SILTING CHARACTERISTICS OF DISTRIBUTARIES IN KANO RIVER PROJECT

BY

ADEOYE, ADEWALE AZEEZ

B.Sc.(Hons) Unilag

A thesis submitted to the Postgraduate School, Ahmadu Bello University Zaria in partial fulfillment of the requirements for the degree of M.Sc. (Water Resources and Environmental Engineering)

May, 1994

DECLARATION

I hereby declare that the work presented in this thesis is from original research and the thesis has not been presented to any university for higher degree examination.

All references in this work have been duly acknowledged.



ADEWALE ADEOYE

CERTIFICATION

This thesis entitled: "Silting Characteristics of Distributaries" in Kano River Project by ADEOYE, Adewale Azeez meets the regulations governing the award of the degree of Master of Science (Water Resources and Environmental Engineering) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Dr. L. I. Odigie	
Chairman, Supervisory Committee	*Date*
Dr. P.R. Maurya	
Member, Supervisory Committee	*Date*
Dr. L.I. Odigie	
Head,	*Date*
Department of Water Resources	
and Environmental Engineering	
Dean, Postgraduate School	*Date*

DEDICATION

To my beloved friend Late Issa Abiona Egbeyale who passed away to the world beyond on the 4th February, 1990.

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ABSTRACT

A study of the evaluation of the performance of the Water Distribution system in the Kadawa sector of the Kano River Project was carried out by Jimoh, O.D. in 1991.He came up with siltation of the distributaries as one of the problems affecting the efficient water distribution system within the irrigation system.

This study has thus examined the silting characteristics of distributaries during the 1991/92 dry season farming in Kano River Project. The Kadawa lateral canal, distributary canal and field channel were selected for the study.

The amount of bed load discharge (2.62 g/day) is small as compared with the total sediment load (23.22 g/day). The bed load discharge is found to be 11% of the total sediment load.

About 1082 m^3 of sediment were scour, out of which 838m^3 are deposited as at the time of study in the selected portions, of the canal system. This has greatly changed the bed configuration of the canals. As a result, the hydraulic efficiency of the distributary and field channel was 56%.as against 64% obtained by Jimoh (1991) This section of the canal is not lined. However, the hydraulic efficiency of the lined lateral canal was 91%. This lined section is not infested with weeds.

Sediment transported through the canal system is predominantly silt and clay. This aids rapid growth of weeds.

Recommendations on how to reduce the siltation problem and improve on the efficiency of the canals were made.

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GLOSSARY

1. Sector

It is a unit of the irrigable area with only one inlet for diverting water from the main canal.

A sector has only one lateral canal.

2. Lateral Canal

It is the secondary canal that convey water from the main canal to the tertiary canals.

3. Distributary Canal

It is the tertiary canal in the irrigable area that convey water from the lateral canal to the field channels.

4. Bed Load

It is the sediment that moves by saltation, rolling, or sliding on or near the streambed.

5. Bed Load Discharge

It is the quantity of bed load passing any cross-section of a stream in a unit of time.

6. Hydraulic efficiency

It is the ratio of measured discharge to the designed capacity of the canal at the same depth of flow.

7. Irrigator

He is a staff of the Water Management Department that operates the sector turnout. Each sector in the project has an Irrigator.

8. Clay

It is the sediment particles smaller than 0.004mm in size.

9. Sediment concentration

It is the quantity of sediment relative to the quantity of transporting or suspending fluid, or fluid-sediment mixture.

10. Silt

It is the sediment particles between sand and clay in size (0.004 to 0.062mm)

11. Suspended Sediment

It is the sediment that is supported by the upward components of turbulent currents and that stays in suspension for appreciable lengths of time.

12. Suspended sediment Discharge

It is the quantity of suspended-sediment passing through a stream cross-section in a unit of time.

13. Total Sediment Discharge

It is the total sediment discharge of a stream. In this report, it is the suspended-sediment discharge plus the bed load discharge.

14. Depth Integration

It is a method of sampling to obtain a representative sample of the water sediment discharge from every part of a stream vertical, except in a small unsampler zone near the streambed.

15. Depth Integrated Sample

It is a water sediment mixture that is accumulated continuously in a sampler that moves vertically at an approximately constant transit rate between the surface and a point a few millimetres above the bed of a stream, and that admits the mixture at a velocity about equal to the instantaneous stream relocity at each point in the vertical.

16. Stream Discharge

It is the quantity of natural water passing through a cross section of a stream in a unit of time.

CHAPTER 1

INTRODUCTION

1.1 Objectives of Study

The Institute for Agricultural Research, Ahmadu Bello University Zaira initiated a research on water management practices in Kano River Project. This study, titled: Silting Characteristics of Distributaries in Kano River Project is a unit of the research in water management practices.

The objectives of the study were:

(i) to quantify the sediment input to the canal and determine its temporal and spatial distribution.

(ii) to collect the data needed for a quantitative assessment of the sediment control options and identify the most feasible solutions.

1.2 Statement of Problem

In the past, many hydraulic engineering works have been built on sediment-bearing streams without adequate consideration of the effects of sedimentation on the life and utility of the projects. The presence of sediment caused unforeseen difficulties in operating and maintaining these engineering works, and shortened the economic life for many of them.

In the Kadawa irrigation scheme, 16,000 ha irrigable area was developed under phase I. About 13,674 ha was irrigated during 1987/88 dry season. The balance 2,326 ha was not irrigated due to water management problems (HJRBDA, 1988). Jimoh (1991), for example, reported that the hydraulic efficiency of the main canal was 64% due to retardance effect of

the tall weeds in the canal. Also, the manning roughness coefficient of the reach was increased from 0.030 (the designed value) to 0.053 by the weeds and the hydraulic efficiency of one of the distributary canals was 62% due to silts in the canal (Jimoh, 1991).

However, a study was initiated by the Institute for Agricultural Research, Ahmadu Bello University Zaira to identify the problems facing the irrigation projects. One of such studies was the Evaluation of the performance of Water Distribution system in the Kadawa sector of the Kano River Project by Jimoh, O.D. in 1991. He came up with siltation of the canals as one of the problems affecting the efficient water distribution system within the irrigation system. Thus the study described herein will be focused on the siltation in the canals.

1.3 Description of Kano River Project Area.

The Kano River Project lies between latitude $8^0 30'$ to $9^0 40'$ E and $11^0 30'$ to $12^0 03'$N in the savannah zone of Nigeria. The project area is shown in Figure 1.1. The Kano River Project was initiated in 1970 under the Kano State Ministry of Agriculture and Natural Resources for irrigation purposes. The project has a potential of 62,000 ha irrigable area and the development of the irrigable area was divided into phase I and phase II. The development of the irrigable area under phase I started in 1970 with 22,000 ha. The balance 40,000 ha irrigable area will be developed under phase II. By 1992, only 16,000 ha irrigable area had been developed and development of the area under phase II has not started.

1.3.1 Water Distribution Network

The irrigable area under phaseI is divided into West and East Branch Regions by River Shimar. The West and East Branch Regions cover 13,600 ha and 8,400 ha irrigable area respectively. The West branch region is bounded in the western side by Kano River and eastern side by Shimar River.

