AN INVESTIGATION INTO THE EFFECTS OF CHANGES IN LAND USE ON RUNOFF AND SEDIMENT TRANSPORT RATES FROM THE TURASHA CATCHMENT, KENYA.

BY

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any other University.

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This Thesis has been submitted for examination with my approval as the University Supervisor.

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ABBREVIATIONS AND SYMBOLS

E.A.A.F.R.O.-East African Agroforestry Research Organisation

E.A.M.D. -East African Meteorological Department

C.D.C. -Commonwealth Development Corporation

H.M.G. -Her Majesty's Government

I.B.R.D. -International Bank for Reconstruction and Development

I.T.C.Z. -Inter-Tropical Convergence Zone

M.a.s.l. -Metres above sea level

Mg/l -Miligrams per litre

M.O.W.D. -Ministry of Water Development

T.D.S. -Total dissolved solids

W.H.O. -World Health Organisation

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ABSTRACT

This study was conducted in the Turasha catchment in Nyandarua District,Kenya. The study traces the land use changes between the large scale farming practised by the white settlers prior to independence and subsequent small scale farming practiced by peasant African farmers after independence. The trends in land use are then related to trends in runnoff and downstream sediment loads from the cathment taking into account the possibility of climatic change. The study furnishes information which shows the undesirable hydrological consequences caused by unplanned settlement. The study therefore furnishes information useful for the formulation of land use planning policies and conservation measures for the catchment.

Land use types were delineated stereoscopically and visually on remote sensing pictures to determine their spatial trend between 1962 and 1988. Similarly, annual suspended sediment loads were estimated to determine their trend between the same period. Long term discharge data recorded at the outlet of the catchment were subjected to Time Series Analysis to yield their trend over the study period. Annual peak flow events were applied to the Gumbel and Log Pearson Type III statistical models to reveal their trend.

A linear multiple regression model was fitted to relate sediment load, as the independent variable, and the area covered by the various land use types as the dependent variables.

It was observed during the study period that the area under grassland decreased by 34% while the forest area went down 4%. Both the area under arable and mixed farming increased by 31%. The annual suspended sediment load showed an upward trend being

12,118 tonnes at the beginning and 307,960 tonnes at the end of the study period.

Time series analysis of the discharge data showed random variation. The Gumbel and Log Pearson Type III analysis of flood frequency revealed floods depressed by a factor of 1.8 in more recent years.

Multiple regression analysis between suspended load and area of land use types showed that both grassland and arable area play equally dominant but counteractive roles in generating sediments. While arable area tends to increase their production, the grassland area appears to perform a conservation role and hence a retardation in their production.

CHAPTER 1:INTRODUCTION

1.0 INTRODUCTION

Rapid population increase is a familiar problem especially in the least developed countries, Kenya included. One consequence of high population pressure is that it results in agriculturally favourable land being over exploited with the consequent desiccation in the environment. High Population pressure in turn leads to people occupying whatever land is available including steeply sloping land and other hitherto unused and often environmentally delicate areas. Most favoured among these are the highland areas usually endowed with fertile soils, favourable climate and forestry resources among other natural and human resources.

The study area forms part of the former White Highlands which prior to independence were exclusively for the colonial white settlers. The white Highlands in general comprise the most important high altitude farming areas of Kenya and contain the main national forest reserves.

European agricultural settlement started in 1902 and increased rather significantly during the first world war. By the end of the war there was close to 1,122 white settles farming the entire White Highlands (Odingo, 1968) extending an area approximately three million hectares. The white settler population continued to increase but at a very slow rate. Even as late as 1960 there were less than 4,000 white farmers occupying the White Highlands as a whole. Farming was mainly a large scale activity dictated by economic and ecological considerations rather than short-term quick return activities. After 1960 this system of land use was disrupted by the political changes that were in place due to the imminent transition to independence. The period 1961 to 1966 witnessed a massive transition from white settler to african peasant farming during which close to 35,000 households were settled through a variety of arrangements (Kenya Settlement Department Annual Report 1965/66).

According to population figures, presented later, the study area alone (72,400 hectares) had a population of the order of 34,000 people in 1969 growing to 58,500 in 1979 and is projected at 106,364 come 1993. The projected figure corresponds to a per capita agricultural land of no more than 0.26 hectares perperson. This puts the study area in an acute population pressure on the land originating from a diversity of communities. These communities have introduced different types of land use characterized by subsistence farming, small scale mixed farming, animal husbandry and logging. In light of this situation the study area is bound to have undergone intensive land use. Such activities may have brought with them the problem of increased soil detachment and transport and affected runoff rates. This is critical to the study area and by extension to the whole country which relies a great deal on agriculture for its economic activities and has only 17% (Braun and Mungai, 1982) of the total land area under arable farming. This situation similarly calls for concern because the study area comprises an important source area servicing a large down stream semi-arid area in the Rift valley including Naivasha, Gilgil and Nakuru Municipalities.

In this study, attention is being paid to the study of trends in land use changes that have taken place in terms of their temporal and spatial distribution. Also addressed are the trends in downstream sediment transport in the river Turasha as well as the trends in runoff as reflected at the river gauging station at 2GC4. As Ongwenyi (1979) has observed in the Upper Tana, land use as a single factor exercises a considerable influence on rates of sediment production. Moorhead (1982) has also reported from the Upper Tana that changes in land use may affect trends in sediment deposition. Downstream sedimentation arising from accelerated catchment soil detachment and transportation can lead to rapid siltation of the recently constructed Turasha reservoir and dam thereby reducing its economic life and also increase the water treatment costs. There is therefore an urgent need for obtaining accurate and reliable scientific information to be applied in the development of policy guidelines and activities that can provide equilibrium between nature and human needs so as to avoid irreversible damage to the catchment area while at the same time protecting the Turasha dam and reservoir from undue siltation. The Turasha river drains an environmentally delicate area on the slopes of the Aberdare mountains. This area has undergone tremendous land pressure since the dawn of independence arising from massive peasant settlement. Most of the peasants obtaining plots on the schemes had very little agricultural knowledge and very often no additional capital resources for land development after paying for the initial acquisition of the land from the white settlers. So for the farmers to be able to repay outstanding loans, there may have been a tendency to misuse the land for short-term gains. This may have resulted for example to continuous and expanded cultivation of the land leading to increased sediment transport down the streams which in turn may have lead to deterioration of the water resources and siltation of the Turasha reservoir down stream. This study therefore addresses itself to pertinent issues that may pose major constraints to development in this part of Kenya.

1.1 LITERATURE REVIEW

Studies have been done on trends in erosion changes using aerial photographs. Spatial changes in erosion were studied by Jones and Keech (1966) in Rhodesia. They mapped the severity of erosion in Tribal Trust Lands on the basis of density (length/unit area) of gullies. They considered that there was a close correlation between the degree of sheet and rill erosion and the degree of gully erosion and they did not therefore try to measure the former. They used photographs of 1:25,000 and superimposed a grid with squares representing 648 ha. Within each square they measured the length of gullies and then classified the erosion as follows:

Nil erosion	No gullies
Slight erosion	up to 1.41 m/ha
Moderate erosion	1.42 - 3.29 m/ha
Severe erosion	3.30 - 5.17 m/ha
Very severe erosion	(a) 5.18 - 8.94 m/ha
	(b) 8.95 - 12.23 m/ha
	(c) 12.24 - 15.52 m/ha
	(d) over 15.52 m/ha

Stocking (1972) in Rhodesia, carried out a multivariate analysis to discover which of eight topographical factors could be most closely correlated to the degree of gully erosion measured in three tribal areas. He found that the average slope could account for most variation in gully density. He followed Jones and Keech in assuming that sheet and rill erosion were related to gullying and concluded that the intensity of erosion was more closely correlated with slope than with any factor.

Rapp *et al* (1972) used air photography to determine spatial changes in erosion by measuring either density or frequency of erosion channels by measuring areas of erosion which differ in kind and intensity. He obtained a good correlation between relief ratio and sediment yield.

Studies have also been conducted in erosion changes in time. These studies have been done by measuring changes in gully length, area or volume over a period of years. Franknel and Scogings (1969) in Natal used aerial photography to monitor a large gully between 1937 and 1954. They found that the gully had widened slightly and the head had advanced 15 m.

Brice (1966) in Nebraska studied the development of aerial photographs taken in 1937 and 1952. He classified gullies according to size and topographical location and measured gully growth with the aid of aerial photographs enlarged to a scale of 1:8,000, maps with contours at 3 m vertical intervals and field measurement. Gully extension in valley bottoms between 1937 and 1952 ranged from about 61 m to 1036 m Enlargement of valley head and valley side gullies were calculated on a volume basis and ranged from 48 m^3 on small gullies to 3896 m^3 on very large ones. Reference points are needed when measuring gully growth and Brice was able to use trees, fence corners and houses for this purpose.

Keech (1969) measured changes in area of a few large gullies in the Mondoro tribal trust land in Rhodesia using aerial photography taken in 1946, 1956/57, 1964/65 and 1968. He enlarged the photographs as far as possible and then traced out the gullies. He used local features as reference points to enable matching photography from different years. One gully showed an increase of 21% in area between 1946 and 1968.

Thompson (1964) used aerial photography at a scale1:20,000 measure the advancement of gullies in seven different parts of the U.S.A. He showed that four factors determined the rate of gully head, advancement: the watershed area above the gully head, the slope of the approach channel, a rainfall factor and a soil factor.

Osusanya (1971) used aerial photography at a scale of 1:20,000 to measure change in gully areas in Mtoko Rhodesia between 1955 and 1961. He was able to locate old trees on the aerial photographs which could be used as "tie" points but mentions difficulties in making accurate measurements of gully areas using a planimeter. This was probably because his enlargement of tracings to a scale of 1:10,000 was still too small. He showed that the rate of advancement was a function of gully slope, which he measured stereoscopically, and of watershed area. The gullies he studied were mainly young and "fast eroding into the hills".

Other studies which have been done on land use include those quoted by Ward (1971) who has noted that many experiments have been conducted all over the world using simulated land use. The results are, however, controversial due to the fact that the simulated land use changes are different with examples being: from one forest type to another, a forest cover to an agricultural crop cover and a forest cover to pasture.

Ward (1975) also quotes studies from the USSR which report a decrease in stream flow with the removal of a forest cover. On the other hand, studies at Coweeta quoted by Pereira (1973) showed that after thirty six months of calibration, clear felling on one of the catchments resulted in an increase of 373 mm. depth over the catchment area.

Kairu (1978) studied surface runoff from a set of catchments within drainage area 3B in Kenya using the water balance model with the inputs being rainfall and evapotranspiration. He obtained a good correlation ($r>0.8$) between estimated and observed runoff for the sampled catchments. He attributes this to the importance of climatic factors in explaining the runoff phenomena. However, Kairu did not evaluate the effect of land use change on runoff which the present study endeavours to do.

Blackie (1972) developed a model to utilise the data from the East African Agricultural Forestry Research (EAAFRO) catchments. Previous analysis of the data had been based on the water balance approach. Blackie's model treats rainfall and groundwater storage as the two types of input while the output consists of evapotranspiration, groundwater storage and surface runoff. The outputs were then routed to obtain a predicted streamflow. After some developments on his model, Blackie operated a mine-parameter model with a unit time interval of one day and obtained reasonable representation of the flow from the Kimakia catchment. The results from the model were indicating but not conclusive regarding the hydrological changes that resulted from changes in land use.

Attempts have been made to estimate runoff using land use and assuming all other factors controlling runoff to be constant. In this approach, twin watersheds with similar catchment characteristics are selected for study. During the initial period, a regression equation is established between the flows from both catchments. Subsequently land use is changed on one catchment while the other remains as before thus providing a control so that influences of such factors as climatic change can be accounted for. Any significant deviation from the regression equation between catchment flows in subsequent periods are attributable to the changes in land use. The problem with this type of experimentation is that the changes are usually abrupt. This implies independence between the original situation and that following modification. The present study is a notable modification to this design because the same catchment is used with only a temporal variation rather than using similar catchments. Any climatic change is accounted for by examining the stationarity of long record mean annual areal rainfall. The changes in land use are not abrupt but rather a result of gradual natural human activities spanning over twenty five years. 1962 which marks the transition between European and peasant settlement is used as a the base year.

Some significant work has been done in various countries by various people on trends and periodicities in rainfall, temperature and wind.

Jagonnathan and Parythasarathy (1973) found increasing or decreasing rainfall tendencies over India. They also observed Quasi-biennial oscillations and 11 year (sunspot) cycle exhibited at several stations in both areas.

Parthasarathy and Dhar (1974) observed positive rainfall trend over central India, parts of the adjoining peninsular and over small areas in North West and North East India. Negative trend was observed only over parts of Eastern India. Spectral analysis revealed two major cycle ranges: 2.0 - 3.5 years and 8.0 - 12.0 years.

Winstanley (1973) examined rainfall trend by extrapolating past trend and observed that future rainfall averaged over five or ten years is likely to decrease to a minimum around 2030 A.D.

Tyson,Dyer and Mametse (1975) observed four major cycles in South Africa rainfall. These were 16-20 years, 10-12 years, 3-4 years and Quasi-biennial oscillations. The 16-20 year cycle was more prominent. The results of their analysis indicated that there is little evidence to support that South Africa has undergone progressive desiccation during the period 1880-1972. The analysis covered 157 stations with records covering the period 1910-1972 and fewer stations had records extending back to 1880.

Rhode and Virji (1976) studied trend and periodicities for 35 rainfall stations in East Africa. The data covered time periods ranging from 44 to 83 years. They observed no definite trend except in Northern Kenya where a trend towards increased precipitation is recent years was indicated. The major cycles determined from spectral analysis were 2.0-2.5 years, 3.5 years and 5.0-5.5 years.

Masaya (1975) examined the spectra of rainfall series for 18 stations in Kenya. The data used in the analysis covered time periods extending from 53 to 83 years. He determined the major cycle in the rainfall series to be 2.0 years, 3.4 years and 5.2 years. The 5.2 year cycle seemed more prominent.

Bunting *et al* (1975) examined eleven stations in West Africa for Statistical evidence of trend.

They detected no established trends or periods and concluded that the recent succession of drought years fall within statistical expectation. They also concluded that the Sahelian rainfall is not linked to the frequency of Westerly weather over Britain. The rainfall records were extending 50 years or more.

Rhode (1974) looked at the year to year variations of some hydrological parameters in Kenya. Periodic fluctuations with a period of some 3 to 5 years were demonstrated is the annual rainfall data. The stations had records of observation for the period 1910-1973 with Machakos going back to 1894.

Wood and Lovett (1974) examined the sunspot-rainfall relationship for Ethiopia. They compared the annual rainfall with Zurich sunspot number. A strong statistical correlation between Addis Ababa rainfall and sunspot number was determined. The rainfall peaks were leading the sunspot peaks by an average of 1.3 years.

Lamb (1973, 1974) suggested that the general circulation of the atmosphere is slowly changing, resulting in an equatorward shift of the principal climatic belts. His analysis of the mean yearly rainfall for 1970-72 indicated an extensive zone of deficiency in rainfall in latitudes between 10°N and 20° to 30°N where deficiency had become greater since 1970 than the previous decade. A somewhat similar feature in the same latitudes was revealed in the southern hemisphere.

Ogallo (1977) examined the cyclical variations and trends in the annual rainfall totals for 69 stations spread over Africa. He observed that the rainfall over Africa is oscillatory in nature.

From the literature review cited, it is clear that some useful work seems to have been accomplished in the study of spatial and temporal variation of erosion using air photography notably in Rhodesia, Tanzania, South Africa and the U.S.A. All these studies are still few and rather scattered far away from home. They have little to offer directly in terms of water resources planning, development and management for Kenya. It is apparent that the use of remote sensing information in hydrology-related studies has hardly been explored particularly in this country. The use of such information is attempted in this study by trying to develop a prediction model relating mean annual suspended sediment loads to a combination of the area of main land use types mapped during 1962 and 1988.

One major set of factors which determines the nature of runoff at a river gauging station comprises catchment characteristics which include its geometry hydrology and underlying geology. Among these,the land use component of the hydrological characteristic can change significantly within a short time. Remote sensing pictures provide an easy and convenient way of capturing a scene at any time in space thereby making it possible to determine the spatial and temporal extent of each land use type. A combination of remote sensing information and reference suspended sediment load measurements can be quite handy as it can quickly provide much needed information for water resources planning, development and management through the development of a prediction model relating annual suspended sediment loads to the area of the main land use types mapped. The information gained from this study will go a long way into boosting any plans to conserve the Turasha catchment, its water resources and water resources structures. In this way the area can be assured of sustainable development. The information obtained is also useful in updating the existing literature while at the same time acting as a stimulant to the academic community conducting research along similar lines.

1.2 OBJECTIVES

The first objective of the study is to map and determine the area of the main land use types in the Turasha catchment by tracing them out on aerial photographs and satellite imagery. The year 1962 is chosen to represent the base year as it marks the period when land pressure became critical due to massive peasant settlement. Land use types are to be traced out on air photographs. The most current land use types are to be traced out on **Spot** imagery for 1988. A planimeter is to be used to determine the area of each land use type.

The second objective is to evaluate the trends in long record river flow and sediment loads data using graphical and/or statistical approaches. This is in view of the fact that human activities taking place in the catchment, as depicted by land use, pose a definite short to long term effect on river flow and sediment yield. Agriculture for instance is so widespread that agricultural activities which materially alter the erosion processes are much more important.

Nearly all agricultural operations tend to encourage erosion. By ploughing and tilling the soil, man disturbs and aerates the soil millions of times more quickly and effectively than by any other means thereby accelerating all the physical processes of nature in the soil including erosion itself (Hudson, 1981). Also, wherever vegetation is cleared and the ground is more exposed, there is less vegetation to absorb the energy of the falling rain and so more rainfall erosion and more surface runoff. The effect of climate, if any, is accounted for by testing for stationarity in rainfall data. Secondary and current data on discharge and suspended sediment loads are available for analysis of trend. Trend Analysis is applied to monthly discharge data at 2GC4 covering the period 1952-1987. Trends in suspended sediments will be based on data recorded during 1953 through 1956 and those observed during a part of 1991 and 1992. To facilitate comparison, the few data available are used to generate models which are in turn used to generate predicted values for specified range of flows (0.1-3.0 m^3/s).

The final objective attempts to derive a generalized relationship between annual suspended sediment loads and a combination of the total area of the main land use types using regression analysis. This is intended to provide a prediction model for forecasting future suspended sediment loads based only on the areal extent of the main land use types, which are assumed will remain the same.

1.3 THE STUDY AREA

In this section, the location, physical size and a number of items usually considered influential to runoff, sediment yield and transport, and for which information is available, are outlined. These include climate, geology and soils, population pressure on the land etc.

1.3.1 Location, size and drainage system

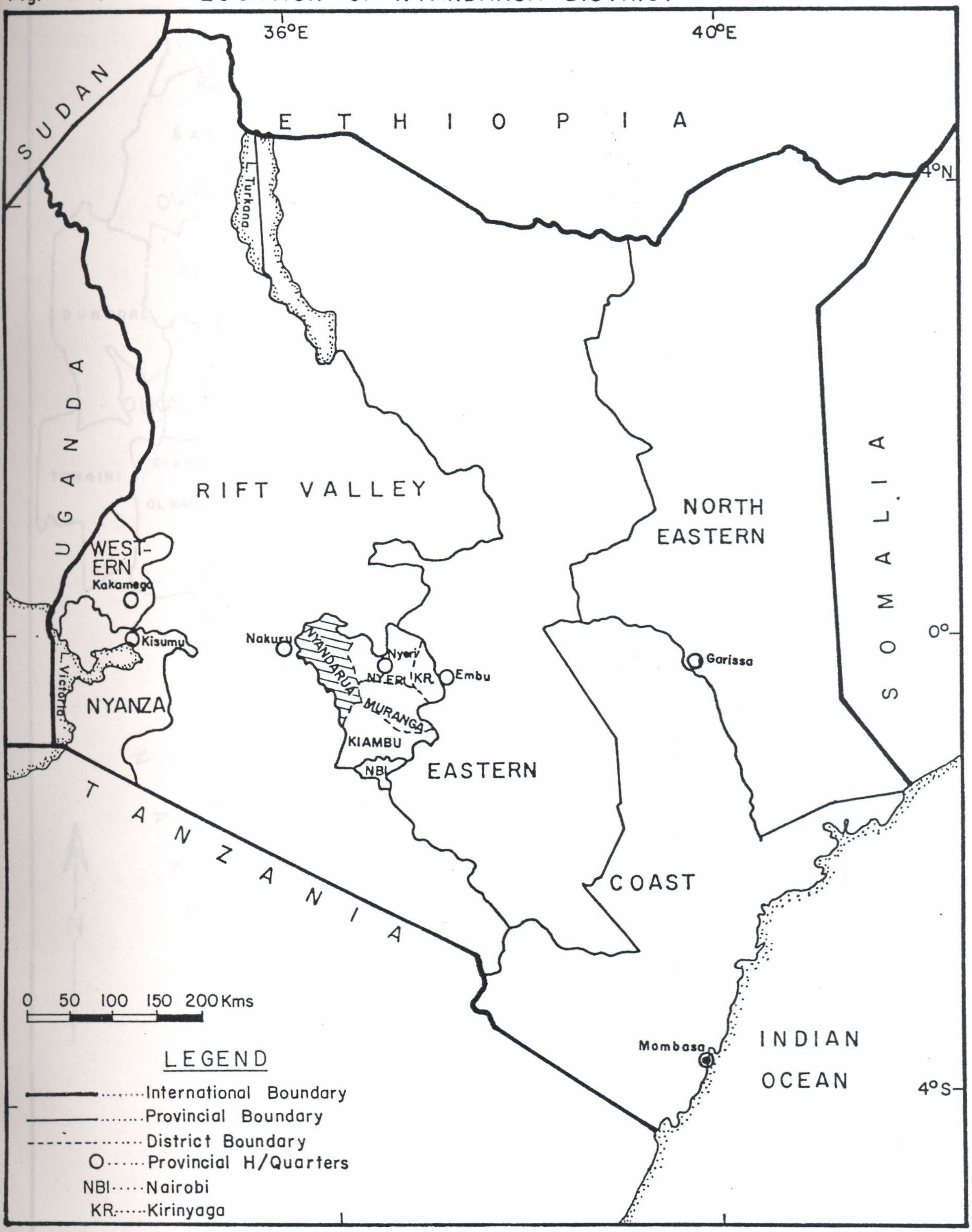
The Turasha catchment is situated on the slopes of the Aberdare Mountains in Nyandarua District of the Rift Valley Province in Kenya. It lies between latitudes 0°25'S and 0°43.4'S and longitudes 36°25'E and 36° 41.5'E and occupies an area of approximately 724 Km^2 which is 21.4% of the entire Lake Naivasha catchment with a total area of 3,400 Km^2. The major river draining this area is the Turasha which is itself a tributary of the Malewa river sustaining 95% of the inflow into Lake Naivasha (MOWD,1990). The main tributaries of the Turasha are Kamirangi, Mkungi and Kitiri. The drainage system is one which has been incised into the quaternary volcanic series which consist of intercalated lavas and pyroclastics. Figure 1 and 2 show the location of the study area.

1.3.2 Climate

Climatic elements give significant influence on the quality and quantity of water. The dry season, because of its associated heat, reduces vegetation and promotes bush or forest fires and soils crack. Because the effects of the dry season precede the rainy season, soils either become pulverised or cracked and severe erosion and landsliding become widespread problems in tropical slopes.

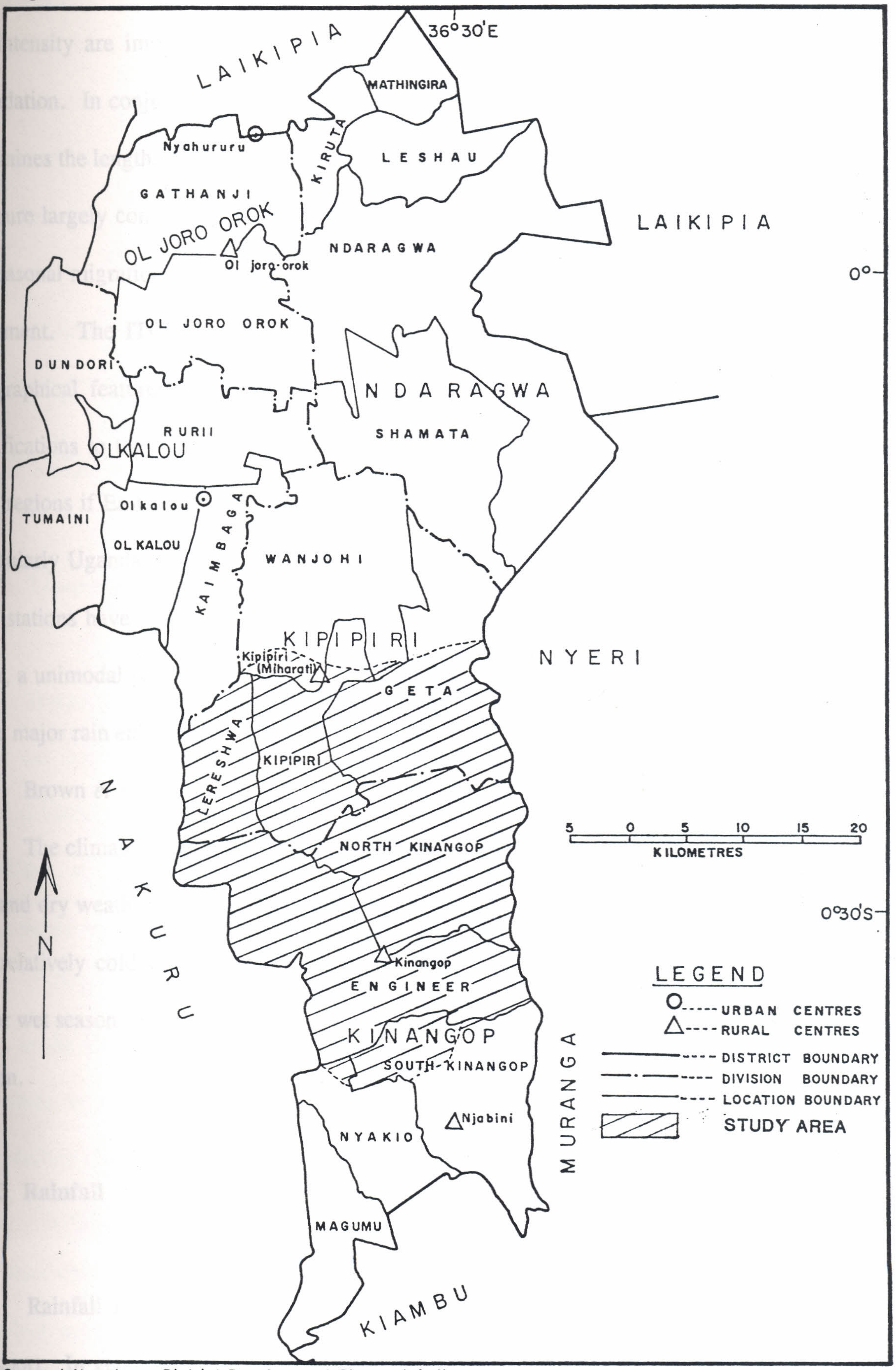
Climatic factors affecting soil detachment and transport are rainfall, temperature, wind,

Fig. I : LOCATION OF NYANDARUA DISTRICT



Source : Survey of Kenya Maps

Fig. 2 : LOCATION OF STUDY AREA



Source : Nyandarua District Development Plan and Author humidity and solar radiation. Among these, rainfall is by far the most important. Both the amount and intensity are important elements. The higher the rainfall the the higher the effect on soil degradation. In conjunction with the general circulation patterns, the geographical position largely determines the length of the season and timing of rainfall maxima and minima while topography and exposure largely control the amount. The seasonal variation of rainfall in East Africa depends on the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) which is related to the sun's movement. The ITCZ is very diffuse in East Africa due to the diversity of topography. The topographical features together with the effects of many large inland lakes introduce significant modifications to the flow patterns so that the rains do not follow the classical ITCZ patterns. In most regions if East Africa the annual rainfall exhibits strong seasonality. Only the western parts, particularly Uganda, receive substantial rain throughout the year. In general, closer to the equator most stations have annual rainfall profiles with two wet and two dry seasons. Further north and south, a unimodal pattern is common. These are by no means universal due to the varying degrees of the major rain enhancing mechanisms (Trewartha, 1961; E.A.M.D., 1962; Griffiths, 1972; Potts, 1971; Brown *et al*, 1973).

The climate over the study area is largely under the influence of the movement of the ITCZ. Hot and dry weather conditions are generally experienced during the period March to May. Rainy and relatively cold weather conditions prevail during the period April to June and constitute the major wet season. The period October to November receives some rainfall and forms the short rainy season.

1.3.3 Rainfall

Rainfall is perhaps the most important climatic factor affecting sediment detachment and transport. In general higher rainfall results in higher erosion hazards. Showers of long duration saturate the top soil with water and reduce the soil stability and consequently promote the risk of erosion and runoff. Distribution of the rainfall is important because a high quantity of rainfall when well distributed is more tolerable and relatively less harmful. The degree of the risk also varies with the structural stability of the soil as indicated later on. The mean long term rainfall distribution for North Kinangop Forest Station No.90.36025 are shown is in Table 1 and schematically shown in Fig. 3.

Table 1: Mean rainfall figures for N. Kinangop rainfall station (90.36025) altitude 2,524 m.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
41	61	75	144	167	92	71	93	106	99	106	71	1126

Source: Kenya Meterological Department records.

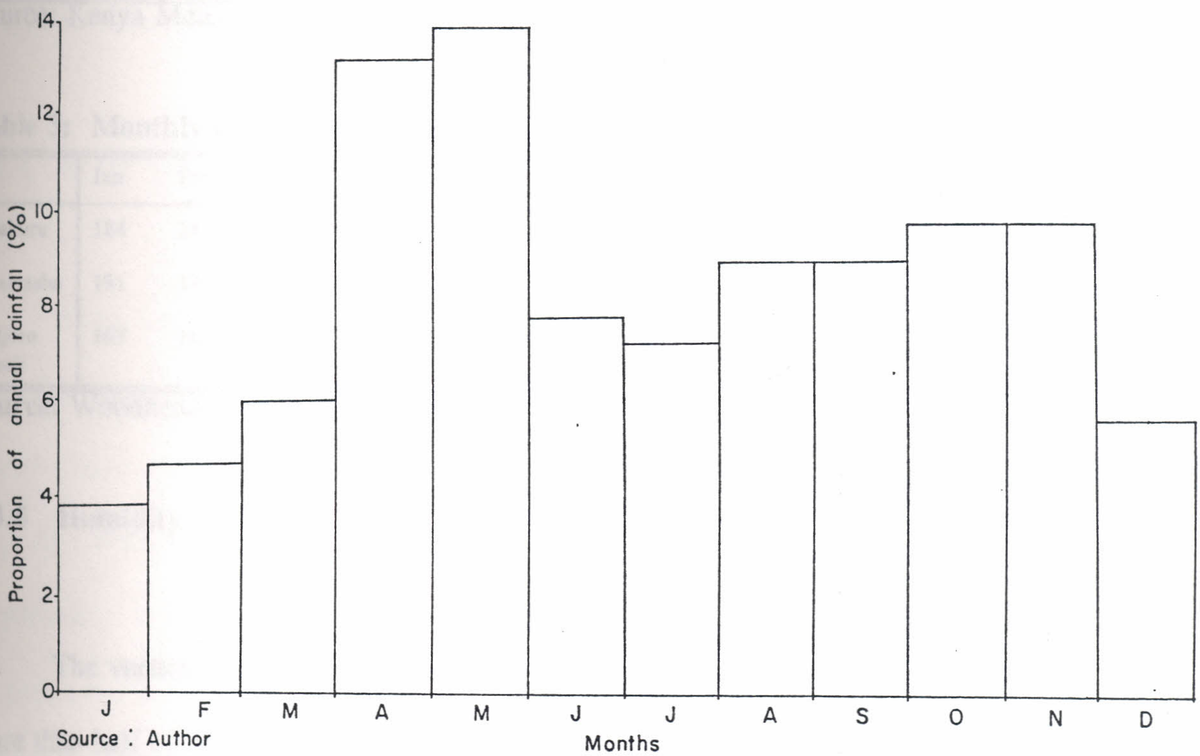
1.3.4: Temperature and evaporation

Temperature and winds affect the rates of evaporation and evapotranspiration which in turn affect soil moisture balance. Average windspeed increases with altitude and so does evaporation potential (Hewitt, 1972). Both factors combine to produce more humid conditions on the lower slopes than at the higher altitudes. This helps in keeping the moisture deficit in the soil low and enhances the seriousness of erosion when rains fall because the soil will saturate fast downslope.

Cold air generated during clear nights on the moorlands of the Aberdare Mountains flows down to the Kinangop plateau causing night frosts nearly every month. Farther away from the Aberdares the frost problem decreases as the valleys provide an outlet to the stream of cold air. Temperature data for North Kinangop Mtarakwa Farm No. 90.36036 are shown in Table 2.

The estimates of evaporation from open water surfaces published by Woodhead (1968) were calculated from meteorological data using Penman's equation. The stations closest to the study area for which evaporation estimates are available are Ol Joro Orok, Naivasha and Nakuru. The data for these stations are shown in Table 3. The mean annual evaporation in the study area from these

Fig. 3 : Rainfall Histogram for North Kinangop Station



Source : Author

figures is 1740 mm.

Table 2: Temperature (°c) data for N. Kinangop Mtarakwa farm No. 90.36036 (Altitude 2,545 m.a.s.l.)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean maximum	21.6	21.9	21.6	19.4	16.9	16.7	16.6	16.4	19.2	19.3	18.9	19.2
Mean	12.2	13.5	13.7	13.5	12.3	11.9	11.3	11.1	12.0	12.9	12.7	12.3
Mean minimum	2.7	5.1	5.7	7.6	7.6	6.0	5.9	5.8	4.8	6.4	6.5	5.2
Absolute minimum	-0.6	-1.1	-0.6	1.1	1.7	2.2	0.6	-1.7	-1.7	-1.1	-1.1	-0.6

Source: Kenya Meteorological Department Records

Table 3: Monthly mean evaporation records (mm) for Nakuru, Naivasha and Ol Joro Orok

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nakuru	184	181	191	133	130	121	120	128	136	130	116	155	1725
Naivasha	191	183	199	148	139	130	130	146	160	180	132	155	1892
Oljoro Orok	167	160	190	149	120	107	100	100	123	131	115	144	1605

Source: Woodhead (1968)

1.3.5 Humidity

The vertical decrease in air pressure reduces absolute humidity. Hewitt (1972) states that more than half of the earth's water vapour exists below 2,500 m above sea level. He attributes the dry conditions above 2,200 m to this vertical decrease in humidity. As pressure decreases the air becomes increasingly ineffective in absorbing the sun's radiation and in holding water vapour. Low humidity in high elevation plus high wind speed may support rapid spread of fires once they start.

Humidity of air determines the rate of evapotranspiration and hence to the storage available in the soil to store more water. Relative humidity values for Nakuru meteorological station (altitude 1,872 m.a.s.l.) and South Kinangop (altitude 2,591 m.a.s.l.) are available

Table 4: **Relative humidity values (%) for Nakuru and South Kinangop Meteorological stations**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Nakuru 0600 GMT	65	65	70	78	80	81	79	77	74	71	74	70	74
1200 GMT	32	33	38	53	55	54	53	51	46	44	50	43	46
S. Kinangop 0600 GMT	80	77	80	85	87	86	89	88	84	81	83	84	84
1200 GMT	67	59	68	75	77	78	81	81	76	70	76	76	74

Source: Kenya Meteorological Department Records.

as the nearest to the study area. They are shown in Table 4.

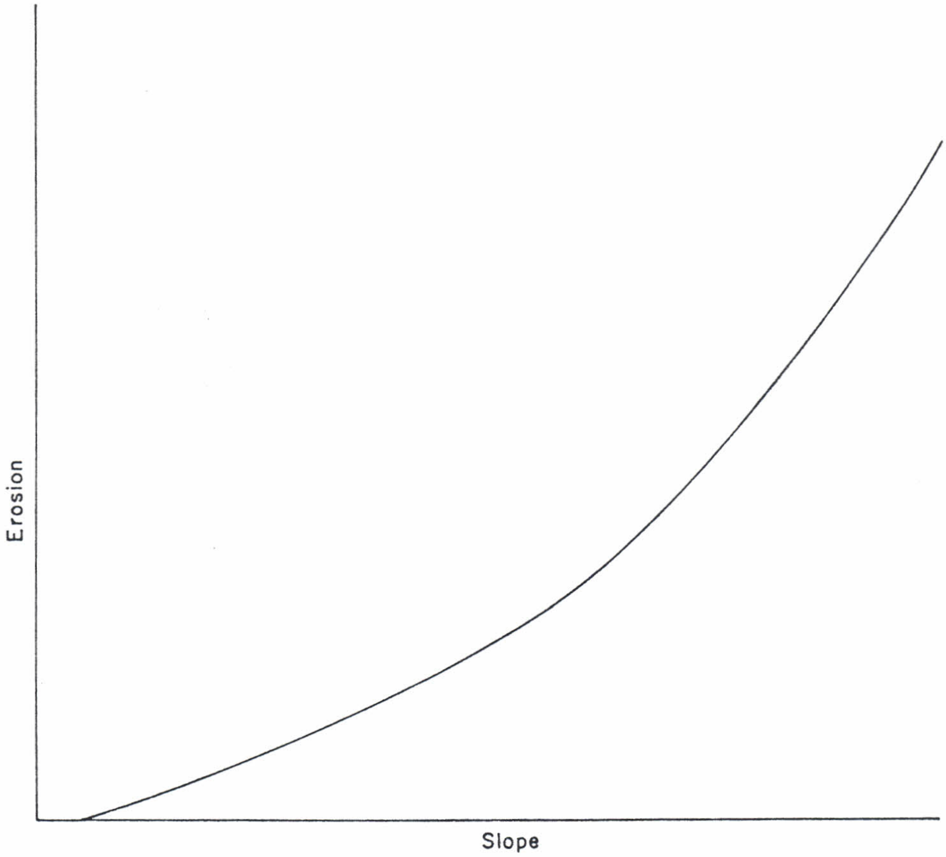
1.3.6 Relief

Relief and slope angles underlie the causes and concentration of rapid mass movements. Of particular significance to resource use is the effect of slope on rates of erosion. The velocity of runoff water varies as the square root of the vertical drop but the erosion increases exponentially (Fig. 4). Water velocity is about doubled when the slope

(expressed as %) is quadrupled. Doubling velocity of water increases the size of particles it can roll or push along sixty four times (Rutter, 1968). The length of the slope is also very important. The longer the slope the greater the volume of excess water accumulating upon it all of which will run down the slope at an ever increasing volume and velocity (Fig. 5). Similar observations have been made by Leopold *et al* (1964) and Cooke/Doorn Kamp (1974).

