinal protection works. The advantage is even greater when it is considered that with these structures it will also be possible to ensure flow regulation.

However, with the dams located in these positions, the problem of protecting the plain between Marile and the Ethiopian border from inundation remains unresolved, and part of this plain - between Luuq and Dolow - is to be served by an irrigation network. There would appear to be no alternative here but to construct flood embankments. However, before anything further is done in this direction it will be as well to undertake the investigation indicated earlier to ascertain the hydrological characteristics of the Dawa Parma and the possibilities of topping the flood peak, so as to arrive at the correct dimensional design of the embankments.

For protecting the land on the left bank in the lower part of the valley between Camsuma and Jamaame from floods deriving from the Farta Tuculle, which receives the peak flows of the Magaday and Webi Shebeli, the Selchozpromexport studies appear to indicate that a solution involving storage of the flood waters would be difficult to implement. The Soviet Report shows the hydrological regime of the Farta at Burfula to be characterized by a 5% probability flood of 230 m^3/s with a volume of over 870 x 10^6 m^3. If it is taken that 20 m^3/s can be spilled downstream, then temporary storage for about 750 x 10^6 m^3 must be found to control the flood. This will be a difficult proposition in this area. Nor would it seem possible to use the Desceck Wadda depression, which is cut off from the Farta Tuculle by a series of sand hills and by quite high dune ridges that can only be surmounted at considerable cost.

So the best solution would appear to be to build flood embankments, as envisaged in the Selchozpromexport Report, the only variation recommended being to shift the alignment of these farther east so as to recover several thousand hectares for irrigation, since these are Class I lands and adjoin the irrigation complex being developed at Jilib and Jamaame.

CHAPTER 2.

UTILIZATION OF STREAMFLOW

2.1 WATER REQUIREMENTS IN THE VARIOUS SECTORS

As exhaustively described in the Agronomic Report (Vol. IV) the development of the Valley hinges around the use of Juba flows to irrigate 221,500 ha net. Assuming maximum utilization (Alternative D of Table 1) the annual requirements at the head end of the districts amount to around 3,285,000,000 m^3. This amount then has to be increased to take account of the losses in the distribution canals; all things considered a 10% increase should suffice, provided that the wetted part of the section is lined or considering that this part will gradually become fairly impervious by the natural deposition of clayey-silty suspended sediment. Thus the gross irrigation requirement is 3,614,000,000 m^3.

It is also considered that the Juba waters will be used to satisfy urban water requirements down the Valley from Dolow to Kismayo. This will amount to an average of 5 m^3/s over the year (maximum 6.50 m^3/s), giving a per capita consumption in 2,010 of 200 l/day.

No allowance is made for industry at this stage. In the assumptions regarding development the actual consumption of water by the industrial sector would be virtually negligible, compared with the irrigation requirements. It is likely that greater industrial development, involving considerable water demand, will coincide with a general economic take-off in all sectors and hence with the introduction of very modern, automated irrigation systems that will save enough water to cover industry's requirements. Similarly, should irrigation spread more rapidly than envisaged (up to 20-25% more land involved) there should be no increase in total water demand, for the same reasons. Indeed:

a. It is reasonable to think that as time goes by the farmers will become more familiar with irrigation practices, and increasingly advanced techniques will be introduced, both as regards the construction of the supply networks and on-farm equipment (watering systems). These will result in considerable economies in water use which, considering what is achieved in more developed countries, could amount to around 20% in all.

b. The crops introduced during the third period will be less demanding, as regards water. Taken together with the irrigation improvements, this should mean that average consumption will be around 8,000 m^3/ha.

c. The monthly demand diagram of these crops can be brought closer to the trend of the natural flow diagram.

A further point to be considered is the base flow needed in the river from the hygienic point of view. It is felt that this should not be less than 10 m^3/s.

Hence, in the case of the selection of Alternative D crop rotation, plus the water supply demand for the towns and the amount of flow needed to ensure hygiene, the total is 4,080,000,000 m^3, in round figures (see Table 2).

Table 1 - Irrigation requirements (at head end of district) - in 10^6 m^3

	A	M	J	J	A	S	O	N	D	J	F	M	Total	
Phase I * (ha 34,000)	55	53	59	67	55	51	69	78	84	83	66	59	779	
Phase II **														
Alternative A	86	219	344	290	197	183	352	354	304	130	95	105	2,659	Without forage in Districts 2 and 5
Alternative B	107	233	355	315	243	222	363	363	329	184	146	162	3,022	With forage in District 2
Alternative C	112	242	364	323	252	231	367	364	333	192	156	172	3,108	With forage in Districts 2 and 5
Alternative D	142	277	379	316	280	253	401	388	331	179	144	195	3,285	With forage in 2 and 5 and rice in Dis. 6
Alternative E	122	265	380	302	241	218	399	390	316	130	95	128	2,986	Without forage in 2 and 5, but with rice in 6

* Flow regulation obtained by means of Saakow Reservoir

** Flow regulation obtained by means of the Baardheere-Saakow system

Tab. 2 - Total water demand (Alternative D)

Month	Irrigation	Canal losses (10%)	Urban Water Supply	Minimum flow in channel	Total
January	179,000,000	17,900,000	13,390,000	26,780,000	237,070,000
February	144,000,000	14,400,000	12,100,000	24,200,000	194,700,000
March	195,000,000	19,500,000	13,390,000	26,780,000	254,670,000
April	142,000,000	14,200,000	12,960,000	25,920,000	195,080,000
May	277,000,000	27,700,000	13,390,000	26,780,000	344,870,000
June	379,000,000	37,900,999	12,960,000	25,920,000	455,780,000
July	316,000,000	31,600,000	13,390,000	26,780,000	387,770,000
August	280,000,000	28,000,000	13,390,000	26,780,000	348,170,000
September	253,000,000	25,300,000	12,960,000	25,920,000	317,180,000
October	401,000,000	40,100,000	13,390,000	26,780,000	481,270,000
November	388,000,000	38,800,000	12,960,000	25,920,000	465,680,000
December	331,000,000	33,100,000	13,390,000	26,780,000	404,270,000

4,086,510,000

In round figures 4,090,000,000

2.2 IRRIGATION BALANCE IN PHASE I

In the first phase, to get irrigation under way immediately or while awaiting completion of the primary regulation structures, agriculture may require a maximum of 780 x 10^6 m^3 for the irrigation of the 34,000 ha already cultivated.

This demand requires a structure that will regulate monthly flows as per the values indicated in Table 1. The natural flows of the Juba ensure that the requirements set forth in the Table are covered with a frequency of 97% in 8 months of the year (from May to December) while shortfalls of varying severity occur in the other four months.

Past sequences of 1, 2, 3, 4 and 5 consecutive months with the minimum streamflow over the whole period of record have been isolated, as have those with flows immediately above. These values constitute the first two critical cases for each sequence and have frequencies of about 1% and 12%. After stripping these values of evaporation losses, they were then used to calculate the capacities needed to provide sufficient compensation to ensure a constant delivery of 27 m^3/s over the whole of each sequence considered. The tabulated results are as follows (in 10^6 m^3):

	Critical Case I			Critical Case II		
	WD	WN	AW	WD	WN	AW
1 month	17	7	63	19	9	61
2 months	36	12	128	37	16	124
3 months	67	23	187	116	79	131
4 months	98	31	249	175	121	159
5 months	358	274	76	506	430	

where:

WD Volume of natural streamflow

WN Volume WD stripped of evaporation losses, estimated at 200 mm/month of the water-surface area

AW Regulation volume for a consumption corresponding to a constant delivery of 27 m^3/s.

The choice of the critical case to be used in the calculations depends, of course, on a reasoned synthesis of economic aspects and an assessment of the reliability of the hydrological data available.

In point of fact, the limited span of time covered by the hydrological record and ignorance of the degree of accuracy thereof mean that the most conservative conditions have generally been chosen. However, every now and then a check has been made to see whether this might not lead to an excessively high economic commitment. In addition account is also taken of the fact that the river situation identified in this way can always be corrected and improved upon, should additional hydrologic data indicate this to be necessary. It will not be possible to make a reasonable critical appraisal of present data until some ten years hence, when the exploitation of the works built will still be very limited and it will still be possible to make such corrections as may be necessary.

2.3 WATER BALANCE IN PHASE II

The final choice on the event to be considered will be made when the works are identified. At this point we shall merely refer to the results of the hydrological calculations in relation to the demand diagram.

The total annual requirement - excluding evaporation losses in storage basins - could have been covered by the natural flows throughout the period of record (1951 - 1964) except in one year when the mean discharge was only 109 m^3/s against the 130 m^3/s required. The event thus has a duration of 93% and the water failure involved is about 16%.

To ensure a positive balance for the whole period, biennial compensation is necessary; this should be generally satisfactory in view of the small number of failures involved. Considering this aim together with that of matching the individual natural monthly flows to the demand diagram - which can be done by including a regulating reservoir - it ensues that a volume of:

1,518 x 10^6 m^3 is needed to cover requirements in 100% of the years
1,140 x 10^6 m^3 to ensure coverage in 93% of the years.

This matter is described in detail in Part II, Para 4.2. The envisaged cropping pattern provides for 43,075 ha under perennial crops and the remaining 178,425 under rotated crops. It should be observed that the bulk of the water failures occur in the Gu season and will not affect the growth of the rotated crops in the Der period. Thus, for 84% of the crops the water failures can be fixed over the period of a season rather than a year, so for those crops the probability of the event moves from 1 year in 15 to 1 season in 29, and hence from 93% to 96.5%. In the case of the perennial crops, the waters must be managed in order to ensure at least the survival of the crops, even if a harvest might not be guaranteed.

CHAPTER 3.

PROPOSED MEASURES

3.1 EXTENSIVE WORKS

The measures which emerge from the investigations and studies made, and described elsewhere, are as follows, proceeding downstream.

a.1 In the upper reaches of the basin between Luuq and Dolow, it is intended to irrigate an area of 16,400 ha net, along the Juba (see Fig.2a.III). This will involve taking water from the Dawa Parma, a left-bank tributary of the Juba, at a water elevation of 302 (elevation on Dolow bench mark described as El. 210 a.s.l.). The water is carried through penstocks designed to convey the maximum irrigation demand of 14 m^3/s, and is first led to a hydroelectric plant where a fall of 30 m is utilized, the water discharging at El. 268.50 m. This plant, with installed capacity of 3,000 kW, will generate electricity for the rural settlements and the town of Dolow. If it ensues that the volume of water conveyed to irrigate the Luuq-Dolow District is too low, some of the electrical energy could be used to pump up water from the Juba a couple of kilometres downstream of the town. It will not be possible to proceed to the more exact dimensional design of the works or to ascertain exactly how much water is available for irrigation until the hydrological and morphological study recommended elsewhere has been completed; this might even indicate the need for a compensating basin to regularize the flows for the urban water supply, if it has been ascertained that the water balance is in line with the Dawa Parma flows alone.

a.2 The Urban Water Supply system also starts from the same intake to convey a maximum discharge of 0.50 m^3/s to the towns of Dolow and Luuq and to the inhabited area up to Marile where it is envisaged 130,000 people will be settled by 2,010. In the first instance only one conduit of the planned twin-conduit line would be built, and one section of the water treatment plant, amounting to one quarter of the total capacity envisaged.

a.3 The urban supply line runs independently from the hydroelectric penstocks and ensures the system of a 70-80-m head. The irrigation conveyance system proper starts from the power-plant tailrace at El. 268. It takes the form of an open canal with a gradient of 0.5‰, running on the right of the district, which it commands with a 20-25 m head. At the head end and along the 74,000 m run a number of branches take off to the left bank and to serve a lift on the right.

a.4 This district lies upstream of the areas where floods will be controlled by dams, so as indicated earlier, it will be necessary to build flood-protection embankments on both sides of the Juba from Dolow to Luuq. The size of these embankments cannot be decided until appropriate hydrological studies have been performed.

b.1 In order to supply the Baardheere-Saakow District (No 2), which covers 47,350 ha net on both banks of the river, lying at an elevation of below 200 m, water will be drawn from Baardheere Dam, with outlet at 130 m.a.s.l. (Fig.2b.III). The conveyance canal, with a head-end capacity of 52 m^3/s, runs in sidehill on the left of the river. The bulk of the canal here will be excavated in mainly rocky ground. After having skirted the town, the canal drops down into the valley near the Anole area which it reaches after a distance of 93,000 m, with a gradient of around 0.5‰. Provision is made for six large syphons along the alignment to cross the broad valleys of tributaries and also the Juba itself in two places. There are also about ten or so branches, one for the 38,000 m right-bank conveyance canal, plus seven pumping stations which lie downstream of about 50% of the total commanded area. These have a maximum head of 75 m and an average of 60 m, the installed capacity being 18,000 kW. To provide power for these pumping stations there will be a hydroelectric plant below Baardheere Dam working on an average head of 45 m and turbining a discharge which will vary depending on the irrigation demand diagram, plus a steady discharge - 100 m^3/s - to generate power for municipal use. In this manner there will be an average head of 45 x 2/1.50 = 60 m available for irrigation use, which is what is required. For municipal use, instead, there will be about 35,000 kW available.

b.2 The second Urban Water Supply on the Juba will run from the dam to feed the towns downstream as far as Dujuuma and beyond. This will be designed for a maximum Q of 1.00 m^3/s and its elevation downstream of the treatment plant will be 120 m a.s.l. As the elevation of Baardheere is around 115 m a booster will be necessary; in the first instance this could be limited to a score or so metres, then increased to 60-65 m in 2,010. The Urban Water Supply line will run alongside the irrigation line as far as the town.

c. Immediately downstream of the District just described comes the 26,600-ha Saakow District (No 3) (see Fig.2c.III). This will be fed with water from the Juba via a weir on the river about 5,000 m upstream of Saakow. Two conveyance canals with a total discharge of 25 m^3/s take off from the weir about 10 m above ground level, one on the left bank for a total of 39,500 m and one on the right for 63,000 m. A third conveyance canal takes off from the latter and crosses to the left bank; the total length of this canal is 60,000 m.

