"SEDIMENT YIELD STUDIES IN THE MATHARE RIVER CATCHMENT"

BY

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Declaration

I declare that this Thesis has not been presented to any University.

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Signed:.......Sharma.................
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(supervisor)

DEDICATION

To my parents, Mr. and Mrs. Nephat Gikonyo, whose sacrifices, commitments and encouragement in seeing me through my education is something I will always remember and which will continue being a source of inspiration.

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LIST OF SYMBOLS AND ABBREVIATIONS

DIUH	Dimensionless unit hydrograph
DIUSG	Dimensionless unit sediment graph
DRH	Direct runoff hydrograph
EDI	Equal discharge increment
ERH	Excess rainfall hyetograph
ETR	Equal transit rate
IUH	Instantaneous unit hydrograph
IUSG	Instantaneous unit sediment graph
MIDP	Machakos integrated development project
POME	Principle of maximum entropy
SCD	Sediment concentration distribution
SDR	Sediment delivery ratio
SLEMSA	Soil loss estimator for Southern Africa
TRH	Total rainfall hyetograph
UH	Unit hydrograph
USG	Unit sediment graph
USLE	Universal soil loss equation
USSCS	United States soil conservation services
a	Inter isochrone areas (km^2)
A	Area (km^2)
A_x	Cross-sectional area of the inlet nozzle (m^2)
b	Width of the discharge vertical (m)
C	Sediment concentration (mg/l)
I	Inflow rate of sediments (unrouted) (kg/h)
d	depth of discharge vertical (m)
e	Base of natural logarithm (2.7183)
E_s	Mobilised sediment (t/km^2)
K	Hydrograph recession constant (h)
K_s	Sediment graph recession constant (h)
MI1	First moment of area of the ERH about origin
MI2	Second moment of area of the ERH about origin
MQ1	First moment of area of the DRH about origin
MQ2	Second moment of area of the DRH about origin
n	Number of linear water reservoirs in catchment
n_s	Number of linear sediment reservoirs in catchment
P	Excess rainfall intensity (mm/h)

P_{net}	Excess rainfall depth (mm)
Q	Water discharge (m^3/s)
Q_{net}	Excess runoff depth (mm)
Q_s	Sediment discharge (kg/s, t/day)
S	Sediment storage (kg)
S_m	Rate of sediment mobilisation (t/h)
t	Time (h, s)
t_p	Time to peak (h)
$U(t)$	Ordinates of instantaneous unit sediment graph (h^{-1})
V	Velocity (m/s)
V_o	Sample volume (m^3)
V_s	Mobilised sediment (t)
V_{ts}	Total volume of pipette analysis suspension (cm^3)
V_w	Volume of pipette withdrawal (cm^3)
X	Routing factor
Y	Outflow rate of sediments (routed) (kg/h) equal to Q_s
I	inflow rate of sediments (unrouted) (kg/h) based on time area sediment histogram

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ABSTRACT

The Mathare catchment comprises an area of 26 Km^2 and is located in the Western suburbs of Nairobi, Kenya. It is currently fitted with instruments for both rainfall measurement and runoff gauging at the Kabete field station. For the purpose of sediment gauging, a bridge was constructed for sediment sampling; two sets of staff gauges installed and a steel container erected for storage of equipment.

Suspended sediment concentration in the river was estimated using four methods; the grab method, the equal discharge increment method, the equal transit rate method and the automatic single stage bottle sampling method. It was observed that there was no significant difference in statistical sense between the first three methods. The single stage automatic bottle sampler showed significant deviation in relation to the grab method.

As a tool for the development of simple field gauging techniques, three methods of discharge measurement, the conventional multi-vertical current meter method, the single point velocity method and the equal transit rate sampling methods were investigated. It was found out that they all yield significantly different results and the last two required calibration to become useful for gauging.

For this catchment, the instantaneous unit sediment graph (IUSG) was developed and tested for the prediction of sediment discharge. This involved development and analysis of the river discharge rating equation and the sediment

graphs. The developed IUSG model produced a lower sediment yield in comparison to that derived from the temporal concentration graph and the flow duration curve analysis methods. The IUSG model based on the multireservoir cascading concept simulated the sediment graphs more accurately than that based on the time area histograms routed through a single reservoir concept.

For the period 27/10/92 to 15/9/93, (324 days) the total estimated sediment yield of the Mathare catchment was 140, 150 and 165 tonnes by IUSG, temporal concentration analysis and flow duration curve analysis methods (uncorrected sediment rating curve) respectively. For the flow duration curve method, with the sediment rating equation adjusted by the correction factor (arising due to the log-normal distribution of the error component in the rating equation), a sediment yield estimate of 179.2 tonnes was obtained. The mean sediment production rate was found to be approximately 6.9 tonnes/km²/yr. Such a low estimate of sediment yield reflects the high level of conservation practices prevalent in the catchment. It is likely that the Mathare reservoir is still in healthy state in terms of siltation. The particle size distribution suggested that the total sediment load of the Mathare river comprises of suspended component with negligible bed load.

1. INTRODUCTION

1.1 Background Information

Sediment load produced by water erosion fills reservoirs and conveyance systems and also act as a carrier of pollutants such as radio active materials, pesticides and nutrients. The clearing of reservoirs and water conveyance systems and the purification of water from sediments is often expensive and time consuming. To make decisions regarding the cleaning and purification of water, information on the amounts of sediments transported with time through a stream to a storage facility is necessary. This information is also useful in predicting the changes in denudation processes occurring in the catchment. The importance of this knowledge cannot be over emphasized as it helps to determine what use the water can be put into or whether it is detrimental to existing uses, pointing out the need of erosion control in the catchment that would be economically justified.

Sediment yield is defined as all the soil eroded from a catchment that is transported to a downstream point. It comprises of two components, suspended load and bed load. The suspended load also referred to as the wash load is that fraction of the sediment load that is carried in suspension by the flowing water usually made up of particles less than 0.062 mm in diameter. This is transported within the moving water in the stream in suspension above the stream bed. Streams and rivers have a high capacity to transport this component and hence sediment yield resulting from this component is source limited. The bed load is that eroded soil which is made up of larger particles exceeding 0.062 mm in diameter. The immersed weight of the moving grain load is carried by intermittent contact with the unmoving bed. These particles travel on or close to the river bed by interrupted motion comprising mainly of jumping, skipping and saltating (Leopold, 1974). The total sediment discharge is obtained as a combination of the total suspended sediment load and the bed load. Where the bed load is insignificant suspended sediment load is considered as the total sediment discharge. This assumption has been found to be valid for two major rivers of Nigeria, Benue and Niger, where both components of the sediment discharge were measured (Oyebande, 1981). It was found that the bedload component varied between 5.0 to 6.5 %. Usually, suspended load forms the bulk of the sediment discharge and is relatively easier to determine by use of sampling techniques. Bedload is evaluated by a consideration of hydraulic factors, and presents more difficulties in measurement.

When a river or a stream serves a small catchment (say 30 Km^2) it can be defined as a small river. In such cases bedload contributes negligibly to total sediment discharge as has been noted by several authors (Chow,1964; Graf,1971; Shen, 1971; Ward, 1980; Oyebande, 1981). Thus bedload can be ignored without introducing large errors in estimating total sediment yield.

Sediment yield is estimated either by gauging or by mathematical modelling. In the case of gauging, the measurements of water discharge and sediment concentration of the stream are measured by use of bottle samplers. The commonly known procedures are equal transit rate (ETR), equal discharge interval (EDI), grab sampling and single stage automatic sampling. The water discharge is measured concurrently with sediment concentrations. The measured discharges and concentrations are subjected to some computational procedures such as temporal concentration graph method or flow duration curve method in order to derive the sediment yields. The sampling procedures such as ETR and EDI are elaborate and time consuming, whereas grab sampling and single stage automatic sampling procedures are time and cost effective. There is need to evaluate the adequacy of the latter procedures in relation to the former more elaborate methods viz. ETR and EDI for use in Kenyan catchments. A need may also exist for calibration of the simple sampling procedures.

Mathematical modelling is an effective way of determining the catchment sediment yields. It is cheaper and faster but requires calibration of the model which in turn requires field data which must be collected through some procedure of sampling. A variety of models have been suggested for use, either for direct evaluation of sediment yield or indirect evaluation by involving the gross erosion and sediment delivery ratios. The dependence of sediment processes on the hydrology of a catchment has also been considered. Sediment simulation is commonly attained by extension of watershed hydrologic models (Flemming, 1971).

The limiting factor in this development is the availability of adequate data on measured sediment erosion, transport,and deposition by which to compare and verify the models developed. In the field of models for direct evaluation of sediment yields, the application of linear systems theory is becoming popular and concepts such as unit sediment graph and instantaneous unit sediment graph (IUSG) have emerged. These concepts are analogous to unit hydrograph and instantaneous unit hydrograph in the operational hydrology and therefore need to be tested for their potentials in predicting the sediment yield in Kenyan catchments.

1.2 Research Objectives

The present study has the following objectives.

(i) To evaluate the grab method of sampling against two other elaborate sampling methods namely:
  (a) Equal discharge increment (EDI) method
  (b) Equal transit rate (ETR) method.

(ii) Assessing the suitability of automatic single stage bottle sampling technique in sediment yield determination

(iii) Estimating the seasonal sediment yield of the catchment by use of the temporal concentration graph and flow duration curve methods.

(iv) Development of the instantaneous unit sediment graph (IUSG) for the catchment and testing it for the prediction of storm sediment yields and thereby seasonal sediment yields.

1.3 Description of the Study Area

The catchment used for the this study was the Mathare river catchment, which drains into the Kabete dam in the western suburbs of Nairobi **(Fig 1.1)**. It covers an area of approximately 26 Km^2, and is situated at an elevation of 1800 - 2000 m above sea level, with an average slope of 4.83 %, mean annual rainfall of 980 mm and a mean annual temperature of 22˘C (Koech, 1986). It is located between latitudes 1˘12′ and 1˘15′ S and longitudes 36˘ 40′ and 36˘ 45′E. The upper region of the catchment is densely populated as it meets part of Nairobi town residential requirements. The people practise horticulture and zero grazing on a commercial basis due to the availability of a large market. An increasing fraction of the land is also being used for peri-urban residential purposes whereas the lower regions are used predominantly for intensive agriculture for maize, beans, vegetables,flowers and coffee. The soils found in the area are deep, well drained and have a dark red colour classified under the FAO-UNESCO soil taxonomy as Nitisols. As documented in previous studies by Mwaniki (1987) and Mwaya (1990), the original bank vegetation of the Mathare river was bushed grassland but exotic trees such as eucalyptus have taken over. The catchment is presently instrumented for rainfall and runoff gauging as shown in **Fig. 1.2** The existing gauging station has a staff gauge and an automatic water level recorder (Ott type). Other existing facilities include, one steel bridge and a wooden bridge.

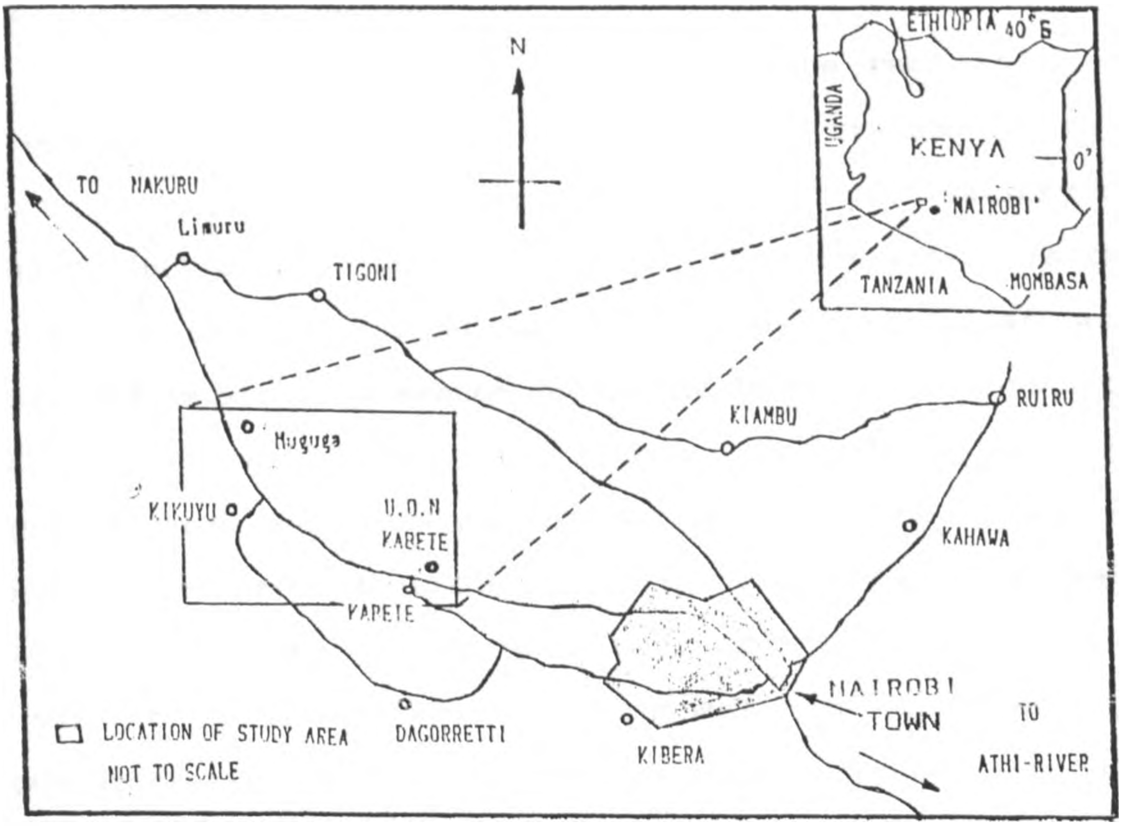


Fig 1.1 Location of the study area.

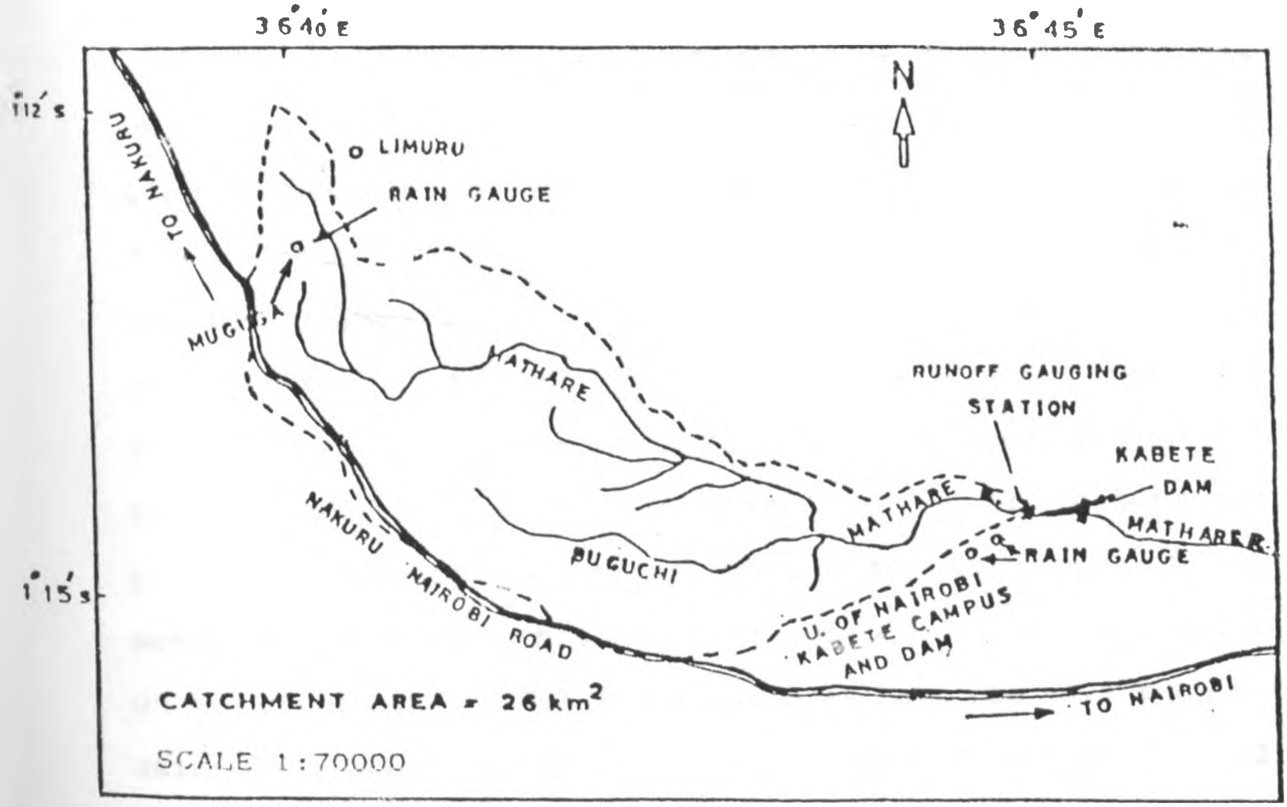


Fig 1.2 Map of Mathare river catchment.

2 LITERATURE REVIEW

Sediment discharge is defined as the rate at which sediments are mobilised in a catchment and transported to a downstream point. This can be expressed in a variety of units such as kg/s, kg/h or t/day. Sediment yield is the seasonal sediment output of a catchment measured at some downstream point. A season may be any desired time duration, but conventionally the time span of a month or year are predominant. In this case the yields would be termed as monthly or annual sediment yields in Kg or tonnes. Sediment load on the other hand is a term used to designate the sediment material that a channel is transporting. Qualitatively, it distinguishes between suspended load and bedload while quantitatively, it expresses on a volume or mass basis the sediment content of a specified volume of water (Woo et al., 1986).

The two routes for the estimation of sediment yield are gauging and mathematical modelling. The particular method used depends on the amount and quality of data available for the catchment in question. Gauging techniques seek to utilise specifically measured water and sediment concentration data for the calculation of the sediment discharge which requires that rigorous measurement programmes be undertaken. Accuracy and precision of the determined yields can be improved by increasing the frequency of the measurements though this has a direct bearing on the costs. On the other hand, modelling techniques have the advantage of using less stringent data for the purpose of sediment yield determination. In most cases, these models seek to convert commonly available hydrological data and information namely rainfall and catchment hydrological characteristics into sediment discharge estimates. They therefore help simulate actual occurrences at a lower cost. Usually, low intensity data collection can provide more meaningful information when fitted within a model and it becomes possible to analyze different scenario's to answer "what if questions". This is commonly attained by changing the model input variables within the expected or foreseen ranges.

2.2 Gauging Techniques For Sediment Sampling

Estimation of total sediment yield relies heavily on the accuracy and frequency of sediment sampling. Sampling methods are used in conjunction with stream flow gauging. Of importance is the determination of quantity of sediments and the size distribution. This information is recorded at suitable time intervals. This could be regular such as in a daily record programme or irregular such as in the partial record or periodic sampling programmes. Other than the type of sampler adaptable for a specific sampling procedure, suitable methods of carrying out the physical sampling exercise are required. These should ensure that the sampling is done correctly and at the desired point within the river which may be done by wading, or by use of bridges, cable ways and boats.

2.2.1 Sampling procedures

(a) Grab (scoop) procedure

In this method, a section of the channel having turbulent flow is chosen so that sediments in suspension are thoroughly mixed with the turbulent water to yield a uniform water sediment mixture. Point samples are then taken at the site by scooping the water sediment mixture into a large mouthed container attached to a suitable rod or by use of an instantaneous sampler which consists of a cylinder equipped with end closure mechanism. The sampler is held horizontally and oriented into the flow by vanes. For this method, use of a bottle sampler with depth integration is gaining in popularity. This is because the sampler can be easily improvised. It consists of a standard container attached to a rod with a hydrometric sinker. The mouth of the bottle is sealed except for two narrow tubes for the water inlet and air outlet.

(b) Equal - discharge increments (EDI) procedure

In the EDI procedure, the channel cross-section is divided into several vertical segments of equal water discharge. Depth integrating bottle samplers are used. This collects a specimen of the water-sediment mixture in a vertical, in which the concentrations at different depths are averaged. The operator lowers and raises the sampler from the water surface to the bottom and back at the centroidal vertical at each equal discharge segment to give depth integrated samples. The downward and upward transit rates can vary but total traverse time should be constant allowing for time compensation in order to attain equal volume samples. A discharge weighted mean for the whole cross-section is obtained from the vertical section sediment concentration means. For particle size analysis, samples must always be of the same volume. This means that the samples are analyzed separately.

The operator requires prior knowledge of the streamflow distribution for the selection of sampling verticals in the cross-section. Sites with stable stage discharge relations are needed. Number of verticals required to define the sediment concentration in the section depends on the accuracy required and resources available for the sampling. The verticals are located at the midpoint of each equal increment in discharge. It should be noted that in order to achieve representative sampling, the number of verticals should not be less than three.

(c) Equal transit - rate (ETR) procedure

In the ETR procedure, single samples are taken over verticals equally spaced over a well defined channel cross-section. The same transit rate must be used for all verticals with the downward rate and upward rate being equal. The water sediment mixture is admitted at a rate proportional to local stream velocity at the intake, and since the verticals have different discharges, the volume of samples collected in different verticals are not the same, but the sample for each vertical is automatically discharge weighted. Using the same nozzles for all verticals in a given measurement ensures that the composite of all the samples will yield the correct mean concentration for the cross-section. The minimum transit rate is chosen such that for that vertical possessing the highest discharge per unit width, there is no overfilling. The same sample bottle can be used for a number of verticals with low flow. Faster rates repeated a number of times in very slow moving water, have been observed to yield better results compared to slow transit rates (Guy and Norman, 1970).

For wide and shallow sand-bed streams where the distribution of the water discharge across the stream is not stable ETR measurements are more applicable. The number of verticals to be used depend on the lateral variation of sediment concentration that can be assessed by pre-sampling. In comparison, ETR measurements have some advantages compared to EDI measurements:

1. No water discharge measurement has to precede the ETR procedure.
2. ETR measurements can be used to approximate stream discharge under specified conditions (Chow, 1964).
3. Less analysis time and work is required in the laboratory as samples are composited to yield one single mean sample for the entire cross-section.
4. ETR procedure is easier to understand and execute.

(d) Automatic sampling procedures

In these procedures, the single stage sampling equipment or pump samplers are used. The pump samplers are more easily automated. They consist of inlet nozzles installed in the flowing water-sediment mixture, connected to storage containers usually bottles through rubber or plastic tubes. Any desired spatial arrangement of nozzles and frequency of sampling can be achieved. For some designs, stage sensors are incorporated so that the samples are collected above predetermined threshold discharges. For others, clock timing mechanisms ensure continuous sample collection at equal time intervals. In order to channel each sample to a new storage container, automatic transfer mechanisms are used. The automatic single stage samplers consist of bottle samplers installed along a vertical in a stream at specific heights above the water surface. These collect samples of the water sediment mixture as the river stage rises. It has been reported by Pathak (1990) that the automatic single stage sampler has been used in small agricultural watersheds with good results for sediment discharge having high temporal variability. Turbidity meters are also used for the automatic determination of suspended sediment concentration. These are first calibrated by use of other sampling procedures and then installed in the river and connected to data loggers or graphers.

2.2.2 Sample sediment concentration determination

There are two common laboratory methods of assessing mass of dry sediments from collected samples.

(a) Evaporation method

This method requires simple equipment and technique and is suitable when the sediments are predominantly sand and silt which settle readily to the bottom. Too much clay in samples in a dispersed state, results in long settling time and the method becomes impractical without the use of flocculating agents to reduce settling time. Too much dissolved salts in samples, not considered as part of the sediment load, yield erroneous results since they end up being included in the final mass prompting the need for a dissolved solids correction.

When the sediments settle, the supernatant fluid is carefully decanted or siphoned off making sure that none of the sediments is removed from the settling container. Remaining material is washed into an evaporating dish and dried in an oven, initially at a temperature less than the boiling point (approximately 80° C) to avoid spattering . After all loose moisture has evaporated, the oven temperature is raised above boiling point (110° C) for a period of one hour. The evaporating dishes are then dry cooled in a desiccator before weighing.

(b) Filtration method

In this case, a crucible fitted in a vacuum aspirator system is usually used. Filtering mediums usually glass fibre filters or asbestos mats are used. Filtering can be done with the sample in a dispersed state or allowing it to settle first, and the supernatant water decanted off. In cases where adequate time is available, or sediment concentrations are low, gravitational filtration can be used. The process takes more time but uses simpler equipment. The filtration method possesses some advantages over the evaporation method such as:

1. less oven and desiccator space is needed.
2. tare weights less likely to change due to sorption of moisture from air.
3. dissolved solids pass through therefore eliminating the need of a dissolved solids correction.

With low sediment concentrations, the filtration method is faster. Upper limit for its use is about 2000 mg/l of sediments containing mostly clay and 10000 mg/l when major portion constitutes sand (Guy and Norman, 1970).

2.2.3 Particle size distribution analysis

Available methods fall into two classes:

(a) Direct methods which include measurements of diameters and circumferences of big particles such as cobbles, boulders and gravel, as well as the semi direct measurements of diameters by sieves.

(b) Indirect methods make use of the theory of sedimentation. The pipette method is the most commonly used in this class, though the bottom withdrawal (BW) tube and the visual-accumulation (VA) tube methods are found in use in some cases. Samples for analysis should have adequate quantity of material for purposes of accurate weighing. As an aid to selection of analysis method based on sizes of particles being dealt with, **Table 2.1** can be used.

Table 2.1. Guide for selection of analysis method

	size range (mm)	Analysis concentration (mg/l)
Sieves	0.062-32	
VA tube	0.062-2.0	2000-5000
Pipette	0.002-0.062	2000-5000
BW tube	0.002-0.062	1000-3500

For purposes of characterising suspended load sediments, a combination of the sieving method and a sedimentation method should be employed. This is because sieving evaluates sizes bigger than 0.062 mm while the sedimentation method is used for those of smaller size. The sieve pipette method is one such combination where sieving is followed by pipette analysis. The pipette analysis requires the withdrawal of a small suspension sample at a fixed point in a sedimentation cylinder after a certain period of time. The time and depth of withdrawal are predetermined on the basis of Stokes law (Kinori and Mevorach, 1984). Tables are available which give recommended values for sizes ranging between 0.002 - 0.062 mm. These recommendations are based on the assumptions such as follows:

1. particles are of spherical shape.
2. average specific gravity of particles is 2.65.
3. suspension viscosity ranging from 0.010087 Ns/m^2 at 20°C to 0.008004 Ns/m^2 at 30°C.

2.3 Computational Methods in Gauging Techniques

2.3.1 Temporal concentration graph method

In this method, mean sediment concentration sampled at a cross-section, together with the water discharge are plotted and continuous curves drawn through plotted points. Daily mean values are determined by numerical weighting procedures or graphical methods. The daily mean sediment discharge is then computed by use of these daily mean values of water discharge and sediment concentration through the formula:

$$Q_S=K_C\times Q\times C \qquad (2.1)$$

where,

Q_s = sediment discharge (t/day)

Q = daily mean water discharge (m^3/s)

C = daily mean concentration of suspended sediments (mg/l)

K_c = 0.0864 a conversion factor assuming a relative density of 2.65 for sediments

This method requires at least daily records of water discharge and concentration. Otherwise when this condition has not been satisfied, a suitable method of estimating missing values has to be employed. Total suspended sediment discharge over a bigger period is obtained by summing daily discharges.

2.3.2 Flow duration sediment rating curve method

This is a method more suitable when only infrequent and occasional data is available. Sediment concentration in mg/l is plotted against water discharge at time of sampling and the average concentration curve for the station defined. This is usually referred to as a sediment rating curve and is of the form,

$$C = \alpha Q^{\beta} \qquad (2.2)$$

Where

C = sediment concentration (mg/l)

Q = water discharge (m^3/s)

α and β are empirical constants.

When plotted on a log-log paper, this gives a straight line (Vansickle and Beschta, 1983). In the past, a sediment rating equation of the form,

$$Q_s = \alpha Q^{\beta} \qquad (2.3)$$

where,

Q_s = rate of sediment discharge (kg/s)

has been used. It has been shown that the development of the rating equation in this form is not statistically correct due to the lack of independency between the sediment discharge Q_s and the water discharge Q as the computation of Q_s involves Q in it. Linear regression theory, the tool used in the development of these rating equations is based on the following assumptions:

(i) The regression variables are random and do not contain common elements in additive, multiplicative or divisional form.

(ii) The error component has a mean of zero and is of homogeneous variance.

(iii) Successive values of the error component are random (zero autocorrelation) and are independent of the regression variables.

(iv) The error component should preferably follow the normal probability law or errors.

Equation 2.3 violates the statistical requirements of independency and hence the statistical parameters (coefficient of correlation and coefficient of determination) are spurious and therefore of limited meaning (Sharma, 1993). **Equation (2.2)** is a statistically correct rating equation which can be improved by including an error component in the multiplicative or additive form resulting in a linear or nonlinear form of the rating equation respectively. Values of C are found to be reasonably steady in the low flow range while the variability increases with increasing values of Q. On the strength of the above factors, and as has been widely advocated in literature, the multiplicative form of the error component is considered resulting in a rating equation of the following form:

$$C= aQ^{b} Z \qquad (2.4)$$

Where Z= correction factor based on the log normal probability distribution of error terms whose value can be determined by fitting the C and Q data and evaluating the standard error of fit in the linearised form. An estimate of Z has been suggested equal to $\exp(S_e^2/2)$, where S_e is the standard error of fit mentioned above (Sharma, 1993). Once the sediment rating equation has been determined, the water flow duration curve for the station is then determined by use of the daily water discharge for the longest period of continuous data available. This is a curve that tells how often the flow is likely to occur over a given period. This involves the selection of the number of days the discharge fell within selected ranges. The number of occurrences in each selected range for each year of record is then determined. From this, the percentage of total time that the discharge was equal or exceeded the lowest discharge of each range is calculated. A plot of the discharge against this percentage on a semi-logarithmic paper gives the flow duration curve. Its use in the determination of suspended sediment yield involves the following details.

(a) From the flow duration curve, the discharge *Q* for incremental values of percent of exceedence is read of as the mid value of the range.

(b) From the sediment rating curve, the sediment concentrations *C* corresponding to these discharges are obtained.

(c) The sediment discharge in t/day for each period is calculated by use of **Equation (2.1).**

(d) Above value is multiplied by the number of days in the period which gives the sediment transported in tonnes and the cumulative sum is the yield over the season.

2.3.3 Other numerical procedures

Several interpolation procedures in mathematical form are listed below for computing sediment load (Walling and Web, 1981).

(a) Average values of concentration and discharge associated with individual samples values are used.

$$V_s = K_c\left(\sum_{i=1}^{N} \frac{C_i}{N}\right)\left(\sum_{i=1}^{N} \frac{Q_i}{N}\right) \tag{2.5}$$

(b) Individual values of concentration and discharge combined to produce a value of sediment discharge representative of each interval.

$$V_s = K_c\left(\sum_{i=1}^{N} \frac{C_i Q_i}{N}\right) \tag{2.6}$$

(c) Loads evaluated as the product of average concentration and the mean discharge for period of record.

$$V_s = K_c Q_r \left(\sum_{i=1}^{N} \frac{C_i}{N} \right) \qquad (2.7)$$

(d) Flow weighted mean concentration is combined with mean discharge for the period.

$$V_s = K_c \left(\sum_{i=1}^{N} C_i Q_{p_i} \right) \qquad (2.8)$$

(e) Loads calculated as the sum of the products of sampled concentration and mean discharge for individual intervals.

$$V_s = \frac{K_c \sum_{i=1}^{N} C_i Q_i}{\sum_{i=1}^{N} Q_i} Q_r \qquad (2.9)$$

(f) Loads calculated as the sum of the products of sampled concentrations and mean monthly discharge.

$$V_s = K_c \left(\sum_{N=1}^{12} C_m Q_m \right) \qquad (2.10)$$

In the above relationship,

V_s= Mobilised sediment (t)

K_c= Conversion factor to take account of period of record

C_i= Instantaneous concentration associated with individual samples (mg/l)

Q_i= Instantaneous discharge at the time of sampling (m^3/s)

Q_r= Mean discharge for period of record (m^3/s)

Q_{pi}= Mean discharge of interval between samples (m^3/s)

C_m= Mean monthly concentration (mg/l)

Q_m = Mean monthly discharge (m^3/s)

N = Number of samples

2.4 Modelling Techniques for Sediment Yield Assessment

2.4.1 The unit sediment graph (USG)

The unit sediment graph is the graph that results from a unit of mobilised sediment occurring over a specified time duration (time unit of the unit hydrograph). The sediment graph is analogous to unit hydrograph as used in operational hydrology. The unit of mobilised sediment has been generally taken as one metric tonne (1000 kg). The relationship between hydrographs and sediment graphs was recognised as early as in the 1940's but was developed further in the 1970's (Rendon-Herrero, 1974). Application of the concepts of the unit hydrograph to develop unit sediment graph has been found to provide good results in sediment yield estimation by various investigators, Rendon-Herrero (1974), Srivastava et al., (1984) and Khumbare and Rastogi (1985). This is based on the fact that the surface runoff that produces a hydrograph is in most cases the cause of and agent for transporting upslope sediments to the streams in the basin. The unit sediment graph is therefor a pulse response function of a linear fluvial system. This can be modelled using the linear reservoir theory and can be described as a lumped unsteady flow model. Various methods of deriving the USG are based on those available for the derivation of the unit hydrograph (UH). Series graph is one such method which has been used successfully by Rendon-Herrero (1974) and Rughuwanshi et al. (1988). Depending on catchment characteristics, the peak of the USG can be found to precede, coincide or lag behind the hydrograph peak.

