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VIABILITY OF THE CHEMERON DAM
PHASE I
PRELIMINARY RECONNAISSANCE

FEBRUARY 1977

Tippetts-Abbett-McCarthy-Stratton
New York Nairobi

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February 3, 1977

Mr. Louis A. Cohen
Director
REDSO/EA
P.O. Box 30261
NAIROBI

Dear Mr. Cohen:

REPORT - VIABILITY OF THE CHEMERON DAM
PHASE I - PRELIMINARY RECONNAISSANCE

In accordance with Article I C. of our Contract No. AID-623-003-T, dated January 12, 1977, we are pleased to submit herewith the report of our findings on the subject study.

The salient points of our findings, conclusions and recommendation are briefly summarized below.

The net water yield from the Chemeron River Basin, which could be depended upon three out of four years, is in the order of four million cubic meters. With essentially complete regulation, this amount of water would only be adequate to irrigate some 400 hectares of land on a single cropping plan or 200 hectares under double cropping.

In order to provide regulation for the above amount of water, a dam with maximum height above the bottom of the Chemeron Gorge of approximately 29 meters and with a crest length of about 390 meters would be required. Under these conditions, an earth/rock fill dam with side channel spillway was found to be less costly than a concrete dam. Nevertheless, the cost would still be high. Preliminary estimates indicate that the cost of an earth/rock fill dam and spillway would be in the order of U.S.$ 720,000. Thus, storage costs to irrigate 400 hectares under single cropping or 200 hectares under double cropping would amount to U.S. $ 1,800 or U.S. $ 3,600 per hectare, respectively.

To the above storage costs would have to be added the costs of delivering water from the dam to the agricultural area and providing the irrigation and drainage systems.

.....2/

REDSO/EA February 3, 1977

In conclusion, while it appears that a storage dam on the Chemeron River would be technically viable, the high total costs for such a small irrigated area would undoubtedly not be economically feasible.

In view of our findings and conclusions, we recommend against proceeding with any further studies on the Chemeron River.

We are honored to have been selected to carry out this study and sincerely appreciate the cooperation and assistance extended by your staff and by officials of the Ministry of Water Development, Government of Kenya.

Very truly yours,
TIPPETTS-ABBETT-McCARTHY-STRATTON

Mario Asin
Regional Manager-East Africa

MA/fj

Enc: As Stated.

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INTRODUCTION

Purpose and Scope

By its contract number AID-623-003-T, executed in Nairobi on January 12, 1977, the U.S. Agency for International Development (REDSO/EA) engaged the firm of Tippetts-Abbett-McCarthy-Stratton, Engineers and Architects, to make a provisional estimate of the viability of Chemeron Dam, Baringo District, Kenya. The terms of reference are included herein as Appendix A. Briefly, these terms call for a reconnaissance study of the dam without consideration of the conveyance of water therefrom nor of the ultimate use of the water. Limiting our study to an analysis of existing data and to a few days' examination of the area in the field, we are to provide provisional answers to the following questions:

1) Is a dam viable at the Chemeron site and are further sutdies justified?

2) What is the possible range of monthly water releases?

3) What is the possible range of construction costs?

Work Performed

We have followed the terms of Appendix A. Six man-days were spent at the site on January 18-19, 1977. Data collection, office analysis, report writing, drafting, etc., were performed in Nairobi between January 13, and February 2, 1977.

Even though the terms of reference abound with such words and phrases as "preliminary", "provisional", "qualitative", and "order of magnitude", we must emphasize that our study is indeed of such nature. We have made a preliminary reconnaissance and it must be recognized that each of our conclusions and recommendations incorporates a certain error of estimate. Reduction of such errors and the preparation of further details and refinements would be the objectives of any Phase II Study that might follow.

DESCRIPTION OF PROJECT AREA

Location

The site of Chemeron Dam and Reservoir is located in Baringo District about five kilometers northwest of Marigot and about 12 kilometers west-southwest of the southern tip of Lake Baringo. Present access is via the channel of the Chemeron River from Road B4 about five kilometers north of Marigot. The first two kilometers of the channel can be traversed with vehicles having two-axle drive and the remaining 800 meters or so must be walked.

A general location map of the project is presented on Figure 1.

General Description

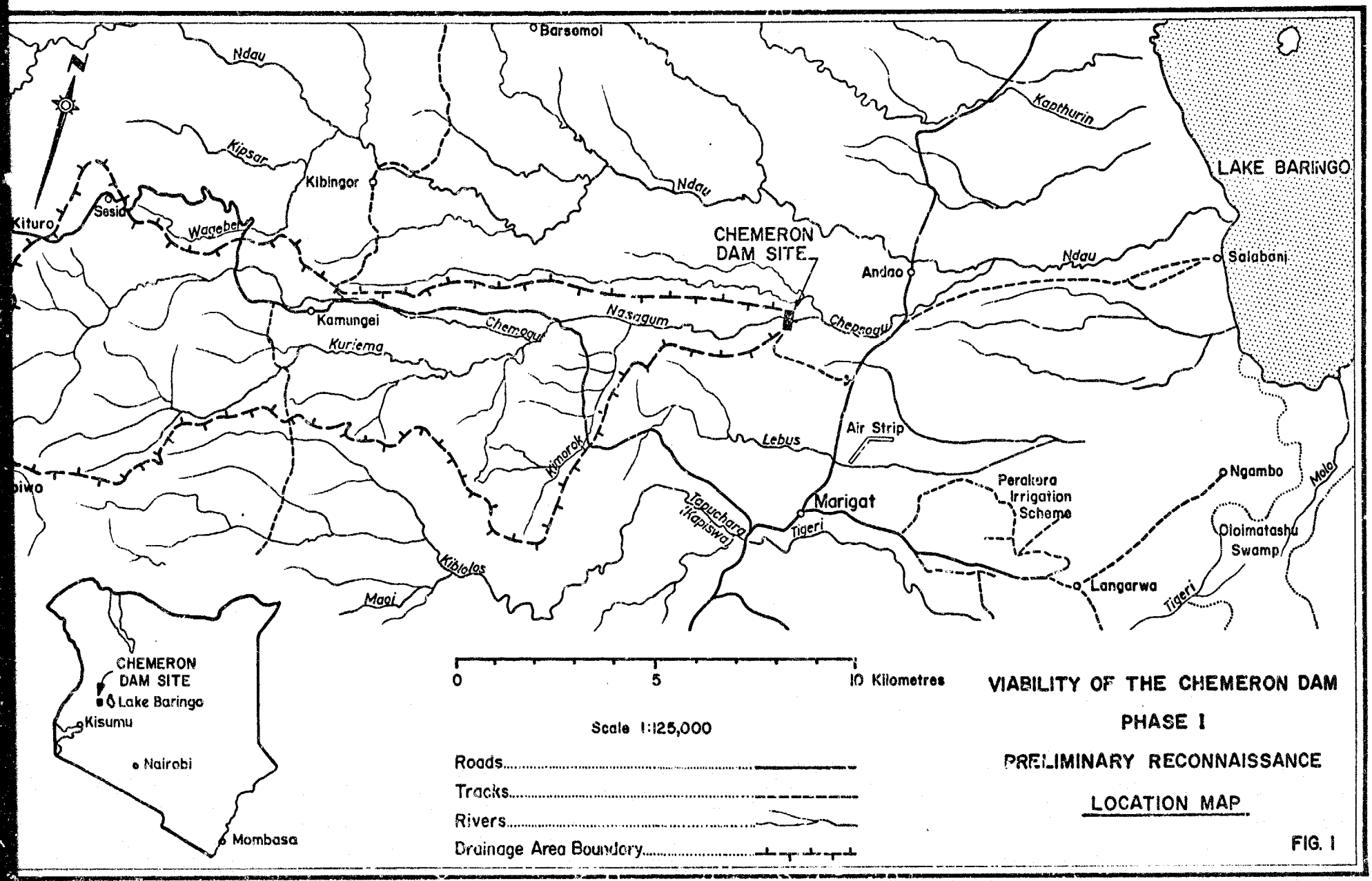
The Chemeron River rises in the Kamasian Hills southeast of Kabarnet and flows easterly to join the larger Ndau River near Road B4 enroute to Lake Baringo. Along its length, the main channel is variously termed "Kuriema", "Nasagum" and "Chepsogu", but local residents refer to it as the "Chemeron", which name is used in this study.

The higher parts of the Chemeron basin are formed of volcanic rocks which are eroded into ridges with approximate north-south orientations (probably controlled by faulting). Proceeding easterly, the volcanic rocks are covered by a thick series of sedimentary deposits whose upper surface is relatively undissected and which dips eastward. This surface is termed the Main Plateau.

The Chemeron River is entrenched 40 meters and more below the Main Plateau. Its floor ranges up to 400 meters in width (averaging perhaps 150 meters) and is generally covered with cobbles and boulders of the volcanic rocks. The river meanders across this floor, undercutting the adjacent cliffs of sedimentary deposits and widening its floodplain.

There is an exposure of hard volcanic rocks at the damsite that drastically effects the river's erosive capacity. On reaching the rock, the transverse shape of channel changes immediately; the relatively wide floodplain disappears and is replaced by a narrow rock gorge with walls approaching the vertical. The gorge is about 600 meters long and downstream from its lower end (at the easterly exposure of rock), the floodplain returns and the transverse profile of the canyon returns to its former shape as the river flows once again through the sedimentary deposits.

The rock gorge forms a local base-level for the river. Above the gorge, the average gradient of the Chemeron is about ten meters per kilometer whereas the gradient is approximately 30 meters per kilometer within the rock-controlled section of the gorge.



VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

LOCATION MAP

FIG. 1

The gorge is about 17 meters high at its upper end and its height diminishes downstream as the top of the rock outcrop dips easterly and finally disappears below the steam bed. At channel level, the gorge is five to seven meters wide. The top of the gorge is about 25 meters wide where it is well defined at the upstream end; downstream the top becomes ill defined but broadens to some 70 to 80 meters. Due to its rather dramatic "slot like" appearance, the gorge has attracted some attention as a damsite.

A local landform is the bench that occurs on both sides of the gorge approximately 18 to 30 meters above the canyon floor and perhaps 20 to 30 meters below the Main Plateau. The bench appears to be the remnant of a stream terrace carved on top of the rock before the river cut the gorge. Now eroded, far from flat and barely recognizable, the bench exerts a great influence on the volume of material that would be needed for the dam's prism.

About two and a half kilometers east of the gorge, the Main Plateau is truncated by an escarpment averaging about 30 meters in height. The alluvial plain of Lake Baringo and its tributary streams occurs to the east of the escarpment and the area that would be irrigated from Chemeron Reservoir is presumably located on the plain. Road B4 closely follows the base of the escarpment.

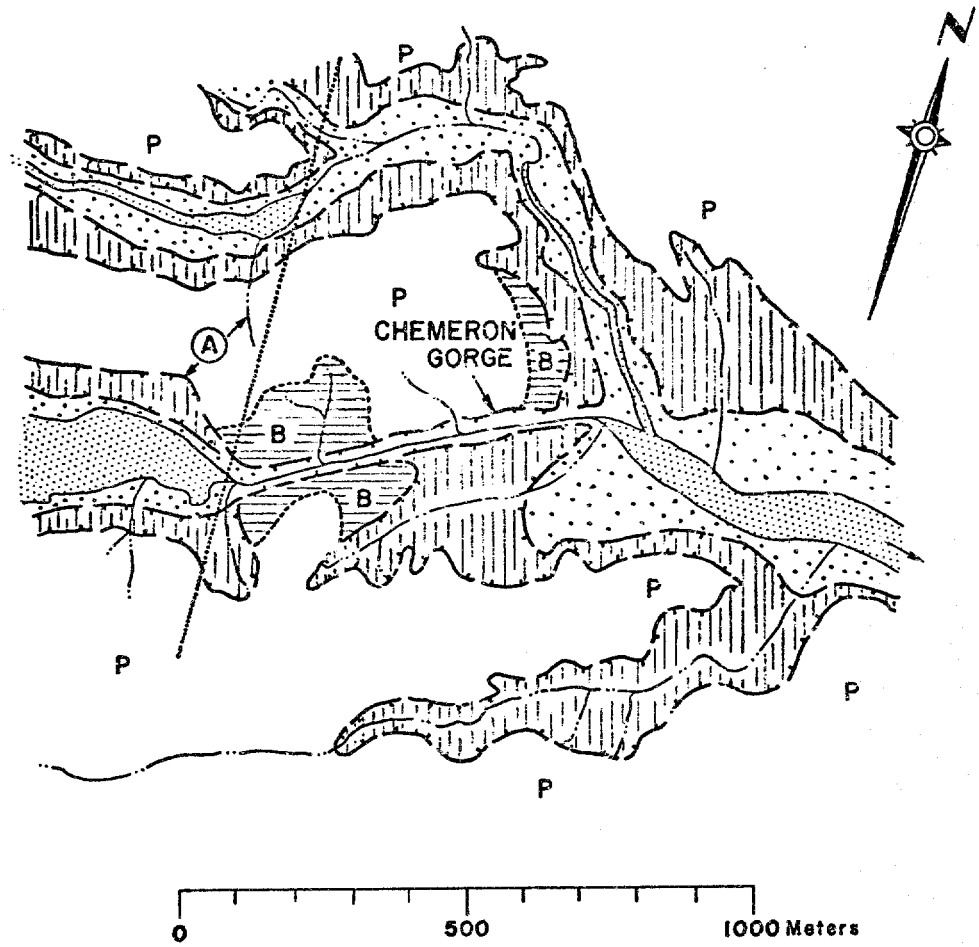
The bench and the Main Plateau, as well as the transitional slopes between them and overbank portions of the Chemeron channel, are covered with vegetation of the thorn-bushland type. The potential for agriculture is quite low and the land-clearing required for construction would apparently have no adverse economic or ecologic effects so long as suitable erosion control is provided.

Except in the gorge itself, there are no rock outcrops near the damsite. Soils on the bench and transitional slopes have high clay contents, and the surfaces are strewn with stream-worked cobbles and boulders derived from weathering of gravel lenses within the sedimentary deposits. Soils of the floodplain are azonal; boulder-gravels predominate but patches of sand and silt are not rare, particularly in the overbank sections of the channel.

The distribution of the several landforms (alluvium of the floodplain, canyon walls, the bench, and Main Plateau) are shown on Figure 2.

Aerial Photography and Mapping

Aerial surveys of the area have been made on several occasions. For the current study, 1961 aerial photography was used in the form of 9 x 9 inch prints with approximate contact scale of 1:50,000. Vertical control is poor; the nearest photo-identifiable point of elevation is about four kilometers southwest of the damsite.



ALLUVIUM (not shown in the gorge)

Stream Channel

Gravel

CANYON WALL (Base not shown where slope is very steep)

B HIGH BENCH (A poorly defined stream terrace carved approximately on the top of the volcanic rocks exposed in the gorge)

P MAIN PLATEAU

FAULT; (approximate location)

This sketch is based on uncontrolled aerial photography (of 1961) and is subject to variable distortion

VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

The area is covered by the following 1:50,000 quadrangles of the Survey of Kenya:

Sheet 90/4, Saimo
Sheet 104/2, Marigat

All of the damsite and reservoir are contained in the Saimo quadrangle which, unfortunately for our purposes, presents neither form-lines nor other elevation data.

An earlier survey was performed on November 18, 1976, by SSGT B. Nicholson, R.E., who ran a line of levels from the upper entrance of the gorge westerly along the channel into the reservoir area for a distance of 960 meters. He also profiled the mouth of the gorge to a height of about 17 meters.

We extended SSGT Nicholson's levels downstream through the gorge for a distance of 770 meters and also ran a transverse line of levels approximately along the axis of the dam. Our profiling station "zero" was established at the upstream mouth of the gorge and our arbitrary elevation datum "zero" was located in the stream channel at the easterly end of our survey. Our elevation "zero" corresponds approximately to elevation 1070 meters.

Nicholson's elevations were transposed to our datum. All elevations, together with the point of vertical control four kilometers southwest of the gorge, were used to guide stereoscopic preparations of the approximate form-lines presented on Figures 7 and 9.

CLIMATOLOGY AND HYDROLOGY

This section comprises a brief presentation of the climatic and hydrologic factors relevant to the design of a small dam.

Rainfall

The mean annual rainfall in the Chemeron River basin increases from approximately 650 millimeters at the proposed dam site to 1300 millimeters near the western boundaries of the drainage basin. Mean annual rainfall lines (isohyets) inside or adjacent to the drainage basin are shown on Figure 3. They were obtained from the "Mean Annual Rainfall Map of East Africa," published by the Survey of Kenya based on all available data up to 1966.