Pumping will also be required in this District, so the weir will be complete with a hydroelectric station. This will provide power for the numerous pumping stations needed in the upstream part of Dujuuma District (No 4), too. The plant will have a maximum discharge of 100 m^3/s available and the head will be around 10 m; the installed capacity will be 8,000 kW.

d. As just mentioned, the Dujuuma District (No 4) comes next downstream running as a long strip along the Juba and interrupted about half way along by a Nature Reserve (see Fig.2d.III). Because of the somewhat discontinuous nature of the 11,100 net ha on both banks of the river, interrupted by the many bends, it is envisaged that the water will be provided from eight independent pumping stations ensuring a total discharge of around 5 m^3/s. As noted, the power for the upstream stations will come from the hydroelectric plant on the Saakow barrage, while that for the lower stations will come from the Faanoole barrage.

The eight pumping stations feed eight autonomous irrigated areas by a similar number of conveyance canals, but the size of these puts them more in the class of District canals. As such, they are dealt with in the Agricultural Report (Vol. IV).

e. The centralized pumping station for the Dufalach-Afmadow District (No 5) is located in this reach of the river (see Fig.2e.III). The 7,800-ha net District runs through a long, narrow depression away from the river on the right, immediately downstream of the Nature Reserve. It is fed at a rate of 7.5 m^3/s by a canal which runs from the pumping station at the downstream extremity of the irrigated area and is some 80,000 m long, commanding the

valley on the left. Two conveyance canals totalling 52,000 m in length take off to feed the right-hand side of the valley.

f. Immediately downstream starts the Faanoole-Jamaame District, originally studied by Selchozpromexport during the course of the Juba River Scheme. The District has been divided into the following subdistricts for ease of reference:

Faanoole-Jilib	26,400 ha net
Touta Island	13,300 " "
Baardheere-Jonte	32,200 " "
Jamaame	20,050 " "
State Farm	10,300 " "
Total	102,250 ha net

The District is served by a barrage at Faanoole and one at Qaliakoko (see Figs. 2.f,g,h,i,j.III).

f.1 As an alternative, the possibility could be examined of diverting all the required discharge at the Faanoole Barrage. However, a realistic assessment of this can only be made at the final design stage (by considering the benefits of generating power which would be virtually lost with the concentrated solution). At this stage, therefore, we have opted for the two-intake solution, as per the Selchozpromexport study. The intake for the Urban Water Supply of the lower Juba valley down to Kismayo would be sited at Faanoole. It would be designed for a maximum of 5 m^3/s.

f.2 The canal alignments are also broadly the same as in the schemes studied previously, but with slight modifications bound up with the new land classification and an increased area of around 3,000 ha obtained by moving the protective dykes to include part of the Farta Tuculle valley in the District.

g. Internally on the right of the river, it is envisaged that the better part of the Desceck Uamo, a net area of 10,000 ha, will be fed with water from the Juba, conveyed via a canal that would follow the line of the present canal and designed for a discharge of around 4 m^3/s (see Fig.2k.III). When hydrological studies have been made for a sufficient number of years, this scheme might also be able to benefit from waters coming from Kenya, regulated by means of a large reservoir which could apparently be built near the desceck and which in any case is needed to prevent the plain being flooded.

The lower part of the Juba valley will be protected from external waters by the reservoir just described and the dykes to protect the Jamaame area from the Farta Tuculle.

h. A semi-fixed barrage will be built in the reach of the river near the mouth to prevent the inflow of seawaters when the Juba flows are at a low level. The movable part of the weir could take various forms, depending on the costs and operating advantages involved. Of course, with this structure causing the Juba flows to back-up, it will also be necessary to raise the banks slightly to contain the maximum flood wave of 7-800 m^3/s.

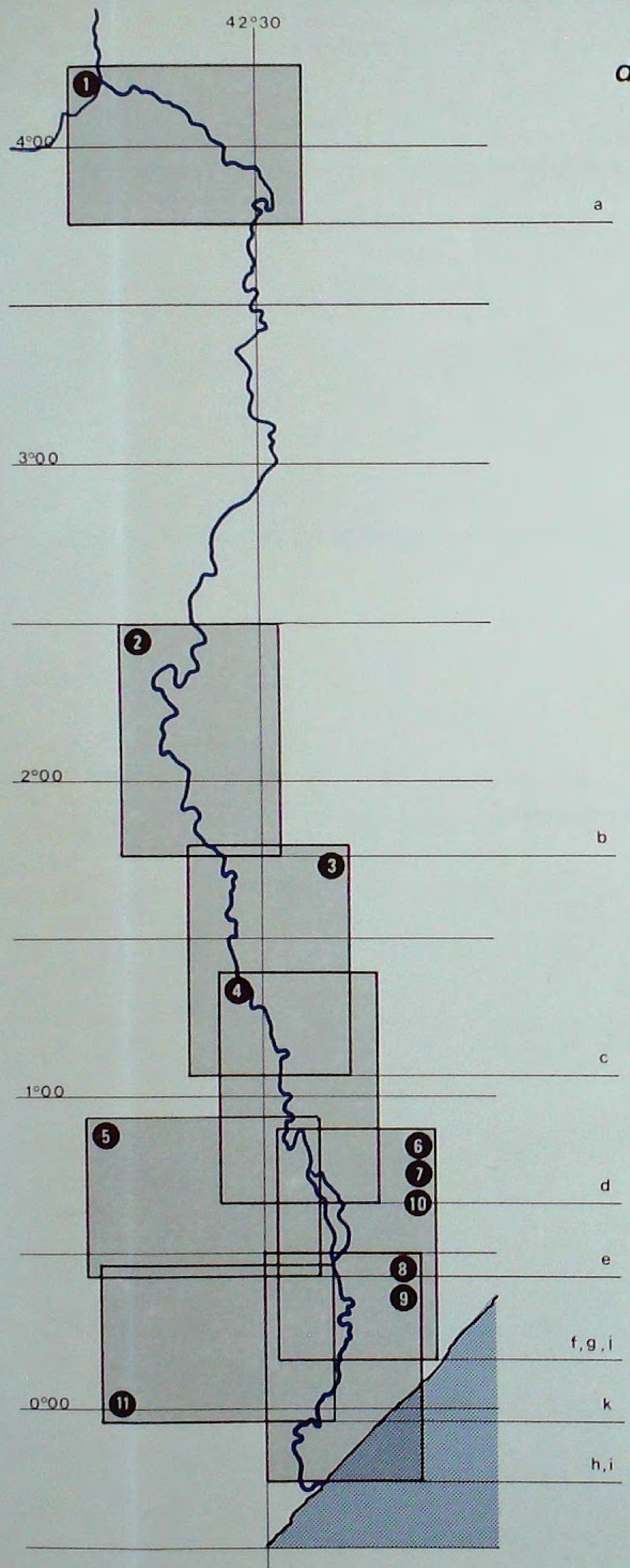
NOTE: The following plans (Fig. 2 a. III to 2 k. III) have a merely indicative value. in fact gross irrigated areas of each district can only be identified once that adequate soil and land surveys have been carried out. The same applies to the irrigation network.

NOTA: I seguenti schemi (da Fig. 2 a. III a 2 k. III) hanno un valore puramente indicativo. Infatti le aree che dovranno essere servite dalla rete irrigua di ciascun comprensorio (aree lorde irrigate) potranno essere identificate soltanto attraverso opportuni rilievi pedologici e topografici. Lo stesso dicasi per le opere di presa ed il sistema di irrigazione.

LEGENDA

Key map

Quadro d'unione



i Fig. reference
Riferimento alla fig.

9 No. of the District
Numero del Distretto

Irrigation engineering

Ingegneria degli schemi irrigui


Dam & reservoir
Diga ed invaso


Diversion weir
Traversa


Conveyance canals
Canali adduttori


Penstock
Tronco in pressione


Pumping station
Impianto di sollevamento


Hydroelectric head
Salto idroelettrico


River crossing
Attraversamento del fiume


Gross irrigated area
Superficie lorda irrigata

Land classification for irrigation suitability

(U.S. Bureau of Reclamation)

Classificazione dei terreni ai fini della suscettivita' all'irrigazione

1st Class
Classe 1

2nd Class
Classe 2

3rd Class
Classe 3

4th Class
Classe 4

6th Class
Classe 6

Proposed links

Collegamenti previsti

Main
Principali

Secondary
Secondari

Tertiary
Terziari

Natural reserve
Riserva naturale

Scale
Scala
1/200,000

Fig. 2. III

LEGEND

COMPRENSORIO 1: LUUQ – DOLOW

DISTRICT 1: LUUQ – DOLOW

fig. 2a.III

fig. 2b.III

DISTRICT 2 : BAARDHEERE–SAAKOW

COMPRENSORIO 2: BAARDHEERE–SAAKOW

fig. 2c.III

DISTRICT 3: DOWNSTREAM OF SAAKOW

COMPRENSORIO 3: A VALLE DI SAAKOW

fig. 2.d. III

DISTRICT 4 : DOWNSTREAM OF DUJUUMA

COMPRENSORIO 4: A VALLE DI DUJUUMA

fig. 2e.III

DISTRICT 5: DUFALACH–AFMADOW

COMPRENSORIO 5: DUFALACH–AFMADOW

fig. 2f.III

DISTRICT 6 : FAANOOLE-JILIB

COMPRENSORIO 6 : FAANOOLE-JILIB

fig. 2g.III

DISTRICT 7 : TOUTA ISLAND

COMPRENSORIO 7 : ISOLA DI TOUTA

fig. 2h.III

DISTRICT 8 : BAARDHEERE–IONTE

COMPRENSORIO 8 : BAARDHEERE–IONTE

fig. 2.III

DISTRICT 9: JAMAAME

COMPRENSORIO 9: JAMAAME

fig.2.1.III

DISTRICT 10: STATE FARMS

COMPRENSORIO 10: AZIENDE DI STATO

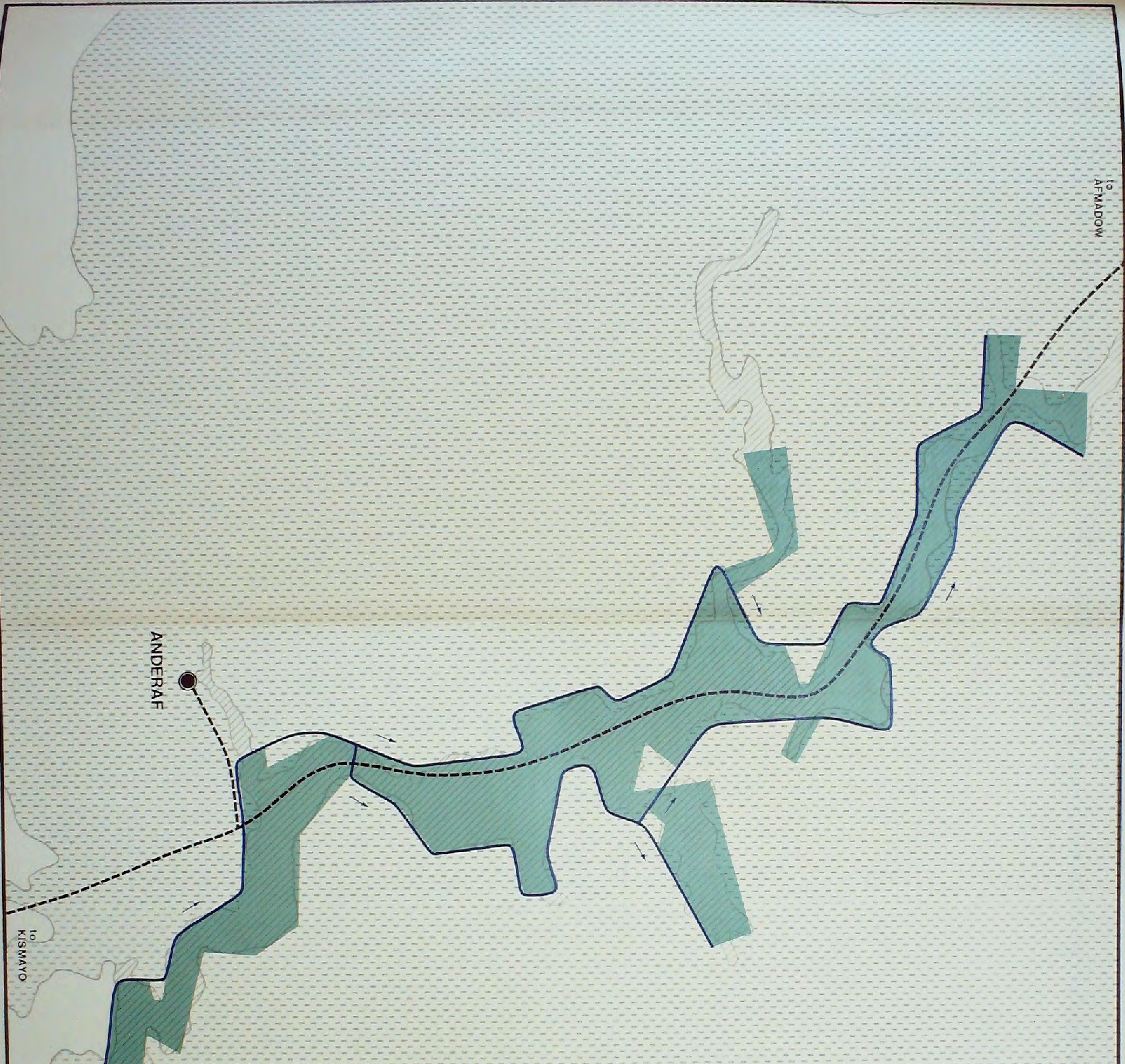


fig. 2k.III

DISTRICT 11: DESCEK UAMO

COMPRENSORIO 11: DESCEK UAMO

3.2 IDENTIFICATION OF RESERVOIR CAPACITIES

As has been made clear in the foregoing, there are two reaches on the Juba where it is feasible to build reservoirs to control floods on the plain and to regulate flows for irrigation, drinking water and hygienic purpose.