Procedures have been developed for estimation of mobilised sediment (Rendon-Herrero, 1978; Williams, 1978; Singh and Chen, 1982; Khumbare and Rastogi, 1985) by using regressional relationships usually of power form between mobilised sediment and excess rainfall. The use of USG model in prediction of sediment yield is restricted to the condition of suspended sediment forming the bulk of the sediment load of the river which is found to be the common case as described earlier. Work done by Rendon-Herrero on a small wash-load producing watershed (Bixler Run near Louisville, Pennsylvania, USA) confirmed the applicability of the concept. In his concluding remarks, he said " The unit sediment graph developed subtly exhibited graphical characteristics that are typical of hydrographs of varying duration". The unit graph analysis has been furthered in the development of the dimensionless unit graphs. In the sediment transfer mode, this is the dimensionless unit sediment graph (DUSG). This represents the characteristic shape of the unit sediment graph plotted in dimensionless terms (Kumar et al., 1990). To convert a USG to a DUSG, the ordinates of the USG are divided by the peak USG ordinate while the abscissa is divided by the time to peak t_p. The reverse conversion also holds true. The major limitation of the USG concept is its total reliance on the measured sediment data on the rising and receding phase of the runoff hydrograph. It lacks any conceptual linkage between sediment concentration graph and runoff hydrograph. Its potential for sediment yield prediction for ungauged catchments is therefore limited.

2.4.2 The instantaneous unit sediment graph (IUSG)

Two different concepts have been used in the definition of the IUSG. Williams (1978) and Singh et al., (1982) defined the IUSG as the distribution of sediment due to an instantaneous burst of the excess rainfall having a unit volume. In this definition the amount of mobilised sediment is not considered. In the second concept, the IUSG is defined as that distribution of sediment which arises from an instantaneous burst of rainfall producing one unit of mobilised sediment (Kumar and Rastogi 1987, Kumar et al. 1990, and Sharma et al., 1992). One unit of sediment is generally taken as one tonne. The latter concept has received greater attention with positive results. The mobilised sediment is the volume of sediment that results from an excess rainfall event. On the other hand, the excess rainfall is that which equals the direct runoff. The IUSG is a theoretical concept of the sediment graph resulting from mobilised sediment of unit amount occurring within an infinitesimally small duration. Singh et al. (1982) noted that though runoff-sediment relationship is not strictly linear, the IUSG peak is related to rainfall excess while the shape factors of the sediment discharge graphs are approximately similar to those of runoff hydrographs. When the IUSG of a catchment is known, any given unit sediment graph of X hour duration can be derived by convolving IUSG flows with mobilised sediment for duration of X hour. Following the concept of instantaneous unit hydrograph (IUH) postulated by Nash (1957), a fluvial system can be represented by a cascade of multiple linear reservoirs (say n_s), each having the same storage constant K_s. By routing a unit inflow volume of mobilised sediment through the n_s linear reservoirs each having a storage parameter K_s a mathematical model for the IUSG can be obtained. The dimensionless form of the IUSG referred to as dimensionless instantaneous unit sediment graph (DIUSG) has been defined and used like its DUSG counterpart (Kumar et al., 1990). Method of moments has been employed to estimate the parameters n_s and K_s which requires the establishment of the first and second moments of both the mobilised sediment histogram and the resulting sediment graph. Sharma et al., (1992) and Kumar and Rastogi (1987), have used the graphical procedure for estimating these parameters. Another method of developing the IUSG is based on time area sediment histogram routed through a single linear reservoir concept. This requires the determination of sediment mobilised, the sediment storage constant and the time of concentration t_c. It is assumed that the mobilised sediment first undergoes pure translation and then attenuation. The translation is achieved by a travel time-area histogram, and the attenuation by routing the results of the above through a single linear reservoir at the catchment outlet (Shaw, 1984; Das and Agarwal,1990; Kumar and Rastogi, 1989). The sediment storage constant is developed by trial and error methods or estimated from the recession phase of the sediment graph. The time of concentration t_c can be determined from empirical relationships, such as the Kirpich's equation (Chow et al., 1988).

$$T_c = 0.00025\left(\frac{L}{\sqrt{S_o}}\right)^{0.8} \tag{2.11}$$

where,

T_c = time of concentration (h)

L = length of catchment longest channel (m)

S_o = river gradient (m/m).

When sediment graphs are available, t_c is determined as the time between the end of the mobilised sediment histogram and the point of inflection of the recession phase of the sediment graph. Singh et al., (1982) and Williams (1978) proposed a method of determining the IUSG based on the assumption that the sediment concentration distribution (SCD) varies linearly with amount of excess rainfall. The storm sediment discharge is computed by convoluting the instantaneous unit sediment graph (IUSG) with the volume of sediment mobilised. It can be expressed on different time scales, for example, per day, week, month,or year. From work done in an upland watershed in Northwestern Mississippi, Singh et al. (1982) reported that despite the fundamental assumption of linearity not being strictly true, the procedure was reasonably accurate for the prediction of sediment yield from upland areas. Williams (1978) developed an IUSG for ungauged watersheds which resulted in sediment graphs that gave good prediction against the measured ones for 50 storms distributed in five watersheds in the Texas Blacklands. This model was evaluated as a product of the IUH and the SCD. A sediment routing function based on travel time and sediment particle size, was used to predict the sediment concentration distribution. Surface runoff was predicted with a retention function applied to the runoff curve number method of the Soil Conservation Service (SCS) of the United States of America (Williams, 1972 and 1978).

The need to test the model under other environments has been pointed out to enable formulation of its utility in sediment yield prediction. A major advantage of the method is that only a limited number of parameters are required and it can be extended to ungauged watersheds as it bears a conceptual linkage between sediment concentration and the runoff hydrograph. This model has shown good predictive accuracy for lower Himalayan watersheds of India (Kumar and Rastogi, 1987).

2.4.3 Sediment delivery ratio based models

Sediment delivery ratio (SDR) is defined as the ratio of the sediments that find its way to a downstream point to the gross erosion from a catchment. The sediment yield is therefore the product of the gross erosion and the SDR. Currently, the general opinion is that sediment delivery ratio decreases with increase in drainage area (Garde and

Kothyari, 1987). Studies carried out in the Yellow river watershed of China on methods of determination of SDR based on fluvial dynamics found out that the SDR for the Dali river basin in China was dependent on watershed characteristics and had little to do with the streamflow. Due to lack of methods of estimating SDR for large watersheds, they proposed the use of the modified delivery ratio using observed sediment regime data in elementary watersheds. The modified SDR is defined as the ratio between the delivery rate of the watershed and the erosion rate of the elementary watershed. Novotny et al. (1986) concluded on the basis of studies done on rural, urban and urbanizing areas of homogeneous land use characteristics, that SDR magnitudes are determined by;

(a) loss of runoff energy due to termination of rainfall in overland flow phase in agricultural catchments,
(b) type of drainage system in sub-urban and urban basins, and
(c) enrichment with fine material and organic fractions during the runoff process.

Based on the SDR concept the gross erosion of a catchment can be converted to the sediment yield at some downstream point or outlet point of the river(s) draining the catchment. This requires that the SDR of the catchment be determined first.

Erosion models are designed to predict the amount of soil that is lost from a catchment based on dynamics of the erosion process. Among the factors that are taken into account are, the erodibility of the soil, the erosivity of the rainfall and ground conditions which are highly influenced by vegetation cover and management practices. Among the common simulation models are universal soil loss equation (USLE; Hudson, 1988), soil loss estimator for southern Africa (SLEMSA; Roberts and Lambert,1990), and the Water erosion prediction project (WEPP; Borah, 1989) models. There are many hydrologic models available with a capability of simulating erosion, sediment transport and deposition from catchments. Some known ones are ANSWERS, CREAMS, SPUR, SWRRB, and AGNPS which are briefly discussed by Borah (1989).

2.4.4 Sediment transport equation based models

There are numerous equations that have been put forward for the determination of sediment carried by water in both open and closed channel flow. Since bedload is better correlated to flow dynamics, most of these equations are directed towards the determination of this component but a few exist for suspended load determination too. Equations existing in record include those based on diffusion (exchange) theory , energy balance, and gravitational theory and are documented in Kinori and Mevorach (1984).

2.4.5 Stochastic models for estimating sediment yield

A stochastic process is the dynamic part of probability theory and such a process is observed whenever a process developing with time is controlled by probabilistic laws (Woolhiser and Blico, 1976). Stochastic models of sediment yield determination are relatively few. Among those developed include, a stochastic model for Arita river in Japan by Munota and Hashino (1971), a stochastic model for ephemeral watersheds in the United States by Lane and Renard (1972), a daily sediment yield model for canadian catchments by Sharma and Dickinson (1979) and two simple stochastic models for rainfall - runoff sediment yield relations for Italian catchments by Caroni et al. (1984). The advantage noted for such models was their ability to generate long series of data by using statistical parameters based on short samples. These models essentially involve the notions of conditional probabilities, simple probability density functions, harmonic functions and Markov or autoregressive processes normally used in time series analysis. Woolhiser and Blinco (1976) developed preliminary models of sediment yield as a stochastic process for plots and small watersheds and called for their testing. The latest work in this direction is that of Singh and Krstanovic (1987) who have used the principle of maximum entropy (POME) and reported reasonable predictive ability of their stochastic model when compared against measured data for American watersheds.

2.5 Sediment Yield Scenario in Kenya

2.5.1 Sediment yield studies in Kenya

Not much work has been done in this field in Kenya and most of what has been done is concentrated in the upper Tana catchment where the country's hydro-electric power industry is based. Here, sediment yields have shown to be highly dependent on the landuse, ranging from 300 t/km²/yr in grazing areas to 20 t/km²/yr in forested regions (Ongweny, 1979). The higher yields in Muranga and Nyeri districts are attributed to the higher land pressure and level of cultivation as compared to Embu and Kirinyaga districts. Hillslope experiments have been carried out in order to measure the characteristics of runoff and soil erosion in relation to main controlling variables such as landuse, vegetation cover, soil type and hillslope gradient. The results further confirm that sediment yield production for the catchment had been grossly underestimated and threatens the existence of the reservoirs built on the main Tana, viz. Kindaruma, Kamburu, Gitaru, Kiambere and Masinga reservoirs (Ongweny, 1979). From studies carried out by Charania (1988), it has become evident that a sampling program for assessing the sediment discharge from this catchment need not be carried out at all times of the year. Allowing for 5% error in estimation of the discharge reduced the sampling period by about 40% in a year. Similar work has been done in Baringo district in the Katiorin catchment, where the sediment yield was shown to be highly variable temporally and spatially depending on the above factors (Sutherland and Bryan, 1991).

Sediment mobilisation to the reservoir built on Turkwel gorge for hydro-electric power production has also raised a lot of concern. Sediment yield of the river Suam which feeds this reservoir has been quantified as high, though no direct evaluations have been made. On one of the tributaries of the river Suam, sediment gauging between 1983 and 1986 revealed a suspended sediment transport of the order of 300 tonnes/day and at the same time identified that the bed load component of this river as not being insignificant. Though the gauging facility which comprises of a US D48 sampler and a cable way is still in place, presently no work is going on.

In Machakos district where a lot of soil conservation effort has been directed (Thomas, et al., 1981), various rivers had sediment gauging programmes functioning in the past. This was especially possible when such activities were funded by the Machakos Integrated Development Programme (MIDP). These programmes have since collapsed and the gauging facilities left to degenerate in the face of poor financial and equipment support.

For the study catchment, over the months of April and May 1991, sediment yield studies were carried out by grab sampling and gravimetric analysis by Omoro (1991). Over this period, a total runoff volume of 274061 m^3 and a sediment yield of 75.682 tonnes were obtained . Based on data for the above period, three forms of sediment discharge rating equations were developed and compared against gauged sediment discharge. It was observed that the corrected log linear form gave the best results and hence was recommended for use. Some work has been done by Dunne et al. (1979) where a method of assessing erosion rates in the semiarid lowlands of Kajiado district by use of ground lowering measurements against datable references was investigated. The advantages of the method were found to be it's simplicity, and the possibility of obtaining useful information from the past by using dating techniques. This was especially the case when the datable reference was in the form of trees whose age could be approximated by aerial photo interpretation, or by counting the growth rings. Erosion rates between 2 and 4 mm/yr were estimated for the hillslope of Athi-Kapiti plains. With a measured bulk density of 1.05 g/cm^3, this corresponds to rates of 2100-4200 t/km^2/yr. Much higher values of 8-14.7 mm/yr (8400-15435 t/km^2/yr) were recorded on the Kilimanjaro lavas. Suspended sediment records on major stream outlets were noted not to reflect erosion rates as the sediment delivery ratio of the area is close to zero. This points out the importance of understanding the sediment delivery ratio concept before any attempts are made to link observed sediment yields and gross erosion from a catchment. Sediment yield of the Perkerra river serving a catchment area of 1310 km^2 has been evaluated and shown to be of the order of 19520 t/km^2/yr (Dunne, 1979).

2.6 The Need For More Work

Information on non-point pollution has become more important on the realisation of the problems it results in. This has led to the increase and expansion of study activities. Most developing countries lack the resources for extensive field studies and measurements and Kenya is no exception. There is therefore an urgent need to formulate evaluation techniques that would be in the cost ability of this country. Use of modelling is in this light recommended but this again calls for the testing and calibration of the models suggested for use. For the determination of sediment yields of rivers, reduction of costs incurred in conventional gauging techniques also needs to be addressed. This can be achieved by optimizing the sampling frequency for sediment concentration, use of simple sampling equipment and procedures, as well as the use of simplified discharge measuring techniques. The use of single point velocity method for discharge measurement has been suggested as a cheap alternative to conventional current meter stream discharge gauging or the use of flow measuring devices. Likewise, grab sampling could be a simple and cost effective means of sampling the suspended sediment, whose potential needs to be investigated.

3. MATERIALS AND METHODS

The research study involved analysis of sediment yield in the Mathare river, by use of four sampling procedures.

(i) Equal discharge increment (EDI) procedure

(ii) Equal transit rate (ETR) procedure

(iii) Grab procedure

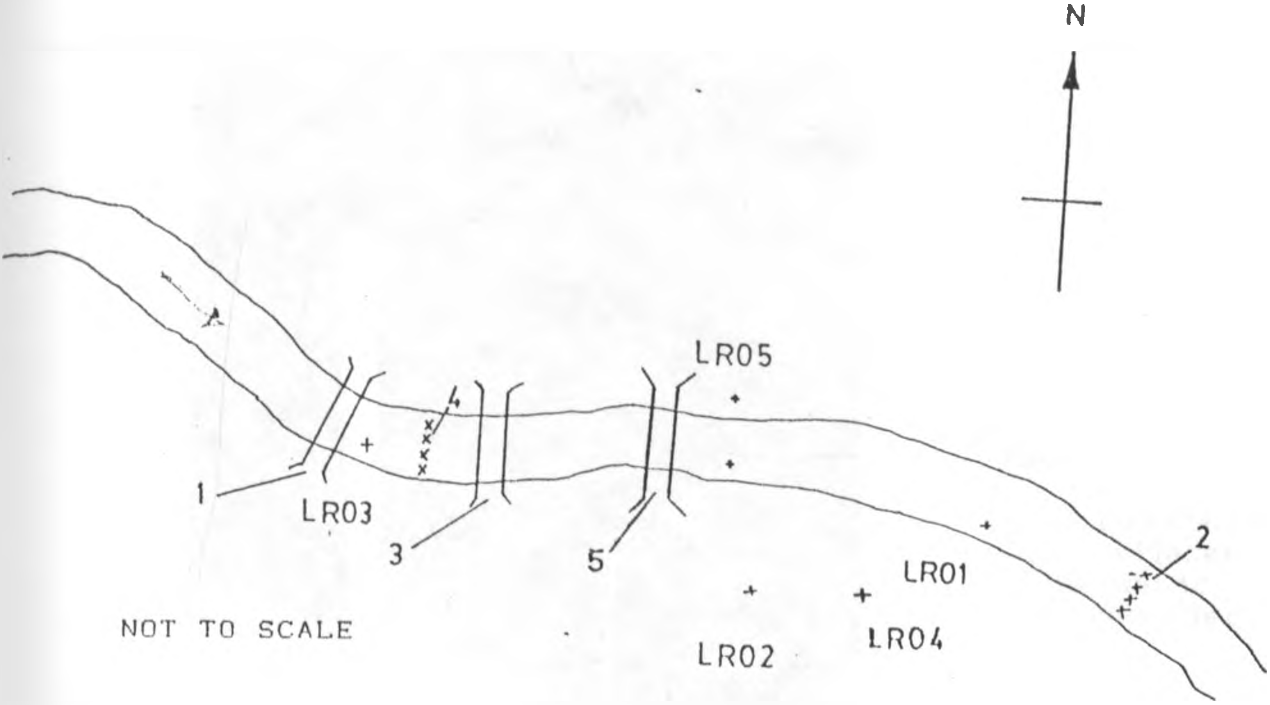
(iv) Automatic single stage sampling procedure.

In order to implement the above procedures, it was essential to establish a number of facilities and to carry out hydrometric measurements.

3.1. Hydrometric Measurements

3.1.1. Provision of gauging facilities

Two sets of compound staff gauges were installed at the site to cover the observed peak stage of three metres **(Plate 1)**. A steel box container for temporary storage of stationery and equipment was fabricated and installed at the site 6 m from the water level recorder housing **(Plate 2)**. This was made up of a 14 gauge checkered steel plate and had the dimensions of 0.7 m x 0.7 m x 1.1 m. It was installed at a height of 1.5 m from the bottom supported by four stands made up of 51 mm angle iron. It contained two compartment. The existent water level recorder **(plate 3 and 4)** at location LR02 **(Fig. 3.1)** was used to develop a continuous stage graph for the entire study period except on occasions when it was faulty. The already existent steel bridge **(plate 5)** permitted sampling above the control section while a



ITEM NO.

1. CONCRETE - STEEL BRIDGE (OLD)
2. NATURAL ROCK WEIR
3. WOODEN BRIDGE
4. NATURAL ROCK WEIR
5. CONCRETE STEEL BRIDGE (NEW)

LACATION

LR01	LOWER STAFF GAUGES
LR02	WATER LEVEL RECORDER
LR03	UPPER STAFF GAUGES
LR04	STEEL STORAGE CONTAINER

Fig. 3.1 Site layout of Mathare river gauging site

Plate 1

Set of two staff gauges adjacent to the water level recorder.

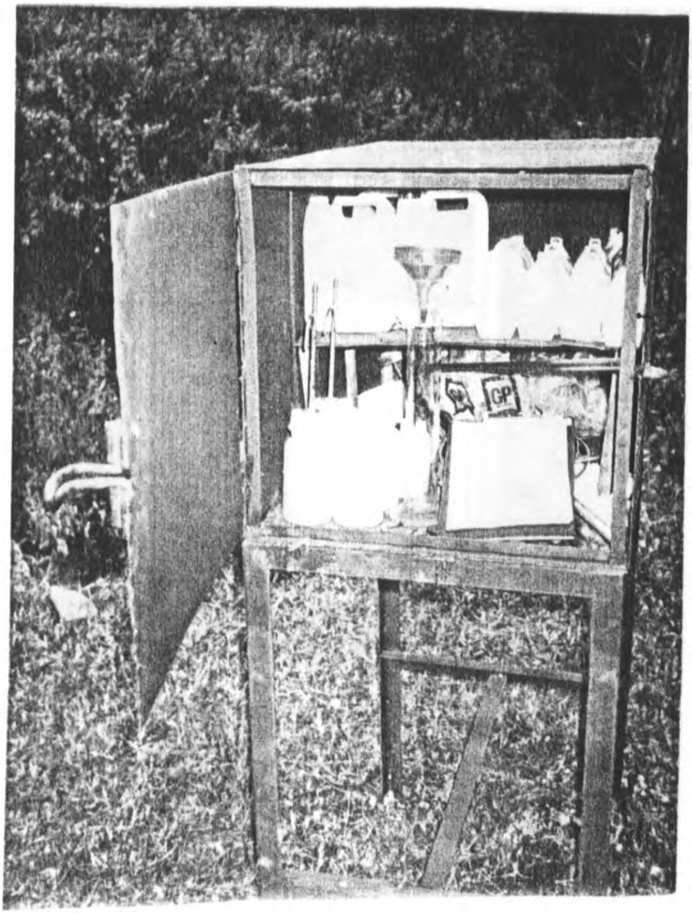


Plate 2

Equipment storage box at the gauging site.

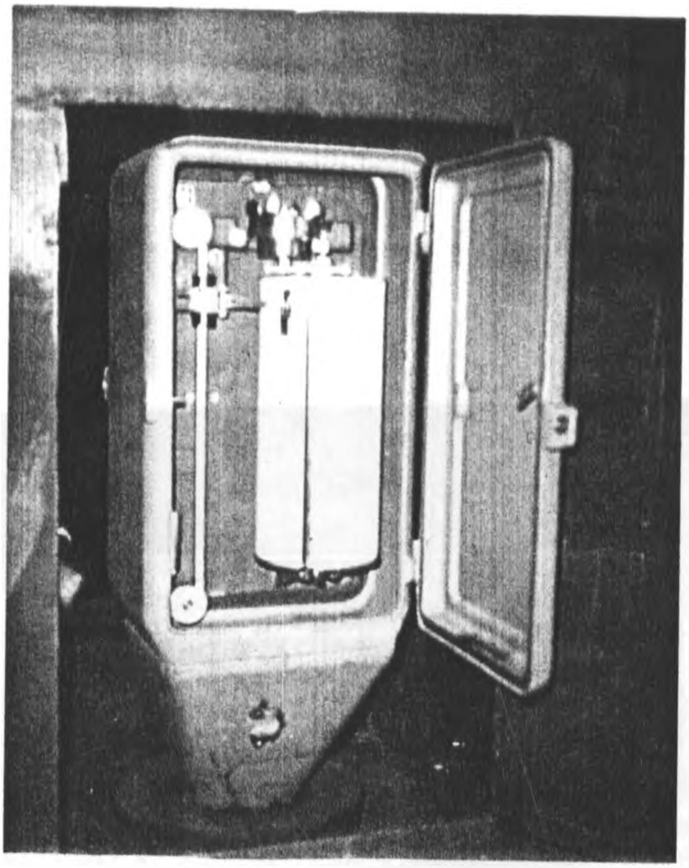


Plate 3

Water level recorder showing graph paper mounting and the plotting mechanism.

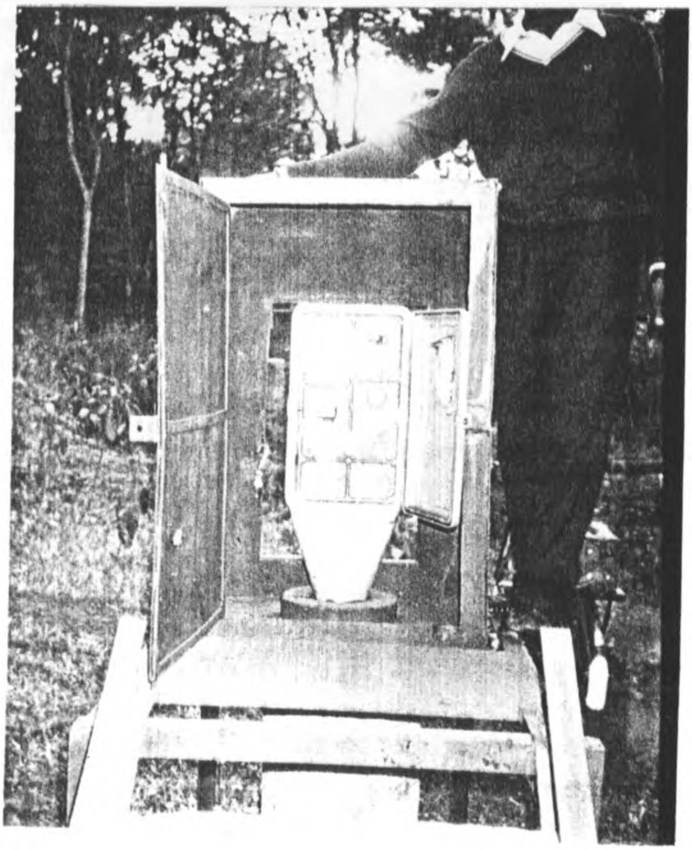


Plate 4

Water level recorder showing mechanism for adjusting to achieve appropriate plotting ratios.

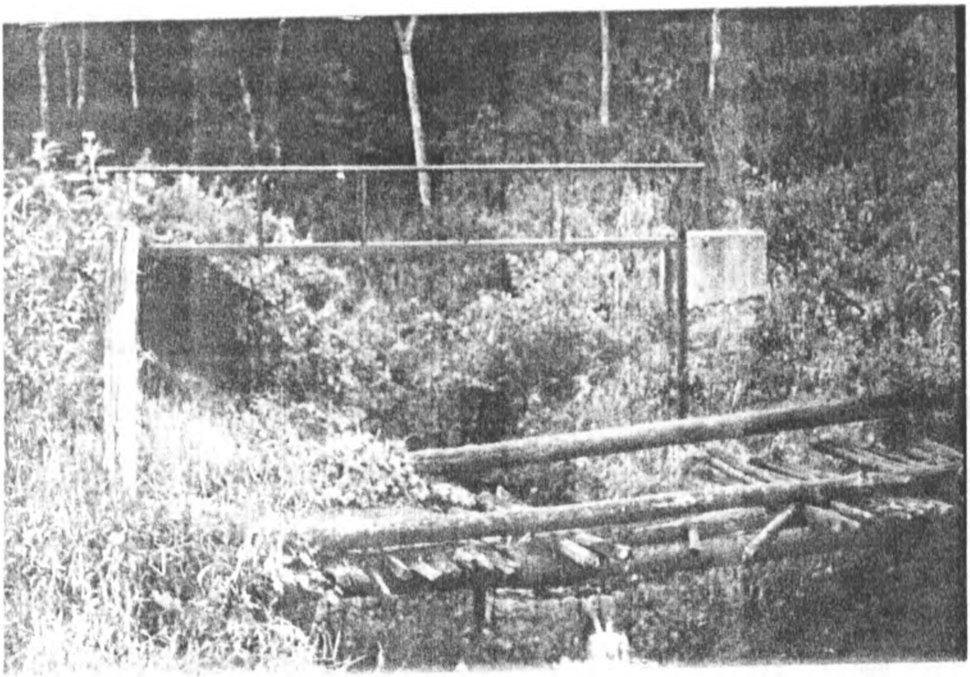


Plate 5 An old wooden bridge with the constructed upper steel bridge in the background.

second bridge **(Plate 6)** was constructed near location LR02 **(Fig. 3.1)**. This bridge had a span of 6 m and a width of 0.8 m and was made up of a steel structure comprising of 250 mm square tubes, 51 mm and 25 mm angle iron with a floor of 14 gauge checkered steel plate. Concrete pillars constructed on either side of the river were used for anchorage. The site layout of the gauging site is shown in **Fig 3.1** and the pictorial view in **Plate 7**

3.1.2 Automatic single stage sampling equipment

The automatic sampling equipment was installed in the river to collect samples for specified river stages occurring at any time of the day. It consisted of six bottles held vertically in specified river stage positions on a board with a vertical height difference of 10 cm. This board was installed into the river by fixing it on an angle iron driven into the river bed. The equipment was fabricated by use of one litre plastic bottles. Inlet nozzles of 6 mm diameter were machined from copper tubing and inserted into the plastic bottle cocks. The outlet nozzle was fixed on the upper part of the container. This is shown in **Fig 3.2** and was installed in a turbulence zone of the gauging station labelled as location **LR05**. The assembly of the device is shown in **Plate 8**. The equipment was inspected and samples collected on a daily basis. The samples so collected were analyzed together with the other manually collected samples.

Plate 6 Lower bridge with position of the staff gauges shown.

Plate 7 The layout of the gauging site.

Plate 8 The single stage bottle sampling equipment.

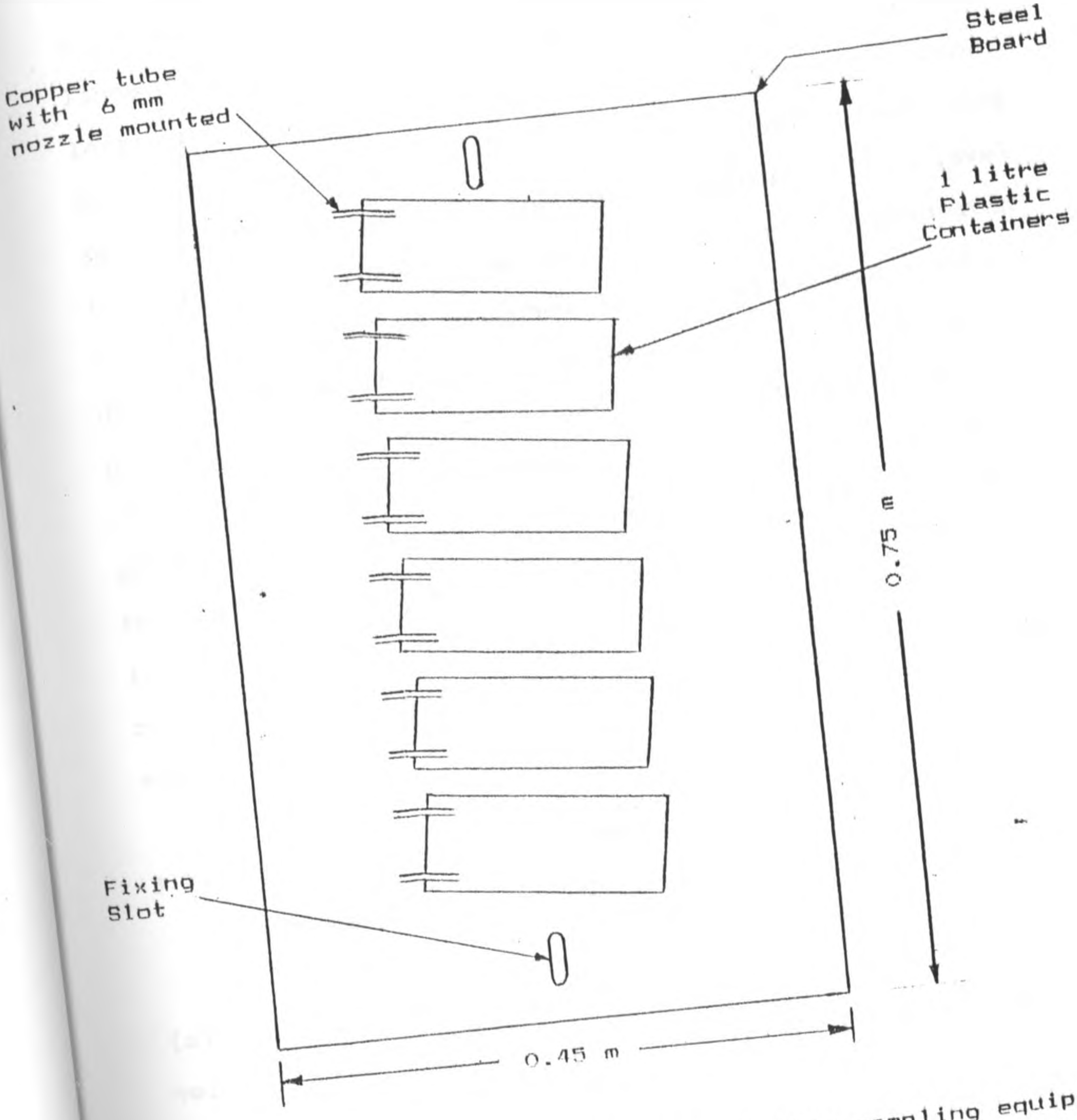


Fig 3.2 Automatic single stage bottle sampling equipmemt

3.1.3 Defining river cross-section for discharge rating

The river cross-section was established for both the upper and lower bridges by use of survey procedures. Level lines were established across the bridges using an engineers level, ensuring that it was perpendicular to the stream flow. For this purpose, a bench mark existent at the site was used as the reference point in the survey exercise. This level line was counterchecked by double mass method. A graduated rod with a footplate attached to the bottom was used to determine the depth of the river bed from the level line. A plumbline was incorporated to define the vertical depth. This depth was read of directly from the wading rod whose graduation was zero at the bottom , and a maximum value at the top,to the nearest centimetre. A plot of the depth at intervals of 25cm across the stream was used to define its cross-section. The configurations at both cross-sections are shown in **Appendix** I and II.