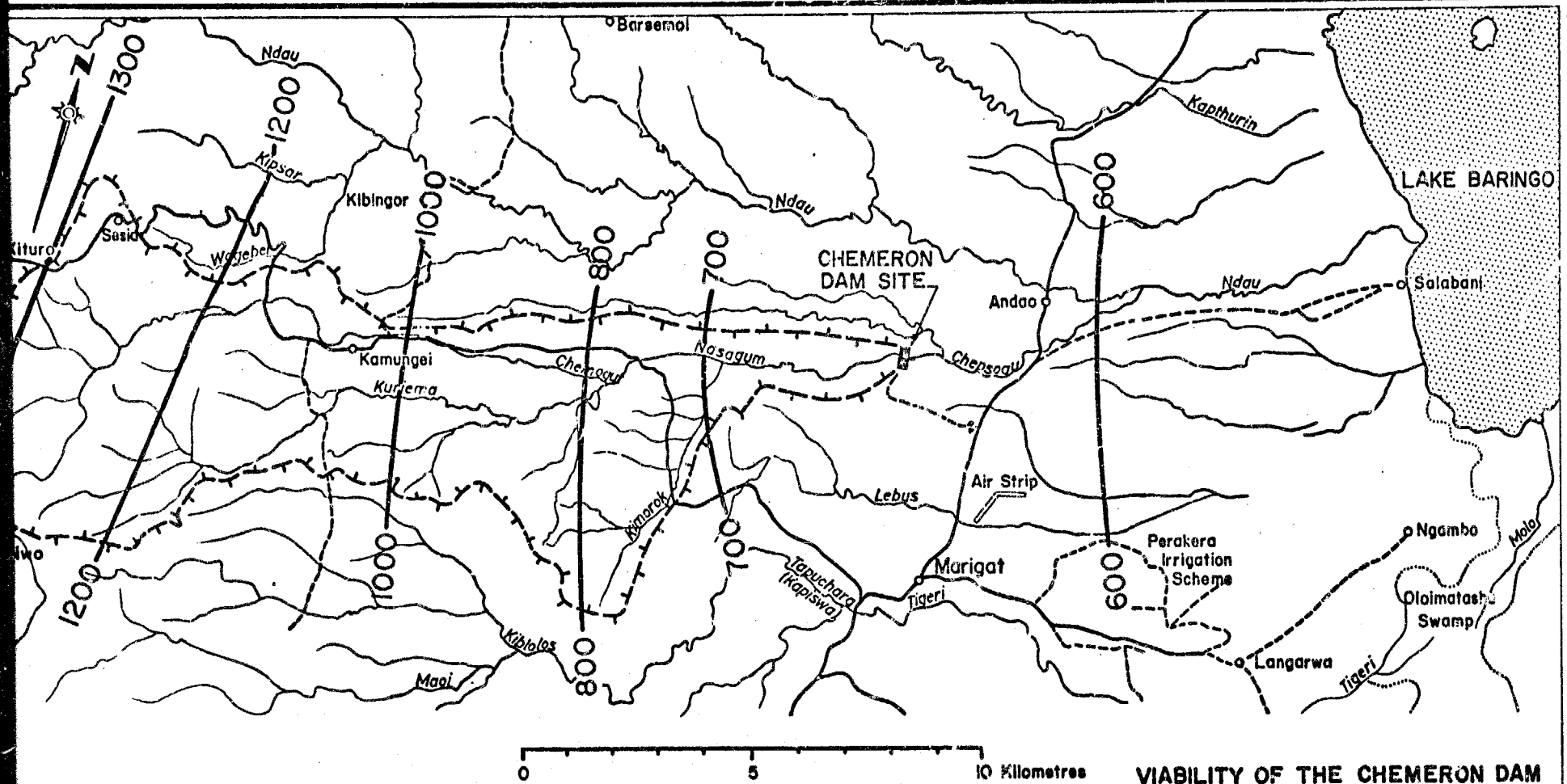
Two rainfall stations near the project area were selected for the estimation of runoff and floods. Gaps of records were filled with the data collected from nearby stations. The basic information of the two selected stations is summarized below.

Registration No.	Location	Altitude (m)	Length of Record(Yrs.)	Mean Annual Rainfall (mm)
89.35020	Kabarnet	6,700	59	1,346
89.36026	Hot Spring Dispensary	4,000	31	731

The annual rainfall usually follows a seasonal pattern. Most of the rainfall occurs from April through August although some years have recorded heavy rainfall in November. From December, rainfall decreases rapidly to a minimum during January and February. The month-to-month variation of rainfall in the project area is illustrated in the following tabulation:

	Mean Monthly Rainfall (mm)	
Month	Sta.89.35020	Sta.89.36026
January	29.9	24.1
February	46.2	23.5
March	78.3	51.9
April	186.5	105.0
May	167.7	79.9
June	130.1	61.6
July	203.9	106.1
August	223.2	95.5
September	82.9	56.9
October	57.6	49.5
November	84.9	48.0
December	54.8	29.3

The nearest rainfall station to the damsite is the station of Perkerra Irrigation (89.35163), located at Marigat. However, it was not selected for the estimation of runoff and floods due to its short length of record.



0 5 10 Kilometres

Scale 1:125,000

FALL ISOHYET (mm)

Roads

Tracks

Rivers

Drainage Area Boundary

VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

MEAN ANNUAL RAINFALL

FIG. 3

Evapotranspiration

Evaporation is the transfer of water from the liquid to the vapor state. Transpiration is the process by which plants remove moisture from the soil and release it to the air as vapor. The term evapotranspiration, sometimes called consumptive use, describes the total water removed from an area by transpiration and by evaporation from soil, snow, and water surface. Since transpiration is essentially the evaporation of water from the leaves of plants, rates of transpiration will be about the same as rates of evaporation from a free water surface if the supply of water to the plant is not limited. Estimated free-water evaporation may, therefore, be assumed to indicate the potential evapotranspiration from a vegetated soil surface. In general, the months with the highest rate of potential evapotranspiration are the months with least precipitation.

The potential evapotranspiration in Kenya has been studied by the East African Agricultural and Forestry Research Organization. The estimation was based on the Penman formula which is a function of daily radiation, sunshine duration, daily maximum and minimum temperatures, dew point temperature, and wind velocity. The estimated monthly and annual values of the potential evapotranspiration in the vicinity of the Chemeron damsite are tabulated below:

Month	Estimated Potential Evapotranspiration in mm *
January	205
February	195
March	212
April	187
May	190
June	173
July	167
August	182
September	193
October	199
November	182
December	189
Annual	2274

* Data obtained from T. Woodhead, "Studies of Potential Evaporation in Kenya," East African Agriculture and Forestry Research Organization, 1968.

Runoff

Runoff is that part of rainfall which travels over the ground surface and through channels to reach the basin outlet. As the Chemeron Basin is located in a semiarid region, channels are usually dry throughout most of the year, bearing water only during and immediately after a severe storm.

Since the Chemeron River has not been gaged, runoff must be determined by indirect methods. Usually, two types of approach may be used in the derivation of synthetic runoff data. One is to transpose runoff data from an adjacent basin with similar hydrologic properties; the other is to obtain runoff data from rainfall records through a rainfall-runoff model. There are several gaging stations established in the nearby streams. However, they are equipped only with staff gages, which do not provide continuous information for estimating the volume of runoff resulting from a storm. In this study, therefore, runoff data were derived from rainfall records. Since the month-to-month variation of water availability is relevant to reservoir capacity and yield, the quantitative assessment of streamflow was made on a monthly basis.

Attempts were made to correlate the monthly runoff to monthly rainfall by plotting rainfall against runoff, but the points were so scattered that no line of best fit could be drawn. Thus, it was decided to derive the streamflow data from storm rainfall records instead of monthly rainfall records. The total runoff in a given month is equal to the summation of runoffs resulting from the storms occurring in that month. The model developed by the U.S. Soil Conservation Service was used for synthesizing storm runoff from storm rainfall. The detailed procedures are described in Appendix B of this report.

The mean annual runoff, computed from the 30 years of synthetic streamflow records (1947-1976), is equal to 0.26 cubic meters per second or 8.17 million cubic meters per year. The maximum and minimum runoffs are 19.23 and 0.70 million cubic meters per year, respectively. The following tabulation indicates the estimated flows which are dependable during 50, 75, 80 and 90 percent of the time:

Percent of Time	Annual Runoff (Million cubic meters)
50	8.05
75	4.64
80	4.43
90	2.28

The dependable flow for each month was also estimated during this study. The following table indicates the estimated flows which are dependable during 50, 75, 80 and 90 percent of the time in each month:

Month	Dependable Monthly Flows (million cubic meters) Percent of Time 50	75	80	90
January	0	0	0	0
February	0	0	0	0
March	0.084	0	0	0
April	0.696	0.358	0.232	0.084
May	0.506	0.063	0.042	0
June	0.380	0.127	0.105	0
July	1.075	0.295	0.169	0.084
August	1.117	0.654	0.274	0.127
September	0.148	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0

Design Flood

In addition to the runoff estimations discussed in the previous section for reservoir regulation, the probable maximum flood was used for sizing the spillway. The probable maximum flood was derived from the probable maximum precipitation. The probable maximum precipitation is defined as the greatest depth of precipitation for a given duration meteorologically possible for a given basin at a particular time of year, and has been estimated for Kenya by the East African Meteorological Department. The estimation was based on a theoretical approach in which the actual storm mechanism was considered. The detailed derivation procedures for the probable maximum flood are presented in Appendix B.

The capacity of the spillway was determined by routing the maximum probable flood through the reservoir. Results of the flood routing disclosed that the design flood is approximately 480 cubic meters per second with a spillway 30 meters long. The surcharge level corresponding to the design flood is approximately four meters above the crest of the spillway.

GEOLOGY

General Surface Geology

The local exposed geological sequence is summarized as follows:

(Top)

1. Alluvium
2. Colluvium and residual deposits
3. Kapthurin beds
4. Lake Hannington phonolites

(Base)

The several units are described below, from bottom to top, and the tentative relations between them are shown on Figures 4 and 5. Certain geological complications are described in Appendix C.

Lake Hannington Phonolites - The lavas exposed within the gorge are of two distinct types:

(a) Upper "agglomerate"

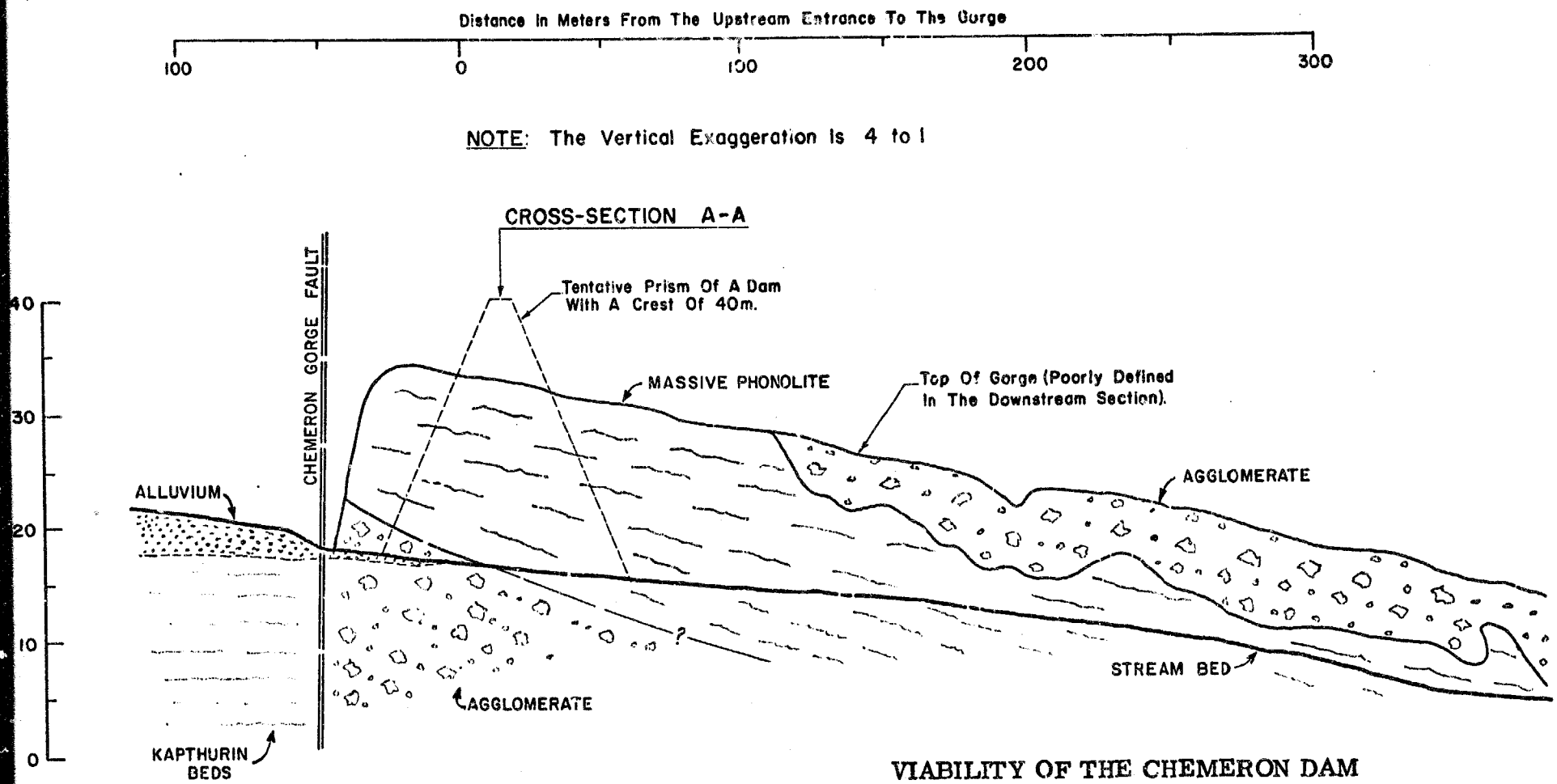
(b) Central massive phonolite

(c) Lower "agglomerate" (as "a")

The "agglomerate" (a term of uncertain validity: see Appendix C) consists chiefly of subrounded blocks up to a meter or so in diameter, set in a fine matrix. The composition appears to be phonolitic, and these beds are abundantly fractured and deeply weathered. Both the upper and the lower occurrences are lithologically identical.

The lower occurence of agglomerate is at the very upstream entrance to the gorge where it is overlain by the massive phonolite. The contact appears to be concordant and dips downstream 10 to 15 degrees.

The massive phonolite is dark gray to near black, finely crystalline, nonporphyritic and hard. Although bedding is not evident, it exhibits a vague flow structure in places and engulfed blocks of different volcanic composition are occasionally found. Its greatest exposed thickness is about 17 meters. The contact between the massive phonolite and the overlying agglomerate is extremely irregular, suggesting that the former was far from frozen when the latter was emplaced.



The Line Of The Section Bears About N 62°E; The View Is Of The North Wall Of The Canyon.

VIABILITY OF THE CHEMERON DAM

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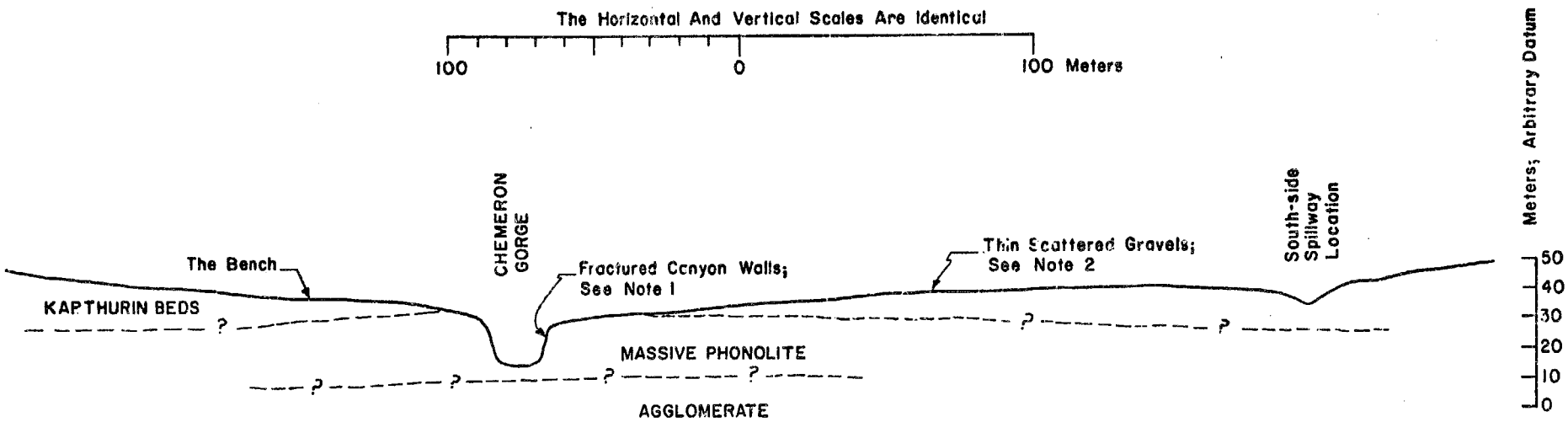
GEOLOGIC SKETCH OF THE NORTH WALL OF THE GORGE

FIG. 4



NOTES:

1) Prominent fracturing of the phonolite on the walls of the gorge is largely a surface phenomenon.

2) The surface of the bench is covered with boulders derived from the erosion of the Kapthurin beds. Due to the scale of this drawing, they are not shown.

3) The bearing of this section is about N 19°W. The view is downstream.

VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

PROVISIONAL GEOLOGIC SECTION ALONG THE AXIS

FIG. 5

The massive phonolite is finely fractured, yet due to the general competence of this rock, one receives the impression that most of the fractures are only surface phenomena and that they may become tight within a couple of meters, or less, from the wall of the gorge.