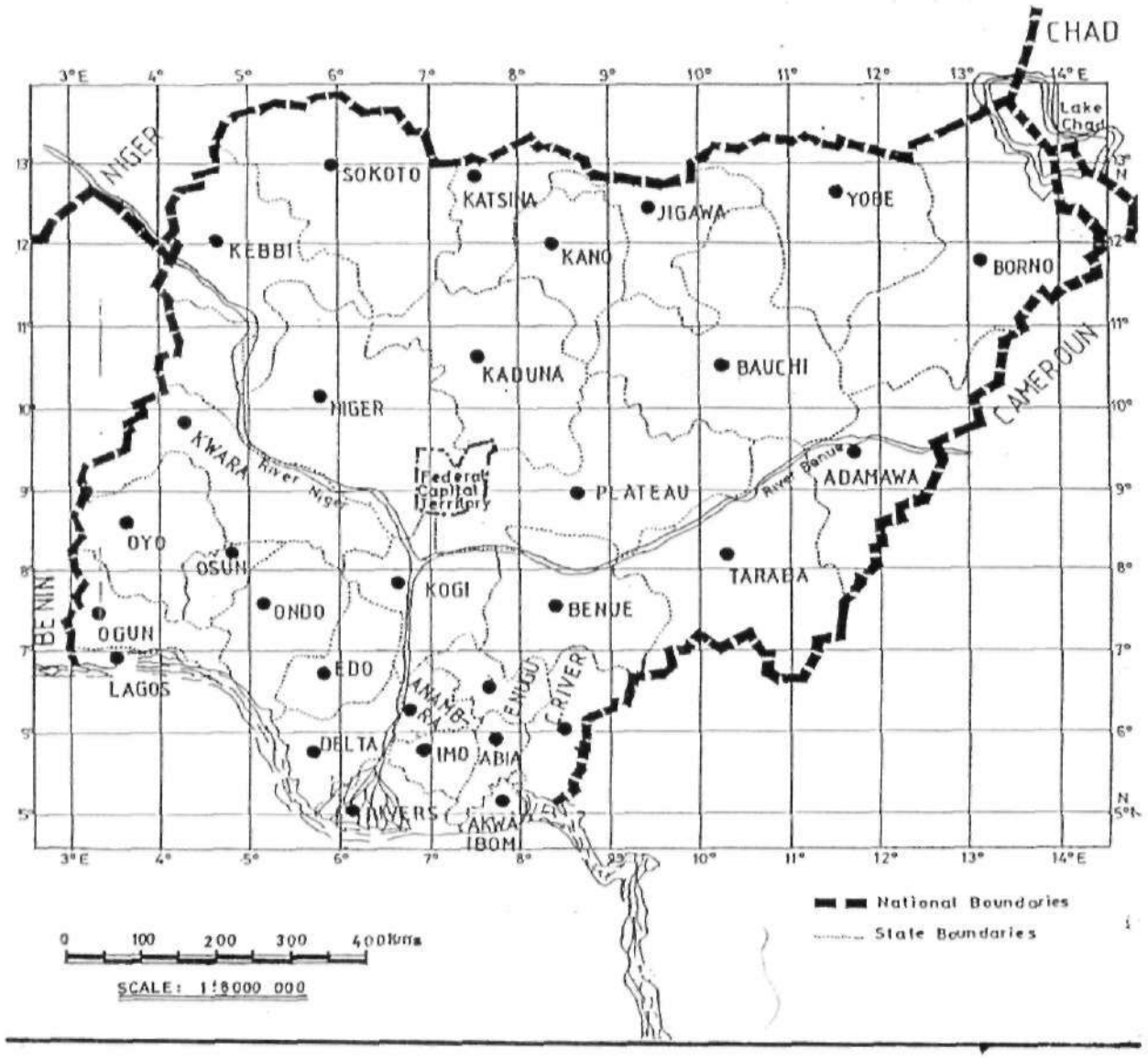


FIG. 1
MAP OF NIGERIA
KANO STATE LOCATION

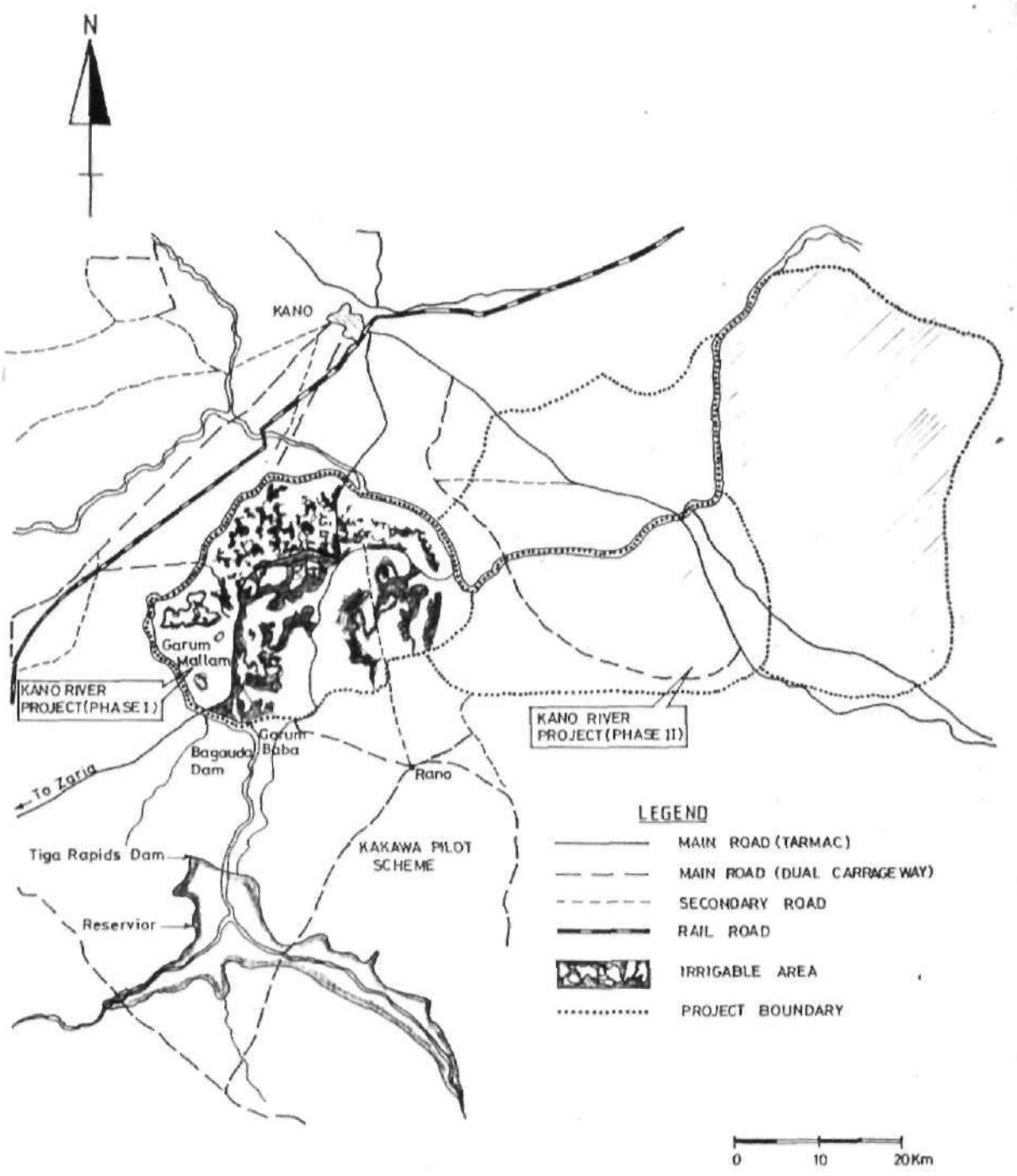


FIG.1.1 KANO RIVER PROJECT – PROJECT AREA MAP

SOURCE: (a) Nwa and Martins 1982
(b) Malaysia Int. Consultant 1984

The multipurpose Tiga dam in Kano state supplies water to both regions. The dam has an active storage capacity of 1,845 million cubic metres and is situated at about 19 Km away from the beginning of the irrigable area under phaseI. Water from the dam is conveyed through a 4 Km unlined canal to Ruwan Kanya Reservoir. The reservoir has a designed total storage capacity of 57.6 million cubic metres. The reservoir was designed to supply water only to the irrigable area under phase I. The water from the reservoir flows through a 6 Km unlined canal to Rano Regulator. At the regulator, the supply to the West Branch Region and the three upper sectors in the East Branch Region is controlled. The spill upstream of the Rano regulator flows into the east branch canal.

The discharge from the regulator is conveyed through a 3 Km unlined canal to Garum Baba Headwork where the main diversion into the west branch canal takes place. The west branch canal is a 22 Km lined canal and is divided into 29 sectors. Each sector has a lateral canal that takes water from the west branch canal through the sector turnout. The sector turnout consists of a sluice gate at the west branch canal, joined by a pipe culvert to a stilling basin. The water from the basin flows over a broad crested weir into the lateral canal. The flow over the weir is controlled by undershot gate. When the difference between water level in the basin and the crest of the weir is 450mm (designed upstream head), the flow over the weir will be supercritical. A 50% change in the level of flow in the west branch canal, will reduce the discharge by 10% (Malaysia Int. Consultant, 1984). According to the report, flows in the west branch canal must be greater than 25% of its capacity for this operation to be attained.

The lateral canals which are supposed to be lined, distribute water through the distributary turnouts to the unlined distributary canals. The flow in the distributary canals are diverted into the field channels through field turnouts. The features and operation of the distributary and field turnouts are similar to the sector turnouts.

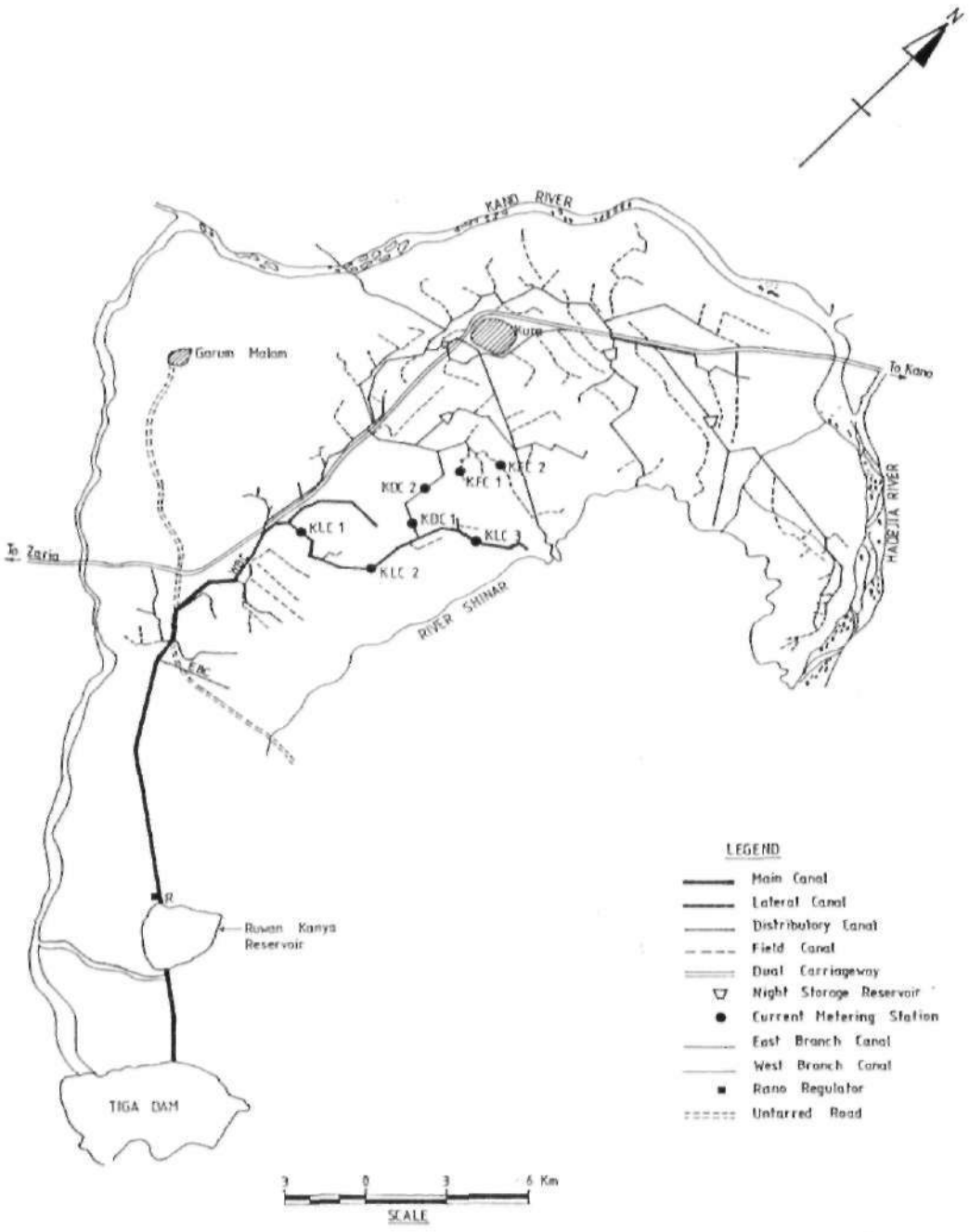


FIG. 1.2 METERING SECTIONS (KADAWA SECTOR)

(Source - Malaysia Int Consultant 1984)

1.4 Development of sediment measurements

The subcommittee on sedimentation of the Inter-Agency Committee on Water Resources (1963), reported that since the earliest times, man has experienced difficulties due to sediment carried by natural streams. Although a knowledge of the manner in which fluvial sediment is transported and deposited would have aided in avoiding or overcoming many of these difficulties, sediment investigations did not begin until comparatively recent years. The first investigations were made in Italy in the latter part of the 17th century, but so far as can be determined, it was not until the early part of the 19th century that quantitative measurements of sediment carried by natural streams were made by Gorsse and Subuors in Rhone River in 1808 and 1809.

The development of irrigation along rivers was often difficult because of the heavy loads of sediment carried by these streams. In order to find a solution to the sediment problem, sediment discharge measurements were started in many of these rivers in the latter part of the 19th century. Samples were first collected in the Rio Grande in 1889 and 1890 by the US Geological Survey and have been taken more or less continuously since 1897 by other agencies.

US Geological Survey(1945), measured suspended-sediment loads on streams in many basins. Several new methods and concepts have been developed by the Survey. The turbulence flume was developed to obtain total sediment discharge so that the relations between total suspended sediment discharge and bed-load discharge, and between measured sediment discharge and unmeasured sediment discharge could be studied. The modified Einstein method and direct velocity relationships were devised to aid in determination of the coarse sediment discharge. The foregoing development deals primarily with determinations of suspended sediment discharge.

Davies (1898), undertook measurements of the heavier material moving on or near the stream bed for the proposed Nicaraguan canal. The use of bed load discharge samplers has been developed extensively in Europe since 1930. Total sediment discharge is being measured effectively by the Tennessee Valley Authority on two small streams. Suspended sediment that passes a weir is measured by means of an automatic suspended sediment sampler which continuously diverts a small portion of the flow into a tank. The volume of sediment that is deposited in the basin upstream from the weir is measured at regular intervals by standard surveying methods, and samples of the deposited sediment are analysed for density and grain size.

A comprehensive program for the development of sediment sampling equipment was begun in 1940. The samplers developed by the project have revolutionized sediment sampling techniques throughout the world. US Geological Survey(1943),used the new sampler at a routine sediment sampling station on the Iowa River near Coralville. This equipment has almost entirely replaced other types of sampling equipment.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Mechanism of Sediment Transport

Movement of the particles begins when the momentum flux parameter of the jet exceeds a certain critical value. For momentum-flux parameters slightly above the critical value, the sediment is transported primarily along the bed as bed load. Depending upon the relative size of the particles of the bed and the magnitude of the momentum-flux parameter of the jet, the mechanism of transportation may be one or the combination of any of the three kinds of transportation phenomena namely :

(i) rolling

(ii) saltation

(iii) suspension

Graf (1971) described three kinds of transportation phenomena as follows :

Rolling : The bed particle is rolled or slide along the bed by the fluid dynamic thrust. It is substantially in continuous contact with the bed.

Saltation : This is a transitional type of movement between rolling and suspension. If the solid remains stationary on the bed, then the fluid dynamic thrust will not be parallel with the stream but will have an upward component. If the speed of the current is increased until the solid is dislodged, it will move away from the bed and travel in a trajectory. Saltating particles are strongly accelerated near the bed and begin their motion almost vertically upward, being gradually accelerated horizontally in the direction of flow. Their trajectory reaches a height few millimetres above the bed and then gradually curves back to the bed at a great distance downstream from the starting point. The reason for descending being that

when water borne, the solid soon acquires the velocity of the adjacent water filaments and the dynamic thrust declines. The steep velocity gradient assists in this type of motion.