3.1.4 Discharge measurements

Three methods were used for monitoring the discharges.

(a) Discharge was measured by use of multiple verticals and velocity area procedures where the velocity was measured by use of a current meter shown in **Plate 9.** The data for this procedure was recorded in discharge measurement sheets shown in **Appendix III.** This meter was of the horizontal axis type commonly referred to as a propeller meter (Ott make from West Germany). It had a propeller of 125 mm diameter (propeller

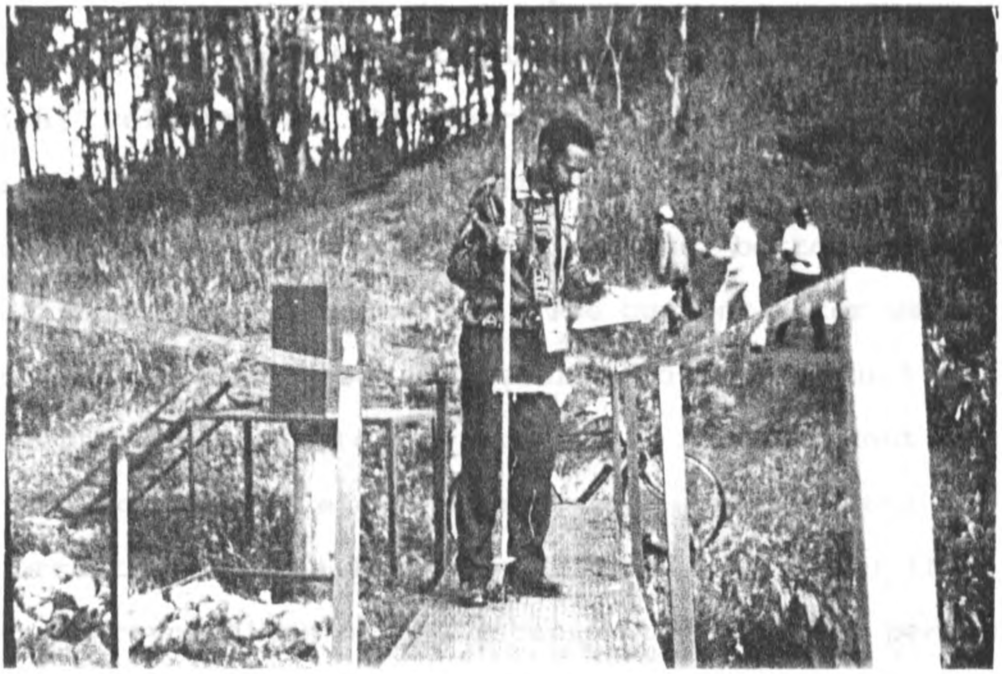


Plate 9   Current meter used for discharge rating.

no. 1-110049) and was used while attached to a 20 mm diameter rod for which calibration equations were available. The discharge measurement was carried out for rating the natural weir using a velocity area method. The channel was subdivided into 25cm sections along the bridge and the water velocity at 0.2 and 0.8 of the section depth from the water surface measured. This was used for the computation of the mean vertical velocity as the average of the two. For each section, the total water depth was measured by use of a graduated rod whose zero was at the bottom with the graduations increasing upwards. The current meter was fixed on to the graduated rod and lowered to 0.2 and 0.8 of the flow depth. One minute was allowed to pass without making any readings on the electro-mechanical counter attached to the current meter to allow for stabilisation. After this the number of revolutions of the meter propeller for a period of 120 seconds were recorded by timing 120 seconds between the activation of the start and stop buttons of the digital counter. The current meter readings were used to calculate the velocities of the water by use of the calibration equations shown below;

$$V = 0.2281\,N_c + 0.023 \qquad \text{for} \qquad N_c \le 0.67 \qquad (3.1)$$

$$V = 0.2475\,N_c + 0.010 \qquad \text{for} \qquad N_c \ge 0.67 \qquad (3.2)$$

Where,

V= Point stream water velocity (m/s)

N_c= Number of current meter revolutions per second (rps)

Since the measurements were made with the wading rod held vertically, no corrections were necessary for inclination. The above data was used to evaluate the mean velocity for the section areas and to compute the discharge for each calibration event by use of the mid section water discharge formula (Guy and Norman, 1970) shown below.

$$Q=\sum_{i=1}^{N} V_i d_i \left(\frac{b_{i+1}-b_{i-1}}{2}\right) \qquad (3.3)$$

where,

Q = water discharge at the cross-section (m^3/s)

V_i= mean velocity at the i^{th} vertical (m/s)

b_i= lateral distance of the i^{th} vertical from datum point (m)

d_i= depth of the i^{th} vertical (m)

N= Total number of verticals used

Discharge computations were made by use of a computer program presented in **Appendix VII.**

The calculated discharges were used to calibrate the natural rock outcrop weir of the gauging site by the development of a two parameter rating equation which was used to convert the autographic water level recorder stage graph into a stream hydrograph.

(b) Discharge computation was carried out from single point velocity measurement taken to be representative of the stream velocity. The single point velocities were measured by use of the current meter as outlined above at 0.5 of the flow depth recorded at the middle of the river section for various stages. The discharge was computed as the product of the measured velocity, and the cross-sectional area of flow. The area used was that obtained from the summation of that for all the verticals in the scheme shown in (a) above.

(c) Discharge was also computed from the ETR samples. The volume of sample, size of nozzle used and time taken to collect the samples were taken while sampling for sediment distribution using the equal transit rate (ETR) scheme. This procedure is based on the assumption of the water inlet velocity at the nozzle being equal to the streamflow velocity and was computed by use of the equation shown below.

$$V = \frac{V_o}{t\, A_x} \qquad (3.4)$$

Where,

V = velocity of water (m/s)

V_o = volume of the sample (m^3)

t = time taken to collect the sample (s)

A_x = cross-sectional area of the nozzle (m^2)

The computations were made by use of a computer program which was developed, and is presented in **Appendix VII.**

3.2 Sediment Sample Collection

Sediment samples were taken at the gauging station for suspended sediment concentration analysis. These were collected and labelled. The recorded information consisted of sample number, gauge height, water temperature, method of sampling, the section depth, air temperature, water temperature, time taken for the measurements over all the vertical sections, cross-section area of the gauge section, width of the section, gauge height change over the recording time and the general appearance and condition of the gauging station. A bicycle was available for transporting the samples to the soil and water laboratory for gravimetric analysis.

3.2.1 Sampling procedure

Sampling was carried out using 1 litre plastic bottle samplers mounted on a brass carrier. This was attached to a series of one meter long wading rods fastened together to achieve the desired wading depth as shown in **Plate 10.** All samples were depth integrated but were collected according to the requirements of the particular sampling scheme. A distinction was made between the different samples collected based on method and time of collection by adopting a systematic labelling technique. The letters G, T or D were used to indicate which of the three methods grab, ETR or EDI was used. This was followed by the date of collection and then the time. The labelling was done on the container of each sample collected by use of adhesive labels. A periodic sampling programme was carried out for the four sampling methods, EDI, ETR, grab and automatic single stage.
Verticals for the EDI and ETR methods were predetermined to yield the number of samples to be taken in each case at the defined river cross-section.

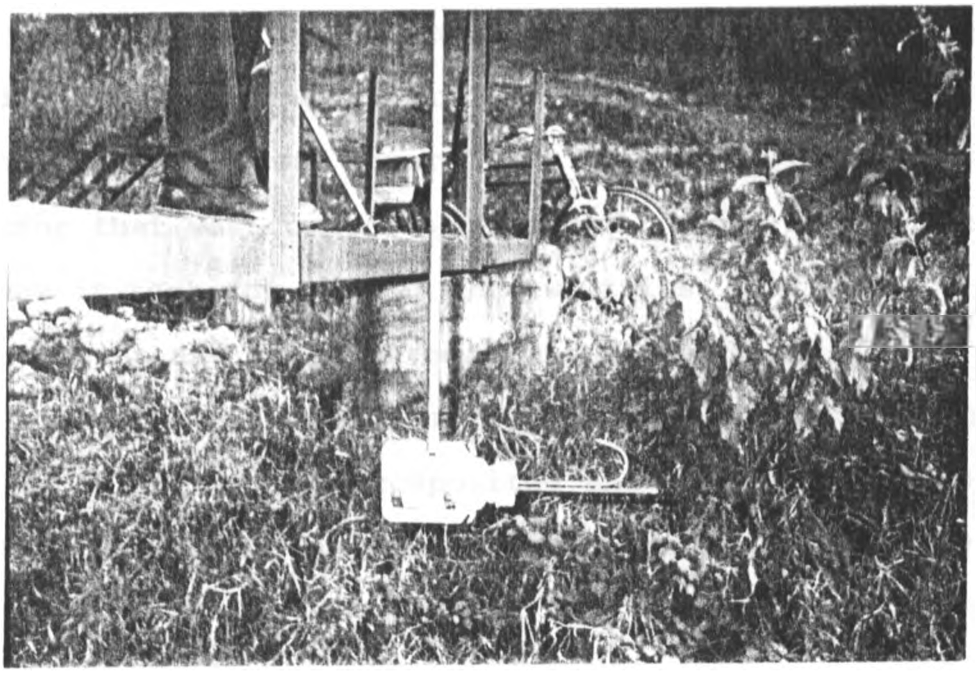


Plate 10 Bottle sampler being operated from the top of the bridge.

3.2.2 Development of verticals and sampling in the ETR scheme

Some pre-sampling was carried out for the determination of lateral variation in sediment concentration across the river. Since this was not high, five verticals were selected for the collection of ETR samples as they were considered to be adequate. Sampling was done while standing on the bridge. The bottle sampler was lowered and raised at a constant rate, a factor that was counterchecked by a record of the time in seconds it took for each of the two trips. This was subject to judgement and a lot of caution was exercised to see that the downward and upward rates were constant and equal. Samples collected were composited and stored in five litre plastic containers then transported to the laboratory for analysis.

3.2.3 Development of verticals and sampling in the EDI scheme

The stream discharge was measured through velocity area method using verticals spaced at 25 cm for selected river stages namely, 0.15, 0.25, 0.35, 0.45, 0.55, 0.65m. The cumulative discharge was plotted against the distance from the reference point which was the water surface and channel intersection along the river bank on one side. Based on some pre-sampling, the sediment concentration across the channel was seen to be lowly variable and hence a total of five sampling verticals were settled on as being adequate. From these plotted graphs, the five verticals of equal discharge increment were obtained by evaluating the bounding distances from the reference for sections carrying 20% incremental discharges. Through interpolation and extrapolation, the results were used to determine the sampling verticals for the whole range of encountered stages. Data used in this analysis is presented in **Appendix IV.** The results are shown in **Table 3.1** and are given to the nearest 5cm. These are graphically represented in **Figs. 3.3** and **3.4.**

Table 3.1 Location of verticals for EDI measurements

	Location of verticals of 20% incremental discharge				
Stage (m)	1st (cm)	2nd (cm)	3rd (cm)	4th (cm)	5th (cm)
0.15	0-70	70-110	110-140	140-170	170-250
0.25	0-80	80-115	115-145	145-190	190-275
0.35	0-75	75-105	105-145	145-180	180-300
0.45	0-75	75-110	110-150	150-190	190-300
0.55	0-75	75-105	105-150	150-200	200-325
0.65	0-90	90-130	130-175	175-225	225-350

Depending on the river stage during time of sampling, the sampling verticals were established by use of **Table 3.1.** Working from the bridge, the sampling bottle was lowered and raised by use of the wading rod along the centroid of each equal discharge vertical defined. Samples collected in this

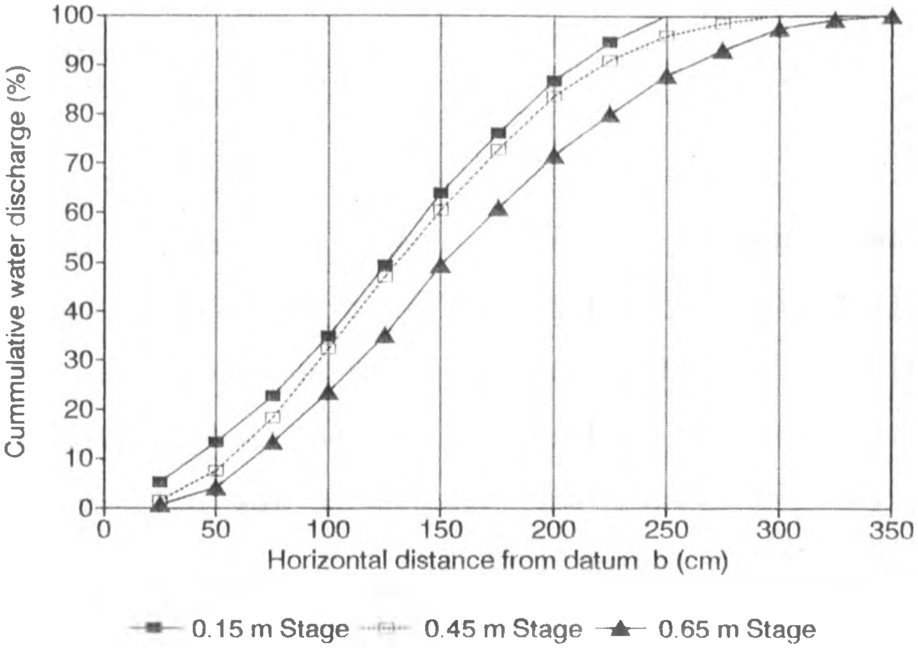


Fig 3.3 Cummulative discharge graphs

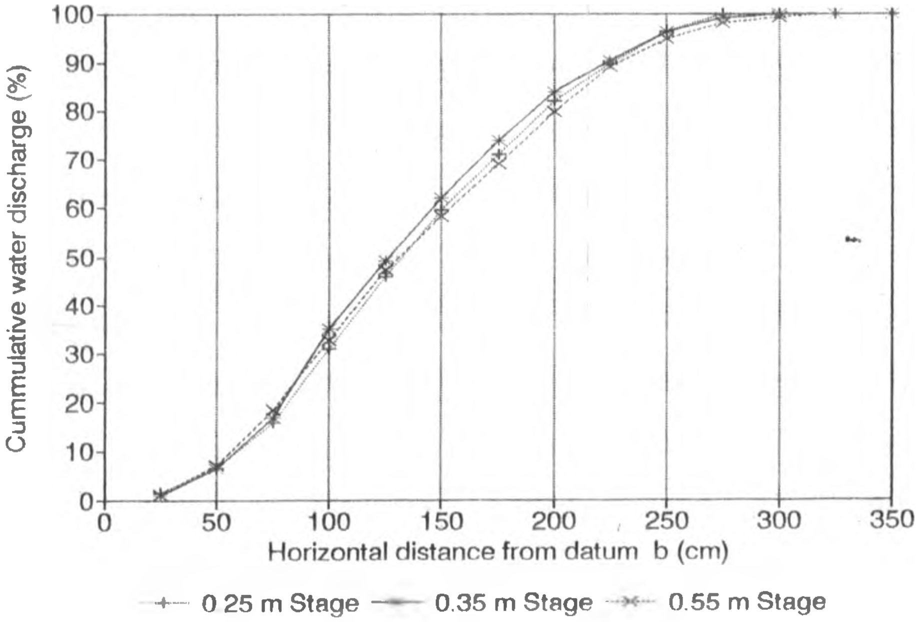


Fig. 3 4 Cummulative discharge graphs

scheme were stored in one litre plastic containers each to be analyzed separately.

3.2.4 Grab sampling

For the grab method, a depth integrated sample was collected at the turbulence zone marked **LR03** **(Fig. 3.1)**, while standing on the wooden bridge shown in **Plate 5**. This sample was stored in a one litre plastic bottle. The frequency of sampling was increased immediately following observed rainfall events. For the development of sediment graphs, grab sampling was carried out at three hour intervals whenever practically possible.

3.2.5 Automatic single stage sampling

Since sediment load is dependent on the river stage while sampling was only carried out during the day, certain high stage flows of the river which came in the night were missed out of the sampling programme. To cover such periods samples were collected over the rising phase of the discharge hydrograph by use of a stage controlled automatic sampler. This was accomplished by use of the automatic single stage sampling equipment described in section 3.1.2. The river stage entered in the sample labels in this case was the staff gauge reading corresponding to the bottle position height. The sediment concentrations obtained from these samples were statistically compared with those obtained by the grab sampling method described.

3.3 Laboratory Analysis of Samples

3.3.1 Sediment concentration analysis

Sediment concentrations were analysed using the filtration method with filter paper (No. 42) as a filtering medium. Filtering was carried out with the sediment samples being allowed to settle first, and the supernatant water decanted off. There was therefore no need for dissolved solids correction since such solids were eliminated during the decantation and the remainder passed through during filtration. Sediment concentrations encountered were all below 1000 mg/l and therefore there were no problems experienced with the use of the method. From the field, the volume of each sample was measured to ascertain that spillage had not occurred while transporting the samples from the gauging site. The samples were then transferred with labels to sedimentation cylinders, with 2% copper sulphate and aluminium potassium sulphate (ALUM) added to stop algae growth and act as a flocculation agent respectively. They were then left for a period until clear supernatant water could be seen after sedimentation had taken place. For all the samples analyzed this period was fixed at 24 hours such that samples collected on a particular day were filtered the following day. The supernatant water was siphoned or decanted off, and the remaining sludge together with labels transferred to the filtration unit. This unit consisted of a perforated conical filter placed over a plastic funnel and kept over a one litre plastic container for the collection of the filtrate **(Plate 11)**. The conical filter was obtained

Plate 11 Gravity filtration system.

by folding a circular filter into four quarters and later opening it up with two of the quarters attached. With this set up, the sludge was poured to undergo gravity filtration.

The collected residue was transferred with labels to evaporating dishes and dried in an oven at a temperature of 80° C until all moisture was lost. The drying period was 24 hours. The dry sediments were then cooled in a desiccator and weighed. The sediment concentration was evaluated from the above recorded measurements by a gravimetric method from the following equation.

$$C = \frac{M_s \times 10^6}{V_o} \tag{3.5}$$

Where,

C = sediment concentration (ppm)

M_s = mass of dry sediments in sample (gm)

V_o = volume of sample (cm^3)

Records for this analysis were entered into proforma sheet shown in **Appendix V.**

3.3.2 Particle size analysis

Particle size analysis was carried out for four composites of dried sediment samples by use of the sieve-pipette method. These composites were prepared on the basis of time of sampling and are shown in **Table 3.3.**

Table 3.2 Sample particulars for particle size analysis

Sample number	Period of collection
1	October - November
2	December - January
3	February - March
4	March - June

Particle size distribution analysis was done on the basis of these four composite sediment samples covering most of the study period. After the preparation, the composites were oven dried for a period of 24 hours before cooling and then dry sieving. As discussed previously, particles greater than 0.062 mm size were analyzed by use of sieve analysis while those of smaller size were analyzed by use of the pipette method. The sieve sizes used were 2, 1, 0.5, 0.25, 0.125 and 0.062 mm. Vigourous shaking was carried out for a period of 15 minutes by use of the sieve analysis equipment shown in **Plate 12**. The mass of the empty sieves before sieving and that of the sieves and trapped sediments combined were measured and recorded in the particle size analysis sieve-pipette record sheets shown in **Appendix VI**. The mass of each size fraction was recorded for evaluating the percentage fraction of the respective sizes and for use in the development of the gradation curves.

For the sieve pipette method, the pan material in the above

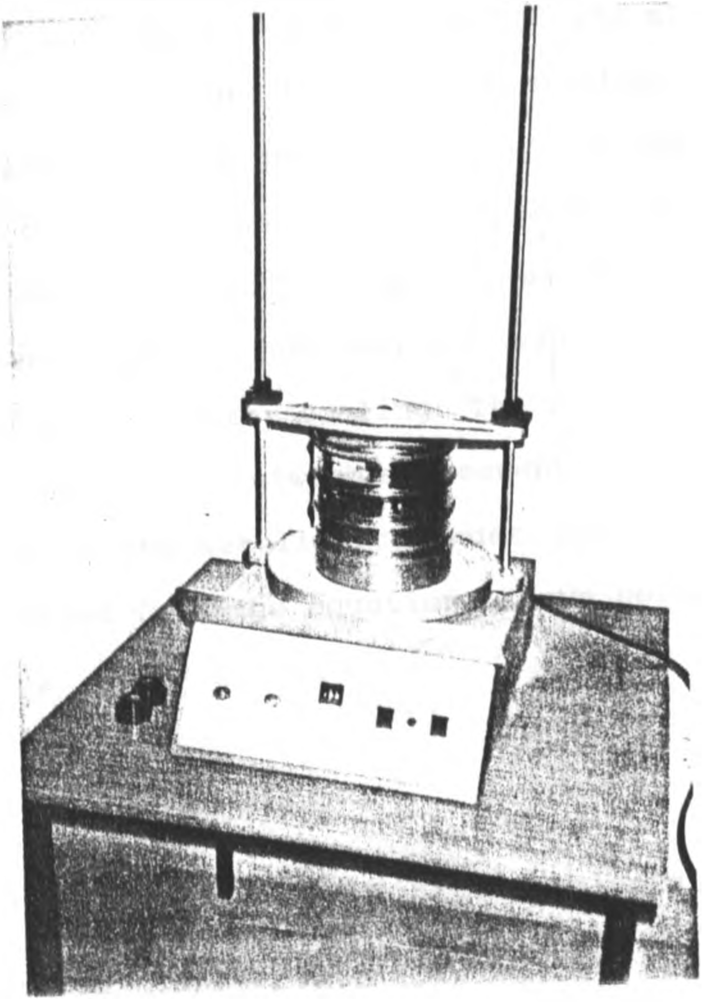


Plate 12 Sieve analysis equipment

procedure was transferred to a settling cylinder where distilled water was added to make up to the 750 ml mark. The temperature was recorded and the stirring started. To obtain pipette extracts for each particle size diameter, a table (USDA, 1979) outlining the time of pipette withdrawal for given temperatures and depth of withdrawal was used. The withdrawals were emptied into weighed evaporating dishes, dried and then weighed after cooling. The pipette was rinsed with distilled water once between subsequent withdrawals, and the rinse added to the settling cylinder. The volume factor V_f used was derived from the equation shown below

$$V_f = \frac{V_{ts}}{V_w} \qquad (3.6)$$

Where, V_{ts} = total volume of pipette analysis suspension (cm^3)

V_w = volume of pipette withdrawals (cm^3)

Mass of sediments in each pipette withdrawal was calculated as the product of dry mass of sediments after oven drying for 24 hours and the volume factor. The ratio of this value to the mass of total sediments in the sample provided the percentage of total sediments finer than the given size.

3.4 Data analysis

3.4.1 Water discharge

The measured discharges and stages of flow were used to develop discharge rating equations by the method of least squares. Since linear regression algorithm was used for data fitting, various transformations were tried and that giving the highest coefficient of determination (R^2) was finally chosen for further use.

3.4.2 Sediment concentration and distribution

Sediment concentrations resulting from the different sampling methods were compared statistically using the paired t-test. The sediment rating curve was developed using linear regression between the sediment concentration evaluated from the sampling and water discharge for the different storm events in the log domain. From the sediment rating curve, the seasonal sediment discharge of the catchment was computed by use of the flow records and flow duration analysis.

3.4.3 Development and use of the IUSG model

For all mobilised sediment events, sediment concentrations were measured at three hour intervals with the exception of parts of the events occurring during the night. The concentrations were used in conjunction with the stage graph and the discharge rating equation to develop the sediment graphs for individual events. By a treatment analogous to hydrograph separation, the base sediment flow was separated by the straight line method. The area under the resultant sediment graphs gave the total mobilised sediments for the event. A total of 14 events were realised and 10 of these events were used for the development of the IUSG model parameters while the remaining 4 were used to test its applicability. In application, the IUSG was used to generate the sediment graphs in the same way as the IUH is used to generate the storm hydrograph. This involved convoluting the USG developed from a discretisation of the IUSG with the mobilised sediment. The excess rainfall hyetograph (ERH) was derived from hydrological information described as follows. Rainfall intensities at 30 minute intervals were calculated for each rainfall event producing runoff from the autographic rainfall charts, recorded at Kabete meteorological station. The 30 minute interval was chosen because bigger intervals were found to cover widely varying intensities. Calculated intensities were used to develop the total rainfall hyetograph (TRH). The discharge hydrograph was developed from the stage graph obtained from the water level recorder. The direct runoff was obtained by the straight line method of separation as outlined in Chow et al. (1988). The direct runoff Q_{net} (m^3) was calculated as the area under this hydrograph. Based on the assumption that the rainfall is evenly distributed over the entire catchment, the excess rainfall depth (P_{net}) in mm was then calculated by use of the equation shown below.

$$P_{net}=\frac{Q_{net}}{A}\times 10^{-3} \qquad (3.7)$$

where A is the catchment area in km^2

This was used to establish a Phi index such that the area in the TRH above this index was equal to P_{net}, converted to the units of mm. The portion of the TRH above this index was extracted to give the excess rainfall hyetograph (ERH).

The relationship between total excess rainfall and total mobilised sediment was determined through regression analysis in the log domain. Total excess rainfall was determined from a 30 minute ERH while total mobilised sediment was obtained as the area under the sediment graphs developed. Finally, the ERH was converted into a mobilised sediment histogram by an application of the above developed relationship. This histogram was used in the convolution exercise.

The convolution operation was carried out using a numerical approach as described in Chow et al. (1988).

$$Q_{sj} = \sum_{i=1}^{j \leq T} V_{si} U_{j-i+1} \qquad (3.8)$$

Where,

Q_{sj} = sediment graph ordinate (t/h)

V_{si} = mobilised sediment (t)

U_j = USG ordinate (h^{-1}).

Development of the USG involved the discretisation of the IUSG. A summation curve of the IUSG was obtained by mathematical integration and consequently converted into a 30 minute USG by a graphical lagging method. A computer program was written for the above discrete convolution equation in the Turbo Pascal programming language **(Appendix VII)**. By the use of this programme and the excess rainfall hyetograph, the sediment graph for each rainfall event producing runoff was generated and plotted against that derived from the grab sampling programme for comparison.

The sediment yields of all the storms that fell within a specified period were determined and summed. The total sediment yield as a summation of the individual storm sediment yields was compared against that obtained by the temporal concentration curve method and the flow duration curve method.

(a) Derivation of the IUSG using multireservoir cascading concept

As an adaptation of the multireservoir cascading concept of IUH postulated by Nash (1957), a synthetic IUSG was developed. The method of moments was used for estimation of parameters as is done in rainfall excess-runoff hydrograph generation. Following Chow et al. (1988), the first and second moments about the time origin of both the mobilised sediment histogram and the resulting sediment graph with the base sediment flow separated divided by the total mobilised sediment were determined. These are respectively, $\boldsymbol{M_I s_1}$, $\boldsymbol{M_Q s_1}$, $\boldsymbol{M_I s_2}$ and $\boldsymbol{M_Q s_2}$. This being analogous to the first and second moments of the ERH and DRH in hydrograph analysis were related to the IUSG model parameters n_s and K_s by the relationships:

$$M_{Qs1}-M_{Is1}=n_sK_s \tag{3.9}$$

$$M_{Qs2}-M_{Is2}=n_s(n_s+1)K_s^2+2n_sK_sM_{Is1} \tag{3.10}$$

From this equations the values of $\mathbf{n_s}$ and $\mathbf{K_s}$ were computed for 10 mobilised sediment events.

The outflow of sediment discharge from the n_s $^{\text{th}}$ reservoir computed by use of the following equation:

$$Q_s(t) = \frac{V_s}{\Gamma(n_s)} \frac{1}{K_s} \left(\frac{t}{K_s}\right)^{(n_s-1)} e^{\left(-\frac{t}{k_s}\right)} \tag{3.11}$$

Where;

V_s = A E_s

A = Watershed area contributing to sediment outflow (km^2)

E_s = Mobilised sediment (t/km^2)

$Q_s(t)$ = Sediment outflow (t/h)

V_s = Suspended sediment load (t)

Γ stands for the notation of gamma function and $\Gamma(n) = (n-1)!$. This being a theoretical concept is useful since it characterizes the catchment's response to rainfall without reference to the rainfall duration and is related to the catchment geomorphology.

By differentiating the above expression with respect to time, with the boundary conditions

$$\frac{dQ_s}{dt} = 0 \text{ when } t = t_p$$

it can be shown that $t_p = (n-1)K_s$ hence,

$$Q_s(t) = V_s(n_s-1) \frac{n_s}{t_p \Gamma n_s} \left[\frac{t}{t_p} e^{\left(-\frac{t}{t_p}\right)}\right]^{n_s-1} \tag{3.12}$$

where t_p = time to peak of sediment graph (h)

(b) Derivation of the IUSG using the time area histogram routed through a single reservoir concept

The time area diagram of mobilised sediment was determined as described below.

For 10 mobilised sediment events, the time of concentration t_c was determined by a graphical method. The mobilised sediment histogram and the resulting sediment graph were plotted on a common time axis. The value of t_c for each event was taken as the time between the end of the mobilised sediment histogram and the point of inflection of the recession phase of the resultant sediment graph. The average time of concentration t_c was determined as 6.35 h. This was subdivided into six equal parts of 1.06 h (approximately 1 h) each. A profile of the Mathare river which is the longest channel of the catchment was drawn from a topographic map and the subdivided values of t_c located along the profile **(Fig. 3.5)**. These were transferred to the topographic map and extended approximately along the contour as a means of locating the isochrones on the catchment **(Fig. 3.6)**. The areas bounded by each set of isochrones were measured using a dot matrix grid and are presented below.