The top of the exposed volcanic rocks dips easterly at an average rate of 3.5 degrees, and disappears under the river channel about 350 meters from the upstream entrance to the gorge (see Figure 4 for the stationing adopted in this study).

Kapthurin Beds - A thickness of about 60 meters of the deposits termed the Kapthurin beds is exposed in the cliffs above and below the gorge. The deposits consist mostly of reddish-brown sandy claystones and yellowish-brown well sorted coarse siltstones, both of low permeability. Gravel lenses also occur in all exposures. A few fragments of pumice were found as float (but not in place) and as seen from a distance, several beds had a tuff-like aspect;thus it is possible that the Kapthurin beds include some pyroclastic units.

These deposits are well bedded wherever exposed. They dip gently to the east at about one to two degrees.

Colluvium and residual deposits - Much of the bench and many of the slopes between the floor of the river channel and the Main Plateau are covered with boulders, the residue of erosion of the sedimentary deposits. Several slopes, particularly above the damsite, appear to consist of colluvial deposits (i.e., soil-like masses emplaced gravity). Neither the residual gravels nor the colluvium are important in the local geologic scene.

Alluvium - Both above and below the gorge, the Chemeron River flows across a relatively wide floodplain formed principally of cobble-and boulder-sized gravels of volcanic rocks. Scattered patches of sand and silt occur erratically. The alluvium consists of channel and overbank sections and there is at least one low alluvial terrace ;however, these components were not distinguished in this reconnaissance study.

Faulting - To the east of the damsite (1.5 to 2.3 kilometers) the Kapthurin beds are displaced by a series of north-south trending faults and front the alluvium of the Baringo plain along abrupt escarpments some 30 to 35 meters in height. The faults are part of the Rift System;all are apparently of normal type, downthrown on the east, but stream offsets indicate that there is some right-lateral horizontal displacement as well. The very fresh physiographic appearance of the escarpments indicates that the displacements are relatively recent, yet the seismic record indicates that the possibility of damaging earthquakes can be discounted (at least in the reconnaissance stage of investigation).

The gorge owes its presence to a fault that has elevated the Lake Hannington phonolites with respect to the Kapthurin beds. The fault plane is either vertical or steeply dipping toward the east, and the displacement is at least 18 meters (although it may be greatly more). The fault was traced into the first ravine north of the Chemeron and its strike was found to be almost exactly north-south, but no evidences of it were found in the canyon of the Ndau River, about two kilometers north of the damsite. No evidences of displacement were observed within the overlying Kapthurin beds;thus, the fault probably is a part of an earlier stage of Rift activity, is not active, and imposes no seismic hazard to a dam, even though it is located only a few meters from the possible axis. In this study, the fault is referred to as the Chemeron Gorge Fault and its location is shown on Figures 2 and 4.

Qualitative Assessment of the Dam's Foundation

At the dam axis (station 0 + 12 on our survey), both the floor and the walls of the gorge are formed of the competent massive phonolite. While foundation treatment details cannot be predicted in advance of exploratory drilling, the following conditions are tentatively assumed:

1) The natural slope of the canyon walls is 70 to 75 degrees. This slope would have to be reduced below the impervious core (some 10 meters wide) and blasting would be required. If done expertly, most of the open fractures now exposed in the gorge would be removed by excavation of the rock.

2) The canyon floor is about 13 meters wide and it would be trenched to a depth of two meters along a width of ten meters. Again, blasting would be required.

3) Dental work on the floor and slope sections of the trench should not be complex. Broken rock should be removable by hand labor through chipping, crowbarring and wedging.

The upper "agglomerate" may not be found along the axis. If it does occur, its excavation should impose no serious problem although blasting would be required.

By far the most serious problem of foundation treatment concerns the lower "agglomerate" which may underlie the canyon floor as shallowly as two meters at the axis section. If so, it will be intercepted in the core trench and special treatment will be required. The competence of the agglomerate in bearing, when saturated and loaded, and its permeability, may both be unfavorable. In the absence of physical testing of these properties, no quantitative statements can be made;however, the following provisional observations are made:

1) Should the lower agglomerate occur within (or shallowly below) the core trench, expensive treatment may be required.

2) Should its permeability be found to be high, consideration should be given to the installation of an impervious blanket over its entire wetted outcrop, both below the prism and upstream thereof.

3) Should the lower agglomerate be rather thin and overlie the Chemeron beds (as described in section 5 of Appendix C), foundation treatment will be simple and relatively cheap. In the floor of the core trench, excavate a cut-off trench perhaps two meters wide that penetrates the agglomerate and reaches impermeable units of the Chemeron beds, and backfill the cut-off with the same impervious material to be used in the dam.

The previous discussion concerned the gorge itself. Above the gorge (say, above 30-32 meters on our elevation datum), no serious foundation problems are anticipated. Residual soils and colluvium on the bench should be removable by bulldozer, followed by hand labor; and core material (to rise only to 42 meters if a 44 meter dam is selected) can be bonded by scarifying and rolling.

The preceeding comments on foundation treatment refer to the dam of rock-fill design that will be described under "Chemeron Dam", below. Should a concrete dam be adopted, whether of arch or gravity type, an entirely different system of foundation treatment would have to be adopted and the cost thereof would be dramatically higher. It is almost impossible to estimate the cost of treatment for a concrete dam prior to drilling and detailed geological studies, but U.S. $ 250,000 is suggested as a minimum. Indeed, this high value is one of the reasons why we do not recommend the use of a gravity dam at the Chemeron site.

Qualitative Assessment of the Reservoir

The reservoir is contained within the relatively impermeable Kapthurin beds and no significant amount of seepage should occur in any direction, horizontally or vertically. Further, the volume of water to be held in or released from bank storage will be so low that it can be ignored.

Some of the Kapthurin cliffs within the reservoir are nearly vertical. As water is impounded and the pool elevation rises, the lower portions of the cliffs will become saturated, the cliffs will become unstable, and the upper sections will collapse by landsliding. The resultant loss of reservoir capacity will not be important and stabilization should be reached in a couple of years.

Qualitative Assessment of the Spillway Site

The spillway site is described under "Chemeron Dam", below. No geological problems are foreseen. The spillway channel would be formed within residual gravels, colluvium, and principally in the Kapthurin beds. No rock should be encountered; all excavation should be common and easily performable by bulldozer. Obviously, protection against erosion and scour would have to be provided.

Qualitative Assessment of Construction Material Availability

All materials needed for a rock and earth fill dam prism should be found within a half kilometer of the site. As to be noted in more detail below, the following provisional volumes would be needed:

	Volume of material (cubic meters) for a crest elevation of:		
Type of material	35 m	40 m	45 m
Random fill	9,000	19,000	40,000
Core and transition	5,000	11,000	23,000
Rock fill	10,000	22,000	48,000
TOTAL	24,000	52,000	111,000

Some rock fill would be obtained from foundation treatment, but most would come from the gravels of the Chemeron floodplain upstream from the dam, and all of the random fill could come from spillway excavation. The total volume would be 19,000, 41,000 and 88,000 cubic meters for dams with respective crest elevations of 35, 40 and 45 meters. Assuming an excavation in the floodplain of only two meters, the area of the resultant borrow pits would be about one half, one and two and a half hectares, respectively. Because almost any likely type of dragline can work at depths greater than two meters the actual areas of the borrow pits would probably be much less.

Core and transition material is abundantly available in the Kapthurin beds and could be bulldozed from benches cut into the more moderate slopes. The estimated volumes are 5,000, 11,000 and 23,000 cubic meters for dams with crests of 35, 40 and 45 meters, respectively. Most or even all of this volume could be provided from spillway excavation.

Some sand and fine gravel would be needed for concrete. The gravel can certainly be screened from the alluvium of the floodplain, but the provision of sand may be more complicated. We have not investigated the volume of the sand component in the alluvium, but we tentatively suggest that: (1) all of the required sand could be obtained from that source; and (2) both washing and screening facilities would be needed.

Qualitative Assessment of Water Availability

During construction, water would be needed for washing sand and gravel, making concrete, bringing core and transition material to optimum moisture during emplacement, and, to a lesser extent, for human needs. We suspect that the volcanic rock of the gorge serves as a barrier and impounds ground water in the alluvium of the floodplain; that is, there is probably a local underground water supply within the alluvium, perched above the relatively impermeable Kapthurin beds. If so, the depth to the perched water table should be moderately shallow and perhaps within the reach of a dragline or even hand labor. This possibility must be examined in any future study, for the only alternate is the expensive hauling of the water requirement.

Should this perched water body actually exist and should its volume be rather large, it might be a source of an irrigation supply for a small area of land, if the dam is found to be infeasible.

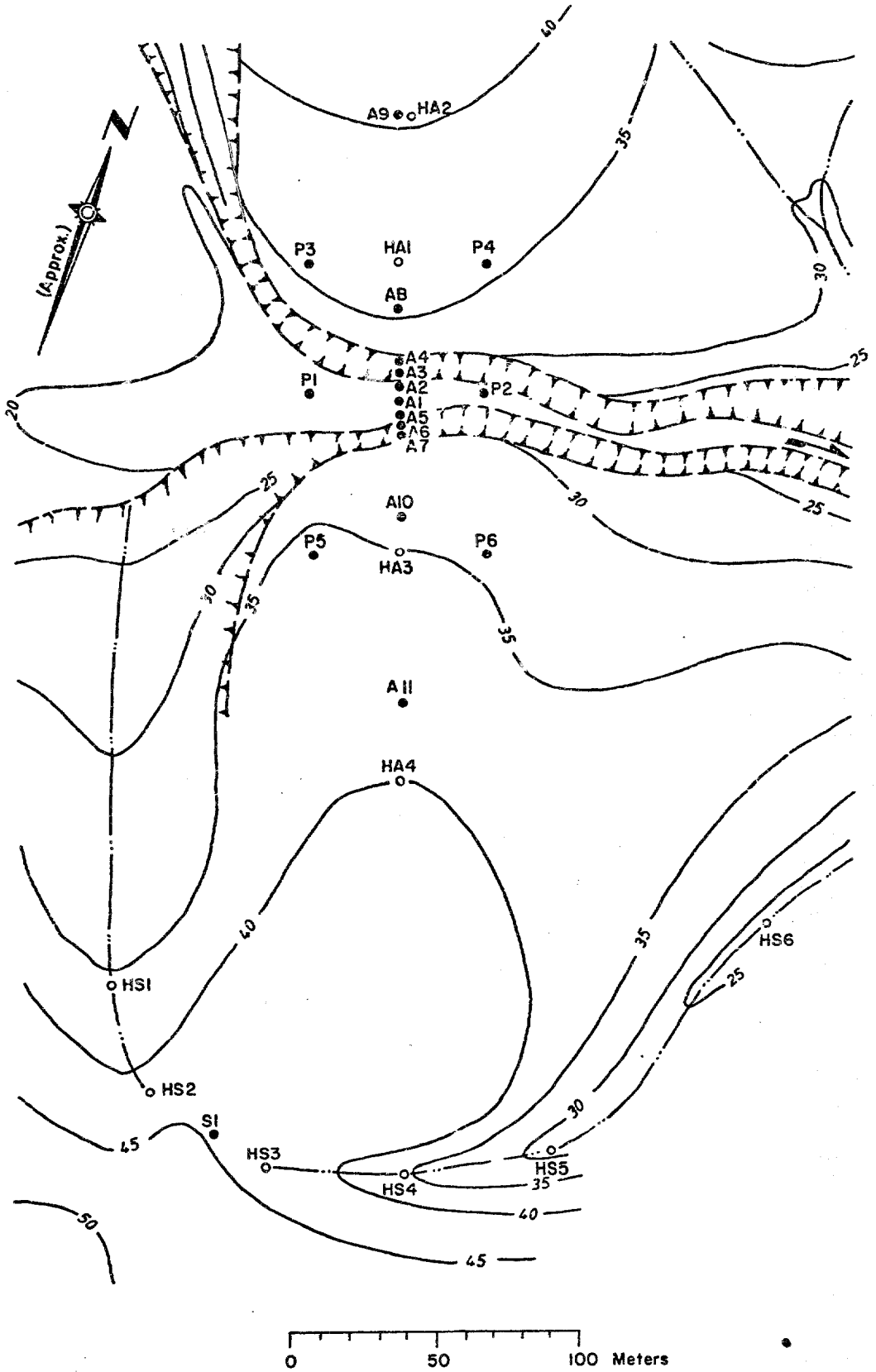
Exploratory Drilling

Two types of subsurface explorations would be required: (1) diamond drilling, with coring at minimum diameter of NX; and (2) hand-dug pits. Suggested site locations are shown on Figure 6 and the proposed schedule is summarized in Table 1.

A provisional optimum program would include 20 diamond-drill holes, with a total drilling depth of 410 meters. Four holes should be drilled at an angle (perhaps 30 degrees) into the walls of the gorge and the remainder could be vertical. Bids have not been solicited for this work, but the cost should be roughly in the order of U.S. $ 25,000 if sites are levelled and water is supplied to the driller without charge.

To establish the nature of excavation on the bench and in the spillway and to determine the volume of construction materials in the floodplain, 20 hand-dug pits are proposed, each of three meters depth. Each should be completed with 12 man-days of labor at a cost of roughly U.S. $ 15 for a total of about U.S. $ 300 (materials not included: two pangas, two shovels, one pick and one crowbar per three-man team).

Any effort to reduce total construction costs by curtailing the drilling program should be resisted. Such "saving" would be at the price of reduced safety. However, should some circumstance dictate a reduction, proposed holes A1, A3, A6, A11, P1, and P2 should be retained at all costs.



● Diamond-drill Hole
o Hand-dug Pit

VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

TABLE 1

PROPOSED SCHEDULE OF EXPLORATORY DRILLING

I. DIAMOND DRILLING

No.	Type *	Depth, m
AXIS SECTION		
A1	V	20
A2	V	10
A3	A	10
A4	A	15
A5	V	10
A6	A	15
A7	A	10
A8	V	30
A9	V	20
A10	V	30
A11	V	20

No.	Type *	Depth; m
PRISM SECTION		
P1	V	20
P2	V	15
P3	V	35
P4	V	35
P5	V	35
P6	V	35
SPILLWAY SECTION		
S1	V	15
CONTINGENTS		
2, at 15m ea.	V	30

(* V = vertical drill ; A = angle drill)

TOTAL DEPTH = 410 m

Note: In any reduced drilling program, holes A1, A3, A6, A9, A11, P1 and P2 above should be retained.

II. HAND-DUG PITS

Location	Nos. (incl.)	No. each	Depth, ea;m	Total depth; m
Axis Section	HA1 - HA4	4	3	12
Spillway Section	HS1 - HS6	6	3	18
Reservoir Section	(5 ea)	5	3	15
Contingents	(5 ea)	5	3	15
	TOTAL	20		60

CHEMERON DAM

Location and Type

Looking downstream from the reservoir area toward the damsite, the silhouette of the Chemeron gorge appears to be almost U-shaped, and one might be tempted to think that a dam rising only to the height of the gorge would be successful. However, the elevation of the floodplain is substantially higher than that of the canyon within the gorge; five meters of elevation are "lost" within a horizontal distance of only 150 meters from the mouth of the gorge. A dam rising only to the upper lip of the gorge (say, to elevation 34 meters on our datum) would store a total only 1.6 million cubic meters of water (see Figure 7), of which the useful storage, due to sedimentation, might be only in the order of 0.6 million cubic meters. This small amount of useful storage would not irrigate much more than 50 hectares of land.

It would also appear, at first sight, that the gorge provides a natural site for a concrete dam. Investigation of this alternative, however, indicated that, for the same storage volume, the cost of a gravity, overflow dam would greatly exceed that of an embankment dam with a side-channel spillway. The primary reasons for the relatively high cost of a concrete dam are: (1) the expected extremely high cost for foundation treatment as discussed under GEOLOGY, above; and (2) the probable additional cost of hauling large quantities of sand needed for the mass concrete, in view of the suspected scarcity of this material in the vicinity of the damsite.

On the basis of readily available construction materials a zoned rock and earth fill dam was provisionally selected. The location of the selected axis of the dam is shown on Figure 7.