Suspension : Suspension of sediment occurs as a result of turbulent mixing within the mixing fluid, being kept by the upward components of the turbulent currents.

2.1.1 Initiation of Motion

Committee on sedimentation of the American Society of Civil Engineers (1966), reported that the process of initiation of motion is statistical in nature and that Einstein (1942) was the first to develop a transport relation based on statistical concepts. Because of the statistical nature of the entertainment process, there is no truly critical condition for initiation of motion for which motion begins suddenly as the condition is reached. Data available are based on critical shear stress and on a more or less arbitrary definitions of critical conditions.

Krammer (1935), for example, defined the following three intensities of motion near the critical or threshold condition :

(i) Weak movement-- indicates that a few or several of the smallest sand particles are in motion in isolated spots with small quantities so that those moving one square centimetre of the bed can be counted.

(ii) Medium movement--indicates the condition in which grains of mean diameter are in motion in uncountable numbers. Such movement is no longer local in character. It is not yet strong enough to affect bed configuration and does not result in appreciable sediment discharge.

(iii) General movement--indicates the condition at which sand grains up to and including the largest are in motion and movement is occurring in all parts of the bed at all times.

Water flowing over a bed of sediment exerts forces on the grains that tend to move or entrain them. The forces that resists the entrainment action of the flowing water differ according to the grain size distribution of the sediment. For coarse sediments such as sands and gravels, the forces resisting motion are caused mainly by the weight of the particles.

Finer sediments that contain appreciable fractions of silt or clay or both, tend to be cohesive and resist entrainment mainly by cohesion rather than by the weight of the individual grains. Also, in fine sediments, group of grains are entrained as units whereas coarse non-cohesive sediments are moved as individual grains. Cohesion of fine sediment is a complicated phenomenon that appears to vary with mineral composition and environment.

2.2 Distribution of sediment in a stream

2.2.1 Types of sediment transportation

Sediment transport is a coordinated or dependent combination of bed movement, saltation, and suspension, the parts of which cannot be accurately considered separately except in the case of bed movement when no material is in suspension

Gilbert(1914), demonstrated that streams of water carry forward debris in various ways. The simplest is that in which the particles are slid or rolled. Sliding rarely takes place except where the bed of the channel is smooth. Pure rolling, in which the particle is continuously in contact with the bed, is also of small relative importance. If the bed is uneven, the particle usually does not retain continuos contact but makes leaps, and the process is then called saltation. With swifter current, leaps are extended, and if a particle thus freed from the bed be caught by an ascending portion of a swirling current, its excursion may be indefinitely prolonged. Thus borne it is said to be suspended, and the process by which it is transported is called suspension. There is no much distinction between saltation and suspension, but the distribution is never the less important, for it serves to distinguish the two methods of hydraulic transportation which follow different laws. In suspension the important factor is the upward component of motion in parts of the complex current while in other transportation, including saltation, rolling, and sliding, the important factor is in motion parallel with the bed and close to it.

According to the mechanism of transport two major modes may be distinguished:

1.	Bed load	- movement of particles in contact with the bed by rolling, sliding and jumping.
2.	Suspended load	- movement of particles in the flow. The settling tendency of the particle is continuously compensated by the diffusive action of the turbulent flow field.

A sharp distinction is not possible. A general criterion for the beginning of suspended load is a ratio of shear velocity and fall velocity $U^x/W \cong 15$. Sometimes also saltation load is mentioned. This is the mode where particles bounce from one position to another. This is only important for particle movement in the order of 2 - 3 times the diameter so that this mode of transport can be considered as bed load.

According to the origin of the transported material a distinction is made as follows:

(i). **Bed -material Transport**	This transport has its origin in the bed, which means that the transport is the bed, which means that the transport is determined by the bed and flow conditions (can consist of bed load and suspended load).
(ii). **Wash load**	Transport of particles not or in small quantities in the bed. The material is supplied by external sources(erosion) and no direct relationship with the load conditions exists (can only be transported as suspended load, generally fine material < 50 m). It can have influence on turbulence and viscosity and therefore have some influence on the flow.

Wash load is not important for changes in the bed of a river but only for sedimentation in reservoirs etc.

2.2.2 Types of Sediment Concentration

The distribution of sediment throughout a stream cross section is expressed in terms of sediment concentration. Two types of suspended sediment concentration are recognised :

(i) Spatial or Static concentration, and

(ii) Discharged weighted Concentration.

Spatial Concentration is the quantity of sediment relative to the quantity of fluid in a fluid - sediment mixture. In this report, it is dry weight of sediment per unit volume of water - sediment mixture or the ratio of the dry weight or the ratio of the dry weight of sediment to the total weight of sediment to the total weight of water - sediment mixture, in a sample. Spatial concentration at a point in the cross section is the sediment concentration in a small volume of the water - sediment mixture at the point. Spatial concentration in a vertical is the sediment concentration in the water - sediment mixture in a small uniform column that is located at the vertical, and that extends vertically from the stream bed to the water surface. Spatial concentration in a cross section is the concentration of sediment in the water - sediment mixture contained in a unit length of channel at the cross - section. The turbidity, density, and other fluid properties of the water - sediment mixture are related to the spatial concentration.

Ideally , spatial concentration could best be sampled by instantaneously enclosing the desired volume of the water - sediment mixture and removing that volume as a sample.

Discharge- Weighted Sediment Concentration is the quantity of sediment discharge relative to the discharge of transporting fluid, or fluid -sediment mixture; or the concentration of sediment in a fluid-sediment discharge. Discharge weighted concentration at a point in the cross-section is the concentration of sediment in the water - sediment discharge through a

small area of cross section at the point. Discharge - weighted concentration in a cross section is the concentration of sediment in the discharge through the entire cross section.

The discharge - weighted concentration may be multiplied by the stream discharge to obtain the discharge of sediment. The discharge - weighted concentration at a point in the cross section can be obtained from a point integrated sediment sample. The discharge - weighted concentration in a sampling vertical can be obtained from the concentration in a depth integrated sample for the vertical or from point - integrated samples that are weighted according to the velocity and depth each sample represents in the vertical.

2.2.3 Vertical Distribution of Suspended Sediment

The suspended sediment concentration generally is at a minimum at the water surface, and at a maximum near the stream bed. The coarsest fractions of the suspended sediment, which are usually sand, exhibit the greatest variation in concentration from the stream bed to the water surface. The fine fractions, silt and clay, are usually uniformly distributed over the depth of the stream, or nearly so. The bed material of a stream with a suspended load of sand, silt, and clay particles tends to be predominantly sand and will contain only traces of silt and clay material. For conditions of steady uniform flow, the concentration, C , of a given size fraction of suspended sediment in a natural sand bed stream varies with depth in such a manner that a plot of (d - y) / y against C is a straight line on log-log paper, in which d = stream depth, y= distance above bed to a point, and C = the concentration of the size fraction at the point.

The presence of dunes or antidunes in streams alternately decreases and increases the local depth. Changes in local depth are associated with large scale eddies that bring about maximum percentage fluctuation in momentary concentration of sediment in suspension. In sand bed channels, the distribution and concentration of the coarse part of the suspended

sediment (bed-material load) are related to the composition of the bed material. In channels with semi-rigid boundaries consisting of cobblestones or cobblestones and boulders, the distribution and concentration of the coarse part of the suspended sediment are not similarly related to the composition of the bed material. In such streams, the concentration of the coarse part of the suspended sediment generally is less than that for streams flowing in sand bed channels of comparable depths and velocities.

Instantaneous or momentary fluctuations in suspended-sediment concentrations are related to scale and intensity of stream turbulence and particle size of sediment in the bed of the stream. Maximum deviations from mean concentration values are to be found in streams where the suspended sediment consists largely of sand. In contrast, minimum deviations from mean concentration values occur in streams where the suspended sediment consists largely of silt and clay, Thus, the amount of the momentary fluctuation in concentration of the suspended sediment at any depth varies with the ratio of the concentration of the sand fraction to the total concentration. The amount of fluctuation also is affected by bed configuration.

Benedict (1948) and Hubbell (1956), found that the concentration for depth integrated samples collected consecutively for selected stream verticals varied as much as 24% from the mean value in shallow sand bed streams. The distribution and concentration of sand particles with depth are also affected by water temperature and concentration of fine sediment.

Lane and Hanson (1949), in a study of sediment transport in the lower Colorado River, found that the suspended load discharge varies approximately 2.5 times from summer to winter for equivalent water discharge for sediment particles smaller than 0.3mm .

Brice (1964), in a review of data from the middle Loup River at Dunning, found that as the water temperature decreases, the suspended sediment concentration increases. Also, the dune height decreases at a temperature near 32^0F and the mean stream velocity increases.

The change in roughness is probably related to a slight change in velocity through a critical value below which the height of the dunes is decreased.

2.2.4. Lateral distribution of suspended sediment

The lateral distribution of suspended sediment at a stream cross-section varies with velocity and depth, channel slope, bed form, particle size of sediment in transport, and inflow from immediate upstream tributaries. The variation in concentration in a cross-section is given in terms of the average concentration for the cross-section for several small rivers. The concentration at each stream vertical is determined from depth or point-integrated samples. Natural streams seldom have symmetrical cross-sections or straight channels. In medium to deep streams with typical meanders, the velocity and concentration usually increases from the inside to the outside of the bend.

2.2.5. Lateral Distribution of Bed Load Discharge

In sand bed channels under conditions of reasonably steady discharge and channel equilibrium, the percentage of total load moved as bed load varies and as the cross-section changes in the direction of flow. In narrow deep sections with high velocities, a larger percentage of the total load is moved as suspended load; in wide shallow sections, the converse generally is true. At a cross-section, the bed load discharge per unit width is a function of the bed composition and of the local velocity; the maximum rate of transport generally is at the lateral location where the velocity is highest. Bed load discharge is also changed by viscosity of the water-sediment mixture, particularly if the flow-transport relationships are such that a slight change in velocity through a critical value results in a change in bed form (Brice, 1964)

In streams with lateral variation of bed roughness in the cross-section, the rate of bed load movement may be expected to vary approximately as the concentration of suspended sediment immediately above the bed.

2.3 Measurement of Suspended Sediment Discharge

2.3.1 Suspended Sediment Concentration

Generally, suspended sediment samples are taken to determine the sediment discharge of the stream, or to determine both sediment discharge and the particle size distribution. These measurements actually apply only to the short period of time for which the samples represent stream conditions. Determination of the suspended sediment discharge continues to be the predominant phase of sediment investigation, but increasing emphasis is being placed upon studies of particle size and size distribution.

If the sediment carried in suspension were uniformly distributed within a stream cross-section, the suspended sediment discharge could be determined fairly simply. Then a single sample taken at any point would indicate the average suspended sediment concentration for the cross-section. The sediment discharge would be the product of the sediment concentration, the stream discharge, and a conversion factor for the units of measurement used. Unfortunately, however, the concentration of fluvial sediment varies more or less throughout any cross-section of a stream, and these variations must be taken into account if an accurate measurement of sediment discharge is to be made.

Suspended sediment concentrations are based on laboratory analysis of the water-sediment mixture obtained with a suspended sediment sampler The corresponding water velocity and discharge are usually obtained from current meter measurements. The sediment discharge per unit area at a point, or per unit width at a vertical, in the stream is computed from the sediment concentration and stream discharge. It is important to obtain at least some basic

data on any stream where a sediment problem is to be studied. Computations based on few data may be considerably in error, they will generally be better than estimates based entirely on data from other streams. Sediment concentration may vary widely from one stream to another. Thus, without local data, an estimate of sediment concentration may be in error several hundred percent. The error may be significantly reduced with only a few field measurements and the improved accuracy will usually justify the cost of at least a small sampling program.

2.3.2 Determination of Water Discharge

Stream flow data must be obtained for any detailed suspended sediment study. The velocity of flow in a stream varies from point to point in any cross-section. It is usually higher near the centre of the stream than at the banks, and it is also higher near the surface than near the bottom. The maximum velocity usually occurs at or just below the surface along the deepest point of the stream. It is impractical to measure the velocity at every point in a cross-section. Measurements are made at a number of systematically located points and the velocity is assumed to vary between measured points according to some reasonable rule. Usually a number of verticals in the cross-section are one or more points in each vertical. Extensive investigations have shown that the mean velocity in a stream vertical can usually be determined with an ample degree of accuracy from measurements at one, or only a few, properly selected points in the vertical. The velocity and depth at a vertical may be assumed to apply for half the distance to the next vertical. If verticals are equally spaced, the discharge for a given vertical is multiplied by the width between verticals to obtain the discharge that the vertical represents.