Table 3.3 Inter isochrone area for the Mathare catchment

No	Area km^2
1	0.50
2	1.75
3	3.25
4	7.25
5	9.25
6	4.50

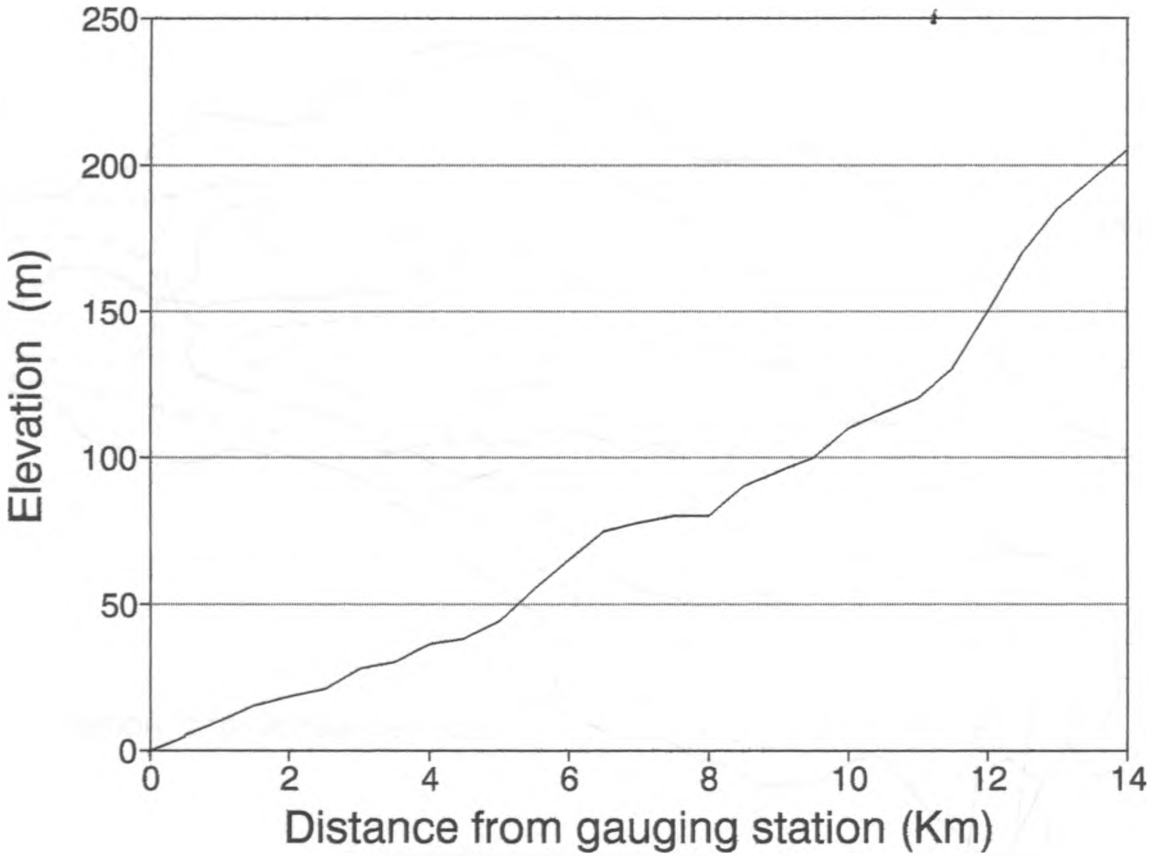


Fig 3.5 Crossection of the Mathare river

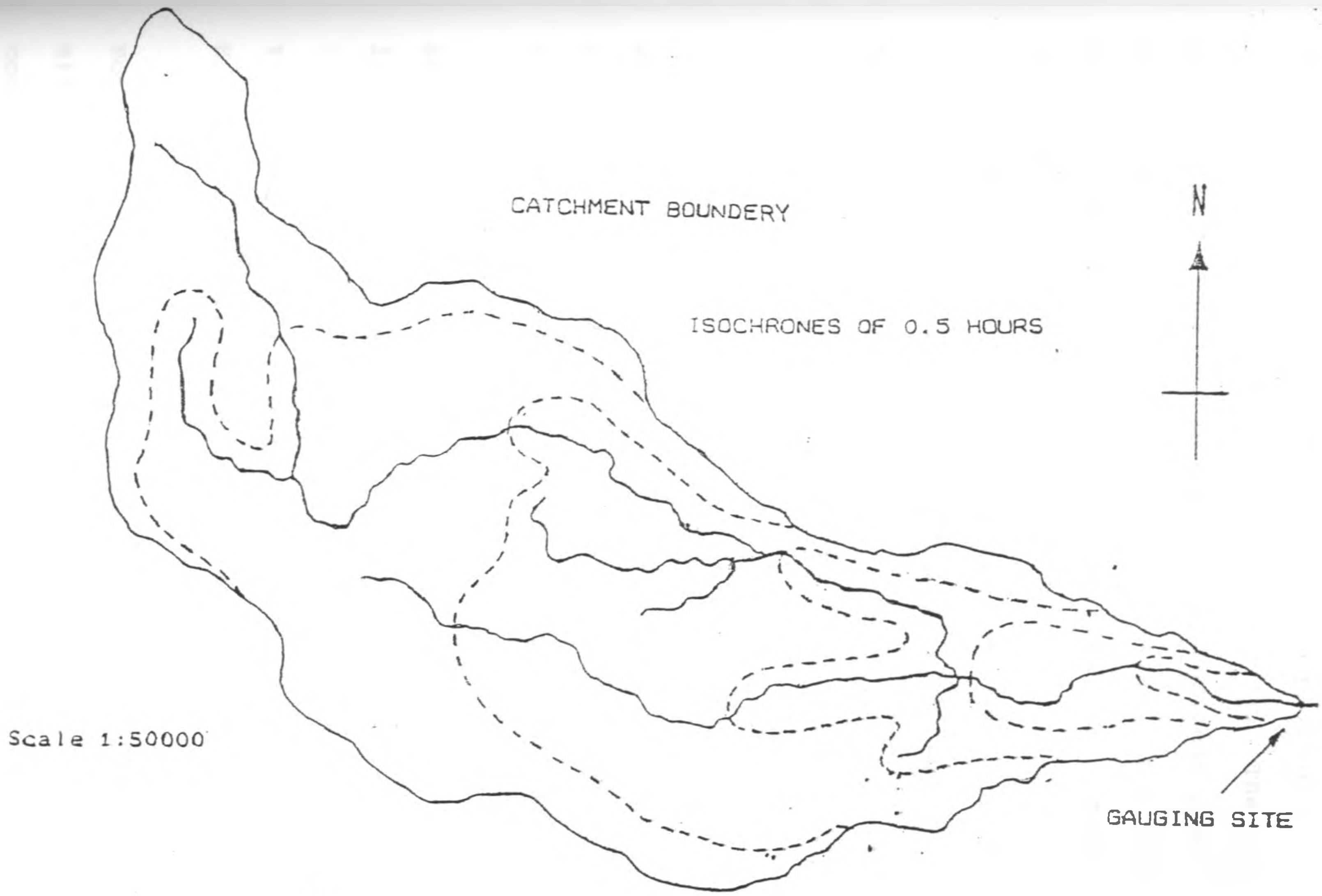


Fig 3.6 Map of Mathare catchment showing location of isochrones

The time area diagram was obtained as a plot of these areas against time of concentration **(Fig. 3.7).** The time area diagram can be regarded as translation sediment graph. With an assumed sediment mobilized of 1 t/km^2, the time area diagram represented sediments mobilized in tonnes with sequence of translation.

Routing was carried out through the single linear reservoir **(Equation 3.12)** together with the continuity **(Equation 3.13)**

$$S = K_s Y \qquad (3.13)$$

$$\bar{I} - \bar{Y} = \frac{\Delta S}{\Delta t} \qquad (3.14)$$

where,

S = sediment storage (t)

Y = outflow rate of sediment (t/h), equivalent to Q_s in the preceding analysis.

Δt= routing period (h)

ΔS= change in storage (t)

I = average inflow rate of sediment (t/h)

Y = average outflow rate of sediment (t/h)

K_s = catchment sediment storage constant (h^{-1})

Note, K_s here has different value than that in **Equation 3.11** although conceptually they represent the same storage constant. Furthermore, it might be noted that the term Y is being used in place of Q_s for simplicity while writing the mathematical expressions.

Using i as a subscript for the routing time, the continuity

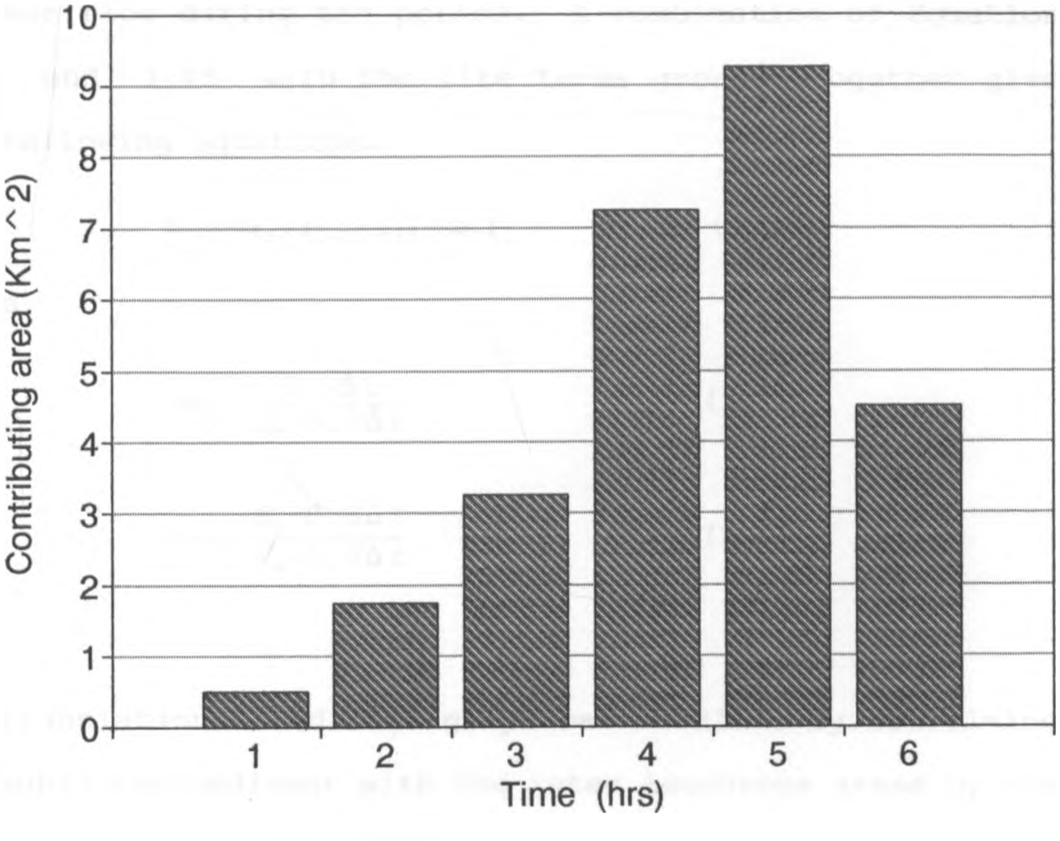


Fig. 3.7 Time area diagram of sediment flow

equation can be expressed as,

$$\frac{I_i+I_{i+1}}{2}\Delta t-\frac{Y_i+Y_{i+1}}{2}\Delta t=S_{i+1}-S_i \qquad (3.15)$$

based on the assumption that the average flows at the beginning and end of a short routing period Δt equals the average flow during the period. A combination of **Equation 3.13 and 3.15** with the like terms grouped together give the following equations.

$$Y_{i+1}=\omega_0(I_{i+1}+I_i)+\omega_1 Y_i \qquad (3.16)$$

where,

$$\omega_0=\frac{0.5\Delta t}{K_s+0.5\Delta t} \qquad (3.17)$$

$$\omega_1=\frac{K_s-0.5\Delta t}{K_s+0.5\Delta t} \qquad (3.18)$$

The translational sediment graph was obtained by convolving the mobilised sediment with the inter isochrone areas by use of the equation shown below.

$$I_j=\sum_{i=1}^{j} a_i X_{j-i} \qquad (3.19)$$

where,

a= inter isochrone area (km^2)

X= mobilised sediment ($t/km^2.h$)

I= ordinate of the translation sediment graph (t/h)

j= number of incremental areas between successive isochrones

i= a counter.

In discrete form, the convolution is presented as shown below,

$$I_1 = X_1a_1$$

$$I_2 = X_2a_1 + X_1a_2$$

$$I_3 = X_3a_1 + X_2a_2 + X_1a_3$$

$$I_4 = X_4a_1 + X_3a_2 + X_2a_3 + X_1a_4$$

$$I_5 = X_5a_1 + X_4a_2 + X_3a_3 + X_2a_4 + X_1a_5$$

$$I_6 = X_6a_1 + X_5a_2 + X_4a_3 + X_3a_4 + X_2a_5 + X_1a_6$$

$$I_7 = X_7a_1 + X_6a_2 + X_5a_3 + X_4a_4 + X_3a_5 + X_2a_6\ X_1a_7$$

.

.

.

$$I_j = X_ja_1 + X_{j-1}a_2 + X_{j-2}a_3 \ldots$$

The values of I obtained above were the ones used in **Equation (3.16)** in order to obtain the outflow sediment graph i.e., values of Y_1. A program was developed for the generation of the IUSG ordinates based on the above equations **(Appendix VII)**. In the program, the time area diagram and the mobilised sediment were expressed at time intervals equal to the routing period. This time interval was fixed at 1 hour (60 minutes) in the current analysis. The optimal value of the catchment sediment storage constant K_s was estimated from the data on the recession limb of the sediment graphs. At the point of inflection, the inflow to the channel has ceased and beyond this point, the flow is entirely due to withdrawal from the channel storage. Values of K_s for individual mobilised sediment events were obtained by involving the slopes of the recession limb of the sediment graphs at the point of inflection, which were located graphically and computed using the following equation.

$$K_s = -\left(\frac{Q_{si}}{\frac{dQ_{si}}{dt}}\right) \qquad (3.20)$$

where,

Q_{si} = Sediment discharge at point of inflection (t/h)

dQ_{si}/dt = slope of sediment graph at point of inflection.

Generation of sediment graphs from the IUSG model was carried out using the normal convolution procedure with the mobilised sediments for 10 observed mobilised sediment events. Other 4 mobilised sediment events were used for testing the applicability of the model in predicting suspended sediment discharge.

3.4.4 Temporal concentration graph method

The seasonal sediment yield was determined by use of the temporal concentration graph method. Sediment concentrations measured gravimetrically by the grab sampling procedure were plotted against time to yield a concentration time graph. The daily mean sediment concentration was worked out for all days from above graph. This involved calculating the mean of the time weighted sediment concentration for every day from the concentrations measured by the grab method.

The daily mean sediment discharge was then computed by use of these daily mean values of water discharge and sediment concentration by use of **Equation (2.1)**.

Since at least daily records of water discharge and concentration for the grab sampling method existed, the need of predicting missing values was not realised. The summation of these daily discharges over a specified period was used to derive the total suspended sediment discharge over the period.

3.5.5 Flow duration curve analysis

The sediment rating equation developed for the catchment was used in conjunction with the water discharge flow duration curve. This was developed as follows;

(a) Based on the upper and lower limits of the observed mean daily discharges, suitable ranges of discharge class were selected for frequency analysis.

(b) The available stage graphs were converted to daily mean discharges by use of the developed rating equation.

(c) The frequency of occurrence of the discharges for each class was established.

(d) The percent time that the lower discharge in each class equalled or exceeded was calculated.

(e) A plot of the mid ordinate of each discharge class against the percent above on a semi-logarithmic paper gave the flow duration curve.

This flow duration curve was used to determine the sediment yield over the season of flow record in conjunction with the sediment rating equation as described below.

(a) According to the variation of the flow duration curve, ranges of frequency (the abscissa in the curve) were selected in such a manner that the covered ranges of discharge were moderately uniform.

(b) The discharge corresponding to the mid ordinate of the above ranges was read off from the curve.

(c) From the sediment rating curve, the sediment concentration corresponding to the obtained water discharge was calculated and the sediment discharge calculated according to **Equation (2.1).** The uncorrected and corrected versions of sediment rating equation (viz. **Equations 2.3** and **2.4**) were used.

(d) The sediment yield corresponding to each abscissa range was calculated as the product of the sediment discharge above, the frequency difference for each range and the number of days for the flow record analyzed.

4 RESULTS AND DISCUSSION

4.1 Comparison Between Sediment Concentration in EDI, ETR and grab Samples

The data for concentration of the samples obtained simultaneously by the three sampling techniques ETR, EDI and grab are given in **Appendix VIII, (Table a)**, and the graphical comparison presented in **Fig. 4.1.** This data was analyzed for statistical differences by use of the paired t-test carried out at 89 degrees of freedom for the 1% and 5% levels of significance. The results are shown in **Table 4.1.**

Table 4.1 **Results for paired t-test comparison between sediment samples based on different sampling methods**

METHODS COMPARED	CALCULATED t-STATISTIC	LEVEL	REMARK
GRAB/EDI	- 0.151	5%	No significant difference
		1%	No significant difference
GRAB/ETR	- 0.440	5%	No significant difference
		1%	No significant difference
EDI/ETR	- 0.302	5%	No significant difference
		1%	No significant difference

($t_{0.05}$,89 = ± 1.990)
($t_{0.01}$,89 = ± 2.639)

It can be inferred from the above results that the three sampling methods do not give different results for the Mathare river and therefore any one of them is equally reliable. A selection of any of them for use in a sampling programme should be based on factors such as equipment availability, ease of execution, ease of data handling,

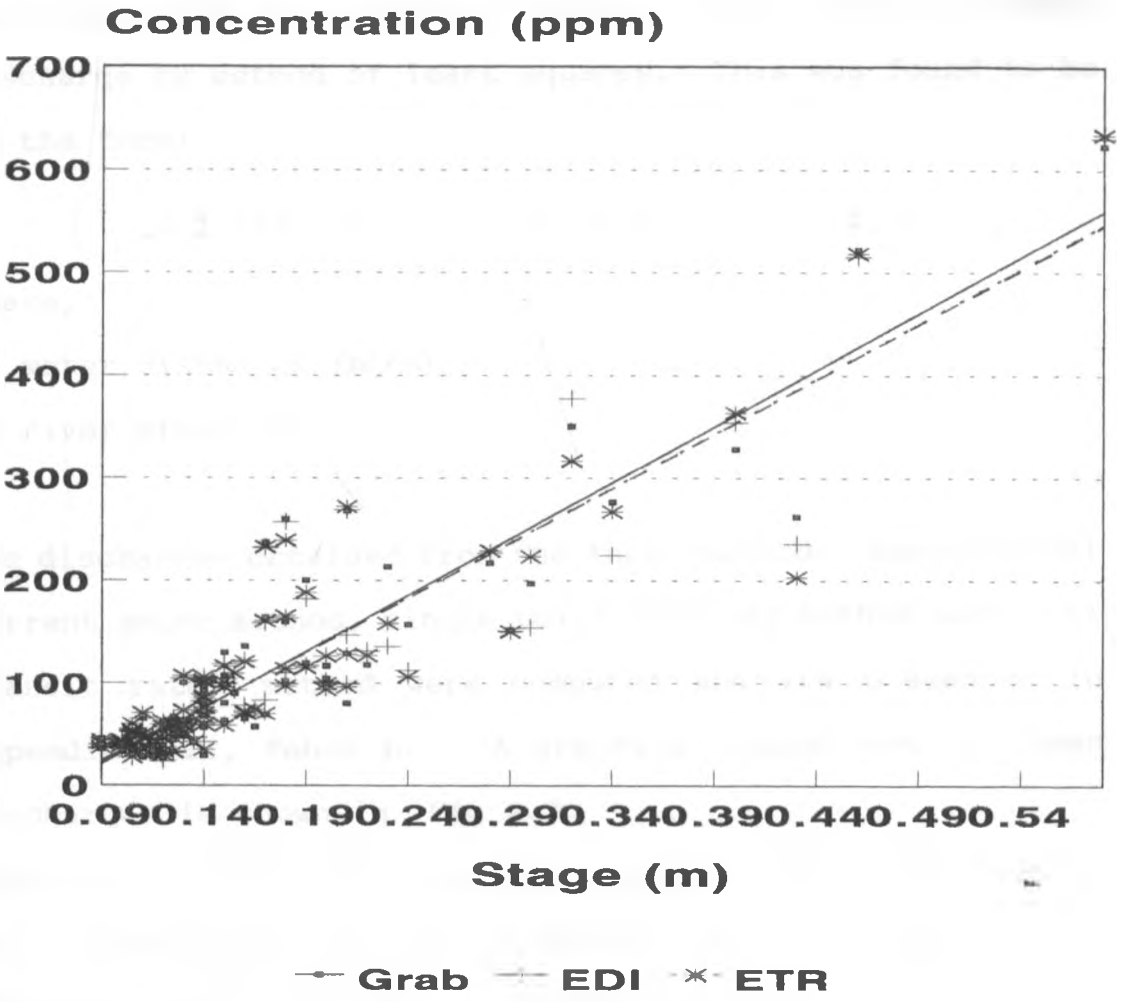


Fig. 4.1 Concentration comparison between sampling methods

costs, etc. The findings also suggest that there is low spatial variation in sediment concentration along a vertical.

4.2 Discharge Rating Equations

A two parameter discharge rating equation was developed from the collected data of river stage and water discharge by method of least squares. This was found to be of the form;

$$Q= 2.983h^{1.95} \qquad R^2= 0.96 \qquad (4.1)$$

where,

Q= water discharge (m^3/s)

h= river stage (m)

The discharges obtained from the three methods, conventional current meter method, single point velocity method and equal transit rate method were computed and are presented in **Appendix VIII, Table b.** A graphical comparison of these discharges is shown in **Fig 4.2.**

These were compared by use of the paired t-test at 98 degrees of freedom and at both the 1% and 5% levels of significance and the results are shown in **Table 4.2.**

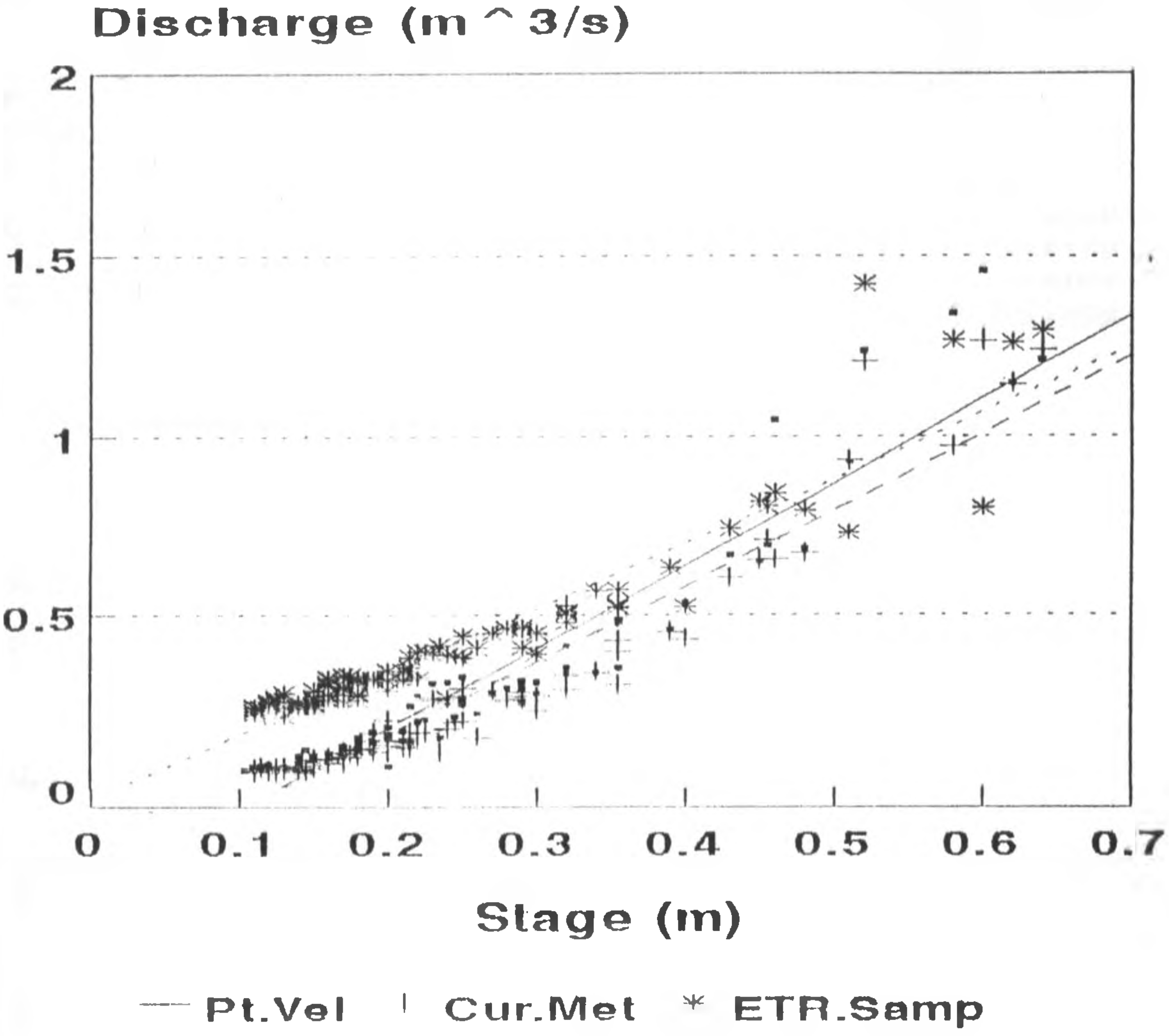


Fig. 4.2 Discharge comparison

Table 4.2 **Results of paired t-test comparison between discharges obtained by different methods**

METHODS COMPARED	CALCULATED t-STATISTIC	LEVEL	REMARK
Q Vs Q_{pv}	- 4.364	5%	Significant differece
		1%	Significant difference
Q Vs Q_{ETR}	-18.723	5%	High significant difference
		1%	High significant difference
Q_{pv} Vs Q_{ETR}	-12.858	5%	High significant difference
		1%	High significant difference

$(t_{0.05}, 92 = \pm 1.987)$
$(t_{0.01}, 92 = \pm 2.633)$

where,

Q = Discharge evaluated from the conventional multiple vertical current meter method (m^3/s)

Q_{pv} = Discharge computed from single point velocity measurements (m^3/s)

Q_{ETR} = Discharge derived from data on ETR sampling (m^3/s).

The values of the test statistic in **Table 4.2** therefore indicate that discharges measured by all the above methods are significantly different from each other. However, based on the above table and graphical comparison **(Fig. 4.2)**, it can be seen that the ETR discharge estimation deviates more from the other two. The trend indicates that the stream would be yielding a discharge of approximately 0.1 m^3/s when the river stage is zero which is not true. This implies that the assumption of nozzle water inlet velocity being equal to the stream velocity at point of intake is not strictly valid.

Since the method overestimates discharge, it can be inferred that the nozzle inlet velocity is greater than the streamflow velocity.

To facilitate the use of both the single point velocity and ETR discharge estimates, they have been calibrated against the conventional current meter discharge method by curve fitting techniques using linear, exponential and power relationships. Their modified forms are shown below.

$$Q= Q_{pv} - e^{9.59h} \qquad R^2=0.94 \qquad (4.2)$$

$$Q= Q_{pv} - 0.745\,h^{2.645} \qquad R^2=0.91 \qquad (4.3)$$

$$Q= Q_{ETR} - 0.172 \qquad R^2=0.92 \qquad (4.4)$$

The discharge obtained from ETR procedure and that obtained from the single point velocity measurement can be expressed as follows.

$$Q_{ETR}= 1.234\,h^{0.796} \qquad R^2= 0.86 \qquad (4.5)$$

$$Q_{pv}= 2.046\,V \qquad R^2= 0.91 \qquad (4.6)$$

where,

V = Single point velocity (m/s)

h = gauge height reading (m)

The above study suggests that single point velocity and ETR methods of discharge measurements should be discouraged and the conventional multi-vertical current meter method pursued in view of its familiarity with hydrologic practice and wide documentation.

4.3 Particle Size Distribution

The particle size distribution of the sampled sediments based on the sieve pipette method is shown in **Table 4.3**. It can be seen from these results that the sampled sediments fall predominantly in the range of 0.125 - 0.002 mm. Lack of sizable amounts of sand indicates that the sediment transport of this river constitutes largely of suspended sediments. It is therefore valid to describe the sediment mobility in the river by a consideration of the suspended sediments alone. The underlying assumption of the negligible bed load component is reinforced by the above results of the particle size analysis.

Table 4.3 Sample particle size distribution.

	Percent Finer Than				
Sieve size	Sample A	Sample B	Sample C	Sample D	Mean
1.000	100.00	98.40	100.00	100.00	99.02
0.500	99.51	96.72	97.66	100.00	98.47
0.250	97.33	93.89	96.01	97.58	96.20
0.125	89.56	84.57	91.88	93.68	89.92
0.062	71.37	69.98	71.04	59.01	67.85
0.031	65.74	65.18	65.36	56.55	63.21
0.016	50.71	46.01	43.57	39.34	44.91
0.008	22.54	27.80	25.57	30.32	26.56
0.004	8.45	14.38	12.31	15.57	12.68
0.002	0.94	3.83	2.84	0.82	2.11

The mean gradation curve was plotted **(Figure 4.3)** and the following values correspond to characteristic grain diameters

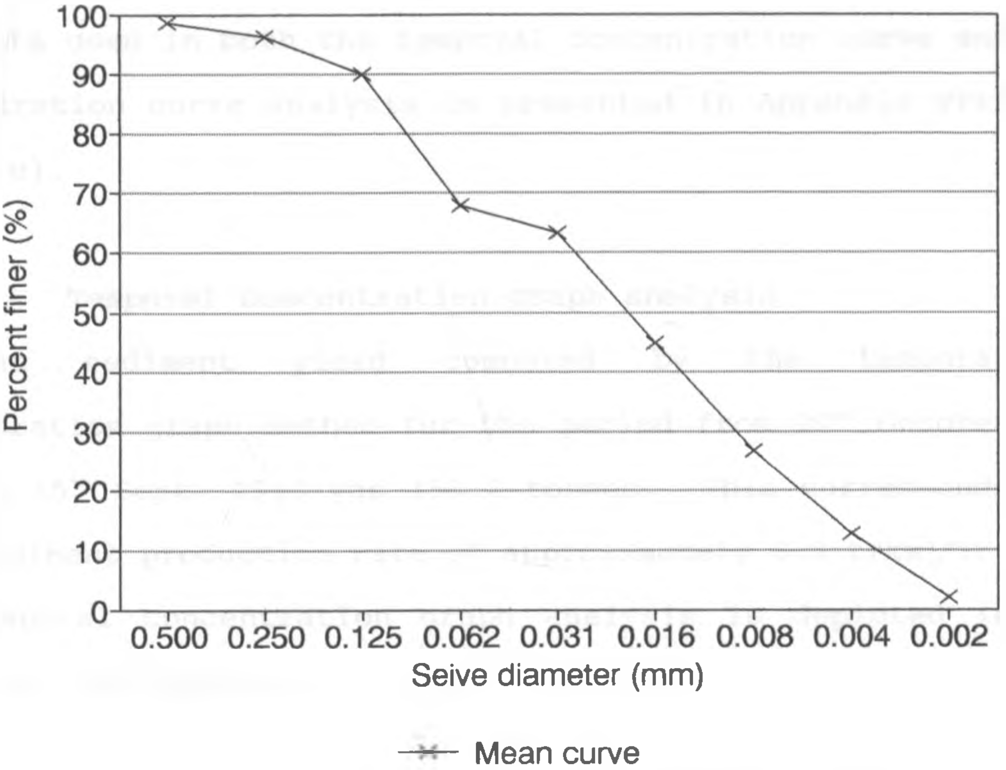


Fig. 4.3 Particle size distribution (seive pipette method)

d_{40} = 0.014 mm

d_{50} = 0.020 mm

d_{60} = 0.028 mm

d_{90} = 0.125 mm.