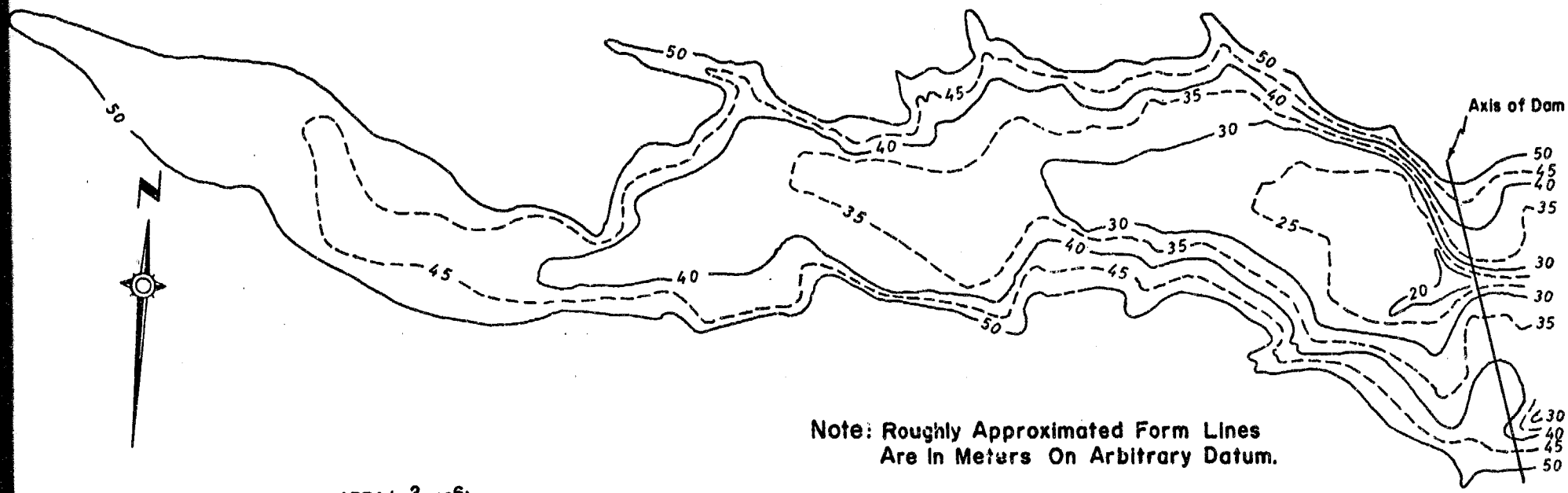
Reservoir Area

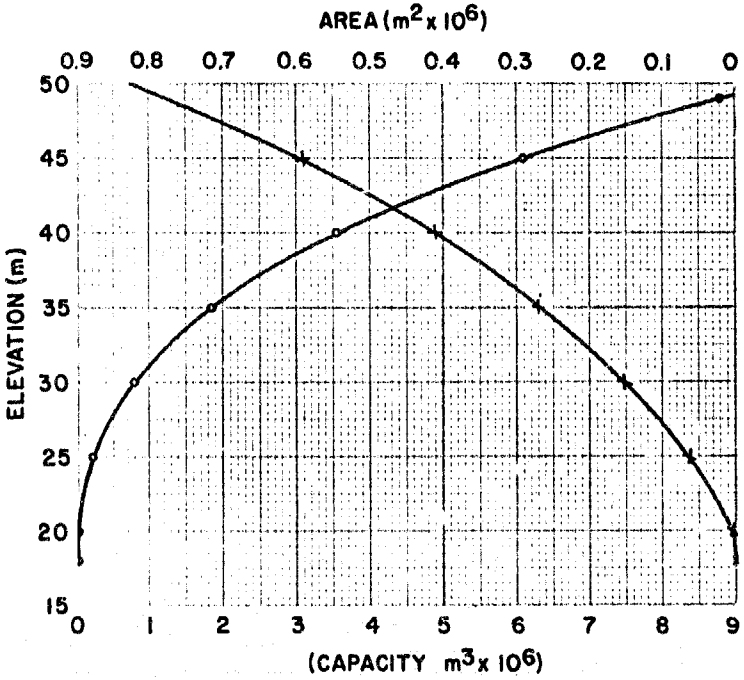
The impounding area behind the Chemeron Gorge damsite has a slope of from one to one and a half percent. Provisional topography of the area is presented on Figure 7, together with the reservoir area/capacity curve.

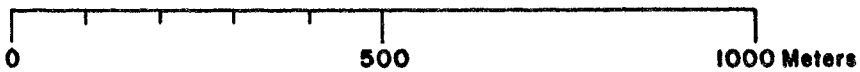
As was noted in the GEOLOGY section, above, no significant amount of seepage losses would be expected, either horizontally or vertically. Evaporation losses would be appreciable, however, amounting to some 2,200 millimeters per year, or about 600,000 cubic meters of water, at elevation 35 meters.

Provisional Plan and Section

The provisional plan of the Chemeron dam is presented on Figure 8 and the provisional maximum section is presented on Figure 9. The crest length of the dam would be approximately 390 meters, and the maximum height at crest elevation 44 meters would be approximately 29 meters.







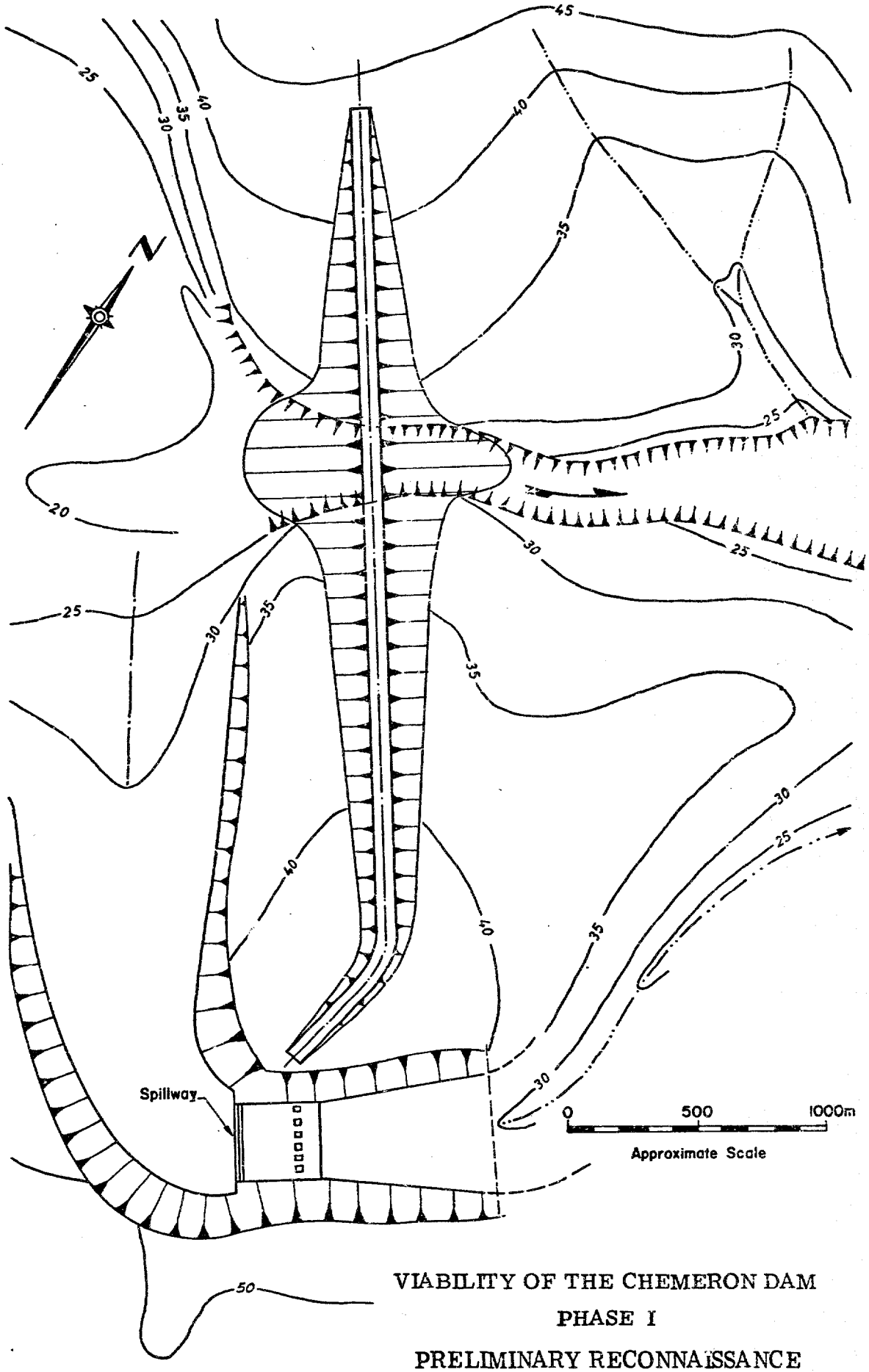
VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

PROVISIONAL TOPOGRAPHY OF RESERVOIR AREA

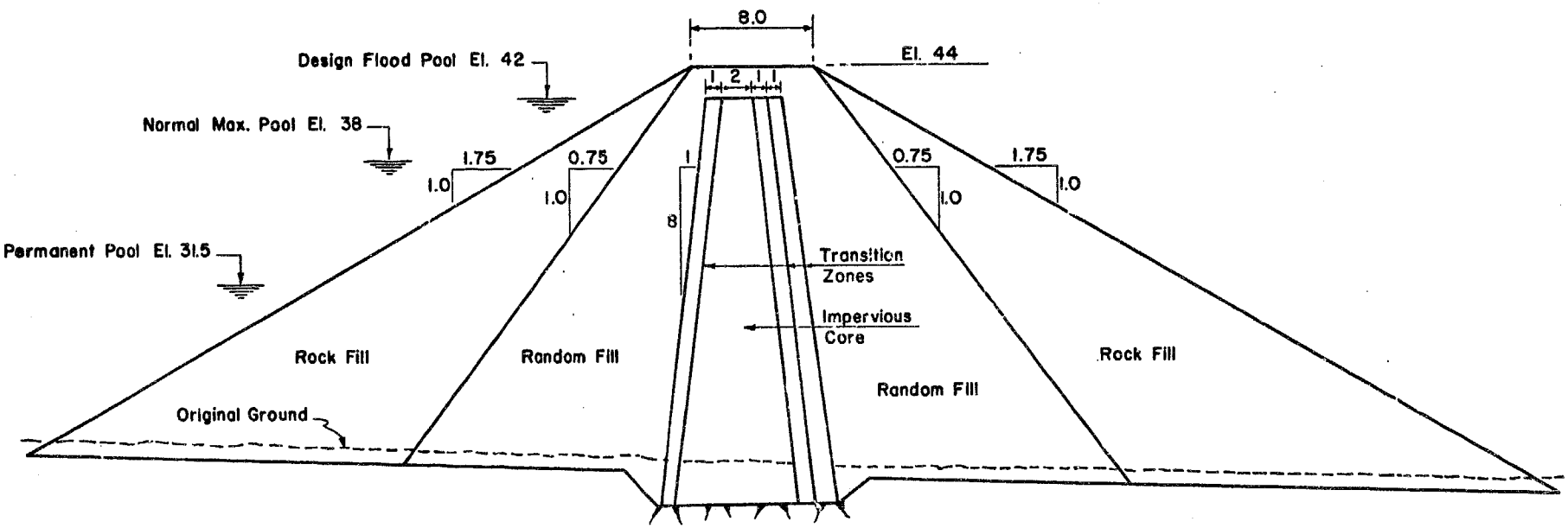
FIG. 7



VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE



APPROXIMATE MAXIMUM SECTION

Note: All dimensions and approximate elevations in meters

VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

PROVISIONAL SECTION OF CHEMERON DAM

FIG. 9

A zoned, rock/earth fill dam was selected due to the ready availability of appropriate construction materials in the immediate vicinity of the damsite.

A crest elevation of 44 meters (arbitrary datum) was chosen as the most economic section in that an approximate balance between spillway excavation and the random and core fill quantities was struck at this elevation. Further, the operating reservoir capacity at this crest elevation would permit complete regulation of the estimated 75 percent probability runoff from the Chemeron Basin. Consequently, alternative dam heights are neither presented nor costed in this report; lower dams would cost more and have less storage; insufficient runoff is available to consider higher dams.

As may be seen on Figure 9, the embankment section consists of an impervious core and transition zones, adjacent random fill sections, and a rock fill shell to provide stability.

The entire base of the dam would be cleared and excavated to an average depth of about one meter. The slope of the gorge walls would have to be flattened by blasting in the vicinity of the core, say over a ten-meter witdth, for stability and water-tightness. A required additional two meters of excavation would be expected under the impervious core section for water-tightness. In addition, it is possible that a cutoff trench would be required across the valley floor, backfilled with impervious material; the trench would be in the order of two meters wide by five meters deep to reach the expected impermeable units of the Chemeron beds (see Appendix C).

It is expected that all core and random fill materials would come from spillway excavation. The rock fill shell would come from the stream bed in the reservoir area. Transition zone materials would be screened and washed and would come from either spillway excavation or bulldozed from benches cut into the more moderate slopes of the Kapthurin beds (see Figure 5).

Estimated quantities of fill materials are as follows:

Core and transition	20,000 cubic meters
Random fill	34,000 cubic meters
Rock fill	42,000 cubic meters
Total	96,000 cubic meters

Outlet works would consist of a simple hand operated slide gate and pipe founded on a bench cut in the gorge and passing under the dam at an elevation of about 31 meters (arbitrary datum).

Spillway

The schematic plan of the provisionally selected spillway is shown on Figure 8. The spillway is located on a natural saddle leading to the Chemeron River downstream from the dam via an existing gorge. Excavation

quantities would be in the order of 50,000 to 60,000 cubic meters; no rock excavation is expected.

The spillway section itself would comprise a concrete trapezoidal broad-created weir about three meters high by 30 meters long, end walls, and a concrete stilling basin with side walls. In the order of 2,000 cubic meters of reinforced concrete would be required. Depth of flow over the weir for the 480 cubic meter per second design flood would be in the order of four meters. The spillway channel down to the Chemeron River would have to be excavated in a series of drops, due to the relatively steep natural slope of about five percent, and protected against excessive scour and erosion by means of rock-filled cribs, gabions or some such scheme.

The preceeding description is of a spillway on the south side of the river. There, excavation quantities would be relatively low but the costs of erosion protection in the ravine east of the spillway channel would be relatively high. There is an alternate spillway location on the north side of the river; it is shown by the letter "A" on Figure 2. Excavation of the spillway channel at the northern location would be much more voluminous than at the southern site; however, erosion control measures would be substantially cheaper. Detailed cost comparisons, at such time as topography is available, might possibly favor the alternate site because of the following apparent advantages:

1) the northern ravine has a much higher natural flood capacity than the southern; and

2) the massive phonolite of the Chemeron Gorge also crops out in the northern ravine and would stabilize the ravine's floor against scour.

Diversion During Construction

Due to the relatively small volumes of excavation and embankment, it is estimated that the dam and spillway could be built in six to eight months so long as : (1) adequate heavy equipment and labor is provided; and (2) cement, aggregates, core transition materials, pipe, gates, etc., are stockpiled in advance.

In view of the above, it is expected that the dam can be built without regard to diverting flow during construction. Runoff from the Chemeron Basin is generally either nil or minor during the six-month period October through March. Should unseasonal flow occur the water could be allowed to overtop the partially completed embankment without severe damage or failure since the shell is rock fill. It would perhaps be advisable to keep a stock of cabled mats or fencing on hand which could be anchored to the downstream face and top of fill should such flow occur.

Access

Access to the site during construction would not be feasible along the

channel of the Chemeron River. There, slopes are too steep and the danger imposed by floods too great.

The best access appears to be from Road B4 about 3.2 kilometers north of Marigot. The damsite is about three kilometers from that point. One or more hairpin turns would be needed to climb the 25 meters or so between the Baringo alluvial plain and the Main Plateau, but once attaining the latter surface, the remaining road construction should be relatively simple.

Alternate access may be gained from Road C51 about 3 kilometers west of Marigot. About four kilometers of roadway and at least two ravine crossings would be needed.

Qualitative Assessment of Sediment

No sediment data exist for the Chemeron River. Published sediment rating curves for other basins of similar size and somewhat similar rainfall conditions gave widely ranging results when applied to the Chemeron Basin. It is expected, however, that sediment yield is high (perhaps one to five percent of annual runoff) due to the storm nature of runoff and the large eroded areas observed during aerial reconnaissance of the basin.

Construction of the Chemeron Dam, then, would also have to include a certain degree of watershed management. It is assumed, for the purpose of this preliminary reconnaissance, that the sedimentation rate could be kept down to one percent of annual flow by volume, through the construction of numerous check dams both on the main stream above the reservoir and on the many small tributaries. Such check dams would be cheap and would comprise nothing more than rocks piled one to two meters high by labor intensive means. A 100 - man labor party would cost only some U.S. $ 30,000 per year for this purpose.

Sediment yield could be further reduced by scratching and seeding eroded areas with suitable perennial grasses and attempting some degree of grazing control.

Approximately one million cubic meters have been reserved in the reservoir as permanent pool and sediment storage. Theoretically, at an average runoff of eight million cubic meters, this pool would be filled with sediment in some 12 years under the above assumption of one percent sediment yield if check dams are constructed. To attain a longer period before encroachment on the operating pool, additional watershed stabilization measures, such as grass seeding and perhaps terracing, would be required.

All of the above assumptions would have to be confirmed through a sediment sampling program at such times as the river is flowing.

Provisional Reservoir Operation Studies

The purpose of reservoir regulation is to smooth out the peaks and valleys of streamflow so as to obtain greater beneficial use of the available water. Water is stored at times of excess flow for later use at times of low flow.

A mass curve, which is a cumulative plotting of net reservoir inflows, was constructed based on 30 years of synthetic streamflow data. The slope of the mass curve at any time is a measure of the inflow rate at that time, as indicated on Figure B6. The lowest annual runoff in the past 30 years was approximately 0.70 million cubic meters (occurred in 1965).