A detailed examination has been made of the two reaches at the Preliminary Design level, taking account of the reservoir capacity needed to solve the relevant problems in Phase I, when the matter of flood protection will not be tackled, and in Phase II, when this will be the main objective.

To determine the order of magnitude of the volumes involved, let us first summarize the basic data, assessed earlier:

Phase I

Reservoir for flow regulation to ensure a minimum of 27 m^3/s

Critical Case I : 250×10^6 m^3
Critical Case II : 160×10^6 m^3

Phase II

Reservoir for flow regulation to cover monthly Urban Water Supply, hygienic and irrigation demand (the latter according to the Cropping Pattern D requirement - Table 1) (see Para 2.3)

Critical Case I : $1,518 \times 10^6$ m^3
Critical Case II : $1,140 \times 10^6$ m^3

Reservoir for flood control, assessed according to the 1961 flood hydrograph and related to a maximum downstream flow of 700 m^3/s

Critical Case I : $2,400 \times 10^6$ m^3
Critical Case II : $1,250 \times 10^6$ m^3.

These values have to be corrected to take account of the additional volumes required to cover the storage function, while taking account of the superimposition of the two functions.

The net volume in the case of Phase I has to be increased to allow for siltation; the net volume already takes account of evaporation. Solid discharge is around 10-12 x 10^6 m^3/year, the sediment part being around 80%. Since the filling of the reservoir can be assured with the flows of November and December only the whole sediment in these two months is considered deposited. Moreover as the reservoir is emptied from January to April around 60% of the sediment of these four months must be also considered. Therefore it can be assumes a deposit between 2-3.5 x 10^6 m^3 every year. So the total amount in ten years - the time it is considered Phase I will last - will be 20-35 x 10^6 m^3.

Thus the total requirement in Phase I is:

	Minimum	Maximum
Net volume	160×10^6 m^3	250×10^6 m^3
For silting	20×10^6 m^3	35×10^6 m^3
Seepage losses 5%	10×10^6 m^3	15×10^6 m^3
Total	190×10^6 m^3	300×10^6 m^3

To take account of the loss of capacity because of silting, when tackling the question of the size needed for a reservoir to cope with Phase II requirements, a 50-year silting period has been considered. Regarding the actual allowance made for silt, it is taken that the average annual volume of sediment transported is 10 to 12 x 10^6 m^3 and that water velocities in the reservoir throughout its life will be very low. While lacking any actual analysis on this matter, it is felt that although over 90% of the sediment consists of silts and clays, virtually all of it will be deposited in the 120-150 km long reservoir. Thus, to be on the safe side, it has been decided to allow 10 x 10^6 m^3 a year for silting over the fifty-year period, or 500 x 10^6 m^3 in all. This figure should be checked at the final engineering stage.

In first approximation, it is considered that a volume of 300 x 10^6 m^3/year must be allowed to make up for the evaporation loss. This corresponds to evaporation of 2 m per year from an average pool area of 150 km^2, which has been taken as the average of the various areas at the levels which may occur in the reservoir over the year.

As the functions of flood control and flow regulation are combined, a preliminary examination has been made of the extent to which these two functions overlap in time. This shows that total reservoir capacity required can be considerably less than the simple sum of the volumes needed for the two functions.

The following points emerge from a comparison of the filling trend of the reservoir volume reserved for regulation on the one hand and the flood hydrograph on the other.

The monthly streamflow diagram for Baardheere (Part II - Chapter 3) shows that in fourteen years the flood peak never occurred in January and February, as the maximum streamflow never exceeded 260 x 10^6 m^3, though it did occur during the May to December period. The flood hydrograph plotted by Selchozpromexport (on which the flood-control volume is calculated) covers a 100-day period, so the most unfavourable flood, as far as our calculations are concerned, would be in the last quarter of the year, because that part of the reservoir required for regulation - which concerns mainly the provision of compensation for the dry months of January to April - will then be at its fullest, having received the contribution of the mid-year months. The volume available for an end-December flood is thus at its lowest.

From the sequence of monthly reservoir balances, indicated in Annex 3 of Part II of this Volume, it ensues that in the October-December quarter preceding the driest year of the period of record (1955) the reservoir received the following volumes: October 1,164 x 10^6 m^3, November 382 x 10^6 m^3 and December 338 x 10^6 m^3. So taking account of deliveries (see Table 2), the compensation position is as follows:

	Natural flows 10^6 m^3	Deliveries 10^6 m^3	Balance 10^6 m^3
October	1,164	481	+683
November	382	466	- 84
December	338	404	- 66
Compensation over quarter			+533

This is the volume by which the capacity reserved for flood control is reduced in the case of 100% flow regulation. Considering the same situation for the 1952-1953 period (the Second Critical Case in the 14 years of record), we have:

	Natural flows 10^6 m^3	Deliveries 10^6 m^3	Balance 10^6 m^3
October	1,187	481	+706
November	769	466	+303
December	133	404	-271
Compensation over quarter			+738

The volume reserved for flood control is reduced by this amount, when 93% flow regulation is ensured.

This means that assuming that regulation is completely guaranteed to cover all requirements, a restraint may be placed on reservoir operation to ensure that on October, 1st,(having secured the reserves for evaporation and silting) the basin must be no fuller than 985 x 10^6 m^3, i.e. 1,518-533. So the volume to be reserved for control of the 100-year flood (2,400 x 10^6 m^3) is brought down to 1,867 x 10^6 m^3, i.e. 2,400-533, which can be considered as 1,870 x 10^6 m^3, in round figures.

Likewise, in Critical Case II, assuming a similar operational restraint, with filling not exceeding 402 x 10^6 m^3, i.e. 1,140-738, the flood-control volume would come down to 1,662 x 10^6 m^3, i.e. 2,400-738, or 1,660 x 10^6 m^3, in round figures.

To complete this exploratory study, considering random conditions (that will need to be checked by controls and hydrological data processing on the Juba) an analysis has been run assuming extremely severe conditions, namely a biennial repetition of the low-flow years, so that the maximum absolute total shortage is combined with the maximum absolute shortage in the quarter. Without repeating the calculations of the kind indicated above, the natural flow in this case would be 1,575 x 10^6 m^3, i.e. 927 + 502 + 146, and the delivery 1,351 x 10^6 m^3, which would result in the flood-control capacity being reduced to 2,176 x 10^6 m^3, i.e. 2,400 - 224.

This matter is taken up again in Paragraph 3.4.

As mentioned, the points made above are valid purely from the qualitative aspect. To confirm them from the dimensional aspect, too, a study will be required at the Final Design level. However, it is felt that at this stage of the plan it will suffice to make the reduction indicated very roughly above and then to run further checks later, including those on previous hydrological studies.

So for Phase II a dam capable of ensuring the following storage volumes will be needed:

For flood control and flow regulation	2,800 x 10^6 m^3	3,400 x 10^6 m^3
For silting	500 x 10^6 m^3	500 x 10^6 m^3
For evaporation	300 x 10^6 m^3	300 x 10^6 m^3
Total	3,600 x 10^6 m^3	4,200 x 10^6 m^3

3.3 SEARCH FOR DAM SITES

Bearing in mind the range of storage volumes involved, a detailed survey has been made from the geomorphological aspect to single out the most suitable dam sites.

a. From an initial examination it would appear that in the stretch between Dujuuma and Saakow there exists a general possibility of constructing a spreading basin with a shallow depth of water providing sufficient volume for Phase I. Only lands unsuitable for crop-growing would be drowned.

The landform here is very uniform. The cross slopes are negligible downstream and increase upstream to 1.5%. Along the course of the river the ground slope varies from 0.25‰ to 0.28‰. There is a virtually unlimited amount of non arable land available.

From the geological aspect, there is 2-3 m of alluvial cover over a limestone bedrock. In the middle of the valley there are more recent alluvials than at the sides where an eluvial soil is present. The particle size of the material tends to be on the fine side and it is virtually impermeable.

These geological and geotechnical points have been ascertained by field surveys and investigations and there can be no doubt as to the feasibility of the scheme, as detailed in the Geological Report (Part I of this Volume).

The morphological details were ascertained by a field survey of two broad cross sections and the plotting of the air photos of this area at 1:20,000 with 2-m contours. The resulting map also shows the 57 alignments that have been traced on the maps and for which profiles have been developed.

In view of the degree of detail achieved by the investigations, it is possible to state that the barrage will consist of a weir in the river channel and dykes running from there to the side of the valley. The structure will lie on the Juba immediately upstream of Saakow where the sideslopes are about 1% and the lengthwise gradient of the valley is 0.26‰.

Two sections were chosen for comparison to select the most economic solution; the first lies near Alignment No 3 and the second is some 4,000 m away at Alignment No 8. The first section has the advantage of a short conveyance canal and the second a narrower section to dam.

The calculations that have been made indicate that the cost curves of the two sections intersect at a height of about 8 m - on the weir sill - which would give a storage volume of about 120 x 10^6 m^3.

Since in all the hypotheses explored in Chapter 3.2 regarding both phases and critical cases, the volume estimated to be necessary exceeds this in every instance, Section 8 has been chosen, being the cheapest for the required volumes. During the course of the examination it emerged quite clearly just how costly it would be to try to obtain a reservoir of the size needed for Phase II, in this reach. Indeed, taking the pool level to a height of 24 m above the plain would involve dykes 26-27 m high and the crest length would be about 4,500 m. This would be a dam in the full sense of the word and would produce a reservoir with storage of about 800,000,000 m^3. As will be appreciated, at these levels, the unit cost of stored water is certainly very high.

If the storage depth is kept to the 10-16 m range (12-18 m to the crest), the dyke lengths would be around 2,100-2,900 m and the capacity 300-600 x 10^6 m^3. These ratios are quite acceptable, considering the low average height of the dyke above plain level (6-9 m), and the particularly economic

nature of the structure involved.

Thus, when examining the barrage, account has been taken of the extent to which it meets Phase I needs, in the two critical case hypotheses. For these two Phase I storage values required, an overspill height of 12 m has been adopted to take account of the Second Critical Case and 14 m for the First. These give capacities of 205 x 10^6 m^3 and 300 x 10^6 m^3, respectively.

Fig.3.III shows the curves of the volumes for the two dam sites and Fig.4.III shows schematic cross sections. It ensues that at the chosen site the dyke would be 1,225 and 1,700 m long, in the two storage hypotheses considered.

Both the engineering properties of the foundation soils and the landform of the valley indicate that an earth dyke would be the most preferable structure. Furthermore, the presence of suitable clayey-silty materials and limestone on site will ensure economic construction. In the river channel proper, the dyke gives way to a fixed masonry or lean-concrete weir with a Croager profile. On the upstream toe of the dyke there will be a filter which will run right under the structure to a drain built on the downstream side (see Fig.5.III).

The upstream slope of the dyke will have a 0.30 m thick revetment of rip-rap, turned over at the upper edge of the dyke, while the downstream face will be thickly grassed. Where there are game trails, the revetment will also be extended to the downstream face the slope will be appropriately lowered to 1/2 to allow elephants to pass without damaging the dyke. The system to protect the dyke from damage by game will be completed by means of a relatively shallow guard trench with a very low slope cut a score or so metres from the foot of the downstream side of the dyke and fed permanently from the dam by means of a small pumping unit and pipeline. The slope of this ditch could be 0.1‰, obtained by inserting a number of beddrops, the top width would be 3.50 m and the side-slopes 2/3. It would be fed with something like seventy litres of water per second.

It is envisaged that several gated outlets will be provided in the fixed weir, with the sill set 1 m above the bottom, to allow for future hydroelectric installations and to pass catastrophic floods. The choice of a fixed weir is dictated by the idea of avoiding any complicated gate operations. Even if this aspect were automated, supervision and maintenance would be particularly costly in the beginning, as the site is isolated from the areas to be developed.

However, considering the limited period during which the barrage here will be operating independently, it has been preferred not to rely on the fixed structures to pass the catastrophic 100-year flood, as this would have been too costly a solution. Provision is therefore made for the incorporation of movable gates, which only need attention in November and December. Indeed, the barrage is conceived to allow total opening of the bottom outlets at the end of the Gu season, so as to ensure the minimum of silting by permitting the maximum free flow of the influent discharges. During that period the weir can remain unattended up to November when it is necessary to control the influent flows so as to fill the reservoir. This is 100% possible statistically, since there is an absolute minimum streamflow of 700 x 10^6 m^3 in the two months concerned. Control must also be exercised to guarantee the passage of floods which may continue to the end of December. As from January the weir can be left unattended again, with all the outlets closed except the diversion with a discharge limiting device set for 27 m^3/s. This situation can continue until the end of the dry season, which can be advised from Dolow by radio some 410 km away.

The characteristics and hydraulic operation of the barrage are described further ahead (1).

b. Regarding the feasibility of a reservoir in the reach between Baardheere and Harriento, inspection of the area from low-flying aircraft showed that there exists a broad range of possibilities within the range of volumes required for Phase II, namely around 4,000 million cubic metres, so topographic surveys were initiated. These were run northwards from Baardheere for over fifty kilometres and farther upstream for another twenty kilometres in the Marile area. Using this ground control, the air photos covering the Luuq-Baardheere area were plotted at 1:20,000, with 10-m contours. This made it possible to examine the situation of the places concerned, from the point of view of the geometric aspects of the reservoir between Luuq and Harriento, and the conditions at possible dam sites between Harriento and Baardheere. Nine sites were selected at what appear to be the most favourable places. These were duly surveyed topographically at large scale and then covered by detailed geological and geophysical investigations.

The general geological situation in the reach most suitable for damming is as follows. The valley is entrenched in limestone formations the bedding of which is virtually horizontal or dips gently to the north-west. The valley has rocky terraces grading down towards the Juba. The rock cliffs rise at between 20 and 50% from the stream channel, fairly symmetrically, to reach the lower rock terrace.

