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A NEW ESTIMATE OF SEDIMENTATION RATES ON THE UPPER TANA RIVER

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ABSTRACT

This paper examines the rates of sedimentation in the Upper Tana Catchment. It reviews the previous estimates of sediment yields which are based on suspended sediment measurements and based on data now available suggests that there was a great underestimation as to the rates of sedimentation and outlines areas for further research.

INTRODUCTION

The Tana River is the largest river in Kenya and the country's major surface water resource. Most of its runoff originates above the site of the new Kamburu dam (see figure 1). In order to utilize this water resource for irrigation and power generation, two dams have been built and a third one is under construction and the feasibility study for the super-dam above Kamburu is now being undertaken.

Because of the interest in the Tana River, several reports have been written but three of those are more relevant in the present paper. In 1959, Sir Alexander Gibb and Partners, Ltd. wrote a "Report on the Water Resources of the Upper Tana River." This document covers the part of the basin above the Kindaruma dam site. In 1965, the consulting firms of Acres International and ILACO compiled a "Survey of the Irrigation Potential of the Lower Tana River Basin," covering the hydrology of the river downstream from the Kindaruma site. In 1974 a consulting firm wrote another report on the hydrology of the river above the proposed Gtaru scheme, but relied heavily upon the results of the earlier Gibb report. Each of these reports considered the probable rate of silting of the reservoirs to be built on the river. The consensus was that the sediment yields at the dam sites were low.

During the past few years, we have been studying the transport of sediment on the Tana River and elsewhere in Kenya. We have concluded that the rate of sedimentation at the dam sites has been underestimated by each of the consultant groups referred to above. In this report, we submit a new estimate of the rate of sedimentation at the sites of interest. We do not know whether these new calculations significantly alter the economics of the project, but we feel that the appropriate government agencies should be informed of the facts that have become available. We particularly want to stress the degree of uncertainty that exists in the prediction of sedimentation rates in such an environment. This point is extremely important if any sites should be considered for reservoir construction downstream of the present Kindaruma scheme. Finally, we offer some suggestions of what might be done if the rate of sedimentation in the present dam sites is considered a problem, or before any other dams are built downstream of the present ones.

THE AREA

The Upper Tana River drains the eastern slope of the Aberdare Mountains, the western and southern slopes of Mount Kenya and the lower areas west and south of Mount Kenya (see figure 1). The drainage area above the Kamburu dam site is approximately 9520 sq. km.

The patterns of rainfall, runoff, and land use which affect the sediment yield of the Tana are all strongly correlated with the large-scale geologic and topographic pattern of the region. Figure 2 shows the distribution of the two major rock groups in the basin. Trachytic, phonolitic and basaltic lavas underlie the highland parts of the catchment, while the lower one-quarter of the basin lies on Precambrian gneisses of the Basement Complex (see Government of Kenya, 1970). The distribution of rainfall, shown in figure 3, reflects these major geologic and topographic features, and in turn controls the pattern of runoff, vegetation, soils and land use, and therefore the rates of soil loss from different parts of the Upper Tana basin.

The tributaries of the river originate at high elevations in the steep, volcanic highlands of the Aberdare Mountains and Mount Kenya, where rainfall is heavy (>1750 mm.) and the land is clothed with dense, evergreen forest. The soils of these areas are deeply weathered loams with high infiltration rates and low erodibility. Erosion rates in these areas are low, in spite of the steepness of the land.

Between the elevations of 1200 m. and 1800 m. the rainfall is high (1000-1750 mm.), hillslopes are steep, and soils are loamy, but the former woodland vegetation has been removed and replaced by hand-cultivated agricultural crops, such as maize, vegetables, coffee and bananas. These crops do not provide a good ground cover, and so the rate of erosion is greatly accelerated, in spite of the generally low erodibility of the soils.

Below 1000 m. rainfall is too sparse (<700 mm.) to support anything but marginal farming and heavy grazing by cattle, sheep, and goats. This land is underlain by granitic rocks of the Precambrian Basement system which weather to coarse, sandy soils. The organic content, structure and infiltration capacity of these soils are all poor. The sparse vegetation cover and poor soil characteristics favour soil erosion, in spite of the fact that hillslopes in this zone are less steep than in the two higher zones.

The drainage basin of the Upper Tana, therefore, can be divided into 3 zones in which sediment yields should be markedly different. These zones are: the forest zone, the humid cultivated zone, and the subhumid zone of marginal farming and grazing.