4.4 Sediment Yield Determination

Data used in both the temporal concentration curve and flow duration curve analysis is presented in **Appendix VIII (table c).**

4.4.1 Temporal concentration graph analysis

The sediment yield computed by the temporal concentration graph method for the period from 27th October 1992 to 15th Sept. 1993 was 150.2 tonnes. This corresponds to a sediment production rate of approximately 6.5 t/km²/Yr. The temporal concentration graph analysis is depicted in **Figs. 4.4 through 4.6.**

4.4.2 Flow duration curve analysis

A sediment rating curve and flow duration curve **(Fig. 4.7 and 4.8)** were established for the gauging site. The sediment rating curve was of the form;

$$C = 769.7\,Q^{0.928} \qquad (4.7,a)$$

or

$$\ln C = 6.646 + 0.928 \ln Q \qquad R^2 = 0.68 \qquad S_e = 0.401 \qquad (4.7,b)$$

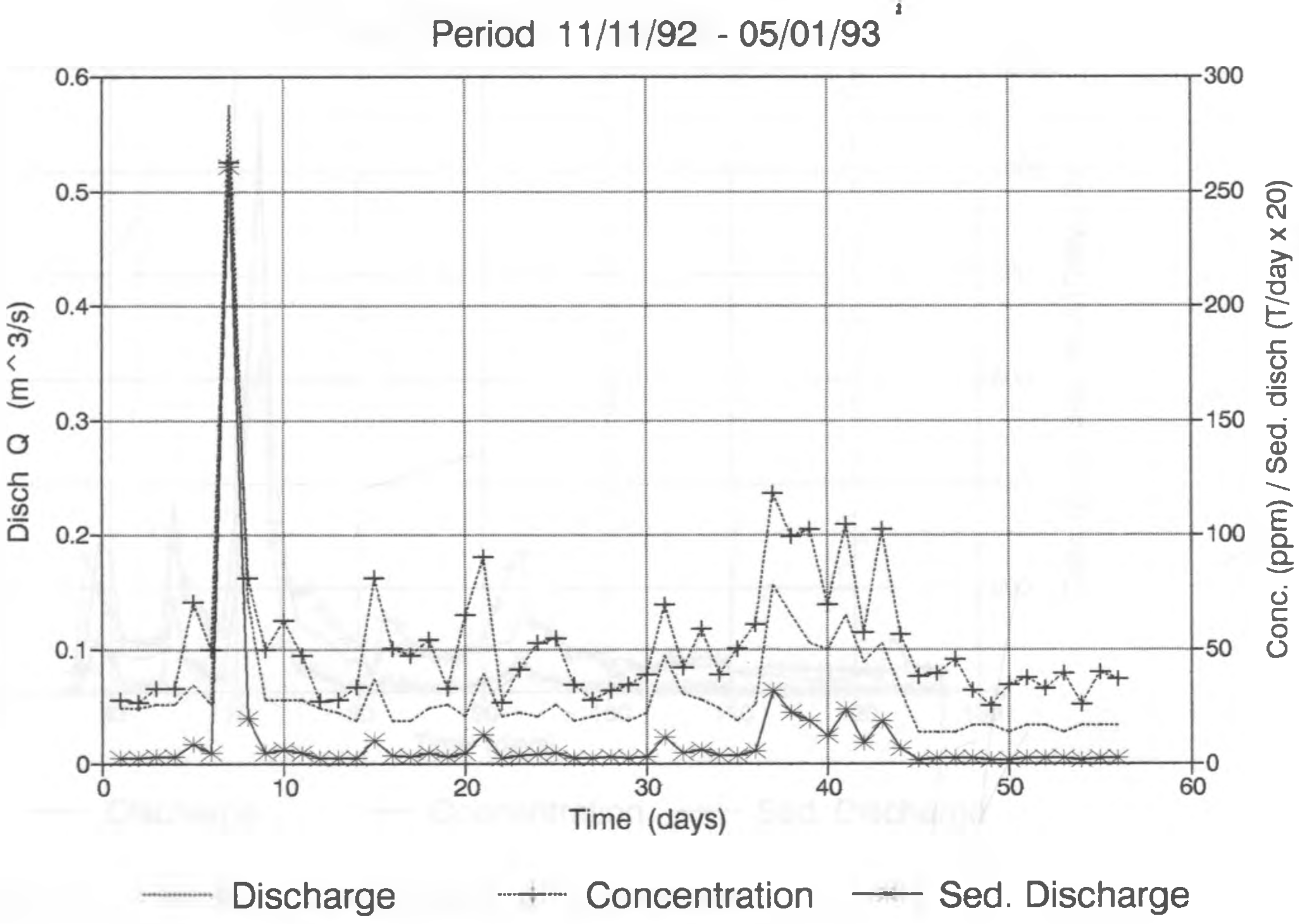


Fig. 4.4 Temporal concentration graph analysis.

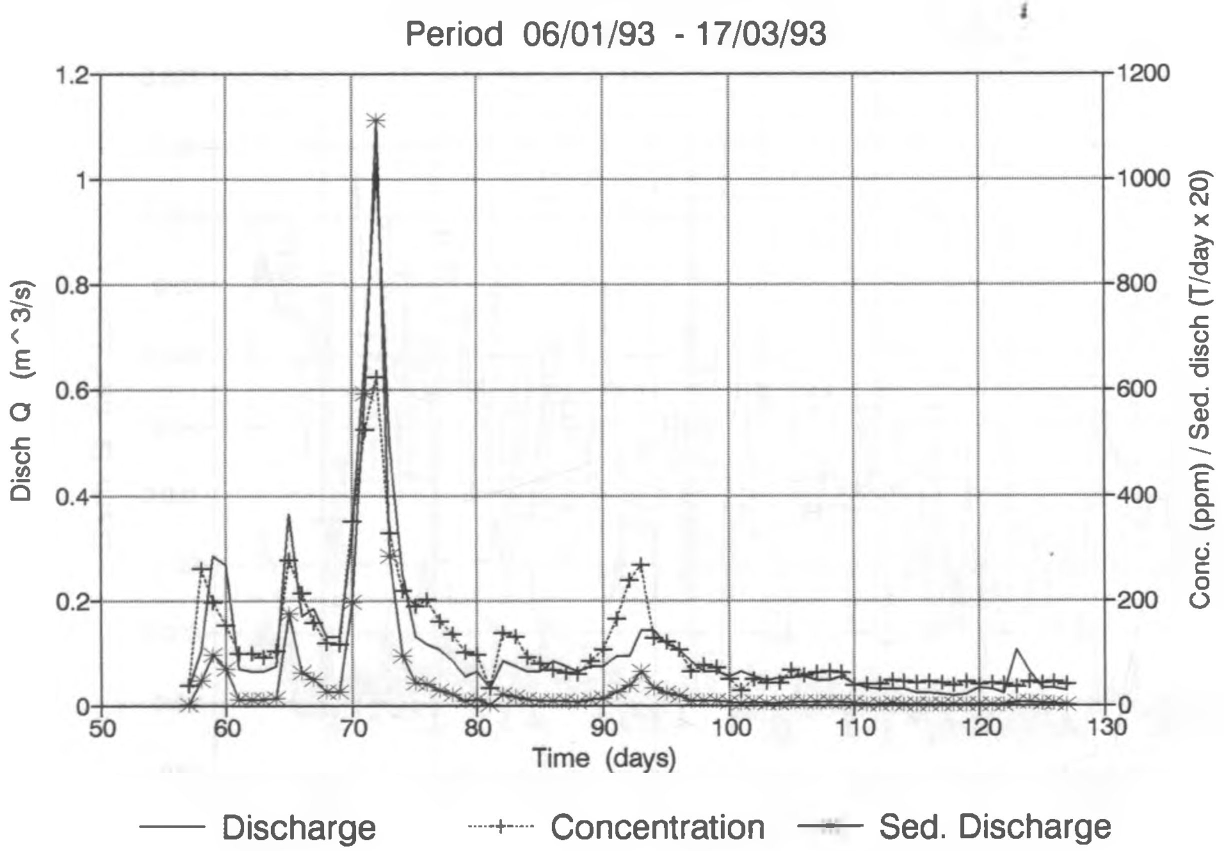


Fig. 4.5 Temporal concentration graph analysis.

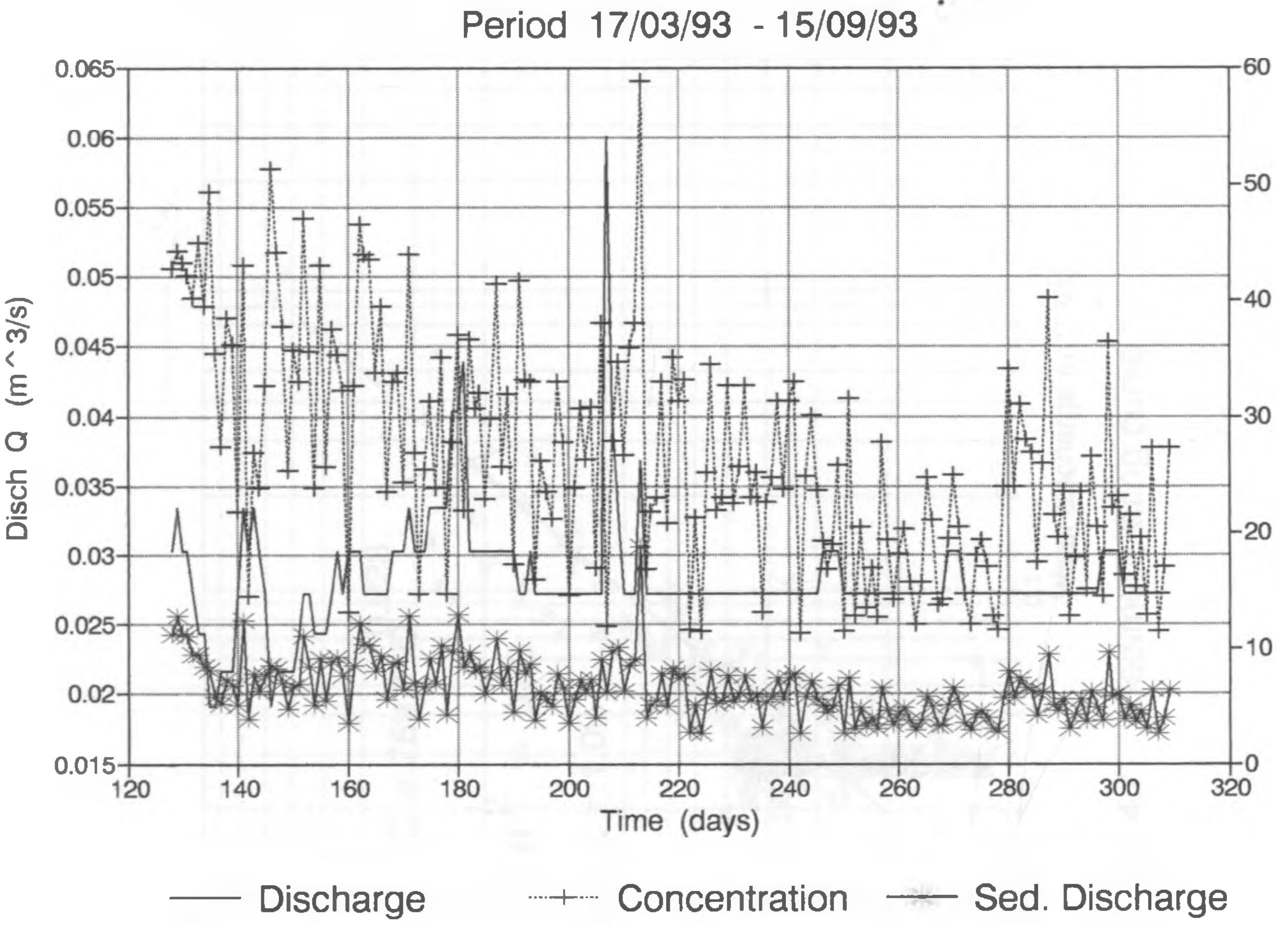


Fig. 4.6 Temporal concentration graph analysis.

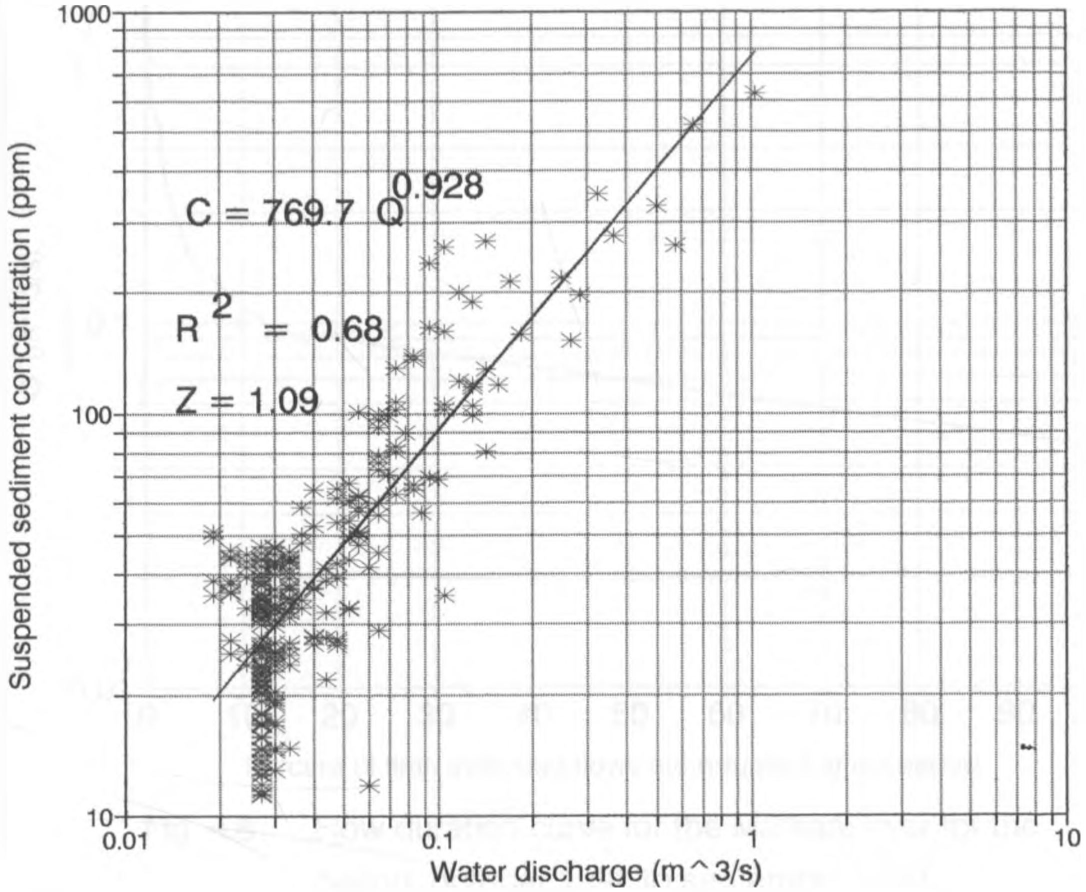


Fig. 4.7 Sediment rating curve

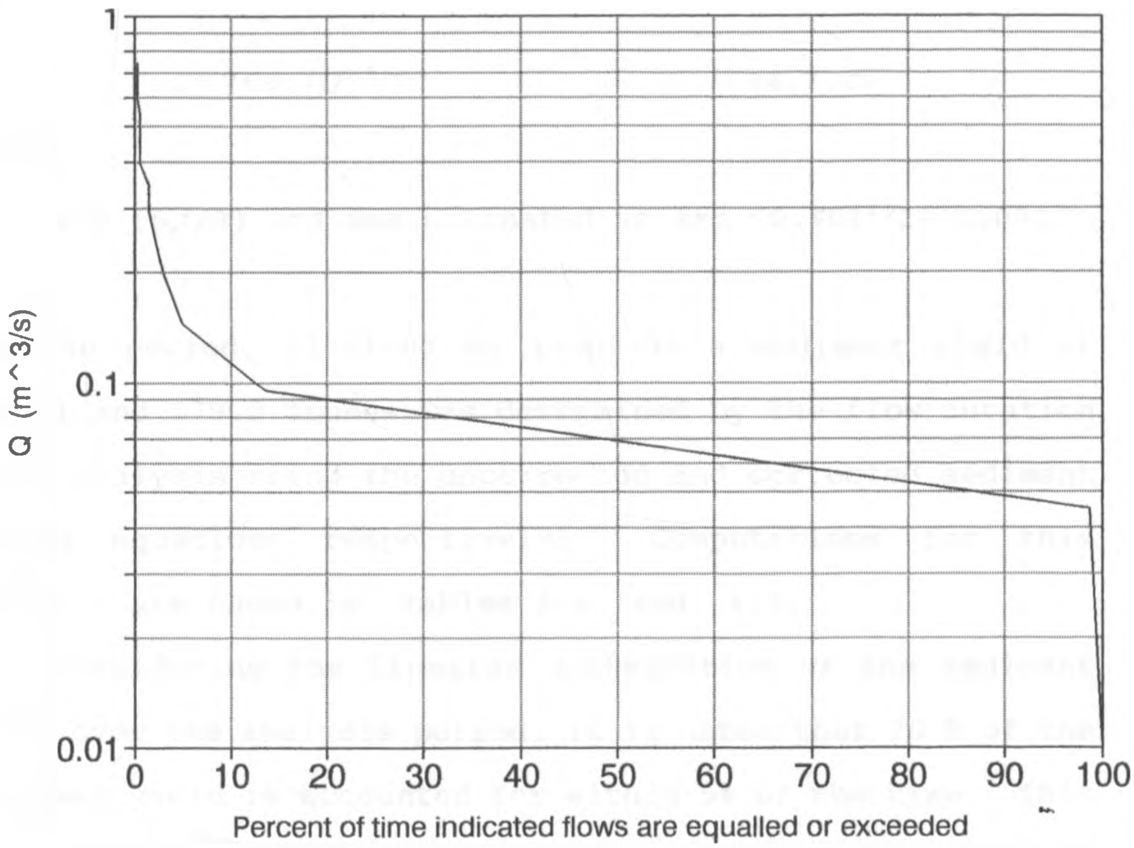


Fig. 4.8 Flow duration curve for the Mathare river for the period october 1992 to september 1993.

where ,

C= sediment concentration (mg/l)

Q= water discharge (m^3/s)

R^2= coefficient of determination and

S_e= standard error of estimate of the log-linear fit.

The corrected version of the **equation (4.7,a)** can be written as

$$C = 769.7 Q^{0.928} Z \qquad (4.7,c)$$

where,

Z= exp ($S_e^2/2$) and was estimated as exp ($0.401^2/2$)=1.09.

For the period, 11-11-92 to 15-09-93 a sediment yield of 164.71 and 179.2 tonnes was determined by the flow duration curve analysis using the uncorrected and corrected sediment rating equations respectively. Computations for this analysis are shown in **Tables 4.4 and 4.5.**

Considering the timewise distribution of the sediment yield over the analysis period, it is noted that 70 % of the sediment yield is accounted for within 5% of the time. This emphasises the significance of heavy rainfall intensities on the erosion and subsequent sediment delivery processes though occurring only over a very small fraction of time. Charania (1988) in his study in Tana catchment came with similar conclusions. It was found out that big reductions in sampling time could be achieved with only an introduction of small errors in estimated sediment discharges.

Table 4.4 **Frequency and discharge ranges for the flow duration curve analysis**

Discharge range m^3/s				
Lower Range	Higher Range	Frequency	percent time lower discharge was equalled exceeded	cumm. days
0.00	0.02	4	100.00	4
0.02	0.07	275	98.76	279
0.07	0.12	28	13.62	307
0.12	0.17	6	4.95	313
0.17	0.22	3	3.10	316
0.22	0.27	2	2.17	318
0.27	0.32	0	1.55	318
0.32	0.37	3	1.55	321
0.37	0.42	0	0.62	321
0.42	0.47	0	0.62	321
0.47	0.52	0	0.62	321
0.52	0.57	1	0.62	322
0.57	0.62	0	0.31	322
0.62	0.67	0	0.31	322
0.67	0.72	0	0.31	322
0.72	0.77	1	0.31	323
0.77	0.82	0	0.00	323
0.82	0.87	0	0.00	323
0.87	0.92	0	0.00	323
0.92	0.97	0	0.00	323
1.17	1.22	0	0.00	323
1.22	1.27	0	0.00	323

Table 4.5 Sediment load computation by the flow duration curve method

Limits %	Interval	Mid ordinates	Disch. m³/s	Conc. ppm	Sediment discharge t/day	Sediment yield tonnes
0 - 5	5	2.5	0.200	172.70	2.984	48.19
5 - 10	5	7.5	0.120	107.50	1.115	18.00
10 - 15	5	12.5	0.100	90.77	0.784	12.67
15 - 20	5	17.5	0.090	82.31	0.640	10.34
20 - 30	10	25.0	0.085	78.06	0.573	18.51
30 - 40	10	35.0	0.076	70.56	0.462	14.92
40 - 50	10	45.0	0.071	66.05	0.405	13.09
50 - 60	10	55.0	0.062	58.25	0.312	10.08
60 - 70	10	65.0	0.050	47.71	0.206	6.66
70 - 80	10	75.0	0.045	43.26	0.168	5.43
80 - 90	10	85.0	0.040	38.78	0.134	4.33
90 - 100	1	95.0	0.030	29.70	0.077	2.49
Total						164.71

4.4.3 Instantaneous unit sediment graph (IUSG) analysis

The mobilised sediment was found related to the excess rainfall through the following relationship

$$V_s = 4.47\ P_{net}^{1.953} \qquad R^2 = 0.93 \qquad (4.8)$$

Where;

V_s is total mobilised sediment in tonnes

P_{net} is total excess rainfall depth in mm.

The IUSG model parameters n_s and K_s (based on multireservoir cascading concept) were determined by method of moments from the measured sediment graphs and are presented in **Table 4.6.** The total storm sediment yield was estimated by convolving the 30 minute unit sediment graph (USG) obtained from the IUSG, with mobilised sediment. A graph of mobilised sediment versus excess rainfall based on the entire duration of each event is shown in **Fig. 4.9.**

Table 4.6 **Instantaneous unit sediment graph parameters for the Mathare catchment based on multireservoir cascading concept by the method of moments**

Rainfall event	n_s	K_s	P_{net} mm	V_s Tonnes
03/11/92	6.503	6.288	0.395	0.75
15/11/92	5.410	6.328	0.158	0.12
16/11/92	6.200	5.944	1.490	9.96
07/12/92	6.213	6.348	0.960	4.22
10/12/92	6.278	5.730	0.377	0.68
16/12/92	5.932	5.891	0.610	1.74
15/01/93	5.441	5.837	0.785	2.85
18/01/93	5.327	6.241	1.330	7.97
20/01/93	5.913	6.308	4.830	98.54
11/02/93	5.735	6.084	0.375	0.67
Average	5.895	6.100		

The parameter K_s for the IUSG based on the time area sediment histogram routed through a single linear reservoir concept was computed graphically using **Equation (3.19).** Values of K_s determined from the 10 calibration events are shown in **Table 4.7.**

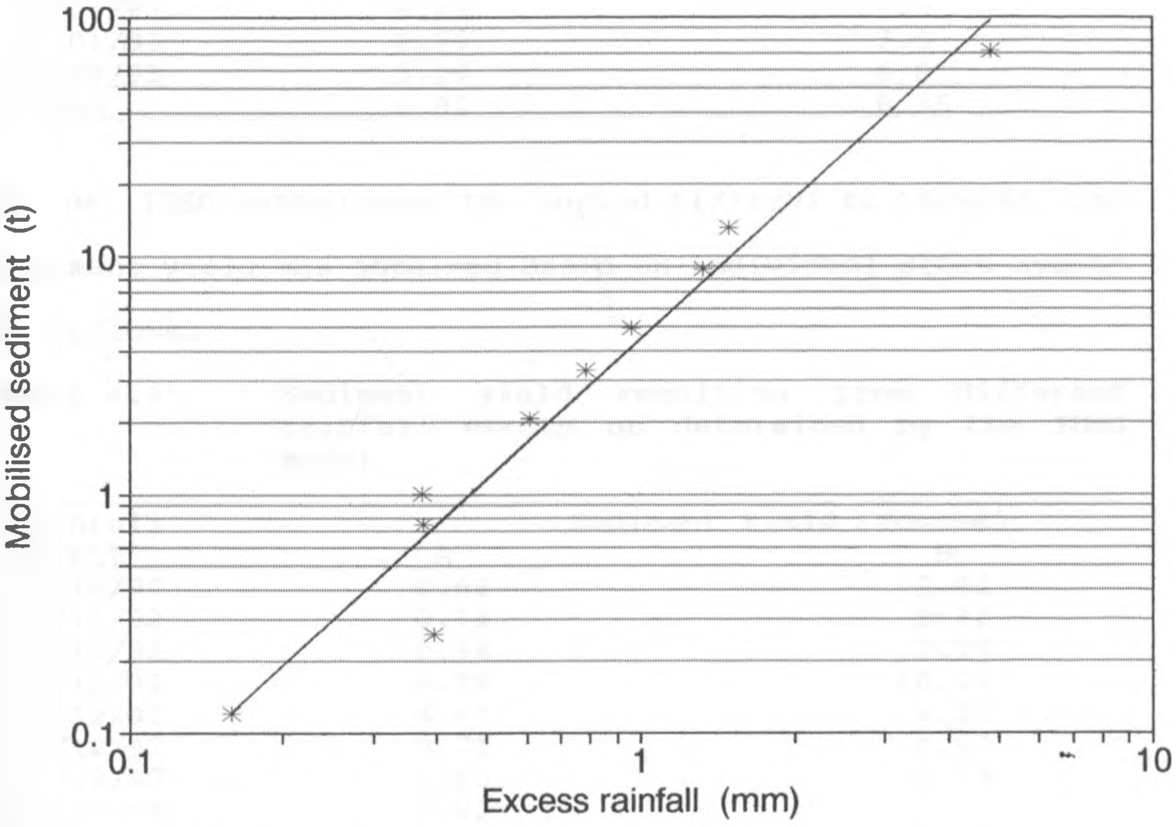


Fig. 4.9 Mobilised sediment versus excess rainfall.

Table 4.7 Instantaneous unit sediment graph parameter K_s for the Mathare catchment based on the time area concept by graphical method and values of time of concentration (t_c)

Rainfall event	K_s Hours	t_c Hours
03/11/92	3.81	6.0
15/11/92	6.20	4.0
16/11/92	6.31	7.5
07/12/92	7.29	7.0
10/12/92	10.54	6.0
16/12/92	9.00	7.5
15/01/93	10.50	4.5
18/01/93	6.49	7.5
20/01/93	2.79	7.5
11/02/93	5.29	6.0
mean	6.82	6.35

By the IUSG method over the period 11/11/92 to 15/9/93, the sediment yield was obtained based on individual storm events as follows;

Table 4.8 Sediment yield resulting from different rainfall events as determined by the IUSG model

Rainfall event	Sediment Yield (Tonnes) A	B
27/10/92	0.61	0.63
03/11/92	0.74	0.72
15/11/92	0.14	0.15
16/11/92	9.76	10.21
07/12/92	4.47	4.25
10/12/92	0.71	0.63
16/12/92	1.65	1.74
01/01/93	0.02	0.02
07/01/93	6.35	6.31
13/01/93	5.91	6.04
15/01/93	2.78	2.69
18/01/93	8.21	8.01
20/01/93	96.83	97.66
11/02/93	0.74	0.71
Total	138.92	139.77

where,

A: IUSG model based on multireservoir (6) cascading concept.

B: IUSG model based on time area histogram routed through a single linear reservoir concept.

For all mobilised sediment events, the sediment graphs were regenerated using the IUSG model described above. Predicted sediment yields by the IUSG model determined using concept A and that determined by concept B were 138.92 t and 139.77 t for the period 27-10-92 to 15-09-93 respectively. The regenerated sediment graphs for 4 mobilised sediment events are compared against measured in **Figs. 4.10 - 4.13** for the two IUSG models. It should be noted that the number of reservoirs in concept A were taken as 6 i.e. the rounded of value of $n_s = 5.895$. It can be seen that in both cases, the model based on concept A simulated the sediment graphs more accurately than that based on concept B. The results suggest that the Mathare reservoir is safe against siltation and would be expected to serve its purpose for the designed life unlike so many reservoirs elsewhere.

The above calculations give on average a total sediment yield of 139.35 t corresponding to a sediment production rate of 6.04 $t/km^2/yr$. In comparison, this yield is lower than that obtained by temporal concentration graph method. Based on the latter, the average sediment production rate of the catchment is 6.5 $t/km^2/yr$ which can be classified as low. This implies that the catchment is well conserved despite the high population pressure characterised by intensive farming and increased construction activities.

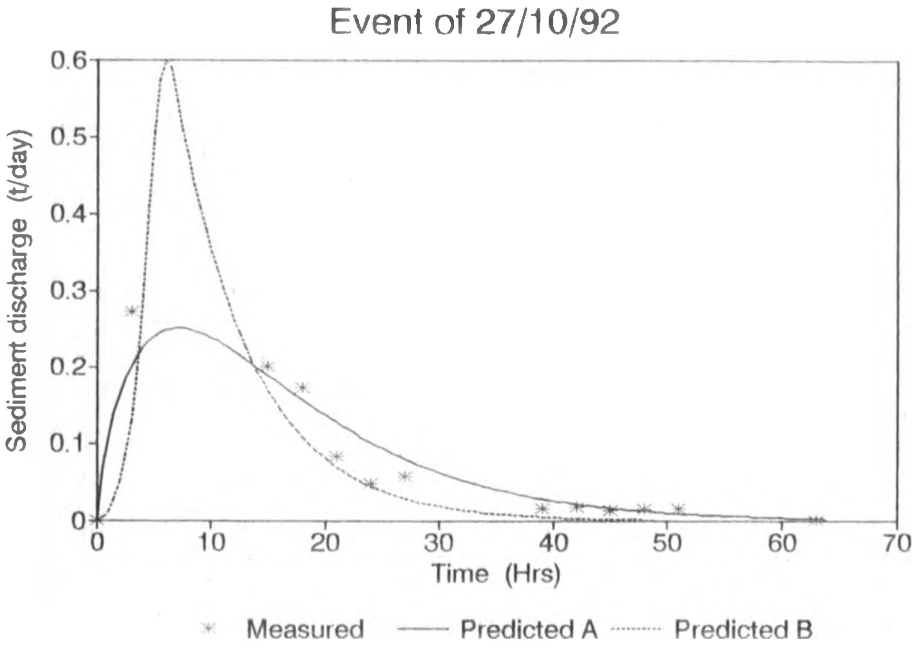


Fig. 4.10 Sediment graphs by IUSG concepts A and B

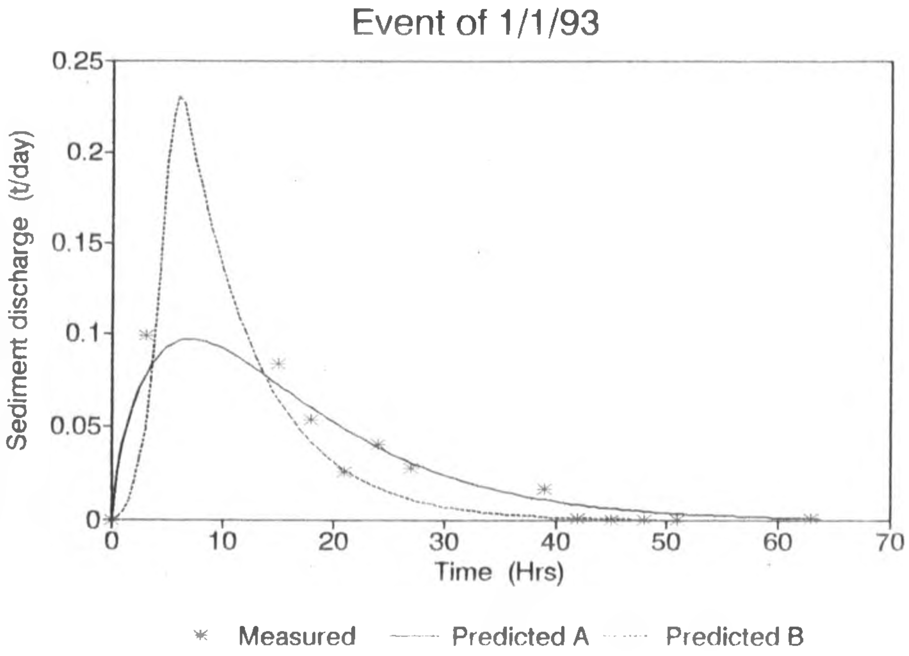


Fig 4 11 Sediment graphs by IUSG concepts A and B

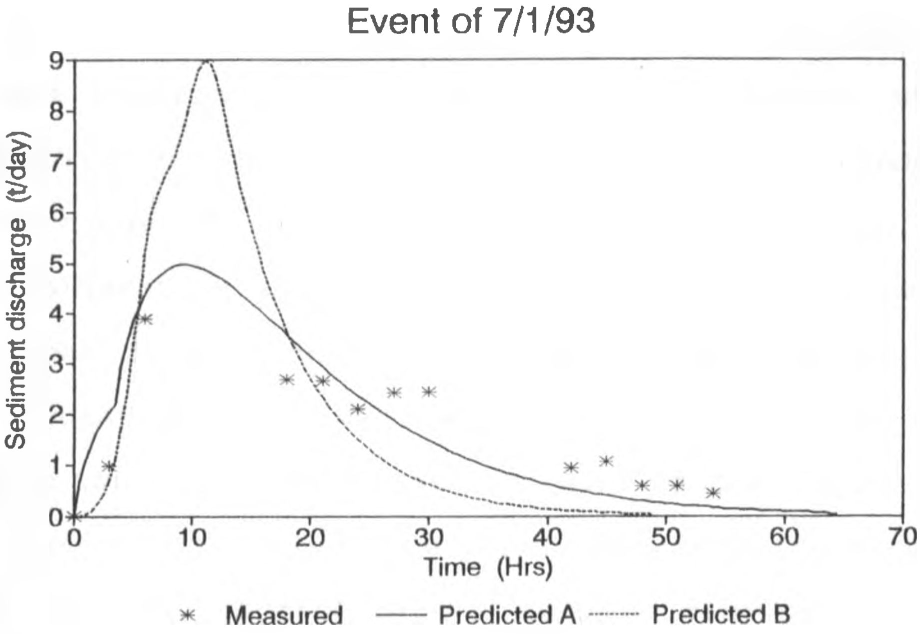


Fig. 4.12 Sediment graphs by IUSG concepts A and B

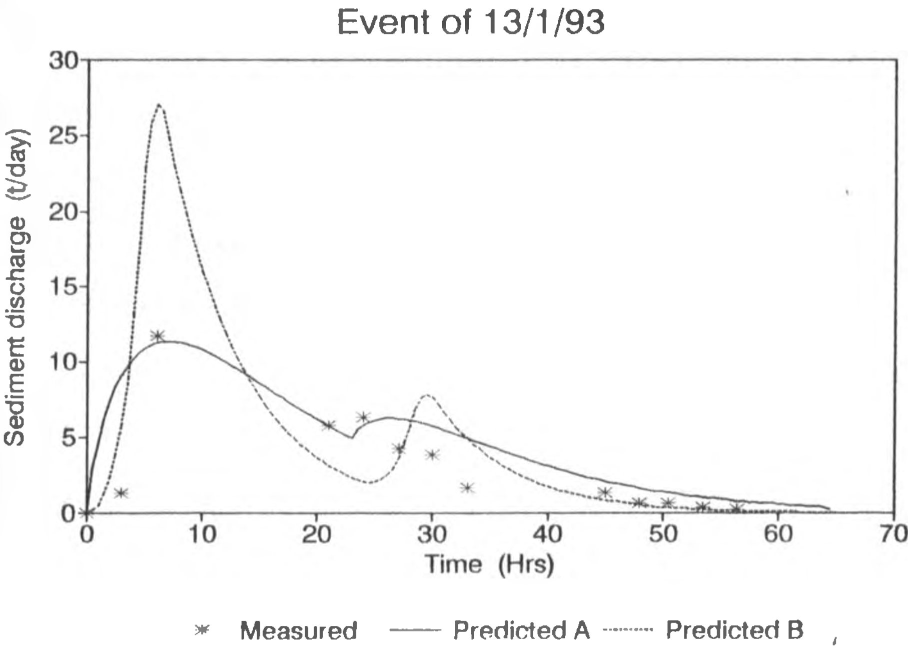


Fig. 4.13 Sediment graphs by IUSG concepts A and B

The IUSG model provides useful information on the time distribution of sediment discharge. A useful application of this information, is in the establishment of suitable sampling schedules when characterising the suspended sediment discharge of a river. One such procedure involves a consideration of the area under the regenerated sediment graphs from which the average sediment concentrations is calculated. The times when this concentration is realised on both the rising and recession phase of the sediment graph are located. This gives the times when sampling should be done to provide representative average sediment concentration values for the whole mobilised sediment event, and for the specified excess rainfall. Regenerated sediment graphs based on this model have an important application in the management and control of water use from rivers especially where pumping equipment is in use. Periods of critical sediment load conveyance are established, and equipment is protected from damage at such times.