For a given capacity of 1.8 million cubic meters, the month-to-month reservoir operation conditions were also examined. The streamflow data of 1950 and 1960 were used for this provisional reservoir operation study because the annual flows in these two years were close to the estimated dependable flow during 75 percent of the time. It was discovered that, for a constant release throughout the year, the maximum annual yield to be expected from the proposed reservoir is equal to about 3.5 million cubic meters. A more optimum annual operation schedule would be to release water for seven to eight months, from March through October or November. The total annual yield based on the latter operation schedules would be expected to be approximately 4.0 million cubic meters. Three typical case studies are illustrated in Tables 2 through 4.

Table 2 reflects a constant monthly release schedule throughout the year (using 1960 synthesized runoff) of roughly 110 liters per second. Such reservoir operation would result in spillage of about 540,000 cubic meters and permit year-around cropping on some 100 or so hectares.

Table 3 is also based on 1960 synthesized runoff and is representative of a double cropping release sequence during the periods February through May and July through October. Such scheduled releases would amount to about 225 liters per second per month and would be adequate to double crop in excess of 200 hectares. No spillage would occur.

Synthesized runoff for 1948 was used for the operation study summarized in Table 4. Under this release schedule, amounting to 231 liters per second monthly over two four-month periods, January through April and June through September, with a total spillage of 574,000 cubic meters, some area in excess of 200 hectares could be irrigated under double cropping. It is noted that 1948 represents an annual probability of flow of about 70 percent.

Order - of - Magnitude Cost Estimate

Rough estimates of quantities of excavation, fill and concrete were made on the basis of form lines approximated from two profile lines surveyed in the field and stereoscopic study of 1961 aerial photographs at contact print scale of approximately 1:50,000. Unit prices used were generally based on GOK Water Department tender rates published in 1975 to which an annual escalation rate of 15 percent was applied.

TABLE 2 RESERVOIR OPERATION STUDY - CASE I

iption	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
*	(mcm)	0	0	0.759	0.337	0.084	0	1.560	1.455	0.105	0	0.337	0	4.637
	(m)	0.205	0.195	0.212	0.187	0.190	0.173	0.167	0.182	0.193	0.199	0.182	0.189	2.274
T.	(mcm)	0.054	0.047	0.040	0.041	0.042	0.036	0.032	0.056	0.068	0.066	0.050	0.050	0.582
ge Loss	(mcm)	0.005	0.005	0.004	0.004	0.004	0.004	0.003	0.006	0.006	0.006	0.005	0.005	0.057
	(mcm)	0.288	0.288	0.288	0.288	0.288	0.288	0.288	0.288	0.288	0.288	0.288	0.288	3.456
se	(lps)	112	112	112	112	112	112	112	112	112	112	112	112	
ge	(mcm)	0.487	0.147	0.574	0.578	0.328	0	1.237	1.800	1.543	1.183	1.177	0.834	
ge	(mcm)	0	0	0	0	0	0	0	0.542	0	0	0	0	0.542

* Based on the streamflow data of 1960

TABLE 3 RESERVOIR OPERATION STUDY - CASE II

ription	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
w *	(mcm)	0	0	0.759	0.337	0.084	0	1.560	1.455	0.105	0	0.337	0	4.637
T.	m	0.205	0.195	0.212	0.187	0.190	0.173	0.167	0.182	0.193	0.199	0.182	0.189	2.274
	mcm	0.055	0.053	0.055	0.050	0.046	0.033	0.032	0.053	0.068	0.060	0.049	0.057	0.611
age Loss	mcm	0.006	0.005	0.006	0.005	0.005	0.003	0.003	0.005	0.007	0.006	0.005	0.006	0.062
ase	mcm	0	0.236	0.582	0.582	0.582	0	0.582	0.582	0.582	0.236	0	0	0.396
	lps	0	225	225	225	225	0	225	225	225	225	0	0	
ge	mcm	1.063	0.769	0.885	0.585	0.036	0	0.943	1.758	1.206	0.904	1.187	1.124	
age	mcm	0	0	0	0	0	0	0	0	0	0	0	0	0

* Based on the streamflow data of 1960

TABLE 4 RESERVOIR OPERATION STUDY - CASE III

ription	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
w *	mcm	0	0	0.021	0.696	0.063	1.328	1.602	0.738	0.822	0.148	0	0	5.418
T.	m	0.205	0.195	0.212	0.187	0.190	0.173	0.167	0.182	0.193	0.199	0.182	0.189	2.274
	mcm	0.070	0.060	0.053	0.037	0.039	0.033	0.041	0.060	0.065	0.072	0.066	0.064	0.660
ge Loss	mcm	0.007	0.006	0.005	0.004	0.004	0.003	0.004	0.006	0.007	0.007	0.007	0.006	0.066
se	mcm	0.250	0.600	0.600	0.600	0	0.600	0.600	0.600	0.250	0	0	0	4.100
	lps	231	231	231	231	0	231	231	231	231	0	0	0	
ge	mcm	1.267	0.601	0.009	0.064	0.084	0.783	1.733	1.800	1.800	1.800	1.664	1.594	
ge	mcm	0	0	0	0	0	0	0	0.005	0.500	0.069	0	0	0.574

* Based on the streamflow data of 1948

It is estimated that construction of the Chemeron Dam and Spillway would cost in the order of U.S. $ 720,000, as summarized in Table 5. On the basis of an active storage pool of 1.8 million cubic meters, this would mean a cost of U.S.$ 0.40 per cubic meter of storage, a very high figure. As noted above under the heading, Provisional Reservoir Operation Studies, the most optimum release schedule would ensure double cropping on only about 200 hectares of land; thus, the order-of-magnitude of storage costs alone would amount to roughly U.S.$ 3,600 per developed hectare, or U.S. $ 1,800 per annually cropped hectare. On top of the capital cost of storage would have to be added the following capital costs: (1) transmitting the water from Chemeron Dam to the irrigated area; (2) irrigation distribution system; and (3) drainage system.

While it appears that construction of a dam and spillway on the Chemeron River is technically viable, which fact and actual cost estimates can only be determined after detailed site topography and exploratory drilling and test pit program are carried out, it is very doubtful that such a project would be economically feasible.

TABLE 5
ORDER-OF-MAGNITUDE COST ESTIMATE
CHEMERON DAM AND SPILLWAY

Item	Unit	Quantity	Cost (U.S.$)
Clearing	LS	-	3,000
Excavation			
Common	m^3	12,000	24,000
Rock (trench)	m^3	800	18,000
Rock (blasted)	m^3	3,000	30,000
Fill			
Rock	m^3	42,000	126,000
Random	m^3	34,000	119,000
Core & Transition	m^3	20,000	100,000
Outlet Works	LS	-	20,000
Spillway	LS	-	250,000
Access Road	LS	-	30,000
		Total	720,000

CONCLUSIONS AND RECOMMENDATION

On the basis of the findings summarized in the preceding sections of this report, the following conclusions and recommendation are made.

Conclusions

1. The mean annual rainfall in the vicinity of the area which would be irrigated is about 600 millimeters.

2. Potential evapotranspiration in the vicinity of the reservoir area is nearly 2.3 meters per year.

3. The amount of annual surface water runoff from the Chemeron River Basin is in the order of 4.64 million cubic meters 75 percent of the time (three years out of four).

4. The probable maximum flood at the Chemeron damsite is approximately 480 cubic meters per second.

5. The Chemeron Gorge is cut into hard volcanic rocks that would provide the foundation of the main parts of the dam. The principal volcanic unit is a massive lava flow with very low permeability and high competence in bearing, but the same properties of a lower "agglomeratic" unit are questionable. Blasting would be needed for rock excavation.

6. Spillway excavation would be in common material.

7. The reservoir area is formed of relatively impermeable sediments; therefore, leakage would probably not be a problem. The floor of the reservoir area is thinly veneered with gravels that may perhaps contain a perched body of ground water.

8. Materials for the dam's prism would be available within a half kilometer of the site. Sand and fine gravel for making concrete should also be available but washing and screening facilities may be required.

9. Adequate subsurface exploration would require 20 diamond-drill holes, having a total depth of about 410 meters, and 20 hand-dug pits totalling about 60 meters.

10. A prominent fault at the entrance to the gorge is considered to be inactive and imposes no seismic hazard to the dam.

11. A series of faults some two kilometers east of the site must be considered as being active. However, regional seismicity is relatively low and no unsolvable design problems are foreseen.

12. A zoned, earth/rock fill embankment dam with side channel spillway is the most economic means of storing adequate water.

13. The dam and spillway could be built in six to eight months without providing costly diversion works so long as sufficient heavy equipment is provided and mobilization and material stockpiling are completed prior to the construction period.

14. Some watershed stabilization works, e.g. check dams upstream from the reservoir on both main stem and tributaries, would be required, otherwise the reservoir could silt up within four to six years.

15. A dam with maximum height of about 29 meters above the bed of the Chemeron Gorge would provide operating storage of some 1.8 million cubic meters which could effect essentially complete regulation of the 75 percent probability runoff (net 4.0 million cubic meters after deducting evaporation and seepage losses).

16. The regulation noted in 15., above, would be adequate to irrigate roughly 200 hectares under double cropping or 400 hectares under single cropping.

17. The cost of constructing the Chemeron Dam and Spillway would be roughly in the order of U.S. $ 720,000.

18. While a dam appears to be technically viable, the abnormally high cost of storage, due to low and erratic streamflow, is indicative that an irrigated agriculture development with the Chemeron River as a source would not be economically feasible.

Recommendation

In view of the foregoing conclusions and the apparent negative economic feasibility of the project, it is recommended that no further studies be carried out on the Chemeron River.

Viability of the Chemeron Dam

Phase I

Preliminary Reconnaissance

APPENDIX A

TERMS OF REFERENCE

SCHEDULE

ARTICLE I - STATEMENT OF WORK

A. OBJECTIVE

With a very limited time frame, make a provisional estimate of the viability of the Chemeron Dam. Specifically: determine whether further studies are justified.

This objective will be approached in two phases, of which only the first is outlined herein:

PHASE 1: PRELIMINARY RECONNAISSANCE
PHASE 2: FURTHER STUDIES

B. SCOPE OF WORK

Step 1: Assemble the readily available data

Working in Nairobi, collect as much of the following as possible:

a) Maps

b) Rainfall and runoff records

c) Location of the damsite

d) Delineation of the drainage area

e) Geological information

Step 2: Field Inspection

Limited to 1 to 2 days in the field (including travel time) assess the following:

a) Inspection of axis pointed out to the Consultant in the field by a qualified member of REDSO/Nairobi;

b) Visual axis geology, including a qualitative assessment of the holding characteristics;

c) Availability of a natural spillway;

d) Comments on possible availability of construction materials;

e) Hydrologic characteristics of the basin and of the flow regime.

Step 3: Studies and Conclusions

The studies will consist of:

a) A preliminary review of hydrological data, including available rainfall and runoff information, the rainfall/runoff relation, synthetic runoff data, mass curve of available flow, annual and monthly frequency analyses, and the relation between storage and normal pool elevation;

b) A preliminary review of geological data, including qualitative assessments of the suitability of the axis and the reservoir, the availability of construction materials, and recommendations for exploratory drilling, as permitted by available information in Nairobi;

c) Provisional reservoir operation studies giving indicative monthly water releases;

d) Order-of-magnitude cost estimates to enable preparation of a preliminary cost vs. storage curve; and

e) Conclusions and recommendations.

Viability of the Chemeron Dam

Phase I

Preliminary Reconnaissance

APPENDIX B
HYDROLOGY

APPENDIX B

HYDROLOGY

This is a brief presentation of the detailed procedures used in estimation of storm runoff and the probable maximum flood.

Storm Runoff

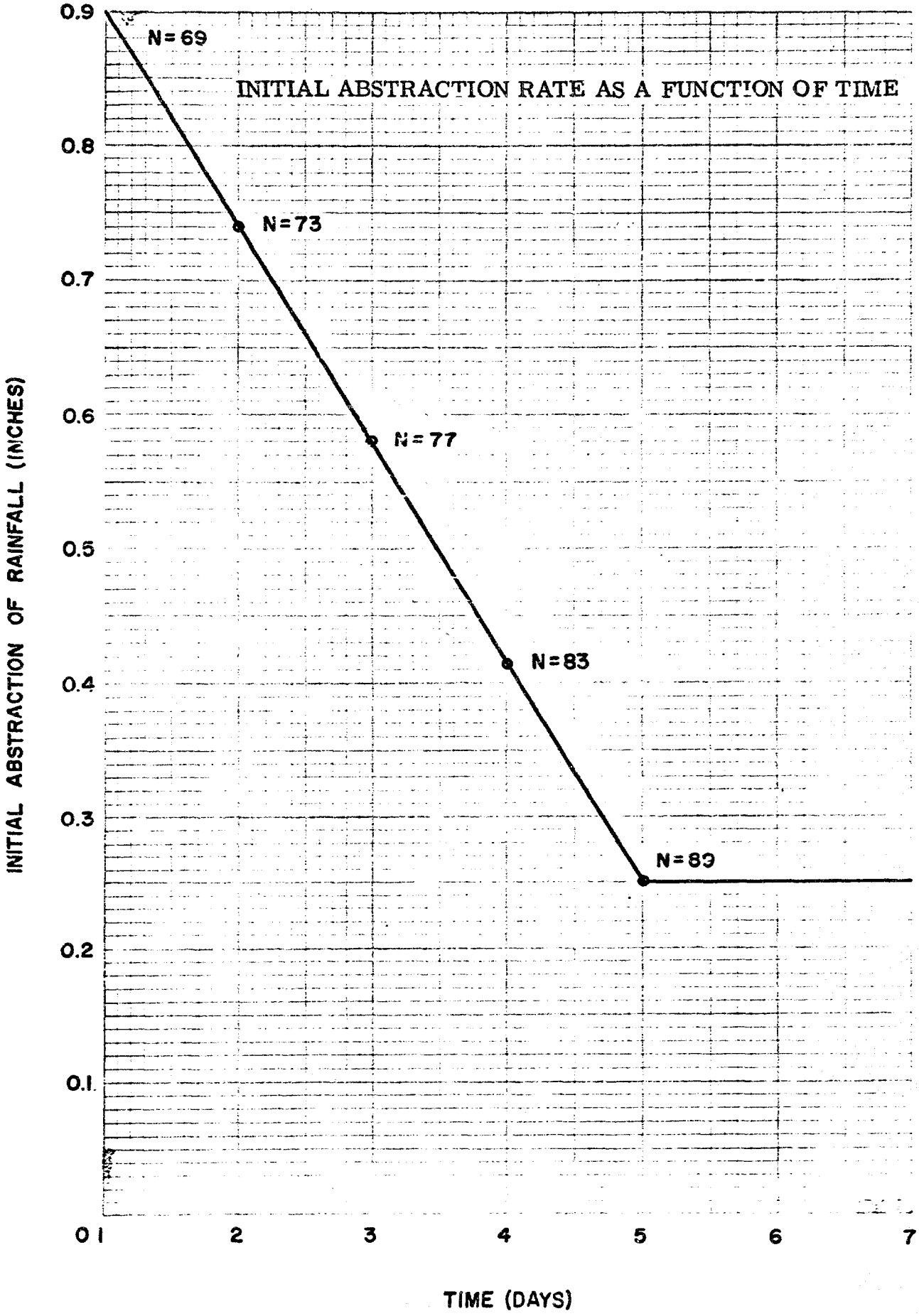
The method used in estimation of storm runoff is that developed by the U.S. Soil Conservation Service. The basic equation of this method is:

$$Q = \frac{[P-2(100-N)/N]^2}{P+8(100-N)/N}$$

where Q is storm runoff in inches, P is storm rainfall in inches, and N is the runoff curve number which is a function of land use, soil cover and vegetation density. As the soils in the Chemeron Basin have a moderate rate of water transmission and the range land has approximately 70 percent of the area with plant cover, the runoff curve number was estimated to be 69.

The runoff curve number is also a function of the antecedent soil moisture condition of the watershed. The curve number for wet antecedent moisture condition is greater than that for dry condition because the initial abstraction rate decreases with the increase of soil moisture content. In this study, the runoff curve numbers were adjusted according to the initial abstraction rate, as shown on Figure B1. The group of curves used for estimating runoff volumes are shown on Figure B2.

As mentioned previously, rainfall records collected at Kabarnet (Sta. 89.35020) and Hot Spring Dispensary (Sta. 89.36026) were used for the estimation of storm runoff. In view of the isohyetal pattern, rainfall characteristics on the eastern two-thirds of the drainage basin may be represented by the station at Hot Spring Dispensary; and rainfall characteristics on the western one-third may be represented by the station at Kabarnet. Runoff was estimated according to the rainfall records at each station. The weighted value was considered to be the total runoff from the drainage basin.