The rock outcrops are seen to be intersected by tectonic fracture planes striking E-W, N-S, NW-SE and NE-SW or thereabouts. These are also the directions followed by the tributaries, which may meander to some extent, cutting into the limestone formations outcropping on the banks and in the bed.

The formation in outcrop in the reach suitable for damming is the Waajid. This consists of fossiliferous and oolitic limestones and marls.

In the bottom part of the valley, beneath the lower rock terrace the Colalio Member is in outcrop. This is formed of corals, calcirudites, oolitic limestones and coquina. Then follows the Carow Member which can be seen in some stretches of the valley bottom. This member consists mainly of shales and marls. The bedding is horizontal or dips slightly to the NW.

In the basin that would be drowned by the reservoir the rocks of this formation are oolitic limestones, marls, quartzy sandstones and limestones. The tail end of the reservoir may lie on the Mao Member of the Waajid. This consists of gypsums and anhydrites with marls and limestones.

Scattered basaltic rocks outcrop in the banks of the Juba both at the dam site and in the reservoir basin.

At the present state of knowledge it is considered that the rock formations at the dam site and in the reservoir have negligible permeability.

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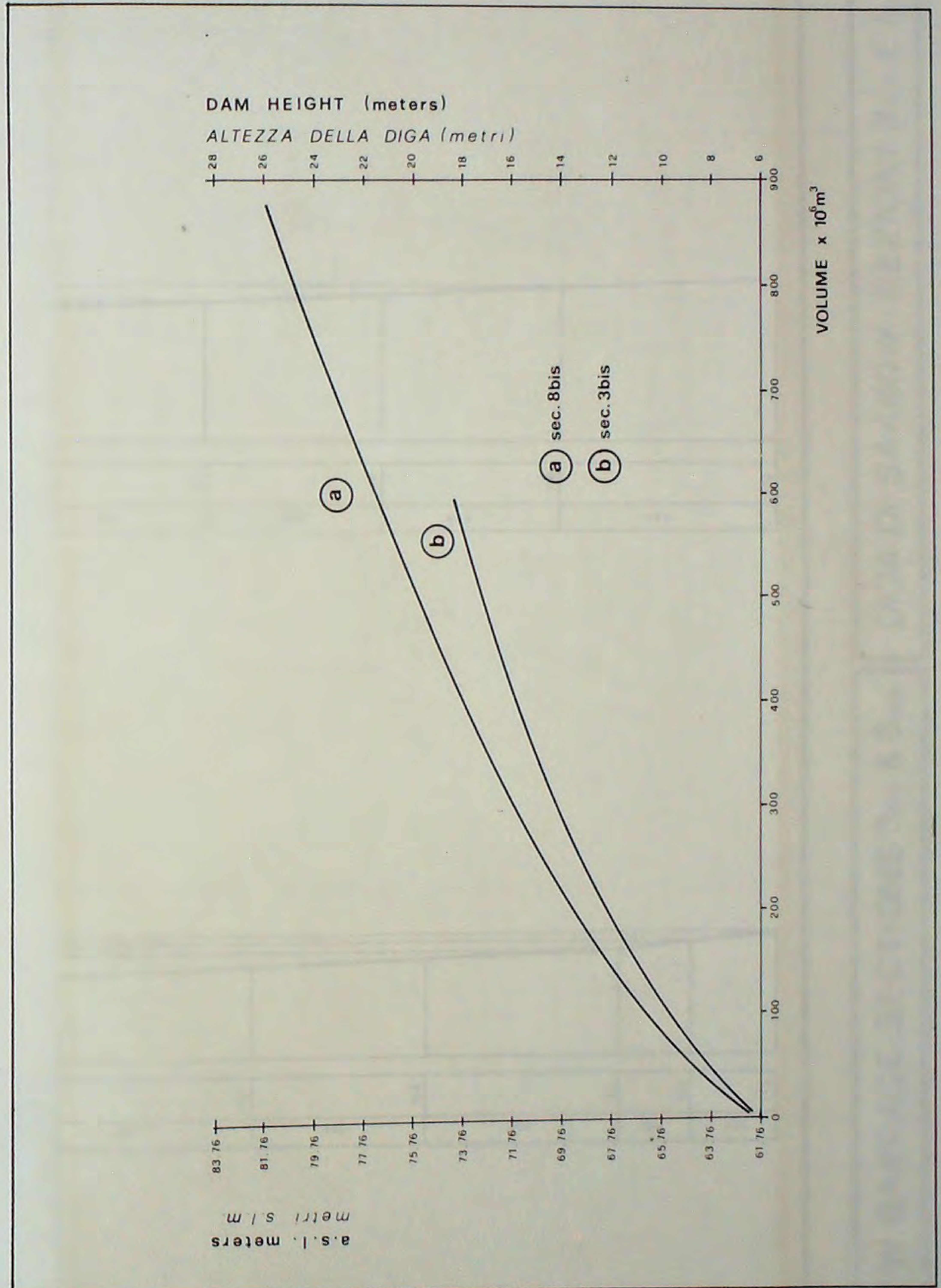
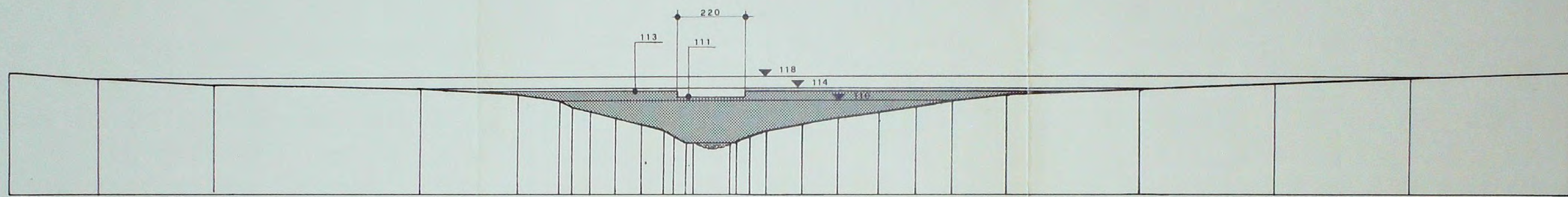
(1) In the first version of the Report (July 1975), it was assumed that the economic life of the Saakow Reservoir would only be 15 years, i.e. until the Baardheere Dam comes into operation. However, the additional information acquired in the interim now enables us to think of it in permanent terms, with much more complex functions.



SAAKOW: STORAGE VOLUMES DIAGRAM AT SEC. 8bis & 3bis
SAAKOW: CURVA DEGLI INVASI ALLE SEZ. 8bis e 3bis

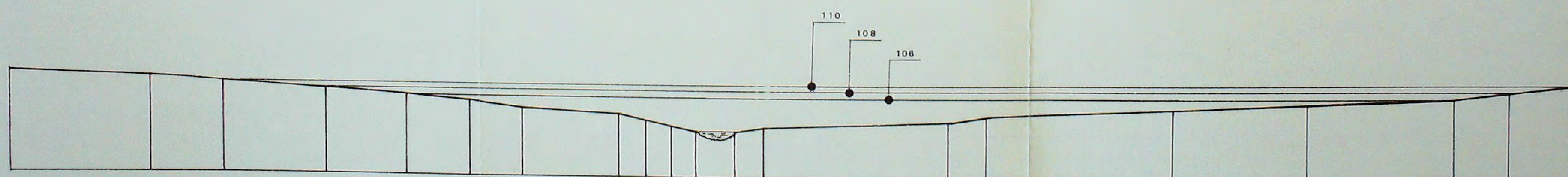
fig. 3.III

SECTION 8Bis



Ground Level	Partial Lenght
120	300
118	390
116	700
114	330
112	140
110	42
108	60
106	80
104	86
102	74
100	34
98	40
96	20
95.90	122
95.90	24
96	45
98	56
100	112
102	116
104	136
106	120
108	120
110	180
112	440
114	444
116	442
118	544
120	

SECTION 3Bis

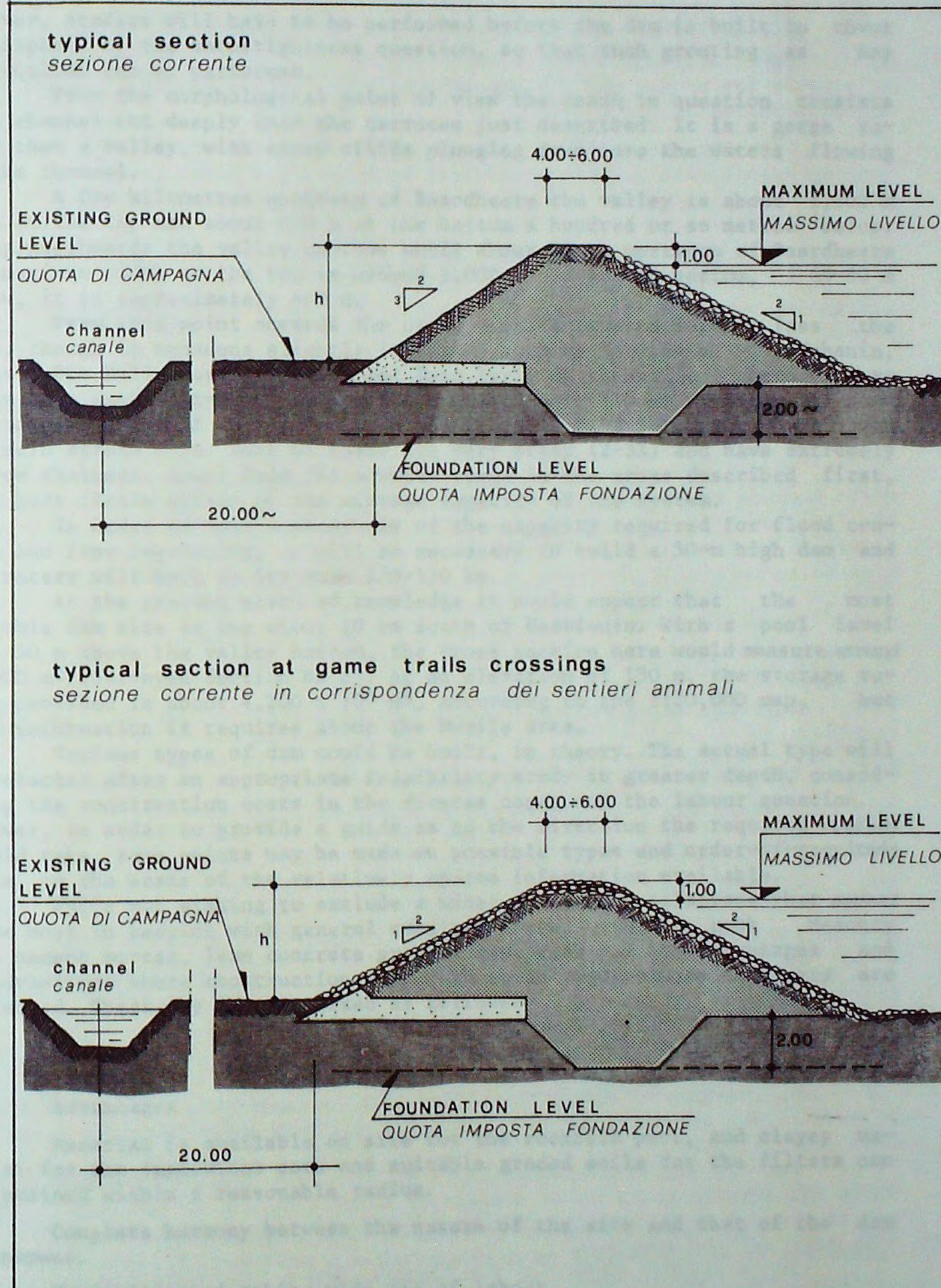


Ground Level	Partial Lenght
114	476
112	250
110	348
108	270
106	216
104	180
102	322
100	90
98	84
96	80
94.70	126
94.70	94
96	610
98	120
100	616
102	440
104	484
106	180
108	204
110	

DIGA DI SAAKOW : SEZIONI 3_{bis} E 8_{bis}

SAAKOW BARRAGE: SECTIONS 3_{bis} & 8_{bis}

fig. 4. III



SAAKOW DAM : TYPICAL CROSS SECTIONS
DIGA DI SAAKOW : SEZIONI TIPO

fig. 5 .III

However, studies will have to be performed before the dam is built to cover all aspects of the watertightness question, so that such grouting as may be required can be performed.

From the morphological point of view the reach in question consists of a channel cut deeply into the terraces just described. It is a gorge rather than a valley, with steep cliffs plunging down into the waters flowing in the channel.

A few kilometres upstream of Baardheere the valley is about 1,500 m wide at the top and about 800 m at the bottom a hundred or so metres below. Going northwards the valley narrows until about 20 km upstream of Baardheere the maximum width at the top is around 1,000 m and at the bottom, 60-80 m below, it is approximately 400 m.

From this point onwards the cross section remains more or less the same, though it broadens slightly in places such as Harriento, Sabanin, Yaahsõ, Bio Ball, Bargiab, Balli and Teso Yeri, up to Marile where there opens up a vast flat-lying region starting for over 110 km upstream of Harriento. The slope of the channel in this reach is 0.3‰. Numerous bohol join the main stream here. Most of these are very steep (2-3%) and have extremely narrow thalwegs. Apart from those which occur in the areas described first, they have little effect on the storage capacity of the system.

In order to have a reservoir of the capacity required for flood control and flow regulation, it will be necessary to build a 50-m high dam and the waters will back up for some 120-130 km.

At the present state of knowledge it would appear that the most suitable dam site is one about 10 km south of Harriento. With a pool level some 50 m above the valley bottom, the cross section here would measure around 20,000 m^2 (Surveyed Section No 2). At an elevation of 150 m, the storage volume provided is about 4,200 x 10^6 m^3, according to the 1:20,000 map, but more information is required about the Marile area.

Various types of dam could be built, in theory. The actual type will be selected after an appropriate feasibility study in greater depth, considering the construction costs in the diverse cases and the labour question. However, in order to provide a guide as to the direction the required studies should take, some points may be made on possible types and order-of-magnitude costs, on the basis of the relatively sparse information available.