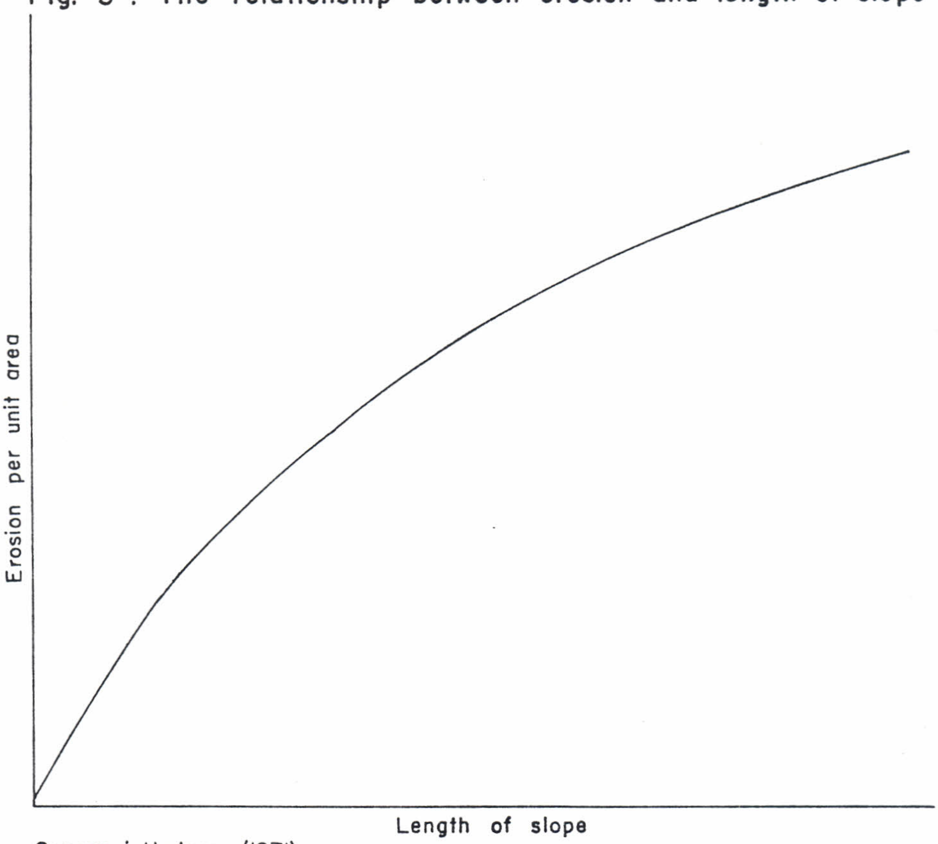
The Turasha catchment is characterised by a variety of relief features. The area on the Kipipiri mountains and the valleys in the lower part of the catchment has relief generally exceeding 30%. The hilly parts, minor scarps and footslopes have an undulating to rolling relief ranging 5-15%. The Central plateau area occupying the majority of the catchment has relief ranging 2-8%. The upland areas are gently undulating to rolling (2-16%).

Fig. 4 : The relationship between erosion and slope



Source : Hudson, (1971).

Fig. 5 : The relationship between erosion and length of slope



Source : Hudson, (1971)

1.3.7 Vegetation

A cover of the soil by vegetation, be it natural or secondary in origin, is of the highest importance in order to break the energy of raindrops and to reduce runoff by increased surface retention. Vegetation removal reduces infiltration capacity which subsequently increases runoff and erosion. This assertion is supported by Selby (1976) in South Auckland district, New Zealand, where he observed that infiltration rates into forest soils are three to four times as great as those into grassland soils. The consequence of decreased infiltration and increased runoff must lead to lower soil saturation rates. Table 5 summarises results from studies which have been conducted in the tropics and subtropics indicating the effects of soil cover on erosion control.

Forest and good grassland appear to form the best cover for the soil absorbing the kinetic energy of the downpours and reducing runoff. The data also make it clear that proper

Table 5: Soil cover and water erosion

Vegetation cover	Slope (%)	Runoff (%)	Soil loss (t/ha/yr)
Grass 100%	36	6.9	0.026
Grass 20%	20	29.0	12.0
Natural forest	7-15	2.4	0.24
Citrus plus mulch	7	2.6	4.3
Citrus without mulch	7	9.2	18.9
Crops plus mulch	7	13.9	13.0
Crops plus bare soil or fallow	7	21.0	43.6
Bare soil	7	39.0	89.4
Natural fallow	7	-	5.3

Source: Anonymous (1981)

management is very important. The main role of vegetation in reducing erosion is through interception of rainfall and absorption of the kinetic energy of the raindrops which reduces soil splash and detachment and maximizes infiltration by reducing surface sealing and thus reducing runoff. Vegetation reduces erosion through decreased surface velocity. They physically restrain soil movement by their roots and maintain high infiltration rate and capacity. Their presence improves soil aggregation and porosity. The high rate of transpiration reduces soil moisture resulting in increased storage capacity. Vegetation also acts as filters to soil particles and increase organic matter content.

In the study area, the well-drained soils on the Aberdare mountains are covered by cedar forest. The base of the mountains with clay soils of impeded drainage are covered by open grassland comprising mainly themeda and themeda pennisetum species. In the river valleys can be observed forest clearings and also scrub of podo and cedar types. At the exit of the basin around the damsite are found upland evergreen and semi-deciduous bushland consisting of tarchonanthus and acacia.

1.4. REGIONAL GEOLOGY AND SOILS

The study area lies in the main rift of the Rift Valley which is part of the Great Rift system and has a feature of a trough with complex faulting of general orientation from the North to the South.

The Rift Valley is intersected with varied tectonic structures such as faults oblique to its axis and secondary minor troughs perpendicular to it. The entire stratigraphic sequence consists of Tertiary to Recent volcanic pyroclastic rocks, with intercalation of lake sediments which are tuffaceous in part (Shackleton, 1945; Thompson, *et al*, 1958; Thompson, McCall, 1967).

The Tertiary epoch of the Rift Valley system commenced with the down warping of the precambrian Metamorphic Basement Complex along well defined fault lines, roughly represented today by the eastern and western walls of the Rift Valley in the Nakuru area. This resulted in the disruption of the ancient drainage pattern and the formation of sub-miocene lakes and sediments within the Rift troughs.

The down warping was accompanied by the outpouring of lavas on a vast scale to form fissures and vents long since buried by later volcanics. These fissures are believed to have paralleled the major fault lines and the lavas subsequently flowed both into the troughs and also eastward and westwards beyond the Rift walls, effectively blanketing the Basement series over considerable distances.

Later eruptions, generally on a smaller scale, were confined to the major volcanic centres of Londiani, Kilombe, Menengai and Eburru and to the North-south zones of intense faulting in proximity to the existing Rift walls. This later and more quiescent stages of volcanism was accompanied by the deposition of a variety of pyroclastics in the form of ashes, tuffs and agglomerates. On this was imposed a drainage pattern which reworked and eroded the unconsolidated material resulting in considerable terrestrial deposition of volcanic detritus within the Rift troughs.

There is evidence that during certain protracted periods of geological time, the lakes occupied more extensive areas than those of the present day and that the final stages of grid faulting within the Rift troughs successfully disrupted both the drainage pattern and sedimentary basins of deposition.

Generally speaking the study area is still a zone of constant instability and tectonic readjustment and in terms of surface water storage this fact must be taken into account. The surface of the northern part of the study area is mainly covered by recent volcanic deposits. This is underlain by pliocene tuff formations which included vitric pumice tuffs, ignimbrites and wedded tuffs with lacustrine sediments, graded tuffs and diatomite. The North-eastern part consists mainly of basalt comprising vesicular olivine basalt of pliocene-miocene age and olivine basalt of miocene age, basalt and agglomerate of simbara series, mainly in the Kipipiri forest area, and the Laikipian type of basalt in the lower eastern fringes of Kipipiri mountain all of which belong to periods ranging from miocene to pleistocene. Alluvium covers some parts along the rivers. The central and uthern parts are covered by pyroclastic rocks and sediments of upper to middle pleistocene eriods. Fig. 6 shows a simplified geology of the study area. The geology of this area has given se to a variety of soils with different properties and potentialities. The soils found in the study area re discussed below.

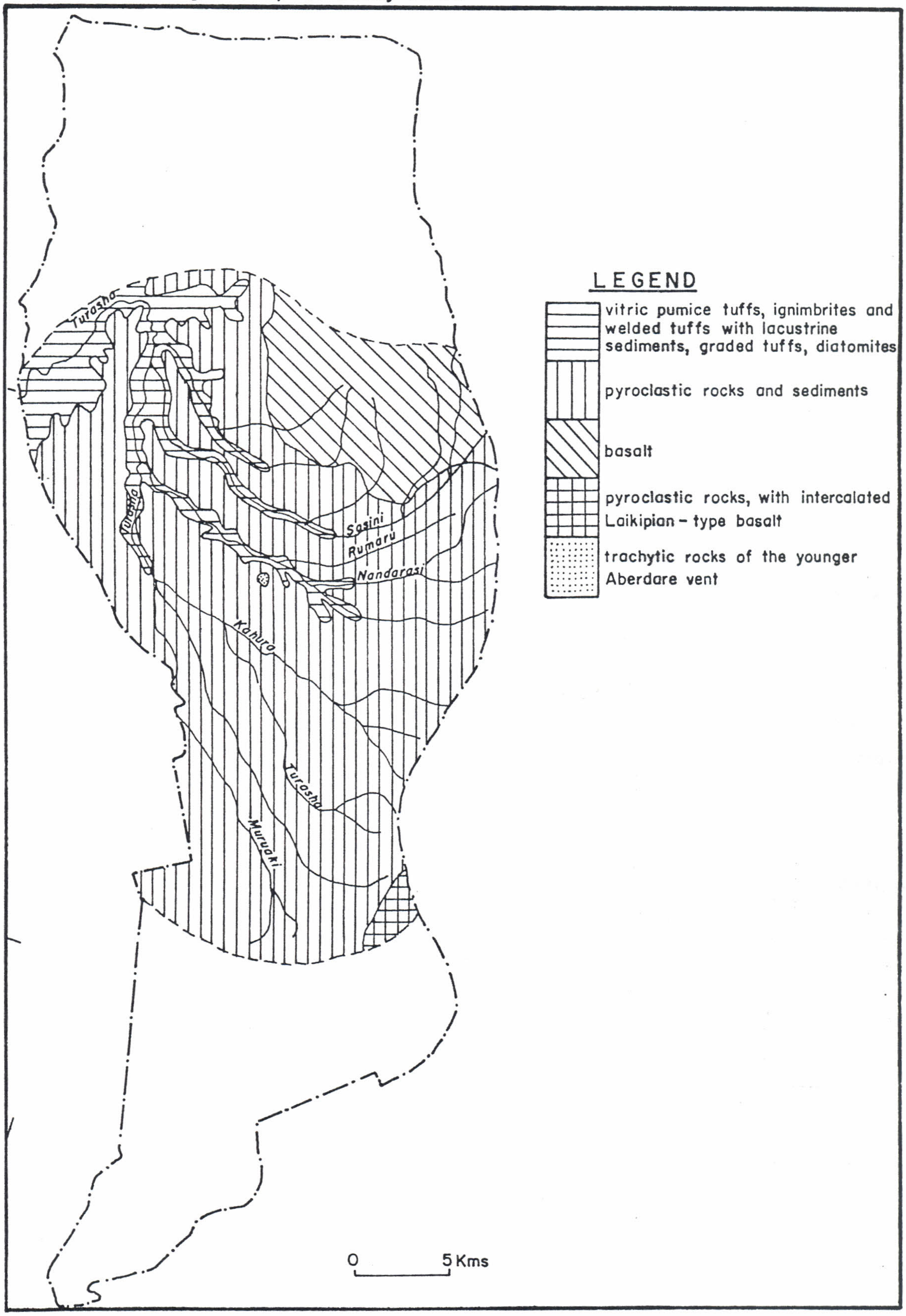
Rachilo (1978) has mapped the soils of the area into a number of classes. The first soil ategory is that which is mainly found on the Kipipiri mountains. It comprises Lithosols and Andosols. These soils are shallow to moderately deep (less than 8 cm deep), stony or rocky. Texture is clay/loam. Slopes are generally over 30%. They are symbolised M on the soils map (Fig.7).

The second category of soils is that occurring on the hills and minor scarps (symbolised H) within slopes of 5-15%. The soils found north-west of the North Kinangop trading centre are typical examples. These soils are developed from trachytes of the young Aberdare Vent. They have been classified as Lithosols. Soil depth is typically less than 30 cm. They are predominantly rocky clay but also loam in places.

Another class of the soils in the area is that which is developed on the footslopes on undulating to rolling slopes (5-16%). These soils are found north-west of the North Kinangop trading centre and are symbolised by the Geologic signature F on the soils map. They are classified as vertic Luvisols, sodic phase. Texture is clay loam to clay. Acrisols are found at the foot slopes of the Aberdares.

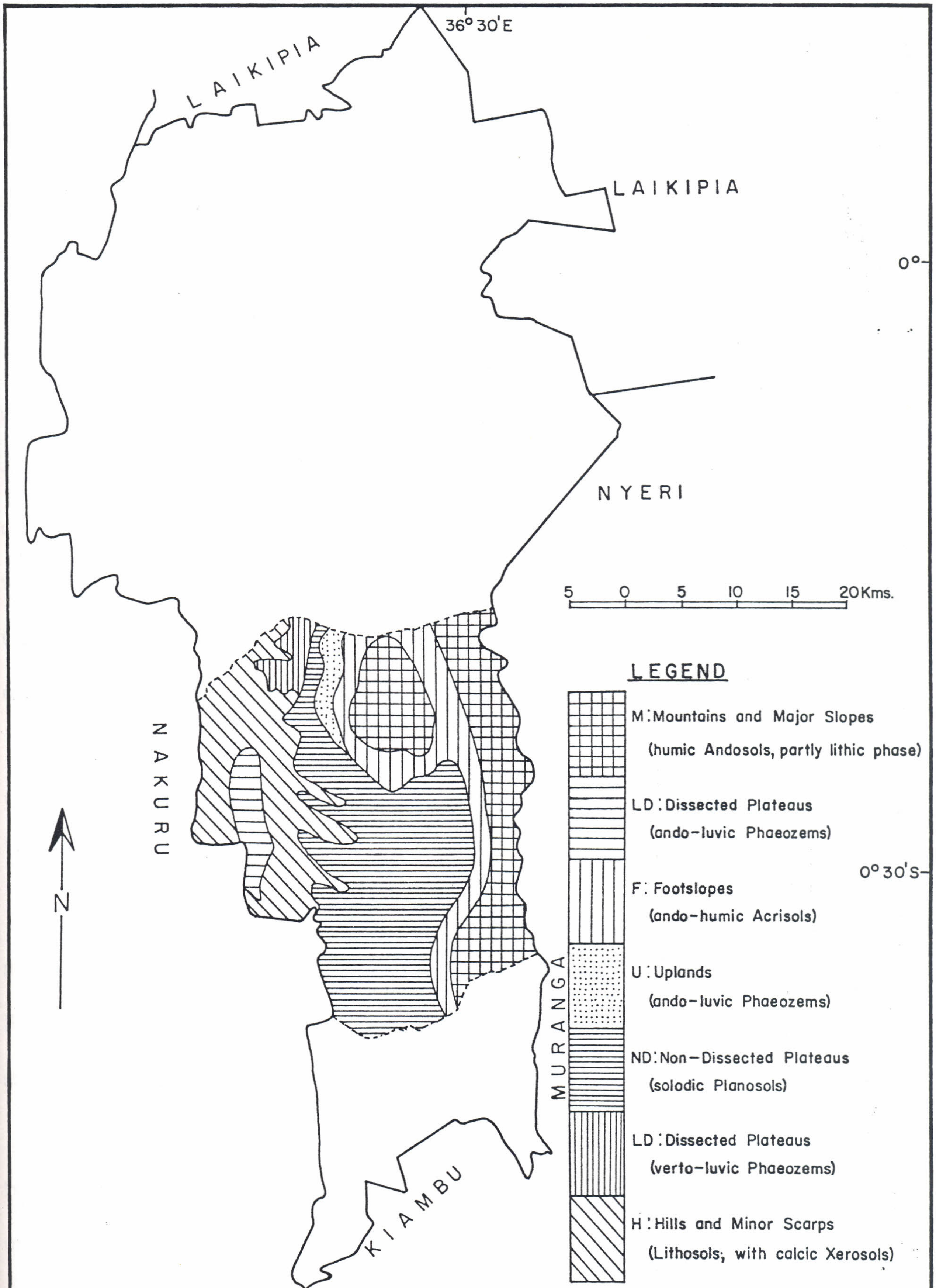
Yet another class of soils found in this area is that developed in dissected plateaus (LD). This is in fact the predominant soils class in this area. The western part is much more dissected than the central and southern area giving rise to contrasting soil types within the plateau. Shallow, rocky soils exist to the north-west and are classified as Lithosols. Slopes are flat to undulating (2-8%). These are intermingled with eutric cambisols, lithic phase of shallow depth. To the north-west are found calcic luvisols, partly lithic phase. Relief is mainly undulating (5-8%).

Fig. 6 : Geologic Map of Study Area



Source : Adopted from J. R. Rachilo (1978).

Fig. 7 : Soils and Topography of the Turasha Catchment



Source: Adopted from Farm Management Handbook, 1983.

major soil type occurring in the plateau is a deep imperfectly drained clay soil underlain with silty ay loam to clay soil. These soils have been classified as dystric planosols. Relief is 0-4%.

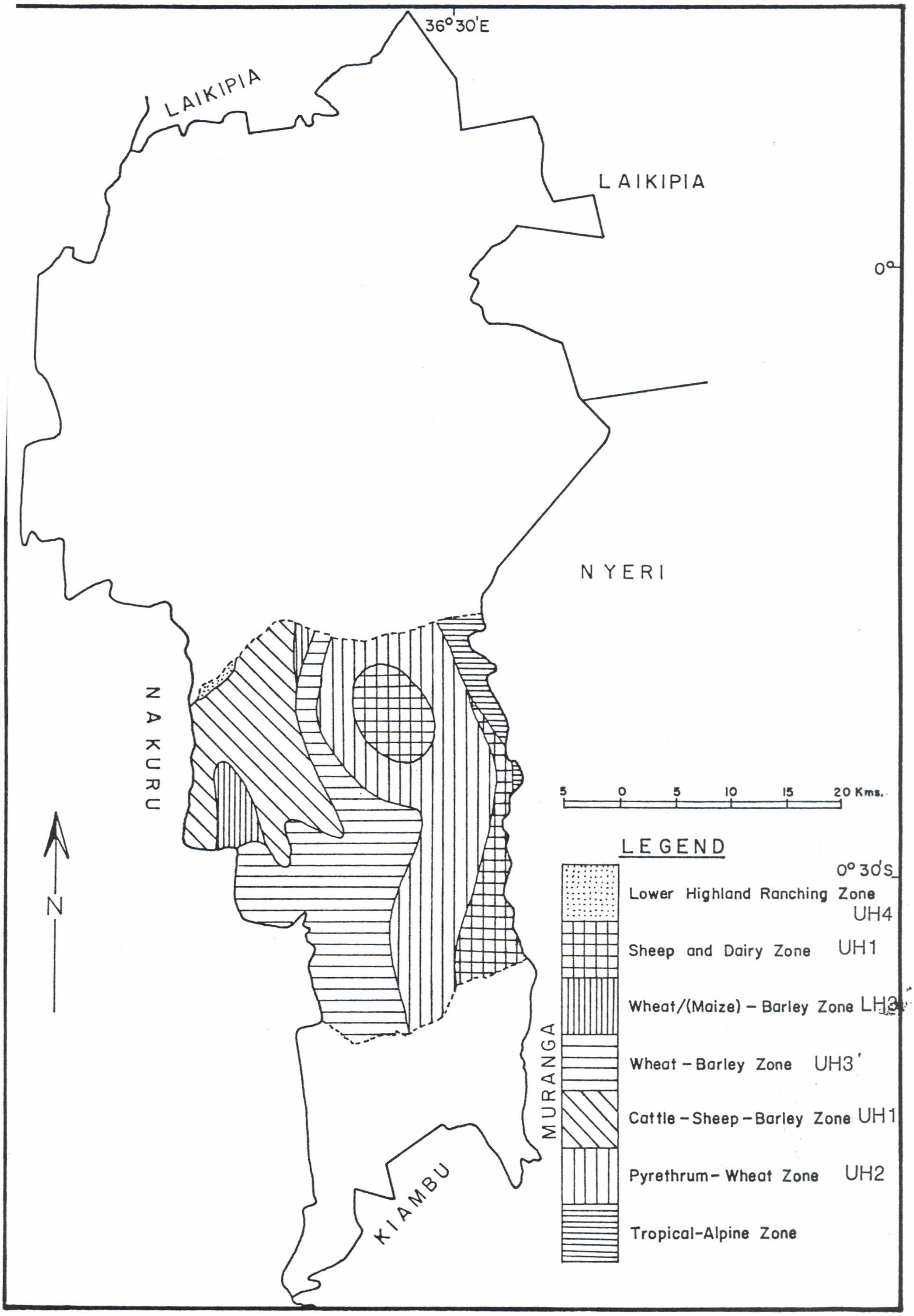
Distinct soils are also found developed on uplands (U) on the footslopes of the Kipipiri ountain. The general relief of the area is gently undulating to rolling (2-16%). The top soil is ilty loam to silty clay loam and that of the subsoil is clay loam. These are classified as orthic uvisols.

Other soils are those found developed in river Alluvial plains and Terraces, in the ottomlands as well as valleys. Those developed in the alluvial plains are mainly luvisols (various phases) with fine sandy clay top soil. Soils of the bottomlands and soils of the valleys consist of complex soils with a top soil texture being is clay. The soils of the valleys consist of complex soils with a top soil texture being gravelly clay loam to clay loam and the subsoil ranging from clay loam to clay. The various soils have been put into a number of agricultural uses that are discussed in the next section.

1.5 POPULATION PRESSURE ON THE LAND AND AGRICULTURAL ACTIVITIES

Since the dawn of independence around 1960, the former White Highlands under which the study area falls, underwent massive peasant settlements. Between 1961 and 1965 the entire White Highlands were being resettled at a very high rate (Table 6). The largest single concentration of settlement took place in the Kinangop plateau.

According to the 1979 census, Nyandarua district had 233,302 persons of whom no more than 11,277 lived in the urban settlements. The rural population consisted of 220,144 persons for whom a total rural area of 267,200 ha was available and 208,500 ha were suitable for agriculture and livestock. About 1 ha was available for each person. Most of the area consists of Unit UH2 (Fig. 8) which is suitable for pyrethrum and wheat and Unit UH3 for wheat and barley during ig. 8 : AGRICULTURAL ACTIVITIES IN THE STUDY AREA



Source : Adopted from Farm Management Handbook, 1983.

European settlement. Roughly speaking the productivity of 2 ha in UH2 is comparable to 4 ha in LH3 and one of more than 12 ha in unit UH4. Unit UH2 consist of phaeozems suitable for pyrethrum and wheat. It also has plenty of natural pastures and is suitable for oat growing. Unit UH1 is composed of planosols and is suitable for sheep, natural pasture and oats. Units UH4 is mainly suitable for ranching. LH3 is suitable for wheat,maize and barley.

The period 1961-66 witnessed a massive transition from white settlement during which, according to the figures above, close to 35,000 households were settled. The per capita land and agricultural land availability (Table 7 and 8) show that the Turasha catchment is experiencing a delicate balance. The situation is bound to have gone worse since that time because of increased population as per the projected figures for 1993.

Table 8 shows that the Turasha catchment was already experiencing acute population pressure in 1979. In 1979 the per capita agricultural land availability was about 0.4 ha and was down at 0.26 ha in 1990.

Table 6: **Summary of settlement schemes in the hihlands**

Type of Scheme	No. of individual schemes	Estimated final acreage	Estimated final Plots
H.M.G/W.G. Schemes (High density schemes)	82	801,872	26,231
I.B.R.D/C.D.C. (Low density Scheme)	36	187,757	5,166
Co-operative schemes	15	172,107	1,256
Ol Bolossat	1	10,826	150
Ol Kalau Salient	1	119,916	1,829
Kilombe (Administered by local authority)	1	12,434	100
Total	136	1,304,912	34,732

Source: Kenya Settlement Department Annual Report 1965/66

Table 7: **Per capita land availability (1979 and 1993)**

Location	Total No. of people		Total land area	Per Capita land availability (ha/person- all land)	
	1979 (census)	1993 Projection	(Km^2)	1979	1993
N.Kinangop	13,819*	22,493*	260*	1.9**	1.2**
Magumu	11,318*	18,681*	190*	1.7**	1.0**
Wanjohi	12,000*	19,443*	203*	1.7**	1.0**
Kipipiri	16,094*	26,305*	244*	1.5**	0.9**
Geta	11,887*	19,442*	61*	0.5**	0.3**

Source: *-Ministry of Planning and National Development
**-Author

Table 8: **Per capita agricultural land (1979 and 1993)**

Division	Area of agricultural land	No. of People		Agricultural land per person (ha/person)	
	(km^2)	1979	1993	1979	1993
Kinangop	230*	61,199*	90,973*	0.38*	0.25**
Kipipiri	188*	44,399*	65,973*	0.42*	0.28**

Source: **-Author
*-Ministry of Planning and National Development

1.6. AVAILABLE INFORMATION

1.6.1 Remote sensing data

Aerial photographs and satellite imagery provide a comprehensive record of what the land was like in the past and are therefore indispensable tools for any study of trends in land use. They enable land to be viewed much more quickly than by any other means and they provide valuable information on the changes which may have taken place.

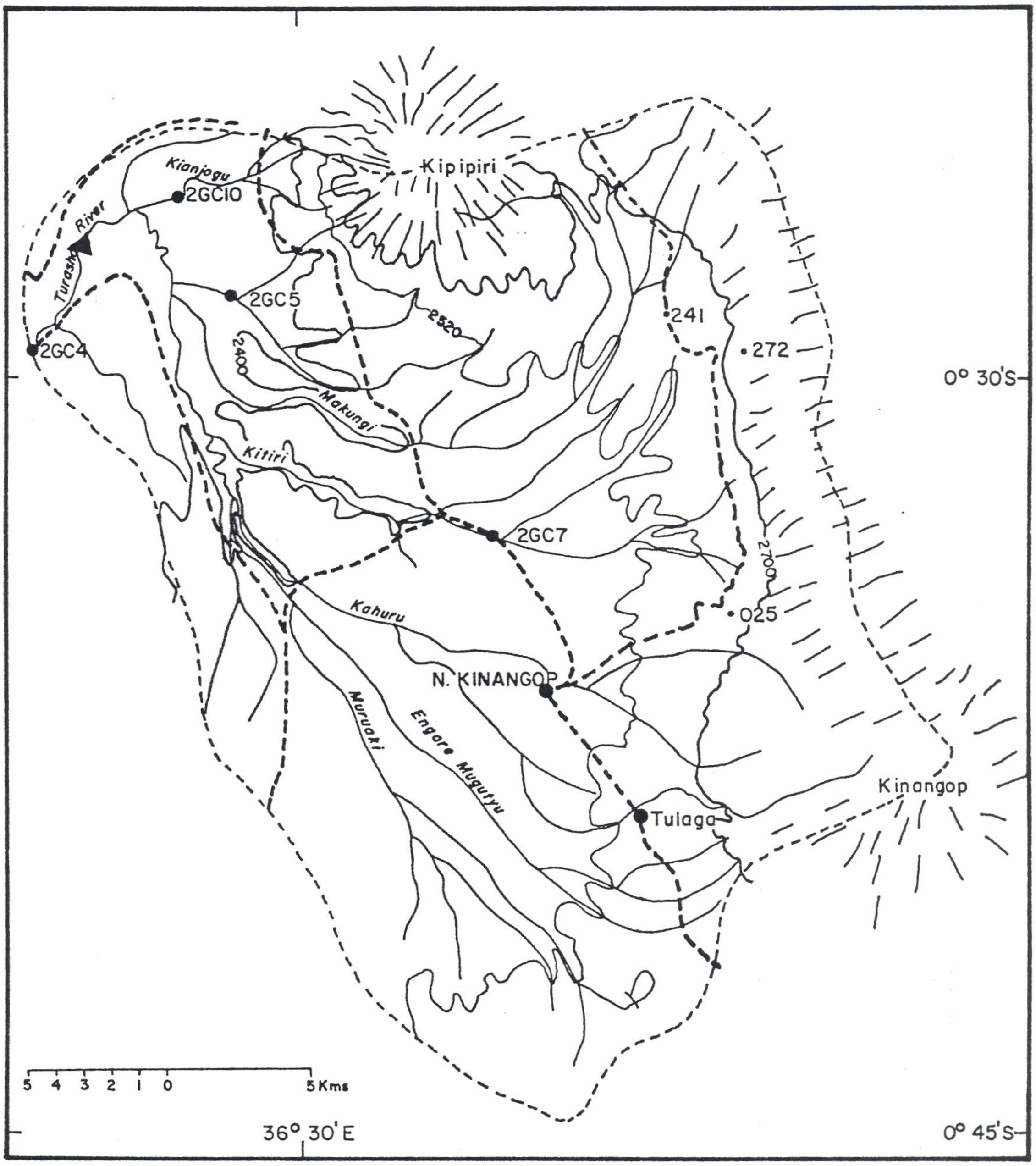
The Turasha catchment was covered during air photography in 1947 and 1948 at scale 1:24,000, in 1962 at scale 1: 12,500 and 1976 at scale 1: 12,500. Satellite pictures covering the area are locally available for 1987 and 1988 at scale 1:100,000 and 1:200,00 respectively. Remote sensng pictures posed certain specific limitations curtailing their use in this study.

The air photographs for 1948 were rendered useless due to a great amount of cloud cover. Those for 1947 did not provide complete area coverage. In any case both river flow and sediment data are unavailable for these periods. The 1962 photographs provided a complete coverage, had a negligible problem of cloud cover and were taken at a fairly suitable scale. They also coincided with the base period taken as 1962 for which river flow data are available. The suspended sediment data observed between 1953 and 1956 have been adopted for this period as there are no other data available around this time. The satellite imagery providing a complete coverage of Turasha catchment is available for 1988 at a scale of 1:200,000. The one for 1987 is at a better scale of 1:100,000 but offers only partial coverage. The imagery for 1988 has therefore been preferred although the scale is rather too small because it provided a total cover for the study area at one scale. Because of the small scale such features as river valleys which were distinguishable on the aerial photographs could not be traced. For this reason some adjustment has to be made for the area of those land use units which may have 'consumed' the river valleys evident on the 1962 photography.

1.6.2 River flow data

There are a number of river discharge measuring stations on the Turasha river and its tributaries. These include 2GC1, 2GC4, 2GC5, 2GC6, 2GC7, 2GC8, 2GC9 and 2GC10. The location of some of these is shown in Fig.9. Most of these operated for only short periods and were thereafter abandoned for unknown reasons. The only station which seems to have been fairly consistently observed is 2GC4 at the outlet of the Turasha catchment. It has records dating back to 1952 on daily basis even though quite frequently observations were not made. The records have been converted into flow volumes (m^3) and computerized by the Ministry of Water Development head office. The reliability of the river flow records is subject to be affected by the quality of the stage records and also by the precision of the relevant rating tables. For this reason homogeneity tests have to be applied. This is discussed in section 2.7.1. Continuous records are available at 2GC4 between the years 1954 and 1983. These have been used to extract the flood hydrographs such as hose shown in Fig.10A through 10F. These hydrographs have been used to provide peak flow discharge used in flood frequency analysis in section 2.8.

Fig. 9 : Map of Turasha Catchment showing Gauging Stations



Source : Mochiemo (1992)

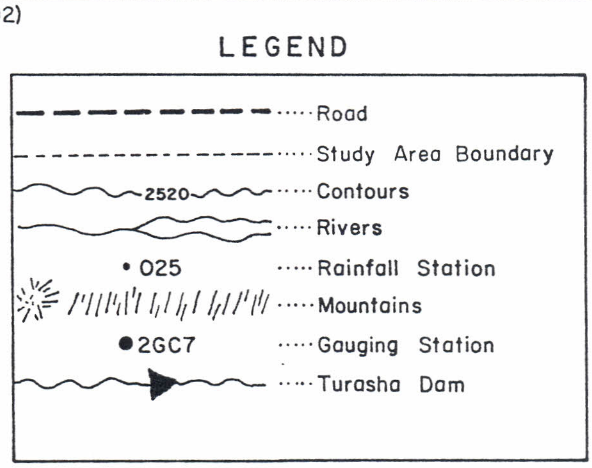
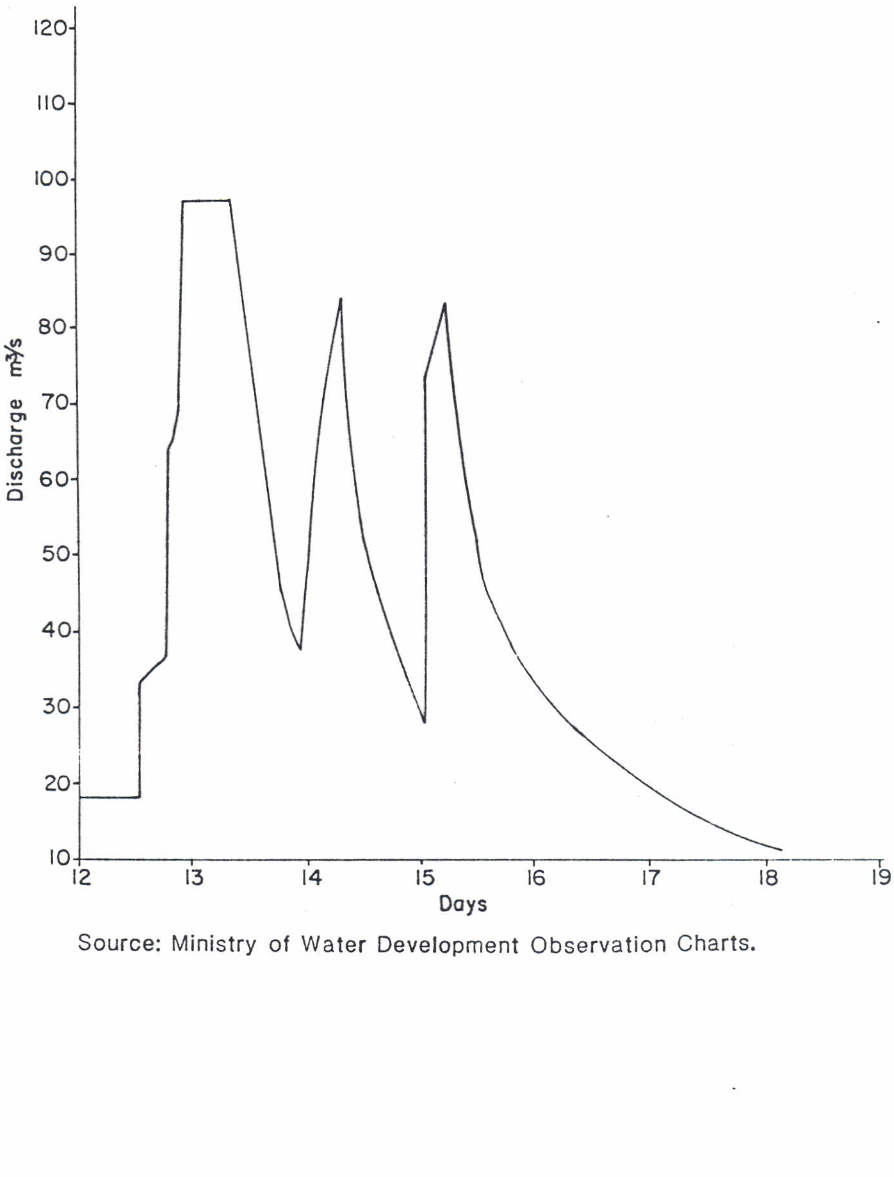
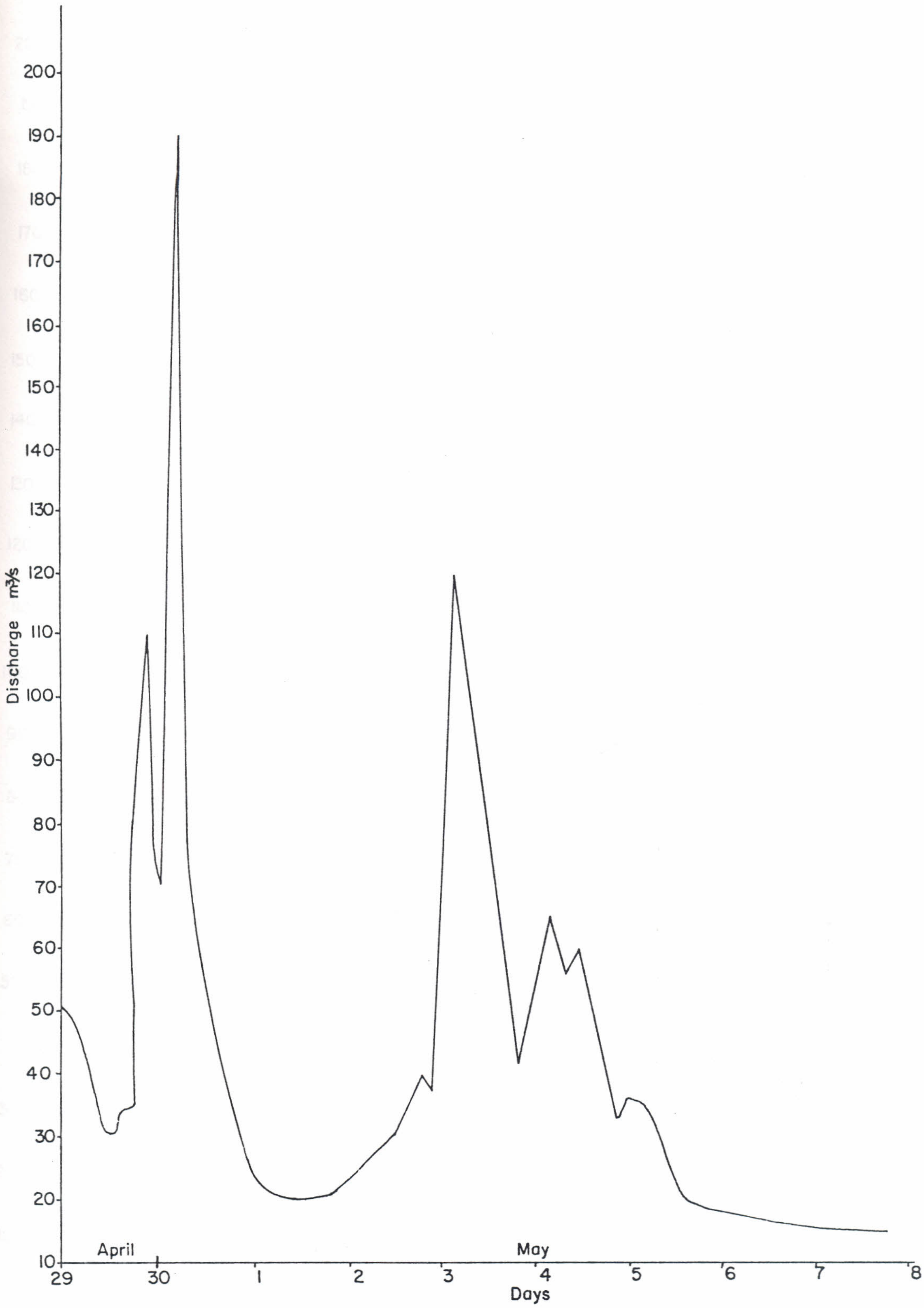