2.3.3. Determination of Instantaneous Suspended Sediment Discharge

The suspended sediment concentration in a stream usually varies from the surface to the bottom, and in some instances from the side to side. The sediment distribution may be illustrated by Figure 2b where the lengths of the arrows represent sediment concentrations at the same points at which velocities were shown in Figure 2a. Figure 2d represent the velocity distribution at vertical CE, and Figure 2e the distribution of sediment concentration in that vertical. The mean sediment concentration in vertical 2e is the spatial concentration for the sampling vertical. The sediment discharges for the vertical CE are shown in Figure 2f . They are obtained by multifling the velocities in Fig. 2d by the corresponding concentrations in Fig. 2e. Velocity can be expressed qualitatively as volume per unit time and unit cross sectional area,. Concentration can be expressed as weight of sediment per unit volume. Therefore, the product of the two equals weight of sediment discharged per unit of time, per unit of area. The mean discharge in vertical 2f divided by the mean velocity from 2d equal the discharge weighted concentration for the sampling vertical.

The sediment discharge or the weight of suspended sediment passing the cross section per unit time, is represented by the enclosed volume of Fig. 2c in the same way that the stream discharge is represented in Fig. 2a. Sediment discharge is generally obtained by multiplying the discharge - weighted concentration in each vertical by the stream discharge that the vertical represents and adding the products.

Sediment discharge = Discharge weighted concentration in each vertical X Stream Discharge that the vertical represents

$$= \sum_{i=1}^{n} [\, Q_S \;\; X \;\; Q_W \,]$$

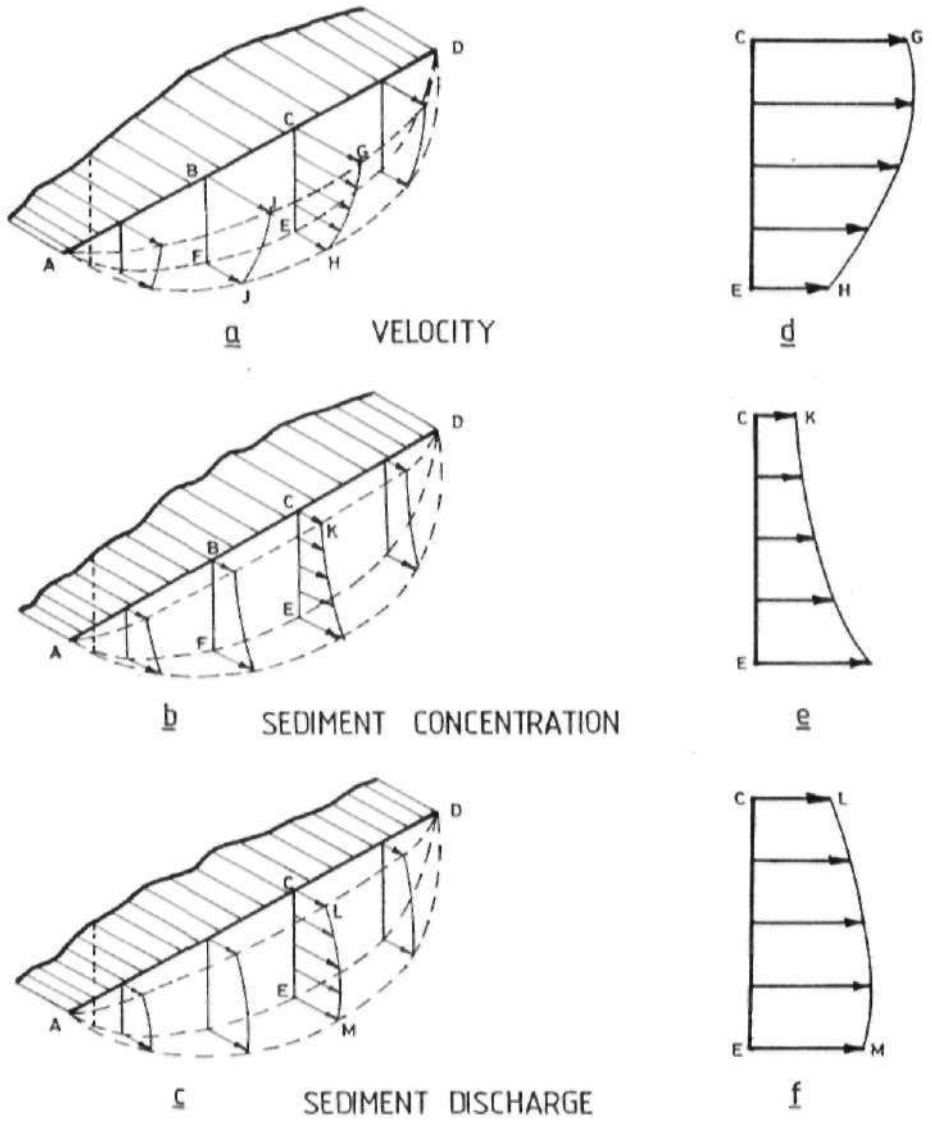


FIG. 2 – VELOCITY, SEDIMENT CONCENTRATION AND SEDIMENT DISCHARGE IN STREAMS

(SOURCE: INTER AGENCY COMMITTEE ON SEDIMENTATION REPORT 1940)

The basic concept of the computation of sediment discharge is often modified to fit the needs of a specific sampling program. Computations based on point-integrated samples are a modification of the basic method of determining suspended sediment discharge. Depth - integrated samples require a different treatment. If sediment is fine and most of the total depth is sampled, the concentration in the depth-integrated sample may be taken as equal to that for the entire vertical.

2.3.4. Number and Location of Sampling Verticals

For practical reasons sediment concentration should not be measured at a larger number of sampling verticals. Consequently, some system for selecting a limited number of sampling verticals must be used.

The common methods that are used to locate the transverse position of sampling verticals in sediment measurements are as follows :

(a) Single vertical at mid-stream

(b) Single vertical at thalweg or point of greatest depth

(c) Verticals at 1/4 , 1/2 , and 3/4 width

(d) Verticals at 1/6 , 1/2 , and 5/6 width

(e) Four or more verticals at midpoints of equal width sections across the streams.

(f) Verticals at centroids of sections of equal water discharge.

The number and locations of verticals to be sampled should be governed by the degree of accuracy required in the investigation, the size and shape of cross-section, the particle size of the sediment, the ratio of the sediment discharge being carried at the time of sampling to the total sediment discharge during the period under consideration. The particle size and the accuracy required are probably of greatest importance.

The simplest practice is the selection of a single sampling vertical at midstream or at the point of greatest depth. However, a single vertical should be used only in a very small stream or in certain types of routine sampling. A method that uses sampling verticals at the 1/4 , 1/2 , and 3/4 points in the width of a stream cross-section is convenient and practical. It may be used when distribution of stream discharge is not known. This method provides more information concerning the distribution of sediment and a more accurate sediment discharge than the single vertical method.

2.3.5. Sampling a vertical by Depth-Integration

There are two basic methods of sampling suspended sediments to obtain the representative sample in a stream vertical. The depth integration method is used for most routine measurements of sediment discharge. The point-integration method is used in some large streams and to define vertical distribution of sediment.

Depth-integrated samples are taken with a sampler that has an intake which points directly into the current. The sample is collected at a rate about proportional to the stream velocity at the intake. The sampler traverses the depth of the stream at a uniform speed, the sampling time in any fraction of the vertical is about proportional to the depth of the fraction; and the volume of the partial sample from any fraction is about proportional to the depth and velocity (discharge per unit width) of the fraction.

Streams less than 5m deep are usually depth-integrated on a round-trip basis. The sampler is lowered to the bottom of the stream at a uniform rate and raised back to the surface at a uniform rate, but not necessarily the same rate. During transit, the velocity in the intake nozzle is nearly equal to the local stream velocity at all points in the vertical. The air in the sample container is compressed by the inflowing liquid so that its pressure balances the external hydrostatic head. If the speed of lowering the sampler is such that the rate of air

contraction exceeds the normal rate of liquid inflow, the actual rate of inflow will be higher than the local stream velocity and some inflow may occur through the air exhaust. If the speed of lowering the sampler is too slow, the sample container will be filled before the transit is completed, circulation will take place, and some outflow through the air exhaust line will occur. In practice, transit time should be adjusted o that the sample container is not completely filled. This will avoid error in sediment content of the sample due to outflow through the air exhaust. The transit velocities of the ampler for descending and ascending trips need not be equal, but the velocity for each trip must be content to avoid error in sampling.

Theoretical maximum and minimum values of R_T / U, the ratio of the sampler transit velocity, R_T , to the mean stream velocity at the sampling vertical, U , are determined from Boyle's law and stream velocity. The permissible transit rate should not exceed 0.4 of the mean velocity to avoid excessive angles between the nozzle and the approaching flow. The practical maximum sampling depth for 3.2mm and 4.8mm diameter nozzles is limited to about 5m when the depth-integrating sampler is lowered and raised at a uniform rate.

2.4 Determination of Bed Load Discharge

The bed load discharge, i.e. the quantity per unit time of sediment that moves past a section by bouncing, rolling or sliding along a stream bed , may be measured, or it may be computed by indirect methods.

Bed load may be determined in four main ways :

(a) The most direct method of measuring bed load discharge is with a slot or trap that extends across the bed of a stream and catches the bed load that comes down the stream. The quantity of bed load collected per unit of time is the bed load discharge of the stream.

(b) Bed load discharge can be determined from several samples taken with a portable sampler that collects the bed load discharge from a narrow width of the stream bed. Sometimes estimates of bed load discharge can be made from indirect measurements such as Einstein (1942)

$$\Phi = S/[D^{3/2}(g\,\Delta^{1/2})]$$

S = transport in m3/ms transport = volume of grains

For conversion to total volume, S has to be divided by $(1-\varepsilon)$ in which ε = porosity.

$\Delta = (\rho s - \rho w)/\rho w$

D = grain size

Φ = dimension-less

(c) Bed load discharge can be computed from bed material samples and the hydraulic parameters of the stream flow.

(d) Bed load discharge can be obtained by subtracting suspended-sediment discharge from total sediment discharge.

2.4.1. Bed load Samplers

The development of bed load samplers has been closely associated with individual project studies. The samplers have been classified according to their type of construction and principle of operation - basket types, pan types, and pressure-difference types. The basket and pan types cause an increased resistance to flow and resultant lowering of stream velocity at the sampler. This reduction in the stream velocity reduces the rate of bed load movement at the sampler, with the result that some particles accumulate at the entrance to the sampler and others are diverted away. The pressure-difference type is designed to eliminate the reduction in velocity, and thus any change in rate of bed load movement at the entrance to the sampler. Calibrations of these samplers have indicated a mean efficiency of about 45%

the basket or pan type and about 70% for the best designed pressure-difference type. The efficiency of a sampler, i.e., the ratio of the trapped sediment to that actually moved as bed load per unit of time, varies with sampler characteristics, method of supporting ampler, hydraulic conditions, particle size, bed stability, and bed configuration.

2.4.2. Bed Load Traps

Bed load traps are slots, trenches, or small pits that are placed in the stream bed to catch sediment that moves as bed load. The sediment caught in the trap is removed and measured. Parshall (1933) designed a "vortex-tube" and trap for removal of coarse bed load from a stream or canal. This device was designed to function, not as a bed-load sampler, but as a means of preventing coarse sediment from entering and depositing in irrigation canals, power turbines, etc. The vortex tube with a slot along the top is placed in the stream bed at an angle of 45 degrees to the flow. The shape of the vortex tube is not critical providing the sediment once trapped is not washed back into the stream. The sediment and a small amount of water is washed out at one end of the vortex tube. The tubes that were tested removed about 80% of the bed load that was coarser than 0.50mm. Trap-type samplers are capable of collecting nearly 100% of the bed load. However, they are costly because they are difficult to place in a stream bed and the trapped material must be either pumped or dug out of the sampler.