4.5 Evaluation of Automatic Single Stage Bottle Sampling Equipment

The concentrations obtained by the automatic single stage bottle sampling equipment are shown alongside those derived from grab sampling in **Table 4.9.**

Table 4.9 **Single stage bottle sampling equipment concentrations**

Date	Stage (m)	I Conc. (mg/l)	II Conc. mg/l)
15/11/92	0.15	97.42	86.34
16/11/92	0.15	107.52	146.75
	0.25	187.86	121.23
	0.35	458.41	317.54
	0.45	486.89	571.47
07/12/92	0.15	102.73	162.86
	0.25	211.58	176.09
10/12/92	0.15	85.04	95.65
	0.25	141.60	148.87
16/12/92	0.15	73.52	104.62
	0.25	197.23	137.89
01//1/93	0.15	87.37	125.97
07/01/93	0.15	72.19	105.64
	0.25	218.26	274.48
	0.35	375.75	365.73
13/01/93	0.15	102.38	118.31
	0.25	174.03	168.54
	0.35	492.42	359.07
15/01/93	0.15	86.74	100.40
	0.25	163.92	169.52
18/01/93	0.15	79.61	127.58
	0.25	163.07	159.67
	0.35	362.33	398.59

I Measured or interpolated from grab sampling

II Measured by the single stage bottle sampler

A statistical comparison was done by use of the paired t-test and the results ($t_{calculated} = -5.724$ against $t_{0.05}$, 22 $= \pm 2.074$ and $t_{0.01}$, 22 $= \pm 2.819$) indicate that concentrations by these methods are significantly at variance from each other. Such indications prompt one to be cautious in improvising the automatic stage based bottle sampler for reliable estimation of the catchment sediment yield.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on findings reported in the foregoing chapters, the following conclusions are in order.

1. Of the four sampling methods investigated, grab, equal discharge increment , equal transit rate and single stage bottle sampling, the first three gave statistically similar results and hence for small rivers, any of the three can be used with comparable degrees of accuracy.

2. The simplified discharge measuring techniques i.e. discharge by single point velocity measurement and that estimated from ETR sampling procedure, did not provide good estimates and hence should not be used unless a calibration is first done against a multi-vertical current metering technique.

3. The IUSG model based on multireservoir cascading concept simulated the sediment graph more accurately than the one based on the time area sediment histogram routed through a single reservoir concept. The number of routing reservoirs was found equal to 6 and the value of storage parameter K_s was found to be 6.1 h. The value of storage parameter K_s in the time area concept based IUSG was found to be equal to 6.82 h.

4. For the study period (324 days), the sediment yield determined by the temporal concentration curve analysis was 150.2 tonnes. That obtained by the flow duration curve analysis method was 164.7 and 179.2 tonnes for the uncorrected and corrected sediment rating equations respectively. The yield determined from the IUSG model based on the multireservoir cascading concept was 138.9 tonnes while that based on the time area histogram routed through a single reservoir concept was 139.8 tonnes. The particle size distribution confirmed the hypothesis that the suspended sediment constitutes almost all of the sediment load with the bed load being negligible.

5.2 Recommendations

Based on the findings of the study, it is recommended that grab sampling should be used as it is cheap and compares favourably with the other more elaborate procedures. The automatic single stage bottle sampling equipment should be improved to be of meaningful use in gauging for sediment discharge. A stage controlled sampler that collects samples over both the rising and recession phase of the hydrograph, should be investigated as it would provide more meaningful information.

As a tool for the prediction of sediment yield as well as its timewise distribution, the IUSG model developed by method of moments based on the concept of multiple linear reservoir in cascade, is recommended. It should however be noted that over the study period, lower amount of rainfall was observed in comparison to the recorded average and it is further recommended that the IUSG model testing be extended to cover higher rainfall periods. The findings based on the IUSG should be used in deriving the timings and frequency of the sediment sampling.

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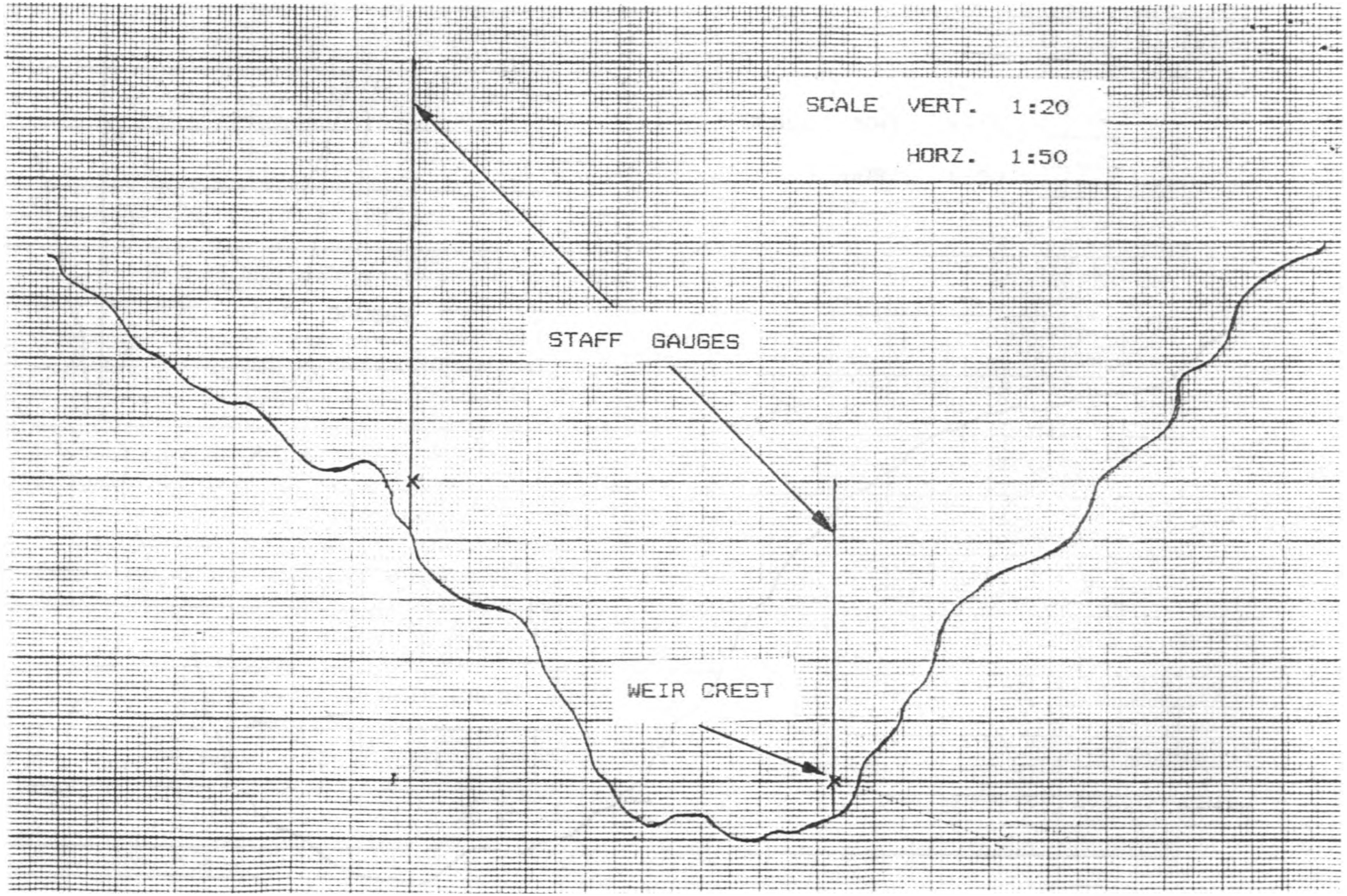
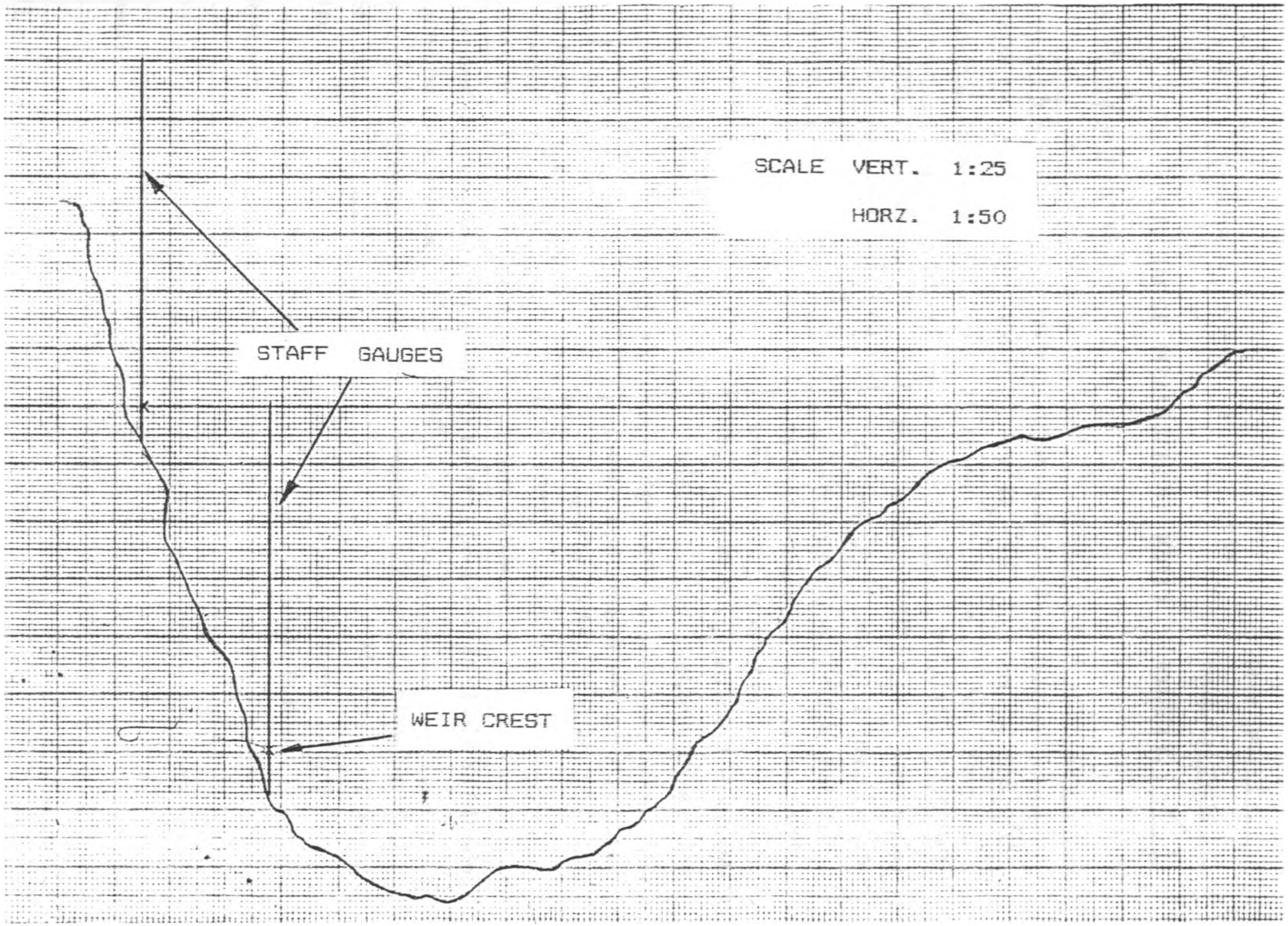
APPENDICES

Appendix I River crossection at upper bridge section.



Appendix II River crossection at lower bridge section.



Appendix III Discharge measurement sheets.

Form No. 6

Meas. No. 1

Comp. by JKG

Checked by ✓

Appendix III Discharge measurement sheets.

DISCHARGE MEASUREMENT NOTES

Sta. No. MATHARE (KABETE)

Date 14/1/93 Party GIKUHTO / NDURW

Width 308 cm Area 2.227 m² Vel. ____ G. H. 32.0 cm Disch. 0.328 m³/s

Method C.M. No. secs. 120 G. H. change 1 cm in ½ hrs. Susp. ____

Method coef. — Hor. angle coef. — Meter No. ____ Prop. No. 1-110049

GAUGE READINGS				
Time		Recorder	Inside	Outside
Weighted M.G.H.				
G.H. correction				
Correct M.G.H.				

Date rated 14/1/93 Used rating for rod ✓ susp. Meter 1 ft. above bottom of wt. Tags checked YES

Spin before meas. GOOD after GOOD

Meas. plots ____ % diff. from ____ rating

Wading, cable, boat, upstream, downstr., side bridge ✓ ____ feet, mile, above, below gauge and ____

Outside staff gauge found 32.0 changed to 33.0 at ____

Correct ____

Levels obtained ____

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%), based on following conditions: Cross section NO DEBRIS

Flow Moderate Weather CHILLY, NO RAIN

Other ____ Air 17.5 °~~F~~C

Gauge ____ Water 17.0 °~~F~~C

____ Record removed ____ Intake flushed ____

Observer ____

Control ____

Remarks ____

GOOD MEASUREMENT

G. H. of zero flow 0 ft.

UPL

Appendix III continued

.0 .10 .20 .30 .40 .50 .60 .70 .75

River at —

Angle coef.	Dist. from initial point	Width	Depth	Observation depth	Rev-olu-tions	Time in sec-onds	VELOCITY At point	VELOCITY Mean in ver-tical	Adjusted for hor. angle or	Area	Discharge
	25	25	31	0.2	18	120		0.051		0.039	0.002
				0.8	11	120					
	50	25	65	0.2	56	120		0.117		0.120	0.014
				0.8	43	120					
	75	25	78	0.2	97	120		0.177		0.179	0.032
				0.8	65	120					
	100	25	88	0.2	118	120		0.240		0.208	0.050
				0.8	105	120					
	125	25	97	0.2	109	120		0.209		0.231	0.048
				0.8	84	120					
	150	25	111	0.2	91	120		0.184		0.260	0.048
				0.8	78	120					
	175	25	104	0.2	87	120		0.166		0.269	0.044
				0.8	63	120					
⊙	200	25	96	0.2	82	120		0.158		0.250	0.039
				0.8	60	120					
	225	25	97	0.2	42	120		0.092		0.241	0.020
				0.8	31	120					
	250	25	89	0.2	29	120		0.070		0.233	0.016
				0.8	20	120					
	275	25	27	0.2	27	120		0.066		0.145	0.010
				0.8	18	120					
	300	25	15	0.2	14	120		0.043		0.053	0.002
					7	120					
										2·227	0·328

.80 .85 .90 .92 .94 .96 .97 .98 .99 1.00 .99 .98 .97 .96 .94 .92 .90 .85 .00

.0 .10 .20 .30 .40 .50 .60 .70 .75

APPENDIX IV Data for development of EDI verticals

	DISCHARGE (m^3/s)					
stage (m)	0.15	0.25	0.35	0.45	0.55	0.65
b (cm)						
25	0.004	0.004	0.003	0.009	0.011	0.009
50	0.006	0.013	0.019	0.037	0.057	0.045
75	0.007	0.024	0.035	0.065	0.107	0.122
100	0.009	0.038	0.061	0.083	0.136	0.137
125	0.011	0.038	0.047	0.089	0.138	0.149
150	0.011	0.035	0.043	0.082	0.104	0.191
175	0.009	0.029	0.040	0.074	0.102	0.154
200	0.008	0.028	0.033	0.065	0.099	0.138
225	0.006	0.020	0.022	0.044	0.088	0.114
250	0.004	0.017	0.020	0.030	0.056	0.103
275		0.009	0.009	0.016	0.029	0.071
300			0.003	0.009	0.013	0.057
325					0.006	0.021
350						0.013

b= Width from the right hand side bank (water level recorder side) of the stream

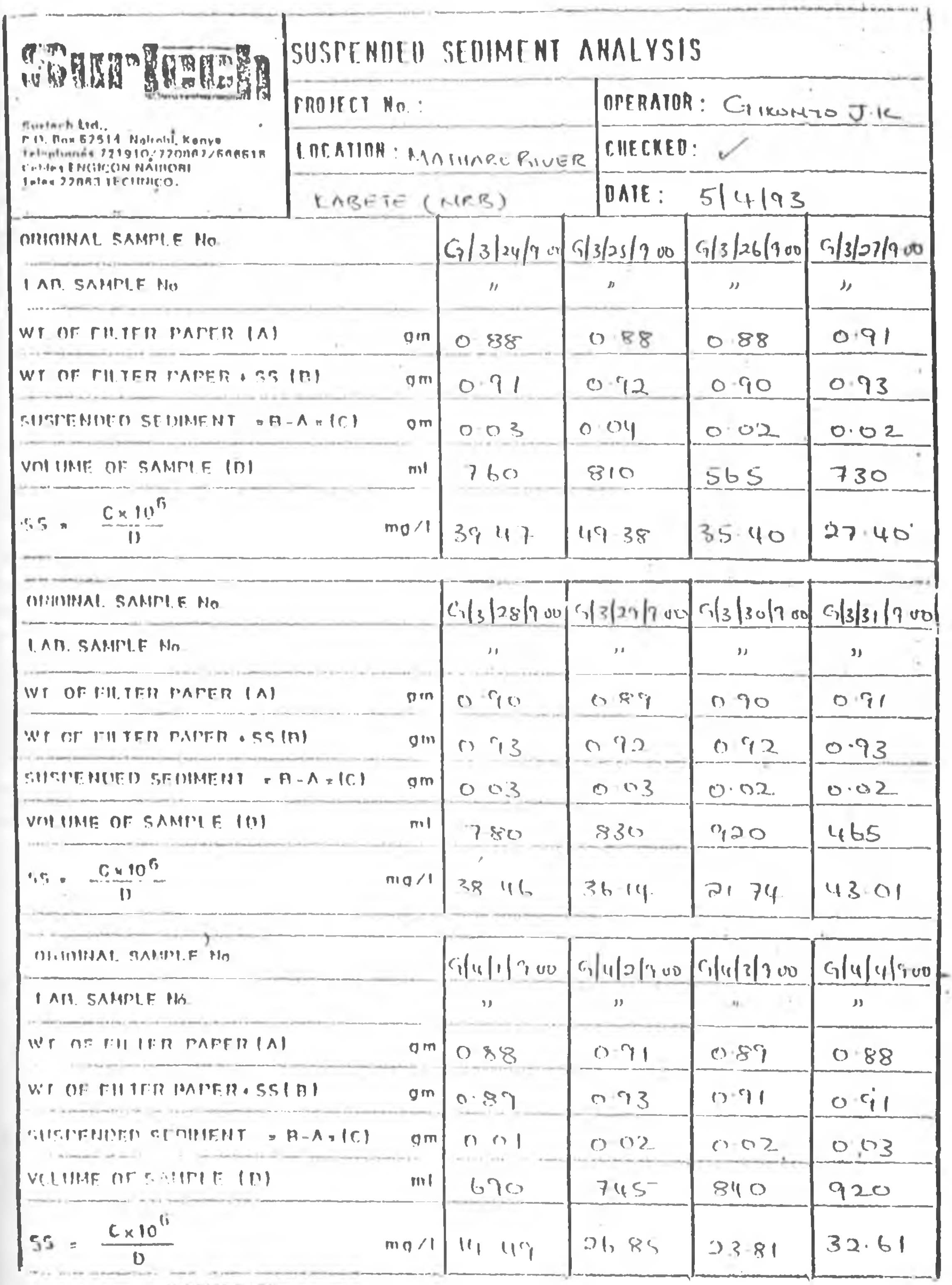
CUMMULATIVE DISCHARGE (m^3/s)					
0.15	0.25	0.35	0.45	0.55	0.65
0.004	0.004	0.003	0.009	0.011	0.009
0.010	0.017	0.022	0.046	0.068	0.054
0.017	0.041	0.057	0.111	0.175	0.176
0.026	0.079	0.118	0.194	0.311	0.313
0.037	0.117	0.165	0.283	0.449	0.462
0.048	0.152	0.208	0.365	0.553	0.653
0.057	0.181	0.248	0.439	0.655	0.807
0.065	0.209	0.281	0.504	0.754	0.945
0.071	0.229	0.303	0.548	0.842	1.059
0.075	0.246	0.323	0.578	0.898	1.162
0.075	0.255	0.332	0.594	0.927	1.233
0.075	0.255	0.335	0.603	0.940	1.290
0.075	0.255	0.335	0.603	0.946	1.311
0.075	0.255	0.335	0.603	0.946	1.324

APPENDIX IV **continued**

PERCENT CUMMULATIVE DISCHARGE

0.15	0.25	0.35	0.45	0.55	0.65
5.33	1.57	0.90	1.49	1.16	0.68
13.33	6.67	6.57	7.63	7.19	4.08
22.67	16.08	17.01	18.41	18.50	13.29
34.67	30.98	35.22	32.17	32.88	23.64
49.33	45.88	49.25	46.93	47.46	34.89
64.00	59.61	62.09	60.53	58.46	49.32
76.00	70.98	74.03	72.80	69.24	60.95
86.67	81.96	83.88	83.58	79.70	71.37
94.67	89.80	90.45	90.88	89.01	79.98
100.00	96.47	96.42	95.85	94.93	87.76
100.00	100.00	99.10	98.51	97.99	93.13
100.00	100.00	100.00	100.00	99.37	97.43
100.00	100.00	100.00	100.00	100.00	99.02
100.00	100.00	100.00	100.00	100.00	100.00

Appendix V Suspended sediment analysis sheets.



Surtech Ltd.,
P.O. Box 62514 Nairobi, Kenya
Telephones 721910/720082/606618
Cables ENGICON NAIROBI
Telex 22083 TECHNICO.

SUSPENDED SEDIMENT ANALYSIS

PROJECT No. :

OPERATOR : GIKONYO J.K

LOCATION : MATHARE RIVER KABETE (NRB)

CHECKED : ✓

DATE : 5/4/93

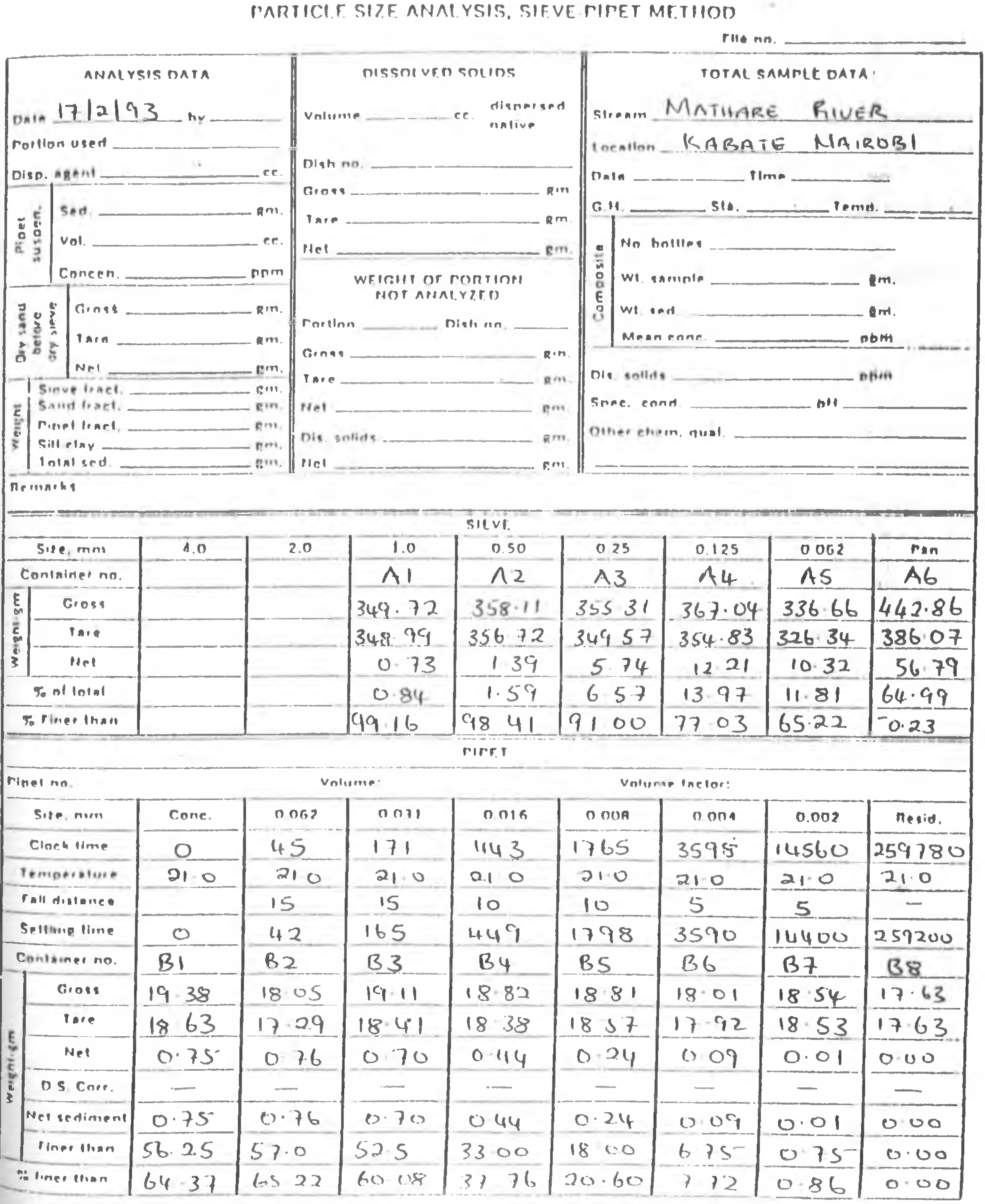
ORIGINAL SAMPLE No		G/3/24/9 00	G/3/25/9 00	G/3/26/9 00	G/3/27/9 00
LAB. SAMPLE No		"	"	"	"
WT. OF FILTER PAPER (A)	gm	0.88	0.88	0.88	0.91
WT. OF FILTER PAPER + SS (B)	gm	0.91	0.92	0.90	0.93
SUSPENDED SEDIMENT = B - A = (C)	gm	0.03	0.04	0.02	0.02
VOLUME OF SAMPLE (D)	ml	760	810	565	730
$SS = \frac{C \times 10^6}{D}$	mg/l	39.47	49.38	35.40	27.40

ORIGINAL SAMPLE No		G/3/28/9 00	G/3/29/9 00	G/3/30/9 00	G/3/31/9 00
LAB. SAMPLE No		"	"	"	"
WT. OF FILTER PAPER (A)	gm	0.90	0.89	0.90	0.91
WT. OF FILTER PAPER + SS (B)	gm	0.93	0.92	0.92	0.93
SUSPENDED SEDIMENT = B - A = (C)	gm	0.03	0.03	0.02	0.02
VOLUME OF SAMPLE (D)	ml	780	830	920	465
$SS = \frac{C \times 10^6}{D}$	mg/l	38.46	36.14	21.74	43.01

ORIGINAL SAMPLE No		G/4/1/9 00	G/4/2/9 00	G/4/3/9 00	G/4/4/9 00
LAB. SAMPLE No		"	"	"	"
WT. OF FILTER PAPER (A)	gm	0.88	0.91	0.89	0.88
WT. OF FILTER PAPER + SS (B)	gm	0.89	0.93	0.91	0.91
SUSPENDED SEDIMENT = B - A = (C)	gm	0.01	0.02	0.02	0.03
VOLUME OF SAMPLE (D)	ml	690	745	840	920
$SS = \frac{C \times 10^6}{D}$	mg/l	14.49	26.85	23.81	32.61

C/TESE/71

Appendix VI Particle size analysis record sheets



PARTICLE SIZE ANALYSIS, SIEVE-PIPET METHOD

File no. ______

ANALYSIS DATA

Date 17/2/93 by ______
Portion used ______
Disp. agent ______ cc.
Pipet suspen. Sed. ______ gm.
Vol. ______ cc.
Concen. ______ ppm
Dry sand before dry sieve Gross ______ gm.
Tare ______ gm.
Net ______ gm.
Weight Sieve fract. ______ gm.
Sand fract. ______ gm.
Pipet fract. ______ gm.
Silt-clay ______ gm.
Total sed. ______ gm.

DISSOLVED SOLIDS

Volume ______ cc. dispersed native
Dish no. ______
Gross ______ gm
Tare ______ gm.
Net ______ gm.

WEIGHT OF PORTION NOT ANALYZED

Portion ______ Dish no. ______
Gross ______ gm.
Tare ______ gm.
Net ______ gm.
Dis. solids ______ gm.
Net ______ gm.