PREVIOUS ESTIMATES OF SEDIMENT YIELDS

Sediment yields for a drainage basin are usually calculated with the aid of a flow duration curve and a sediment rating curve for a station at the outlet of the basin. The flow duration curve is calculated from observations of daily mean discharge of the river at the gauging station. The sediment rating curve is obtained by intermittent sampling of the concentration of suspended sediment at the station. From the sediment concentration and the water discharge at the time of sampling the rate of sediment transport (tonnes per day) is calculated and plotted against the discharge (see figure 4).

Flow duration curves and sediment rating curves are available for 7 stations on the main stem of the Upper Tana and its major tributaries. The stations are listed in table 1 and their locations are shown on figure 1.

In the Gibb report (1959) sediment rating curves for 6 stations mentioned in Table 2 were plotted by eye through the points on graphs like figure 4. The daily flow records for the period 1947-58 were used with these sediment rating curves to calculate the annual sediment yields. The average annual sediment yields for the period are listed in Table 2.

In 1965, the Acres ILACO report gave an estimate of the sediment yields of the Thiba at station 4 DD1 and the Tana at station 4ED3. These calculations were obtained with the same sediment concentration data used in the Gibb report with a few more samples collected at 4ED3. The sediment rating curves were again fitted by eye, and water discharges for the period 1948-65 were used to compute the annual sediment yields. The average annual values thus obtained are listed in Table 2, and they agree reasonably well with those of the Gibb report, being 76 per cent of the 1959 value at 4DD1 and 85 per cent of the earlier figure at 4ED3.

The consultants writing the Gtaru Report seem to have accepted the values from the Gibb Report for the tributaries and the Acres/ILACO value for the mainstream of the Tana at Station 4ED3.

Table 1

STATIONS ON THE TANA RIVER AND ITS TRIBUTARIES FOR WHICH SEDIMENT YIELDS CAN BE CALCULATED

R.G.S. No.	*River*	*Station*	*Drainage Area* (km^2)
4 AC 3	Sagana	Kiganjo town	1418
4 BC 2	Sagana	Sagana town	2650
4 BE 1	Maragua	Maragua town	357
4 CA 2	Chania	Thika town	517
4 CB 4	Thika	Thika town	331
4 DD 1	Thiba	Machanga village	1970
4 ED 3	Tana	Kamburu	9520

Table 2

AVERAGE ANNUAL SEDIMENT YIELDS FOR THE UPPER TANA AND ITS TRIBUTARIES DURING THE PERIOD 1947–58 AS GIVEN IN THE GIBB REPORT (1959), AND DURING THE PERIOD 1947–65 AS GIVEN BY ACRES/ILACO.

R.G.S. No.	*River*	*Sediment Yield* (*tonnes/yr*)
Gibb Report (1947–58)		
4 AC 3	Sagana	85,000
4 BE 1	Maragua	335,000
4 CA 2	Chania	41,000
4 CB 4	Thika	131,000
4 ED 3	Tana	411,000
Acres/ILACO Report (1948–65		
4 DD 1	Thiba	100,000
4 ED 3	Tana	350,000

The most striking feature of the sediment yields listed in table 2 is that the sum of the values for the tributaries is greater than that for the downstream station, 4ED3. Yet the drainage area of the tributaries above the various gauging stations constitutes less than 50 per cent of the catchment above 4ED3. Furthermore, the ungauged portion of the drainage basin has vegetation, soil and land use conditions which are conducive to high rates of soil erosion. One would expect, therefore, that the rate of sediment transport past station 4ED3, the present site of the Kamburu dam,* would be much greater than that given in table 2.

There are only two possible explanations for this discrepancy. First, a large amount of sediment might have been deposited between the gauging stations on the tributaries and 4ED3. We have examined the channel of the Tana on aerial photographs and in the field and we have not found any deposits of the necessary size. Where the streams flow over lava, their gradients are steep and their valleys narrow. There is very little opportunity for deposition, which is limited to a few point bars of coarse gravel with a little sand. Further downstream, the main Tana has a well developed floodplain, but there are no signs of deposition of large amounts of sediment along this reach. We see only the normal cutting and filling that can be observed on any other meandering stream which is migrating back and forth across its floodplain.

The second possible explanation is that there are deficiencies in the estimates of sediment yields because of limitations of the data used for the original calculations. We will review these deficiences in the next section where we present our own estimate of sediment transport rates at the important dam sites.