While not wishing to exclude a wider range, the solutions that appear to be most in keeping with general conditions are, rockfill, rock masonry with cement mortar, lean concrete gravity dam. Each has its advantages and disadvantages where construction times, manpower requirements and costs are concerned. These may be summarized as follows:

- Rockfill

Advantages

1. Material is available on site for the rockfill part, and clayey material for the impervious core and suitable graded soils for the filters can be obtained within a reasonable radius.

2. Complete harmony between the nature of the site and that of the dam embankment.

3. Possibility of making wide use of labour.

Disadvantages

1. As it will not be possible to overtop the dam it will be necessary to provide for bottom outlets and surface spillways to handle a catastrophic flood estimated at 2,400 m^3/s.

2. With the large volume of rock involved, construction times will be lengthy unless considerable mechanical equipment and plant is used.

- Masonry

Advantages

1. The same as for the rockfill dam, as regards materials and labour.

Disadvantages

1. Consumption of cement for mortar and probable difficulty in finding skilled masons in the area.

Though this type of dam can no longer be built in most parts of the world because of the high costs involved and the lack of security offered by the finished structure, it is mentioned in this instance just in case the situation regarding labour may be favourable. This is an aspect that will have to be carefully checked.

- Concrete gravity dam

Advantages

1. Rapidity of construction owing to the smaller volume of aggregate involved.
2. Dam can be overtopped and spillway works will not be costly.
3. Offtake can be incorporated in dam embankment.
4. Wide use of local labour.

Disadvantages

1. Consumption of costly, difficult-to-supply cement.
2. Need to carry foundations down to sound rock, and possibility of having to consolidate the bedrock.

In order to frame a broad estimate of costs, it is necessary to make certain assumptions stemming from an on-site inspection of the area involved.

In the case of the rockfill dam with an impervious core and double filters on the sides, it is taken that the upstream and downstream faces will have 1.5/1 slopes.

For the dam foundations, it is assumed that it will be necessary to strip the surface talus to an average of about 2 to 3 m on the right bank and to about 5 to 6 m on the left bank, while on the bottom, some 5 m of stripping will be involved.

It is planned to have a 8-m diameter 300 m long tunnel on the right of the dam for the bottom outlet, while the surface spillway will be cut in

the rock on the left. The irrigation intake would also be on the left, at an elevation of 130 m. There is a second outlet at the foot of the dam, which could be used for a hydroelectric plant.

3.4 THE BAARDHEERE-SAAKOW INTEGRATED SYSTEM

The study of the geomorphological conditions in the valley described in the previous chapter shows that a reservoir of limited capacity can be created upstream of Saakow and another to the north of Baardheere that is theoretically sufficient for any solution in relation to the volumes involved.

The volumes needed to regulate the flows in the two phases of development have also been defined and it has been seen that the Saakow reservoir by itself could provide the regulation needed for Phase I.

Examination of the various possible alternatives clearly shows that it is advisable to build a barrage at Saakow in the immediate future to regulate Phase I flows. This barrage will then operate together with the Baardheere Dam when this is built some ten years hence, providing an integrated system.

When it is considered that the programme for development of the arable areas cannot be initiated until flow regulation is provided, it is apparent why a barrage is needed without delay (1).

The barrage cannot be built at or near the site of the Baardheere Dam, as the two structures would interfere with one another. If it were decided to build the barrage on the same site as the main dam then the construction of the bottom outlet and the foundation would have to be tackled straight away, thus delaying the entry into operation of the flow-regulation reservoir. If the smaller structure were built upstream, it would be destroyed when the main dam is ready, and if it were built some little way downstream, the stored water would interfere with the main dam. In all these cases too, the structure would only be temporary and the investment would be lost at the second phase of development; hence it would be impossible to achieve the integrated system dealt with below.

Thus there is really no other choice but to build the Phase I flow regulating basin at Saakow. Basically, this will fulfil the following functions:

a. The reservoir will be such as to provide annual regulation of flows until Baardheere Dam is in operation, so as to ensure a discharge of not less than 27 m^3/s in the dry quarter of the year. This is the amount of water needed by the multi-annual crops to be grown on 34,000 ha of land to be

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(1) In the Preliminary Report (June 1975) an estimate was made of the benefits that would stem from a structure with an economic life of ten years. Even in this instance it was ascertained that the internal rate of return was c. 40%.

developed during the first ten years of the Project (1).

b. It will allow the incorporation of a small hydroelectric station in the weir to enable pumps to be used at certain periods for irrigating given areas.

c. Having fulfilled its regulating function in Phase I, once the Baardheere Dam is operational the Saakow Barrage will assume its final role as the headworks for the irrigation district downstream and will provide water at a sufficient head to ensure that the lands are commanded by gravity. In this second and last Phase, the maximum use will be made of the discharges regulated upstream for the constant generation of electric power, possibly increasing the number of turbines.

d. In Phase II the reservoir will permit de-modulation of the flows only partially regulated by the Baardheere Dam, so as to permit the production of power in the major dam with a rectangular diagram.

e. By means of adept operation in Phase I, it will be possible to:

- Discharge natural flows without storage of waters during the first part of the Gu floods, which are extremely saline and must be disposed of rapidly.

- Favour discharge without any (or with the least possible) expansion of water in the reservoir, so as to control the sedimentation of transported solid content according to a predetermined plan.

- Favour intense leaching of the below-standard soils downstream to make them suitable for agricultural use.

- Ensure a power generation diagram most closely in keeping with the region's needs.

It might also be possible to ensure the supply of that water vector desired for feeding the Inter River area in such ways and with such quantities of water as may subsequently be determined.

Point d. requires some further clarification: in a hypothetical operational situation without the Saakow barrage the Baardheere Dam would have to regulate flows to exactly suit irrigation demand. Use of the waters for generating power would be decidedly marginal, being so closely bound up with irrigation as to be ill-adapted to municipal use or any other use, for that matter, not concerning irrigation consumption. Yet it is considered of basic importance for the development of the Baardheere area to have cheap electricity for power and lighting for municipal use, which require a virtually rectangular diagram and would otherwise be very expensive. Therefore, an examination has been made of the implications of a different type of regulation at Baardheere; instead of being bound up with a diagram of total discharge that varies with water consumption for irrigation, one part would be variable according to the demand of the irrigation district immediately downstream, while another would be constant for the generation of hydroelectricity for municipal use. This second part of the flow must subsequently be demodulated

(1) Until the Baardheere dam is put into operation there would be almost no protection of irrigated areas from floods. In any case the Saakow dam itself is not damaged even by the 1% floods which is allowed to overflow.

by the Saakow Reservoir to suit the consumption diagram downstream of there. Moreover it will be used to produce power for the numerous pumping stations for irrigating the bottom lands downstream of Dujuuma.

This new function envisaged for the integrated Baardheere-Saakow system is decidedly advantageous. Suffice it to consider the demand situation at Baardheere where only 50% of the district can be commanded by gravity, while the remaining water has to be lifted some 60 m, on average. As indicated in Para 3.1, this means allocating a diverted peak discharge of 52 m^3/s plus a like amount to drive the turbines to produce the power consumed by the pumps. In the most cautious hypothesis, based on the two-year period with the lowest streamflows, there remains a discharge of about 100 m^3/s to be regulated by the Baardheere Dam with a constant diagram over the year, as required for municipal use.

With regulation to suit this situation - See also Table 18 and Para 4.2 of Part II - larger storage capacities are needed in the Baardheere and Saakow Reservoirs than in the solutions concerned solely with complete satisfaction of the irrigation demand, in phase I by Saakow and in phase II by Baardheere. Calculations indicate that in the case of the integrated system a total regulating reserve of 1,605 x 10^6 m^3 is needed at Baardheere and 328 x 10^6 m^3 at Saakow (1), if it is wished to ensure coverage of demand in all years (100%).

In the Second Critical Case, instead, the volumes are 1,340 and 169 x 10^6 m^3, respectively. Comparison of these values with those for the unintegrated solution may be summarized thus (in 10^6 m^3):

	At Baardheere		At Saakow	
	Cr. Case I	Cr. Case II	Cr. Case I	Cr. Case II
Integr. scheme	1,605	1,340	328	169
Indep. reservoirs	1,508	1,140	250	160
Difference	87	200	78	9

However, with the integrated solution the availability of net flow in the October-December quarter deductible from the volumes reserved for flood control is more favourable (see Para 3.2 in this regard) and so the solution leads to a substantial reduction in the cumulative volume of the Baardheere Reservoir. Indeed, referring to the points made in Para 3.2 and on the basis of the same line of argument used there, the following figures have been derived for quarterly compensation. These can be taken as the volumes by which the storage reserved for flood control can be reduced (see Part II, Tables 13 and 18).

(1) See Part II - Annex 3.

a. Flow regulation in the 100% duration year (10^6 m^3)

Month	Natural flows	Deliveries	Compensation
October	1,164	321	+843
November	382	310	+ 72
December	338	341	- 3
	Quarterly compensation		+912
	In round figures		900

b. Flow regulation in the 93% duration year (10^6 m^3)

Month	Natural flows	Deliveries	Compensation
October	1,187	321	+866
November	769	310	+459
December	133	341	-208
	Quarterly compensation		+1,117
	In round figures		1,100

So the storage needed for flood control in Case a. is $1,500 \times 10^6$ m^3, i.e. 2,400 - 900, while in Case b. it is $1,300 \times 10^6$ m^3, i.e. 2,400 - 1,100.

In relation to the absolute minimum streamflows that occurred in the October-December quarter, amounting to $1,575 \times 10^6$ m^3, there exists the further extreme possibility, calculated below (10^6 m^3):

Month	Natural flows	Deliveries	Compensation
October	927	321	+606
November	502	310	+192
December	146	340	-194
Totals for minimum quarter	1,575	971	+604
	In round figures		600

To provide more indications of a purely qualitative nature, we give below the cumulative capacity calculated for flood-control and flow-regulation requirements in the new hypothesis of Integrated Operation, henceforth referred to as Hypothesis 2.

Included for comparison are the figures for the original hypothesis (see Para 3.2), henceforth called Hypothesis 1, considering the possible alternatives connected with the utilization of the total annual streamflow (satisfaction of demand in all 14 years of the period or in 13 of them) in the two hypotheses of control of the 100-year flood, with $W = 2,400 \times 10^6$ m^3 and the 20-year flood, with $W = 1,250 \times 10^6$ m^3.

Alternative of flow regulation in the 100% and 93% duration year, with control of the 100-year flood

		100%	93%	100% and absolute minimum flow in Oct-Dec quarter
Hypothesis 1	Regulation	1,518	1,140	1,518
	Control	1,870	1,660	2,176
	Cumulative	c.3,400	2,800	c.3,700
Hypothesis 2	Regulation	1,600	1,340	1,600
	Control	1,500	1,300	1,800
	Cumulative	3,100	c.2,600	3,400

Alternative of flow regulation in the 100% and 93% duration year, with control of the 20-year flood

		100-year flood and 100% regulation	20-year flood and 93% regulation	100-year flood and absolute minimum flow
Hypothesis 1	Regulation	1,518	1,140	1,518
	Control	720	510	1,026
	Cumulative	c.2,200	1,600	c.2,500
Hypothesis 2	Regulation	1,600	1,340	1,600
	Control	350	50	650
	Cumulative	c.2,000	c.1,400	c.2,200

Examination of all the possible combinations - leaving aside the problem of Saakow for the moment - shows that the Hypothesis 2 solution for Baardheere Reservoir i.e. dual-purpose control (irrigation and power), is definitely the best.

Cumulative volumes can vary from a minimum of 1,400 x 10^6 m^3 to a maximum of 3,400 x 10^6 m^3, so the total reservoir capacity would need to be (10^6 m^3):

	Absolute minimum	Absolute maximum
Cumulative	1,400	3,400
Silting	600	600
Evaporation	100	200
	2,100	4,200

We feel that the absolute maximum given by the above hypotheses can be ignored. This involves the absolute minimum hydrologic year conciding with the absolute minimum October-December streamflow; though this is not impossible, it is highly improbable and has not been found statistically. On the other hand, considering the cumulative volume immediately lower than the absolute maximum, namely 3,100 x 10^6 m^3, the occurrence of that event would involve a reduction of 300 x 10^6 m^3 on flow regulation which, if properly handled, would have little effect on agricultural production.

There is also the fact that the minimum value and the other more moderate values of the cumulative volume involve acceptance of the fact that the lands are only protected against floods that occur once every twenty years, thus excluding more serious ones; the damage caused by the latter would either have to be accepted or else money spent to provide other kinds of protection.

This thesis does not seem acceptable for three reasons:

1. The amount of damage would be high, considering not only that to production but also that to people and the infrastructure, which would certainly be notable. Thus the useful capacity for controlling the 20-year flood would only be 60% efficient in controlling the 100-year flood, reducing the flood wave from 2,400 m^3/s to 1,050 m^3/s, against a maximum of 700 m^3/s that can be accommodated in the channel downstream.

2. As the lands must be protected, it is easy to make an economic comparison of the greater cost of providing embankments instead of ensuring flood abatement in reservoirs. Indeed, the comparison run in Para 1 for a 1,800 m^3/s flood also holds good for lower values.