2.4.3. Selection of a bed load discharge sampler

The ideal bed load discharge sampler cuts out, or samples, a definite width of the stream sediment transported as bed load and it collects all the solids from this sampled width. Such performance can be obtained only by careful design of the entrance and the separation mechanism to fit the conditions encountered in different streams. The ideal sampler does not alter the flow pattern upstream, it offers no obstruction to particles approaching the sampler, and it rests securely in contact with the bed. Generally, the dimensions of the entrance will be

governed by the size of particles in the bed. The height of the opening should be at least twice the maximum grain size, while its width may vary from about 100 to 200 times the average diameter of particles in the bed. Whenever possible a screen should be used for the separating mechanism but when the stream carries great quantities of organic material that would clog a screen during the sampling period, separation must be obtained by a local velocity reduction.

The box or basket-type sampler is the only one which can be used in mountainous stream carrying coarse gravel; for given entrance dimension, it is the smallest and the least cumbersome sampler to handle. It has the disadvantage of creating considerable back pressure which deflects the slow moving bottom layer around the sampler but only retard the faster flowing upper layer. Therefore, a high percentage of the fine material rolling or slidding along the bottom at a low velocity is deflected, while the same size material moving by saltation at a higher velocity is more readily trapped.

The pan type samplers seems to be best suited for streams which have comparatively smooth sand beds with a relatively low rate of bed load discharge all of which takes place in the bottom layer. For sandy beds the pressure- difference type of sampler seems to be the most satisfactory, especially when the entrance section is small and the frame flexible enough to ensure a snug fit against irregularities of the bed.

The final selection of the best bed load discharge sampler for the particular conditions in a given stream can be based only on a thorough calibration that duplicates all conditions of the river as closely as possible. The calibration is necessary because the efficiency with the sediment size, discharge, etc. Regardless of the type of sampler that is used, the calibration is as important as the measurements themselves. With the exception of the slot-type sampler, no bed-load discharge sampler that has been designed is completely adequate for anything but a boulder-or gravel-bed stream.

2.5. Determination of Total Sediment Discharge

In routine sediment investigation suspended sediment discharge is often measured and sometimes bed load discharge is determined also. Generally the total sediment discharge of the stream is what is actually desired.

There are several methods of determining total sediment discharge in a stream.

(a) The total load may be suspended in a turbulence flume, a special weir or a natural turbulence section, so that it can be sampled with a suspended sediment sampler.

(b) A portion of the flow can be diverted from the stream and analysed for suspended-sediment concentration, and the bed load can be trapped in such a way that it can be measured.

(c) The total sediment discharge can be obtained from the addition of the measured suspended sediment discharge, and the bed load discharge. Bed load discharge may be computed using a transport formula based on sizes of bed material and characteristic of the flow.

(d) The Total sediment discharge can be determined from measurements of sediment deposits in a reservoir.

The turbulence flume consists of a sense of baffle and sills arranged to create artificial turbulence. The baffles are usually designed so that all the sediment is suspended, and the capacity of the flow to transport sediment must be adequate to carry in suspension the quantity of sediment available for transport. Under favourable conditions a turbulence flume can be used to suspend the total sediment load so that it can be sampled with a suspended-sediment sampler.

The most usual way of obtaining the total sediment discharge of a stream is by adding the measured suspended-sediment discharge to a bed load discharge that is measured indirectly or that is obtained by analytical methods. The main problem are

(i) The un-sampled zone for suspended-sediment,

(ii) Selection of the best analytical method for computing bed load discharge and

(iii) Adjustment or correction of the computed discharges so that they represent the total sediment load but without overlap of the suspended- sediment and bed load discharge.

The total sediment discharge of a stream during a long period of time can be estimated from the volume of sediment deposited in a reservoir to which the stream contribute its flow during the period. The volume of accumulated sediment is determined by surveys and the specific weight of the sediment in place is determined or computed. Sometimes the sediment discharge or yield determined from reservoir surveys is more accurate than a determination based on suspended- sediment samples. If the retention time for the reservoir is so short that all the sediment is not deposited, the quantity lost in the outflow should be measured or estimated.

2.6 Sediment Control Measures

Canal sediment siltation can be greatly reduced if sediment control structures are in incorporated at the in takes or head reaches of canals. There are many sediment control options, some more expensive than other, depending upon local conditions such as the size of the sediments, and whether or not water is available for sediment flushing. Three means of controlling sedimentation could be considered, either singly or in combination, when a new scheme is to be designed or an existing system is to be rehabilitated. These are:

(i) Routine desilting of the canal system.

(ii) Controlling the entry of sediments at the canal intake (sediment exclusion)

(iii) Trapping and then extracting sediment from the canal close to the intake (sediment extraction)

The first of these option is rarely satisfactory as the sole means of sediment control when appreciable sediment loads are settling in canals.

2.6.1. Sediment Excluders

Irrigation canal intakes range in size and complexity from simple stone and brushwood deflector contracted by farmer to divert water to a few small fields to barrage on major river that divert water to irrigation systems connoting of hundreds of kilometres of canal and thousands of hectares of irrigated land. A canal intake used for medium scale schemes consists of a raised weir constructed across the river, with a gate sluicing channel adjacent to a gated irrigation intake. Intakes are usually located at the outside of river bend. Thus at a bend the large sediments moving near the river bed are deflected towards the inside of the bend and are not drawn in to canal intake. Conventional intakes are operated in several ways. In the "still pond" method, the intake configuration and the gate are set so that the velocity of the flow in the region upstream of the canal gates is reduced. This has two effects: Firstly, a flow pattern curving away from the intake gates is introduced, which sweeps the large bed sediments away from the canal gates. Secondly, some sediment settles to the river bed upstream from the intake, and is thus not diverted into the canal. The sluice gates are opened intermittently to flush the sediment deposits that build up in front of the intake structure. Alternatively, the sluice gates are kept open and convey water from the lower layers of the river flow, which contains the highest sediment concentrations, downstream and past the intake. Water from the upper layers of the river flow, where sediment concentrations are lower, and diverted to the canal.

Sediment excluder can be effective in reducing entry of coarse sediments that are transported near the bed of the river, they are not very effective at controlling fine sediments.

2.6.2. Sediment Extractors

Sediment extractors are built in a canal close to intake gate to divert sediment before it can settle in the canal. There are two types of device in common use. These are continously operating extractors, and settling basins. Extractors divert water and sediment flowing near the bed of a canal to an escape channel, which returns it to the river downstream of the intake. Since sediment concentrations are highest close to the canal bed, diversion of the bottom 10% of the flow can result in between 50% and 80% of the sediment load being extracted. The vortex Tube and Tunnel extractors are commonly used.

Settling basin consist of an enlarged canal section, usually constructed just downstream from the intake. The water velocity is very low in the settling basin because of the large cross sectional area. Therefore, sediment which can no longer be carried by the water drop out of suspension. Sediment carried in the flow enters the basin where all but the finest size fractions settle. As the bed level rises, the flow velocity in basin increases, and the particle size and concentration of the sediment leaving the basin and entering the canal also increases. When the basin is full of sediment, it is flushed by opening low level sluices at the downstream end. During flushing all the incoming flow is diverted through the sluices. This means that the canal has to be closed for some hours every one or two weeks during the flushing operation. In systems where a continuos flow of irrigation water must be maintained, paralleled settling basins operating alternately are used to control sediment without interrupting irrigation supplies.

CHAPTER 3

RESEARCH AND METHODOLOGY

3.1 Introduction

A survey of the Kadawa lateral and distributary canals was carried out. The survey was aimed at establishing the bed profile and also selecting sections of the canal whose hydraulic and physical feature conform with the requirement for measuring both suspended-sediment and bed load of the selected canal. Seven sections numbered KLCI, KLC2. KLC3, KDC1, KDC2, KFC1, and KFC2 were selected (Figure 1.2)

Section KLC1 is lined. There are no needs in the canal at this ections. A staff guage was installed at this section to record the depth of flow in the canal. Sections KLC2 and KDC1 are not lined. The submerged weeds at these sections were cleared before measurement. Section KLC3 and KDC2 are not lined. The canal at these sections are weedy. Section KFC1 is not lined. There are no weed at this section. A staff guage installed at this section to record the depth of flow during measurement. Section KFC2 is not lined and the canal at this section is weedy.

Measurements were carried out between February and May 1992. Although some measurements were carried out uptill July 1992 but were not used in the final analysis due to some inconsistency in the data. Data were collected only for these short periods as a result of the economic factors and logistics problems.

Data collected included suspended sediment concentration, bed load concentration, grain size of sediment, water level, water discharges and geometric properties of the canal.

3.2 Sediment Measurements

3.2.1. Suspended- Sediment Measurement

Suspended load is the sediment that is supported by vertical components of the velocities in turbulent flow while being carried forward in the stream by horizontal component of the velocities. Studies have shown that suspended sediment concentration in a stream usually varies from the surface to the bottom, and in some instances from side to side, with a minimum at a water surface and a maximum near the stream bed. However, suspended sediment measurements were taken for sampling verticals at 1/4, 1/2, and 3/4 points in the width of the canal using a US DH-48 depth integrating hand sampler at the selected sections mentioned above.

The sampler with an intake nozzle of 3.2mm was lowered to the bottom of the canal at a uniform rate and raised back to the water surface at a uniform rate. The sampler was stopped only momentarily at the bottom to reverse direction and sampling was continuous during these periods of transit. The average of the three samples in a sampling vertical was taken for laboratory analysis of the water-sediment mixtures.

The water-sediment mixture samples were analysed for the sediment concentration using the vacuum pump technique. The technique involves sealing the filter with a small volume (10mls) of distilled water. An amount of 100 mls of well-mixed sample was filtered through the filter and oven dried for 1 hour at 105^{o}C. It was cooled in a dessicator and weighed. The cycle of drying, cooling, desiccating and weighing was repeated until a weight which is less than 4% of the previous one was obtained.

Thus, the sediment concentration is calculated as:

$$\text{concentration, in mg/l} = \frac{\text{dry weight of sediments (g)}}{\text{volume of water-sediment mixture taken (mls)}} \times 10^6$$