NEW ESTIMATE OF SEDIMENT YIELDS

Suspended sediment data collected by the Ministry of Water Development between the years 1948 and 1965 were used to construct sediment rating curves for stations 4BC2, 4BE1, 4CA2, 4CB4, 4DD1, and 4ED3, as shown in figure 4. The lines were fitted to the data point by least-squares regression. The original data are filed in the Ministry of Water Development, Nairobi, and the plotted points for each station are portrayed in the report by Dunne (1974), who discusses the nature and limitations of the data.

The sediment rating curves were then used, together with the flow duration curves for each station for the period 1956-70*, to calculate the average annual sediment yield from the basins. The computed yields are listed in table 3. Two aspects of the data are immediately clear. The first is that the average annual sediment yields computed from the later period exceed those for the earlier period listed in table 2. The later yields vary from 105 to 467 per cent of the earlier values. Secondly, as with the earlier reports, the sum of the sediment yields for the tributaries exceed the yield at 4ED3, even though the gauged tributary area comprises only 61 per cent of the larger catchment. In fact, the differences between the tributary yields and the downstream yield are even greater in the later period than during 1947-58. We discuss both of these problems in greater detail below.

DISCREPANCY BETWEEN UPSTREAM AND DOWNSTREAM YIELDS

We have previously pointed out that we were not able to find field evidence of large-scale deposition between the tributary gauging stations and 4ED3. The discrepancy between the computed yields, therefore, must result from some inadequacy of the original data.

In figure 4, the sediment rating curves for all the tributary stations are remarkably parallel, their slopes (the exponents in the power function

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*Data collection at stations 4DD1 and 4ED3 was terminated by the construction of the Kamburu dam and reservoir.

*For station 4BC2 flow data were only available on computer tape for the period 1960-70, so the calculations for this station are for the shorter period only.

relating sediment transport rate to stream discharge) lie between 1.97 for 4DD1 and 2.27 for 4BC2. The exponents indicate the rate at which sediment transport increases with discharge, and in a general way, therefore, they reflect the sediment-producing characteristics of the catchments. Because the tributary catchments have similar geology, physiography, rainfall, runoff and land use, it is not surprising that the rate of increase of sediment production with discharge is similar in each catchment. Secondly, the curves for all the tributaries are defined by the large number of field samples 86-115), including a sufficient number of samples at high flows to give a good distribution of points along each sediment rating curve.

Table 3

AVERAGE ANNUAL SEDIMENT YIELDS FOR THE PERIOD 1956–70

Station	*River*	*Drainage*	*Sediment Yield (tonnes/yr)*
4 BC 2*	Sagana	2650	1,098,826
4 BE 1	Maragua	357	581,479
4 CA 2	Chania	517	191,453
4 CB 4	Thika	331	147,520
4 DD 1	Thiba	1970	297,957
4 ED 3	Tana	9520	866,504

*1960–1970 only.

The graph is less satisfactory for station 4ED3. Fewer samples were collected at this station (57) and they were concentrated at low flows. The few points for high flows fall well above the best-fit line, whose position is mainly determined by points at low discharges. The data suggest, therefore, that the computed slope of the best-fit sediment rating curve for 4ED3 is too low to represent adequately the sediment transport rate at high flows. Such an error can have a particularly strong effect upon the estimated sediment transport rate at high flows, if the curve developed on the basis of much lower flows is extrapolated. Such an extrapolation is always necessary in computing sediment yields because it is extremely unlikely that the rare, highest discharges will have been sampled.

A few recent sediment samples have been collected (by Ongweny) at two stations that are close to two of the previously mentioned stations, which have been inundated by the Kamburu reservior. Samples were collected at station 4DD2, 20 kilometers upstream from 4DD1 on the Thiba River. The few measurements so far available plot within the scatter of points used to define the sediment rating curve for 4DD1 in figure 4, and they straddle the curve. The sediment rating curve for the river seems to have remained stable, therefore.

A few measurements of suspended sediment data have also been made at 4DE2, a station on the main Tana River immediately below the confluence of the Sagana and the Thika, and 35 kilometers upstream of the former site of 4ED3. The points so far available for this station are for moderately high discharges and they all plot well above the curve shown in figure 4. Too few points are presently available for the construction of a sediment rating curve for the new station, but the data confirm the suspicion that the 4ED3 curve shown in figure 4 has a slope that is too low, and that it greatly underestimates sediment transport rates when it is extrapolated to the high discharges which are responsible for the majority of the sediment loss from a catchment.