Fig. 10A: Flood Hydrograph in May, 1958 at 2GC4



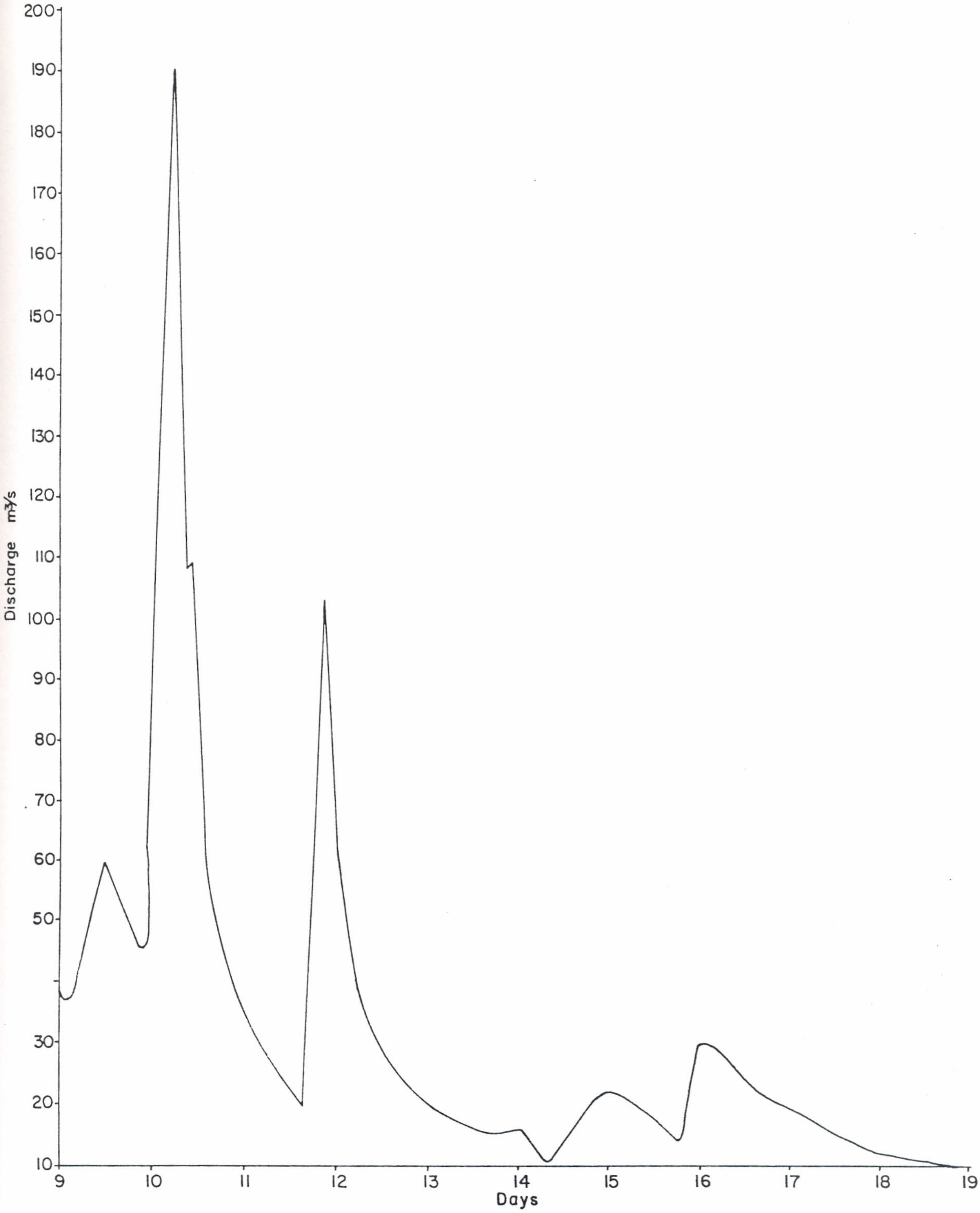
Source: Ministry of Water Development Observation Charts.

Fig. 10B : Flood Hydrgraph in April and May 1977 at 2GC4



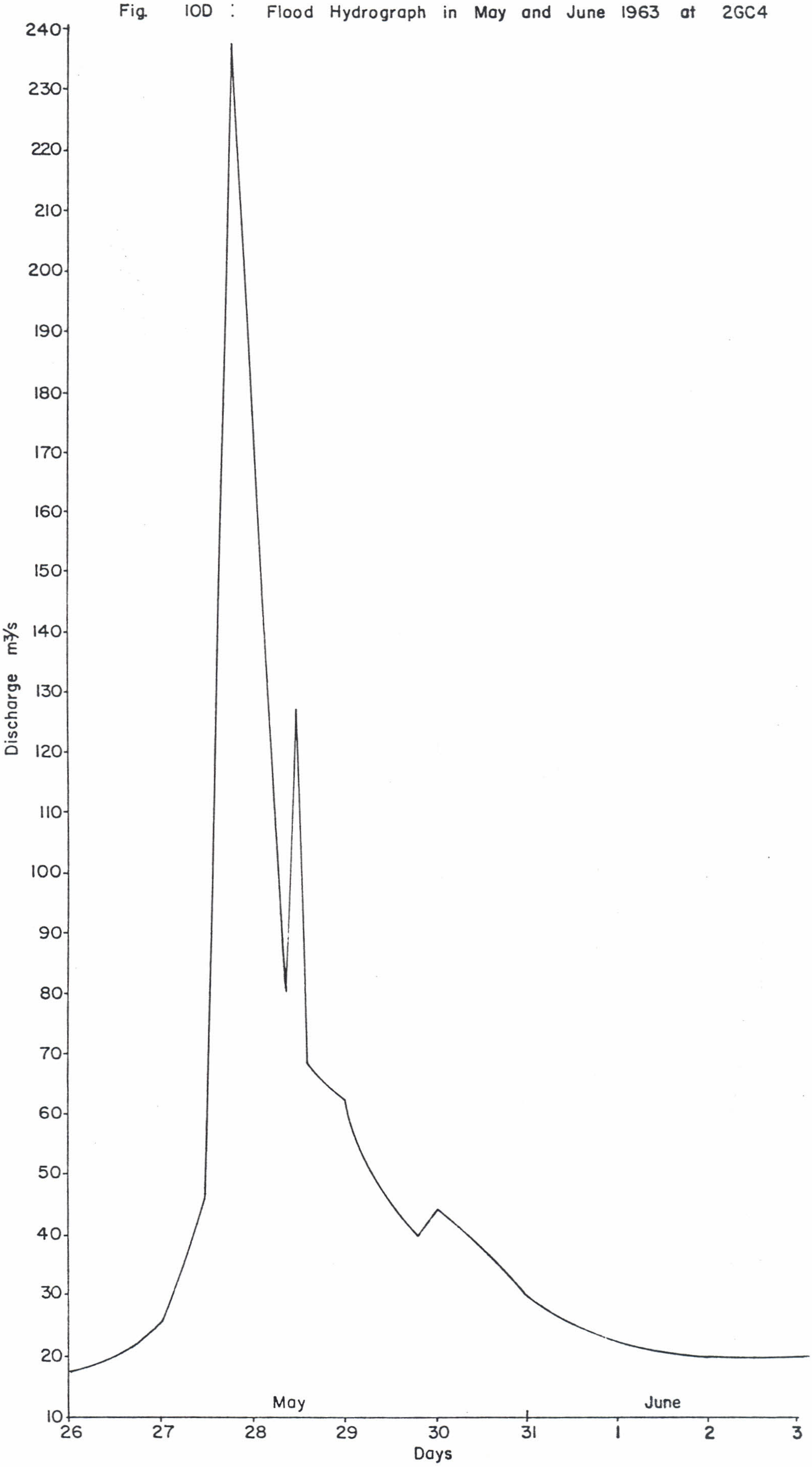
Source: Ministry of Water Dev. observation charts

Fig. 10C : Flood Hydrograph in May 1962 at 2GC4



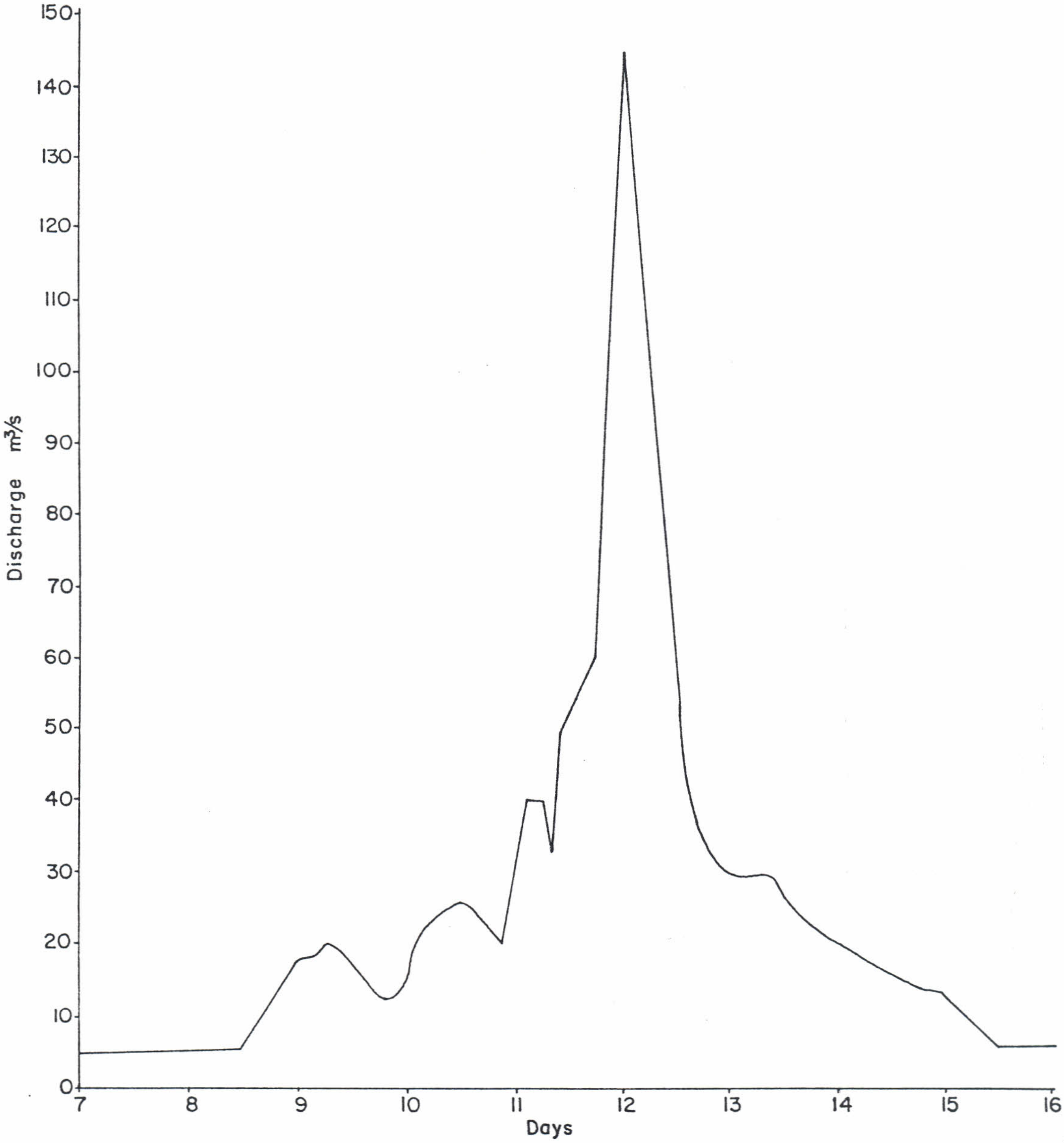
Source: Ministry of Water Dev. observation charts

Fig. 10D : Flood Hydrograph in May and June 1963 at 2GC4



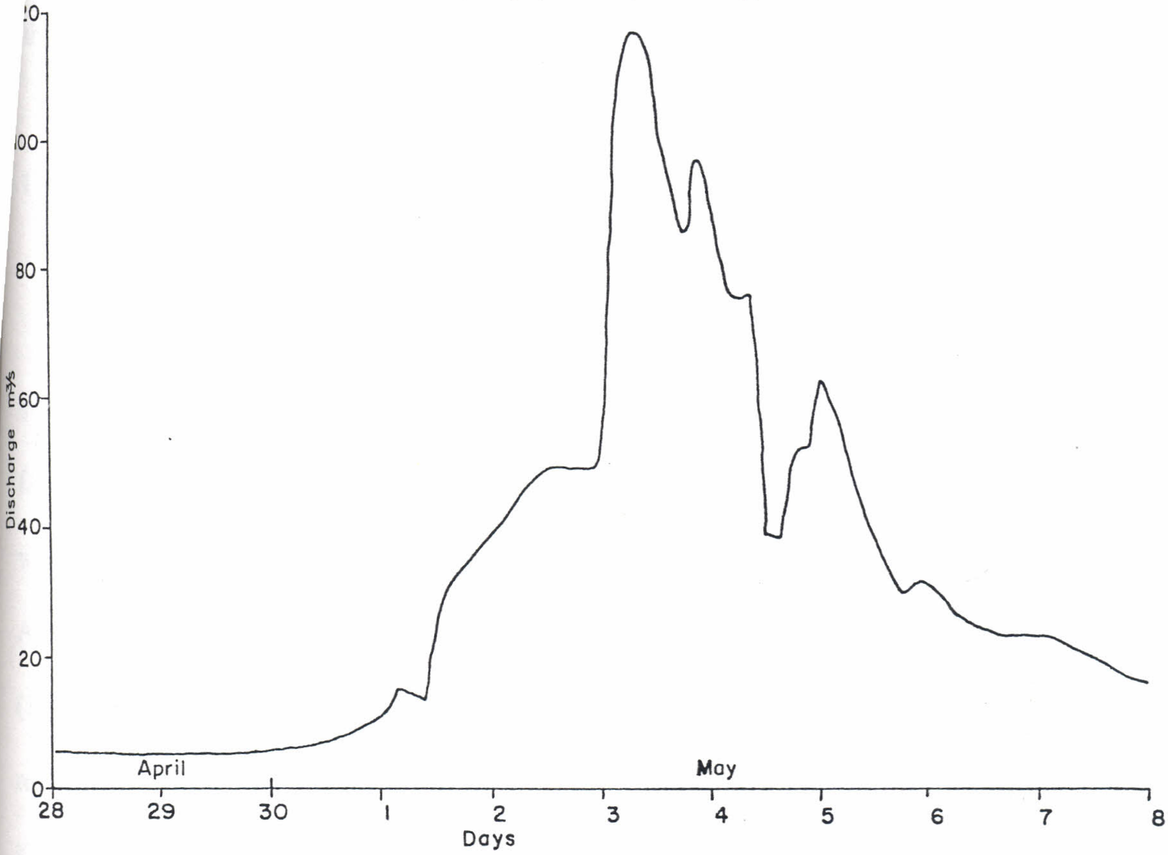
Source: Ministry of Water Dev. observation charts

Fig. 10E : Flood Hydrograph in May, 1967 at 2GC4



Source: Ministry of Water Dev. observation charts

Fig. 10F : Flood Hydrograph in April & May, 1978 at 2GC4



Source: Ministry of Water Dev. observation charts

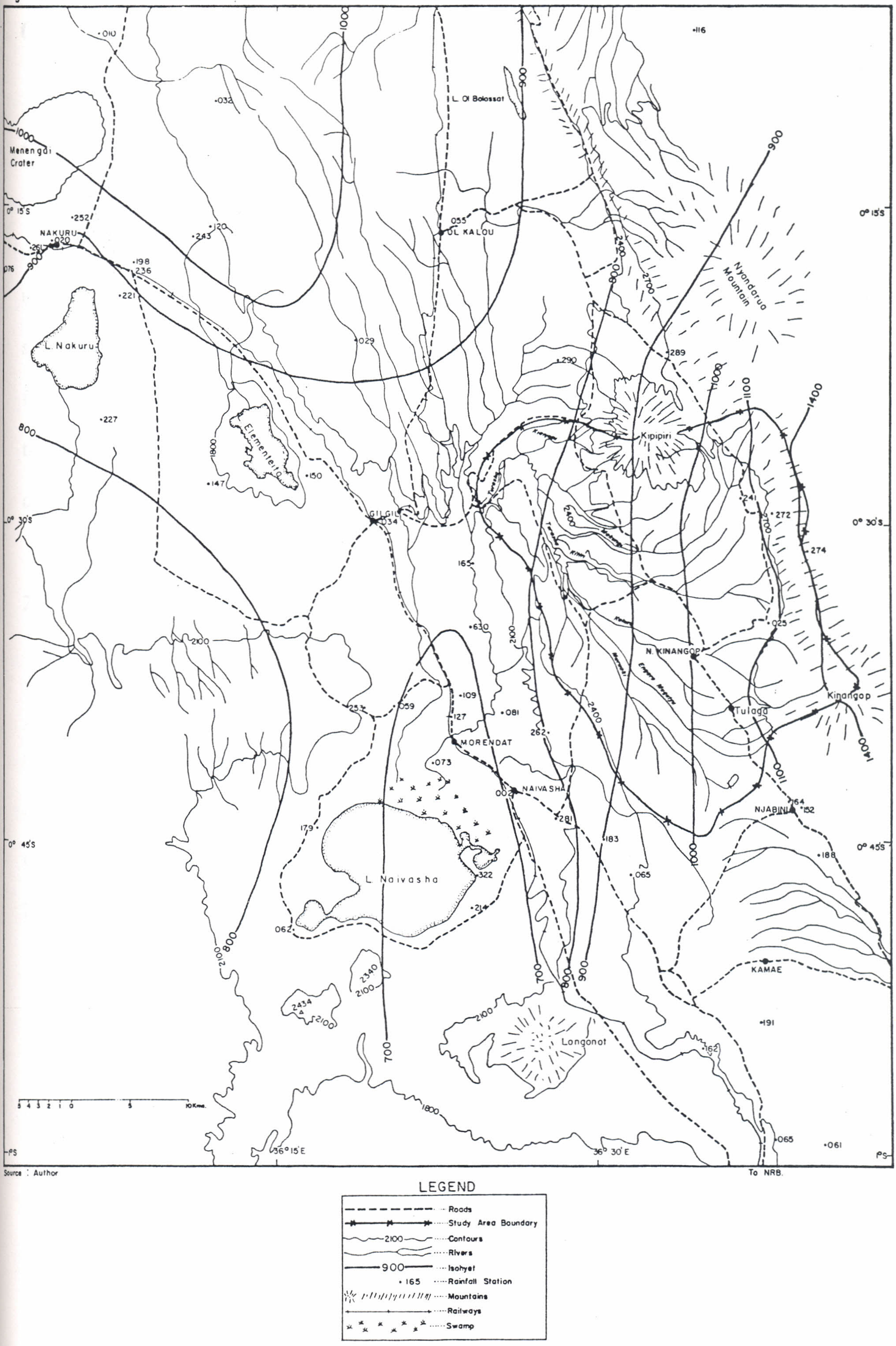
1.6.3 Suspended sediment data

Suspended sediment data observations are generally few. The Ministry of Water Development conducted a fairly systematic suspended sediment sampling and analysis for four years in the mid 1950s. Data are available for the years from 1953 through 1956. Weekly records covering several months during this period are available. These have been used to estimate the annual suspended sediment loads as discussed in section 2.4.

1.6.4 Areal annual rainfall

Twin or multiple watershed experiments which have be carried out to study runoff, use similar watersheds for replication purposes. The reason usually is to provide a control for such factors as climatic change. The substitute for this for such studies as the present one which deals with the same catchment at different periods in time is to test for stationarity in the climatic factors. Areal annual rainfall can be used for this purpose where long-term records are available. WMO (1967) recommends a data sample of at least thirty years and this means that at least sixty years records are necessary to test for stationarity. This is realizable in the study area at the North Kinangop station No. 90.36025 which has maintained observations since 1915. However there is evidence that the Turasha catchment does not receive a homogenous distribution of rainfall. Rather, the rainfall increases with increasing altitude being highest in the Aberdare Mountains and becoming less farther away (Fig.11). There is only this one rainfall station in the study area with a reasonable period of records. For this reason it is necessary to consider records for a larger region and apply the isohyetal method to obtain a more reliable areal annual rainfall as discussed in section 2.6.1.

Fig. 11 : MEAN ISOHYETAL MAP OF STUDY AREA



CHAPTER 2: RESEARCH METHODOLOGY

2.0 INTRODUCTION

This chapter deals in greater detail about the methods applied in this study. The methods used include analysing information on remote sensing facilities namely aerial photographs and satellite imagery. The other methods had to do with field work and include ground surveys, river flow measurements and suspended and solution loads transport sampling. The issue of bedload transport is also discussed here. The other aspect addressed here involves the methods applied to data analysis.

2.1 DELINEATION OF LAND USE TYPES ON REMOTE SENSING PICTURES

One major set of factors which determines the nature of runoff at a river gauging station comprises catchment characteristics which include the area, shape, topography, soil and land use. Among these, it is only the land use characteristics which can change within a short time. The others take very long to change and may be assumed to be constant over short time periods. The land use characteristics were therefore of central interest in this study.

The methods adopted in this study were based on air photo and satellite imagery analysis. Air photographs were available for 1947, 1948, 1962 and 1976. However, owing to problems of cloud cover and incomplete areal coverage, only photographs for 1962 and 1976 are amenable to analysis. The photographs for 1962 were used to delineate the base land use types because this year marks the approximate transition between European and Peasant settlement. Similarly satellite imagery for 1988 was used to delineate the most current land covers for this period. The mapping of land use enables determination of the temporal and spatial extent of each land use type.

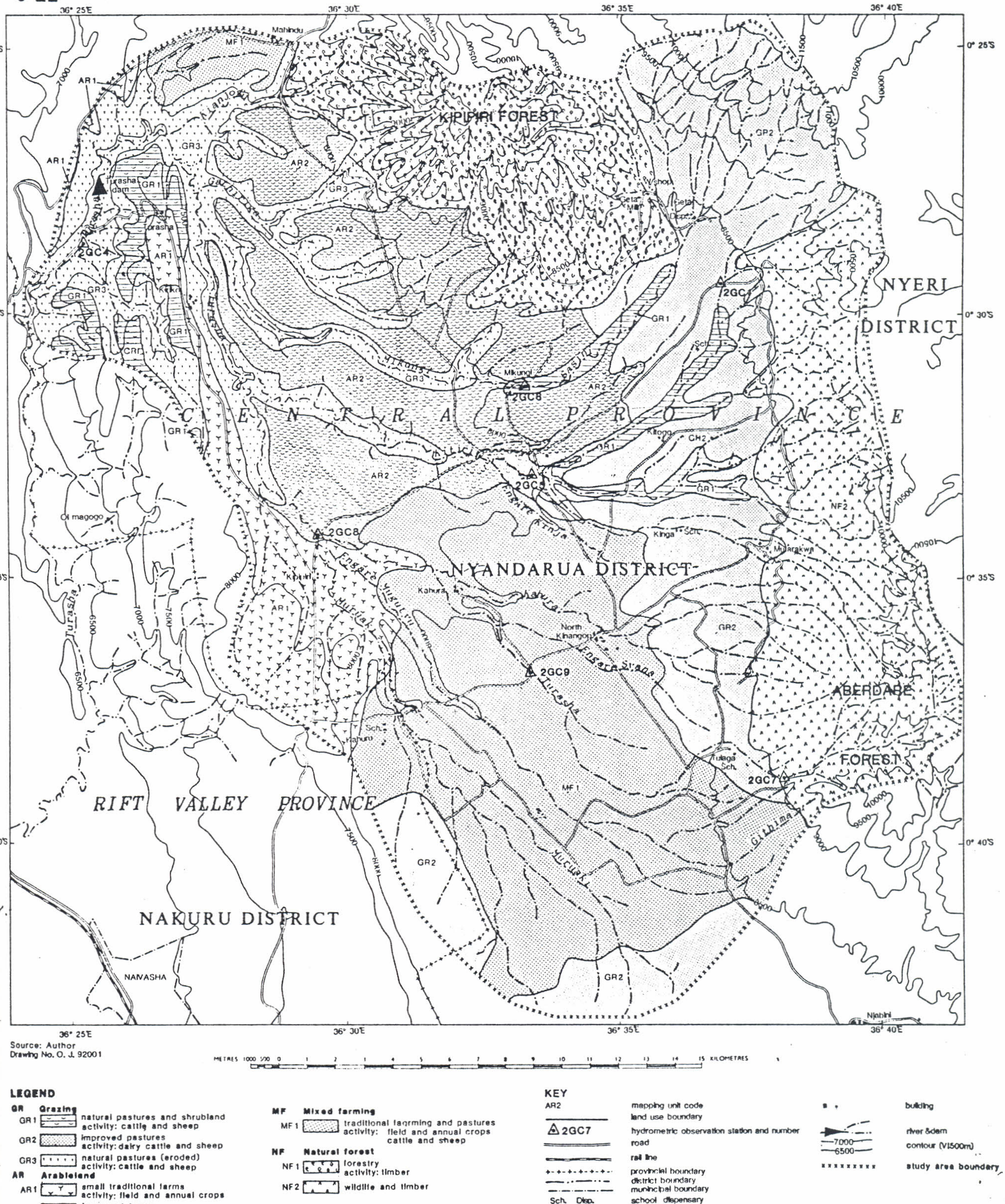
Identification of cultivated land was difficult in some areas where it became apparent that there were small parcels of land which would have to be enlarged before they can be measured and would take a long time to measure. This was particularly so with the satellite picture which was taken at a scale of 1:200,000. Sometimes it became difficult to delineate cultivated areas which may have been left fallow at the time of taking photographs. For this reason it became necessary to apply field checks as briefly outlined below.

2.2 FIELD METHODS

2.2.1 Ground surveys

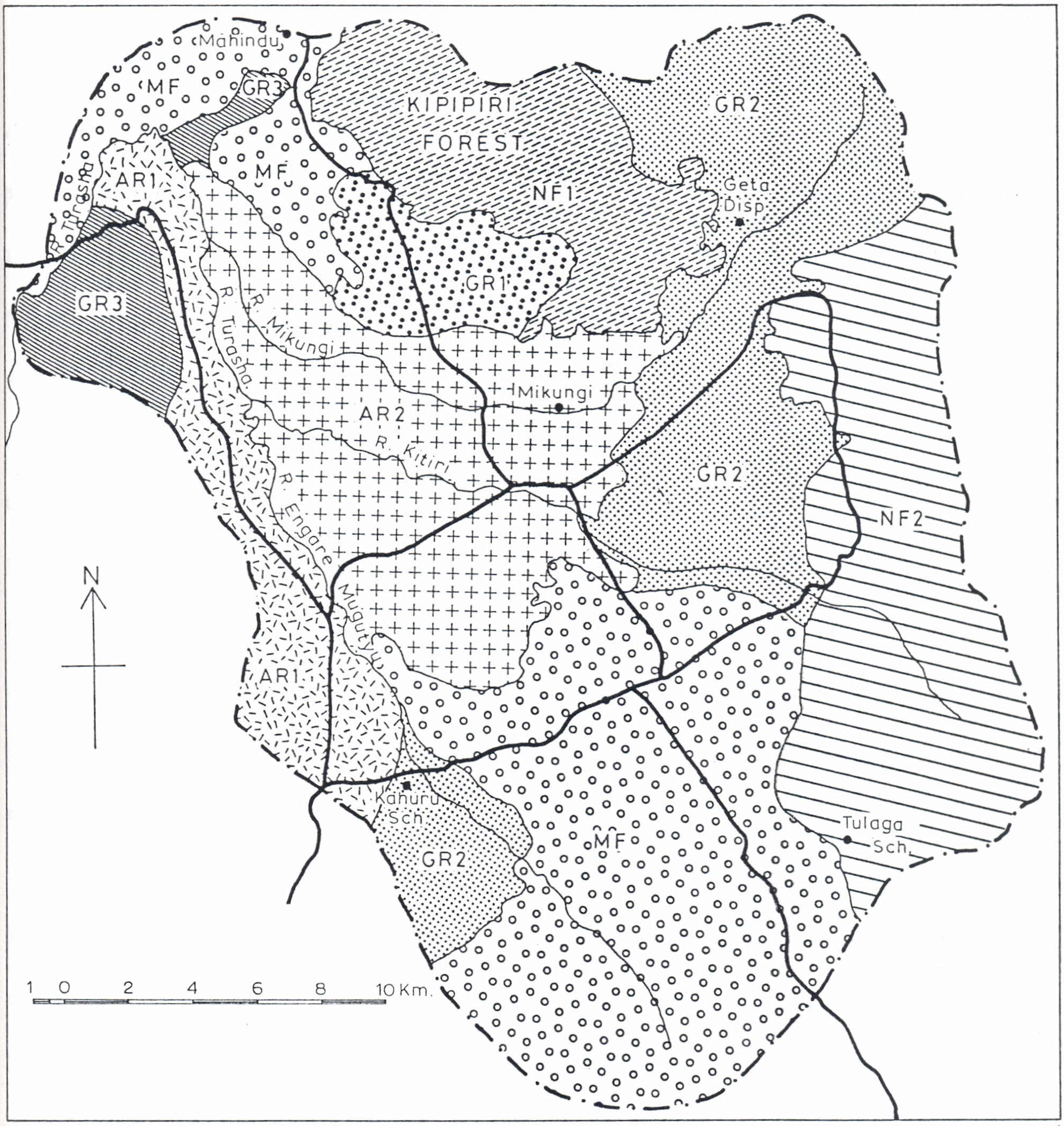
Two field trips each lasting two weeks were made to the study area to, among other things, perform ground 'truthing' as an aid to understanding the actual land covers in the study area. Owing to impassable roads during the heavy rains, the large size of the study area and limited time which was mainly spent on river gauging to obtain accurate flow results to facilitate computation of sediment loads, it was not possible to follow a scheduled sampling procedure. Observations had been planned for every 0.5 km distance along two main routes which provided motorable tracks. At this interval it had been planned that visual estimates be made on an area of 10,000 m^2 on each side of the road and the different land covers marked on the aerial photographs to enable easier and faster photo-interpretation. The compromise made was to make random observations on what was considered the major mapping units. These consisted mainly of grassland (improved or unimproved), mixed farming, arable farming and forests. The forested area was quite distinct and posed no particular problem in its identification. The mapping units delineated are shown in Fig. 12 and 13.

Fig. 12 LAND USE MAP OF THE TURASHA CATCHMENT AREA (1962)



Source: Author
Drawing No. O. J. 92001

Fig. 13: LAND USE MAP OF THE TURASHA CATCHMENT AREA (1988)



Source: Author

LEGEND

GR **Grazing**

- GR1 — Natural pastures and shrubland activity: cattle & sheep
- GR2 — Improved pastures activity: dairy cattle and sheep
- GR3 — Natural pastures (eroded) activity: cattle and sheep
- MF — Mixed farming (traditional farming and pastures activity: field and annual crops cattle & sheep)

AR **Arableland**

- AR1 — Small traditional farms activity: field and annual crops.
- AR2 — Improved farms activity: field & annual crops.

NF **Natural Forest**

- NF1 — Forestry activity: timber
- NF2 — Wildlife and timber.

- Land use bounda
- Road
- Building
- River
- Study area bou

2.2.2 Sediment transport

Sediment moves in the stream as suspended sediment in the flowing water and as bedload which slides or rolls along the channel bottom. Saltation is used to describe the movement of particles which seem to bounce along the bed. These processes are not independent. Material which appears as bed load at one section may be in suspension at another. Wash load consists of the fine material washed into the stream during rainfall and which normally travels through the system without redeposition. It consists of the finest particles of silt and clay that are washed to the rivers. Suspended bed material load consists of mainly silt and fine sand and a little coarse sand which is deposited intermittently on the bed as it moves downstream. The wash load material and the suspended load constitutes what is often referred to as the suspended sediment load of a stream. In turbulent flow the gravitational settling of particles is counteracted by upward transport in turbulent eddies. Since the concentration of suspended material is greater near the bottom of the stream, upward moving eddies carry more sediment than down-ward moving eddies. The system is in equilibrium if gravity movement and turbulent transport are in balance and the amount of suspended material remains constant. Many analytic and experimental studies of suspended-load transport exist. Most effort has been directed toward deriving a function which would describe the vertical variation of sediment concentration in the stream. Such a function combined with a vertical distribution of velocity would permit calculation of suspended-load transport. However, such a function can only apply to a limited particle-size range and must be summed over the total range of particle size. Further, large and variable wash-load component also precludes a reliable computation of total suspended load. Hence, methods of suspended load-measurement independent of a knowledge of the sediment-concentration gradient are applied. One such common method is through the use of a current meter. It was used in the present study as will be outlined below.

.2.3 Suspended sediment measurement

Sampling and analysis for suspended sediment loads was carried during the short rains in November 1991 and also during the long rains of April 1992. These two periods provided a range of flow conditions which was considered reasonably representative for the study because these are the times when the best distribution of rainfall over the entire catchment can be expected. The rainy seasons offer the best periods for sampling because this is the time when runoff emanates from all parts of the catchment thereby giving a weighted areal distribution of runoff and hence a fair picture of sediment transport rates.

A total of twenty one samples were obtained from the gauging station at 2GC4 situated at the outlet of the catchment. Following the completion of the Turasha Dam in 1991, 2GC4 now lies downstream of the dam. Therefore to obtain representative suspended sediment samples, sampling and gauging had to be done upstream of the dam where it was clear the backwater influence of the reservoir cannot be felt as the water was flowing freely.

Samples were secured in a half-litre DH-48 depth integrating hand sampler. This includes one sample collected from a roadside storm runoff at the upper part of the catchment. The depth integrating sampler was lowered through the river and then raised to the surface to obtain an integrated sample with the relative quantities collected at any depth being proportional to the velocity (or discharge) at that depth. Traverses were made at vertical sections spaced 0.5 m apart across the river to determine the total suspended sediment load for the sections. This approach minimises the error in estimating the sediment loads through its integrating approach. The method is, however, rather inaccurate at low sediment concentration but is acceptable when the concentration is greater than 0.1 gm/l as was the case in the present study. Because of the shape of the sampler, the nozzle could not be lowered to the riverbed and consequently some portion of the depth near the bed was not sampled. This may represent a large error at shallow depths (Colby, 1957). Manual sampling proved a difficult method to capture the high flow peaks due to inaccessibility of the observation points after rains.

The collected samples were analysed at the Ministry of Water Development's Central Water Testing Laboratory in Nairobi. The samples were filtered through Whatman GF/C filter paper with circles 9.0 cm diameter and the sediments dried. The concentration of suspended sediment was determined as the difference in filter paper weight after and before filtration expressed in mg/l of dry sample.

In order that sediment loads could be calculated, concurrent current meter measurements were made at six-tenths of the mid-section depth to obtain the number of revolutions for a fixed duration of 50 seconds at the same vertical sections that were sampled. An A. Ott current meter No. 69029 on a rod of 20 mm diameter was used. The total discharge was obtained by computing the average velocity in each vertical using a conversion formula pertinent to the equipment used, and then multiplying it with the area of the vertical section extending half-way to adjacent verticals. The formula used was:

$$V = 0.2269\,N + 0.026 \quad \text{when } N < 0.64$$

$$V = 0.2505\,N + 0.011 \quad \text{when } N > 0.64$$

Where:

N = Number of revolutions per second

V = Velocity in meters per second.

The river sections obtained are shown in Appendix A together with the total discharge through each of them.