3. The low degree of reliability of the hydrologic data available, the limited nature of the time series usable and the impossibility of deriving exact values (at the measuring stations) of discharges exceeding the channel capacity, all point to the advisability of adopting the most cautious flood-protection criteria, not least because this additional caution is relatively inexpensive in terms of construction costs. Indeed, considering that in any case the basic volume of the flow-regulation reservoir, with allowance for silting and evaporation, is around 2,000 x 10^6 m^3, the marginal cost of water at Baardheere increases but slightly as the dam height is raised, as is apparent from the following table. This refers to a gravity dam, but the

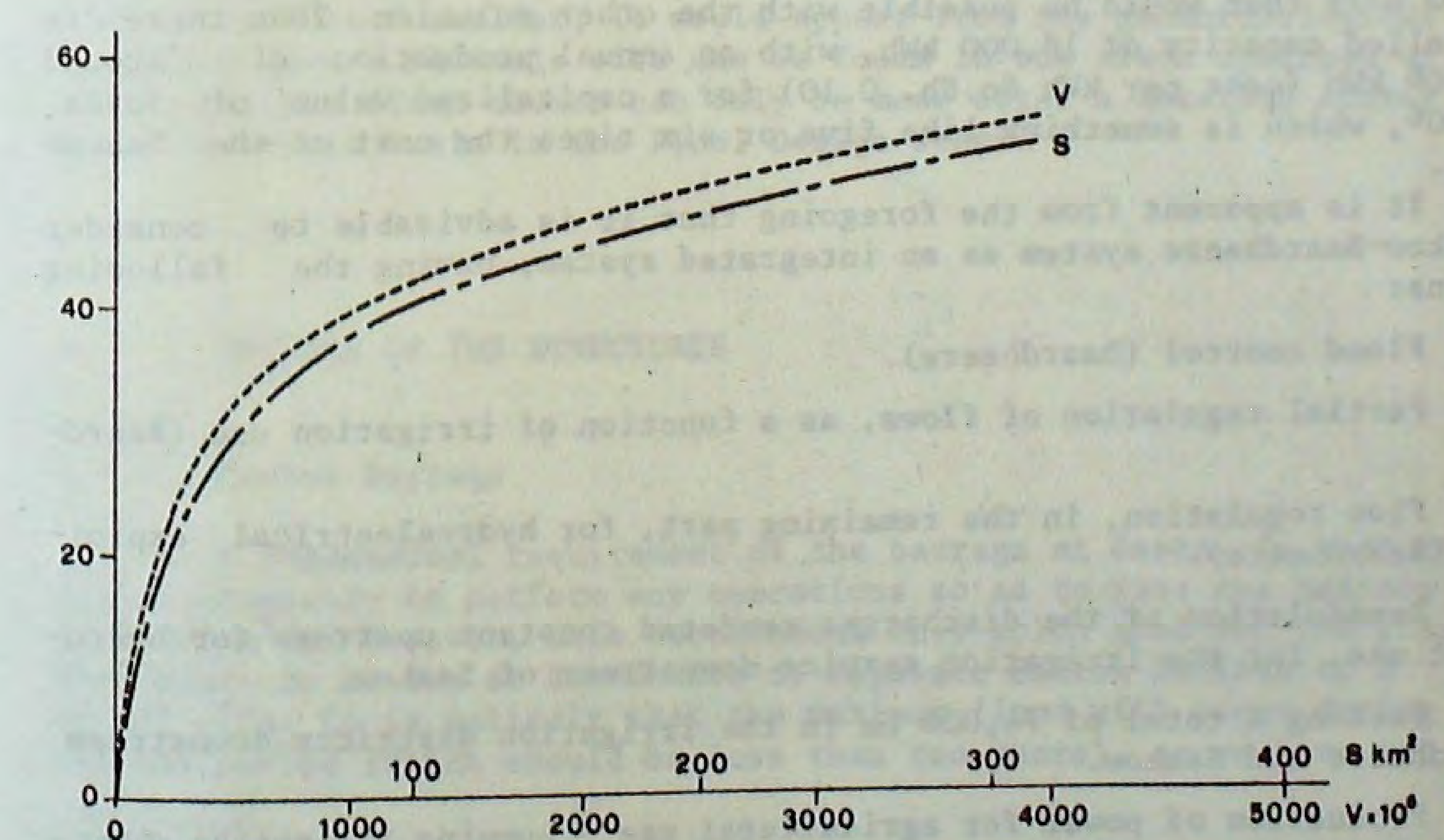
principle holds good equally for other types too:

H	V Conc. 10^6 m^3	V Conc.	W 10^6 m^3	W	C So.Sh.	C/W So.Sh./100
60	501	88,000	4,275	1,527	475	2.08
55	413	78,000	2,748	1,037	500	2.62
50	335	70,000	1,711	711	535	3.43
45	265		1,000		585	

where H is the storage height of the dam, V conc. is the volume of concrete in the dam, V is the change in volume of concrete as dam height varies, W is the volume of water stored and W the change in that volume, while C is the cost of concrete per cubic metre.

A similar comparison, but for the cost of concrete constant with height, provides the unit costs C/W in 1/100ths of So.Sh. per cubic meter stored with the variation of height from 45 to 50 m, from 50 to 55 m and from 55 to 60 m; these costs are 2.88, 3.77 and 4.92, respectively (see Fig. .III).

Fig. 6.III - Curves of storage capacity and area of Baardheere reservoir



Consideration of the marginal costs aspects of this trend indicates the advisability of opting for dimensions on the safe side. Indeed, it costs only 25 to 30 x 10^6 So.Sh. more to provide the additional volume to control a 100-year flood instead of a 20-year event (volume difference of 1,150 x 10^6 m^3).

This is not a high figure, if one considers the amount of damage that is avoided or the saving in cost in not having to provide embankments along the river.

Thus it is apparent that the size of the Baardheere Reservoir should be somewhere between the cumulative values of 3,100 x 10^6 m^3 for regulation in 100% of the years and 2,600 x 10^6 m^3 in 93%. The total capacity (i.e. including allowance for silting and evaporation) would be 3,900 and 3,400 x 10^6 m^3, respectively. The most appropriate solution may be selected at the Final Design stage when a more thorough examination of the marginal costs of stored water compared with the benefits of irrigation development can be made using more accurate costs.

Turning now to the question of the size of Saakow Reservoir, it should be first made clear that the capacities considered in the earlier tables refer to different functions and are not, therefore, directly comparable. They are, however, if they are related to the choice of the function of the barrage, whether integrated with Baardheere or independent. In the case of the integrated scheme the total storage volume is about 330 x 10^6 m^3 (excluding storage for losses). The additional cost of having a larger volume than in the case of independent reservoirs has to be compared with the benefits introduced by integration (hydroelectric use) considered in toto, seeing that this item results in economies in the case of Baardheere.

Broadly, the hydroelectric benefit can be assessed by considering the greater production for municipal uses stemming from the turbining of a constant 50 m^3/s than would be possible with the other solution. Thus there is an installed capacity of 18,000 kWh, with an annual production of around 150 x 10^6 kWh (cost per kWh So.Sh. 0.10) for a capitalized value of So.Sh. 200 x 10^6, which is something like five or six times the cost of the Saakow Barrage.

It is apparent from the foregoing that it is advisable to consider the Saakow-Baardheere system as an integrated system, having the following functions:

a. Flood control (Baardheere).

b. Partial regulation of flows, as a function of irrigation use (Baardheere).

c. Flow regulation, in the remaining part, for hydroelectrical exploitation (Baardheere).

d. Demodulation of the discharges rendered constant upstream for hydroelectric use, for the irrigation service downstream of Saakow.

e. Feeding a total of 74,000 ha in the irrigation districts downstream of Baardheere and Saakow.

f. Production of power for agricultural use - pumping irrigation water - and municipal use - lighting and emf in towns - (Baardheere and Saakow with a total installed capacity of around 65,000 kW).

Consequently, it is proposed that the Saakow Reservoir should have a volume of 373 x 10^6 m^3, determined thus:

	10^6 m^3
Volume to re-regulate constant inflows to required variable outflows	328
For silting	30
For seepage losses	15
Total	373

So with a barrage at Section 8 on the 1:20,000 map, the sill of the weir would need to be 15 m above ground level.

For the Baardheere Dam, the total volume proposed at this stage of the Project (the definitive figure will be indicated at the Final Design stage) is as follows:

	10^6 m^3
Cumulative volume for regulation	3,100
For silting	500
For evaporation (1)	200
Total	3,800

With this storage volume the crest of the dam would be at an elevation of 150 m a.s.l. and it would thus rise some 55 m above the valley bottom. As indicated earlier, it would appear from the geomorphological investigations that a suitable site can be found in the reach upstream of Baardheere, but the final choice can only be made after a detailed survey of the whole reservoir basin in the Final Design stage.

3.5 DETAILS OF THE STRUCTURES

3.5.1 Saakow Barrage

A fundamental requirement of the barrage at Saakow is that it should not be necessary to perform any operations so as to pass the maximum flood of 2,400 m^3/s. However, this requirement only holds good for the first period when there is no dam at Baardheere to regulate Saakow inflows to a maximum of 700 m^3/s. It is unlikely that the maximum flood will occur during the initial period (which should be less than ten years), so we have not consid-

(1) Reduced from 300 x 10^6 m^3 in the general hypothesis because the pool area will not remain for long at the maximum involved in controlling an exceptional flood.

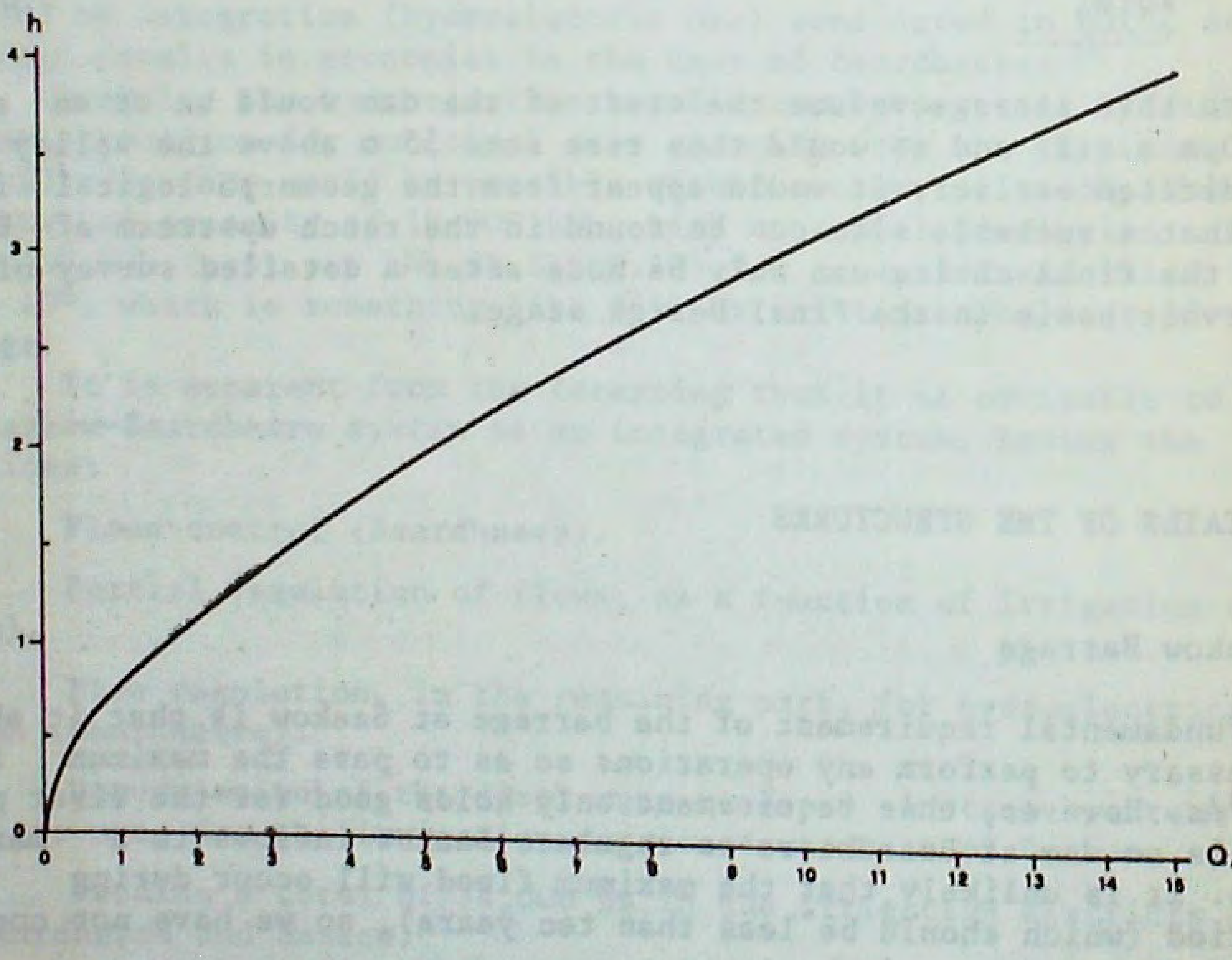
ered the costly solution that would be involved in ensuring that the maximum flood could be passed with the barrage unattended and the bottom outlets closed. It is felt that it will suffice to be able to discharge 1,000 m^3/s with a head of 1 m on the weir and a freeboard of 1.3 m below the dyke crest, while also allowing for a short spill of 2,000 m^3/s discharge, which could be handled by utilizing part of the freeboard.

In calculating the flow on the weir sill, account was taken of test results obtained on models of similar works to obtain the value of to be applied in the formula

$$Q = \mu \, l \sqrt{2g} \; H^{3/2}$$

By means of this formula it was possible to determine the stage-discharge relation, taking H as being the head of water on the sill, without any great error (see Fig. 7.III).