We therefore suggest that the field data used to construct the sediment rating curve for 4ED3 are inadequate for that purpose and should *not* be employed as the basis for making estimates of the rate of sedimentation at the important reservoir sites on the Upper Tana. We suggest that until better data become available, an *approximate* rate of sediment transport during the 15 years from 1956-70 can be estimated as outlined below. We also discuss the difficulties of projecting this rate into the future, and suggest some further studies that would be valuable.

ESTIMATE OF SEDIMENT TRANSPORT RATE ON THE UPPER TANA

The pattern of major sediment inputs to the Upper Tana at the Kamburu reservoir is shown in figure 5. This diagram also includes computed values for each of the inputs. The figures in parentheses are the drainage areas of the various sub-basins. The numbers without parentheses are the estimated yields of sediment in thousands of tonnes per year. The areas which are shaded are those for which the sediment yields were computed from adequate sediment rating curves and flow records for the period 1956-70, as listed in table 3. For the unshaded areas sediment yields were estimated as described below, and as discussed in more detail in a larger manuscript (Dunne, 1975):

1. For the *Ruambuthambi* catchment: the sediment yield per unit area was assumed to be the same as for that part of the adjacent Thiba drainage which lies below the Mount Kenya Forest Reserve. This yield was 194 tonnes/km.²/yr. or 28,000 tonnes/yr. from the Ruambuthambi. The two areas have very similar climate, geology, topography, and land use.
2. For the *Mathioya* catchment, the sediment yield per unit area estimated from those of its neighbours. The Upper Sagana basin, had a yield of 415 t/km.²/yr. while the Maragua catchment to the south of the Mathioya lost 1355 t/km.²/yr. The Mathioya has similar climate, geology, and land use to the adjacent basins, and

is of intermediate steepness. Its sediment yields was therefore taken as the arithmetic mean of the two figures given above, viz. 885 t/km.²/yr., or 389,000 tonnes/yr. from the Mathioya.

3. For the *Upper Saba Saba—Kabuka* drainages the sediment yield was taken to be the arithmetic mean of those from the lower, cultivated portions of the Maragua (1684 t/km.²/yr.) and the Thika (530 t/km.²/yr.). This calculated yield was 1107 t/km.²/yr., or 397,000 tonnes/yr. from the Upper Saba Saba and Kabuka basins.
4. For the *Lower Sagana—Thika—Tana* drainage area it is much more difficult to estimate the sediment yield. The only possibility is to use distant, but similar regions of Kenya as a guide. Dunne (1975) has shown that a large area of the Uaso Nyiro basin, north of Mount Kenya, had a mean annual sediment yield of 676 t/km.²/yr. between 1956 and 1970. This area of 6133 km. lies downstream of the confluence of the Uaso Nyiro and the Uaso Narok and above Archers Post. On the north the area is bounded by the Seiyya drainage and on the south by the wet foothills of Mount Kenya and the Nyambeni Hills. Grazing dominates the land use of the drier northern part of the basin, where rainfall is approximately 300-400 mm. The wetter southern margin lies mostly between the 750 and 1000 mm. isohyets, where the land is cultivated. The geology and topography are also similar to those of the Upper Tana, namely, gently rolling hills on the Precambrian Basement rocks with volcanic lavas on the wetter foothills. It is not unreasonable, therefore, to assume that the sediment yield of the Upper Tana which lies between the 650 and 1000 mm. should be similar to, but probably a little higher than that of the Uaso Nyiro subbasin. We have therefore estimated the yield to be approximately 700 t/km.²/yr. A little to the south of the Upper Tana area, in the Precambrian Basement hills around Kitui, the small (25 km.²) Kalundu basin, which is cultivated and grazed, has a sediment yield of 1075 t/km.²/yr. Because this basin is smaller, steeper, and slightly wetter than the Sagana—Thika—Tana area, this figure of 1075 indicates an upper limit for the sediment yield of the larger area. Our estimate of 700 t/km.²/yr., therefore, seems reasonable, and leads to a sediment yield of 1,926,000 tonnes/yr. from this area.

If the sediment yields from the various subbasins are now totalled, we arrive at a figure of 3,034,000 tonnes/yr. passing station 4ED3 on the Tana River during the period 1956-70. This value is more than 8 times that used by the consultants and 3.5 times that calculated from the inadequate sediment rating curve for the 4ED3 station, and given in table 3.