TOTAL SAMPLE DATA:

Stream MATHARE RIVER
Location KABATE NAIROBI
Date ______ Time ______
G.H. ______ Sta. ______ Temp. ______
Composite No. bottles ______
Wt. sample ______ gm.
Wt. sed. ______ gm.
Mean conc. ______ ppm
Dis. solids ______ ppm
Spec. cond. ______ pH ______
Other chem. qual. ______

Remarks

SIEVE

Size, mm	4.0	2.0	1.0	0.50	0.25	0.125	0.062	Pan
Container no.			A1	A2	A3	A4	A5	A6
Weight-gm Gross			349.72	358.11	355.31	367.04	336.66	442.86
Weight-gm Tare			348.99	356.72	349.57	354.83	326.34	386.07
Weight-gm Net			0.73	1.39	5.74	12.21	10.32	56.79
% of total			0.84	1.59	6.57	13.97	11.81	64.99
% Finer than			99.16	98.41	91.00	77.03	65.22	0.23

PIPET

Pipet no. Volume: Volume factor:

Size, mm	Conc.	0.062	0.031	0.016	0.008	0.004	0.002	Resid.
Clock time	0	45	171	443	1765	3595	14560	259780
Temperature	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Fall distance		15	15	10	10	5	5	—
Settling time	0	42	165	449	1798	3590	14400	259200
Container no.	B1	B2	B3	B4	B5	B6	B7	B8
Weight-gm Gross	19.38	18.05	19.11	18.82	18.81	18.01	18.54	17.63
Weight-gm Tare	18.63	17.29	18.41	18.38	18.57	17.92	18.53	17.63
Weight-gm Net	0.75	0.76	0.70	0.44	0.24	0.09	0.01	0.00
Weight-gm D.S. Corr.	—	—	—	—	—	—	—	—
Weight-gm Net sediment	0.75	0.76	0.70	0.44	0.24	0.09	0.01	0.00
Weight-gm Finer than	56.25	57.0	52.5	33.00	18.00	6.75	0.75	0.00
% finer than	64.37	65.22	60.08	37.76	20.60	7.72	0.86	0.00

Laboratory form Particle Size Analysis, Sieve-Pipette Method

Appendix VII Computer programs developed for data analysis.

Program for computation of discharge based on a velocity area method

```
PROGRAM  DISCHARGE(INPUT,OUTPUT) ;
const    T = 120;
var      Vn: integer;
         b,d,R02d,R08d,nd,V,A,Q,Qcum:
         array [1..100] of real;
         i,j,k,Datasets:integer; Stage, Ta, Tw: real;
         Date:string;
         lst: text;
         length:(s);

Begin
     assign (lst, 'prn');
     rewrite (lst);
begin
     writeln (' What are the number of sets of data that need
to');
     writeln (' be analysed  [ Datasets]? ');
     readln (Datasets);

  begin
  for k := 1 to Datasets do
    begin

     writeln;
     writeln ('Enter the value of  "Vn"  which should be
the');
     writeln ('number of verticals in the section');
     readln (Vn);
     writeln ('Enter DATE that river was gauged  dd-mm-yy');
     readln (date);
     writeln ('what is the river stage in cm?');
     readln (Stage);
 {   writeln ('what is the temperature of air in deg C?');
     readln (Ta);
     writeln ('what is the temperature of the water in deg
C?');
     readln (Tw);
   }     writeln ('input values of depth of verticles ,d, in
cm');
     for i := 2 to Vn+1 do
         begin
              read (d[i]);
         end;
              writeln ('input values of Rev. count at 0.2d
,R02d,');
     for i := 2 to Vn+1 do
         begin
              read (R02d[i]);
         end;
              writeln ('input values of Rev. count at 0.8d
,R08d,');
     for i := 2 to Vn+1 do
         begin
```

```
            read (R08d[i]);
        end;
        for  i:= 2 to Vn+1 do
        begin
            nd[i] := (R02d[i] + R08d[i]) / (T * 2);
        end;
        for i := 2 to Vn+1 do
        begin
            if nd[i] <= 0.67 then
               V[i] := (0.2281 * nd[i]) + 0.023

            else
               V[i] := (0.2475 * nd[i]) + 0.010;
        end;
        for i := 2 to Vn+1 do
            begin
            b[1] := 0;
            b[2] := 25;
            b[3] := 50;
            b[4] := 75;
            b[5] := 100;
            b[6] := 125;
            b[7] := 150;
            b[8] := 175;
            b[9] := 200;
            b[10] := 225;
            b[11] := 250;
            b[12] := 275;
            b[13] := 300;
            b[14] := 325;
            b[15] := 350;
            b[16] := 375;
            b[17] := 400;
            d[1] := 0 ;
            A[i] := ((b[i] -b[i-1]) * (d[i] + d[i-1])) /
20000;
        end;
        for i := 2 to Vn+1 do
            begin
            Q[i] := A[i] * V[i] ;
            end;
            Qcum[1] := 0;
        for i := 2 to Vn+1 do
            Qcum[i] := Qcum[i-1] + Q[i];

        writeln (' Date    ',Date);
        writeln (' The stage was =                    ',
Stage:5:2,'cm');
    {    writeln (' The water temperature was =', Tw:5:2,'
deg C');
        writeln (' The air temperature was =   ', Ta:5:2,'
deg C');
     }        writeln   ('   The   total   discharge   was
=',Qcum[Vn+1]:7:3,' m^3/s');
        writeln;
        writeln;
```

```
     write ('R02d  ');
  for i  := 2 to Vn+1 do
  begin
       write (R02d[i]:6:0);
  end;
         writeln;
         writeln;
      write ('R08d  ');
  for i := 2 to Vn+1 do
  begin
       write (R08d[i]:6:0);
  end;
         writeln;
         writeln;
     write ('   V  ');
  for i := 2 to Vn+1 do
  begin
     write (V[i]:6:3);
 end;
     writeln;
     writeln;
     write ('   A  ');
  for i := 2 to Vn+1 do
  begin
     write (A[i]:6:3);
  end;
     writeln;
     writeln;
     write ('   Q  ');
  for i := 2 to Vn+1 do
  begin
     write (Q[i]:6:3);
  end;
     writeln;
     writeln;
     write ('Qcum  ');
  for i := 2 to Vn+1 do
  begin
     write (Qcum[i]:6:3);
  end;
     writeln;
     writeln;
           writeln (lst,'  ');
           writeln (lst,'  ');
           writeln (lst,'  ');
           writeln (lst,'  ');
           writeln (lst,' Date    ',Date);
           writeln (lst,' The stage was =
',Stage:5:2,'cm');
   {        writeln (lst,' The water temperature was =
',Tw:5:2,'deg C');
           writeln (lst,' The air temperature was   =   ',
Ta:5:2,' deg C');
   }         writeln (lst,' The total discharge was =
',Qcum[Vn+1]:7:3, ' m^3/s');
```

```
           write (lst,'R02d ');
    for i  := 2 to Vn+1 do
    begin
           write (lst,R02d[i]:8:3);
    end;
           writeln (lst,'   ');
           write (lst,'R08d');
    for i:= 2  to Vn+1 do
    begin
           write (lst,R08d[i]:8:3);
    end;
           writeln (lst,'   ');
           write (lst,'   V') ;
    for i:= 2 to Vn+1 do
    begin
         write (lst,V[i]:8:3);
    end;
        writeln (lst,'  ');
        write (lst,'   A');
    for i := 2 to Vn+1 do
    begin
         write (lst, A[i]:8:3);
    end;
        writeln (lst,'  ');
        write (lst,'   Q');
    for i := 2 to Vn+1 do
     begin
          write (lst, Q[i]:8:3);
     end;
         writeln (lst,'   ');
         write (lst,'Qcum');
     for i := 2 to Vn+1 do
     begin
          write (lst, Qcum[i]:8:3);
     end;
         writeln (lst,'   ');
         writeln (lst,'   ');
         writeln (lst,'   ');
end;
end;
end;
end.
```

Program for computation of discharge based on ETR sampling data

```
PROGRAM  DISCHARGE(INPUT,OUTPUT) ;
         USES CRT,PRINTER;

     {This program computes the river discharge based on the
     equal transit rate   [ETR]  sampling technique .  It
     has been developed in order facilitate the approximation
     of discharge as a secondary objective in stream sediment
     analysis.}

const    K= 28.2743334;
var      Vn: integer;
         b,d,Ve,Vo,A,T,Q,Qcum:
         array[1..100] of real;
         i,j,P:integer; Stage, Ta, Tw : real;
         Date:string;
         realfile: file of real;
         lst: text;

Begin

     assign (lst, 'prn');
     rewrite (lst);
  begin
     writeln;
     writeln ('Enter the value of  "Vn"  which should be
equal to');
     writeln ('the number of verticals ');
     readln (Vn);
     writeln ('Enter DATE that river was gauged  dd-mm-yy');
     readln (date);
     writeln ('what is the river stage in cm?');
     readln (Stage);
     writeln ('what is the temperature of air in deg C?');
     readln (Ta);
     writeln ('what is the temperature of the water in deg
C?');
     readln (Tw);
         writeln ('input values of distance from initial
point ,b, in cm');
     for i:= 2 to Vn+1 do
         begin
              read (b[i]);
         end;
         writeln ('input values of depth of verticles ,d, in
cm');
     for i := 2 to Vn+1 do
         begin
              read (d[i]);
         end;
         writeln ('input values of Volume of samples, Vo in
cm^3');
     for i := 2 to Vn+1 do
         begin
```

```
           read (Vo[i]);
       end;
    for j := 1 to 5 do
       begin
       writeln ('input values of Time taken to collect the
samples at');
       writeln ('the various verticals,  " T " ');
    for i := 2 to Vn+1 do
       begin
           read (T[i]);
       end;
    for i := 2 to Vn+1 do
       begin

             Ve[i] :=  Vo[i]/ (T[i] * K );
       end;
       for i := 2 to Vn+1 do
          begin
          b[1] := 0;
          d[1] := 0 ;
          A[i] := ((b[i] -b[i-1]) * (d[i] + d[i-1])) /
20000;
       end;
       for i := 2 to Vn+1 do
       begin
          Q[i] := A[i] * Ve[i] ;
       end;
          Qcum[1] := 0;
       for i := 2 to Vn+1 do
          Qcum[i] := Qcum[i-1] + Q[i];


       writeln ('Date    ',Date);
       writeln ('The stage was=                    ',
Stage:5:2,' cm');
       writeln ('The water temperature was =' ,Tw:5:2,' deg
C');
       writeln ('The air temperature was =', Ta:5:2,' deg
C');
        writeln   ('The   total   discharge   was
=',Qcum[Vn+1]:7:3,'m^3/s');
       writeln;
       writeln;
       write ('   Ve');
   for i:= 2 to Vn+1 do
   begin
       write (Ve[i]:8:3);
   end;
      writeln;
      write ('   A ');
   for i:= 2 to Vn+1 do
   begin
       write ( A[i]:8:3);
   end;
      writeln;
      write ('   Q ');
```

```
    for i:= 2 to Vn+1 do
    begin
         write ( Q[i]:8:3);
    end;
        writeln;
        write (’Qcum ’);
    for i:= 2 to Vn+1 do
    begin
         write ( Qcum[i]:8:3);
    end;
        writeln;
        writeln;
        writeln (’Do you wish to print output   [0]  Yes ’);
        writeln (’                               [N]  NO’);
          readln (P);
    begin
         writeln (lst,’ Date    ’,Date);
         writeln (lst,’ The stage was =                 ’,
Stage:5:2,’cm’);
         writeln  (lst,’  The  water  temperature  was  =’,
Tw:5:2,’ deg C’);
         writeln  (lst,’  The  air  temperature  was  =   ’,
Ta:5:2,’ deg C’);
         writeln   (lst,’   The   total   discharge   was
=’,Qcum[Vn+1]:7:3,’ m^3/s’);
         writeln (lst,’   ’);
         writeln (lst,’   ’);
         write (lst,’    b ’);
  for i := 2 to Vn+1 do
  begin
       write (lst, b[i]:8:3);
  end;
      writeln (lst,’    ’);
      write (lst,’    d ’);
  for i := 2 to Vn+1 do
  begin
       write (lst, d[i]:8:3);
  end;
      writeln (lst,’    ’);
      write (lst,’   Vo ’);
  for i := 2 to Vn+1 do
  begin
       write (lst, Vo[i]:8:3);
  end;
      writeln (lst,’    ’);
      write (lst, ’    T ’);
  for i := 2 to Vn+1 do
  begin
       write (lst, T[i]:8:3);
  end;
      writeln (lst,’    ’);
         write (lst,’   Ve ’);
  for i := 2 to Vn+1 do
  begin
     write (lst,Ve[i]:8:3);
  end;
```

```
      writeln (lst,'   ');
      write (lst,'   A  ');
   for i := 2 to Vn+1 do
   begin
      write ( lst, A[i]:8:3);
   end;
      writeln (lst,'    ');
      write ( lst,'   Q  ');
   for i := 2 to Vn+1 do
   begin
      write( lst, Q[i]:8:3);
   end;
      writeln (lst,'   ');
      write ( lst,'Qcum  ');
   for i := 2 to Vn+1 do
   begin
      write (lst, Qcum[i]:8:3);
   end;
      writeln (lst,'   ');
      writeln (lst,'   ');
      writeln (lst,'   ');
      writeln (lst,'   ');
end;
end;
end;
end.
```

Program of numerical convolution

```
Program   CONVOLUTION (input, output);

          USES CRT,PRINTER;

const  Kc = 0.000278;
       Tdf1= 66;
       Tdf2= 96;
       Tdf3= 108;
       Tdf4= 120;

Var    i,j,js,ii,jj,kk,ks,n1,No,count,stop1,stop2: integer;
        K,ns,n,Pe,Tdr,dt,f,Tsum,Psum,x,xx,z,zz,fctr,A:real;
        U,S,R,RR,P,t,k1:  array [1..1000] of real;
        Tr, Px, Ro, Pex, Trr: array [1..100] of real;
        Data: text;
        g,SG: file of string;
        greetings:string;
        opt,W:char;

Begin

     clrscr;
     writeln;
     greetings  :=  ('************************     WELCOME
************************');
     writeln;
                          w    r    i    t    e    l    n
('**********************************************************
**');
     writeln (greetings);
                          w    r    i    t    e    l    n
('**********************************************************
**');
     writeln;
     writeln;
     writeln ('                Program Compiled By: Gikonyo
J.K.');
     writeln;
     writeln ('               Under supervision of Dr. T.C.
Sharma');
     writeln;
     writeln ('                             DEPT. OF AGRIC.
ENGINEERING');
     writeln;
     writeln;
     writeln;
     writeln ('This program generates the Sediment graph of
a river based');
     writeln ('on the IUSG model and is the discrete form of
the convolution');
     writeln ('integral.  The ordinates of the sediment graph
derived are in');
     writeln ('the units of Kg/s while time ordinates are in
Hours.');
```

```
     writeln;
     writeln;
     writeln;
     writeln ('Do you wish to continue ?');
     writeln;
     write ('  Yes  [Y]      No [N] ');
     readln (opt);
       if opt = 'y' then begin
     assign (data,'sg');
     rewrite (data);
     writeln;
     writeln;
     count:= 0;
     write ('What is the catchment area in square Km ?    ');
     readln (A);
     writeln;
     writeln;
     writeln ('Give IUSG model specifications');
     writeln ('Input  values for the parameters  Ks and ns
');
     write ('Ks =    ');
     readln (k);
     write ('ns =     ');
     readln (n);
     writeln;
     writeln;
     writeln;
     write ('What is the time increament of the required
graphs in hours ?  ');
     readln (dt);
     writeln;
     fctr:= 1;
     n1:= trunc (n + 0.5);
     f:=1;
       writeln ('********* Define the mobilised sediment
Histogram *********');
       writeln;
       writeln ('                              NOTE');
       writeln;
       writeln ('Ms represents the ordinates for the
Histogram (t/hr)');
       writeln ('T represents the time span  (hrs)');
       writeln;
       write ('What are the number of blocks of the
Histogram?    ');
       readln (stop1);
       writeln ('Input values of  Ms and  T' );
       writeln;
       ks:= 1;
       {Tr[0]:= 0;}
    while n1 > 1 do
       begin
         fctr:= fctr * (n1 - 1);
         n1:= n1 - 1;
       end;
```

```
       for ks:= 1 to stop1 do
       begin
         write ('Vs',ks:3,'=    ');
         readln (Ro[ks]);
         write ('T',ks:3,'=    ');
         readln (Tr[ks]);
       end;
         writeln ('                       PLEASE   WAIT');
         Tdr:= 0;
     for ks:= 1 to stop1 do
       begin
         Tdr:= Tdr + Tr[ks];
         end;

     if Tdr < 4  then
       begin
          if Pe < 20  then
            begin
              ii:= Trunc (Tdf1/dt);
            end
          else
            begin
              ii:= Trunc (Tdf2 / dt);
            end;
        end
     else
          if Pe < 20 then
            begin
              ii:= trunc (Tdf3 / dt);
            end
          else
            begin
              ii:= trunc (Tdf4 /dt);
            end;

      for i:= 1 to ii do
     begin
       t[i]:= dt * f;
       f:= f+1;
     end;
      for i:= 1 to ii do
     begin
       z:= Exp((n-1) * ln(t[i]/k));
       U[i]:= ((A * z * (1/fctr) * (1/k) * Exp (-t[i]/k)) *
24)/(dt*24);
{       write ('U',i:4,'    =', U[i]:6:2,'    ');
        write (data,'U',i:4,'    =', U[i]:6:2,'      ');}
     end;


{    for ks:= 1 to stop1 do
         begin
          write (data,'P',ks:3,'=  ',Ro[ks]:6:2,'  ');
           write (data,'t',ks:3,'=  ',Tr[ks]:6:2,'  ');
         end;}
```

```
        stop2:= trunc (Tdr / dt);
        writeln (data,'   ');
         xx:= 0;
        kk:=1;
   for ks:= 1 to stop1 do
     begin
       xx:= xx  + Tr[ks];
       No:= trunc (xx / dt);
       for i:= kk to No do
         begin
              zz:=  1 * Ro[ks];
              R[i]:= zz ;
              kk:= No+1;
         end;
      end;
    for i:= (stop2 +1) to ii do
      begin
        R[i]:= 0;
      end;
    for i:= 1 to ii do
      begin
{          write ('R',i:4,'   =  ',R[i]:6:2,'   ');
           write (data,'R',i:4,'   =  ',R[i]:6:2,'   ');}
      end;
         writeln ('The Sediment Graph Ordinates are:');
   for j:= 1 to ii do
    begin
      count:= count + 1;
    for j:= count downto 1 do
     begin
    for i:= 1 to count do
     begin
     RR[i] := R[j];
     end;
     end;
    for j:= 1 to count do;
     begin
      P[i]:= U[i] * RR[i];
     end;
      Psum :=0;
    for i:= 1 to count do;
     begin
       Psum:= Psum + P[i];
     end;
   writeln;
{   writeln;
   write ('T',count:4,'    =', t[i]:8:3);
   write (data,'       T', count:4,'    =',t[i]:8:3);
   write ('      ');
   write (data,'    ');
   writeln ('S',count:4,'    =',Psum:8:3);
   writeln (data,'S',count:4,'    =',Psum:8:3);
 }  writeln (data, Psum:8:4);
       end;
       end
  else
```

```
    writeln;
    writeln;
    writeln (' PRESS   <ENTER>  TO EXIT TO DOS');
    readln (W);
end.
```

Program for the generation of sediment graphs for IUSG model based on the time area method

```
Program  Timearea (input, output);
         USES CRT, PRINTER, DOS;

const    CF1 = 24;
         A=26.5;

var      i,j,count1,stop3,stop4,stop5,stop6,stop7: integer;

         x,dt,k,M0,M1,M2,AAs,RRi,INPsum,interval: real;
         AAss,RRRi,Si,S,So,INP: array [1..1000] of real;
         As,Ta,R,Ri: array [1..100] of real;
         data: text;
         Datafile: file of string;


Begin
clrscr;
      Assign (data,'datafile');
      rewrite (data);
      writeln ('What is the time interval of the Time area
diagram ?');
      write ('dt =   ');
      readln (dt);
      writeln;
      writeln;
      writeln ('What is the time interval of the required
Sediment Graphs ?');
      write ('Time increament  =   ');
      readln (interval);

      writeln;
      writeln ('What is the value  " X " in the Muskingum
routing equation');
      writeln;
      X:= 0;
      write ('X =  0 ');
      {readln (x);}
      writeln ('The value of the sediment storage constant
"Ks" is determined');
      writeln ('by trial and error method');
      writeln;
      writeln ('The value of storage parameter Ks is hereby
determined');
      writeln ('by a trial and error method');
      writeln;
      writeln;
      write ('What is the first approximation of Ks     ');
      readln (k);
      writeln;

      writeln ('********** Define the Time Area Diagram
**********');
      writeln;
```

```
{      writeln ('" As " represents the contributing area in
sq Km ');
      writeln ('" T "  represents the time in the time area
histogram in hrs');
      writeln ('This currently equal to ' , dt:8:3);
      writeln ('How many blocks does this time area histogram
have ? ');
      write ('Blocks =   ');
      readln (stop4);
}
       As[1]:= 0.5;
       As[2]:= 1.75;
       As[3]:= 3.25;
       As[4]:= 7.25;
       As[5]:= 9.25;
       As[6]:= 4.5;


       stop4:=6;
       stop3:=100;

       for j:= stop4+1 to stop3 do
         begin
           As[j]:= 0;
         end;

       for j:= 1 to  stop3  do
       begin
         Ta[j] := j * 1;
       end;

       writeln ('   Time (hr)            Area (Km^2) ');

       for j:= 1 to stop4 do
          begin
            writeln ('     ',Ta[j]:5:2,'                 ' ,
As[j]:5:2);
          end;

       writeln;
       write  ('********** Define the Mobilised Sediment
Histogram ');
       writeln ('**********');
       writeln;
       writeln ('                      NOTE');
       writeln ('Vs represents the Histogram ordinates in
t/hr');
       writeln;
       writeln ('T represents the time span of the Histogram
bars in hrs');
       writeln ('currently this is equal to ' ,  dt:8:3);
       write ('What are the number of blocks of the Histogram
?     ');
       readln (stop5);
       writeln;
       writeln ('Input values of Vs and T');
```

```
     writeln;


 for j:=1 to stop5 do
   begin
     write ('Vs',j:3,'=    ');
     read (R[j]);
     end;

  for j:= stop5+1 to stop3 do
    begin
      Ri[j]:= 0;
    end;

  for j:= 1 to stop3 do
    begin
      Ri[j]:= R[j];
    end;

     writeln;
 writeln ('                  *  PLEASE WAIT  * ');
 writeln;
 writeln;
 writeln ('                CONVOLUTION IN PROGRESS');
 delay (2000);
 clrscr;
        count1:= 0;

    for i:= 1 to stop3 do
      begin
        count1 := count1 +1;
          for i:= count1  downto 1 do
             begin
             for j:= 1 to count1 do
               begin
               RRRi[j]:=Ri[i];
                end;
                end;

             INPsum:=0;

    { Si represents the unrouted outflow from the catchment
}

       for j:= 1 to count1 do;
        begin
           AAss[j]:= As[j] * RRRi[j] * (CF1/A);
        end;

           INPsum :=0;

       for i:= 1 to count1 do;
         begin
            INPsum:= INPsum + AAss[i];
            writeln;
          end;
```

```
              Si[i]:=INPsum;
           end;

     M0:=(-1*((k*x)-(0.5*dt)))/(k-(k*x)+(0.5*dt));
     M1:=((k*x)+(0.5*dt))/(k-(k*x)+(0.5*dt));
     M2:=(k-((k*x)+(0.5*dt)))/(k-(k*x)+(0.5*dt));

  writeln ('M0= ',M0:6:3, '      M1 = ',M1:6:3,'      M2 =
',M2:6:3);
  writeln ('M0 + M1 + M2  =   ',M0 + M1 + M2:6:3);
  delay (4000);
  writeln;
  writeln;
  writeln ('                 *  PLEASE WAIT  * ');
  writeln;
  writeln;
  writeln ('                ROUTING IN PROGRESS');
  delay (1000);

     S[1]:= M0 * Si[1];

  for i:= 1 to stop3 do
    begin
        S[i+1]:= (M0*Si[i+1]) + (M1*Si[i]) + (M2*S[i]);
    end;
           i:=0;
          stop5:= (stop3 div (trunc (interval/dt)));
         write ('   Time');
         writeln ('                Sediment discharge');
          write ('   Hours');
          writeln ('                    Kg/s');
          writeln;
          write (data,'   Time');
          writeln  (data,'                          Sediment
discharge');
          write (data,'   Hours');
          writeln (data,'                     Kg/s');
          writeln (data,'  ');
          write ('    0.00');
          writeln ('                      0.0000');
          write (data,'    0.00');
          writeln (data,'                      0.0000');
    for j:= 1 to stop5 do
      begin
        i:= i+ trunc(interval/dt);
        Write (Ta[i]:8:2);
        Write (data,Ta[i]:8:2);
        writeln ('                     ', S[i]:8:4);
        writeln (data,'                    ',S[i]:8:4);
      end;
    writeln (data,'   ');
end.
```

Appendix VII River stage, sample suspended sediment concentration and river discharge data.

Table A   Sample sediment concentration determined from Grab, EDI and ETR sampling

Grab Conc. ppm	EDI Conc ppm	ETR Conc ppm
27.480	37.310	32.850
26.500	23.430	28.850
32.720	32.490	32.260
32.730	31.640	32.030
49.650	64.770	57.690
262.300	235.770	203.210
80.730	99.380	96.550
49.580	64.650	59.020
62.750	64.910	73.060
47.380	45.570	50.760
27.720	39.550	33.610
32.970	26.920	27.120
80.730	99.380	96.550
50.150	52.160	53.330
47.550	54.510	51.410
53.770	50.770	56.450
64.720	64.670	70.590
90.030	93.100	109.760
26.650	33.380	49.380
41.250	40.320	43.010
52.650	36.500	45.980
54.290	45.270	50.790
27.940	38.600	33.610
32.270	33.560	30.300
34.560	33.660	32.130
38.500	48.080	43.960
69.500	82.990	70.180
41.470	46.360	41.960
38.980	44.100	45.450
50.350	52.750	59.700
60.900	56.640	59.910
117.950	131.660	126.980
99.000	101.000	99.530
101.960	99.740	96.890
104.800	102.070	93.960
56.930	72.070	74.590
102.240	110.230	114.050
56.240	58.060	59.130
39.270	36.280	40.620
45.350	39.720	40.680
34.710	39.360	43.240
37.580	44.660	41.030
32.740	36.260	38.010
39.280	35.880	36.300
40.120	38.220	42.640
36.670	36.850	42.110
36.980	40.050	41.670

Table A continued

Grab Conc. ppm	EDI Conc ppm	ETR Conc ppm
259.650	257.250	238.990
197.050	153.900	223.260
151.980	150.590	150.350
99.620	104.910	105.880
92.230	103.010	100.920
102.650	100.130	96.050
276.270	224.510	267.020
213.490	135.990	158.190
157.200	112.410	106.560
116.930	126.030	126.540
350.790	377.730	317.070
522.110	515.180	518.150
623.350	630.590	634.090
328.500	354.270	364.080
217.200	226.250	228.960
200.470	182.100	188.480
159.650	163.530	165.350
136.190	122.290	121.040
100.500	104.790	107.260
96.730	105.260	102.560
34.060	44.320	43.480
129.780	118.640	116.700
92.590	88.820	87.100
78.750	81.830	85.030
67.150	68.220	71.030
63.380	58.390	58.300
60.070	60.730	66.510
107.070	104.480	100.840
164.230	158.900	160.490
236.900	232.030	232.730
267.940	268.720	271.840
129.250	146.810	128.280
120.010	117.280	115.280
64.680	78.270	72.540
75.790	71.570	76.470
72.810	73.230	70.350
50.630	62.540	51.280
28.860	42.020	34.480
51.170	59.760	57.650
43.530	52.620	45.920
67.380	61.360	60.610
57.360	64.650	63.560
62.200	59.050	62.950

Table B River discharge based on various methods measured simultaneously

Date	Stage h (m)	Disch. pt.vel m^3/s	Disch. Cur.Met m^3/s	Disch. ETR m^3/s
17/11/92	0.355	0.477	0.428	0.521
18/11/92	0.180	0.096	0.089	0.273
18/11/92	0.210	0.165	0.136	0.313
03/11/92	0.115	0.068	0.060	0.232
16/11/92	0.110	0.053	0.049	0.233
17/11/92	0.430	0.666	0.604	0.742
20/11/92	0.130	0.063	0.062	0.276
29/11/92	0.125	0.060	0.061	0.253
30/11/92	0.110	0.057	0.053	0.233
04/12/92	0.110	0.065	0.059	0.212
11/12/92	0.170	0.117	0.105	0.272
12/12/92	0.125	0.059	0.053	0.232
14/12/92	0.120	0.070	0.055	0.243
17/12/92	0.250	0.252	0.192	0.439
17/12/92	0.220	0.193	0.144	0.318
18/12/92	0.180	0.092	0.098	0.301
18/12/92	0.200	0.064	0.107	0.283
19/12/92	0.220	0.267	0.161	0.395
19/12/92	0.180	0.123	0.103	0.311
21/12/92	0.200	0.140	0.125	0.314
22/12/92	0.160	0.077	0.070	0.267
23/12/92	0.170	0.104	0.092	0.252
23/12/92	0.180	0.142	0.110	0.31
07/01/93	0.215	0.235	0.162	0.351
07/01/93	0.180	0.145	0.113	0.252
08/01/93	0.290	0.309	0.265	0.458
08/01/93	0.300	0.305	0.264	0.448
09/01/93	0.225	0.194	0.156	0.395
09/01/93	0.290	0.289	0.254	0.407
11/01/93	0.140	0.068	0.058	0.239
11/01/93	0.140	0.070	0.058	0.248
12/01/93	0.125	0.051	0.047	0.25
12/01/93	0.140	0.059	0.051	0.234
13/01/93	0.160	0.093	0.078	0.251
13/01/93	0.150	0.089	0.077	0.241
14/01/93	0.320	0.410	0.328	0.51
14/01/93	0.340	0.336	0.335	0.567
15/01/93	0.215	0.126	0.113	0.381
15/01/93	0.230	0.303	0.257	0.389
18/01/93	0.300	0.271	0.221	0.398
18/01/93	0.200	0.155	0.133	0.342
16/01/93	0.240	0.306	0.254	0.261
19/01/93	0.355	0.487	0.398	0.526
19/01/93	0.320	0.332	0.285	0.504
20/01/93	0.600	1.458	1.261	0.799
20/01/93	0.460	1.043	0.654	0.846
21/01/93	0.510	0.930	0.934	0.73
21/01/93	0.580	1.339	0.971	1.264

Table B continued

Date	Stage h (m)	Disch. pt.vel m^3/s	Disch. Cur.Met m^3/s	Disch. ETR m^3/s
22/01/93	0.355	0.349	0.298	0.572
22/01/93	0.400	0.533	0.431	0.525
23/01/93	0.240	0.240	0.167	0.387
23/01/93	0.280	0.290	0.253	0.462
25/01/93	0.190	0.103	0.102	0.31
26/01/93	0.180	0.100	0.089	0.269
27/01/93	0.160	0.090	0.082	0.272
27/01/93	0.180	0.124	0.103	0.318
28/01/93	0.130	0.060	0.057	0.205
29/01/93	0.120	0.063	0.048	0.25
30/01/93	0.150	0.093	0.077	0.238
30/01/93	0.160	0.088	0.076	0.297
02/02/93	0.140	0.072	0.060	0.247
01/02/93	0.170	0.089	0.086	0.291
01/02/93	0.150	0.089	0.085	0.266
02/02/93	0.240	0.240	0.172	0.386
02/02/93	0.245	0.204	0.186	0.382
02/02/93	0.160	0.099	0.088	0.306
05/02/93	0.140	0.094	0.068	0.233
05/02/93	0.150	0.093	0.078	0.257
06/02/93	0.160	0.094	0.085	0.32
06/02/93	0.140	0.069	0.053	0.228
10/02/93	0.150	0.084	0.059	0.228
10/02/93	0.150	0.093	0.082	0.283
11/02/93	0.170	0.101	0.074	0.294
11/02/93	0.220	0.188	0.144	0.395
12/02/93	0.210	0.137	0.117	0.342
13/02/93	0.210	0.137	0.121	0.314
13/02/93	0.170	0.121	0.094	0.328
15/02/93	0.190	0.160	0.117	0.308
15/02/93	0.125	0.049	0.047	0.261
16/02/93	0.160	0.094	0.075	0.257
17/02/93	0.190	0.133	0.158	0.319
17/02/93	0.175	0.097	0.099	0.327
19/02/93	0.250	0.239	0.289	0.378
20/02/93	0.200	0.176	0.195	0.283
20/02/93	0.110	0.054	0.045	0.222
21/02/93	0.235	0.143	0.104	0.413
21/02/93	0.290	0.242	0.277	0.468
22/02/93	0.320	0.351	0.529	0.482
22/02/93	0.270	0.272	0.281	0.446
24/02/93	0.260	0.213	0.145	0.405
24/02/93	0.250	0.322	0.265	0.376
27/02/93	0.145	0.110	0.048	0.235
27/02/93	0.455	0.693	0.711	0.806
02/03/93	0.520	1.234	1.205	1.421
02/03/93	0.390	0.458	0.451	0.632
19/03/93	0.450	0.649	0.652	0.821
19/03/93	0.480	0.682	0.671	0.793
21/03/93	0.620	1.143	1.142	1.257
21/03/93	0.640	1.208	1.238	1.291