The product of total discharge and sediment concentration yields the sediment load for the required period. In computing sediment loadings, it is assumed that one litre of water weighs one kilogramme. When this is the case, the number of mg/l is equivalent to the number of parts per million. The results of the sediment loads calculated are as shown in Table 9. These sediment loads are, for the purposes of this study, approximated to the land use conditions of

Table 9: Suspended sediment data upstream of Damsite

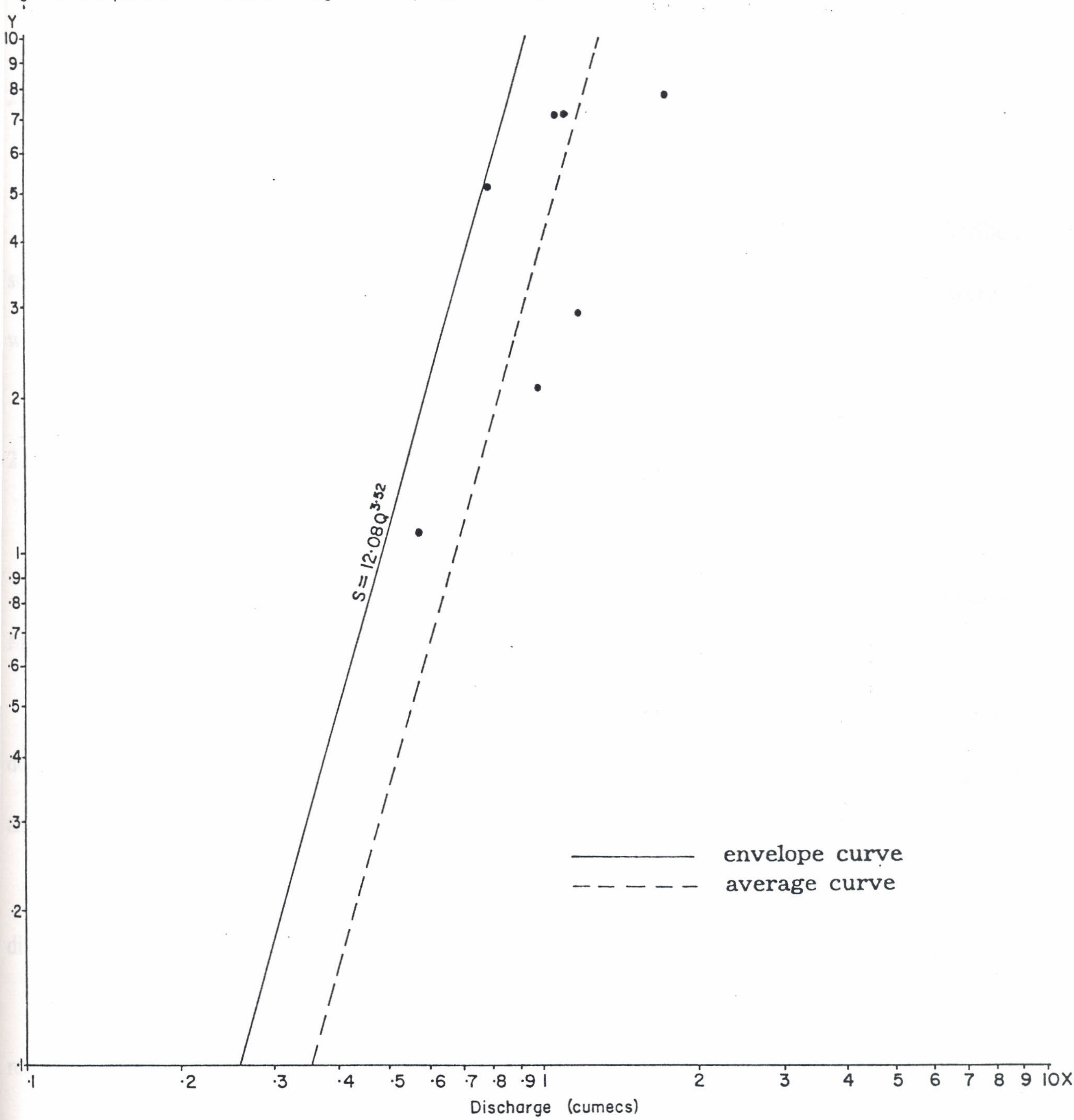
Date sampled	Concentration of suspended sediment solids (mg/l)	Suspended sediments (tons/day)
24.11.1991	12.8	1.931
25.11.1991	5.0	0.489
26.11.1991	5.0	0.489
27.11.1991	42.8	3.387
28.11.1991	30.5	1.945
29.11.1991	75.5	5.257
30.11.1991	22.2	1.872
1.12.1991	28.6	1.702
2.12.1991	20.5	1.262
3.12.1991	51.8	4.849
4.12.1991	24.3	7.928
15.4.1992	19.6	2.042
16.4.1992	28.8	2.978
17.4.1992	18.7	1.482
18.4.1992	4.3	0.341
19.4.1992	76.0	7.311
20.4.1992	38.4	3.393
21.4.1992	34.8	2.670
22.4.1992	*1506.5	_
23.4.1992	10.1	0.800
24.4.1992	23.5	2.143

*-Storm runoff on the roadside

1988 as no more recent satellite pictures were available.

The daily suspended sediment loads obtained were regressed against the flows on a log-log paper to reduce the scatter of extreme values. The resultant regression line is shown in Fig.14A. On the same curve an enveloping curve parallel to the regression line has been fitted and its equation determined. This curve has been established using relatively few observations but owing to their

Fig.14A: Suspended Sediment rating Curve upstream of Turasha dam(1991-1992)



Source : Author

representativeness as has already been noted above they may still give a fair picture of what could be expected from long term data. The envelope curve has been used rather than the regression line because peak flows carry by far the majority of sediments. Using the envelope equation, predicted sediment loads have been computed and are shown in Table 12 for the range of flows 0.1-3.0 cumecs.

2.2.4 Solution load

Measurements for solution loads were carried out in the same way as that described for suspended sediment measurement. At each sampling site an equal number of samples were taken within the same stream cross-section.

2.3 Laboratory physical and chemical tests

Water collected from River Turasha was subjected to physical and chemical tests at the Ministry of Water Development's Central Water Testing Laboratory in Nairobi.

The methods used are only briefly discussed below. Details of the analysis are well documented by Brown, Skougstad and Fishman (1970), Apha (1971), Rainwater and Thatcher (1960) and Hem (1970).

The colour of the water was determined by comparison in a Lovibond Nessleriser using a disc calibrated in Hazen Units with distilled water as their reference.

Turbidity was determined instrumentally by use of Hach Model 2100A Turbidimeter and results expressed in N.T.U. The electrical conductivity was measured with a wheastone bridge mark

'able 10: Water chemistry data

Parameter	Unit	Value						
		May, 1974	April, 1992					
		21	21	22	23	24		25
pH	pHunit H.U.	7.1 90	8.1	7.7	7.8	7.5	7.7	7.3
Colour	mgPt/l	-	50	-				
	J.T.U.	14	-	35	60	85	15	70
Turbidity	N.T.U.	-	3.4	-				
			-	12	13	25	10	20
Permanganate	mg O_2/l	-						
(20 min boiling)			-	8	7	11	7	12
	μs/cm	86						
Conductivity(25°C)			75	126	128	110	122	115
	mg/l	59						
Total Hardness			42	60	52	38	58	40
$CaCO_3$		-						
Total alkalinity	"		-	48	50	46	46	40
		-						
Free Carbon dioxide	"		-	4	8	10	8	1.4
Hardness Calcium								
$CaCO_3$	"	9.2						
Hardness Carbonate			10.4					
$CaCO_3$	"	45						
Hardness Non-Carbonate $CaCO_3$			42					
		14						
Calcium Carbonate	"		Nil					
Alkalinity $CaCO_3$								
		Nil						
Bi-carbonate	"		14					
alkalinity $CaCO_3$	"	45						
			13					

V and results were reported in micro-siemens per cm at 25°C.

The pH of the water which is a measure of the effective hydrogen ion activity was measured using a PYE Model 79-pH meter. All the results of the other tests were expressed in mg/l.

sample and adding N/80 potassium permanganate and incubating the sample. The $KMnO_4$ remaining was determined using N/80 sodium thiosulphate.

Free carbon dioxide was determined using N/22 volumetrically by titrimetric method using N/22 sodium carbonate with phenolphthalein as the indicator.

Table 11: Daily loads of dissolved solids

Parameter	Solute Yield (tonnes per day)					
	May, 1974	April, 1992				
Dates	21	21	22	23	24	25
Parameters						
Iron	0.04	0.01	0.04	0.13	0.02	0.14
Manganese	0.00	0.01	-	0.09	-	-
Calcium	-	1.04	1.03	0.76	0.95	0.87
Magnesium	-	0.85	0.40	0.34	0.54	0.35
Sodium	-	1.56	0.76	0.64	0.59	0.86
Potassium	-	0.58	0.40	0.49	0.33	0.86
Chloride	0.51	0.41	0.32	0.43	0.08	0.18
Fluoride	-	0.52	0.03	0.03	0.02	0.04
Sulphate	-	0.06	0.072	0.03	0.19	0.19
Orthophosphate	0.00	-	-	-	-	-
Total Dissolved Solids	-	7.88	6.12	5.70	5.80	6.23

The concentration of oxygen absorbed in four hours at 27°C was measured by acidifying the sample and adding N/80 potassium permanganate and incubating the sample. The $KMnO_4$ remaining was determined using N/80 sodium thiosulphate.

The alkalinity was determined by titration with N/50 hydrochloric acid using phenolphthalein as the indicator. The carbonate hardness was measured by N/50 EDTA titration while the chloride and sulphate concentrations were measured using "EEL" chloride meter and "EEL" nephelometer head respectively.

Potassium and sodium were determined photometrically using a Gallenkamp flame photometer while calcium was obtained by N/50 EDTA titration.

The difference between total hardness and calcium hardness was computed to give the magnesium concentration in the water samples. Manganese was determined using the persulphate method and the colour was compared with the standards to enable concentration determination. Iron was determined by the ammonium thiocyanate method and the colour of the solution was read on sp 600 spectrophotometer. Table 10 shows the water chemistry data. The total dissolved solids (TDS) concentration was obtained by a sample being evaporated on a previously weighed dish and residue dried at 180°C and weighed again to allow for concentration to be determined.

From chemical analyses it was possible to determine the concentration of total dissolved solids at 2GC4. This concentration varied with discharge. For any given discharge it was possible to compute the solute load in tonnes per day from the dissolved solids concentrations. Insufficient data were available to develop sediment transport rating curves to facilitate computation of annual solute yields. Table 11 shows the computed daily yields of the available data for specific parameters analysed. This approach is akin to that applied for the suspended sediment loads calculated earlier.

2.4 ANALYSIS OF SECONDARY SUSPENDED SEDIMENT DATA

Erosional processes can be observed in the rivers that carry the soil away as sediment load. Monitoring river flows for sediment load provides a practical and sensitive means of registering any changes that take place because of changes in the use of land. This is particularly important in areas experiencing a high pressure on the land. Sediment loads in rivers are also of great value as they affect the economic life of dams and reservoirs.

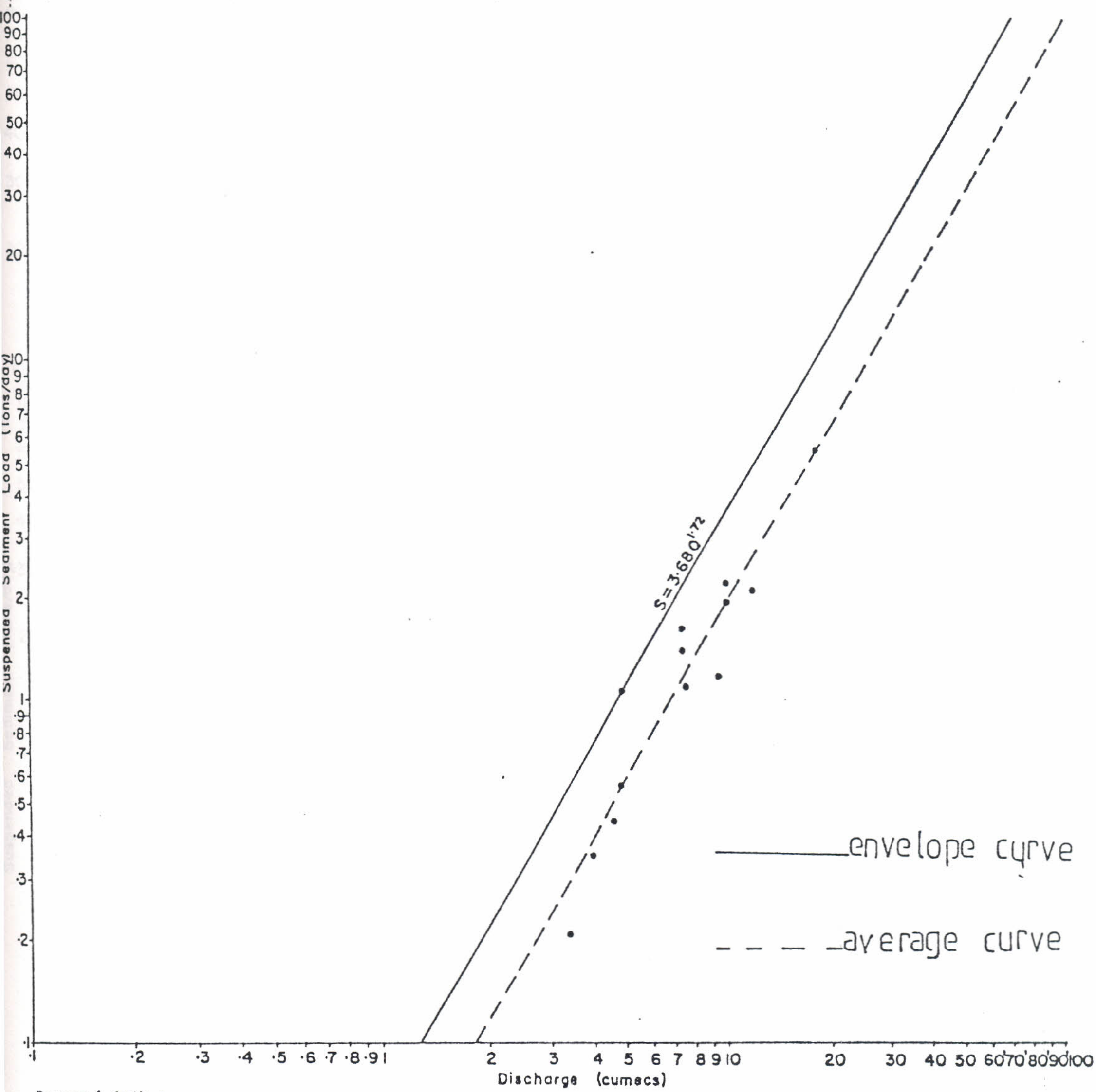
Just like the data on sediment loads obtained during the present study discussed above, secondary data collected by the Ministry of Water Development between 1953 and 1956 at 2GC4 are available. Once more the suspended daily loads were regressed against their respective flows on a log-log paper. The resultant regression lines are indicated in Fig. 14B through 14E. On each of these curves an enveloping curve has been fitted and its equation determined. Again the models so derived have been used to predict sediment loads for the same range of flows applied to the primary data to facilitate comparison. The results are shown in Table 12.

Flow measurements are observed more frequently than sediment measurements. Records, where available, were on daily basis. They can therefore be conveniently combined with the sediment rating curves to estimate the total annual suspended sediment loads. The Flow Duration curve (Fig.15) coupled with the sediment rating curves pertaining to each year was used for this purpose. The flow duration curve provided a weighted average of the range of flows experienced each month while the sediment rating curve provided the pertinent sediment transport rate for the average flow for that month. By summing the products of these two, month by month, the annual sediment loads were obtained.

The annual suspended sediment transport values (Table 13) and respective annual runoff values have been plotted on the Langbein-Schumn (1958) and Douglas (1967) curves relating mean annual sediment production in tonnes/km^2/year to mean annual runoff (Fig.16). From these figures it can be observed that the data fall close to the Douglas curve.

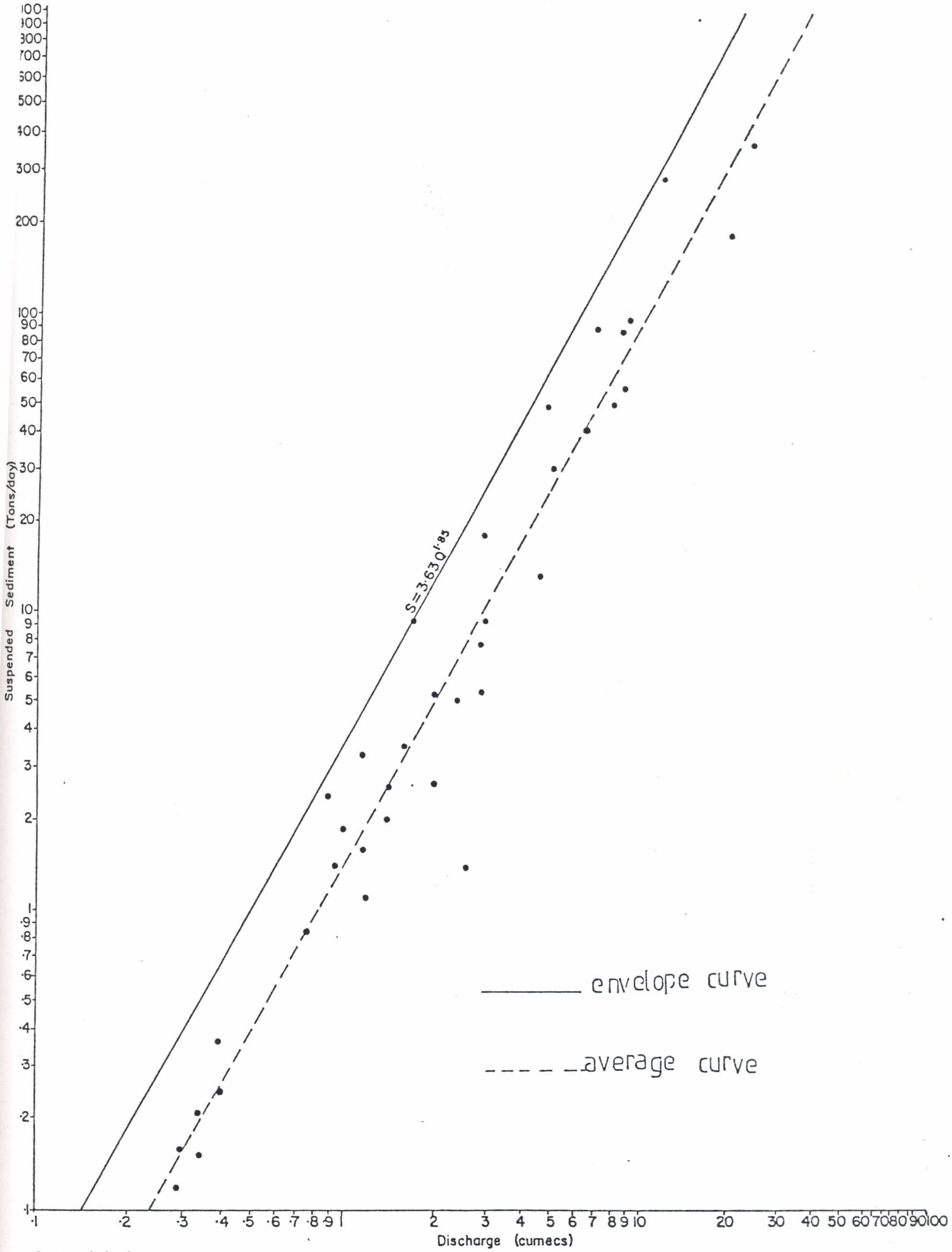
The annual suspended sediment transport data have also been plotted on the Dunne (1977) curves (Fig.17). The data generally fall within the **agriculture > forest** land use. Dunne's curves were mainly drawn from earlier data from various catchments in Kenya. They emphasize the influence of land use on sediment yields. They are a refinement of the Douglas curves.

Fig. 14B: Suspended Sediment rating Curve at 2GC4 (1953)



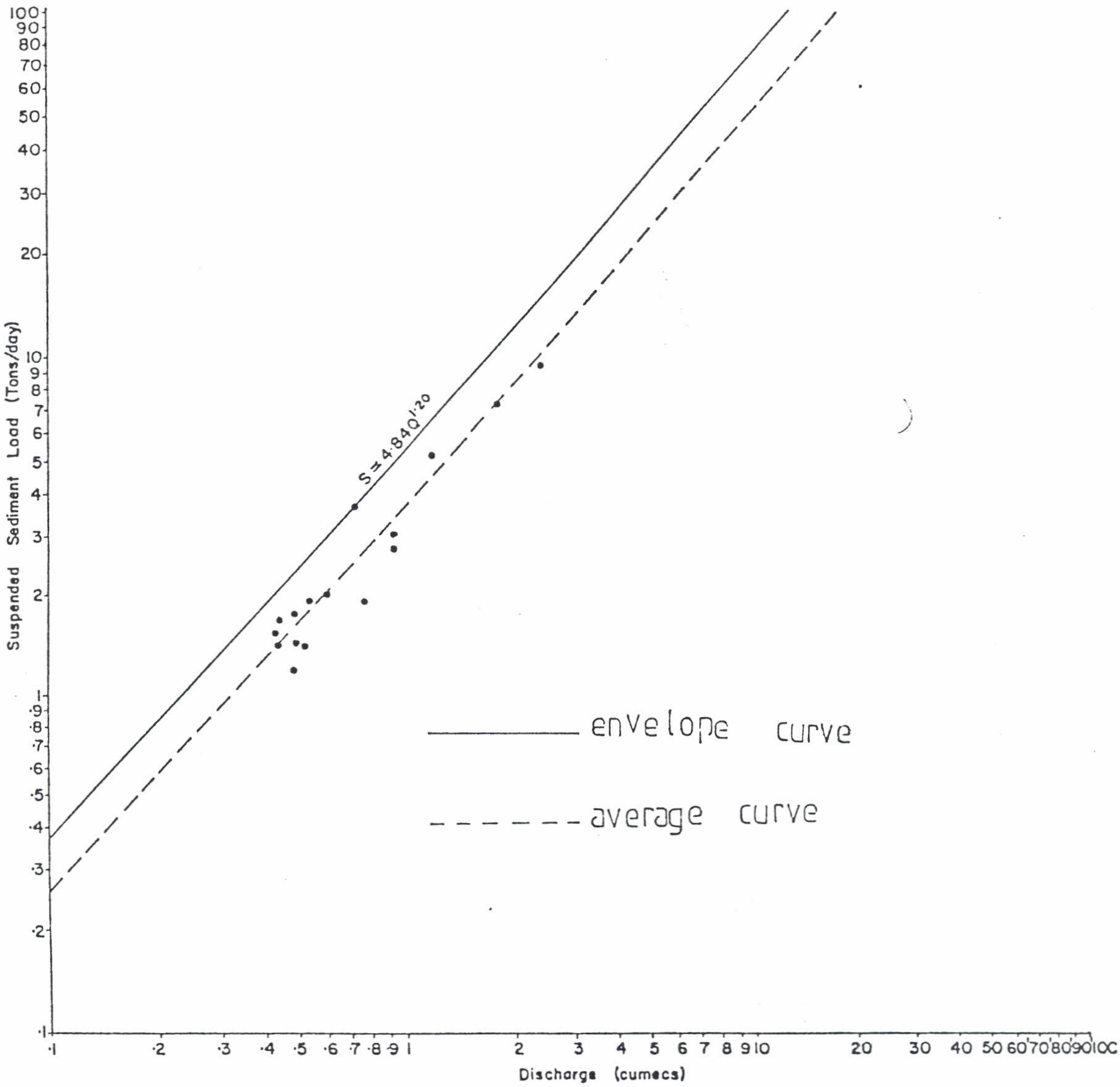
Source : Author

Fig. 14C: Suspended Sediment rating Curve at 2GC4 (1954)



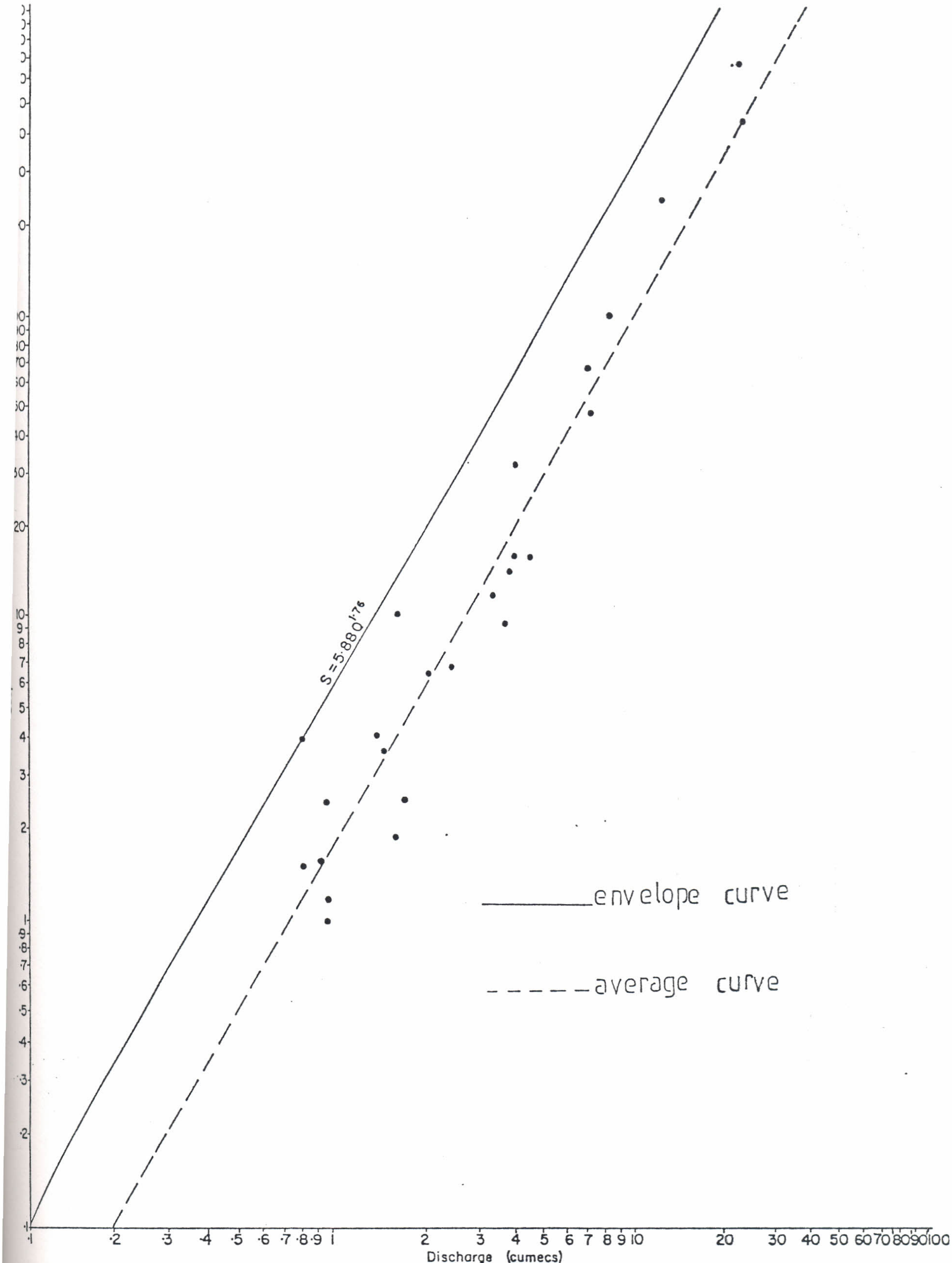
Source : Author

Fig. 14D: Suspended Sediment rating Curve at 2GC4 (1955)



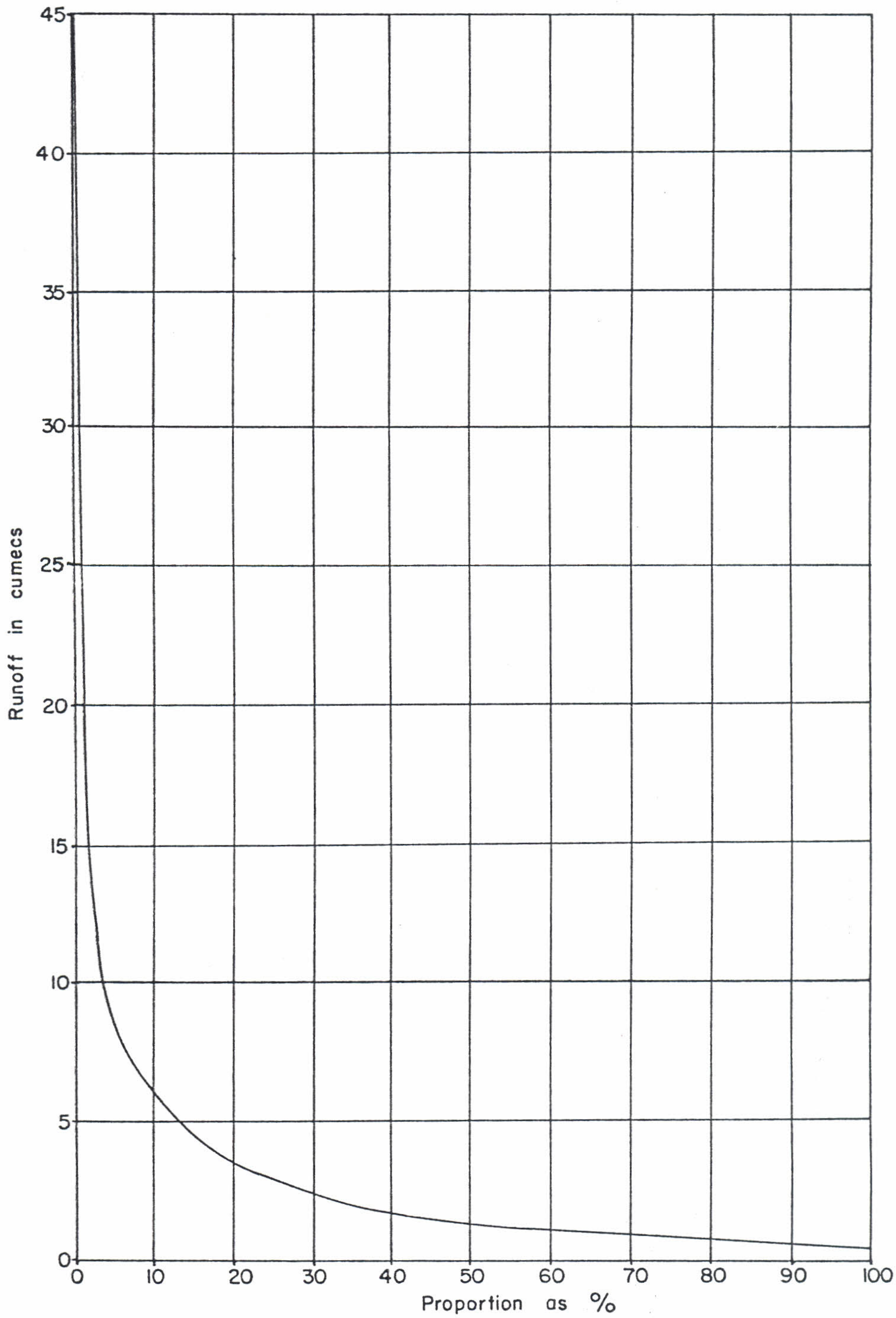
Source : Author

Fig. 14E: Suspended Sediment rating Curve at 2GC4 (1956)



Source : Author

Fig. 15: Flow duration curve at 2GC4.



Source: Author

Fig. 16: Dunne's Curves relating Mean Annual Yield of Suspended Sediment and Annual Runoff within catchments of dominant land use types.

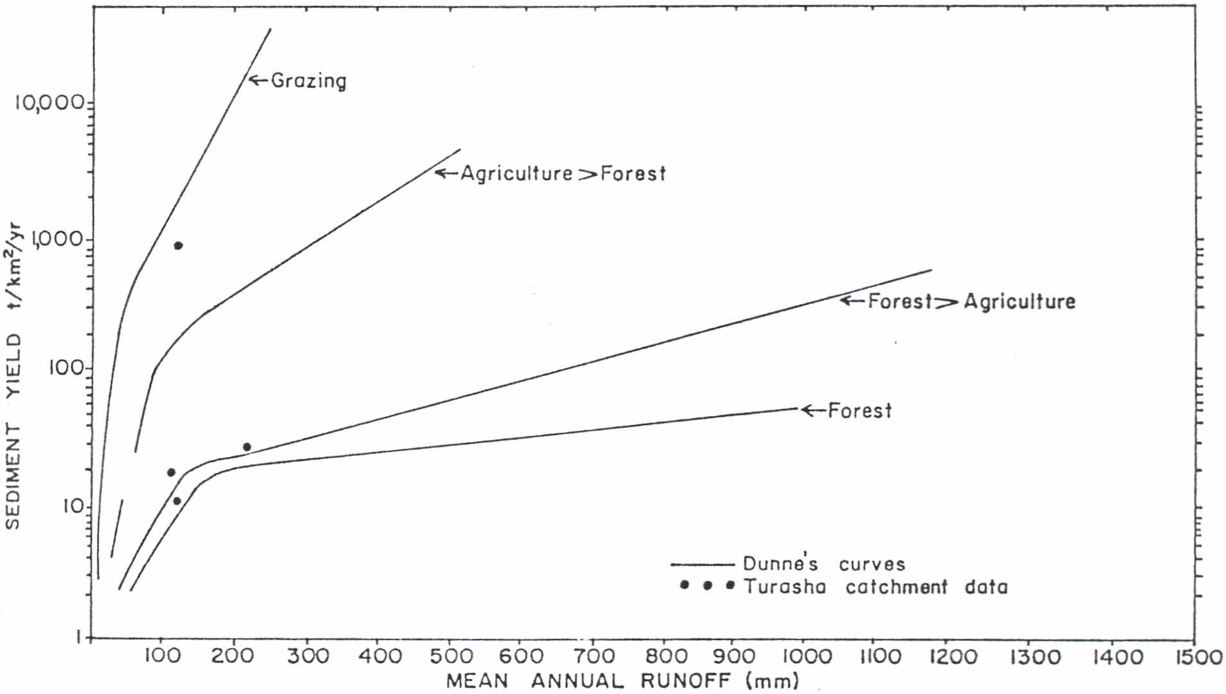


Fig. 17: The relationship between Suspended Sediment and Mean Annual Runoff.

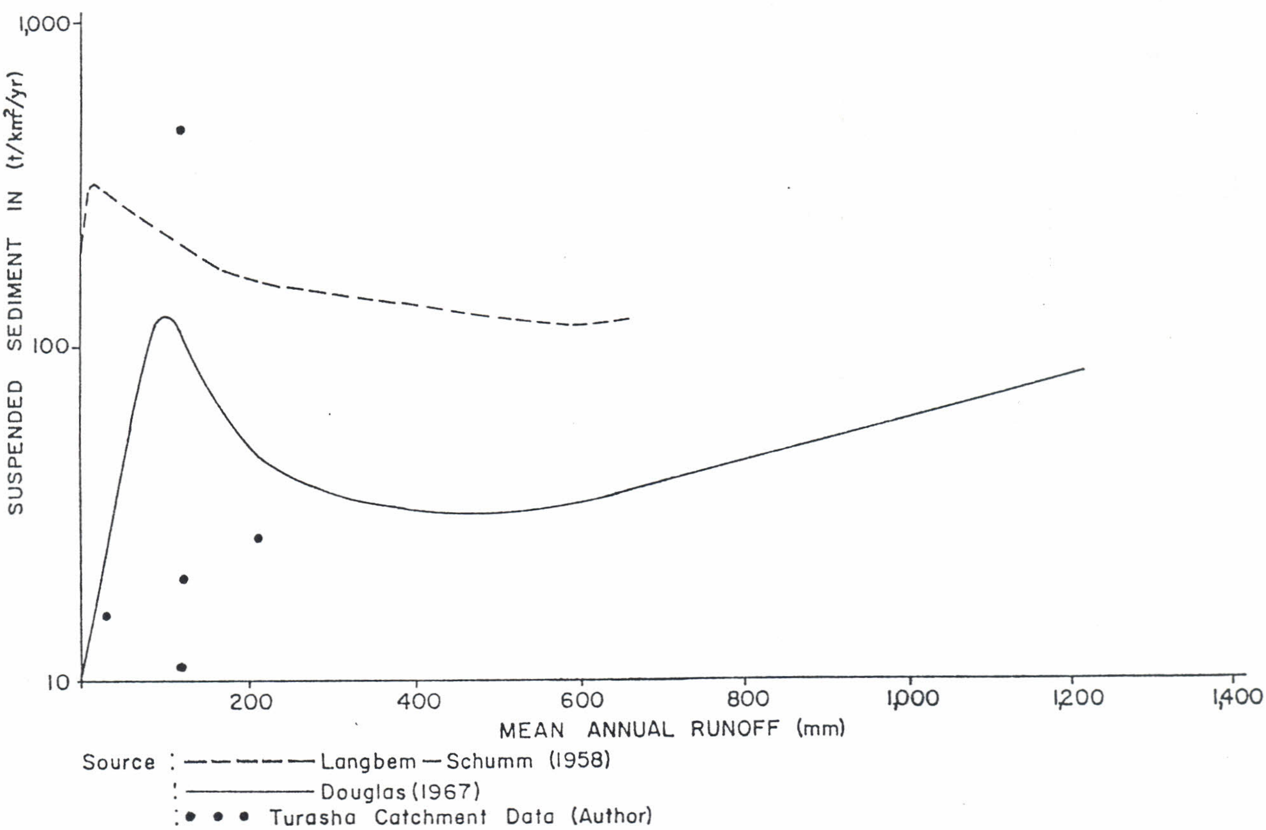


Table 12: Suspended sediment loads (tonnes/day)

Discharge (cumecs)	1953 tons/day	1954 tons/day	1955 tons/day	1956 tons/day	1992 tons/day
0.1	0.07	0.05	0.30	0.10	0.004
0.2	0.23	0.18	0.70	0.35	0.04
0.3	0.46	0.39	1.14	0.71	0.17
0.4	0.76	0.67	1.61	1.17	0.48
0.5	1.12	1.01	2.11	1.74	1.05
0.6	1.53	1.41	2.62	2.39	2.00
0.7	1.99	1.88	3.15	3.14	3.44
0.8	2.51	2.40	3.70	3.97	5.51
0.9	3.07	2.99	4.26	4.88	8.34
1.0	3.68	3.63	4.84	5.88	12.08
1.1	4.34	4.33	5.43	6.95	16.90
1.2	5.04	5.09	6.02	8.10	22.95
1.3	5.78	5.90	6.63	9.33	30.42
1.4	6.56	6.76	7.25	10.63	39.48
1.5	7.39	7.68	7.87	12.00	50.34
1.6	8.26	8.66	8.51	13.45	63.18
1.7	9.17	9.69	9.15	14.96	78.21
1.8	10.11	10.77	9.80	16.54	95.64
1.9	10.10	11.90	10.46	18.20	115.68
2.0	12.12	13.09	11.12	19.92	138.58
2.1	13.18	14.32	11.79	21.70	164.54
2.2	14.28	15.61	12.47	23.55	193.82
2.3	15.42	16.95	13.15	25.47	226.65
2.4	16.59	18.34	13.84	27.45	263.28
2.5	17.80	19.77	14.53	29.50	303.96
2.6	19.04	21.26	15.23	31.60	348.96
2.7	20.31	22.80	15.94	33.77	398.54
2.8	21.62	24.39	16.65	36.01	452.96
2.9	22.97	26.02	17.37	38.30	512.52
3.0	24.35	27.71	18.09	40.65	577.48

Source: Author

Table 13: Annual runoff(mm) and suspended sediment loads

Year	Annual Runoff (mm)	Annual Sediment Load (tonnes/km^2/year
1953	33.7	14.8
1954	113.9	17.0
1955	114.5	10.4
1956	209.4	24.8
1991/92	121.8	425.4

Source: Author

2.5 BED LOAD MATERIAL ESTIMATES

Bed load measurements always present problems because no apparatus or procedure has been universally accepted as completely adequate for the determination of bedload discharges (Hubbel, 1964). It was not possible to obtain a bed load sampler. Ongwenyi (1978) attempted to measure bed load material load in the Upper Tana catchment using a locally designed bed material sampler. He measured the hydraulic parameters of the river and computed bedload according to Einstein (1950). As he has noted, this is a major limitation because the bedload can account for 10-50% of the total load of a stream under consideration depending on geology, land use, slope and climate. He observed through his estimation that bedload accounts for about 6% of the total sediment load for the Tana river at 4DE2. This is in reasonable agreement with the bedload percentage obtained in other tropical environments as shown in Table 14. This figure for example compares closely with

Table 14: Relative Contribution of bedload to total sediment load

River	Proportion of total sediment load (%)	
	Bed load	Suspended load
Upper Tana, 4DE2	6	94
Upper Niger, Baro	6.5	93.5
Lower Niger, Shintaku	5	95
Benue, Yola	6	94
Alpine Mountain River	70	30
Central Asian Rivers:		
a) Mountains	15-23	77-85
b) Hills	5-15	85-95
c) Lowland	1-3	97-99
Volga, U.S.S.R	0.3-2.0	98-99.7
Mississippi, U.S.A.	0.3-10.0	90-99.7
Tyne, Bywell, U.K.	13	87
East Devon Catchments:		
Catchment 1	11	89
Catchment 2	1.3	98.7
Catchment 3	1.8	98.2
Catchment 4	2.8	97.2
Catchment 5	2.2	97.8

Source: Gregory and Walling (1973)

those values obtained for the Upper Niger at Bro, Lower Niger at Shintaku, the Benue at Yola and lies in between the values obtained for the Central Hills Asian rivers and is within the same order of magnitude as obtained in other parts of the world. This is in conformity with the assertions of Sundburg (1967) who has shown that most of the sediment carried by rivers is transported in suspension. Assuming a bed load proportion of 6%, the annual total sediment loads carried by river Turasha have been estimated as shown in Table 15. In computing the suspended loads, use has been made of the flow duration curve developed for 2GC4 shown in Fig.15 coupled with the

Table 15: Mean annual suspended and total sediment loads at 2GC4 (tonnes)

Year	Suspended Sediment Load		Total Sediment Load
	(Tonnes)	mm/year	(Tonnes)
1953	10,682	0.0098	11,323
1954	12,325	0.0113	13,064
1955	7,506	0.0069	7,956
1956	17,961	0.0165	19,039
1991/92	307,960	0.283	326,438

Source: Author

sediment rating curves established for each year of observation. The flow duration curve provided the proportion of the flow within desired ranges while the sediment rating curve provided the pertinent sediment load. By summing the products of these two, the annual sediment loads were obtained.