DISCUSSION OF DIFFERENCES BETWEEN THE EARLIER ESTIMATES AND THE NEW ONE

The sediment rating curves used by the consultants were drawn by eye, and were generally steeper than the least-squares regression lines drawn in fiure 4. They would be expected to lead to higher calculated sediment yields than the yields listed in Table 3. This could not have caused the differences in the estimated sediment transport rates.

The main differences between the earlier and later figures lies in the runoff data used for the calculations. Since 1961 there has been a large increase in average annual runoff and in the number and size of flood peaks throughout the Upper Tana basin. These changes, which were associated with increases in the rainfall of the region, are illustrated in figure 6. Data from all other stations in the Tana basin show the same trends. The change is especially marked in the case of the flood peaks. This is of great significance for sediment yields because almost all of the sediment leaving a basin is carried by the highest few discharges of each year (see Dunne, 1975): If these rare flows are increased, the sediment yields will increase dramatically because sediment transport rates vary approximately as the square of discharge (see figure 4).

It seems, therefore, that the various consultants have underestimated the potential sedimentation rate at the Kamburu reservoir site, the differences between their estimates and the one we propose being due largely to the use of different periods of record. Unfortunately, the flow records for the period before 1956 are not in such easily manipulatable, computerized form as the data we have used.

If the larger flows of the 1960's resulted in greatly increased sediment transport, it is important to ask whether the recent wetter period is likely to continue, or whether it represents only a short fluctuation above average and will eventually decline again to the levels more typical of the 1940's and 1950's. Unfortunately, it is not possible to answer this question with the data presently available.

There are very few long records of stream discharge in Kenya; reliable flood records have only become available since the mid-1940's. There are rainfall records extending back to the turn of the century, but at present we have no simple way of relating rainfall to sediment yield. These rainfall records do, however, show that several relatively wet as the early 1960. It is likely, however, that the consultant's value of sediment transport at the Kamburu dam site is high enough because their value for 4ED3 is so much lower than the sum of the tributary values. Even for the period 1947-58, the sediment yield at 4ED3 must have been much greater than 1,000,000 tonnes per year, judging from their tributary data.

Lamb (1966) has raised an even more troublesome question about future rainfall, runoff, and therefore sedimentation rates in East Africa as well as climatological data from other parts of the world. He concludes that since 1961 there has been a significant shift in the atmosphere circulation which has caused the increased rainfall in East Africa. He further states that when the atmospheric circulation has entered its present mode in earlier periods, the mode has persisted for long periods of time. With our present knowledge this can only be speculation, and we will have to wait for many years before we can judge whether a long-term shift in climate has occurred. If it has, however, the sedimentation rate of the Upper Tana will have undergone a semi-permanent increase, and the values for 1956-70 will be more representative of future conditions than the results obtained by the consultants.

Whether the period 1947-58 or 1956-70 is more representative of the long-term sedimentation rate to the expected of the Kamburu reservoir site, however, a sedimentation rate between 2 and 3 million tonnes/year seems more probable than the 0.35 million tonnes/year favoured by the consultants. A figure of 3 million tonnes/year would mean that approximately 3.5 million cubic meters of storage space in the Kamburu reservoir are being occupied each year by sediment. At this time we cannot say anything about the fate of the sediment which enters the lake. Some of it must occupy live storage space, some must enter dead storage space, and some passes through the dam into the reservoirs downstream. At the dam site we have observed surprising quantities of fine sediment still in suspension.

It should also be emphasized that the sedimentation rates discussed above refer only to suspended sediment. A river also carries a portion of its sediment load by sliding, rolling and bounding along the bed of the channel. The bedload is difficult to measure, and no measurements of this contribution have yet been made in Kenya. It is usual to assume that bedload comprises approximately 10 per cent of the total load of the steam, though it can be higher in some regions. If we accept the 10 per cent figure for the present, however, it places the sedimentation rate at Kamburu even more firmly in the range of 2-3 million tonnes/year.

SUGGESTIONS FOR FUTURE STUDIES

We do not know whether our estimate of the sedimentation rate at the Upper Tana reservoir sites will necessitate a revaluation of the economics of the schemes. Such question is beyond our area of competence. However, if the new estimate is thought to be important, we recommend that further study be undertaken to settle some of the questions which we have raised. Such studies might then point the way to strategies for minimizing the sedimentation in these and other reservoirs in Kenya.

Our suggestions are as follows:

1. The present and planned investments in reservoirs justifies continuation and expansion of studies of sedimentation on the Tana River.