INITIAL ABSTRACTION RATE AS A FUNCTION OF TIME
N=69
N=73
N=77
N=83
N=89
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
INITIAL ABSTRACTION OF RAINFALL (INCHES)
TIME (DAYS)

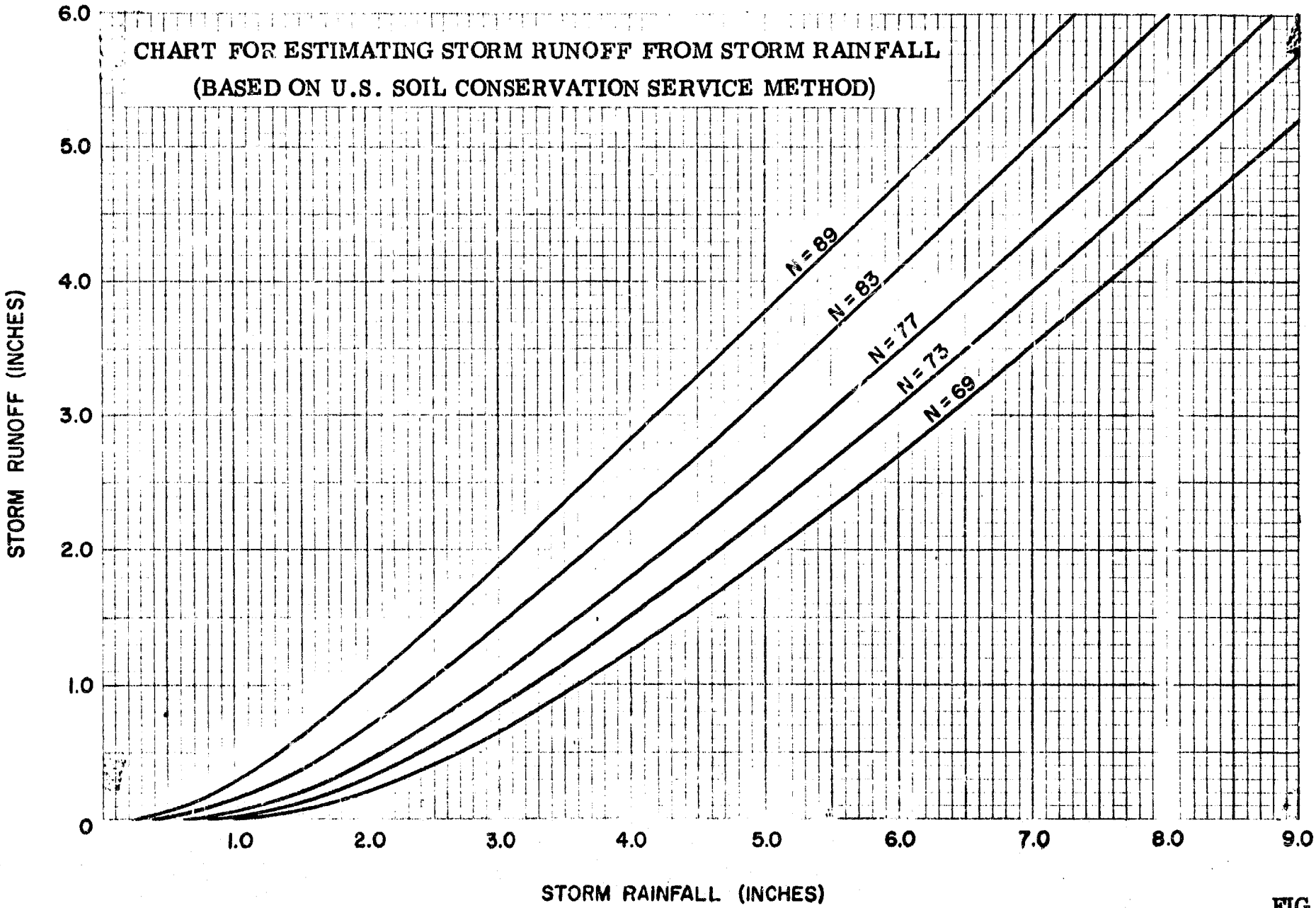


CHART FOR ESTIMATING STORM RUNOFF FROM STORM RAINFALL
(BASED ON U.S. SOIL CONSERVATION SERVICE METHOD)
N = 89
N = 83
N = 77
N = 73
N = 69
STORM RUNOFF (INCHES)
6.0
5.0
4.0
3.0
2.0
1.0
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
STORM RAINFALL (INCHES)

FIG. B2

Maximum Probable Flood

As noted under the report section on CLIMATOLOGY AND HYDROLOGY, the probable maximum flood (PMF) was derived from the probable maximum precipitation (PMP). The PMP estimated by the East African Meteorological Department for inland areas of Kenya is shown on Figure B3. The 6-hour PMP at an elevation of 4000 feet above sea level was estimated to be 275 millimeters. The synthetic unit hydrograph was then constructed according to the following basic equations developed by Linsley, Kohler and Paulhus:

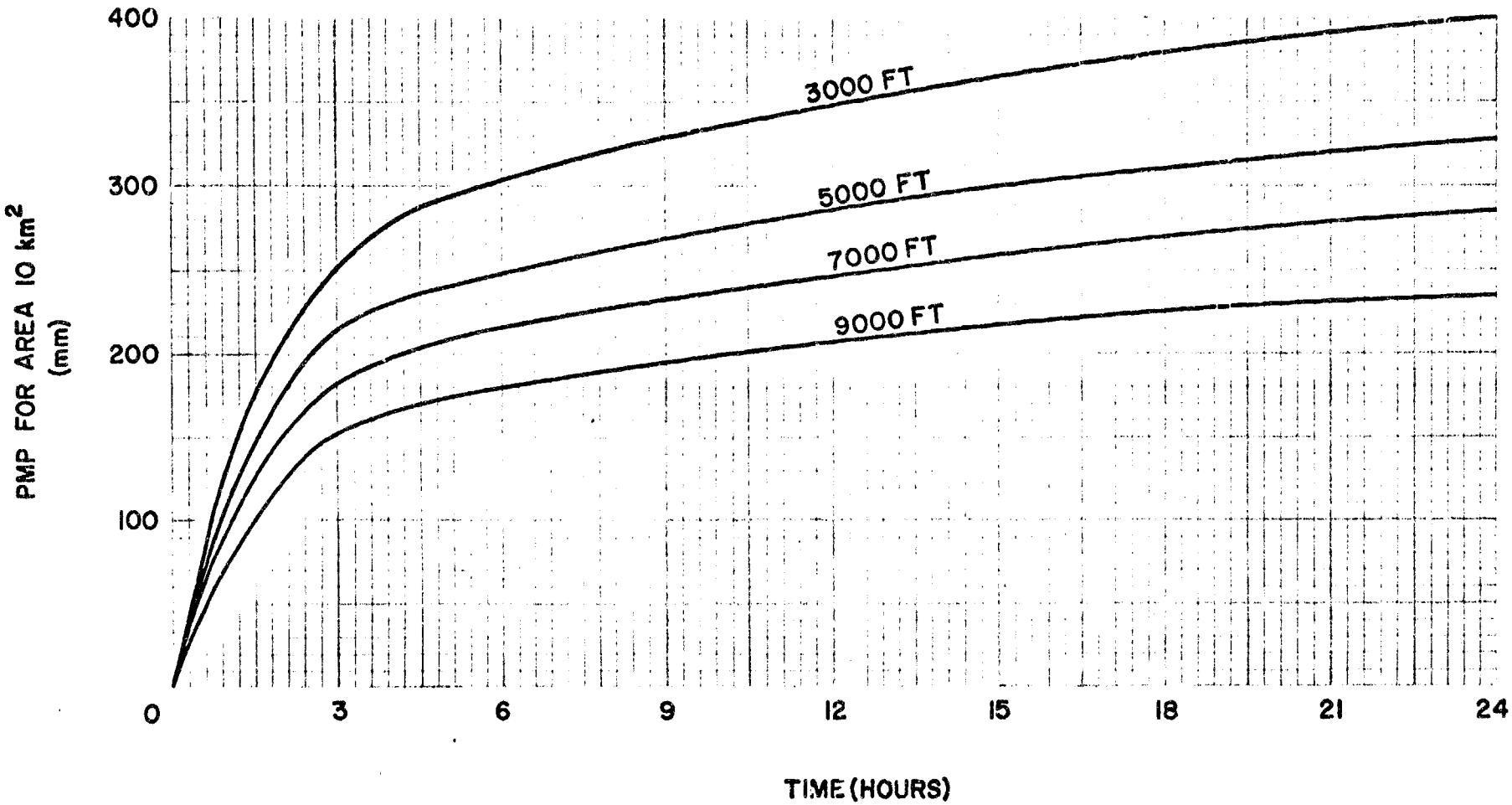
$$t_p = \frac{C_t (L L_c)^{0.38}}{S^{0.5}}$$

and

$$q_p = \frac{640\ C_p}{t_p}$$

where tp is the lag time from midpoint of effective rainfall duration to peak of a unit hydrograph; L is the stream mileage from the damsite to the upstream limits of the drainage basin; Lc is the stream mileage from the damsite to the center of gravity of the drainage basin; S is the basin slope; qp is the peak discharge of the unit hydrograph; and Ct and C_p are coefficients. Some of the notations are illustrated on Figure B4. The peak discharge of the 1-hour unit hydrograph was estimated to be 47.7 cubic meters per second, as shown on Figure B5.

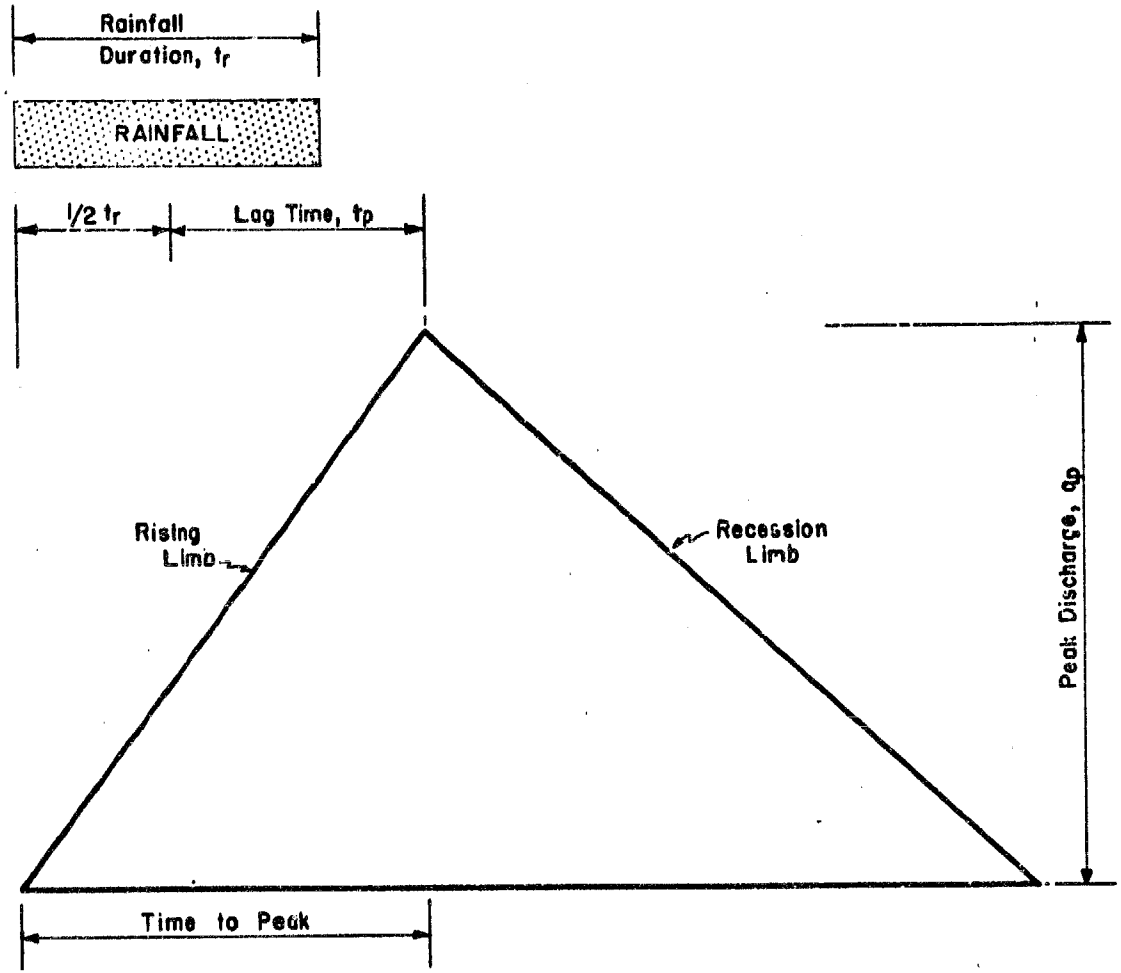
With the PMP and the unit hydrograph, the PMF into the reservoir was estimated to be 495 cubic meters per second.



PROBABLE MAXIMUM PRECIPITATION (PMP) IN INLAND AREAS OF EAST AFRICA

(Based on the East African Meteorological Department Publication Titled, "Probable Maximum Precipitation in East Africa for Duration up to 24 Hours").