2.6 TESTING FOR CLIMATIC CHANGE IN THE STUDY AREA

2.6.1 Estimation of Mean Annual Areal Rainfall

The nature of runoff as measured at the river gauging station is influenced by climatic factors, the major one being rainfall. It is therefore necessary to understand the behaviour of rainfall over the study area on a long term basis before trend analysis can be conducted on runoff data. In this way the influence of climate on runoff can be accounted for.

Mean annual rainfall over the study area for the period 1915 to 1985 is available in hydrometeorological records kept by both the Ministry of Water Development and the Kenya Meteorological Department. These data can be used to find out if there has been any significant change in the temporal climatic regime over the study area. If not, any changes in the pattern of runoff may therefore be attributed to changes in land use. The procedure involves dividing the rainfall records into two halves. The first half is treated as one set of data and the second half as another. But before that can be done, an overview of the available rainfall records is necessary.

The data were available for only one station No.90.36025 and it has been observed from Fig.11 that rainfall is not uniformly distributed in the study area. It is higher on higher altitude and decreases with altitude. Therefore to obtain a fair average of annual rainfall over the years it became necessary to employ the isohyetal method to annual point rainfalls from the neighbourhood within the Lake Naivasha and Lake Nakuru drainage basins. Station locations and pertinent yearly point rainfalls were plotted on a map of 1:250,000 and contours of equal precipitation drawn. The average annual rainfall for the area for each year was then computed by multiplying the rainfall between successive isohytes (taken as the average of the two isohyetal values) by the area between isohyets, totalling these products and dividing by the total area of the entire catchment.

It proved not practical to actually do this for all the seventy years of available data as the amount of work became enormous. Instead sixteen years were selected based on the fact that they had the greatest number of stations with available data. The years considered were 1965 through 1976 and 1982 through 1985. Sample maps of this type analysis are shown in Appendix B. The data for the remaining years were estimated by regressing the annual rainfall values of North

Kinangop rainfall station No. 90.36025, located in the study area, against the values obtained for the selected sixteen years (Fig.18). A linear relationship was obtained of the form:

$$\mathbf{Y = 327.87 + 0.54711X}$$

Where,

Y = Mean Annual Areal rainfall (mm)

X = Annual rainfall at North Kinangop station (mm)

2.6.2 Testing for difference between two variances

The mean areal rainfall data obtained from the procedure above have been subdivided to two approximately equal (1915-50 and 1951-85) halves as shown in Table 16 below. The two sets of data were used to test for stationarity in the rainfall data. The entire rainfall data set is considered stationary if the variances and means of the two groups are not significantly different from each other. From the dataof Table 16 S_1^2, the sample estimate of the population variance σ_1^2, is 21927.39 mm² and S_2^2 the estimate of σ_2^2, is 12898.28 mm².

The two tailed hypothesis can be stated as:

Ho: $\sigma_1^2 = \sigma_2^2$ and H_A: $\sigma_1^2 = \sigma_2^2$. The hypothesis may be tested by calculating

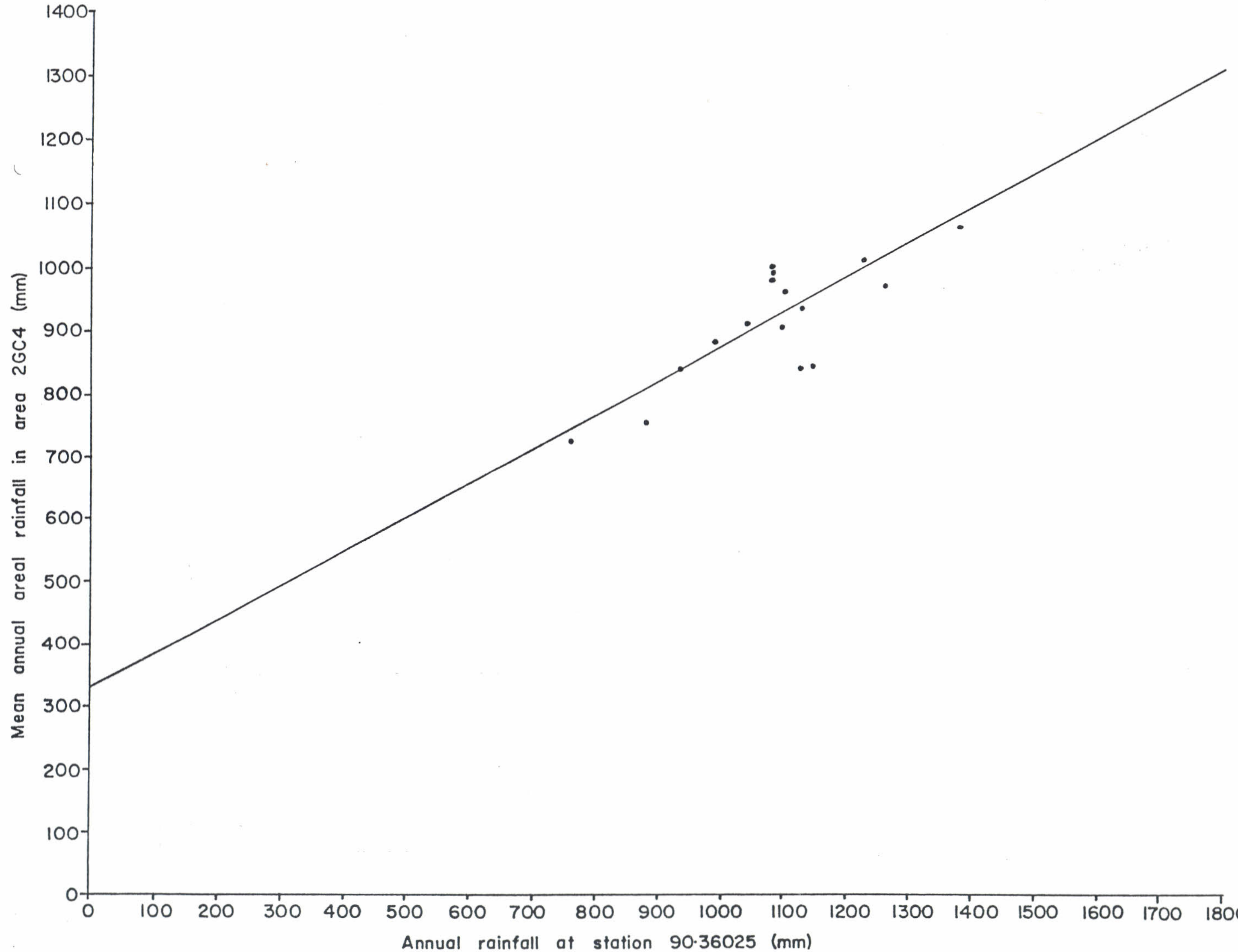
Table 16: Mean annual areal ranfall (mm)

First Half (1915-50)		Second Half (1951-85)	
Year	Rainfall	Year	Rainfall
1915	855.0	1951	1135.0
1916	950.0	1952	900.0
1917	1290.0	1953	748.0

First Half (1915-50)		Second Half (1951-85)	
1918	690.0	1954	980.0
1919	1027.0	1955	918.0
1920	958.0	1956	1025.0
1921	845.0	1957	970.0
1922	1010.0	1958	1125.0
1923	1172.0	1959	790.0
1924	1010.0	1960	856.0
1925	795.0	1961	1150.0
1926	1045.0	1962	1050.0
1927	800.0	1963	1060.0
1928	808.0	1964	1050.0
1929	846.0	1965	840.0
1930	1350.0	1966	936.7
1931	905.0	1967	984.3
1932	888.0	1968	998.5
1933	832.0	1969	726.8
1934	765.0	1970	1075.4
1935	952.0	1971	884.4
1936	1000.0	1972	975.3
1937	1088.0	1973	756.7
1938	895.0	1974	960.7
1939	719.0	1975	885.1
1940	1100.0	1976	905.8
1941	1020.0	1977	1240.0
1942	882.0	1978	1080.0
1943	808.0	1979	940.0
1944	885.0	1980	910.0
1945	875.0	1981	1105.0
1946	952.0	1982	900.0
1947	1130.0	1983	1018.0
1948	929.0	1984	845.0
1949	826.0	1985	1012.0
1950	810.0		

Source: Author

Fig. 18: Mean areal rainfall Correlation against annual rainfall at North Kinangop station (90·36025)



Source: Author

the ratio:

$$F = \frac{S_1^2}{S_2^2} = 1.70$$

From standard tables the critical value $F_{0.05(2), 35, 34} = 1.96$.

Since $F < F_{0.05(2), 35, 34}$, H_0 is accepted. This simply means that the two samples came from populations having equal variances.

2.6.3 Testing for difference between two means

A similar procedure to the preceding one can be applied to the two sample means. Since the sample variances are equal, a t-value may be calculated in a manner analogous to the students t-test.

The two-sample t-test for the two tailed hypothesis, can be stated as:

Ho: $\mu_1 = \mu_2$ and H_A: $\mu_1 = \mu_2$

The t-value for testing the preceding hypotheses concerning two means is:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_{\overline{X}1 - \overline{X}2}}$$

The sample mean $\overline{X}_1$ of the first data sample is 936.44 mm and sample mean $\overline{X}_2$ of the second sample is 963.90 mm. The corresponding sum of squares of the deviation from the mean $(\Sigma X - \overline{X})^2$ denoted as SS_1 and SS_2 are 767452.89 mm^2 and 494526.60 mm^2 respectively.

The number of data points in the first group, n_1, is 36 and that in the second group, n_2, is 35. The degrees of freedom v_1 and v_2 are respectively 35 and 34. By definition S_1^2 and S_2^2 are assumed to define the population variance σ^2. Similarly $S^2_{\overline{X}1 - \overline{X}2}$ approximates the variance $\sigma^2_{\overline{X}1 - \overline{X}2}$

between the means.

It can be shown mathematically that the variance of the difference between two variables is equal to the sum of the variances of the two variables. Therefore,

$$\sigma^2_{\bar{X}1 - \bar{X}2} = \sigma^2_{\bar{X}1} + \sigma^2_{\bar{X}2}$$

Since $\sigma^2_{X} = \sigma^2/n$, we can write

$$\sigma^2_{\bar{X}1 - \bar{X}2} = \sigma^2_1/n_1 + \sigma^2_2/n_2$$

Now, the two-sample t-test requires that we assume

$\sigma^2_1 = \sigma^2_2$, so that

$$\sigma^2_{\bar{X}1 - \bar{X}2} = \sigma^2/n_1 + \sigma^2/n_2$$

Thus to calculate the estimate of $\sigma^2_{\bar{X}1 - \bar{X}2}$ we must have an estimate of σ^2. Since both S_1^2 and S_2^2 are assumed to estimate σ^2, we compute the pooled variance, S_p^2, which is then used as the best estimate of σ^2.

$$S_p^2 = \frac{SS_1 + SS_2}{V_1 + V_2} \quad \text{and} \quad S^2_{\bar{X}1 - \bar{X}2} = \frac{S_p^2}{n_1} + \frac{S_p^2}{n_2}$$

Thus

$$S_{X1 - X2} = \sqrt{\left[\frac{S_p^2}{n_1} + \frac{S_p^2}{n_2}\right]}$$

and

$$t = \frac{X_1 - X_2}{\sqrt{\left[\frac{S_p^2}{n_1} + \frac{S_p^2}{n_2}\right]}}$$

The critical value can be obtained from tables as $t_{\alpha(2), V1 + V2}$. We reject Ho if $| t | \geq t_{\alpha(2), V1 + V2}$.

Otherwise Ho is accepted.

The estimated value of t was -0.855 while the critical one was 1.995 at $\alpha = 0.05$. We therefore accept Ho and conclude that the two samples came from populations having equal means.

2.7 TREND ANALYSIS OF DISCHARGE DATA

2.7.1 Homogeneity of the Data

Most statistical tests assume that the data being used is a sample from a single population. An assumption made here is that the data are homogeneous. Results of a statistical test could manifest heterogeneity in the data being used. A clear example is a significant trend observed in discharge which could be as a result of instability in the gauge site.

Such a feature can make observations before and after a certain period incomparable. It is therefore important to examine the quality of the data which will be used in making statistical inferences.

Homogeneity tests for population with frequency distributions close to normal have been applied by many authors. These include Karl Pearson (1894), Neyman (1937), Baker (1930, 1941, 1958), Rao (1952) and Preston (1953). Homogeneity tests based on cumulative frequency distribution have also been developed by Gumbel (1942), Birmbaum (1953), Kac *et al* (1955), Barlett (1955) among others.

2.7.2 The one sample runs test

One of the non-parametric tests which is very sensitive in testing the hypothesis of homogeneity against an alternative of trend, slippage of mean or some form of oscillations is the Runs Test (Siegel 1956; Thom 1966). A run is defined as a succession of identical symbols which are followed by different symbols or no symbols at all. A series of signs such as ++---- ++++-- ++- is said to have six runs. The number of runs above or below the median in a sample of observations can give some indication of the trend, cycles or random fluctuations in a time series. In testing for homogeneity a null hypothesis of "no homogeneity in the records" is assumed for each of the series and a statistics Z is calculated from the formula:

$$Z = \frac{\tau - \left(\frac{2n_1n_2}{n_1+n_2} + 1\right)}{\sqrt{\left(\frac{2n_1n_2(2n_1n_2 - n_1 - n_2)}{(n_1 + n_2)^2 + (n_1 + n_2 - 1)}\right)}}$$

τ is the number of the observed runs; n_1, n_2 are the number of the observed runs above and below the median respectively.

For a large sample size (N > 40), the Z approximates to a normal distribution with mean zero and variance unity. The significance of the null hypothesis is tested by determining the significance of the calculated Z with reference to a normal table. For one tailed test, the null hypothesis (no homogeneity) is accepted for all Z > 1.96 at 5% significance level. The entire discharge data series observed at the river gauging station 2GC4 were subjected to this test before being applied to trend analysis. The results of this test are summarised in Table 17. They declare the data homogenous.

Table 17: **Data for the homogeneity test**

Month	Runs above and below median	Z
February	14	-1.664
May	19	0.004
August	17	-0.663
November	20	0.169

Source: Author

2.7.3 The major components of discharge series

For any statistical prediction, a good knowledge is required about the nature of fluctuations in the discharge series. The major components of a time series include trend, cyclical variations, seasonal and random variations. The trend describes the long term movements. The cyclical variations represent the periodic and quasi-periodic fluctuations with time periods usually longer than one year. Seasonal fluctuations are of periods less than one year while the random variations represent the unpredictable fluctuations which take place by chance. The trend exhibited by the monthly runoff from the Turasha catchment is examined in this section. The methods applied are discussed below.

2.7.4 The graphical approach

In the graphical method the trend is visualised from a graphical representation of the time series. Several smoothing functions have been used to smooth the graph of the time series. Some of these are described below. In the smoothed graph, the trend at any point in time is represented by a weighted average of the observed values near that point. The most commonly used weights are the binomial coefficients. These have been used by WMO (1966), Rodha and Virji (1976), Ogallo (1977, 1979) among others.

Examination of trend by graphical approaches have some disadvantages which include the following:

i) The methods are based on visual techniques which depend highly on individual judgements.

ii) Some data sets are lost by some smoothing techniques.

iii) Some smoothing techniques generate fluctuations which are not present in the original data.

Smoothing a time series with the moving average methods have also the effects of altering the amplitude (and often the phase as well) of the fluctuations in a time series.

The function which measures the amplitude of variations after the filtering to that before filtering is known as the 'frequency response' R (ß). It is a measure of the dynamic response of the filter for any given frequency of variation ß. The square of the frequency response function is known as the transfer function T (ß). This may give the relationship between the spectra of the original and the filtered time series.

Considering a symmetrical (2n + 1)-termed moving average filter, the smoothed series can be defined by the equation:

$$Y_t = \sum_{t=-n}^{n} W_i X_{t+i}$$

Y_t is the filtered value of the original series, X_t and W_i represent the weighting function. For such a filter, the frequency response function may be expressed as:

$$R(\beta) = W_o + 2 \sum_{k=i}^{m} W_k \text{Cos } 2\pi\beta k$$

$$R(\beta) = \cos^n \pi\beta$$

for a n-termed binomial coefficient filter.

2.7.5 Application of polynomial functions

An alternative approach of describing the trend of a time series is to approximate the observed trend with a polynomial function of the form:

$$X_t = f(t)$$

In this case, the polynomial function f(t) which is a function of time is fitted to the time series X_t. The weakness of this approach is that, quite often the observed trends are unknown functions of time which gradually move with time making it difficult to represent them well with a polynomial function.

2.7.6 Statistical approach

A more objective approach of determining trend in any time series is to subject the series to some statistical tests to examine the statistical significance of the observed trends. There are several statistical methods for examining significant trend in a time series. The most commonly used are the analysis of variance techniques and the methods based on ranks.

2.7.7 Analysis of variance approach

Analysis of variance may be used to search for hydrological trends. In this case the period of study may be divided into groups of at least 30 years record each (normal period) and the means of these sub groups can be compared by using t-test, F-test or Mann Whitney U-test depending on the frequency distribution of the time series (WMO, 1966, Parthasarathy *et al* 1973, Jones, 1975, Granger *et al* 1976).

The disadvantage with this method is the large data sample requirement of 30 years (WMO, 1967).

2.7.8 Rank correlation methods

The rank correlation tests are based on ranks. The tests use a non-parametric measure of correlation based on the ranks. Details of the rank correlation tests have been discussed by Hotelling *et al* (1936), Friedman (1940), Kendall (1938, 1945, 1949, 1961), Siegel (1956), WMO (1966) and others. The most common are the Mann-Kendall and Spearman rank tests.

In this study the Spearman rank correlation method has been applied to investigate trends of monthly runoffs at one river gauging stations (2GC4).

A graphical method namely the binomial smoothing technique is used to present visually all the series indicating statistically significant trends. The binomial coefficients were normalised to sum to unity. The binomial weights applied to smooth the significant series were 0.22 for the i^{th} observation, 0.20 for the i $\pm$ 1 observations, 0.12 for the i $\pm$ 2 observations, 0.05 for the i $\pm$ 3 observations and 0.02 for the i $\pm$ 4 observations. This is a low pass filter suppressing high frequency observations. In this case all fluctuations with periods less than 10 years have been suppressed. Sample trend results are shown in Fig.19A-19E.

2.7.9 The spearman rank correlation method

One of the most powerful tests which can be used to test for linear or non-linear trend against an alternative of randomness is the Spearman rank correlation method (WMO 1966). The Spearman rank correlation τ_s is defined by the equation:

$$\tau_s = \frac{1 - 6 \sum_{i=1}^{N} d_i^2}{N(N^2 - 1)}$$

Where $d_i = k_i - i$, k_i is the rank of the series X_i and N is the number of observations.

For $N > 8$, the significance of the coefficient τ_s may be tested by computing the statistic t given by:

$$t = \tau_s \sqrt{\left[\frac{N-2}{1 - \tau_s^2}\right]}$$

The t value is compared with the probability of the students t-distribution for N-2 degrees of freedom.

Some results of the Spearman rank correlation test are given in the correlograms given in Fig.21A and 21B.

Fig. 19A: Generally decreasing trend followed by some oscillations.

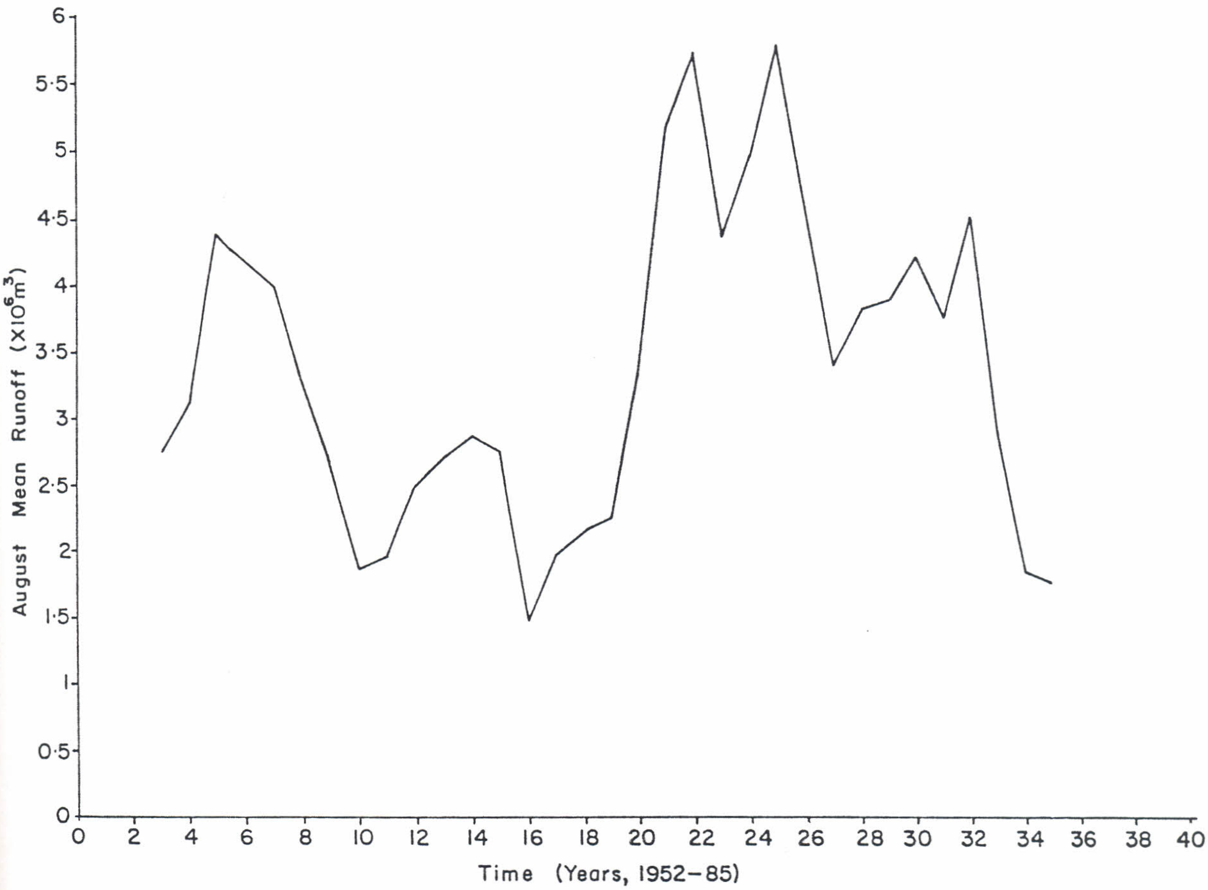
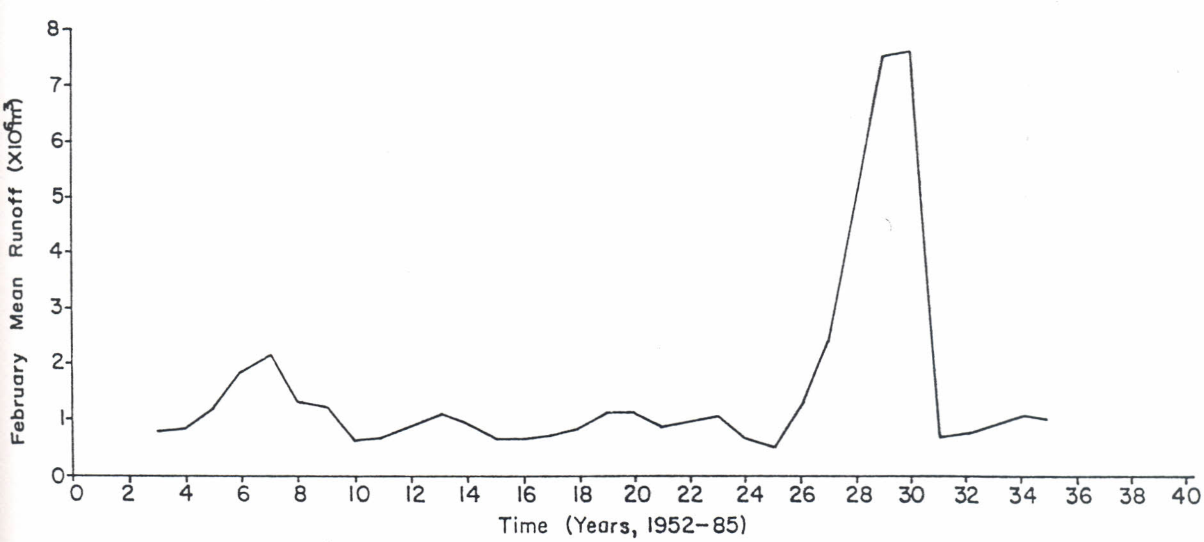


Fig. 19B: Generally decreasing trend followed by an increasing trend.



Source: Author

Fig.19C: Generally decreasing trend.

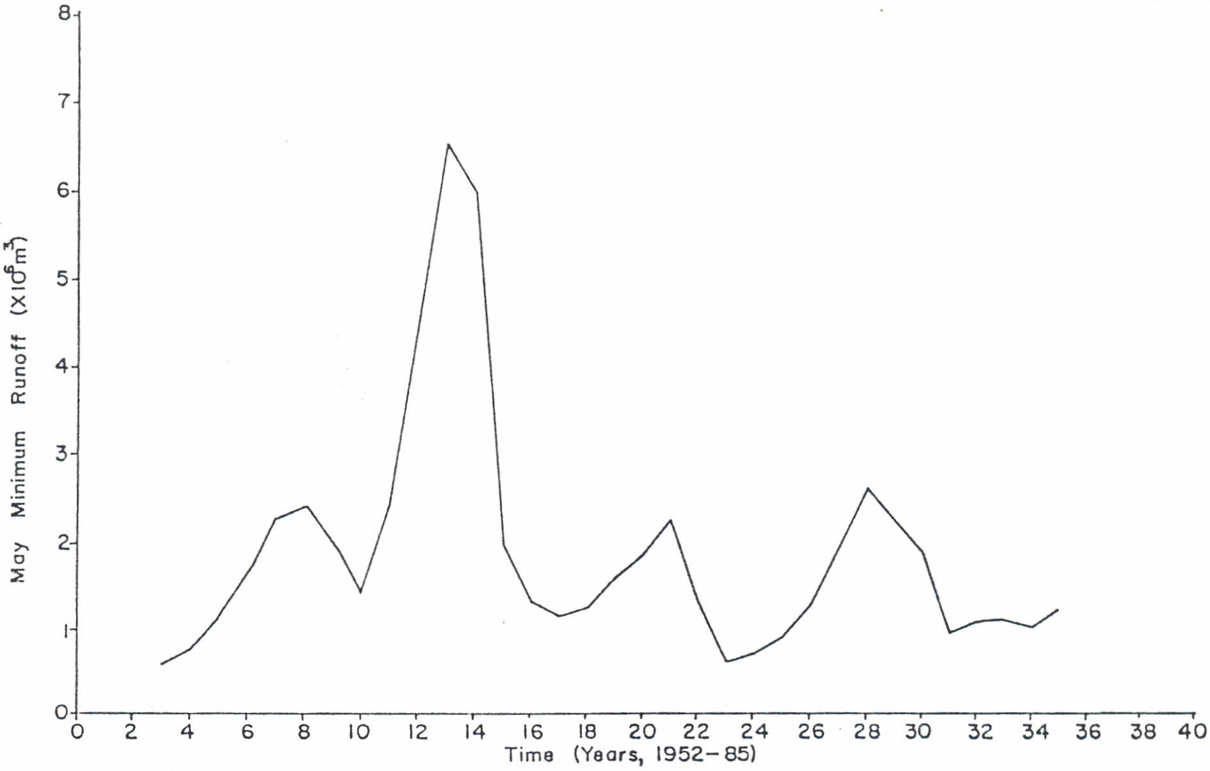
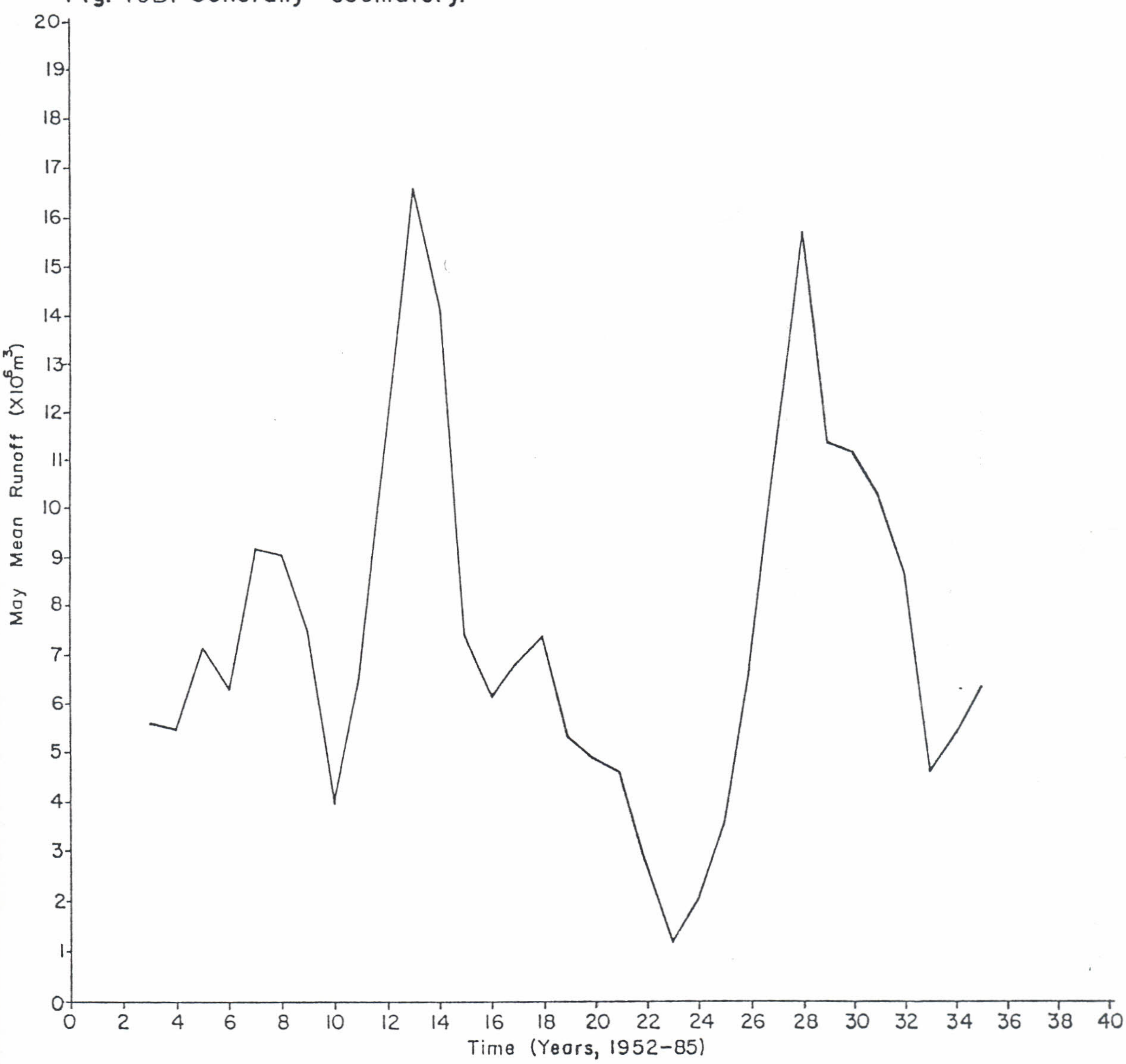
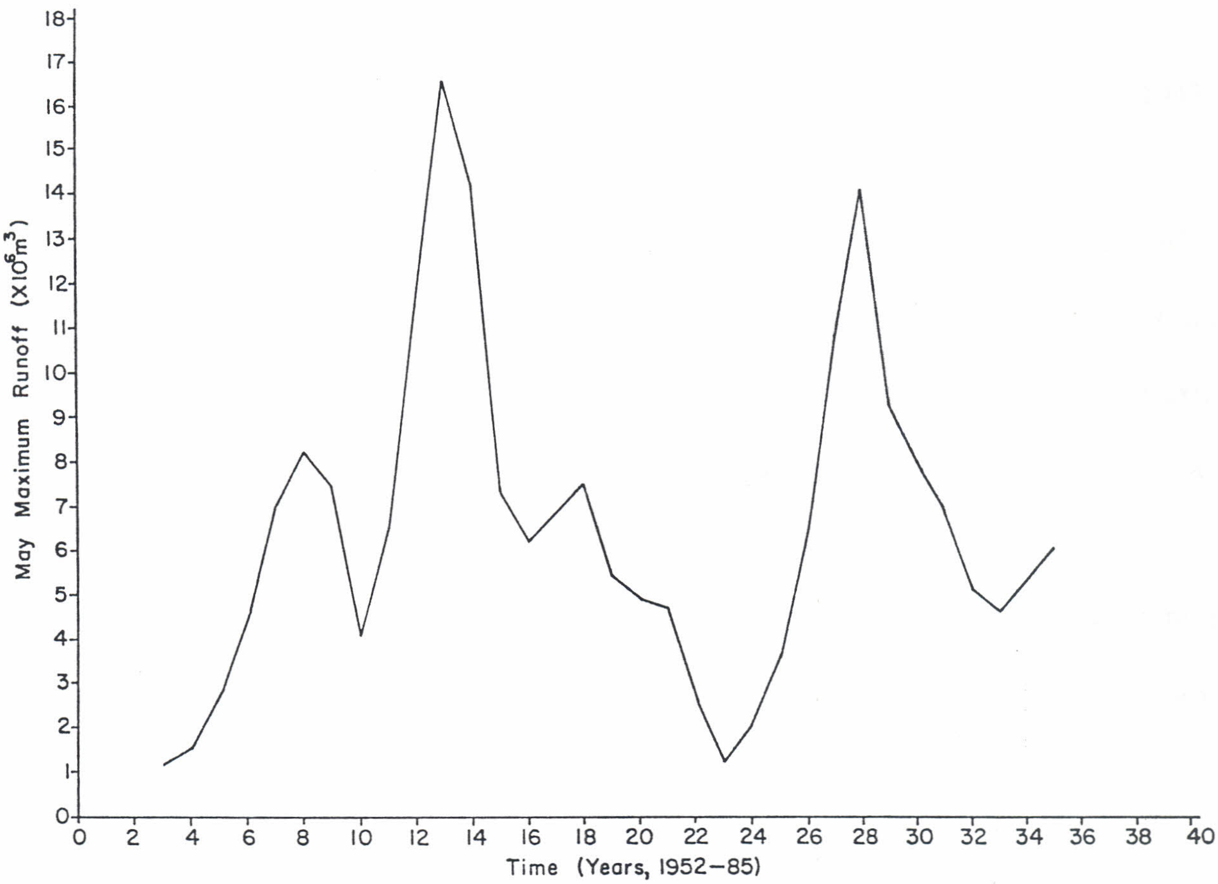


Fig. 19D: Generally oscillatory.