Recently, Ongweny (1974) has begun to study suspended sediment transport in the Tana and its tributaries immediately upstream of the Kamburu reservoir. This and similar work should continue, with special emphasis being placed upon sampling the sediment concentrations at high flows, when most of the sediment transport is accomplished. Much time, effort, and money can be wasted by repeated sampling of sediment concentrations at regular intervals during low flow.

2. An exploratory programme of bedload sampling should be initiated on the Tana River above the Kamburu reservoir. This can be done rather cheaply as an adjunct to the sampling programme for suspended sediment. By simultaneously measuring a few hydralic parameters, a great deal can be learned about bedload transport in a short period of time.
3. The amount of sediment that has already accumulated in the Kindaruma and Kamburu reservoirs should be measured by hydrographic survey as a check on the accuracy of the sedimentation rates computed from stream sampling.
4. The distribution of sedimentary deposits in the reservoirs also needs to be studied to find out how much of the sediment is occupying live storage and dead storage space, and how much is escaping through the dam.
5. An effort should be made to qualify the major processes and sources of sediment contributed to the Tana River. This would involve a study of geomorphic processes on the hillslopes of the drainage basin. It should indicate, for example, where the major effort might be put designing a soil conservation programme.
6. An organized effort to educate farmers on the benefits of soil conservation would reduce sediment contributions to the rivers of the basin. It should be realized, however, that very large reductions of soil loss must be accomplished on hillslopes before any benefits are seen at the lower end of a large drainage basin. Whether it is worth undertaking a soil conservation programme just to reduce sedimentation rates alone is doubtful. But if the soil conservation programme were built into a general rural development plan, it could have important side benefits for the reservoir.
7. Further study needs to be made of the long-term representativeness of the available records of flow and sediment transport. This could be done by relating runoff and sediment records to rainfall records which extend back over a longer period.
8. Further study needs to be made of the possibility raised by Lamb, that East Africa may have entered a new climatic phase during which we might expect consistently higher rainfall runoff

and sediment transport for the foreseeable future. This question is of great significance for all water resources development in Kenya.

REFERENCES

Dunne, T. (1974) Suspended sediment data for the rivers of Kenya; Report to the Ministry of Water Development, Nairobi, p. 108.

Dunne, T. (1975) Sediment yields of Kenya rivers; Report to the Ministry of Water Development, Nairobi.

Government of Kenya (1970) Atlas of Kenya; Government Printer, Nairobi, p. 103.

Lamb, H. H. (1966) Climate in the 1960's: Changes in the world's wind circulation reflected in prevailing temperatures, rainfall patterns, and the levels of African lakes; Geographical Journal, vol. 132, pp. 183-212.

Ongweny, G. S. O. (1974) Hydrology; in Kamburu/Gtaru Ecological Survey, R. S. Odingo (ed.) Department of Geography, University of Nairobi, p. 194.

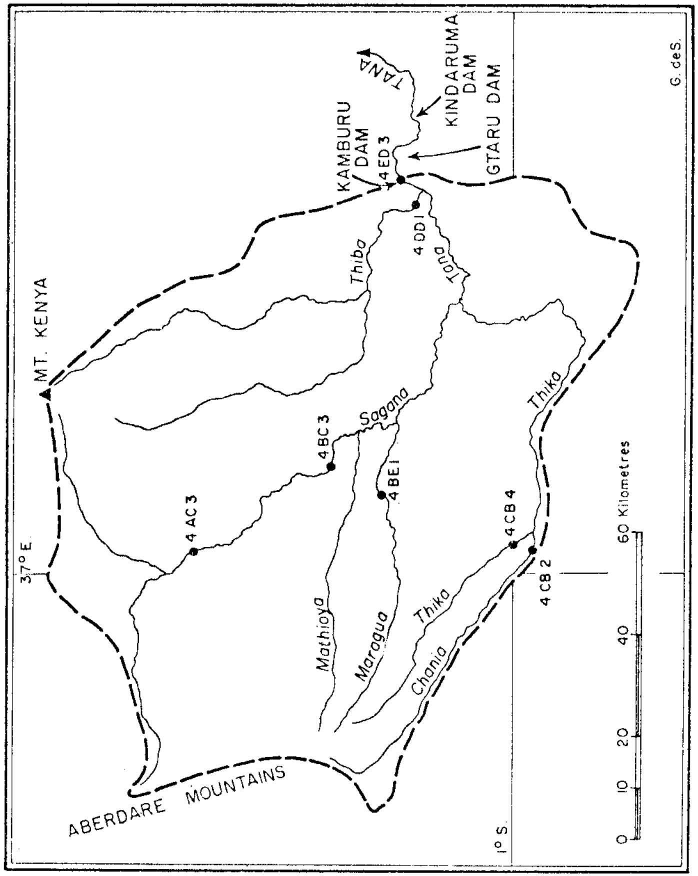

FIG. 1

Fig. 1 Map of the Upper Tana Basin showing the Locations of Sediments sampling Stations referred to in the Text.