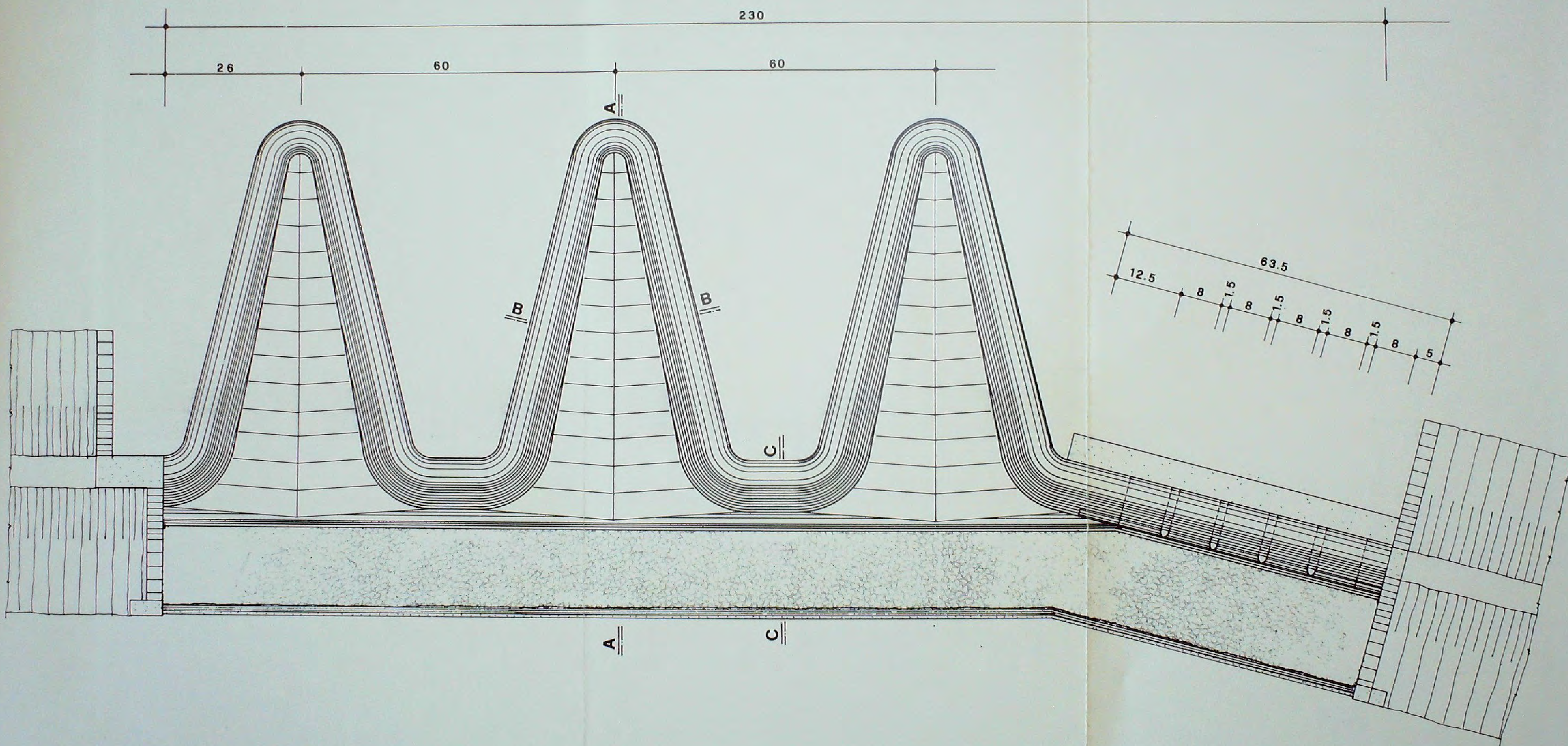
Fig. 7.III - Flow diagram per meter of sill at Saakow barrage



SAAKOW BARRAGE: PLAN & VIEW

DIGA DI SAAKOW: PIANTA E PROSPETTO

fig. 8.III

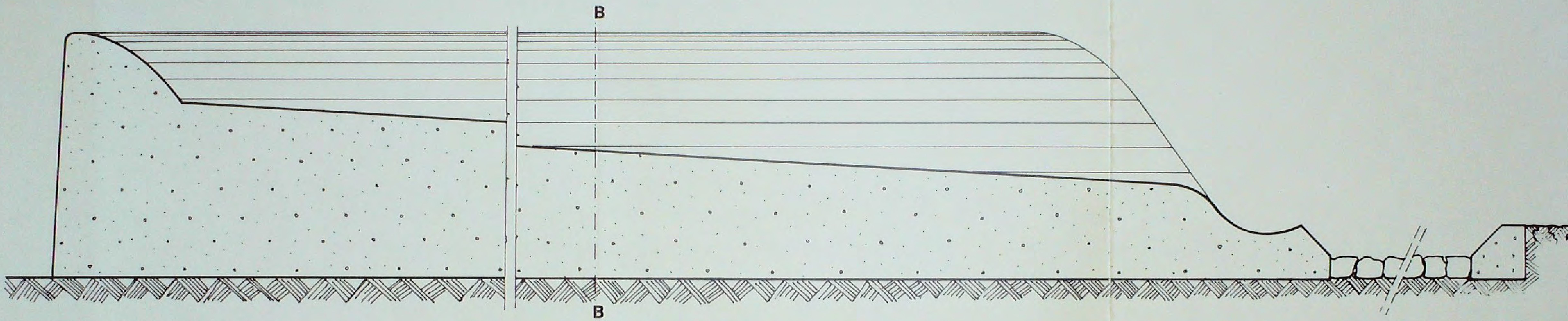


SOGLIA A LABIRINTO

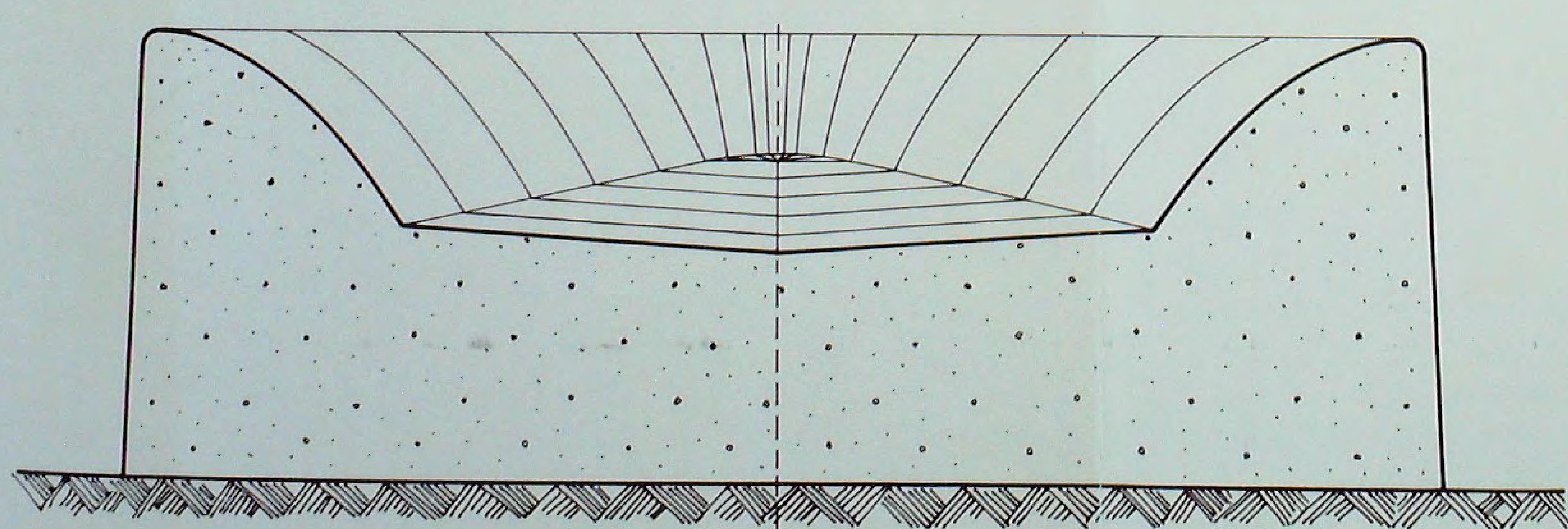
SAW-TOOTH SILL

fig. 9 III

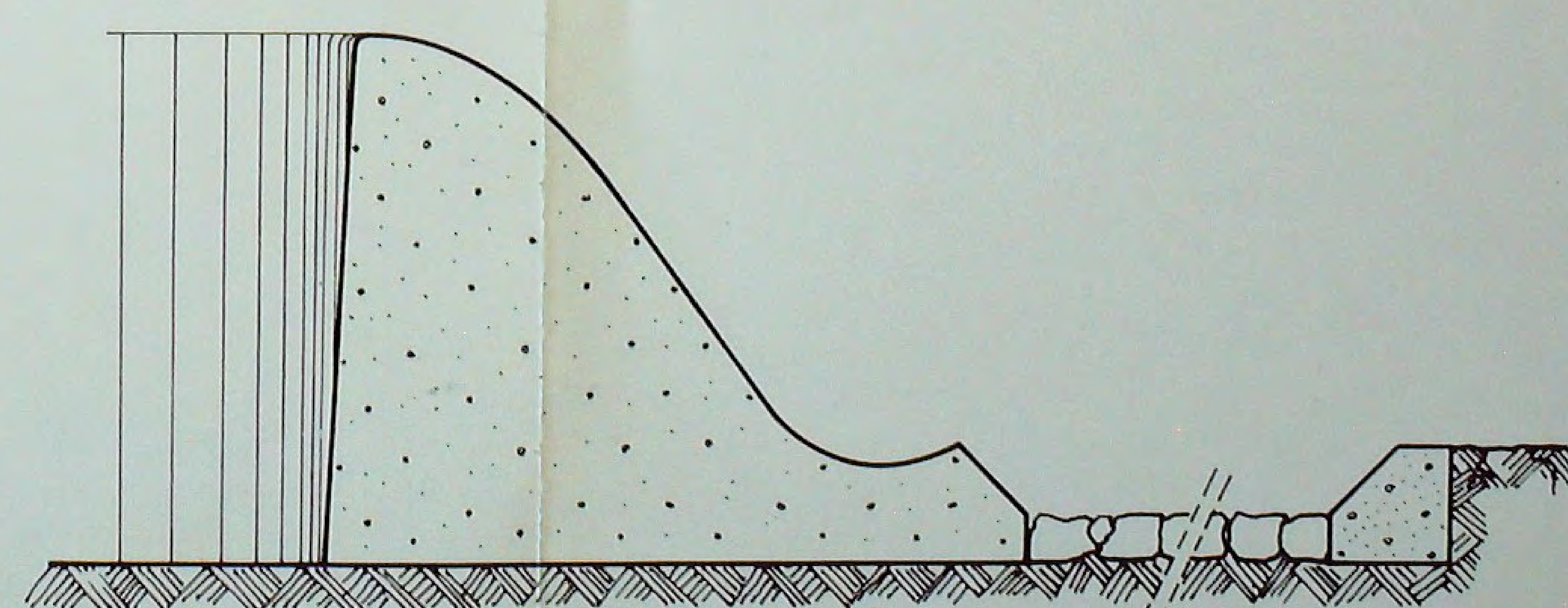
Section A-A



Section B-B



Section C-C



SEZIONI DELLA SOGLIA A LABIRINTO

SAW-TOOTH SILL SECTION

fig.10.III

The next step was to determine the most economical way of passing the flood flows, considering various sill lengths and heads. In the latter case, account was also taken not only of the need for a higher dyke but also the necessity for a stronger one.

The cost differences that emerged were not very significant nor sensitive to the economic characteristics of the work items, especially as regards the increase in cost of the barrage in relation to the depth of water. Investigations on seepage and tests on a trial section of dyke will be needed to clear up these aspects. So at this stage the preference will be given to the solution which ensures the lowest hydrostatic head on the ground, though again, this will require re-examination at the Final Design stage.

With a head of 1 m on the sill and a value of 0.42 derived from model tests for similar projects, the weir can spill 1.86 m^3/s per linear metre. So to spill 1,000 m^3/s a weir length of 538 m is needed. This can be provided most economically by a labyrinth form, not least so as to ensure that the length can be contained within the width of the channel. In all, there would be 478 m of straight sill and 75 m on the curve (the effective length of the latter being only 80% to take account of disturbed hydraulic flow) (See Figs. 8, 9 and 10.III).

A Croager-type profile has been selected to facilitate masonry construction with hand-faced stone blocks over loose rock or lean-concrete fill.

The geological investigation show the bedrock to lie at 1-2 m below the channel bed, so direct foundations in lean concrete can be used. Immediately downstream of the weir face there will be a concave race channel to dissipate the energy of the flows. Huge boulders will be placed in the channel where most of the water eventually falls, while the alluvium at the sides of the channel will be duly protected by longitudinal works.

On the left side of the weir there will be five 8.00 x 3.50-m waterways with the upstream sill 3 m from the bottom and the downstream one at 1 m, to allow for the installation of hydroelectrical equipment. The discharge of these free-flow waterways will amount, with $\mu = 0.45$, to 13 m^3/s per linear metre, i.e. 520 m^3/s, all told, in round figures.

Thus, up to this flow rate, during the period when gates are open there will be no water backed up on the upstream side of the barrage and hence no silt deposition, except from the volume commanded by the lower sill, which will amount to a few thousand cubic metres. It is considered that in the first phase it will be as well to have a small power station for services concerning the barrage itself, such as servocontrols, raising water for watering animals, lighting, etc. Only in the second phase, when the waters are clarified by settling in the Baardheere Reservoir and the huge irrigation plan has reached the take-off stage will it be possible to think of installing the turbines which will operate under the maximum head available at the weir and the minimum discharges required for irrigating the downstream areas plus the drinking water and sewage disposal demand.

The calculation of the best design discharge for the hydroelectric plants will be done at the final engineering stage, though it is considered that with the operating conditions postulated it should be possible to have an installed capacity of 15,000 kW and produce annually about 100 x 10^6 kWh. Apart from hydroelectric use, the waterways in question will provide controlled additional evacuation capacity, since with a head of 12.25 m at the centre of gravity, they should pass around 1,300 m^3/s at a water elevation the same as that on the sill of the weir.

These operating characteristics will be completely modified in Phase II, when gates will have to be controlled continuously, being semi-automated if necessary, to ensure that the downstream demand is satisfied even though inflows may vary because constant flows from Baardheere occur only when the streamflow year coincides with consumption. The barrage works will be completed by stone-filled gabions or masonry walls to protect the banks downstream of the weir and the construction of quarters for the guardian.