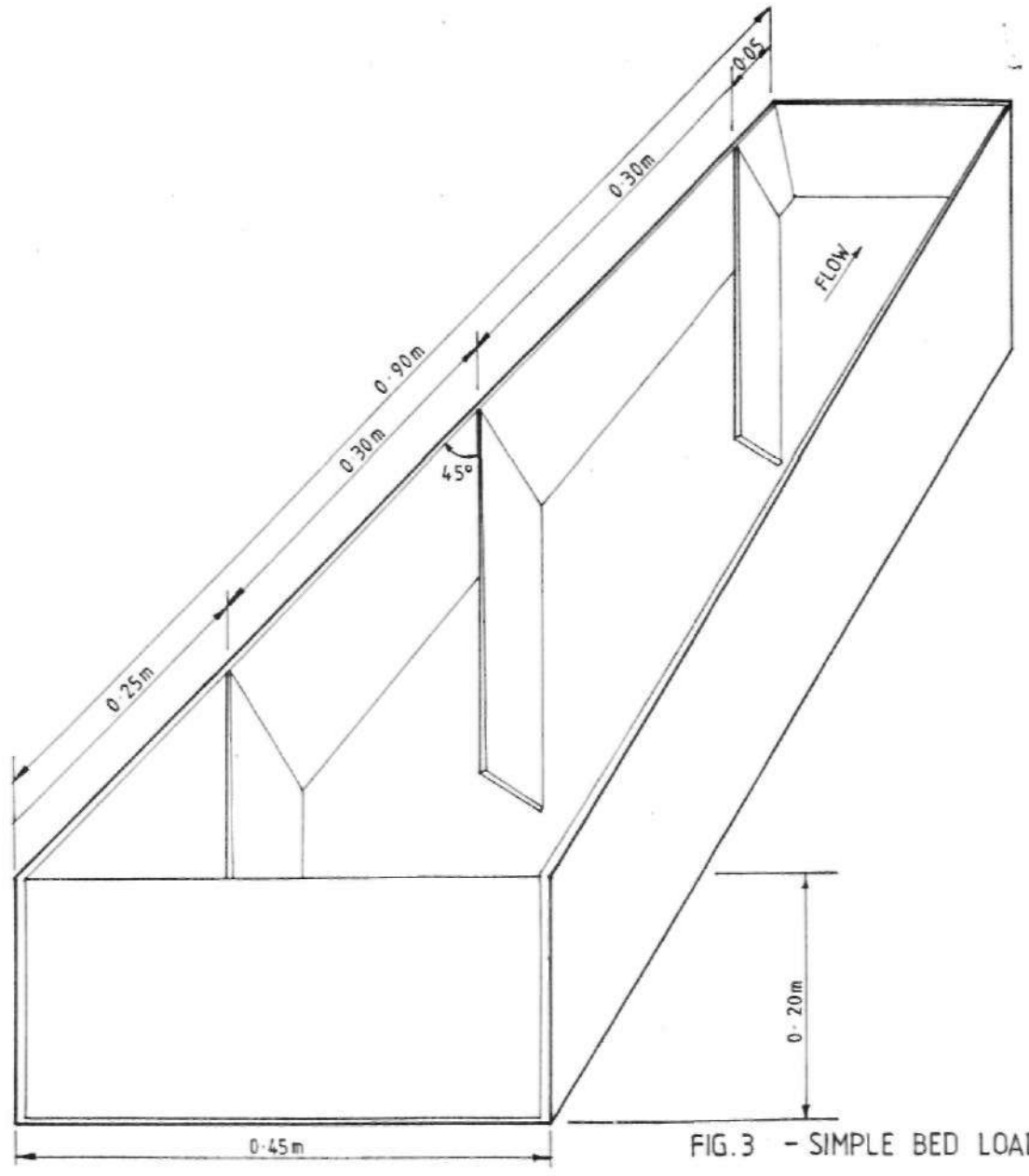
An example of the analysis is presented in section 3.5.1.

3.2.2 Bed Load Measurements

Bed load is the sediment that moves by saltation, rolling, or sliding on or near the canal bed. The devices available for the bed load measurements include pit-type traps, pervious basket-type or pan-type samplers or pressure-difference samplers.

However, these expensive equipment are not locally available for use and as such, due to limited financial resources, such equipment are out of the researcher's reach. Thus, a relatively simple box bed load trap technique was used. The trap designed has the dimension of 0.90m by 0.45m by 0.20m with inner baffles inclined at 45 degrees to the sides of the trap in order to control the sediment trapped from onward movement. (Figure 3.)

The bed load trap is carefully embedded firmly across part of the canal bed at sections KLC2, KDC1, and KFC1 to ensure its safety against the velocity of flow to prevent being swapped away or shifted. Three sections were chosen for the study due to the economic factor for the construction materials for the 'box' trap and inaccessibility of the weedy sections. The bed load measurement was taken on a weekly basis due to the slow accumulation of sediment on the trap.



SCALE : 1:5

FIG. 3 – SIMPLE BED LOAD TRAP

For each measurement period, the trap is carefully lifted up and the sediment trapped neatly removed for laboratory analysis. The samples were oven dried and the sediment was weighed to obtain the concentration by weight.

An example of the analysis is presented in section 3.5.1.

3.3 Discharge and gauging

Discharge measurements were taken at the selected section of the canal using velocity .-Area method. The method involve dividing the sections into a number of equally spaced vertical profiles. The mean velocity at each vertical profile is then determined by using current meter. For average accuracy, sections KLC2 and KDC1 were divided into 15 verticals while section KFC1 was divided into 10 verticals. At each vertical, current metering measurements were taken at two points (at 20% and 80% depth of flow from the water surface) except where the depth of flow was less than 0.5m. In such cases, current metering measurements were taken at one point (60% depth of flow from the water surface). The number of revolutions recorded by the current meter in 50 seconds were converted to velocity by using the calibrating equation of the meter given as:

$$V = 0.883\,n + 0.048 \quad \text{for } n < 1.68$$

$$V = 0.1002\,n + 0.028 \quad \text{for } 1.68 < n < 6 \text{ and}$$

$$V = 0.1029\,n + 0.012 \quad \text{for } n > 6$$

where n is the number of revolution per second and V is the velocity in m/s.

The mean velocity at each vertical profile was given by the average of the velocities at 20% and 80% depth of flow when two point method was used. The velocity at 60% depth of flow was taken as the mean velocity in the vertical when one point method was used.

Current metering measurements were taken along side with the water level and sediment measurements.

Examples of the measurements taken are presented in appendixes A1 to A3. The discharge in each section was computed by mid-section method.

3.4 Particle (Sediment) size and Analysis

Particle size information regarding sediment that may be eroded, transported, or has been deposited is useful in the application of predictive theory on erosion transport, and deposition rates and quantities.

In deposition, particle size is one of the most important aspects in the evaluation of the amount of space a given weight or quantity of transported sediment will occupy . Sieve analysis of the samples collected were carried out .

3.4.1. Sieve Analysis

Three different samples KLC2, KDC1, and KFC1 were collected and analysed. An amount of 200 grams were used for each sample and washed through sieve number 200 to get rid of silts and the remaining amounts were oven dried.

After the oven drying the normal procedures for sieve analysis were followed and the results are as presented in Appendix A4 to A6. The particle size distribution curves were plotted using percentage finer against sieve sizes (Figures 5 to 7)

3.5 Computation of Parameters

The following parameters were evaluated:

(i) Sediment concentration at canal section
(ii) Sediment discharge in the lined and unlined canal sections.
(iii) Hydraulic efficiencies of the canal sections
(iv) Volume of sediment deposition and scour

The data required for this analysis include;

(a) Suspended-sediment concentrations at sections
(b) Bed load concentrations at sections
(c) Discharge at sections
(d) Geometric properties of the canals

The method adopted for measuring suspended sediment and bed load concentrations at each canal section was presented in section 3.2.1. and 3.2.2. respectively. The method adopted for measuring the discharge at each canal section was presented in section 3.3. The geometric properties of the canal at the chosen section were measured (Tables 4.6(a) to 4.6(b))

An example of the analysis of each parameter is presented in section 3.5.1. to 3.5.3. The summary of the results for parameters are presented in chapter 4.

3.5.1 Sediment discharge

The suspended-sediment discharge in each section was computed as follows:

Suspended-sediment discharge (Kg/day) = daily mean Sediment concentration (mg/l) X daily mean water discharge (m^3/s) X conversion factor (1.1574×10^{-5})

1 day = 86400 seconds.

For example,

Suspended-sediment discharge Q_S at KLC1 is computed as follows:

Mean suspended- sediment concentration = 75.58 mg/l

Mean water discharge = $2.466 m^3/s$

Q_S = $75.58 \times 2.466 \times 1.1574 \times 10^{-5}$

= 2.157×10^{-3} kg/day

For Section KLC2

Mean suspended - sediment concentration = 82.24 mg/l

Mean water discharge = $2.40\ m^3/s$

Q_S = $82.24 \times 2.40 \times 1.1574 \times 10^{-5}$

= 2.284×10^{-3} kg/day

For Section KLC3

Mean suspended -sediment concentration = 90.05 mg/l

Mean water discharge = $2.02\ m^3/s$

Q_S = $90.05 \times 2.02 \times 1.1574 \times 10^{-5}$

= 2.105×10^{-3} kg/day

For Section KDC1,

Mean suspended- sediment concentration = 890.66 mg/l

Mean water discharge = $0.314\ m^3/s$

Q_S = $890.66 \times 0.314 \times 1.1574 \times 10^{-5}$

= 3.237×10^{-3} kg/day

For Section KDC2,

Mean suspended-sediment concentration = 948.07 mg/l

Mean water discharge = 0.30 m^3/s

Q_s = 948.07 x 0.30 x 1.1574×10^{-5}

= 3.29×10^{-3} kg/day

For section KFC1

Mean suspended-sediment concentration = 1575.17 mg/l

Mean water discharge = 0.060 m^3/s

Q_s = 1575.17 x 0.060 x 1.1574×10^{-5}

= 1.09×10^{-3} kg/day

For Section KFC2,

Mean suspended-sediment concentration = 1575.85 mg/l

Mean water discharge = 0.057 m^3/s

Q_s = 1575.85 x 0.057 x 1.1574×10^{-5}

= 1.04×10^{-3} kg/day

The suspended-sediment discharge computed is as presented in Table 4.2(a)

The bed load discharge in each section was computed as follows:

Bed load discharge = Mean bed load conc. x 10^{-3} kg/day

For example the bed load discharge Q_b at section KLC2 is computed as follows :

Mean bed load conc. = 3.257 g/day

Q_b = 3.257×10^{-3} kg/day

For section KDC1,

Mean bed load conc. = 2.773 g/day

Q_b = 2.773×10^{-3} kg/day

For section KFC1,

Mean bed load conc .= 1.989 g/day

Qb = 1.989×10^{-3} kg/day

The bed load discharge computed is as presented in Table 4.2(b)

3.5.2 Hydraulic efficiency of sections

The hydraulic efficiency of a section is defined as

$$\eta_e = Q_m / Q_D \times 100\% \qquad (3.1)$$

where Q_m = measured discharge at a depth of flow

Q_D = designed capacity of the section at the depth of flow.

For Section KLC1,

bottom slope, S = 0.002% (NEDECO 1973)

bottom width, b = 1.0m "

Side slope, z = 1.5m "

roughness co-efficient, n = 0.02 "

at depth of flow , d = 0.81m

cross-sectional area, A = (b+ dz) d

= $1.794 m^2$

wetted perimeter, p = $2d(1+ Z^2)^{1/2} + b$

= 3.921 m

Hydraulic radius, R = A/P = 0.458 m

$Q_D = (AR^{2/3} S^{1/2}) / n$

= $2.384\ m^3/s$

But measured discharge at depth of flow,

Q_m = 2.160 m^3/s

Hydraulic efficiency, η_e = Qm/Q_D x 100%

= 2.160 / 2.384 x 100%

= **90.6 %**

For section KLC2,

at depth of flow, d = 0.88 m

cross-sectional area, A = (b +dz) d

= 2.042 m^2

wetted perimeter, p = $2d\ (1+Z^2)^{1/2}$ + b

= 4.173 m

Hydraulic radius, R = A/P = 0.489 m

Q_D = $(AR^{2/3}\ S^{1/2})$ /n (n=0.030)

= 1.889 m^3/s

But measured discharge at depth of flow,

Qm = 1.466 m^3/s

Hydraulic efficiency, ηe = Qm / Q_D x 100%

= 1.466/ 1.889 x 100%

= **77.6%**

For section KLC3

at depth of flow, d = 0.88 m

cross-sectional area, A = (b + dz) d

= 2.042 m^2

wetted perimeter , p = $2d\,(1+Z^2)^{1/2}$ + b

= 4.173 m

Hydraulic radius, R = A/P = 0.489 m

Q_D = $(AR^{2/3}\ S^{1/2}) / n$ (n = 0.030)