Table C **Daily mean sediment concentration by grab method**

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
11/11/92	0.120	0.048	29.750
12/11/92	0.120	0.048	35.380
13/11/92	0.125	0.052	30.340
14/11/92	0.125	0.052	41.650
15/11/92	0.145	0.069	72.980
16/11/92	0.125	0.052	87.610
17/11/92	0.430	0.575	215.540
18/11/92	0.210	0.142	116.520
19/11/92	0.130	0.056	54.570
20/11/92	0.130	0.056	61.250
21/11/92	0.130	0.056	49.570
22/11/92	0.120	0.048	31.510
23/11/92	0.115	0.044	34.270
24/11/92	0.105	0.037	32.970
25/11/92	0.150	0.074	79.150
26/11/92	0.105	0.037	52.750
27/11/92	0.105	0.037	44.560
28/11/92	0.120	0.048	63.770
29/11/92	0.125	0.052	32.860
30/11/92	0.110	0.040	71.750
01/12/92	0.155	0.079	85.920
02/12/92	0.110	0.040	29.650
03/12/92	0.115	0.044	48.340
04/12/92	0.110	0.040	50.150
05/12/92	0.125	0.052	58.090
06/12/92	0.105	0.037	31.450
07/12/92	0.110	0.040	27.830
08/12/92	0.115	0.044	35.540
09/12/92	0.105	0.037	35.570
10/12/92	0.115	0.044	41.400
11/12/92	0.170	0.094	62.500
12/12/92	0.135	0.060	40.470
13/12/92	0.130	0.056	57.750
14/12/92	0.120	0.048	39.940
15/12/92	0.105	0.037	54.340
16/12/92	0.125	0.052	57.900
17/12/92	0.220	0.156	113.950
18/12/92	0.200	0.129	99.000
19/12/92	0.180	0.105	95.340
20/12/92	0.175	0.100	69.300
21/12/92	0.200	0.129	107.800
22/12/92	0.165	0.089	56.730
23/12/92	0.180	0.105	102.230
24/12/92	0.140	0.065	59.240
25/12/92	0.090	0.027	37.340
26/12/92	0.090	0.027	34.270

Table C continued

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
27/12/92	0.090	0.027	45.350
28/12/92	0.100	0.033	32.230
29/12/92	0.100	0.033	25.200
30/12/92	0.090	0.027	34.710
31/12/92	0.100	0.033	37.580
01/01/93	0.100	0.033	32.740
02/01/93	0.090	0.027	39.280
03/01/93	0.100	0.033	26.060
04/01/93	0.100	0.033	40.120
05/01/93	0.100	0.033	36.670
06/01/93	0.100	0.033	36.980
07/01/93	0.180	0.105	259.650
08/01/93	0.300	0.285	197.050
09/01/93	0.290	0.267	151.980
10/01/93	0.145	0.069	99.080
11/01/93	0.140	0.065	99.620
12/01/93	0.140	0.065	92.230
13/01/93	0.150	0.074	102.650
14/01/93	0.340	0.364	276.270
15/01/93	0.230	0.170	213.490
16/01/93	0.240	0.185	157.200
17/01/93	0.200	0.129	118.660
18/01/93	0.200	0.129	116.930
19/01/93	0.320	0.323	350.790
20/01/93	0.460	0.656	522.110
21/01/93	0.580	1.031	623.350
22/01/93	0.400	0.500	328.500
23/01/93	0.280	0.249	217.200
24/01/93	0.200	0.129	189.470
25/01/93	0.190	0.117	200.470
26/01/93	0.180	0.105	159.650
27/01/93	0.160	0.084	136.190
28/01/93	0.130	0.056	100.500
29/01/93	0.140	0.065	96.730
30/01/93	0.100	0.033	34.060
31/01/93	0.160	0.084	139.010
01/02/93	0.150	0.074	129.780
02/02/93	0.140	0.065	92.590
03/02/93	0.140	0.065	78.750
04/02/93	0.160	0.084	67.150
05/02/93	0.150	0.074	63.380
06/02/93	0.140	0.065	60.070
07/02/93	0.150	0.074	83.080
08/02/93	0.150	0.074	107.070
09/02/93	0.170	0.094	164.230
10/02/93	0.170	0.094	236.900
11/02/93	0.210	0.142	267.940

Table C continued

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
12/02/93	0.210	0.142	129.250
13/02/93	0.190	0.117	120.010
14/02/93	0.180	0.105	105.230
15/02/93	0.160	0.084	64.680
16/02/93	0.140	0.065	75.790
17/02/93	0.140	0.065	72.810
18/02/93	0.130	0.056	50.630
19/02/93	0.140	0.065	28.860
20/02/93	0.130	0.056	51.170
21/02/93	0.120	0.048	42.340
22/02/93	0.125	0.052	43.530
23/02/93	0.125	0.052	67.380
24/02/93	0.130	0.056	57.360
25/02/93	0.120	0.048	62.200
26/02/93	0.120	0.048	65.360
27/02/93	0.130	0.056	62.470
28/02/93	0.110	0.040	36.680
01/03/93	0.100	0.033	39.040
02/03/93	0.095	0.030	39.850
03/03/93	0.095	0.030	46.920
04/03/93	0.095	0.030	44.760
05/03/93	0.085	0.024	41.550
06/03/93	0.085	0.024	44.730
07/03/93	0.080	0.022	43.680
08/03/93	0.075	0.019	38.320
09/03/93	0.080	0.022	45.750
10/03/93	0.100	0.033	41.220
11/03/93	0.095	0.030	43.020
12/03/93	0.085	0.024	39.390
13/03/93	0.180	0.105	35.330
14/03/93	0.140	0.065	45.260
15/03/93	0.100	0.033	42.800
16/03/93	0.100	0.033	45.550
17/03/93	0.090	0.027	40.150
18/03/93	0.095	0.030	42.740
19/03/93	0.100	0.033	44.210
20/03/93	0.095	0.030	43.260
21/03/93	0.095	0.030	42.080
22/03/93	0.090	0.027	40.150
23/03/93	0.085	0.024	44.940
24/03/93	0.085	0.024	39.470
25/03/93	0.075	0.019	49.380
26/03/93	0.075	0.019	35.400
27/03/93	0.080	0.022	27.400
28/03/93	0.080	0.022	38.460
29/03/93	0.080	0.022	36.140
30/03/93	0.090	0.027	21.740

Table C continued

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
31/03/93	0.100	0.033	43.010
01/04/93	0.095	0.030	14.490
02/04/93	0.100	0.033	26.850
03/04/93	0.095	0.030	23.810
04/04/93	0.090	0.027	32.610
05/04/93	0.075	0.019	51.280
06/04/93	0.080	0.022	44.120
07/04/93	0.080	0.022	37.740
08/04/93	0.080	0.022	25.320
09/04/93	0.080	0.022	35.710
10/04/93	0.085	0.024	32.970
11/04/93	0.090	0.027	47.060
12/04/93	0.090	0.027	35.500
13/04/93	0.085	0.024	23.810
14/04/93	0.085	0.024	43.010
15/04/93	0.085	0.024	25.640
16/04/93	0.090	0.027	37.500
17/04/93	0.095	0.030	35.290
18/04/93	0.090	0.027	32.260
19/04/93	0.095	0.030	13.070
20/04/93	0.095	0.030	32.610
21/04/93	0.095	0.030	46.510
22/04/93	0.090	0.027	43.960
23/04/93	0.090	0.027	43.480
24/04/93	0.090	0.027	33.710
25/04/93	0.090	0.027	39.470
26/04/93	0.090	0.027	23.530
27/04/93	0.095	0.030	32.970
28/04/93	0.095	0.030	33.710
29/04/93	0.095	0.030	24.390
30/04/93	0.100	0.033	43.960
01/05/93	0.095	0.030	26.850
02/05/93	0.095	0.030	14.710
03/05/93	0.095	0.030	25.480
04/05/93	0.100	0.033	31.250
05/05/93	0.100	0.033	23.810
06/05/93	0.100	0.033	35.090
07/05/93	0.100	0.033	14.710
08/05/93	0.110	0.040	27.780
09/05/93	0.110	0.040	37.040
10/05/93	0.115	0.044	21.860
11/05/93	0.095	0.030	36.590
12/05/93	0.095	0.030	30.610
13/05/93	0.095	0.030	32.000
14/05/93	0.095	0.030	22.900
15/05/93	0.095	0.030	29.850
16/05/93	0.095	0.030	41.380

Table C continued

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
17/05/93	0.095	0.030	25.640
18/05/93	0.095	0.030	31.910
19/05/93	0.095	0.030	17.240
20/05/93	0.090	0.027	41.670
21/05/93	0.090	0.027	33.060
22/05/93	0.095	0.030	32.970
23/05/93	0.090	0.027	15.870
24/05/93	0.090	0.027	26.140
25/05/93	0.090	0.027	23.530
26/05/93	0.090	0.027	21.160
27/05/93	0.090	0.027	32.970
28/05/93	0.090	0.027	27.780
29/05/93	0.090	0.027	14.600
30/05/93	0.090	0.027	23.810
31/05/93	0.090	0.027	30.610
01/06/93	0.090	0.027	26.320
02/06/93	0.090	0.027	30.770
03/06/93	0.090	0.027	16.950
04/06/93	0.090	0.027	37.970
05/06/93	0.135	0.060	11.900
06/06/93	0.110	0.040	27.830
07/06/93	0.100	0.033	34.680
08/06/93	0.090	0.027	26.670
09/06/93	0.090	0.027	35.930
10/06/93	0.090	0.027	37.970
11/06/93	0.105	0.037	58.820
12/06/93	0.090	0.027	16.810
13/06/93	0.090	0.027	21.740
14/06/93	0.090	0.027	22.990
15/06/93	0.090	0.027	32.970
16/06/93	0.090	0.027	20.830
17/06/93	0.090	0.027	35.090
18/06/93	0.090	0.027	31.250
19/06/93	0.090	0.027	33.140
20/06/93	0.090	0.027	11.490
21/06/93	0.090	0.027	21.280
22/06/93	0.090	0.027	11.360
23/06/93	0.090	0.027	25.160
24/06/93	0.090	0.027	34.480
25/06/93	0.090	0.027	21.860
26/06/93	0.090	0.027	22.990
27/06/93	0.090	0.027	32.610
28/06/93	0.090	0.027	22.470
29/06/93	0.090	0.027	25.640
30/06/93	0.090	0.027	32.610
01/07/93	0.090	0.027	22.990
02/07/93	0.090	0.027	25.160
03/07/93	0.090	0.027	13.160
04/07/93	0.090	0.027	22.600

Table C continued

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
05/07/93	0.090	0.027	24.690
06/07/93	0.090	0.027	31.250
07/07/93	0.090	0.027	23.670
08/07/93	0.090	0.027	31.250
09/07/93	0.090	0.027	32.970
10/07/93	0.090	0.027	11.240
11/07/93	0.090	0.027	24.810
12/07/93	0.090	0.027	30.060
13/07/93	0.090	0.027	23.550
14/07/93	0.095	0.030	19.180
15/07/93	0.095	0.030	16.820
16/07/93	0.095	0.030	18.930
17/07/93	0.095	0.030	25.820
18/07/93	0.090	0.027	11.370
19/07/93	0.090	0.027	31.560
20/07/93	0.090	0.027	12.760
21/07/93	0.090	0.027	20.410
22/07/93	0.090	0.027	13.520
23/07/93	0.090	0.027	16.930
24/07/93	0.090	0.027	12.670
25/07/93	0.090	0.027	27.780
26/07/93	0.090	0.027	19.290
27/07/93	0.090	0.027	14.220
28/07/93	0.090	0.027	18.090
29/07/93	0.090	0.027	20.320
30/07/93	0.090	0.027	15.690
31/07/93	0.090	0.027	12.030
01/08/93	0.090	0.027	15.720
02/08/93	0.090	0.027	24.680
03/08/93	0.090	0.027	21.050
04/08/93	0.090	0.027	13.760
05/08/93	0.090	0.027	14.160
06/08/93	0.095	0.030	19.430
07/08/93	0.095	0.030	24.940
08/08/93	0.095	0.030	20.480
09/08/93	0.090	0.027	14.730
10/08/93	0.090	0.027	12.020
11/08/93	0.090	0.027	17.950
12/08/93	0.090	0.027	19.330
13/08/93	0.090	0.027	17.050
14/08/93	0.090	0.027	12.790
15/08/93	0.090	0.027	11.510
16/08/93	0.090	0.027	23.980
17/08/93	0.090	0.027	34.080
18/08/93	0.090	0.027	23.920
19/08/93	0.090	0.027	31.080
20/08/93	0.090	0.027	27.940
21/08/93	0.090	0.027	26.920
22/08/93	0.090	0.027	17.320

Table C continued

Date	Stage Lower (m)	Mean Disch. (m^3/s)	Grab Conc. (ppm)
23/08/93	0.090	0.027	25.970
24/08/93	0.090	0.027	40.210
25/08/93	0.090	0.027	21.540
26/08/93	0.090	0.027	19.530
27/08/93	0.090	0.027	23.460
28/08/93	0.090	0.027	12.710
29/08/93	0.090	0.027	17.840
30/08/93	0.090	0.027	23.520
31/08/93	0.090	0.027	15.090
01/09/93	0.090	0.027	26.510
02/09/93	0.090	0.027	20.440
03/09/93	0.095	0.030	14.410
04/09/93	0.095	0.030	36.450
05/09/93	0.095	0.030	22.120
06/09/93	0.095	0.030	23.060
07/09/93	0.090	0.027	16.230
08/09/93	0.090	0.027	21.580
09/09/93	0.090	0.027	15.290
10/09/93	0.090	0.027	19.520
11/09/93	0.090	0.027	12.810
12/09/93	0.090	0.027	27.200
13/09/93	0.090	0.027	11.380
14/09/93	0.090	0.027	16.980
15/09/93	0.090	0.027	27.250

Appendix IX Sediment graph data for 14 mobilised sediment events.

MOBILISED SEDIMENT EVENT OF 27-10-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.110	39.450	0.000	0.000
3	0.140	113.380	0.033	0.274
6	0.170		0.065	
9	0.160		0.024	
12	0.150		0.024	
15	0.150	134.720	0.016	0.201
18	0.140	129.350	0.016	0.174
21	0.130	63.070	0.016	0.085
24	0.125	49.470	0.011	0.049
27	0.125	58.430	0.011	0.058
30	0.120		0.008	
33	0.120		0.008	
36	0.120		0.008	
39	0.115	52.590	0.004	0.017
42	0.115	55.310	0.004	0.018
45	0.115	42.500	0.004	0.014
48	0.115	49.660	0.004	0.016
51	0.115	52.010	0.004	0.017
54	0.110		0.000	
57	0.110		0.000	
60	0.110		0.000	
63	0.110	46.720	0.000	0.000
66	0.110	42.090	0.000	0.000
69	0.110	51.710	0.000	0.000
72	0.110	49.020	0.000	0.000
75	0.110	42.080	0.000	0.000
78	0.110		0.000	
81	0.110		0.000	
84	0.110		0.000	
87	0.110	39.440	0.000	0.000
90	0.110	28.450	0.000	0.000
93	0.110	41.670	0.000	0.000
96	0.110	32.070	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	0.117

Start at 3.15 p.m

MOBILISED SEDIMENT EVENT OF 03-11-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.120	41.940	0.000	0.000
3	0.180	104.710	0.057	0.517
6	0.270	239.360	0.182	3.767
9	0.230	106.200	0.121	1.109
12	0.220	128.860	0.107	1.190
15	0.200	115.690	0.081	0.808
18	0.190	112.270	0.069	0.666
21	0.180	82.880	0.057	0.409
24	0.170	91.410	0.046	0.364
27	0.170	88.320	0.046	0.352
30	0.160	62.970	0.036	0.194
33	0.150	75.590	0.026	0.169
36	0.150	78.460	0.026	0.176
39	0.145	72.940	0.021	0.134
42	0.145	79.650	0.021	0.146
45	0.145	81.180	0.021	0.149
48	0.140	62.240	0.017	0.090
51	0.140	71.650	0.017	0.103

MOBILISED SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	2.59

Start at 3.00 p.m.

MOBILISED SEDIMENT EVENT OF 15-11-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.140	67.580	0.000	0.000
3	0.170	112.840	0.029	0.287
6	0.210	127.410	0.077	0.847
9	0.190	121.050	0.052	0.544
12	0.170	81.620	0.029	0.208
15	0.160	75.650	0.019	0.124
18	0.150	79.230	0.009	0.063
21	0.140	68.440	0.000	0.000
24	0.140	71.900	0.000	0.000
27	0.140	64.380	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	0.173
1.0	0
1.5	0.173
2.0	0.173

Start at 10.00 a.m.

MOBILISED SEDIMENT EVENT OF 16-11-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.130	56.360	0.000	0.000
3	0.210	133.520	0.086	0.987
6	0.300	219.110	0.226	4.281
9	0.490	621.950	0.672	36.130
12	0.450	486.890	0.562	23.634
15	0.400	326.300	0.436	12.292
18	0.350	276.310	0.324	7.737
21	0.310	289.240	0.245	6.113
24	0.280	228.700	0.191	3.773
27	0.260	170.730	0.158	2.330
30	0.250	168.740	0.142	2.075
33	0.240	151.340	0.127	1.664
36	0.220	145.870	0.099	1.247
39	0.200	121.620	0.073	0.766
42	0.185	87.350	0.055	0.414
45	0.170	96.420	0.038	0.318
48	0.170	87.610	0.038	0.289
51	0.160	74.950	0.028	0.179
54	0.160	82.740	0.028	0.198
57	0.150	73.820	0.018	0.114
60	0.150	78.400	0.018	0.121
63	0.140	64.760	0.009	0.048
66	0.145	82.120	0.013	0.094
69	0.135	60.410	0.004	0.022
72	0.135	52.990	0.004	0.020
75	0.130	67.700	0.000	0.000
78	0.130	81.240	0.000	0.000
81	0.130	54.410	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	26.212

Start at 12.00 p.m.

MOBILISED SEDIMENT EVENT OF 07-12-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.110	41.480	0.001	0.002
3	0.190	142.070	0.077	0.941
6	0.330	277.940	0.299	7.186
9	0.315	313.090	0.270	7.305
12	0.290	272.550	0.224	5.281
15	0.280	218.210	0.207	3.901
18	0.260	162.820	0.174	2.447
21	0.255	182.360	0.166	2.617
24	0.230	115.930	0.129	1.290
27	0.230	158.620	0.129	1.765
30	0.220	189.730	0.115	1.884
33	0.210	113.630	0.102	0.997
36	0.210	120.070	0.102	1.054
39	0.200	101.930	0.089	0.782
42	0.180	132.590	0.065	0.746
45	0.170	96.630	0.054	0.452
48	0.150	87.620	0.034	0.257
51	0.140	90.920	0.025	0.194
54	0.130	105.380	0.016	0.146
57	0.130	75.830	0.016	0.105
60	0.120	81.540	0.008	0.056
63	0.120	72.950	0.008	0.050
66	0.120	70.520	0.008	0.049
69	0.120	65.420	0.008	0.045
72	0.110	63.290	0.001	0.003
75	0.110	58.810	0.001	0.003
78	0.110	37.590	0.001	0.002
81	0.110	46.780	0.001	0.002
84	0.110	39.420	0.001	0.002

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	1.185
1.0	1.185
1.5	0
2.0	6.337
2.5	0
3.0	1.185

Start at 3.45 p.m.

MOBILISED SEDIMENT EVENT OF 10-12-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.120	41.630	0.000	0.000
3	0.160	78.280	0.043	0.292
6	0.250	141.600	0.158	1.930
9	0.180	92.850	0.065	0.518
12	0.180	103.980	0.065	0.580
15	0.170	74.450	0.054	0.344
18	0.170	101.610	0.054	0.470
21	0.150	92.640	0.033	0.267
24	0.150	70.810	0.033	0.204
27	0.145	63.280	0.029	0.157
30	0.140	60.860	0.024	0.127
33	0.140	65.210	0.024	0.136
36	0.140	54.530	0.024	0.114
39	0.140	50.450	0.024	0.105
42	0.140	56.570	0.024	0.118
45	0.130	62.630	0.015	0.084
48	0.130	51.570	0.015	0.069
51	0.130	53.420	0.015	0.071
54	0.130	48.690	0.015	0.065
57	0.125	55.420	0.011	0.054
60	0.125	49.040	0.011	0.048
63	0.125	52.250	0.011	0.051
66	0.120	60.270	0.007	0.039
69	0.120	42.060	0.007	0.027
72	0.120	38.260	0.007	0.025
75	0.120	41.940	0.007	0.027
78	0.120	47.240	0.007	0.030

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	1.49

Start at 2.30 p.m.

MOBILISED SEDIMENT EVENT OF 16-12-92

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.130	56.210	0.000	0.000
3	0.190	111.860	0.061	0.587
6	0.220	142.630	0.099	1.219
9	0.280	165.700	0.191	2.733
12	0.240	192.820	0.127	2.121
15	0.235	123.360	0.120	1.279
18	0.230	142.710	0.113	1.391
21	0.215	137.590	0.092	1.096
24	0.210	128.720	0.086	0.952
27	0.210	120.530	0.086	0.891
30	0.200	143.640	0.073	0.904
33	0.195	112.280	0.067	0.647
36	0.190	118.720	0.061	0.623
39	0.190	93.890	0.061	0.492
42	0.180	103.270	0.049	0.438
45	0.170	86.600	0.038	0.285
48	0.170	72.740	0.038	0.240
51	0.160	91.380	0.028	0.219
54	0.150	69.400	0.018	0.107
57	0.150	73.170	0.018	0.113
60	0.145	54.600	0.013	0.062
63	0.140	62.370	0.009	0.047
66	0.140	49.280	0.009	0.037
69	0.135	63.510	0.004	0.023
72	0.135	52.560	0.004	0.019
75	0.135	63.360	0.004	0.023
78	0.135	57.690	0.004	0.021
81	0.130	50.180	0.000	0.000
84	0.130	43.410	0.000	0.000
87	0.130	62.260	0.000	0.000
90	0.130	39.730	0.000	0.000
93	0.130	58.070	0.000	0.000
96	0.130	63.150	0.000	0.000
99	0.130	54.430	0.000	0.000
102	0.130	43.870	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	2.07
1.0	0
1.5	2.07

Start at 12.30 a.m.

MOBILISED SEDIMENT EVENT OF 01-01-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.110	42.380	0.000	0.000
3	0.130	73.950	0.016	0.099
6	0.150		0.033	
9	0.140		0.024	
12	0.130		0.016	
15	0.130	62.950	0.016	0.084
18	0.125	54.410	0.011	0.054
21	0.120	39.680	0.008	0.026
24	0.120	62.990	0.008	0.041
27	0.120	42.920	0.008	0.028
30	0.120		0.008	
33	0.115		0.004	
36	0.115		0.004	
39	0.115	52.230	0.004	0.017
42	0.110	39.500	0.000	0.000
45	0.110	48.240	0.000	0.000
48	0.110	77.240	0.000	0.000
51	0.110	41.620	0.000	0.000
54	0.110		0.000	
57	0.110		0.000	
60	0.110		0.000	
63	0.110	24.650	0.000	0.000
66	0.110	49.300	0.000	0.000
69	0.110	85.260	0.000	0.001
72	0.110	65.240	0.000	0.000
75	0.110	62.030	0.000	0.000
78	0.110		0.000	
81	0.110		0.000	
84	0.110		0.000	
87	0.110	82.960	0.000	0.001
90	0.110	58.150	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	0.045

Start at 3.10 p.m.

MOBILISED SEDIMENT EVENT OF 07-01-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.120	39.440	0.000	0.000
3	0.140	68.070	0.017	0.098
6	0.180	106.610	0.057	0.526
9	0.210	163.640	0.094	1.323
12	0.260		0.166	
15	0.350		0.332	
18	0.340		0.311	
21	0.320	246.870	0.272	5.794
24	0.310	292.100	0.253	6.375
27	0.290	230.720	0.216	4.311
30	0.280	227.920	0.199	3.917
33	0.250	132.970	0.150	1.727
36	0.240		0.135	
39	0.230		0.121	
42	0.220		0.107	
45	0.200	193.680	0.081	1.353
48	0.190	109.260	0.069	0.648
51	0.180	125.660	0.057	0.620
54	0.175	82.050	0.052	0.365
57	0.160	75.790	0.036	0.234
60	0.150		0.026	
63	0.140		0.017	
66	0.140		0.017	
69	0.140	92.430	0.017	0.133
72	0.135	81.450	0.012	0.086
75	0.135	65.490	0.012	0.069
78	0.135	64.170	0.012	0.068
81	0.130	51.840	0.008	0.036
84	0.130		0.008	
87	0.125		0.004	
90	0.125		0.004	
93	0.125	41.530	0.004	0.014
96	0.125	38.120	0.004	0.013
99	0.120	39.440	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	0.394
1.0	0
1.5	0.394
2.0	0.394
2.5	0
3.0	0
3.5	0
4.0	0
4.5	0.394
5.0	0
5.5	0
6.0	0.394
6.5	0.394

MOBILISED SEDIMENT EVENT OF 13-01-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.110	58.780	0.000	0.000
3	0.200	128.420	0.088	0.980
6	0.240	192.420	0.143	2.374
9	0.290		0.224	
12	0.280		0.206	
15	0.280		0.206	
18	0.270	163.290	0.190	2.676
21	0.250	195.080	0.158	2.660
24	0.250	154.600	0.158	2.108
27	0.270	148.210	0.190	2.429
30	0.260	162.750	0.173	2.439
33	0.240		0.143	
36	0.230		0.128	
39	0.220		0.114	
42	0.210	107.860	0.101	0.942
45	0.200	139.780	0.088	1.067
48	0.185	97.900	0.070	0.595
51	0.180	105.220	0.065	0.587
54	0.170	97.710	0.054	0.453
57	0.160		0.043	
60	0.150		0.033	
63	0.150		0.033	
66	0.140	68.510	0.024	0.143
69	0.135	79.210	0.020	0.135
72	0.130	82.340	0.016	0.111
75	0.130	49.690	0.016	0.067
78	0.120	56.570	0.008	0.037
81	0.120		0.008	
84	0.120		0.008	
87	0.115		0.004	
90	0.115	92.240	0.004	0.030
93	0.115	72.950	0.004	0.023
96	0.110	55.170	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	5.28
22.0	0
22.5	1.35

Start at 1 p.m.

MOBILISED SEDIMENT EVENT OF 15-01-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.110	39.320	0.000	0.000
3	0.170	89.660	0.054	0.415
6	0.290	247.530	0.224	4.784
9	0.270	234.800	0.190	3.846
12	0.250	163.920	0.158	2.234
15	0.260	198.170	0.173	2.969
18	0.260	175.210	0.173	2.625
21	0.240	152.720	0.143	1.883
24	0.235	137.670	0.135	1.611
27	0.220	173.480	0.114	1.714
30	0.210	112.200	0.101	0.979
33	0.210	120.370	0.101	1.051
36	0.200	103.250	0.088	0.788
39	0.180	96.720	0.065	0.539
42	0.170	83.770	0.054	0.388
45	0.150	74.680	0.033	0.215
48	0.140	68.820	0.024	0.143
51	0.130	61.430	0.015	0.082
54	0.130	58.300	0.015	0.078
57	0.120	62.920	0.007	0.040
60	0.115	63.340	0.004	0.020
63	0.115	41.650	0.004	0.013
66	0.115	39.290	0.004	0.012
69	0.115	45.150	0.004	0.014
72	0.110	52.760	0.000	0.000
75	0.110	38.200	0.000	0.000
78	0.110	49.030	0.000	0.000
81	0.110	37.530	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	2.74
1.0	2.74

Start at 1.30 p.m.

MOBILISED SEDIMENT EVENT OF 18-01-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.120	52.390	0.000	0.000
3	0.160	79.860	0.043	0.298
6	0.300	245.810	0.242	5.132
9	0.390	392.700	0.428	14.522
12	0.360	338.830	0.361	10.564
15	0.330	274.340	0.299	7.081
18	0.315	268.030	0.270	6.242
21	0.305	251.160	0.251	5.443
24	0.290	213.290	0.224	4.123
27	0.280	236.650	0.206	4.221
30	0.270	185.300	0.190	3.036
33	0.260	192.520	0.173	2.885
36	0.245	160.730	0.150	2.086
39	0.240	155.360	0.143	1.917
42	0.220	131.300	0.114	1.298
45	0.210	123.620	0.101	1.080

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	16.74

Start at 12.00 p.m

MOBILISED SEDIMENT EVENT OF 20-01-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.140	92.670	0.000	0.001
3	0.410	423.780	0.452	16.534
6	0.620	842.610	1.083	78.871
9	0.790	924.360	1.769	141.291
12	0.630	792.380	1.119	76.638
15	0.600	642.300	1.013	56.209
18	0.550	656.520	0.846	47.993
21	0.500	602.650	0.693	36.077
24	0.460	530.120	0.580	26.571
27	0.420	451.040	0.476	18.557
30	0.390	369.970	0.404	12.915
33	0.360	362.010	0.337	10.536
36	0.350	320.780	0.316	8.747
39	0.340	331.430	0.295	8.444
42	0.330	275.620	0.275	6.542
45	0.310	258.450	0.236	5.272
48	0.300	253.410	0.218	4.765
51	0.290	239.050	0.200	4.126
54	0.290	220.420	0.200	3.804
57	0.270	204.030	0.166	2.920
60	0.250	182.210	0.134	2.107
63	0.240	143.200	0.119	1.470
66	0.230	126.960	0.104	1.144
69	0.230	152.620	0.104	1.376
72	0.220	137.420	0.090	1.074
75	0.200	115.760	0.064	0.644
78	0.190	108.650	0.052	0.490
81	0.180	126.520	0.041	0.444
84	0.180	94.030	0.041	0.330
87	0.180	109.370	0.041	0.384
90	0.170	97.830	0.030	0.250
93	0.170	82.520	0.030	0.211
96	0.170	87.310	0.030	0.223
99	0.160	95.490	0.019	0.158
102	0.160	79.480	0.019	0.132
105	0.160	83.050	0.019	0.138
108	0.150	71.120	0.009	0.058

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	8.37
1.0	68.02
1.5	68.02

Start at 3.00 p.m.

MOBILISED SEDIMENT EVENT OF 11-02-93

TIME (Hours)	GAUGE HEIGHT (m)	SEDIMENT CONC. (ppm)	TOTAL WATER DISCH. (m^3/s)	TOTAL SEDIMENT DISCH. (t/day)
0	0.110	32.650	0.000	0.000
3	0.180	95.420	0.065	0.533
6	0.220	156.410	0.114	1.546
9	0.200	114.530	0.088	0.874
12	0.190	126.290	0.076	0.831
15	0.180	104.380	0.065	0.583
18	0.180	109.610	0.065	0.612
21	0.175	116.150	0.059	0.592
24	0.170	94.620	0.054	0.438
27	0.170	63.930	0.054	0.296
30	0.160	105.800	0.043	0.395
33	0.160	94.620	0.043	0.353
36	0.150	86.550	0.033	0.250
39	0.150	46.280	0.033	0.134
42	0.140	79.410	0.024	0.166
45	0.135	64.600	0.020	0.110
48	0.135	54.940	0.020	0.094
51	0.130	61.070	0.016	0.082
54	0.120	55.630	0.008	0.036
57	0.120	52.260	0.008	0.034
60	0.120	73.580	0.008	0.048
63	0.120	48.590	0.008	0.031
66	0.115	63.750	0.004	0.020
69	0.115	57.020	0.004	0.018
72	0.110	48.610	0.000	0.000
75	0.110	54.130	0.000	0.000
78	0.110	36.680	0.000	0.000

SEDIMENT HISTOGRAM

TIME (Hours)	MOBILISED SEDIMENT (t/h)
0.5	0.67
1.0	0.67
1.5	0.67

Start at 4.45 a.m.