A preliminary estimate of the cost of a barrage with H = 15 m gives the following results:

	Quantity		Unit cost So.Shs.	Total So.Shs.
Rerouting of roads and opening up of 6-m track	km	20	150,000	3,000,000
Lean concrete foundation slab including cost of working in water	m^3	20,000	200	4,000,000
Construction of stone-filled gabions including cost of excavation	m^3	2,500	200	500,000
Levelling and clearing	m^2	300,000	4	1,200,000
Compacted silty-clay diaphragm	m^2	10,000	40	400,000
Excavation and formation of stabilized soil embankment	m^3	150,000	30	4,500,000
Riprap	m^3	5,000	320	1,600,000
Dry material for filters	m^3	5,000	60	300,000
Loose rockfill and mortar masonry	m^3	30,000	150	4,500,000
Hand-placed masonry, sealed with mortar on visible face	m^3	5,000	200	1,000,000
Reinforced concrete (350 kg cement/m^3) incl. reinforcement	m^3	3,000	1,200	3,600,000
Boulders	m^3	2,500	120	300,000
Guardian's house, gates, etc.	say			1,500,000
				26,400,000
Engineering and contingencies (∼ 20%)				5,600,000
	Total			32,000,000

The costs have been estimated assuming the following on-site conditions, aimed at making maximum use of local labour:

- Manual excavation, transport using light vehicles, mechanical compaction roller, hand finishing.
- Rock quarried by explosives and manual operations, transported by raft from Anole (shipments to be organized to suit flows) mechanically loaded onto light trucks and hand placed.
- Masonry work done by hand, mortar mechanically mixed.
- Concrete mixed and transported by truck; aggregate from crushed Anole stone; washed river sand.

It is estimated that around one million working days will be needed to build the barrage, and that with a reasonable organization the job could be completed in less than eighteen months (or in as little as twelve months if more machinery is used).

3.5.2 Baardheere Dam

The Baardheere Dam will have to ensure a storage depth of 55 m, which will provide a volume of 3,800 x 10^6 m^3. The maximum crest height allows a one metre freeboard to cope with waves in the case of a concrete dam and 2.50 m in the case of a rockfill dam. To guide the planner, a description of a dam which, in the light of present knowledge, appears the best suited for Baardheere, is given below.

The 2,400 m^3/s flood wave will be discharged over a spillway which will be incorporated in the dam in the case of a concrete structure and set in the rock abutments if other types of dam are selected. The spillway will have automatic gates. If the gates are 6 m high and the maximum back-up of water above maximum pool level is 1 m, then the spillway will have a capacity of 34.30 m^3/s per linear metre; hence it must be 70 m long, in all.

At a height of 33.80 m above the channel bed (El. 128.80 m) there is a waterway which acts as bottom outlet and intake for the irrigation district between Baardheere and Saakow. The diversion will be in tunnel on the left bank. This will be 5 m in diameter and will operate as a free-surface flow structure when supplying irrigation waters, which will be controlled by an upstream gate to ensure 52 m^3/s even when the reservoir is at the maximum pool level of 128.80 m a.s.l. When the tunnel is being used as a bottom outlet, however, it can operate under pressure (max. 2.1 atmospheres) conveying some 350 m^3/s.

The elevation of 128.80 m has been chosen to provide the silting capacity below this level. In point of fact for a silting capacity of 500 x 10^6 m^3, the outlet could be at an elevation of 128.00. The extra height has been allowed to provide more hydroelectric energy and to command a larger irrigation area. A rapid economic calculation indicates the advantages of this solution. The loss of an additional 100 x 10^6 m^3 beneath El. 128.80 can easily be made good by raising the dam crest 30 cm at a marginal cost (So.Sh. 3-4 million). The reduction of 2 m on the lift of an average 12 m^3/s over the year (some 50% of the district's requirements) leads to a saving of some So.Sh. 2 x 10^6 in capital value, while the extra average head of 1 m for power generated provides a benefit of over So.Sh. 10 x 10^6, based on a discharge of 100 m^3/s.

The bottom outlet is bound up with the diversion for the discharges to be turbined with a constant discharge for feeding the Saakow Reservoir. It must be large enough to pass the flows that arrive at the dam site during the course of construction. If the tunnel is taken as being 6 m in diameter and the piezometric gradient is taken as 1.0%, which means a head of 10 m upstream over the channel bed, a discharge of 400 m^3/s is ensured, which corresponds to a monthly flow duration of 7%. This can be considered as being on the safe side.

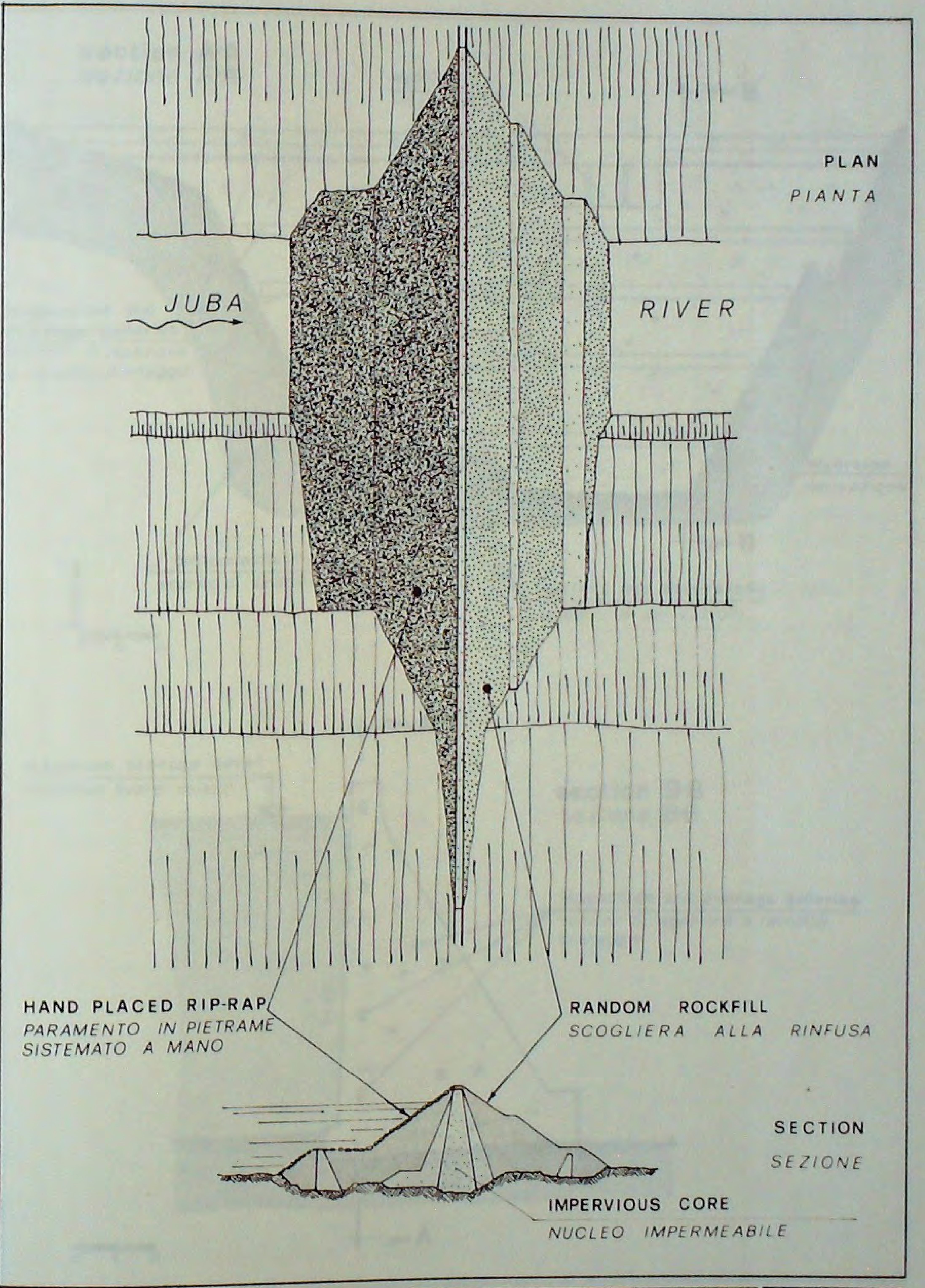
With these characteristics the costs and quantities can be estimated as follows.

ROCKFILL DAM (Fig.11.III)

	Quantity	Unit cost	Total So.Sh.
Rock excavation for rockfill and surface spillway	m^3 300,000	30	9,000,000
Loose rockfill compacted by machinery	m^3 1,350,000	100	135,000,000
Clay core and lateral filters in graded material	m^3 400,000	40	16,000,000
Tunnelling	m^3 30,000	200	6,000,000
Reinforced concrete for tunnel lining	m^3 8,000	800	6,400,000
Steel for RC	kg 400,000	6	2,400,000
Reinforced concrete for surface spillway and tower for operating bottom outlet gates	m^3 40,000	700	28,000,000
Steel for RC	kg 3,000,000	4	12,000,000
Consolidation grouting	say		2,000,000
			216,800,000
Engineering and contingencies (20%)			43,360,000
	Total		260,160,000

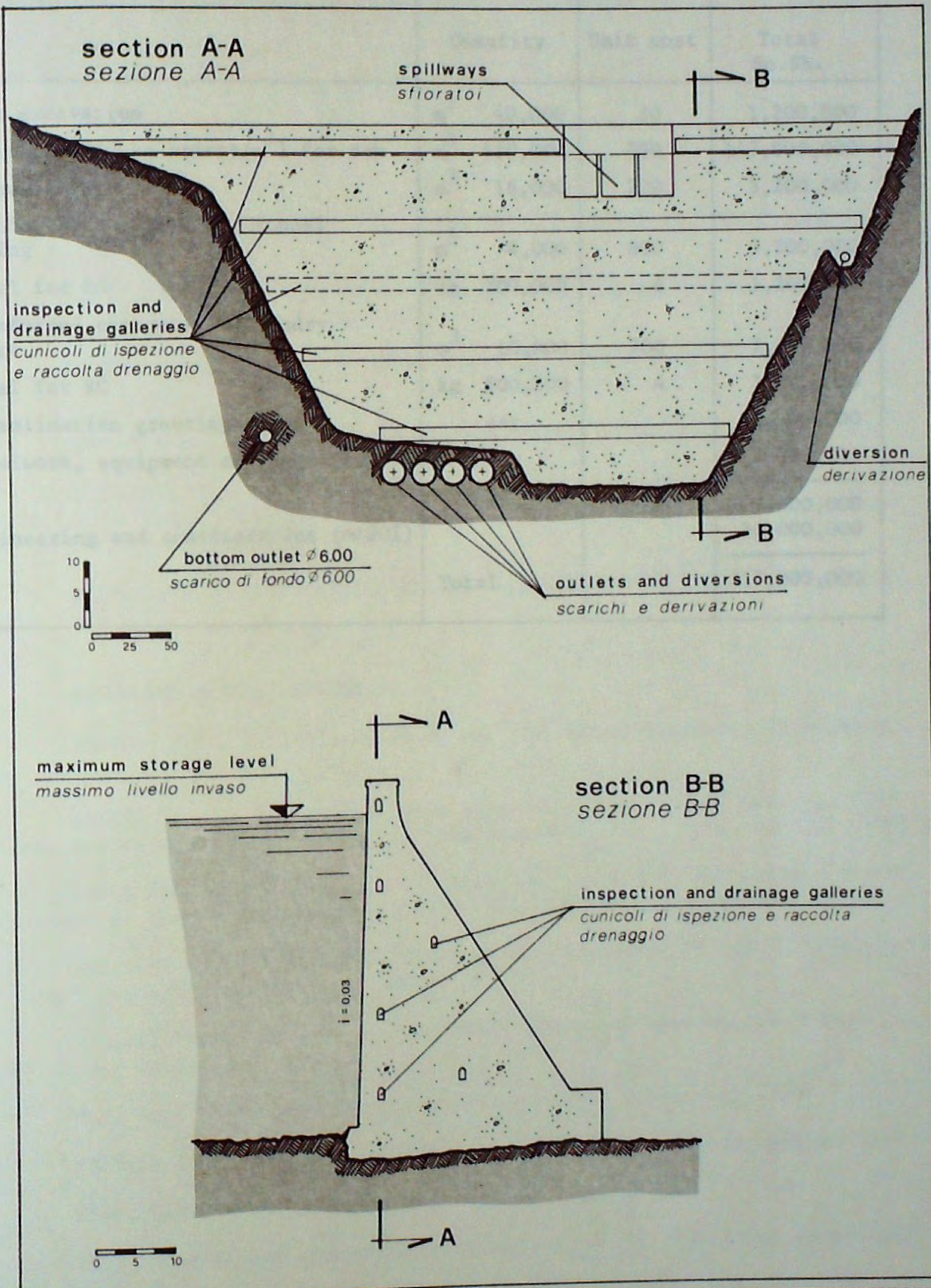
CONCRETE GRAVITY DAM (Fig.12.III)

The slopes of the downstream and upstream faces will be 0.7/1 and 0.005/1. The surface spillway will be in the body of the dam as will the irrigation intake structure. The bottom outlet is in tunnel. The dimensions of these structures are as indicated for the rockfill dam.



BAARDHEERE : ROCKFILL DAM
BAARDHEERE : DIGA IN ROCKFILL

fig.11.III



BAARDHEERE DAM: CONCRETE GRAVITY TYPE
DIGA DI BAARDHEERE: TIPO IN CALCESTRUZZO A GRAVITA

fig. 12.III

	Quantity	Unit cost	Total So.Sh.
Rock excavation	m^3 40,000	30	1,200,000
Concrete (200 kg cement/m^3) for dam	m^3 420,000	350	147,000,000
Tunnelling	m^3 16,000	200	3,200,000
Reinforced concrete for tunnel lining	m^3 4,000	800	3,200,000
Steel for RC	kg 200,000	6	1,200,000
Reinforced concrete for sundry works	m^3 10,000	700	7,000,000
Steel for RC	kg 800,000	4	3,200,000
Consolidation grouting	say		10,000,000
Steelwork, equipment and sundries	say		3,000,000
			179,000,000
Engineering and contingencies (∼20%)			36,000,000
	Total		215,000,000

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