= 1.889 m^3/s

But measured discharge at depth of flow,

Q_m = 1.420 m^3/s

Hydraulic efficiency, ηe = Q_m / Q_D x 100%

= 1.420 / 1.889 x 100%

= **75.2%**

For section KDC1,

bottom slope, s = 0.002% (NEDECO 1973)

bottom width, b = 1.0 m "

side slope, z = 1.5 "

roughness coefficient, n = 0.030 "

at depth of flow, d = 0.48 m

cross-sectional area, A = (b+dz) d

= 0.826 m

wetted perimeter, p = $2d(1+Z^2)^{1/2}$ + b

= 2.731 m

Hydraulic radius, R = A/P = 0.302 m

$$Q_D = (AR^{2/3} S^{1/2}) / n$$

$$= 0.555 \text{ m}^3/\text{s}$$

But measured discharge at depth of flow,

$$Q_m = 0.314 \text{ m}^3/\text{s}$$

Hydraulic efficiency, η_e = 0.314 / 0.555 x 100%

= **57%**

For section KDC2

at depth of flow, d = 0.48 m

cross-sectional area A = (b+dz) d

= 0.826 m^2

wetted perimeter p = $2d(1+Z^2)^{1/2}$ + b

= 2.731 m

Hydraulic radius, R = A/P = 0.302 m

$$Q_D = (AR^{2/3} S^{1/2}) / n$$

$$= 0.555 \text{ m}^3/\text{s}$$

But measured discharge at depth of flow,

$$Q_m = 0.300 \text{ m}^3/\text{s}$$

Hydraulic efficiency, ηe = 0.300 / 0.555 x 100%

= **54.1%**

For section KFC1

bottom slope, s = 0.002% (NEDECO 1973)

bottom width, b = 0.5 m "

side slope, z = 1.0 "

roughness coefficient, n = 0.030 "

at depth of flow, d = 0.29 m

cross-sectional area, $A = (b + dz)\, d$

$= 0.229\ m^2$

wetted perimeter, $P = 2d(1+Z^2)^{1/2} + b$

$= 1.320$ m

Hydraulic radius, $R = A/P = 0.173$ m

$Q_D = AR^{2/3} S^{1/2}) / n$

$= 0.106\ m^3/s$

But measured discharge at depth of flow,

$Q_m = 0.060\ m^3/s$

Hydraulic efficiency $\eta e = 0.060 / 0.106 \times 100\%$

$= \mathbf{56.6\%}$

For section KFC2,

at depth of flow, d = 0.29 m

cross-sectional area, $A = (b+dz)\, d$

$= 0.229\ m^2$

wetted perimeter, $P = 2d(1+Z^2)^{1/2} + b$

$= 1.320$ m

Hydraulic radius, R =A/P = 0.173 m

$$Q_D = (AR^{2/3}S^{1/2}) / n$$

$$= 0.106\ m^3/s$$

But measured discharge at depth of flow,

$$Q_m = 0.058\ m^3/s$$

Hydraulic efficiency, $\eta e = 0.058 / 0.106 \times 100\%$

$$= \mathbf{54.7\%}$$

3.5.3. Volume of sediment deposition and scour at canal sections

The volume of sediment deposition and scour in the canal sections was computed by multiplying the difference in areas of the measured and designed cross-sections by the length of the canal reach. The geometric properties of the lined and unlined canals at the sections KLC1, KLC2, KDC1 and KFC1 are presented in Tables 4.6(a) to 4.6(d) respectively. The geometric properties of sections KLC3, KDC2 and KFC2 could not be measured because the sections were weedy.

For example, measurements taken at section KLC1 were :

Designed cross-sectional area = $3.84\ m^2$

Measured cross-sectional area = $3.84\ m^2$

Length of reach = 4000 m

Volume of sediment deposition/scour = $(3.84\text{-}3.84)\ m^2 \times 4000\ m$

= **nil**

For section KLC2,

Designed cross-sectional area = 3.84 m^2

Measured cross-sectional area = 3.31 m^2

Length of reach = 3000 m

Volume of sediment deposition/scour = (3.84-3.31) m^2 x 3000 m

= **1590.0 m^3**

For section KDC1,

Designed cross-sectional area = 1.44 m^2

Measured cross-sectional area = 1.59 m^2

Length of reach = 2000 m^2

Volume of sediment deposition/scour = (1.44-1.59) m^2 x 2000 m

= **-300.0 m^3**

For section KFC1

Designed cross-sectional area = 0.36 m^2

Measured cross-sectional area = 0.33 m^2

Length of reach = 1000 m

Volume of sediment deposition/scour = (0.36-0.33) m^2 x 1000 m

= **30.0 m^3**

The negative sign indicates that there was more scouring than deposition. The volume of deposition and scour computed is presented in Table 4.6. The cross-sectional area for sections KLC3, KDC2, and KFC2 could not be measured because these sections were weedy. As a result of this, the volume of sediment deposition and scour could not be computed.



PLATE I: A Lateral canal infested with weeds.



PLATE II: A Distributary canal overgrown with weeds.

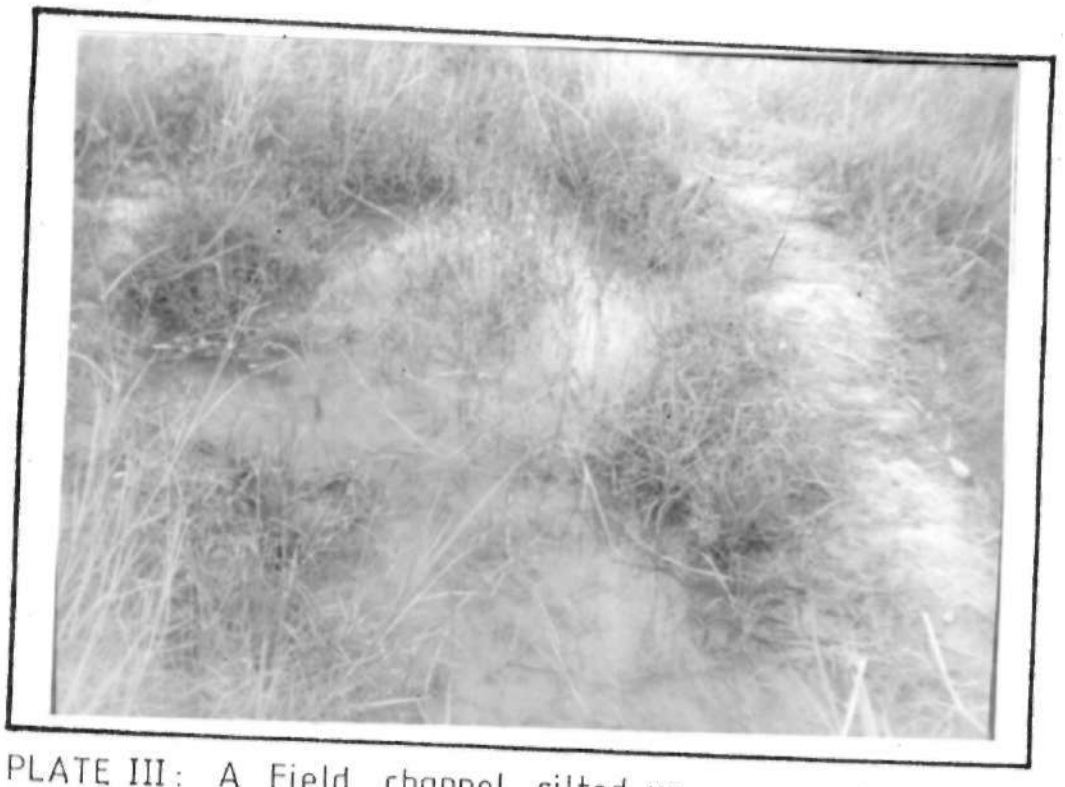


PLATE III: A Field channel silted up.

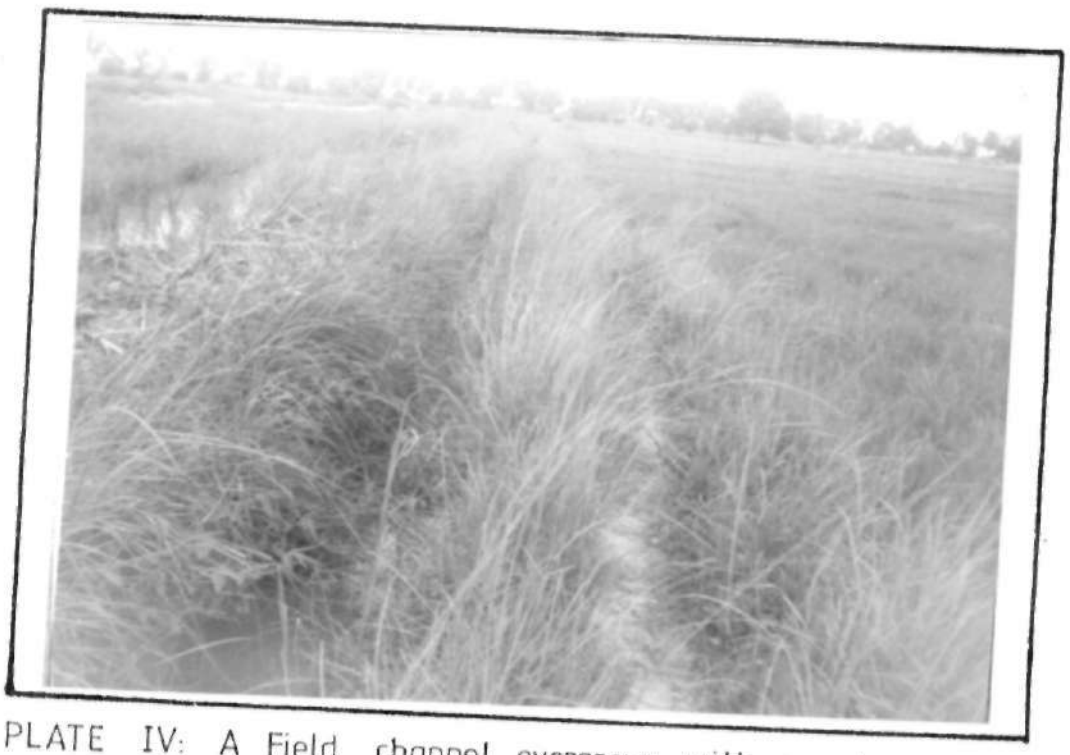


PLATE IV: A Field channel overgrown with weeds.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The following parameters were evaluated during the study. This chapter presents and discuss the parameters.

(a) Sediment concentrations

(b) Sediment discharge

(c) Hydraulic efficiency

(d) Volume of sediment deposition and scour

(e) Particle (sediment) size

4.2 Sediment Concentrations

The summary of the sediment concentrations obtained is as presented in Table 4.1(a) The suspended-sediment concentrations ranged between 0.0756g/l and 1.576g/l. The bed load concentrations ranged between 1.99g/day and 3.26g/day. [Table 4.1 (b)]

Table 4.1(a) Mean Sediment Concentration at sections (25/2/92 - 12/5/92)

Sections	Suspended-sediment concentration
	mg/l
KLC1	75.58
KLC2	82.24
KLC3	90.05
KDC1	890.66
KDC2	948.07
KFC1	1575.17
KFC2	1575.85

Table 4.1(b) Mean Bed-load Concentration at sections (25/2/92 - 12/5/92)

sections	Bed-load concentration
	g/day
KLC2	3.26
KDC1	2.77
KFC1	1.99

4.3 Sediment Discharge

The results of the mean sediment discharge in reaches between the sections is as presented in Table 4.2(a) to Table 4.2(c). Table 4.2(a) shows the suspended sediment discharge in the Kadawa sector for the period between February and May 1992. The suspended sediment discharge at different flows ranged between 1.04×10^{-3} Kg/day and 3.29×10^{-3} Kg/day with a mean value of 0.46×10^{-3} Kg/day.

Table 4.2(a) Mean Suspended-sediment Discharge at sections

Sections	Suspended-sediment discharge x 10^{-3} (Kg/day)	Discharge (m^3/s)
KLC1	2.157	2.160
KLC2	2.284	1.466
KLC3	2.105	1.420
KDC1	3.237	0.314
KDC2	3.290	0.300
KFC1	1.090	0.060
KFC2	1.040	0.058

Table 4.2(b) shows the bed load discharge at different flows in the Kadawa sector. The bed load discharge ranged between $1.99x10^{-3}$ Kg/day and $3.26x10^{-3}$ Kg/day with a mean value of $2.67x10^{-3}$ Kg/day. There was more bed load at section KLC2 than section KDC1 while section KFC1 has the lowest. This finding conforms with a similar study on sediment monitoring technique in Philippines (Brabben, 1989). Brabben identified that the transport of the bed load is primarily dependent on the carrying capacity of the flow, and is governed by hydraulic parameters in particular the flow velocity according to the relation $Q_s = c\,Q^n$ .This agrees with the result obtained with velocity of flow higher at section KLC2 than KDC1 and KFC1, although the three sections were unlined .