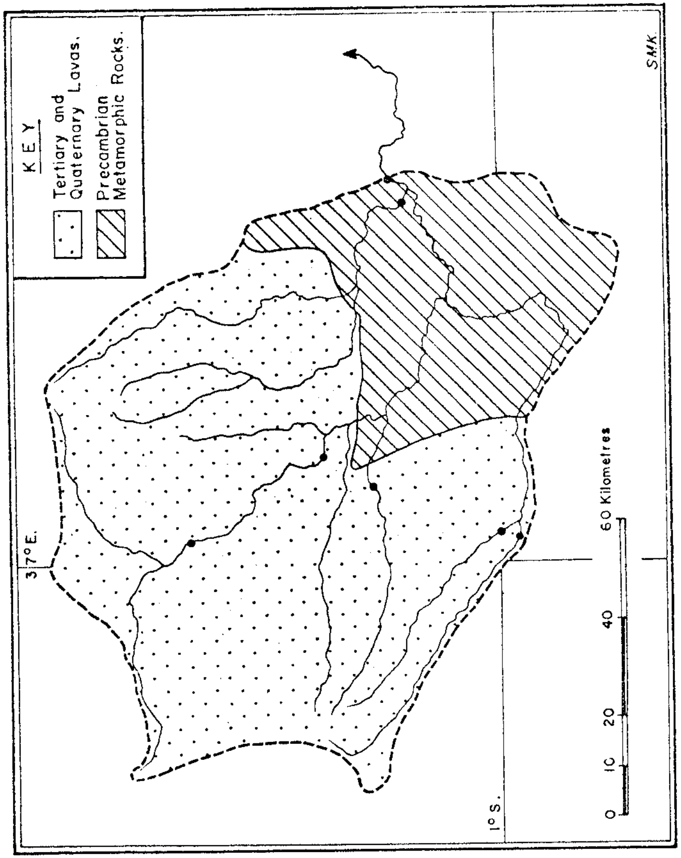

Fig. 2 Simplified Geological Map of the Upper Tana Basin.