Source: Author

Fig. 19E: Generally oscillatory.



Source: Author

2.8 FLOOD FREQUENCY ANALYSIS

Many events conform to one of several standard frequency distributions which have been studied at length and the equation of the distribution well established. The probability of such events can be determined quite easily. Only a very large number of samples (i.e. a long record length) will permit accurate definition of a distribution, and no streamflow records are long enough to possibly establish the appropriate distribution.

Several distributions have been suggested as appropriate for streamflow (Beard, 1943) but there is no real proof of their validity.

Fisher and Tippet (1928) showed that if one selected the largest event from each of many large samples, the distribution of these extreme values was independent of the original distribution and conformed to a limiting function. Gumbel (1945) suggested that this distribution of extreme values was appropriate for flood analysis since the annual flood could be assumed to be the largest of a sample of 365 possible values each year.

Based on the argument that the distribution of floods is unlimited, that is, that there is no physical limit to the maximum flood, he proposed that the probability P of the occurrence of a value equal to or greater than any value X be expressed as

$$P = 1 - e^{-e^{-b}} \quad \text{.......} \quad (1)$$

Where e is the base of Naperian logarithm and b is given by

$$b = \frac{1}{0.7797\sigma}(X - \bar{X} + 0.45\sigma) \quad \text{.......} \quad (2)$$

In equation (2), X is the flood magnitude with the probability P, X is the arithmetic average of all floods in the series and σ is the standard deviation of the series computed from:

$$\sigma = \left[\frac{\Sigma(X - \bar{X})^2}{N - 1}\right]^{1/2} \qquad (3)$$

Where N is the number of items in the series. The probability P is related to the recurrence interval tp by

$$P = \frac{1}{t_p} \qquad (4)$$

The flood data for 2GC4 between the years 1954 and 1983 (Table 18) were divided into two classes of fifteen data points each. Each group was subjected to the Gumbel approach and in each case a straight line fitted to each set of data (Fig.20). To fit the straight line it was sufficient to calculate the return period corresponding to two flows.

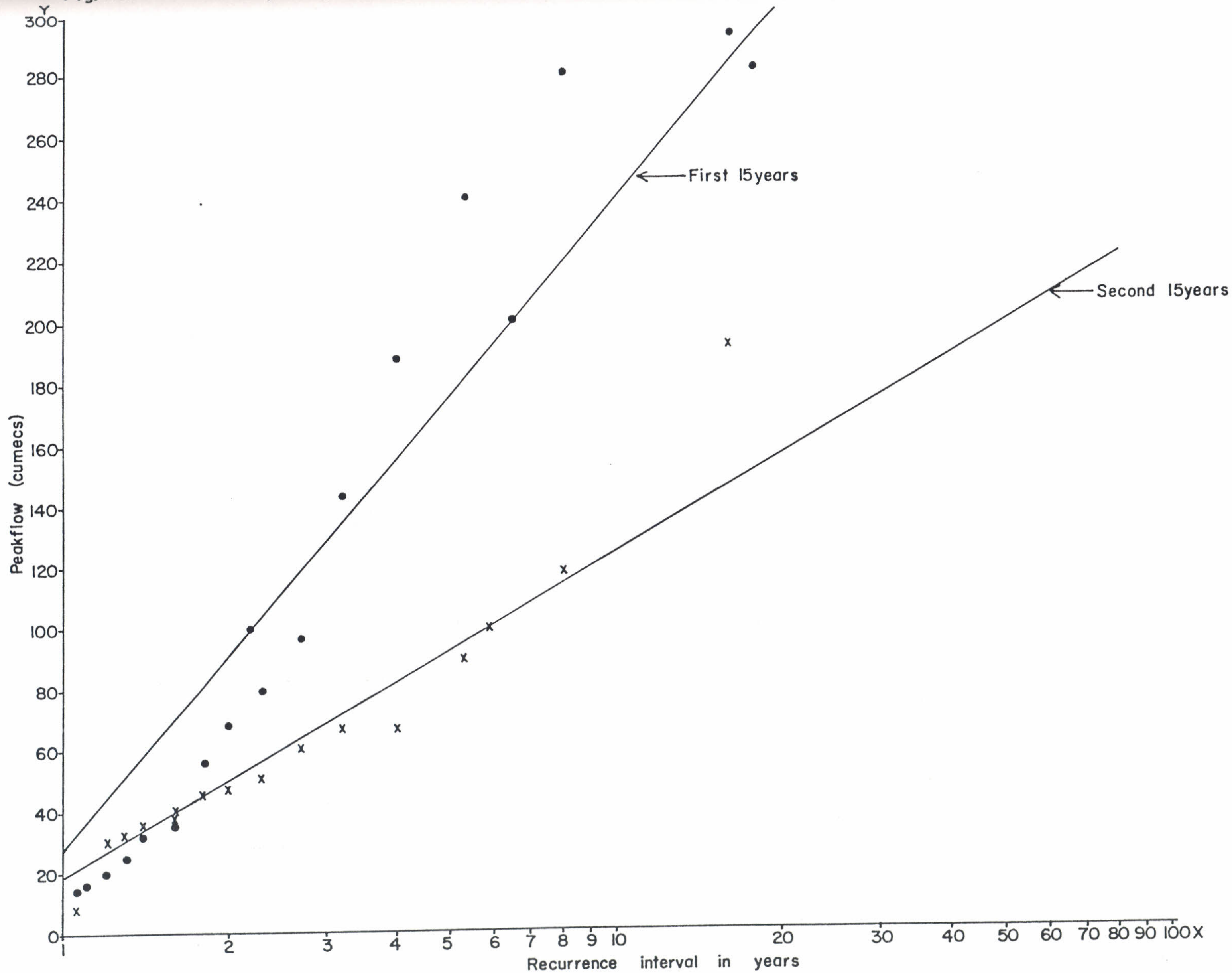
In 1967, the U.S. water resources council adopted the Log Pearson Type III distribution (of which the Log Normal is a special case) as a standard for use by federal agencies. The purpose was to achieve standardisation of procedures. The recommended procedure is to convert the series to logarithms and compute the mean, standard deviation, and skew coefficient g which is

$$g = \frac{N \ \Sigma(\log X - \overline{\mathrm{Log} X})^3}{(N - 1)(N - 2)(\sigma_{\log X})^3}$$

$$\mathrm{Log}\ X = \overline{\log X} + K\ \sigma_{\log X}$$

Where K is selected from a standard table for computed value of g and the desired return period. $\overline{\mathrm{Log}\ X}$ represents the average of the logarithms of all the data points. The two sets of flood data

Fig. 20: Frequency curve of annual floods at 2GC4 (1954 – 1983)



Source : Author

Table 18: Peakflows at 2GC4

Year	Flood Cumecs
1954	68.5
1955	25.2
1956	56.0
1957	36.2
1958	96.8
1959	16.0
1960	14.3
1961	292.0
1962	188.0
1963	239.0
1964	80.4
1965	20.5
1966	32.5
1967	144.0
1968	280.0
1969	31.7
1970	60.6
1971	44.7
1972	34.8
1973	8.3
1974	51.8
1975	38.5
1976	17.4
1977	192.0
1978	118.0
1979	30.6
1980	67.3
1981	90.3
1982	67.3
1983	47.3

Source: Author

have been subjected to this approach.

.9 REGRESSION MODEL RELATING ANNUAL TOTAL SEDIMENT LOAD TO AREA OF LAND USE TYPES

There exists an infinity of functions that can be used to model the mean value of a response vriable Y as a function of one or more independent variables. In this study the linear statistical

model is considered to relate mean annual total sediment load to a combination of the areas of the main land use types mapped in the Turasha catchment. Because the sediment loads model is a funtion of more than one land use unit it is a a multiple linear regression model of the form:

$$Y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k$$

Where $\mathbf{Y_i}$ is the annual toal sediment, $\beta_0, \beta_1, \ldots, \beta_k$ are unknown parameters, ϵ is a random variable representing the error term and $x_1, x_2, \ldots, x_k$ are known constants representing the areas of distinct land use units. Assuming that the expected value of ϵ, $E(\epsilon)$, is zero the above model becomes

$$E(Y_i) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k$$

The physical meaning of this model is that $\mathbf{Y_i}$ is equal to an expected value ,$\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k$, plus a random error. This model accounts for any random behaviour of $\mathbf{Y_i}$. In fact, the error ϵ acknowledges the inability to provide an exact model because of the failure to include all the possible values that may affect $\mathbf{Y_i}$. The net effect of these unmeasured, and often unknown,variables is to cause $\mathbf{Y_i}$ to vary in a manner that may be adequately approximated by the assumption of random behaviour. The model therefore provides a more accurate description of reality than the deterministic component alone.

In this section the method of least squares is applied to derive estimators for the parameters $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$ in the linear regression model. They are too few for analysis using the conventional multiple regression model. They grossly violate the principle of normality. A convenient way to manipulate the linear equations is through matrices. With **n** independent observatiomns $Y_i, Y_2, \ldots, Y_n$ we have:

$$Y_1 = \beta_0 + \beta_1 X_{11} + \beta_2 X_{12} + \ldots + \beta_k X_{1k} + \epsilon_1$$

$$Y_2 = \beta_0 + \beta_1 X_{21} + \beta_2 X_{22} + \ldots + \beta_k X_{2k} + \epsilon_2$$

.

.

$$Y_n = \beta_0 + \beta_n X_{n1} + \beta_n X_{n2} + \ldots + \beta_k X_{nk} + \epsilon_n$$

The **n** equations representing Y_i as a function of the **X's**, **ß's**, and ϵ,s can be simultaneously written as:

$$Y = X\beta + \epsilon$$

In the present case , two independent observations on sediment loads were made namely for 1962 and 1991/92. The number of distinct land use units identfied were four. So the multiple regression model is of the form:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix}$$

$$X = \begin{bmatrix} 1 & X_{11} & X_{12} & X_{13} & X_{14} \\ 1 & X_{21} & X_{22} & X_{23} & X_{24} \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \end{bmatrix}$$

$$\epsilon = \begin{bmatrix} \epsilon_0 \\ \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \epsilon_4 \end{bmatrix}$$

The least squares equations are given by:

$$\mathbf{(X'X)\beta = X'Y}$$

Where $\mathbf{X'}$ is the transpose of $\mathbf{X}$ and $\mathbf{(X'X)^{-1}}$ is the inverse of $\mathbf{X'X}$.

$$\beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \end{bmatrix}$$, the estimators of the parameters $\beta_0, \beta_1, \beta_2$, β_3 and β_4.

Hence $\mathbf{\beta = (X'X)^{-1}(X'Y)}$. From the data of Table 19 the matrix $\mathbf{X}$ is:

$$X = \begin{bmatrix} 1 & 24{,}680 & 13{,}380 & 15{,}692 & 18{,}890 \\ & & & & \\ 1 & 16{,}400 & 17{,}480 & 20{,}600 & 18{,}160 \end{bmatrix}$$

Also from the data of Table 15 the matrix $\mathbf{Y}$ is:

$$Y = \begin{bmatrix} 12{,}118 \\ 307{,}960 \end{bmatrix}$$

So that:

$$\beta = \begin{bmatrix} 282151.48919 \\ -23.89676897 \\ 23.896769008B \\ -0.0000000072 \\ 1.5924761509E\_15 \end{bmatrix}$$

and the prediction equation is:

Yi = 282151 - 23.9(Area of grassland) + 23.9(Arable area)

CHAPTER 3: RESULTS AND DISCUSSION

3.0 INTRODUCTION

A number of analyses have been done in chapter 2 in the process of investigating the effect of changes in land use on runoff from the Turasha catchment. The results of these analyses are discussed independently in this chapter.

3.1 RESULTS FROM DELINEATION OF LAND USE TYPES AND THEIR AREAL EXTENT

Land use types for the base year (1962) were delineated on aerial photographs stereoscopically and a land use map drawn by tracing the units on the photographs onto a transluscent paper. A pantograph was then used to reduce the map to an appropriate scale.

Table 19: Land use mapping data

Land use type	Area (hectares)	
	1962	1988
Grazing	24,680	16,400
Arable farming	13,380	17,480
	15,692	
Mixed farming	18,890	20,600
Forest		18,160

Source: Author

The reduced map was thereafter transferred onto a base map of the study area. The area of the land use units identified was then estimated using a planimeter. Similarly the land use map of the catchment twenty six years later (1988) was developed from satellite imagery and areas of distinct units estimated. Table 19 shows a summary of the results obtained.

Prior to and until independence European farming activities in this area were dominated by mixed farming with the main crop being pyrethrum. Dairying played a most important role mainly for butter fat production and sheep were kept for wool production. Before independence this system of farming had asssumed stability in ecological as well as economic terms.

At independence the White Highlands were opened up to farming by all Kenyans who had the will to do so. One of the counterreactions resulting from this was the departure of the European farmers who flt politically insecure. The farms were subsequently divided and sold to African peasants at a scale of ownership change that affected the farming systems in a significant way.

First, the new settlers were coming in for the first time and were threfore strangers to the entire farming practices that had been established and which, so to say,had become sustainableways for conserving the environment. This change over was in all ways sudden. The new owners went in for short-term crop farming to secure money for loan repayments.

Between 1962 and 1988 the area under grasland had gone down by 8,280 ha or 34%. During the same period arable and mixed farming appear to have enjoyed preferrence as they went up by 4,100 ha and 4,908 ha which a rise of 31% in both cases. The forest cover underwent a reduction by 730 ha from 18,890 ha to 18,160 ha. This too must have contributed to the area under arable and mixed farming in proportions which this study did not ascertain. Overall the Turasha catchment lost 9,010 ha of its best cover (forest and grassland) to mixed and arable farming. This left the land more vulnerable to erosion through the direct impact of rainfall and less regulation in runoff.

Details of crop acreages and livestock census were unavailable but local information points out to the fact that crops such as wheat that were formerly grown by the White settlers have virtually disappeared because the peasant farmers could not afford the expensive technology required for its production. Pyrethrum has undergone similar fate. The substitutes have mainly been maize potatoes and vegetables. Maize has been widely adopted in this area and especially in the lower areas. But where this crop is found there has been a drop in crop husbandry practices. Rotations are not practised and farmers do not generally apply fertilizers. This has led to land deterioration. Although the schemes were planned so that each peasant farmer owned 1-5 dairy cows, this situation may have changed and the number gone much higher because this area is a major dairy farming zone in Kenya. It is quite clear that there has been a change of emphasis in the farming systems following the transition from large scale to peasant farming.

3.2 RESULTS OF SEDIMENT ANALYSIS

The temporal variation of suspended sediment rates, mean annual temporal total sediment loads and solution loads are discussed in this section.

Suspended sediment rating curves were developed for 1953,1954, 1955,1956 and 1991/92 as shown in Fig.14A-14E. The graphs exhibit a fairly good linear relationship between suspended sediment rates and discharge. The suspended sediment transport rates derived from the envelope curves fitted to the preceding figures are shown in Table 12. The rates have been computed for each of the years for the flows ranging from 0.1 cumecs to 3.0 cumecs at intervals of 0.1 cumecs to provide a base for comparison among the years. The data show that for flows less than about 0.8 cumecs there is no obvious pattern in the temporal behaviour of sediment rates. An upward trend is observed above this value signifying the influence of land use cover changes. The threshold value of 0.8 cumecs probably marks the point at which the influence of rainfall in the catchment starts being felt in terms of it bringing erosion material into the Turasha river via streams. The data suggest that this influence becomes more at higher flows as would be expected. Adopting the average values for the period 1953-1956 to represent the base year (1962), it is evident from Table 12 that the suspended sediment rates for 1962 and 1991/92 show a divergence of 1.8 and 20.8 times at flows of 0.8 cumecs and 3.0 cumecs respectively. It has been estimated from the data that the mean annual suspended sediment load averaged over the period 1953-56 is 12,118 tonnes which is equivalent to 0.011 $mm/km^2/yr$ based on an assumed bulk density of 1.5$tonnes/m^3$. The values for 1991/92 are 307,960 tonnes and 0.283 $mm/km^2/yr$ respectively (Table 15). The total sediment loads portray a similar trend. These figures reflect the deteriorating conditions in land cover over the Turasha catchment especially through the loss of grass and forest cover in favour of arable and mixed farming.

3.3 RESULTS OF SOLUTION LOADS AND WATER QUALITY

The results of solution loads and physical analyses are presented in Table 10 and 11. Secondary data available are too few representing only some of the parameters. It was therefore considered illegitimate to make any meaningful comparison between them and the results obtained during this study. However some general observations on the water quality are briefly discussed in this section.

The river water exhibits low contents of dissolved ions. The data from physical analyses indicates the water to be slightly alkaline with low total hardness. These data which pertain to the rainy season show high values for colour and turbidty. In all cases the values of absorbed oxygen, as indicated by the permanganate value, are high meaning that the water is not organically polluted.

The values of free carbon dioxide, bicarbonate and pH show that the water is not corrosive. Fluoride levels are below 0.2 mg/l which is below the WHO standard limit for drinking water quality. The electrical conductivity, which is a measure of the total dissolved salts is low during the rainy season and manifests that the rainfall forming the runoff is low in dissolved ions. The low iron content during the rainy season indicates that it is not essentially bound to organic complexes, but probably exists in the form of ferrous ions.

3.4 RESULTS FROM THE ANALYSIS FOR STATIONARITY IN WEATHER

Long term mean annual areal rainfall obtained using the isohyetal method was tested for stationarity. This was done by dividing the data into two approximately equal sub-series of 36 and 35 years. The sample mean and variance of each sub-series was then determined. The ratio between the sample variances was used to test for their differences by comparing with the critical value from standard tables at a probability of $\alpha = 0.05$. The computed ratio of 1.70 was less than the tabulated standard ratio of 1.96. This condition indicates that the two sample variances are equal for all practical purposes.

In a similar manner the students t-test was applied to test for the difference between the two sample means as outlined in section 2.6.3. The critical value was obtained from standard tables at a probability of $\alpha = 0.05$. Since the absolute value of the computed t-statistic is 0.855 while the critical value is 1.995 it is satisfactory to say that the two sample means are equal.

The results satisfy the necessary and sufficient condition to declare the weather over the Turasha catchment to have remained similar during the period of observation (1915-85).

3.5 RESULTS OF TREND ANALYSIS OF DISCHARGE DATA

The monthly discharge data for the selected months of february, may, august and november at 2GC4 were smoothed by the user-supplied Binomial coefficient method. The weights applied were 0.22 for the ith year, 0.20 for the $i \pm 1$ years, 0.12 for the $i \pm 2$ years, 0.05 for the $i \pm 3$ years and 0.02 for the $i \pm 4$ years. This is a "low pass" filter suppressing high frequency oscillations. This removes fluctuations shorter than ten years.

The "low pass" filter curves obtained may be classified into five categories based on the visual appearance of the curves samples of which are shown in Fig.19A-19E. The categories of observed trends in the monthly discharge data are:

- a generally decreasing followed by an increasing trend.
- a generally oscillatory behaviour
- a generally oscillating followed by a decreasing trend.
- a decreasing trend followed by oscillations

The results indicate that the observed flow discharges (minimum, maximum and the entire data set) during the dry period represented by the February data showed a change from a decreasing tendency to an increasing trend in recent years. The wet season discharge data represented by the data for the month of May showed no appreciable change but merely oscillations. The observed discharges during continental rains represented by data for August did not show a well defined trend. The maximum flows were mainly oscillatory throughout the period of observation. The minimum flows showed change from oscillatory to a decreasing trend. The entire discharge data for this season reversed from a downward tendency to one of oscillations in recent years. The discharge data for the short rains represented by the data for the month of November also showed a mixed behaviour ranging from a decreasing tendency for the minimum flows to one of decreasing-increasing for the peak flows. No type of discharge shows an entirely increasing tendency throughout the period of observation.

3.6 THE CORRELOGRAM

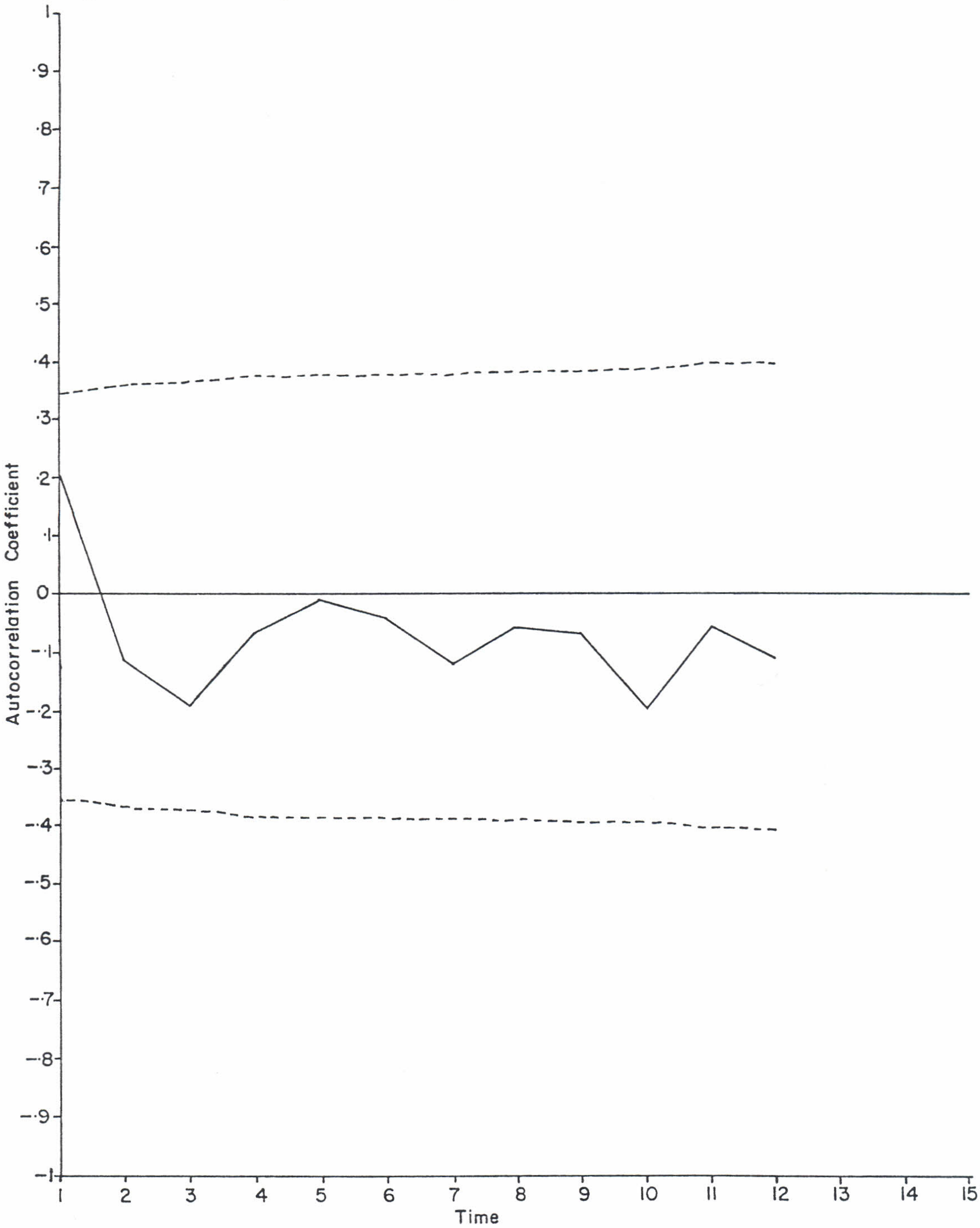
The graphical plot of the autocorrelation values r_k against the time lag k is known as the correlogram. The nature of the correlogram can infer the generating process of the time series. For a periodic process, for example, it is periodic. Auto-correlation values were computed and automatically plotted using the statgraphics package for each of the four seasons under study. Sample correlograms plotted for the first twelve lags are given in Fig.21A-21B. The results showed that there were no purely periodic fluctuations in the correlograms and in general they failed to damp out to zero at the larger time lags.

The lag-one correlation was positive in all cases but both negative and positive everywhere else. Neither negative nor positive significant values of the lag-one correlation were obtained. The significance belt was automatically plotted on the correlograms using the STATIGRAPHICS package so that any auto-correlation value not exceeding the plotted limits is considered not significant. The absence of significant negative values of lag-one correlation suggests the absence of high frequency oscillations. This condition suggests further that the discharge data exhibit white noise indicating the absence of persistence in the data.

3.7 RESULTS OF THE FLOOD FREQUENCY ANALYSIS

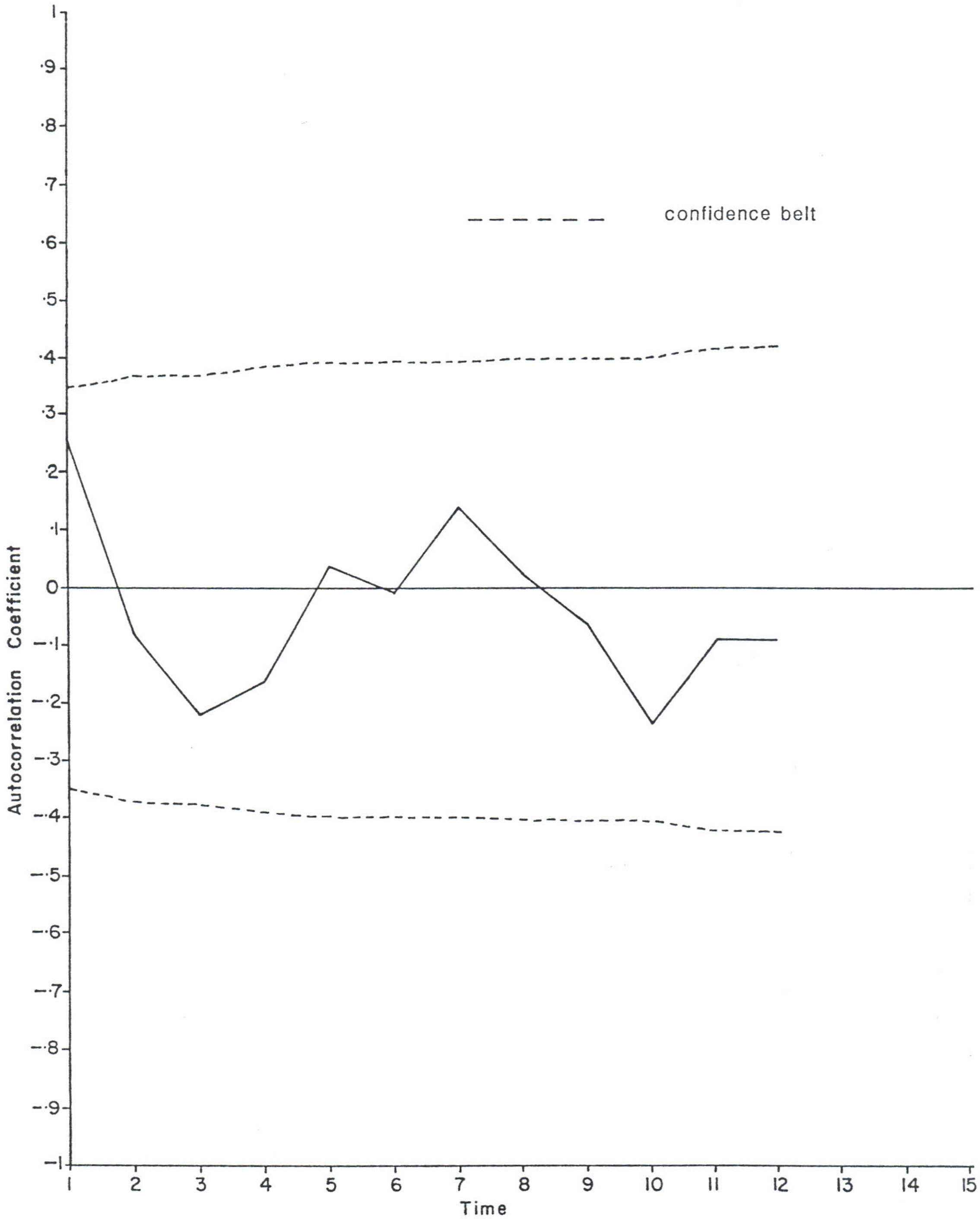
The peak annual discharges were subjected to flood frequency analysis using the Gumbel and Log Pearson Type III approaches. The series of peakdischarges was divided into two subseries

Fig. 21A: Correlegram for May Maximum Runoff



Source: Author

Fig. 21B: **Correlegram for May Minimum Runoff.**



Source: Author

of 15 years each. Each sub-series was then analysed using the two approaches. Table 20 shows some data abstracted from the analysis by the Gumbel plot (Fig.20) of the two sub-series. The data show an indication that the frequency of realising specified floods has gone down with time. This is evident, for instance, from the fact that during the more recent 15 years it took an average interval of six years to realise a peak flow of 100 cumecs which previously occured after every two years on average. This average interval becomes even longer for higher peak flows. The 200 cumecs peak flow was expected at average intervals of 50 years in recent years as compared to the previous expectation at intervals of 6.5 years.

Table 21 shows the magnitudes of the flood frequency obtained for some recurrence intervals from the Gumbel and Log Pearson Type III approaches for the two subseries. The results indicate that the flood magnitudes at each of given recurrence interval havedecreased from their previous

Table 20: Comparison of flood frequency for the first and second 15 years

Peak flow (Cumecs)	Gumbel frequency interval(years)	
	First 15 years	Second 15 years
50	1.3	2.0
100	2.2	5.9
150	2.45	7.3
200	6.5	50.0

Source: Author

levels by an approximate factor of 1.8 during the more recent fifteen years of observation. This indication is portrayed by both the Gumbel and Log Pearson Type III results. The mean annual areal rainfall indicated that the climate over the study area has essentially remained similar so far. The above results therefore depict the recent deteriorating land cover conditions.

Table 21: Magnitudes of flood frequncy (Cumecs)

Recurrence Interval (yrs)	Gumbel		Log Pearson Type III	
	First Half	Second Half	First Half	Second Half
			g = 1.9383151	g = 1.9383151
2	90	50	52	37
5	176	93		
10	240	125	266	126
15	278	143		

Source: Author

3.8 RESULTS OF SEDIMENT ANALYSIS

The observations made from the Langbein-Schumm and Douglas curves and also from th Dunne curves suggest that the sediment production in the Turasha catchment is strongly depende on land use.

Based on the data of Table 15, the average suspended sediment load at the river gaugir station 2GC4 is 98.46 tonnes per square Kilomtre or per year. This is in reasonable agreement wi observations which have been obtained from other parts of the tropical environment (Table 22 This is a further confirmation that the data obtained from the Turasha catchment are a fairly reliab assessment of the sediment production from the Turasha catchment.

Table 22: Suspended sediment yield data from forested and cultivated catchments withir tropical environments

Locality	Sediment yields from forested environment (tonnes/km²/yr)	Sediment yields from cultivated environment (tonnes/km²/yr)
Mbeya, Tanzania	10.35	44.25
Camerun Hills, Malasya	31.65	154.65
Barron, Queensland	8.55	20.40
Millstream, Queensland	9.30	18.45
Northern Rao, Trinidad	2.70	24.00
Apiodoume, Ivory coast	145.50	255.00

Source: Gregory and Walling (1973)

CHAPTER 4: CONCLUSSIONS AND RECOMMENDATIONS

4.0 CONCLUSSIONS

The results emanating from this study indicate that there has been a tendency to put more emphasis on agricultural activities in the study area. This has resulted in the area under arable and mixed farming going up by 31% between 1962 and 1988. During the same period the area under grassland and forest cover were observed to have decreased by 34% and 4% respectively. Maize and potatoes have replaced wheat. In terms of ecological stability the reduction in the area of grass and forest cover is certainly a negative factor exposing the soil directly to the kinetic energy of the downpours. This coupled with the replacement of wheat and potatoes which are less endowed with the ability to conserve the soil has led to a generally increasing tendency in sediment production and transport downstream. This is aggravated by the fact that the change over from European to peasant farming was abrupt and that the peasants were total stangers to the farming practices that had been established. They gave priority to short-term crop farming to secure quick money for loan repayments at the expense of conserving the environment. Because of this, the total annual sediment load went up from abiout 12,118 tonnes in the mid 1950s to 326,438 tonnes in 1991/92 representing a 25-foldrise in approximately thirty seven years.

The results from the long-term mean areal annual rainfall analysis for stationarity suggest that the climate over the Turasha catchment has remained relatively similar during the period under consideration (1915-1985). With the climatic factor accounted for in this way, there is justification in attributing the increasing trends in sediment loads to land cover and landuse activities. To examine trend in the discharge data, the User Supplied Binomial Coefficient method was applied to smooth the series. This 'low pass' filter removes all the fluctuations shorter than ten years. The resultant curves showed that the dry season flows revealed a reversal from a previously decreasing to an increasing trend in more recent years. The long rains data showed no established trend. They were merely oscillatory. The maximum flows showed an oscillatory behaviour too. The minimum flows showed an oscillatory behaviour initially and then a decreasing trend more recently. The entire time series discharge data during the long rains is characterised by a decreasing trend in the earlier years but by oscillations more recently. On the whole the discharge data depict a generally oscillatory character. The lag-one values which were mainly found to be positive and insignificant suggest a random behaviour in the discharge data with mainly low frequency fluctuations. They are therefore free from persistence.

The peak flows of the annual discharges were subjected to flood frequency analysis using the Gumbel and Log Pearson Type III approaches. The results from both analyses concur in suggesting that the average recurrence interval for expecting any given peak flow has tended to be longer in more recent times than was expected previously. Alternatively, the peak dischages for any given recurrence interval has gone down in more recent years by a factor of approximately 1.8.

In view of the foregoing observations and the fact that the catchment has for all practical purposes remained the same in terms of geology (area, shape, slope, topography), hydrology and geology, it becomes evident that the trends in sediment loads and discharge reflect the changes in the extent of land cover and land use activities caused by the high population exerting pressure on the land during their struggle for their survival. The regression model between annual sediment loads and the major land use types identified suggest that grassland and arable farming were the most important land use types governing the sediment transport rates. However, the model was unable to apportion the respective relative contribution of each of the two land use types due to insufficient data. Nevertheless it is evident that the catchment is threatened with severe erosion and the Turasha reservoir is vulnerable to sedimentation of about 10,000 additional tonnes each subsequent year on average. This poses obvious extra treatmenrt costs in the sedimentation tanks besides the obvious consequences in the reservoir.

4.1 RECOMMENDATIONS

1) The construction works at the damsite left a lot of loose soil that hungs dangerously by the reservoir banks on very steep slopes. This soil probably poses the greatest threat to the reservoir sedimentation because during the rains the soil is very easily swept into the reservoir. There is therefore an urgent need to construct embankments and plant suitable grass to stabilise the soil deposited on the reservoir banks if the reservoir is to be saved from this serious danger.

2) The District Development Plan for Nyandarua expects the agricultural sector to be the major potential for promoting economic growth in the district. The higher altitude areas which include the study area are particular targets because they receive adequate rain fall and are generally endowed with better soils. This calls for detailed asssessment and identification of sediment production and potential source areas by employing runoff experimental plots, simulation experiments etc. to provide additonal data for identifying priority areas for conservation and type of measures to be applied. River gauging at varous sections is necessary to evaluate localised land use activities and their contribution to sediment loads.

3) A multivariate approach is needed to incorporate rainfall distribution and intensities, slopes, soil types, specific cover conditions, evapotranspiration, infiltration rates and seasonal reservoir echo-sounding in order to come up with a more complete picture of the erosion and sedimentation problems.

4) At present there seems to be no particular source of pollutants other than the agricultural activities releasing sediments. This situation is likely to change in the future following the high population growth rate, economic and developmental activities. This will result in the discharge of

various pollutants with greater magnitudes. It is therefore advisable to monitor the quality of the river water and establish appropriate measures for watershed management to conserve the water resources from such problems as eutrophication.

5) Agro-forestry trials may be applied in the forested reaches as a conservation measure for the forest areas being encroached upon.

6) A ground water balance assessment is necessary for the overall catchment studies. This should be done with the objective of securing ways for ensuring sustained baseflow.

7) Sediment data estimates can be improved by installing automatic recorders to capture the peak flows. Estimation of bedload also calls for further attention in terms of employing a variety of approaches that take into account the hydraulics of river flow to quantify the channel scours and their contribution to sediment loads.

8) The accuracy of river flow measurements can be improved by applying a variety of methods including the salt dilution method which could be more accurate at flow conditions not favoured by the current meter approach.

9) There is also a need to fit several frequency models to determine the one(s) best fitting the runoff data.