FIG. B3



VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE

SCHEMATIC DIAGRAM FOR A SYNTHETIC UNIT HYDROGRAPH

FIG. B4

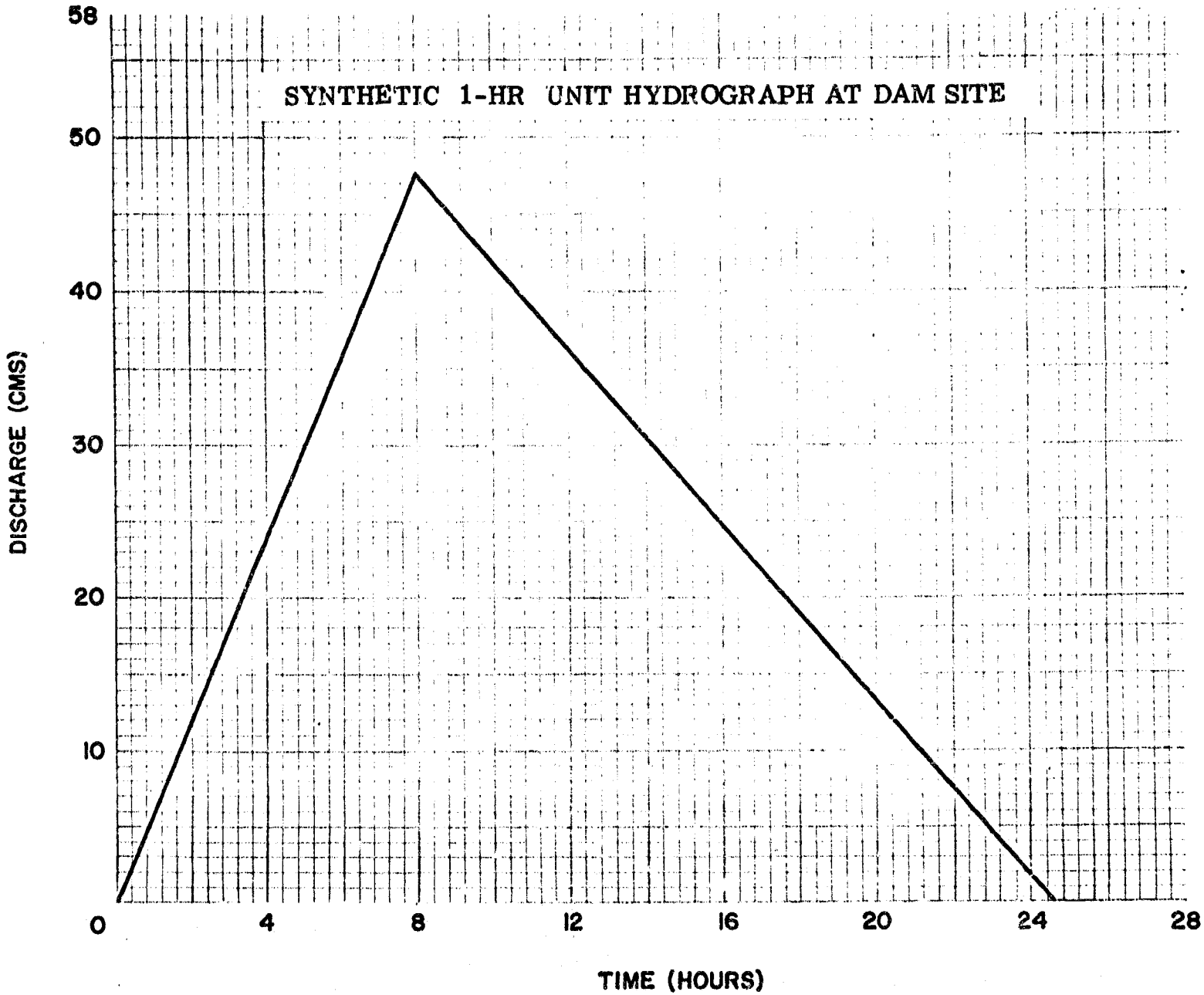
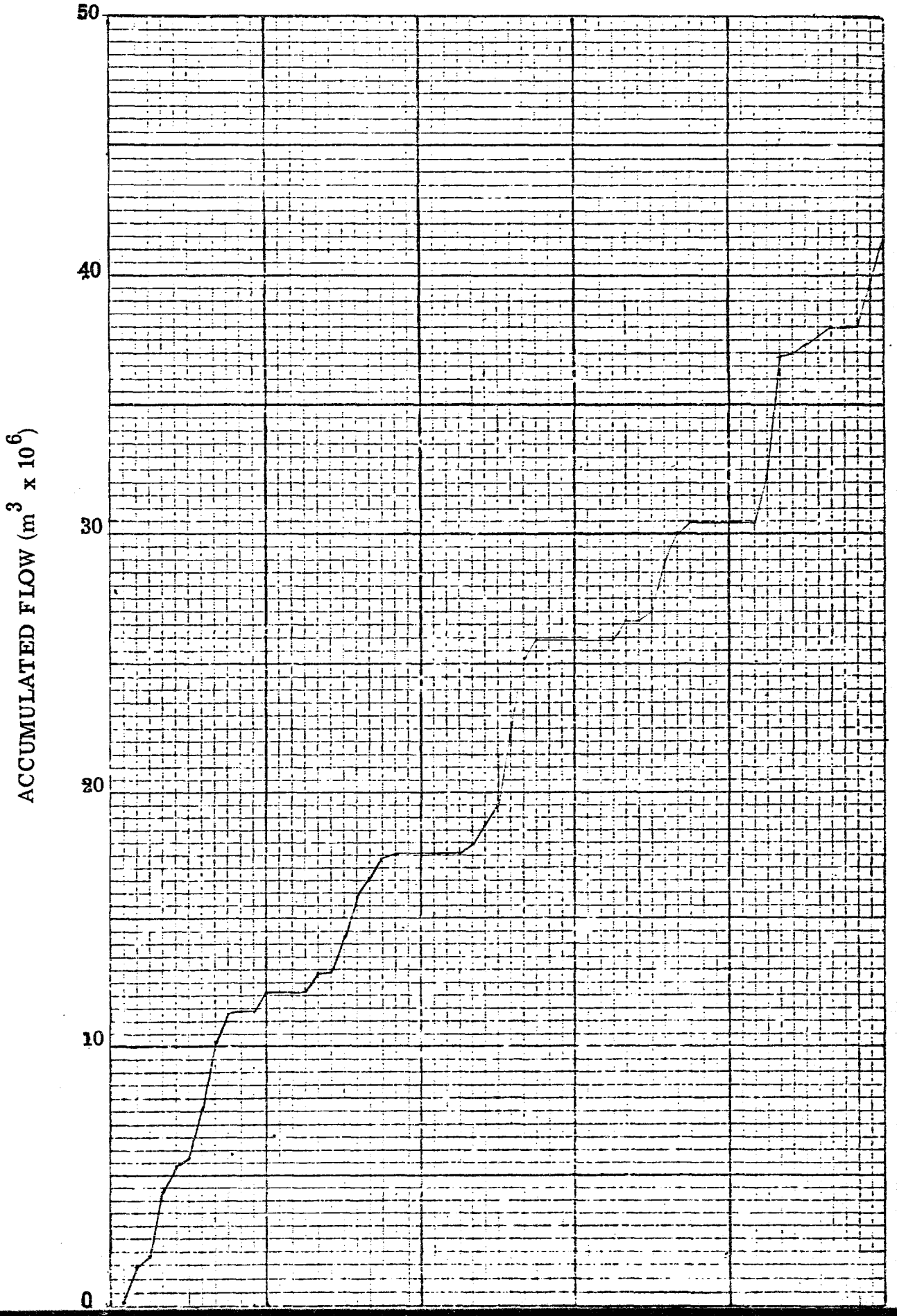
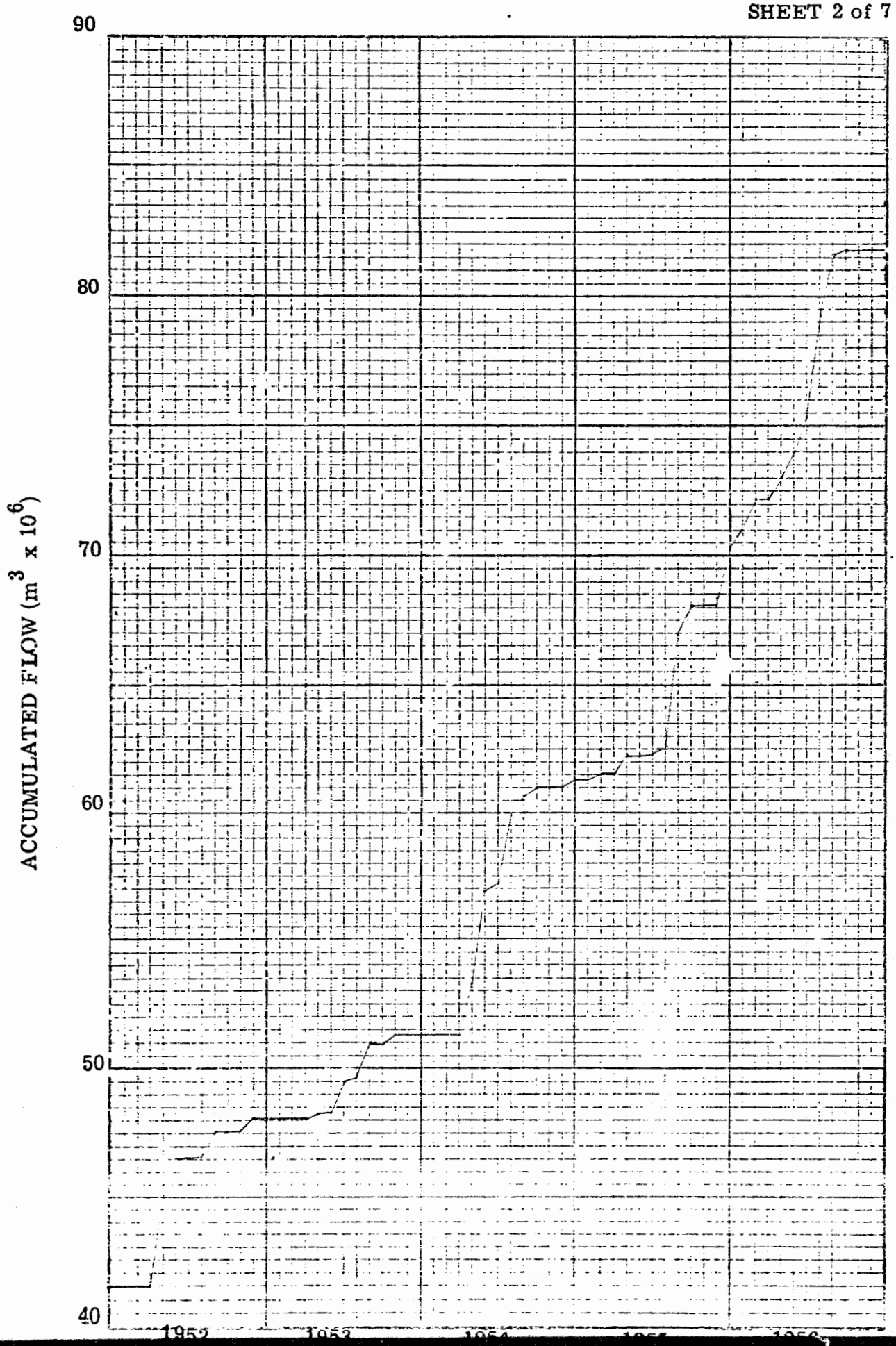
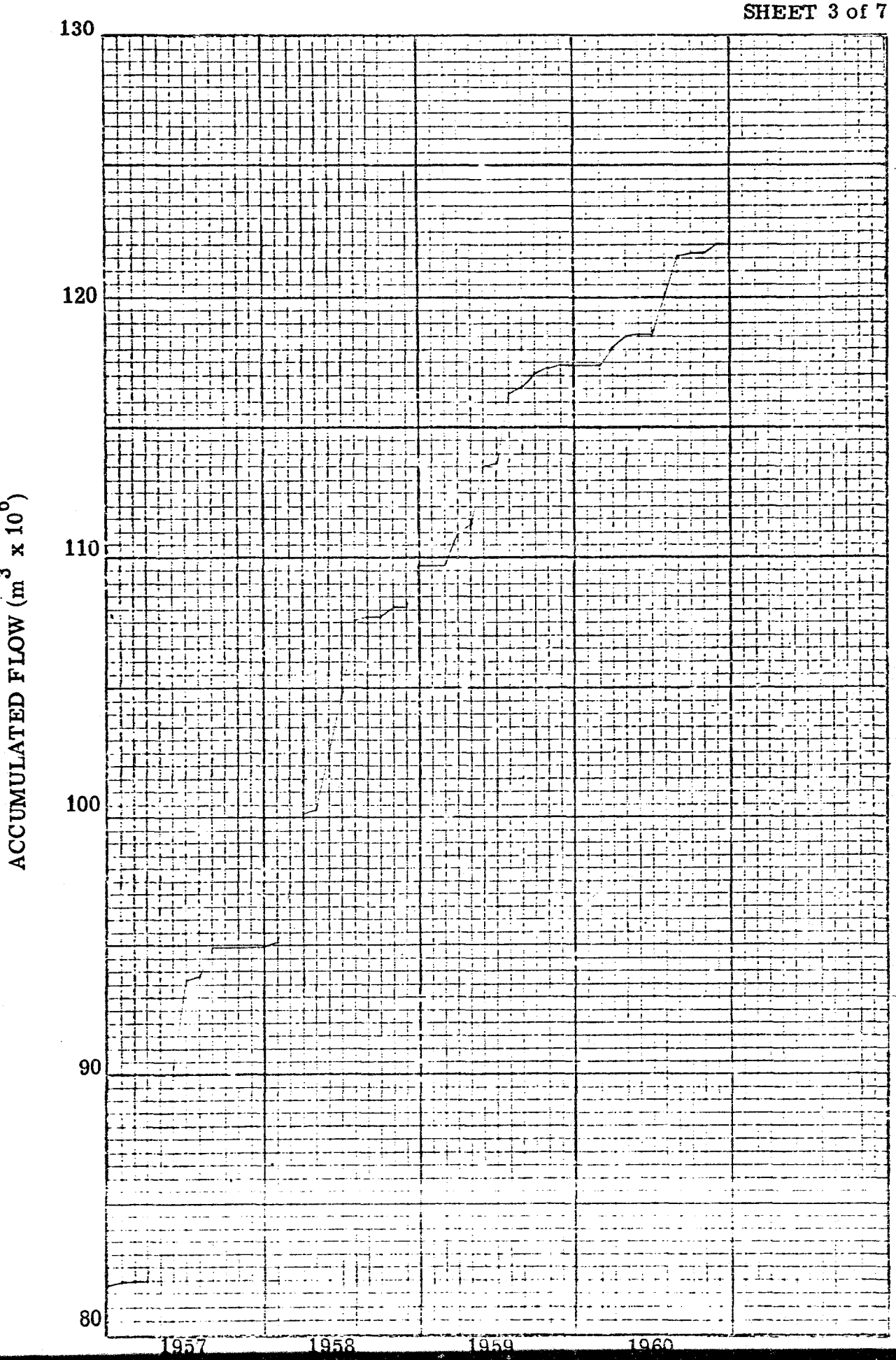
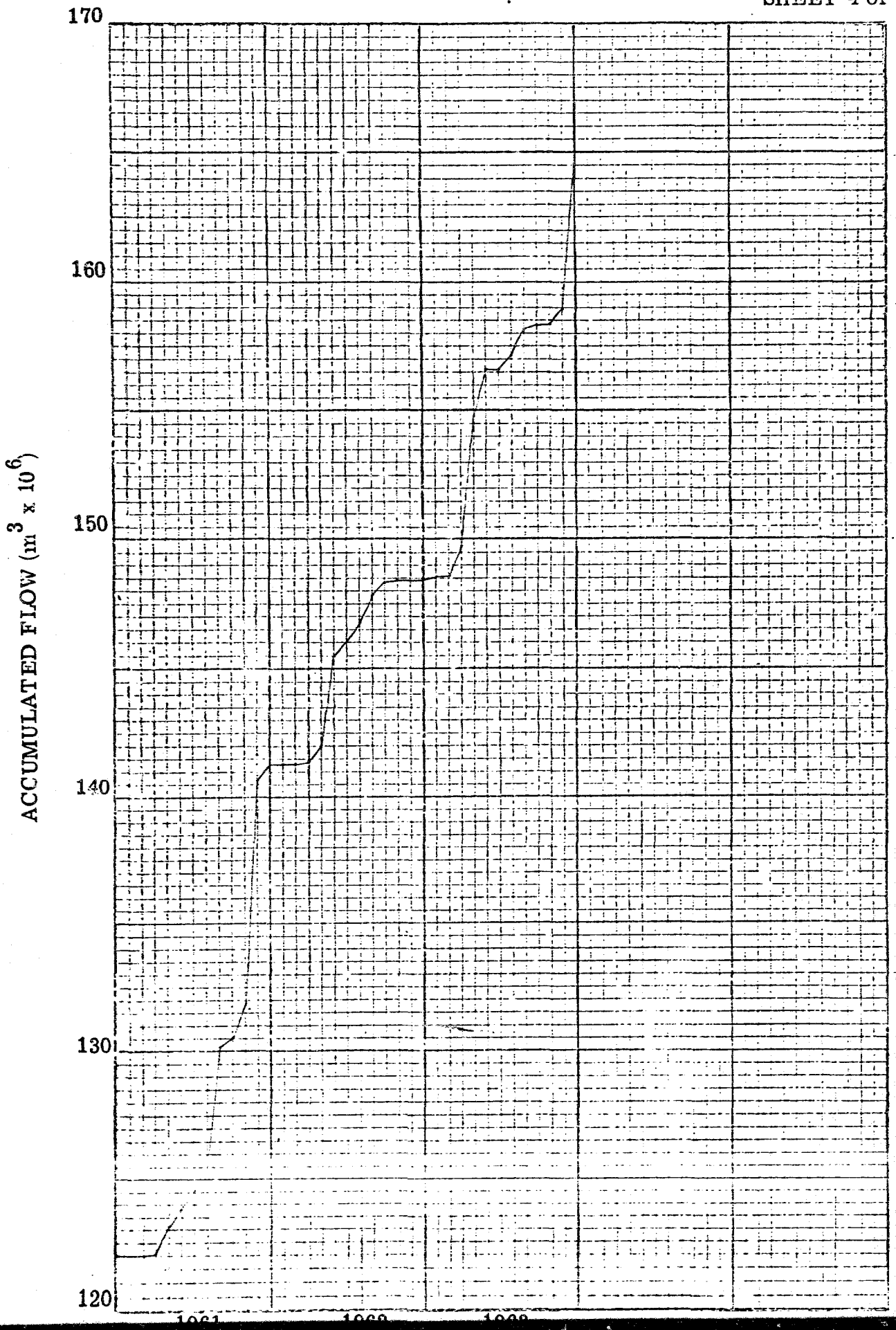

SYNTHETIC 1-HR UNIT HYDROGRAPH AT DAM SITE
DISCHARGE (CMS)
58
50
40
30
20
10
0
4
8
12
16
20
24
28
TIME (HOURS)