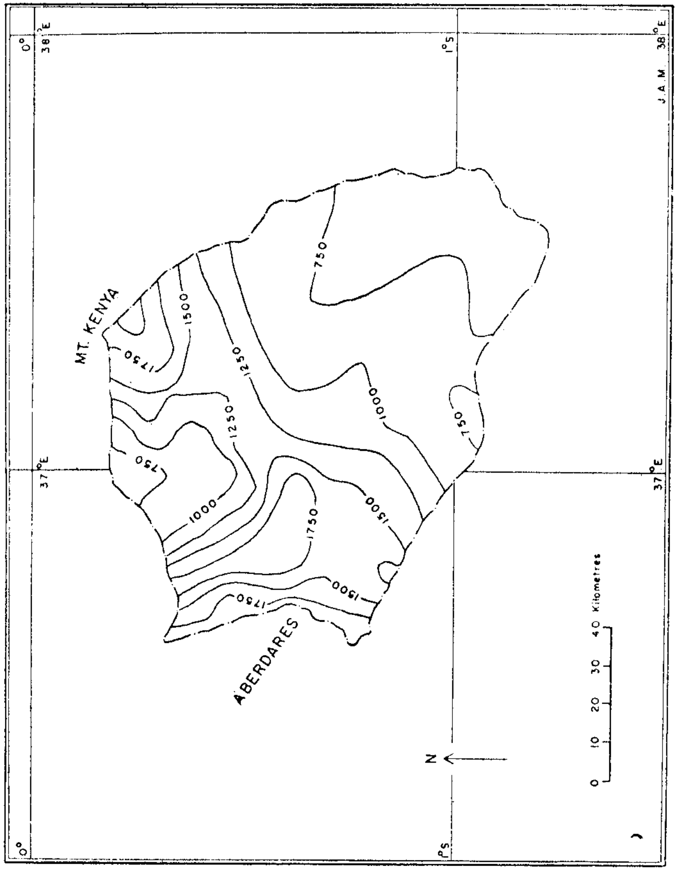

Fig. 3 Mean Annual rainfall (in millimetres) for the Upper Tana River Basin

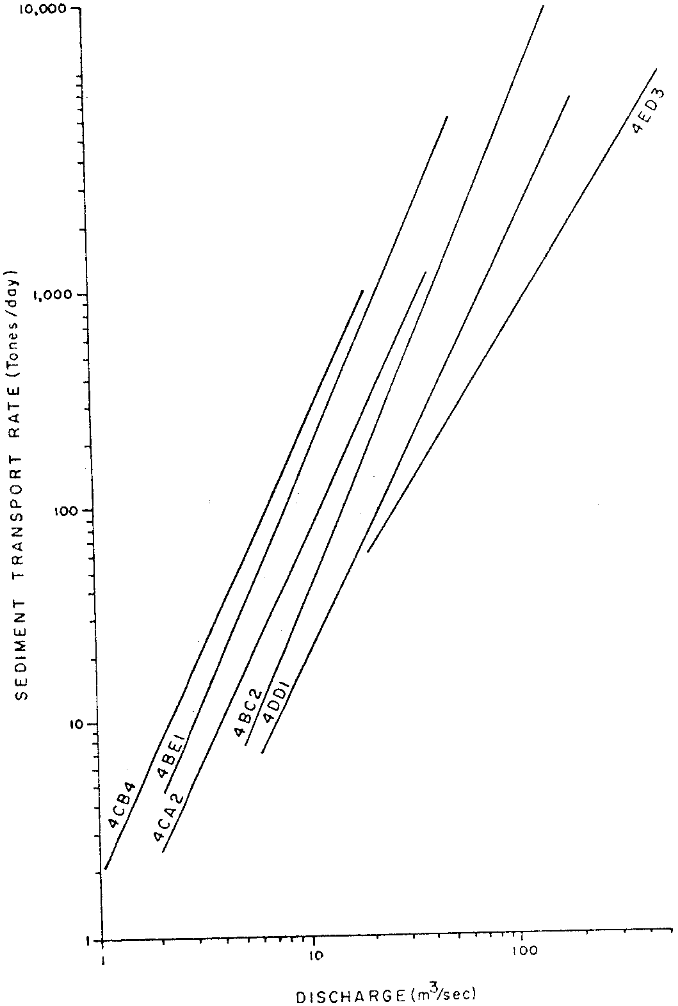

Fig. 4 Sediment rating curves for stations on the Upper Tana and its tributaries. The least-squares regression lines are only drawn over range of discharge for which field samples are available.

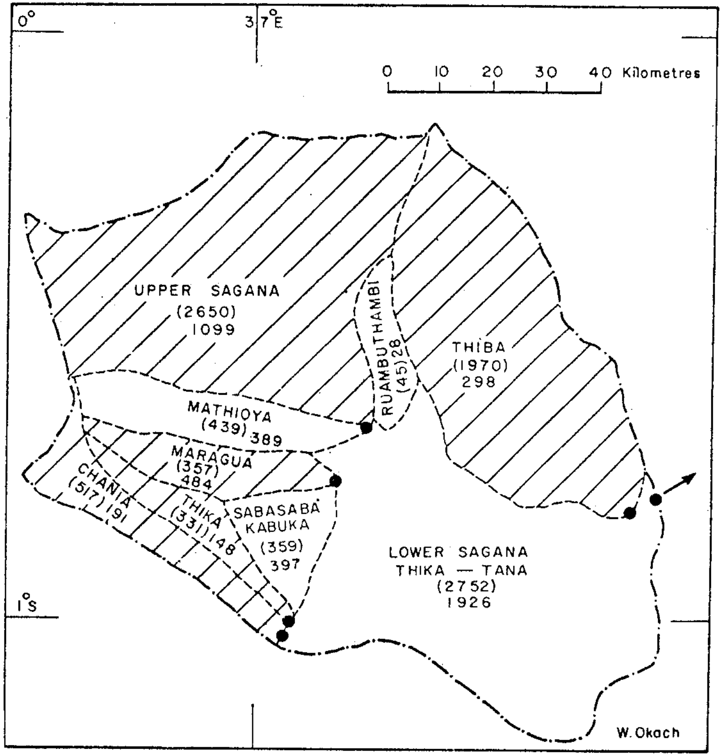

FIG.5

Fig. 5 Measured and estimated yields of sediment from tributory basins of the Upper Tana River. Shaded areas are those for which field data are available. The figures in parentheses are the estimated sediment yields in thousands tonnes per year.