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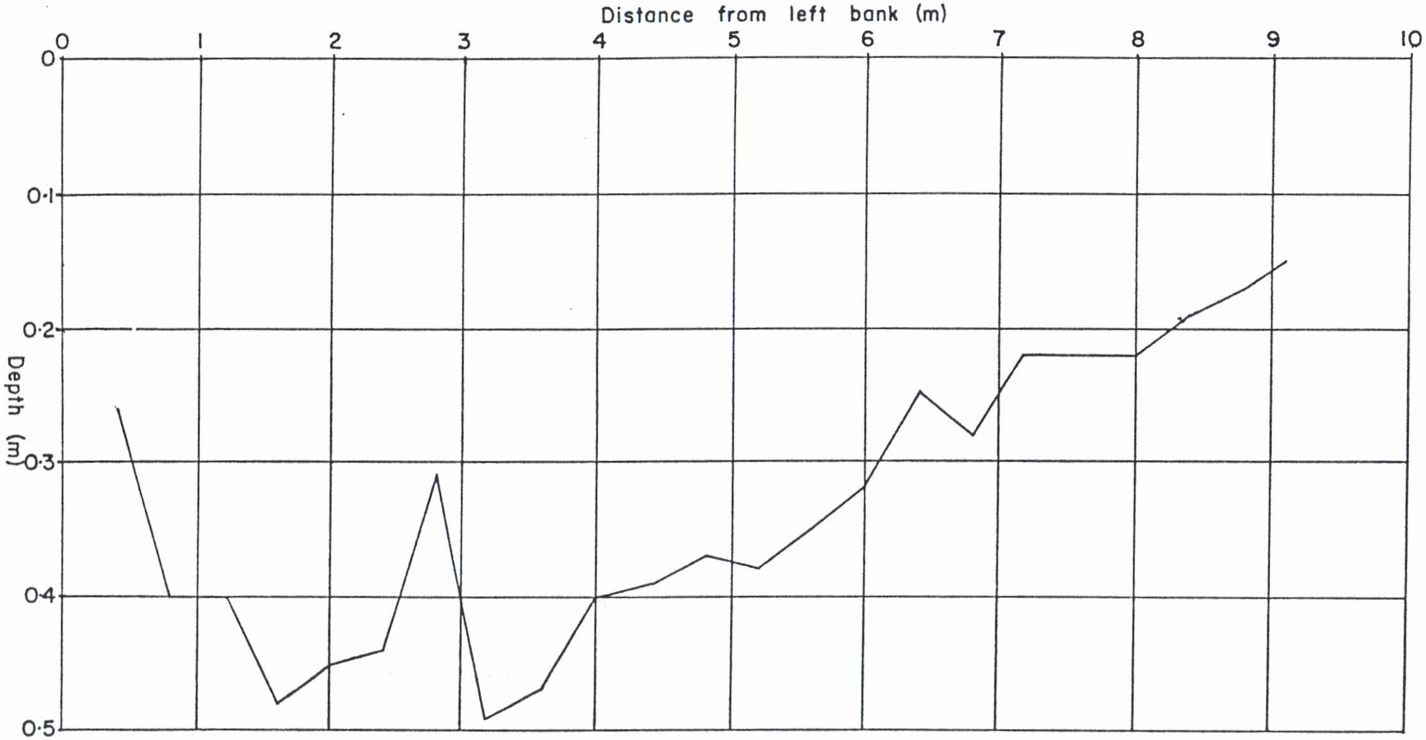
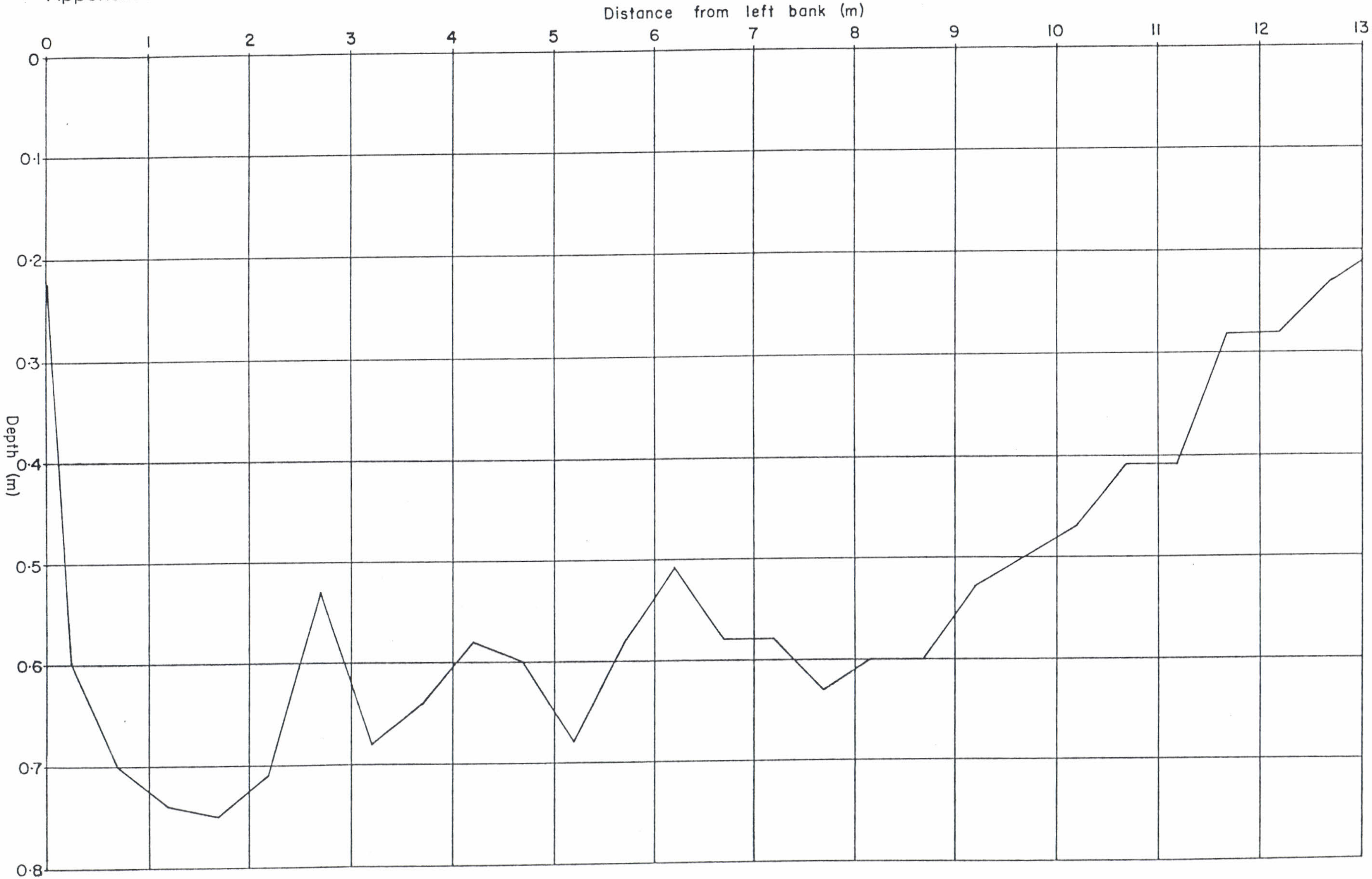
Appendix A.1 River cross-section upstream of Turasha dam on 24/11/91



Current Meter Flow Measurements upstream of damsite on 24.11.1991

Depth(m) (m)	Revolutions (50 seconds	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.26	56	0.292	0.169	0.0493
0.40	94	0.482	0.200	0.0964
0.40	112	0.572	0.200	0.1144
0.48	99	0.507	0.240	0.1217
0.45	94	0.482	0.225	0.1084
0.44	118	0.602	0.220	0.1324
0.31	136	0.692	0.155	0.1073
0.49	128	0.652	0.245	0.1597
0.47	90	0.462	0.235	0.1086
0.40	122	0.622	0.200	0.1244
0.39	90	0.462	0.195	0.0901
0.37	116	0.592	0.185	0.1095
0.38	92	0.472	0.190	0.0897
0.35	102	0.522	0.175	0.0914
0.32	99	0.507	0.160	0.0811
0.25	75	0.387	0.125	0.0484
0.28	51	0.267	0.140	0.0374
0.22	32	0.171	0.110	0.0188
0.22	26	0.144	0.110	0.0158
0.22	24	0.135	0.110	0.0148
0.19	28	0.153	0.095	0.0145
0.17	25	0.139	0.088	0.0122
				1.7463

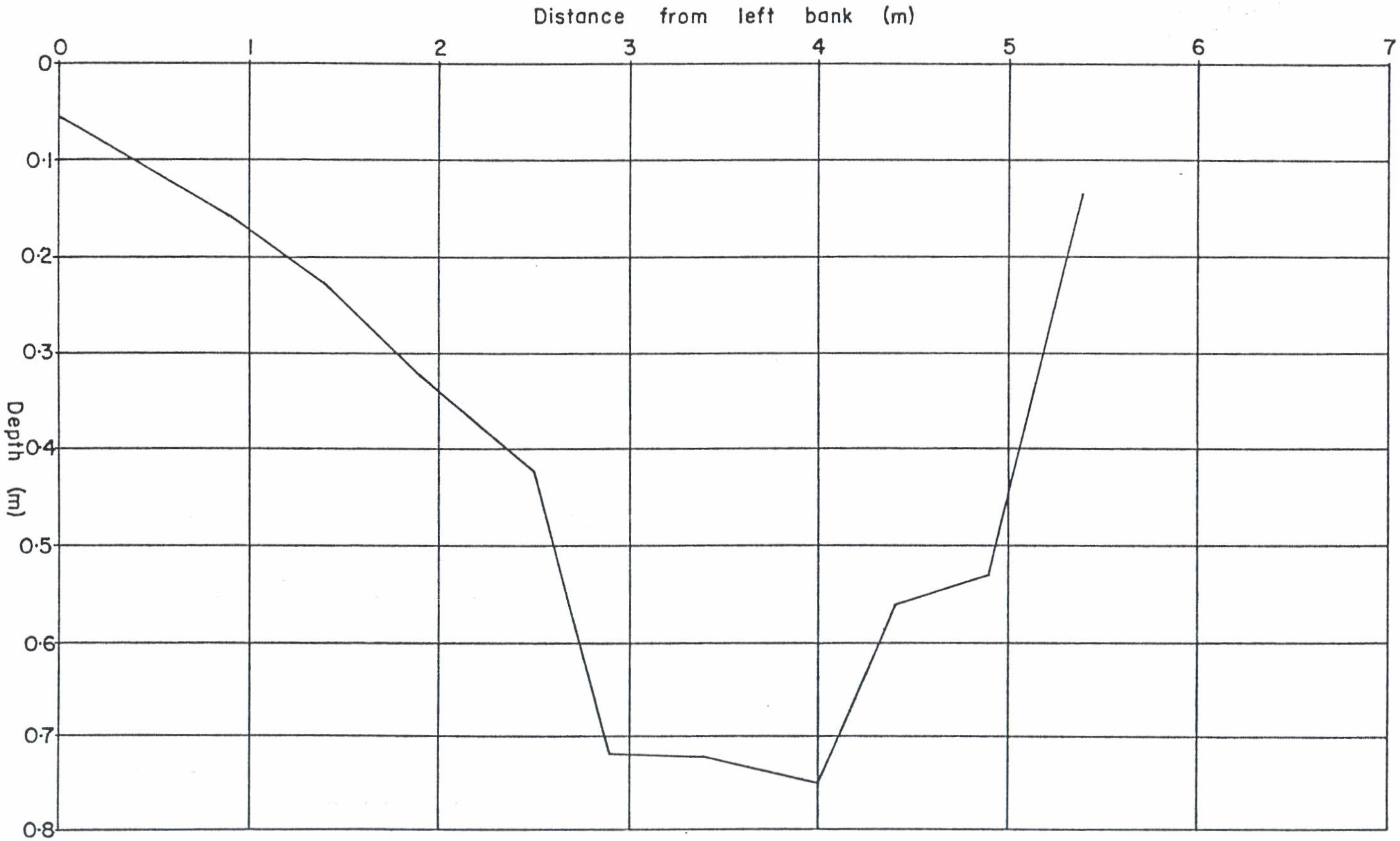
Appendix A.2: River cross-section upstream of Turasha dam,.Date 25/11/1991



Current Meter Flow Measurements upstream of damsite on 25.11.1991

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.70	32	0.171	0.665	0.1137
0.74	38	0.201	0.370	0.0744
0.75	41	0.216	0.375	0.0810
0.71	40	0.211	0.355	0.0749
0.53	33	0.176	0.265	0.0466
0.68	32	0.171	0.340	0.0581
0.64	30	0.162	0.320	0.0518
0.58	30	0.162	0.290	0.0470
0.60	28	0.153	0.300	0.0459
0.68	28	0.153	0.340	0.0520
0.58	34	0.181	0.290	0.0525
0.51	36	0.181	0.255	0.0462
0.58	32	0.171	0.290	0.0496
0.58	30	0.162	0.290	0.0470
0.63	28	0.158	0.315	0.0500
0.60	26	0.144	0.300	0.0432
0.60	22	0.126	0.300	0.0378
0.53	20	0.117	0.265	0.0310
0.50	18	0.108	0.250	0.0270
0.47	16	0.099	0.235	0.0233
0.41	14	0.090	0.205	0.0184
0.41	14	0.090	0.675	0.0608
				1.1322

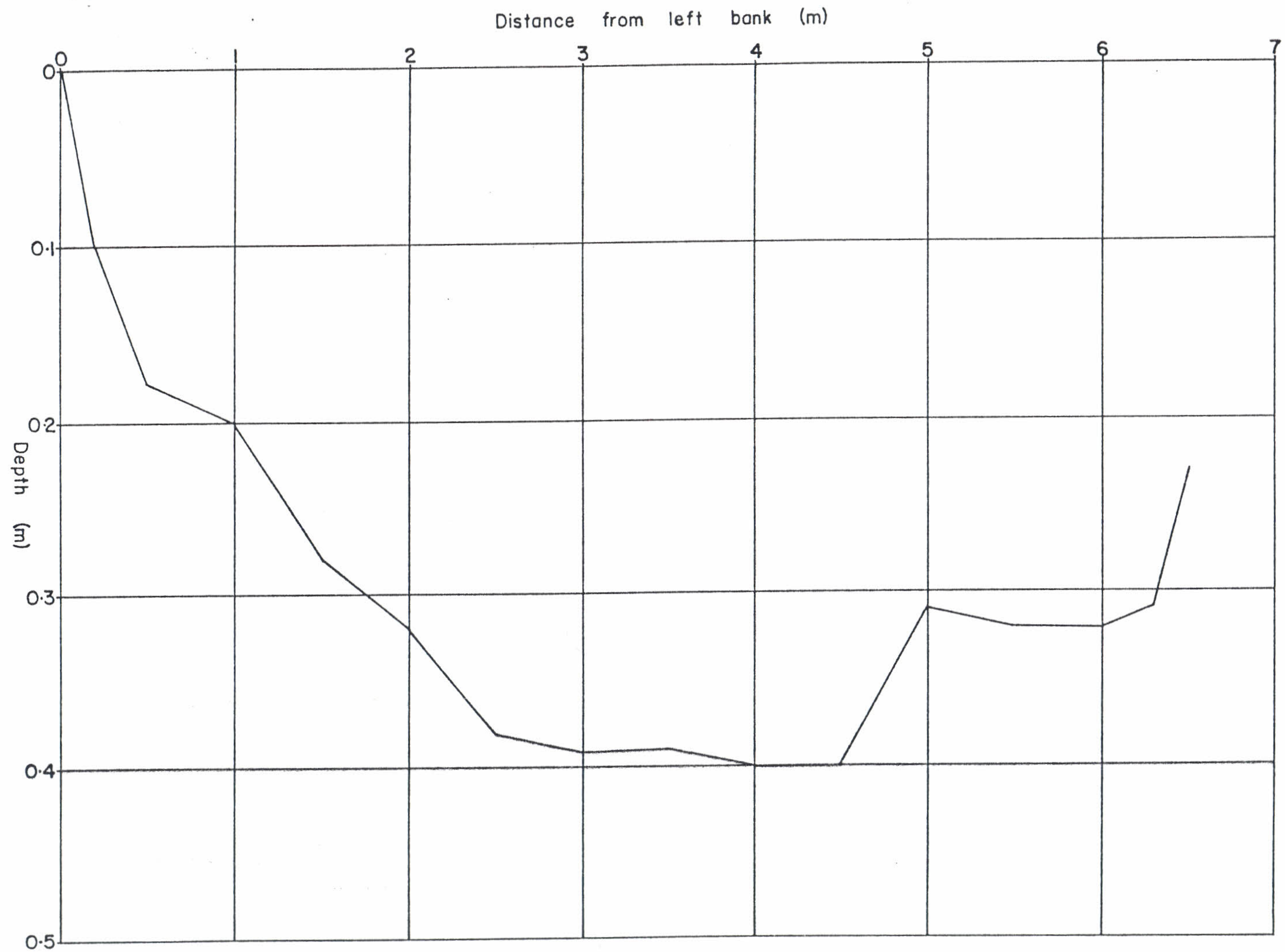
Appendix A.3: River cross-section upstream of Turasha dam,.Date 26/11/1991



Current Meter Flow Measurements upstream of damsite on 26.11.1991

Depth (m)	Revolutions (50 Seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.	30	0.162	0.1725	0.02795
0.22	43	0.226	0.1100	0.02486
0.32	55	0.287	0.1600	0.04592
0.42	54	0.282	0.2100	0.05922
0.70	53	0.277	0.3500	0.09695
0.70	58	0.302	0.3500	0.10570
0.75	61	0.317	0.3750	0.11888
0.56	81	0.417	0.2800	0.11675
0.53	76	0.392	0.2650	0.10388
0.13	54	0.282	0.3750	0.10575
				0.80587

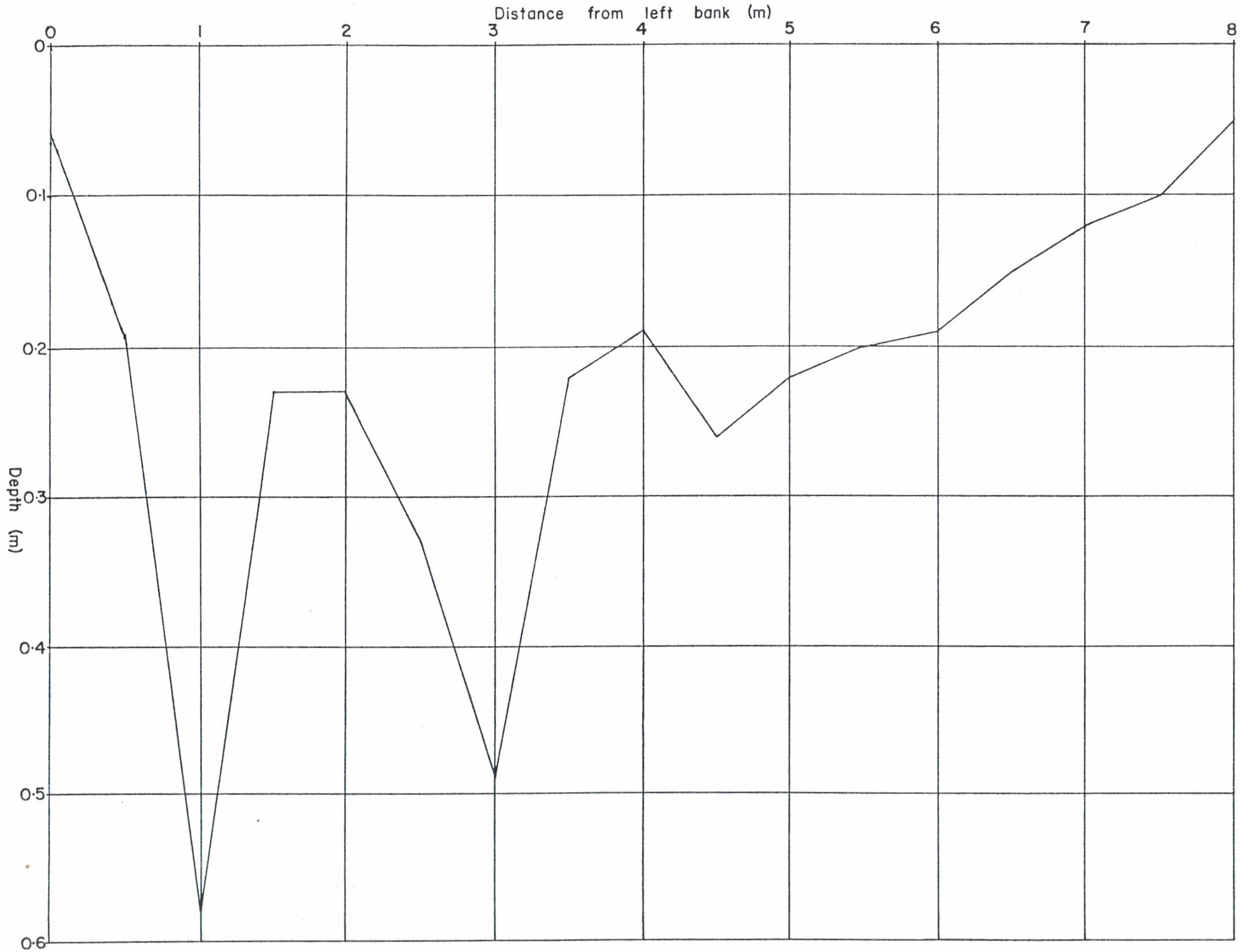
Appendix A.4: River cross-section upstream of Turasha dam on 27/11/91



Current Meter Measurements upstream of damsite on 27.11 1991

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.18	40	0.211	0.135	0.02848
0.20	48	0.251	0.100	0.02510
0.32	140	0.712	0.160	0.11392
0.38	126	0.642	0.190	0.12198
0.39	84	0.432	0.195	0.08424
0.39	66	0.342	0.195	0.06669
0.40	51	0.267	0.200	0.05340
0.40	30	0.162	0.200	0.03240
0.31	30	0.162	0.155	0.02511
0.32	24	0.135	0.160	0.02160
0.32	12	0.080	0.240	0.01920
				0.68886

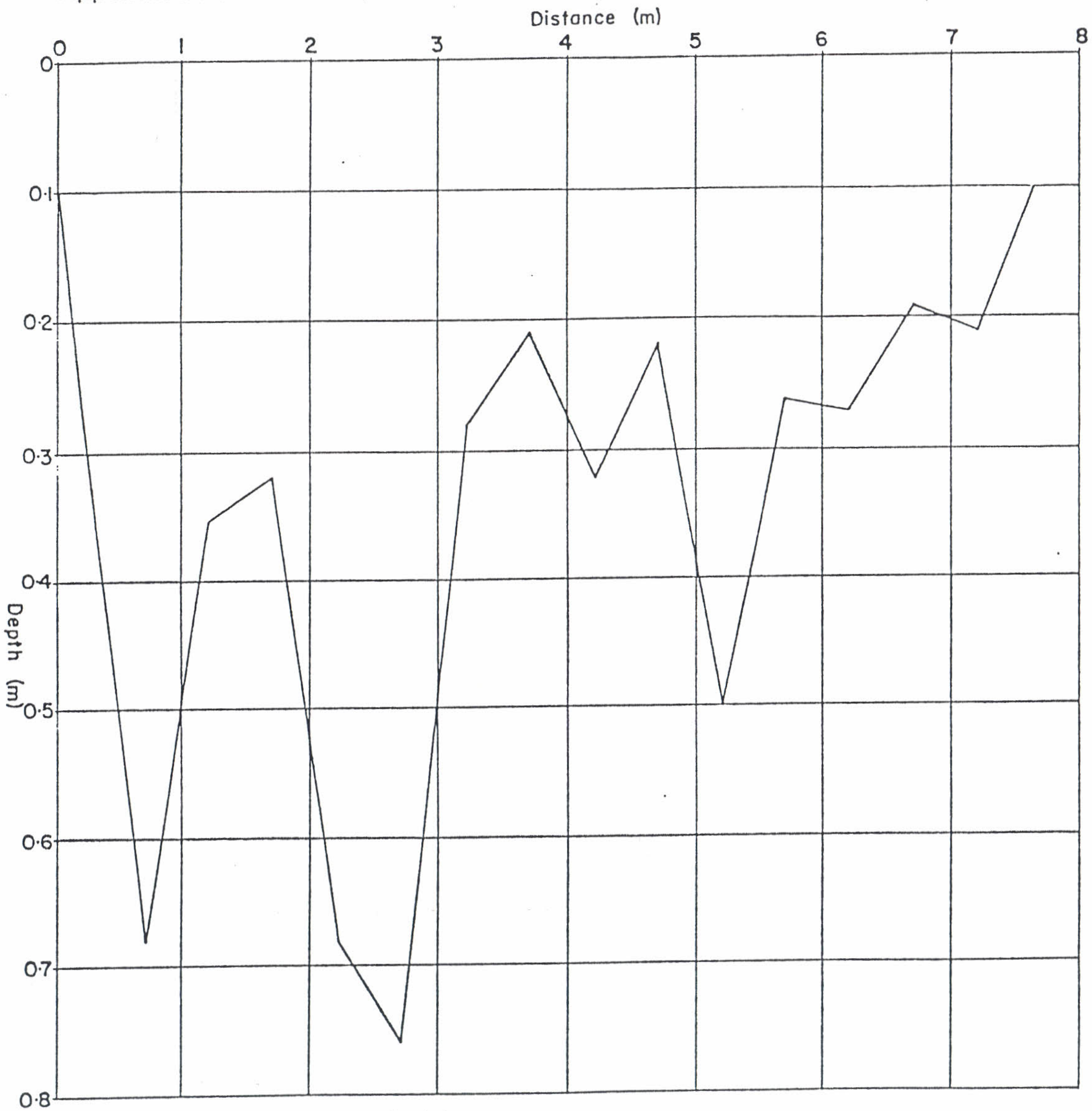
Appendix A.5: River cross-section upstream of Turasha dam,Date 28/11/91



Current Meter Flow Measurements upstream of damsite on 28.11.1991

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.19	91	0.467	0.1425	0.06655
0.58	70	0.362	0.2900	0.10498
0.23	78	0.402	0.1150	0.04623
0.23	64	0.332	0.1150	0.03818
0.33	53	0.277	0.1650	0.04570
0.49	56	0.292	0.2450	0.07154
0.22	70	0.362	0.1110	0.03982
0.19	77	0.397	0.0900	0.03573
0.26	62	0.322	0.1300	0.04186
0.22	62	0.322	0.1100	0.03542
0.20	52	0.272	0.1000	0.02720
0.19	14	0.090	0.0950	0.00855
0.15	9	0.067	0.0750	0.00502
0.12	22	0.126	0.1500	0.01890
				0.58568

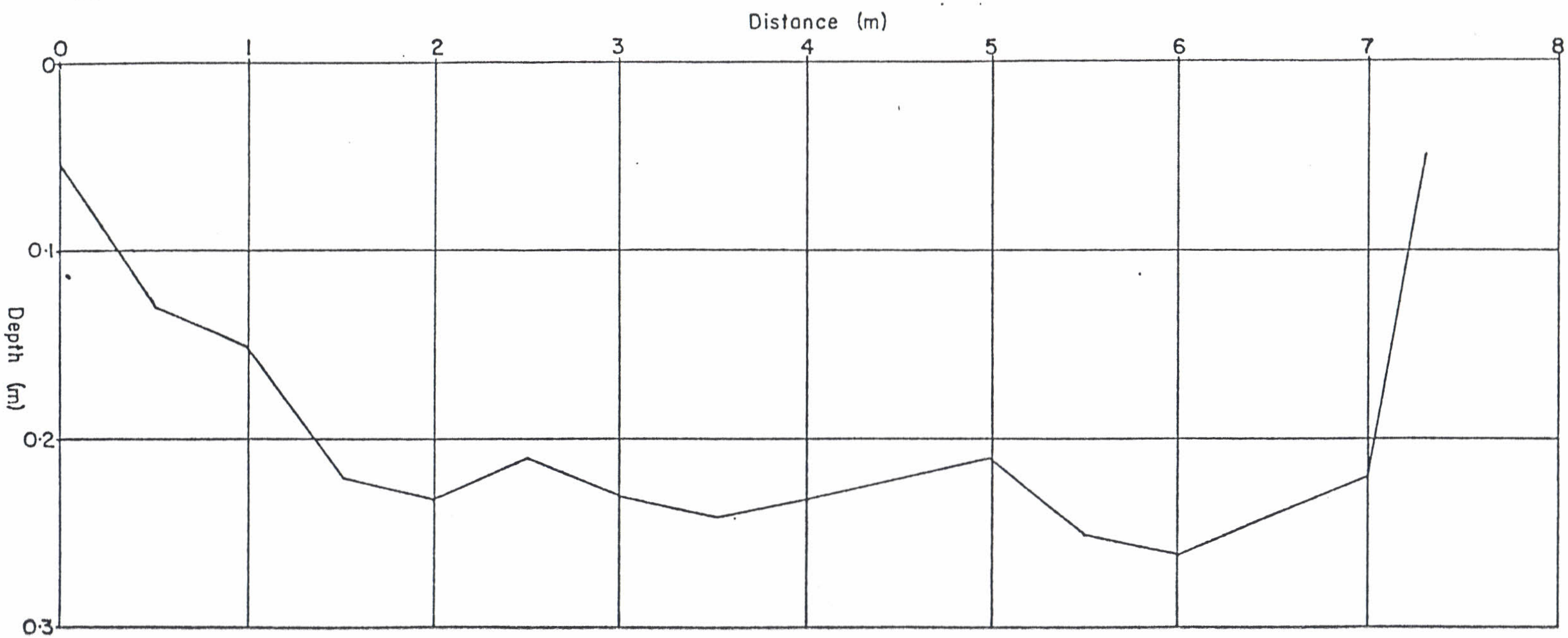
Appendix A6: Turasha upstream of Turasha dam on 15/4/1992



Current Meter Flow Measurements upstream of damsite on 15.4.1992

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.28	149	0.757	0.126	0.09538
0.68	112	0.572	0.340	0.19448
0.35	104	0.532	0.175	0.09310
0.32	87	0.447	0.160	0.07152
0.68	81	0.417	0.340	0.14178
0.76	81	0.417	0.380	0.15846
0.28	107	0.547	0.140	0.07658
0.21	122	0.622	0.105	0.06531
0.32	70	0.362	0.160	0.05792
0.22	96	0.492	0.110	0.05412
0.50	75	0.387	0.250	0.09675
0.26	58	0.302	0.130	0.03926
0.27	27	0.149	0.135	0.02012
0.19	26	0.144	0.095	0.01368
0.21	20	0.117	0.158	0.01843
				1.19689

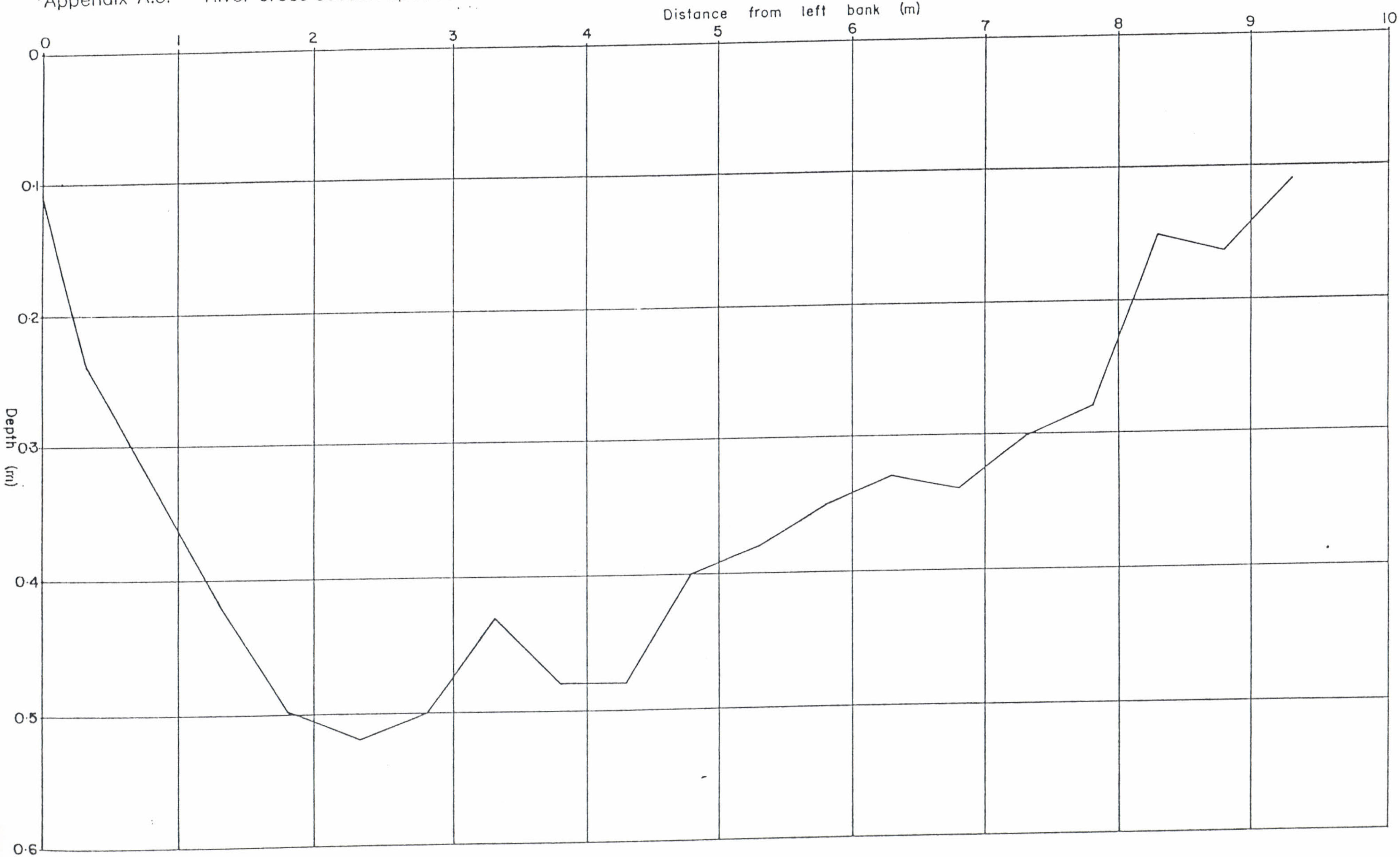
Appendix A.7: River cross-section upstream of Turasha dam: Date 30/11/91



Current Meter Flow Measurements upstream of damsite on 30.11.1991

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.22	110	0.562	0.385	0.21637
0.23	104	0.532	0.115	0.06118
0.21	65	0.337	0.105	0.03538
0.23	57	0.297	0.115	0.03416
0.24	90	0.462	0.120	0.05544
0.23	49	0.256	0.115	0.02944
0.21	31	0.167	0.105	0.01754
0.25	27	0.149	0.125	0.01862
0.26	64	0.332	0.130	0.04316
0.24	37	0.196	0.120	0.02352
0.22	84	0.432	0.275	0.11880
				0.71268

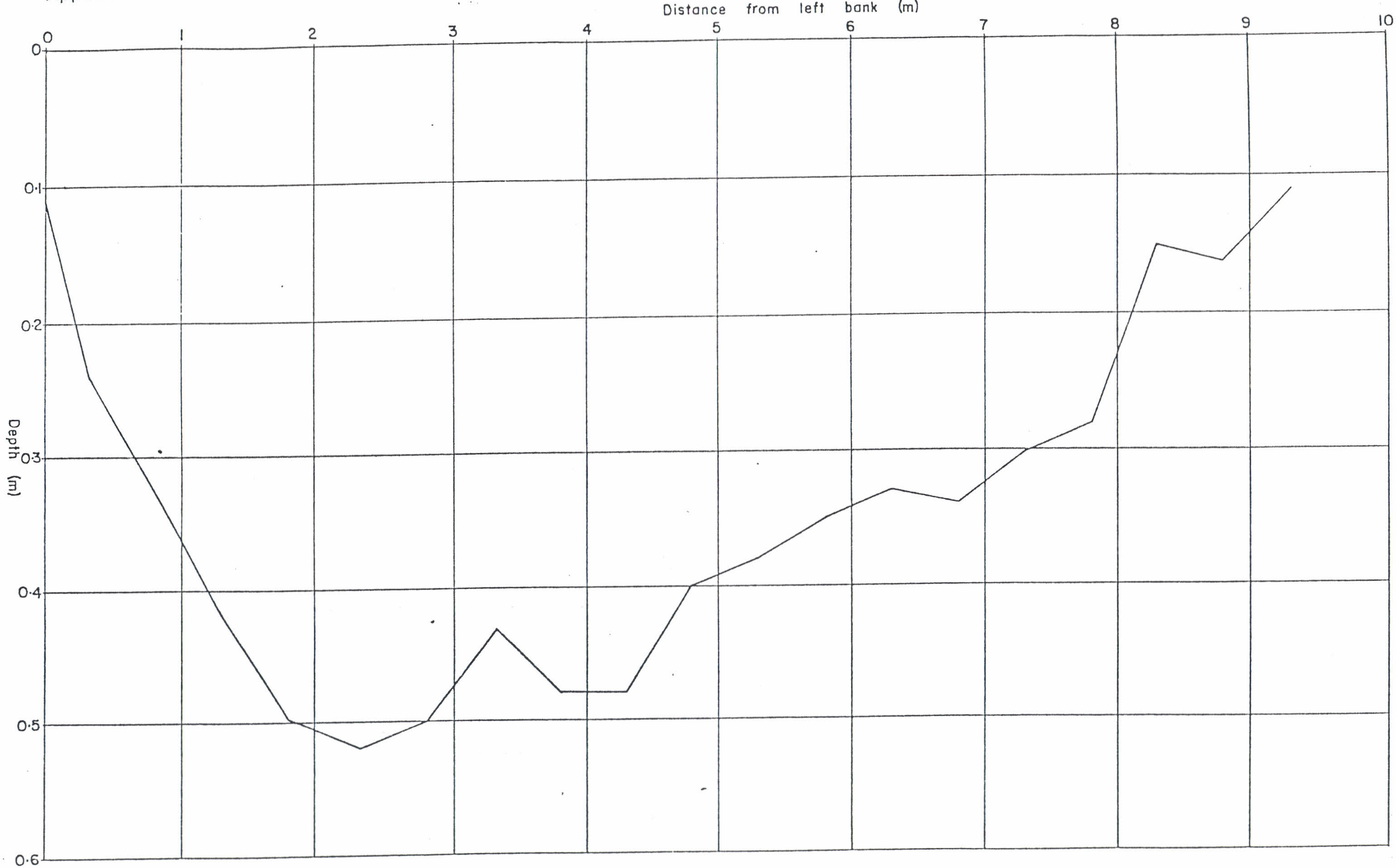
Appendix A.8: River cross-section upstream of Turasha dam on 1/12/91



Current Meter Flow Measurements upstream of damsite on 1.12.1991

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.20	54	0.282	0.120	0.03384
0.32	85	0.437	0.225	0.09832
0.43	112	0.572	0.215	0.12298
0.52	90	0.462	0.260	0.12012
0.60	160	0.813	0.300	0.24390
0.63	90	0.462	0.315	0.14553
0.58	120	0.612	0.290	0.17748
0.62	166	0.843	0.310	0.26133
0.59	119	0.607	0.295	0.17906
0.50	203	1.028	0.250	0.25700
0.43	128	0.652	0.215	0.14018
0.41	93	0.477	0.205	0.09778
0.41	52	0.272	0.250	0.06800
0.41	70	0.362	0.250	0.09050
0.30	136	0.692	0.150	0.10380
0.25	86	0.442	0.125	0.05525
0.27	77	0.397	0.135	0.05360
0.22	64	0.332	0.110	0.03652
0.21	20	0.117	0.105	0.01228
0.18	14	0.090	0.135	0.01215
				2.30962