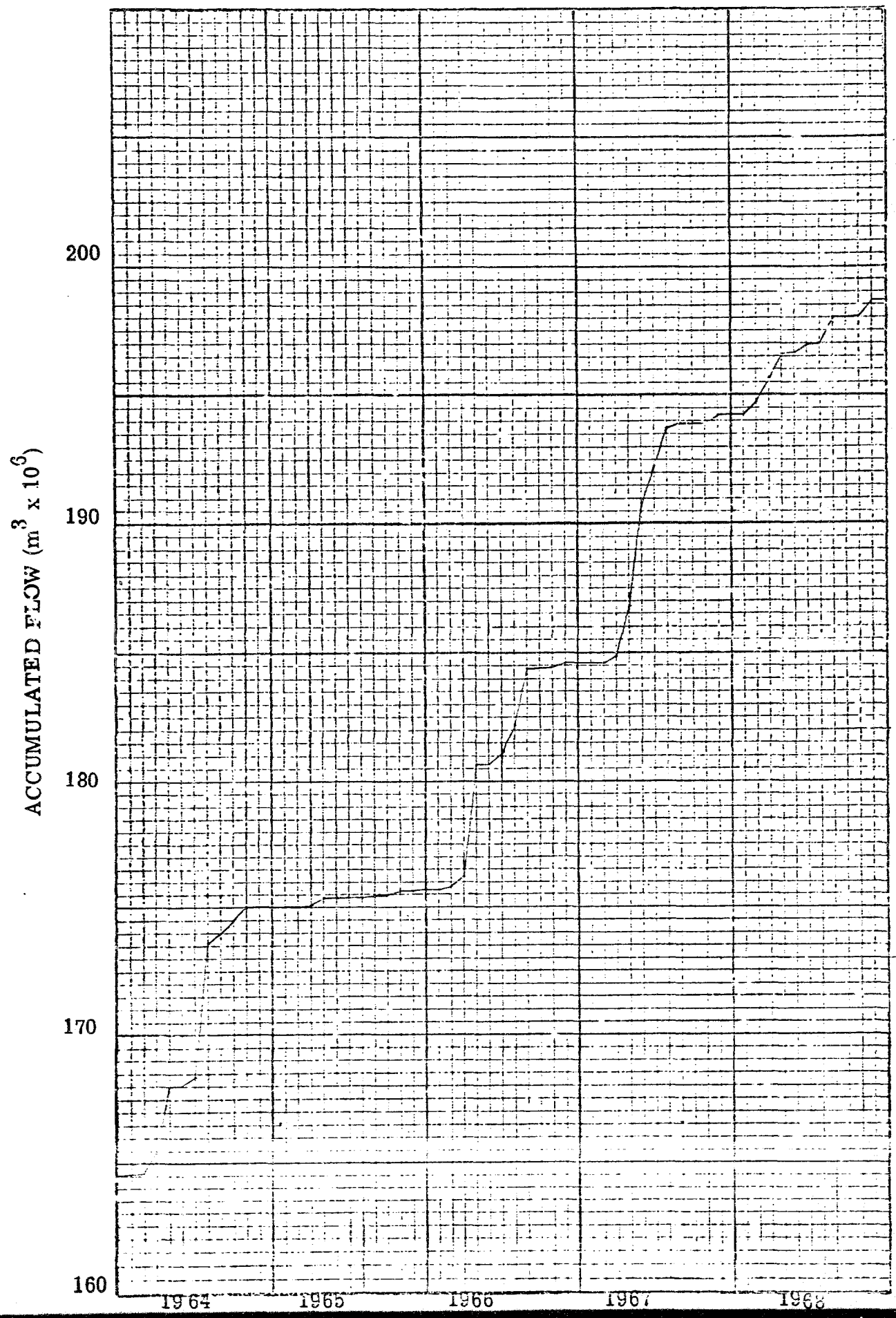
FIG. B5

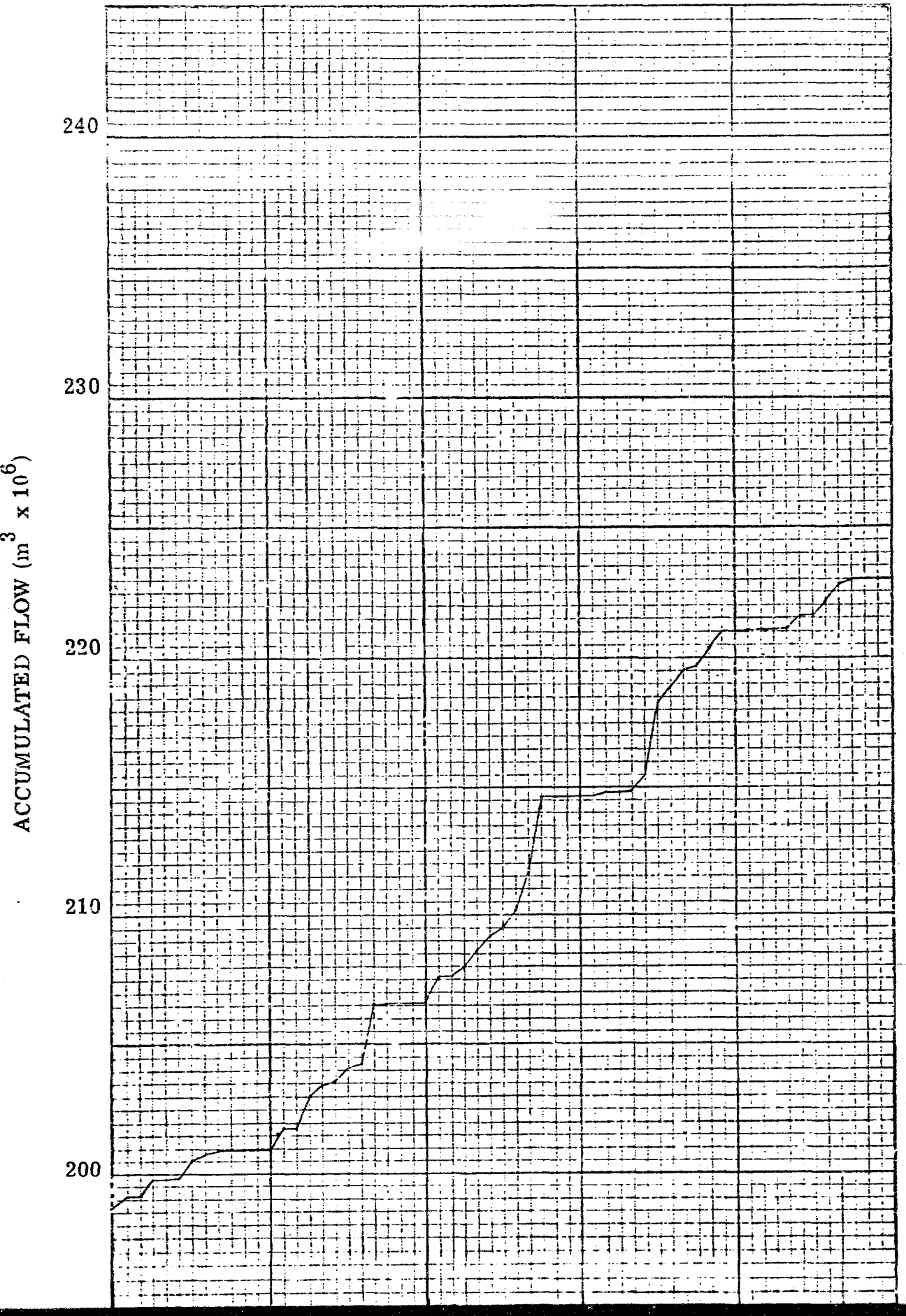

50
40
30
20
10
0
ACCUMULATED FLOW ($m^3 \times 10^6$)

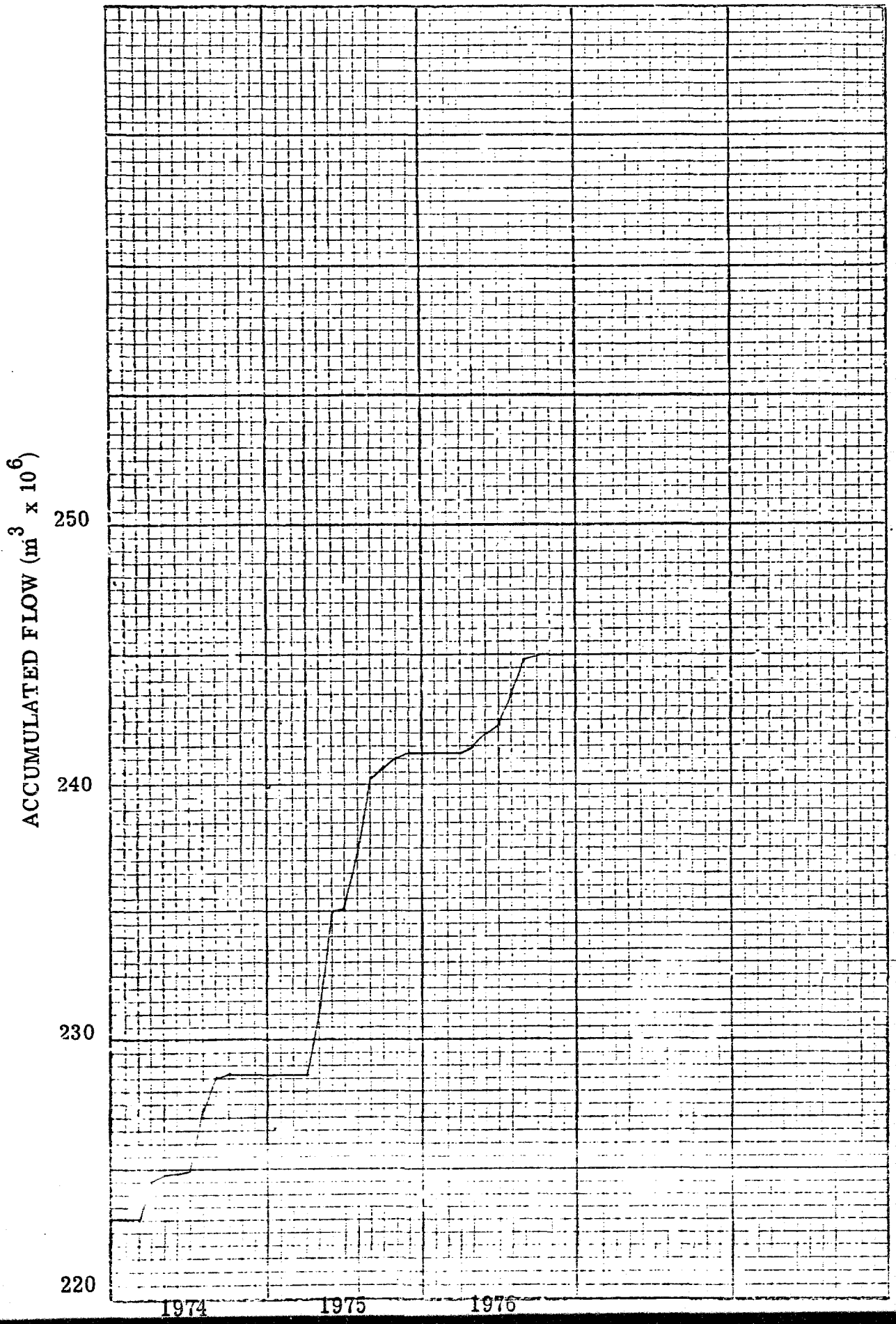

90
80
70
60
50
40
ACCUMULATED FLOW ($m^3 \times 10^6$)
1952
1954


130
120
110
100
90
80
ACCUMULATED FLOW ($m^3 \times 10^6$)
1957
1958
1959
1960


170
160
150
140
130
120
ACCUMULATED FLOW ($m^3 \times 10^6$)
1961
1962
1963


ACCUMULATED FLOW ($m^3 \times 10^6$)
200
190
180
170
160
1964
1965
1966
1967
1968


240
230
220
210
200
ACCUMULATED FLOW ($m^3 \times 10^6$)


ACCUMULATED FLOW ($m^3 \times 10^6$)
250
240
230
220
1974
1975
1976

Viability of the Chemeron Dam

Phase I

Preliminary Reconnaissance

APPENDIX C

GEOLOGICAL NOTES

APPENDIX C

GEOLOGICAL NOTES

1. Previous Work

V.E. Fuchs (1950, Pleistocene events in the Baringo basin, Kenya Colony: Geol. Mag. 87, 149-174) described the Kapthurin beds; his work was not examined in our study. J. Walsh (1969, Geology of the Eldama Ravine - Kabarnet area: Geol. Surv. of Kenya, Rep. 78) and G.J.H. McCall restudied and renamed the Kapthurin sequence, divided it into two and reported on the Chemeron River exposures (Wash, op.cit., pp. 27-29). In this current study, we have followed Walsh's nomenclature.

2. The Phonolite

Walsh refers to the rocks in the Chemeron Gorge as phonolites, apparently correlating them with the Lake Hannington phonolites that he mapped west of Marigot, only a few kilometers from the damsite. Under the hand lens, however, we do not see any feldspathoid minerals (diagnostic of phonolites) and suggest that this rock may actually be a trachyte. The difference is important to petrologists but not to dam designers.

3. The "Agglomerate"

Our geological studies at the site lasted only a few hours and, as a result, we were unable to gain an adequate understanding of the nature of the rock type of the upper and lower volcanic units in the gorge, or of the relation between the upper unit and the massive phonolitic flow. The term "agglomerate" is used in a physical sense because the unit structurally resembles the basaltic agglomerates so common in the geologic record: that is, it "looks like" an agglomeratic accumulation or mud flow of phonolitic (trachytic?) composition. However, its blocky structure could perhaps result from boudinage or might even be a weathering manifestation. Further, the extreme irregularity of the contact between the upper "agglomerate" and the massive phonolite suggests that the former was emplaced as a mud flow that plowed its way across a still pasty floor; however, in places, the contact appears to be gradational! These matters may effect foundation treatment and must be resolved in any future studies of the damsite.

4. The Kapthurin Beds

Walsh (op. cit., p. 27-28) indicates that " ...bouldery torrent-wash ..." is the major local constituent of the Kapthurin beds and that tuffs are quite common. We found clays and silts predominating over gravels and we did not positively identify any tuffs near the damsite. However, we did not climb any cliffs in order to study the sequence bed by bed and thus we recognize that Walsh's lithology may be more accurate than ours.

5. The Chemeron Gorge Fault and Underflow

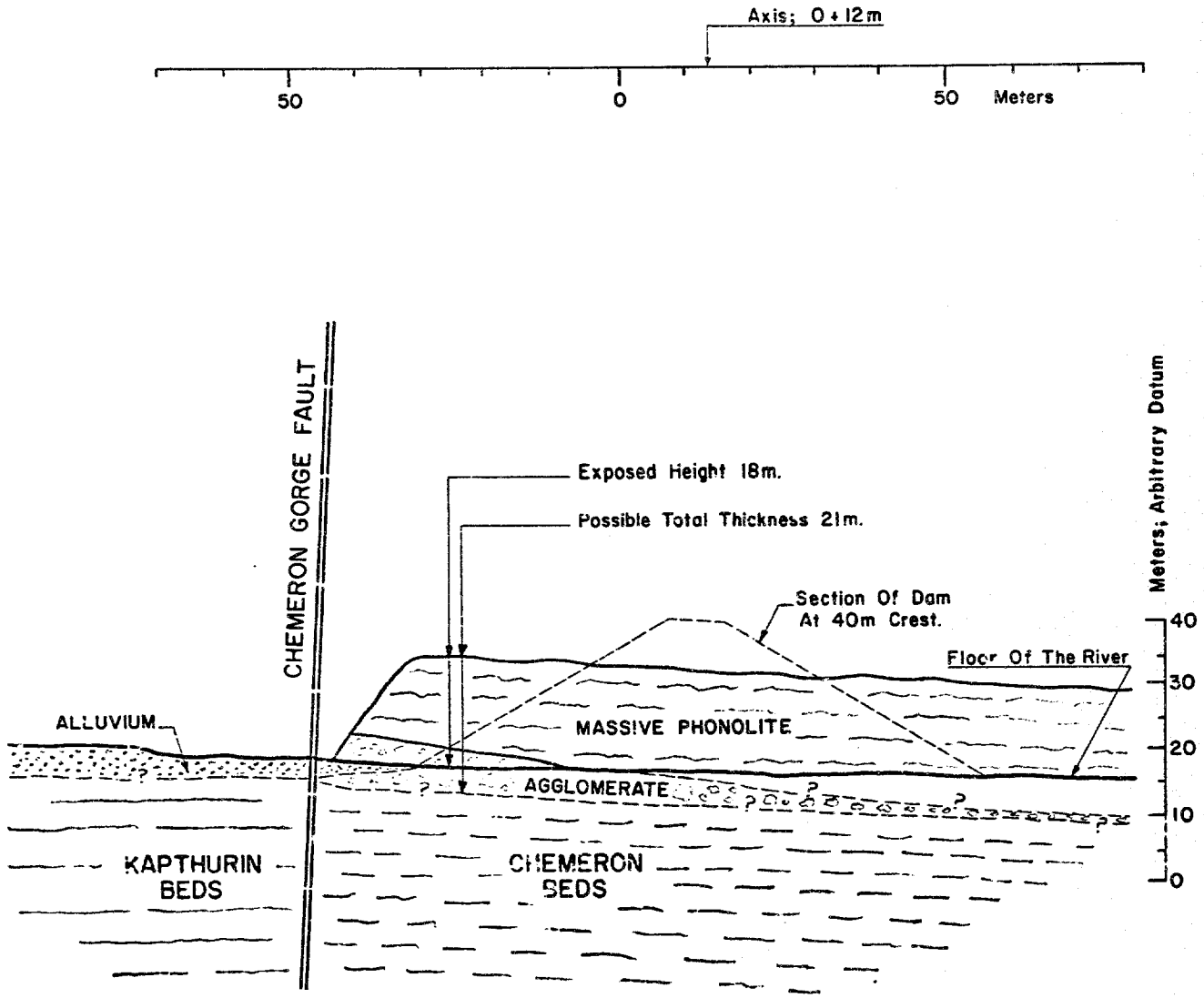
If a dam is constructed in the gorge, what will be the influence of the fault on ground-water underflow? This is an important problem that will need resolution, yet our scope of work was so limited that we gathered no evidence on the matter.

Walsh found lavas in the Chemeron canyon about three kilometers above the gorge that he assigned to the Lake Hannington phonolites and stated that they are "...the same lava as that in.... gorge" (op. cit., p. 27-28). He further stated that they are about 21 meters thick and overlie at least 40 meters of his so-called "Chemeron beds", a series of thinly bedded clayey silts, tuffs and diatomites of apparently low permeability. Should the same lava thickness and geological relations prevail at the gorge, we can estimate the subsurface geological conditions at the damsite. A first approximation is presented in Figure C-1 that is based on an exposed thickness of 13 meters versus a possible total thickness of 21 meters. If the conditions of Figure C-1 actually occur:

1. the depth of the volcanics below the axis would be about five meters and an efficient cut-off curtain could be constructed into the underlying Chemeron beds without great difficulty; and

2. the faulting would place Chemeron beds in contact with those of the Kapthurin in the subsurface. As both are relatively impermeable, ground-water seepage under the dam should be negligible .

Note that these conclusions and the conditions presented on Figure C-1 are based on the unlikely event that the lava's thickness is maintained for a distance of about three kilometers. A different condition is illustrated on Figure 4.



SKETCH OF THE NORTH WALL OF THE GORGE

Illustrating possible subsurface conditions

if the volcanics are 21 m. thick

Note: The horizontal and vertical scales are the same

VIABILITY OF THE CHEMERON DAM

PHASE I

PRELIMINARY RECONNAISSANCE