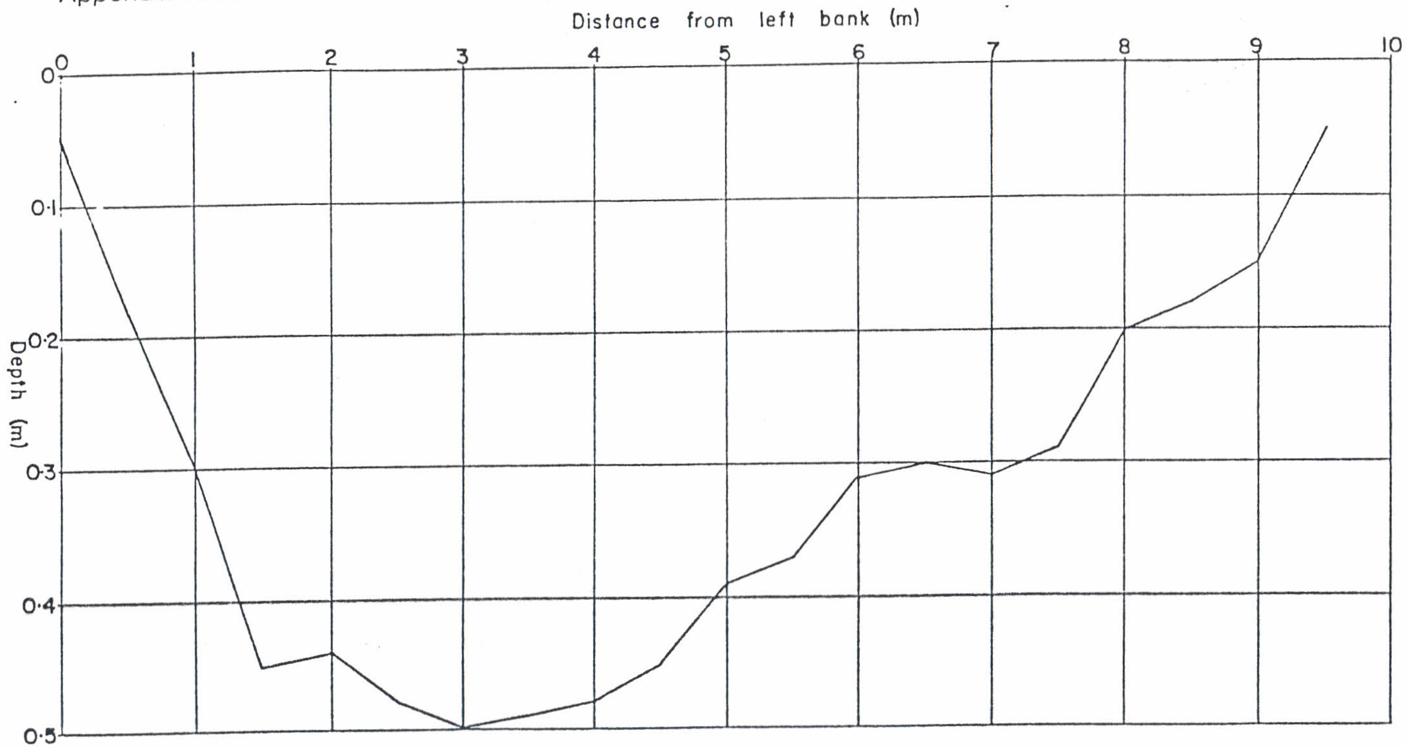
Appendix A.9: River cross-section upstream of Turasha dam on 17/4/92



Current Meter Flow Measurements upstream of damsite on 17.4.1992

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.24	43	0.226	0.025	0.005695
0.33	19	0.112	0.165	0.018480
0.42	86	0.442	0.210	0.092820
0.50	99	0.507	0.250	0.126750
0.52	88	0.452	0.260	0.117520
0.50	107	0.547	0.250	0.136750
0.43	94	0.482	0.210	0.101220
0.48	42	0.221	0.240	0.053040
0.48	97	0.497	0.240	0.119280
0.40	101	0.517	0.200	0.102400
0.38	79	0.407	0.190	0.077330
0.35	81	0.417	0.175	0.072975
0.33	71	0.367	0.165	0.060555
0.34	47	0.246	0.170	0.041820
0.30	49	0.257	0.150	0.038400
0.28	26	0.144	0.140	0.020160
0.15	22	0.126	0.075	0.009450
0.16	13	0.080	0.120	0.009600
				1.205245

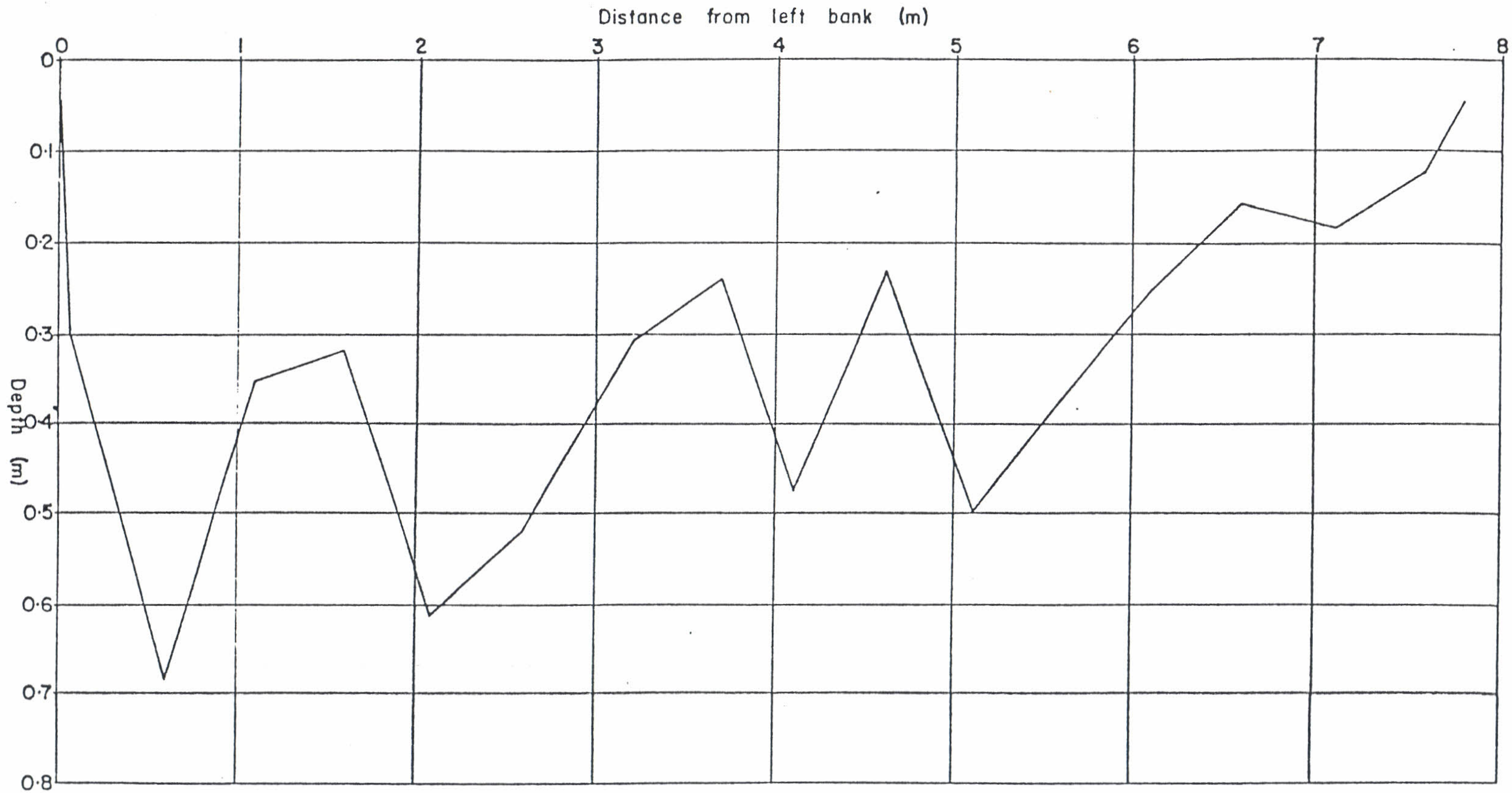
Appendix A.10: River cross-section upstream of Turasha dam on 19/4/92



Current Meter Flow Measurements upstream of damsite on 19.4.1992

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.18	40	0.211	0.063	0.013293
0.30	19	0.112	0.105	0.011760
0.45	72	0.372	0.225	0.083700
0.44	63	0.327	0.220	0.071940
0.48	72	0.372	0.240	0.089280
0.50	79	0.407	0.250	0.101750
0.49	87	0.447	0.245	0.109515
0.48	61	0.317	0.240	0.076080
0.45	74	0.382	0.225	0.085950
0.39	78	0.402	0.195	0.078390
0.37	84	0.432	0.185	0.079920
0.31	79	0.407	0.155	0.063085
0.30	79	0.407	0.150	0.061050
0.31	46	0.241	0.155	0.037355
0.29	41	0.216	0.145	0.031320
0.20	16	0.099	0.100	0.009900
0.18	16	0.099	0.090	0.008910
0.15	13	0.085	0.075	0.006375
0.05	0	0.026	0.125	0.003250
				1.022823

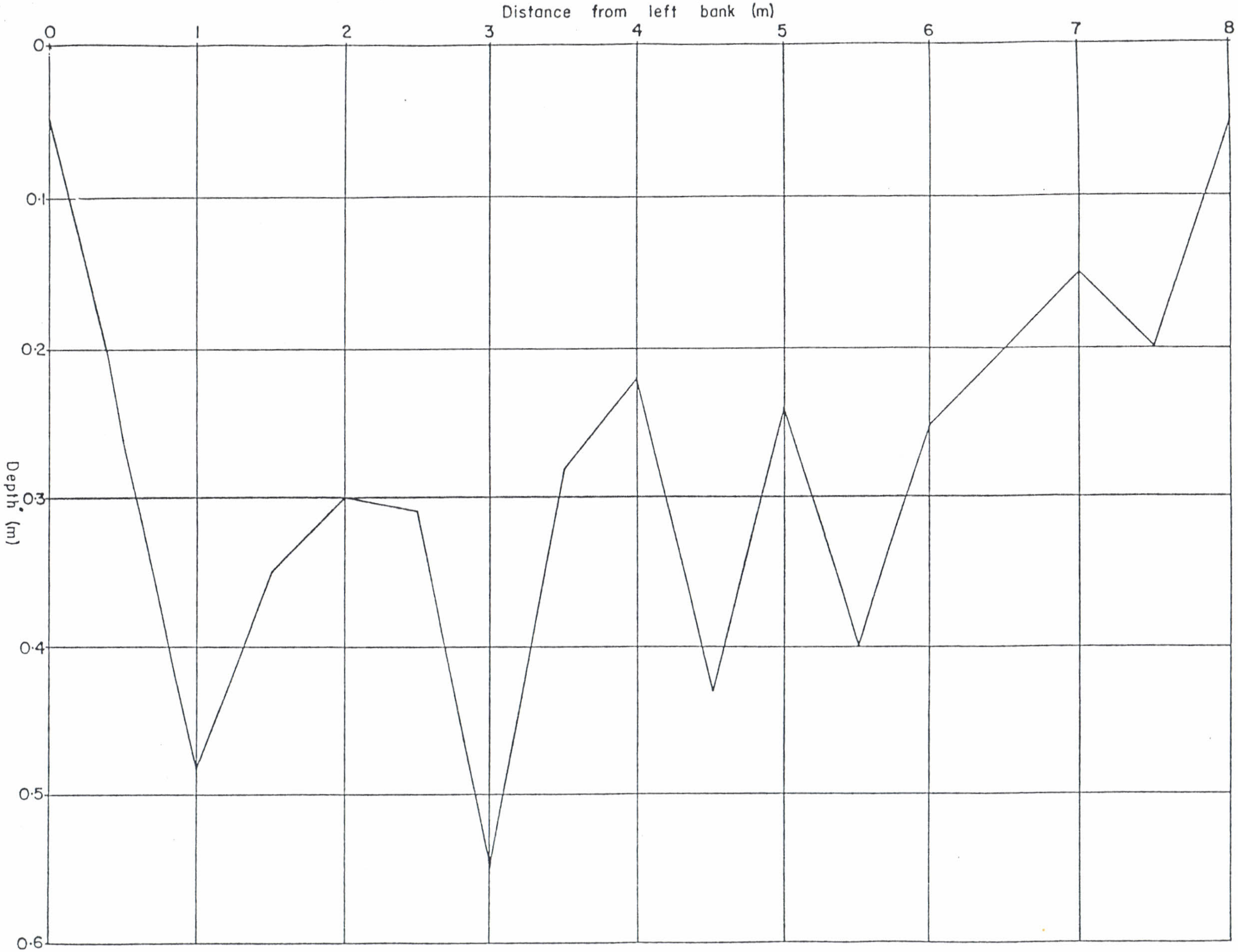
Appendix A.11: River cross-section upstream of Turasha dam,Date 21/4/92



Current Meter Flow Measurements upstream of damsite on 21.4.1992

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.29	119	0.602	0.100	0.060200
0.68	104	0.532	0.442	0.235144
0.35	111	0.567	0.175	0.099225
0.32	96	0.492	0.160	0.078720
0.61	50	0.261	0.305	0.079605
0.52	64	0.332	0.260	0.086320
0.30	99	0.507	0.150	0.076050
0.24	98	0.502	0.120	0.060240
0.47	74	0.382	0.235	0.089770
0.23	79	0.407	0.115	0.046805
0.50	78	0.402	0.250	0.100500
0.37	59	0.307	0.185	0.056795
0.25	26	0.144	0.125	0.018000
0.15	17	0.103	0.075	0.007725
0.18	20	0.117	0.189	0.022113
				1.113462

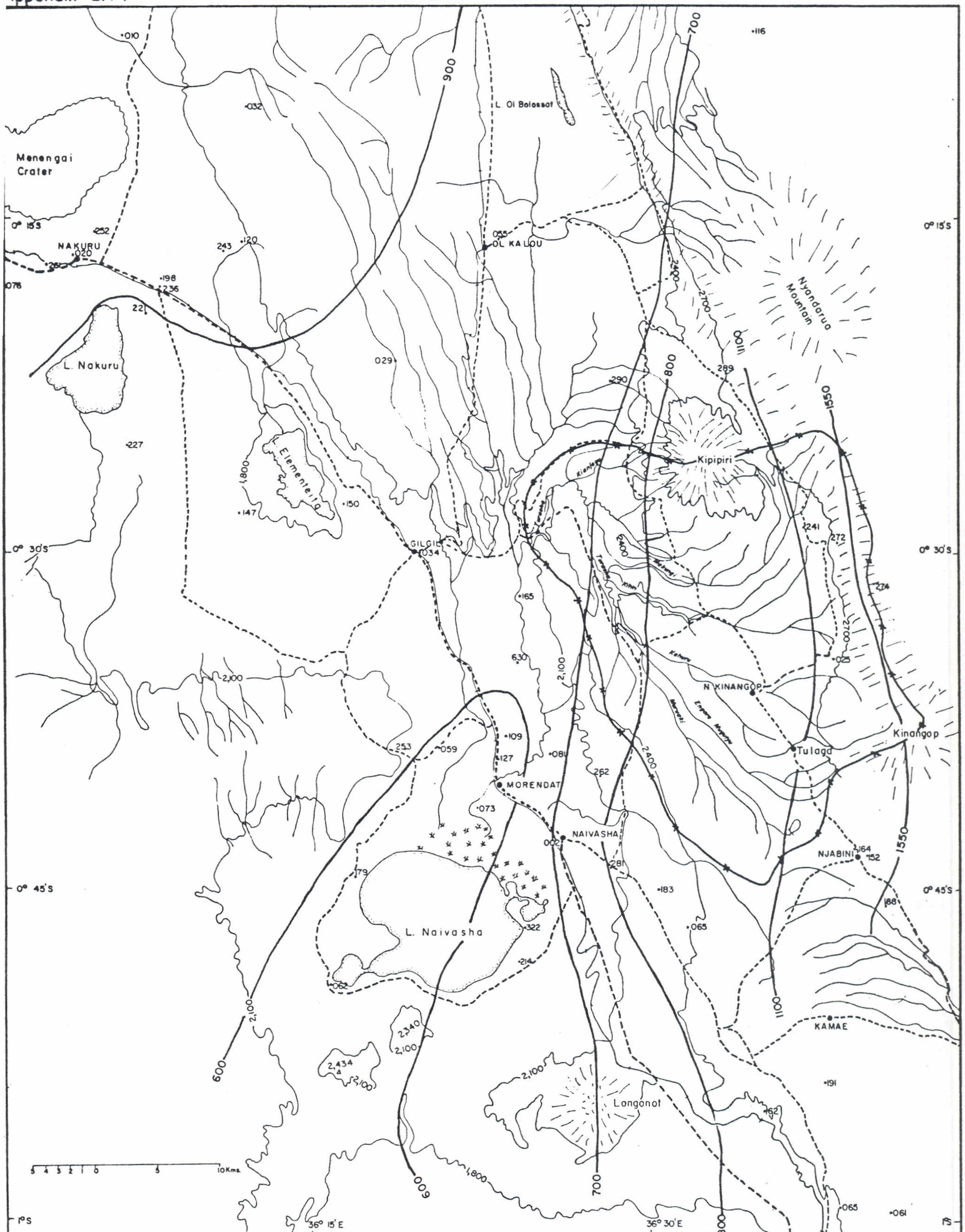
Appendix A.12: River cross-section upstream of Turasha dam,Date 22/4/92



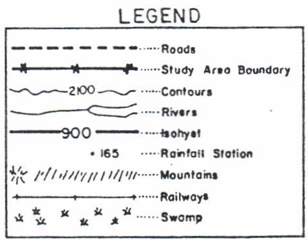
Current Meter Flow Measurements upstream of damsite on 22.4.1992

Depth (m)	Revolutions (50 seconds)	Velocity (m/s)	Area (m^2)	Partial discharge (m^3/s)
0.26	134	0.682	0.195	0.13299
0.48	122	0.622	0.240	0.14928
0.35	92	0.472	0.175	0.08260
0.30	94	0.482	0.150	0.07230
0.31	100	0.512	0.155	0.07936
0.55	80	0.412	0.275	0.11330
0.28	98	0.502	0.140	0.07028
0.22	120	0.612	0.110	0.06732
0.43	88	0.452	0.215	0.09718
0.24	86	0.442	0.120	0.05304
0.40	74	0.432	0.200	0.08640
0.25	42	0.221	0.125	0.02762
0.20	26	0.144	0.100	0.01440
0.15	22	0.126	0.075	0.00945
0.20	22	0.126	0.375	0.04725
				1.05552

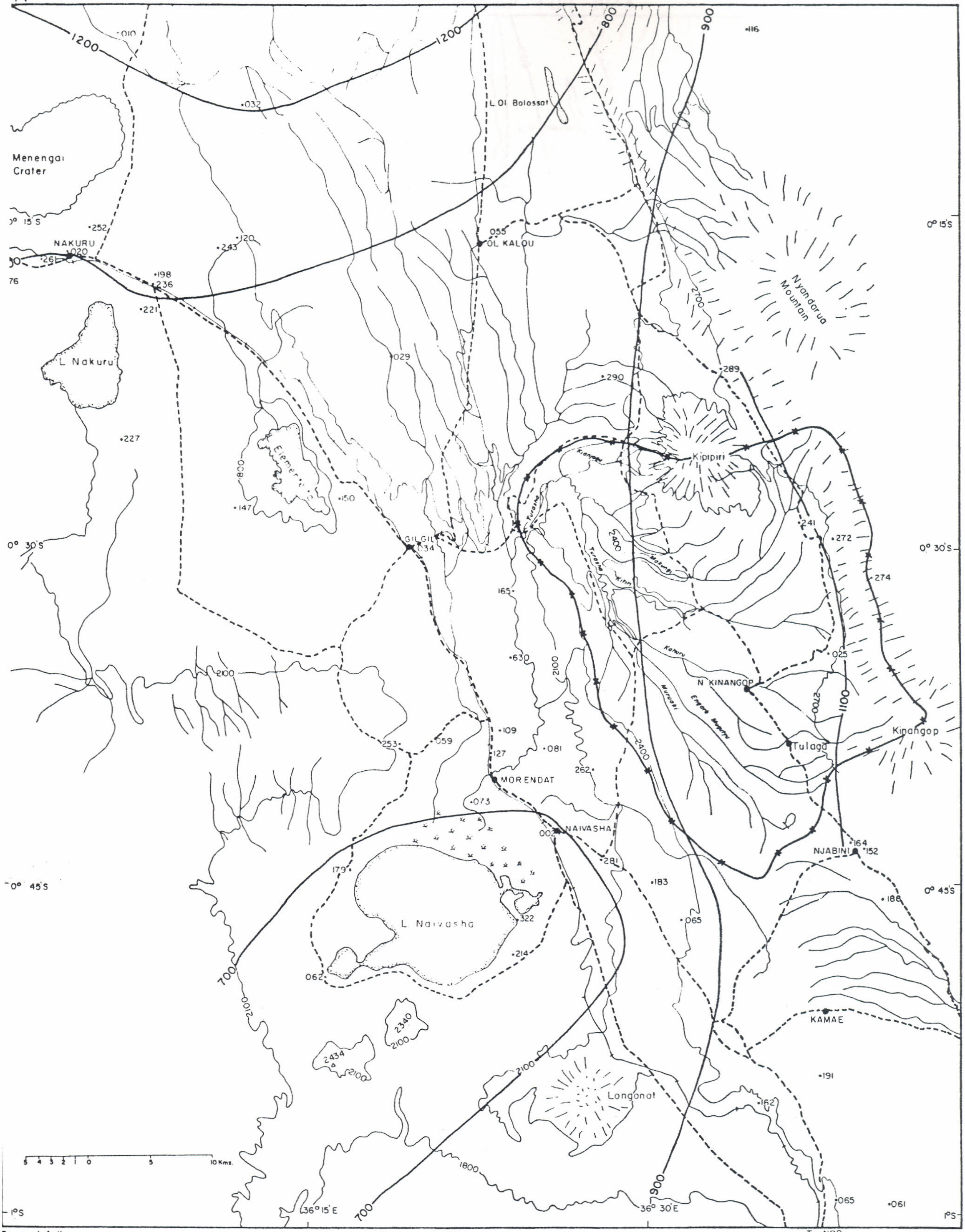
Appendix B.1 : ISOHYETAL MAP FOR 1966



Source : Author

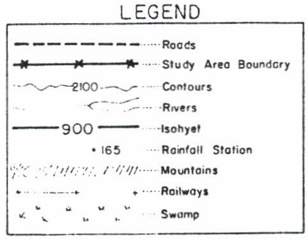


Appendix B.2 : ISOHYETAL MAP FOR 1967

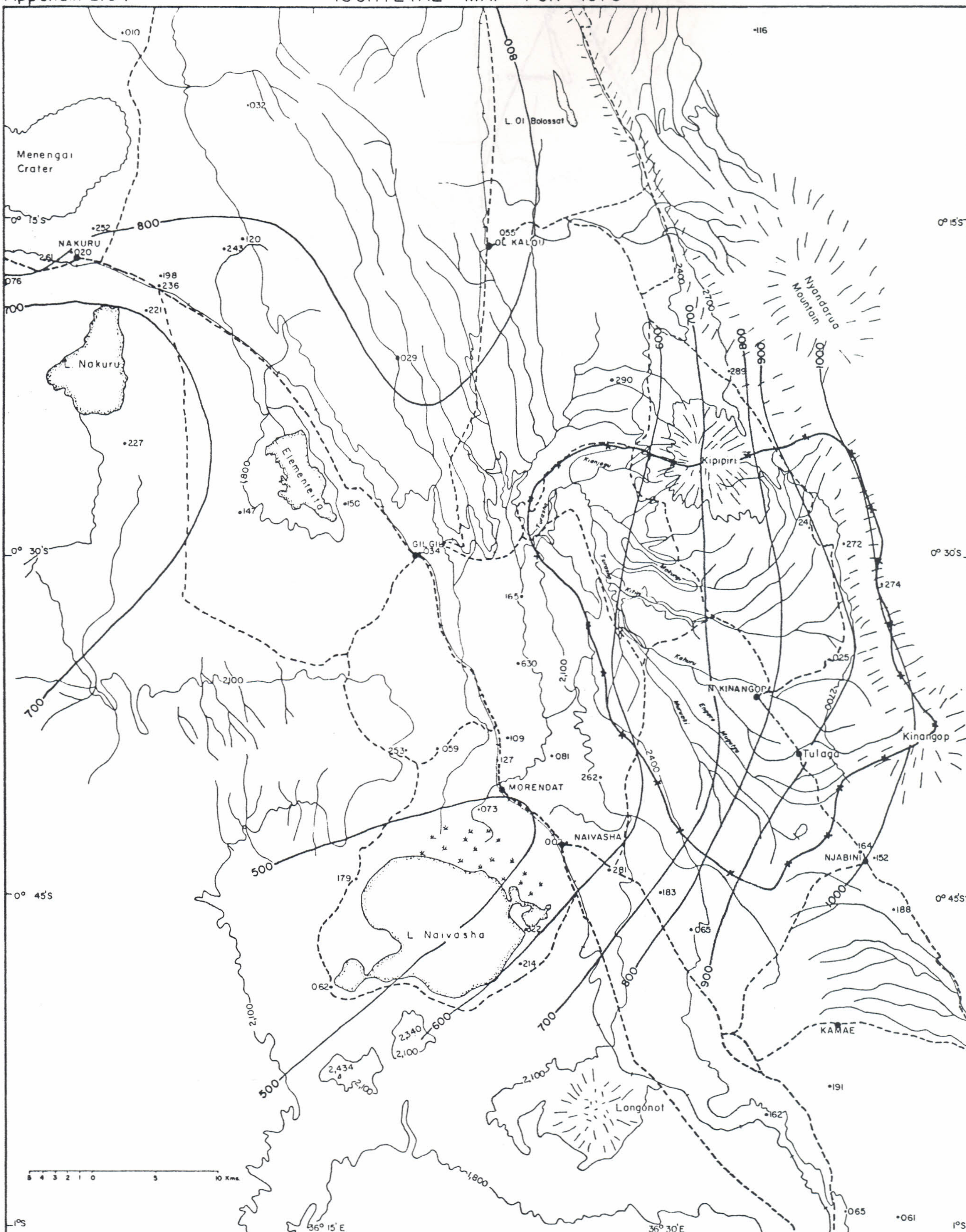


Source : Author

LEGEND

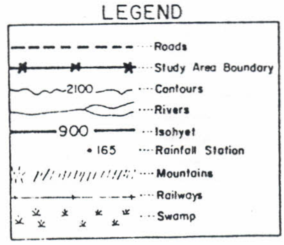


Appendix B.3 : ISOHYETAL MAP FOR 1973

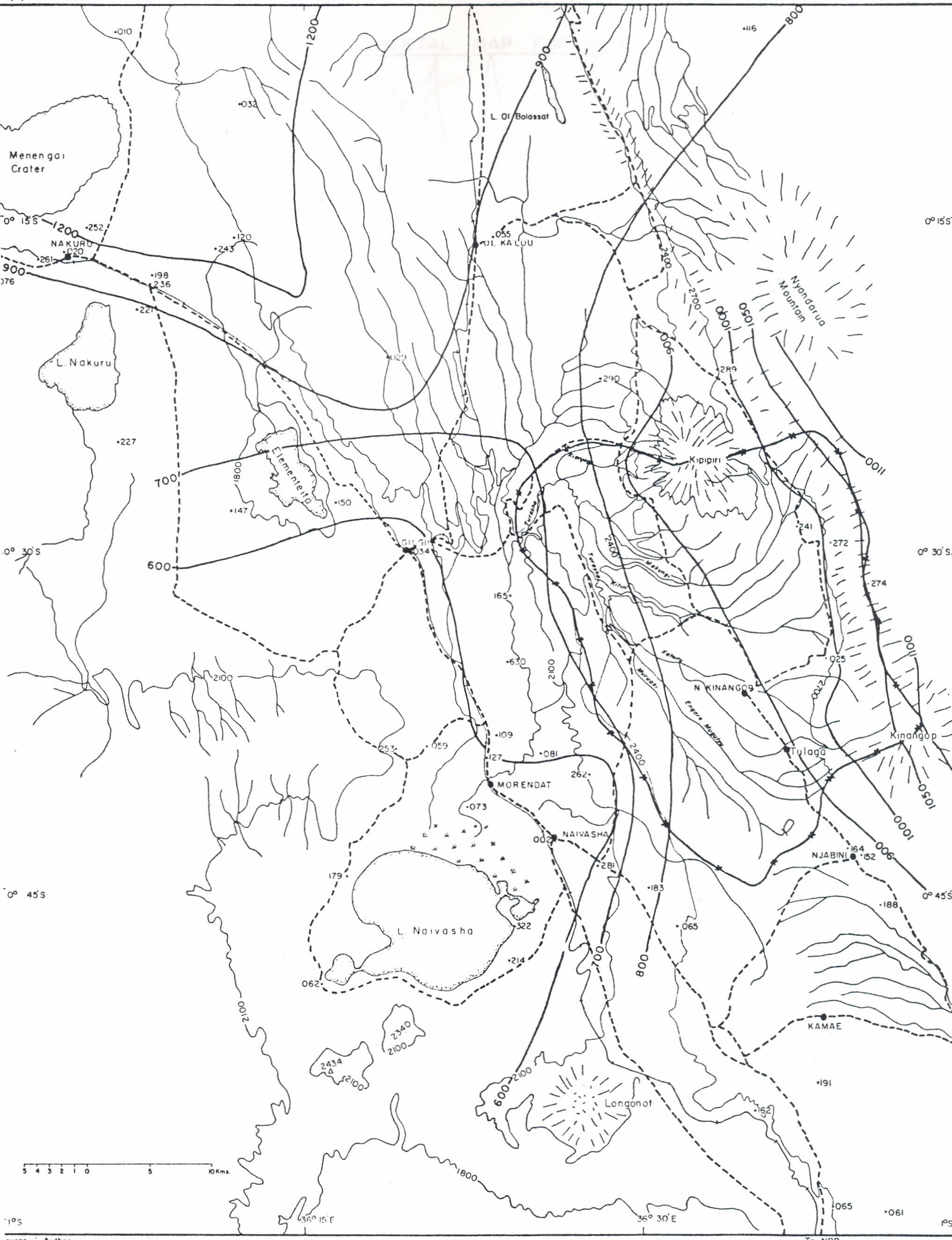


Source : Author

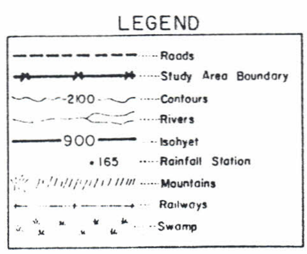
LEGEND



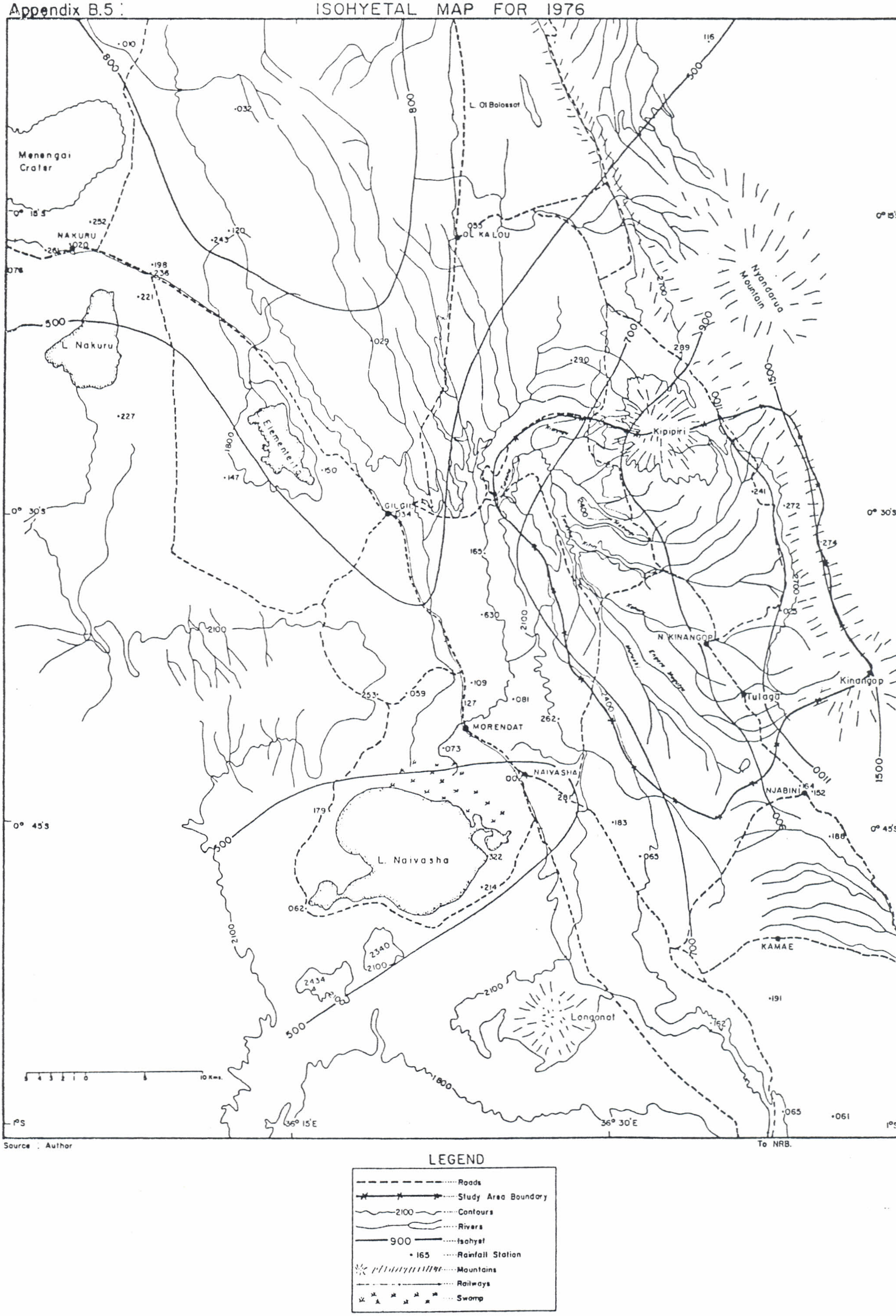
Appendix B.4 . ISOHYETAL MAP FOR 1975



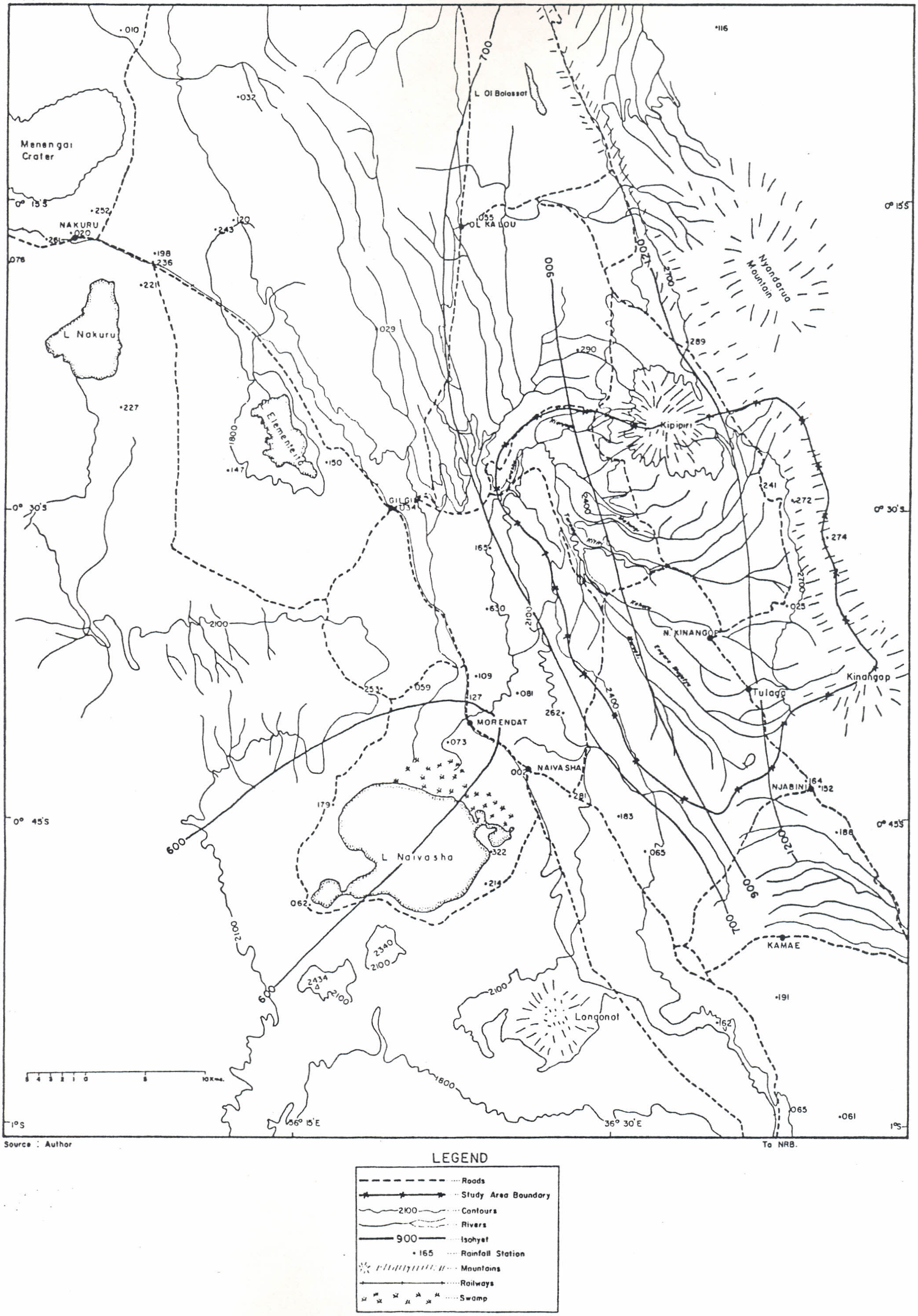
Source : Author



Appendix B.5 : ISOHYETAL MAP FOR 1976



Appendix B.6 : ISOHYETAL MAP FOR 1983



Source : Author