Table 4.2(b) Bed Load Discharge at sections

Sections	Bed load discharge $x10^{-3}$ (Kg/day)	Discharge (m3/s)
KLC2	3.26	1.466
KDC1	2.77	0.314
KFC1	1.99	0.060

Table 4.2(c) shows the total load of each selected section of the canal. The total load ranged between $1.04x10^{-3}$ Kg/day and $6.01x10^{-3}$ Kg/day with a mean value of $3.32x10^{-3}$ Kg/day.

Table 4.2(c) Total Sediment Load at sections

Sections	Total sediment load $x10^{-3}$ (Kg/day)
KLC1	2.157
KLC2	5.544
KLC3	2.105
KDC1	6.007
KDC2	3.290
KFC1	3.080
KFC2	1.040

4.4 Hydraulic efficiency

The hydraulic efficiency of a section is defined as the ratio of measured discharge at a depth of flow to the designed discharge at the same depth of flow. The results of the computation of the hydraulic efficiency of the lined and unlined sections are presented in Table 4.3 to Table 4.5.

(a) The result of the hydraulic efficiency of the Kadawa lateral canal at selected sections is presented in Table 4.3. The hydraulic efficiency of the section ranged between 75% and 91% At sections KLC1, the canal is lined and there are no weeds, thus given a high hydraulic efficiency. At section KLC2, The canal is not lined and there are no weeds. This gives lower efficiency as compared with section KLC1. Section KLC3 is an unlined canal with weeds. This gives the section much lower hydraulic efficiency as compared with section KLC1.

Table 4.3 Hydraulic efficiency of the Kadawa lateral canal at Sections

Section	Depth of Flow (m)	Design Discharge (m^3/s)	Measured Discharge (m^3/s)	Hydraulic efficiency %
KLC 1	0.81	2.384	2.160	91
KLC 2	0.88	1.889	1.466	78
KLC 3	0.88	1.889	1.420	75
			Mean	81

(b) The result of the hydraulic efficiency of unlined canal at section KDC 1 and KDC 2 presented in Table 4.4. The hydraulic efficiency of these sections ranged between 54% and 57%. At section KDC 2 there are weeds in the canal and silt deposits due to low velocity of flow. This makes the hydraulic efficiency of the section as low as 54%.

Table 4.4 Hydraulic efficiency of the Kadawa distributary canal at sections

Section	Depth of flow (m)	Design Discharge (m^3/s)	Measured Discharge (m^3/s)	Hydraulic efficiency %
KDC 1	0.48	0.555	0.314	57
KDC 2	0.48	0.555	0.300	54
			Mean	**56**

(c) The result of the hydraulic efficiency of unlined canal at section KFC I and KFC 2 is presented in Table 4.5. The hydraulic efficiency of these section ranged between 55% and 57%. There are weeds in section KFC 2 and the retardance effect of the weeds on the flow in the canal reduced the efficiency of the canal to this low value.

Table 4.5 Hydraulic efficiency of the Kadawa field canal at sections

Section	Dept of flow (m)	Design Discharge m^3/s	Measured Discharge m^3/s	Hydraulic efficiency %
KFC 1	0.29	0.106	0.060	57
KFC 2	0.29	0.106	0.058	55
			Mean	**56**

The mean hydraulic efficiency of the Kadawa lateral canal was 81%. This value agrees with value of 81% reported by Jimoh (1991) on the same canal. However, the mean value for the distributary (unlined) canal was 56% as against 64% (Jimoh, 1991).

4.5 Volume of Sediment Deposition and Scour

The summary of the volume of sediment deposition and scour in the canal sections is as presented in Table 4.7. The volume of sediment deposition ranged between $30m^3$ and $748.24m^3$. The volume of sediment scour ranged between $240.0m^3$ and $841.77m^3$. The balance between deposition and scour in the canal sections shown in the table, indicates that the amount of sediment subsequently deposited from the canals in which it has been scoured was 89% in section KLC 2, 25% in section KDC 1, and there was no scouring but only deposition in section KFC 1. Figure 4.6 (a) - 4.6 (d) illustrate the design and present conditions of the canal cross-section.

Table 4.6 (a) Geometric Properties for the Lined Reach at Section KLC1

Canal Geometry	Designed Value	Measured Value
	$3.84\ m^2$	$3.84\ m^2$
Ws	4.75 m	4.75 m
d_m	1.30 m	1.30 m
P	5.50 m	5.50 m
R	0.69 m	0.69 m

Table 4.6(b) Geometric Properties for the Unlined Reach at Section KLC 2

Canal Geometry	Designed Value	Measured Value
A	3.84 m^2	3.31 m^2
Ws	4.75 m	3.75 m
d_m	1.30 m	1.04 m
P	5.50 m	5.13 m
R	0.69 m	0.65 m

Table 4.6 (c) Geometric Properties for the Unlined Reach at Section KDC 1

Canal Geometry	Designed Value	Measured Value
A	1.44 m^2	1.59 m^2
Ws	3.00 m	3.50 m
d_m	0.70 m	0.50 m
P	3.50 m	3.93 m
R	0.41 m	0.40 m

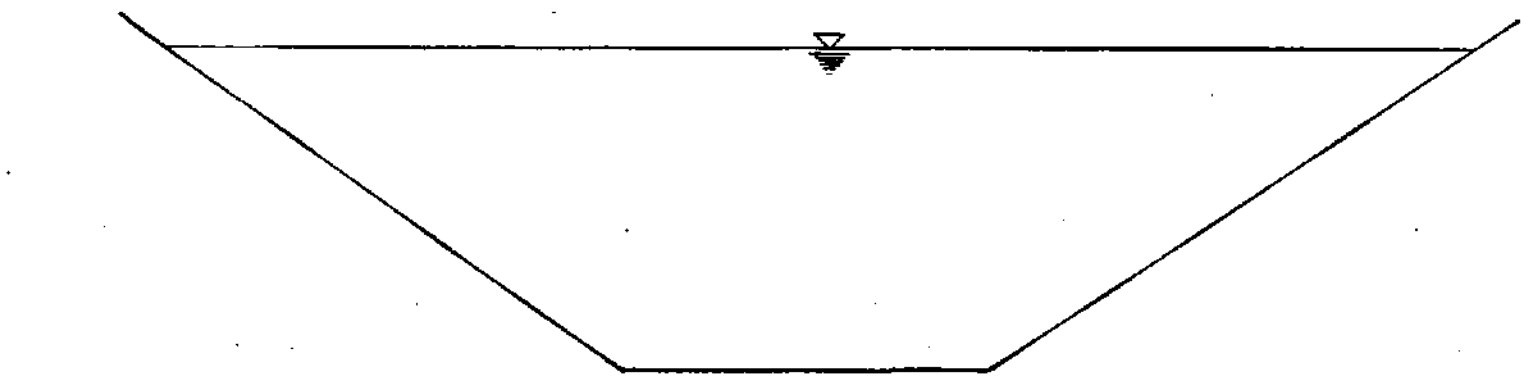


FIG. 4.6(a) SECTION K LC· I

Scale 1 Cm. = 0·2

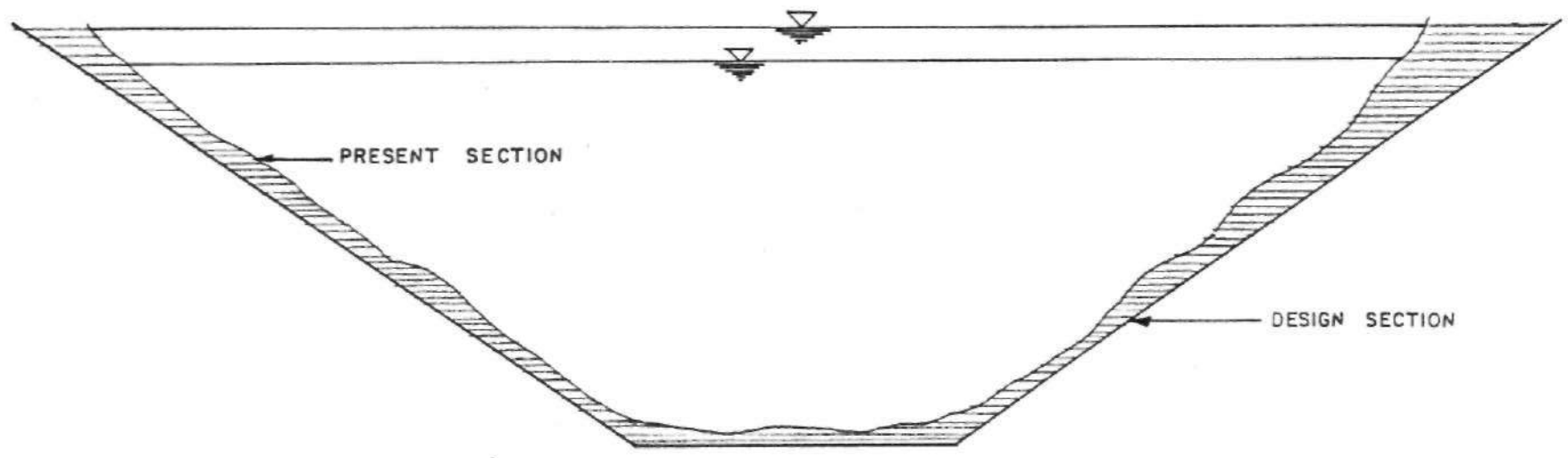


FIG. 4.6(b) SECTION K L C· 2

Scale 1 Cm = 0·2

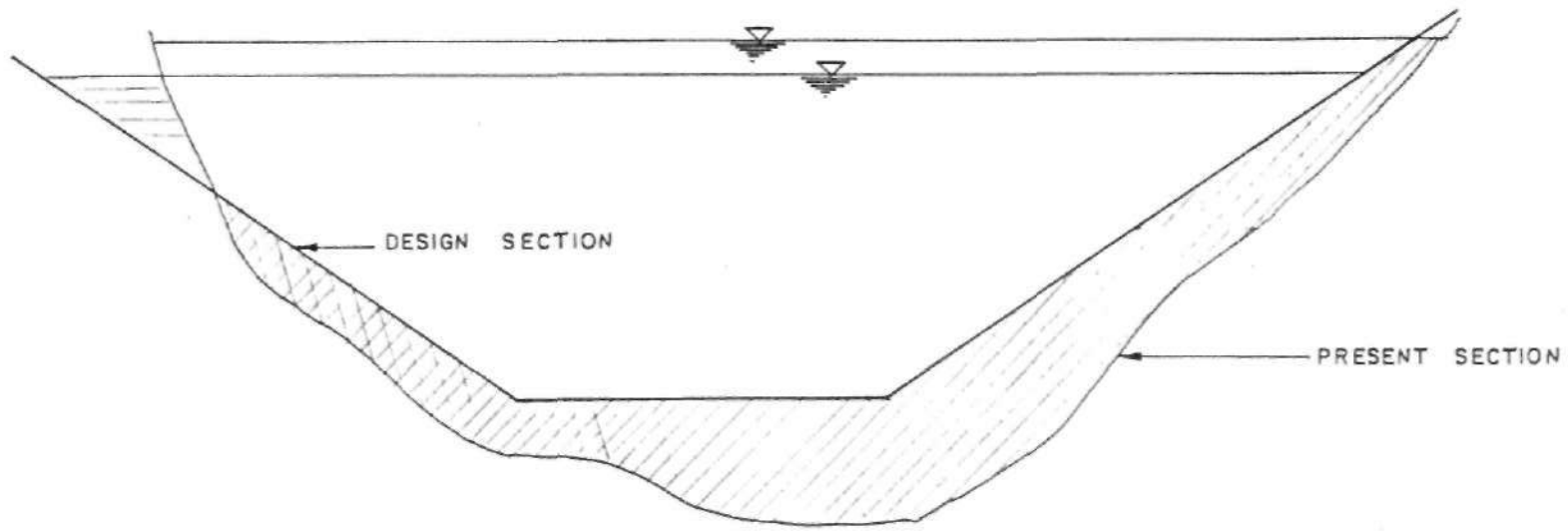


FIG 4.6(c) SECTION K D C· 1

Scale 1 Cm = 0·2

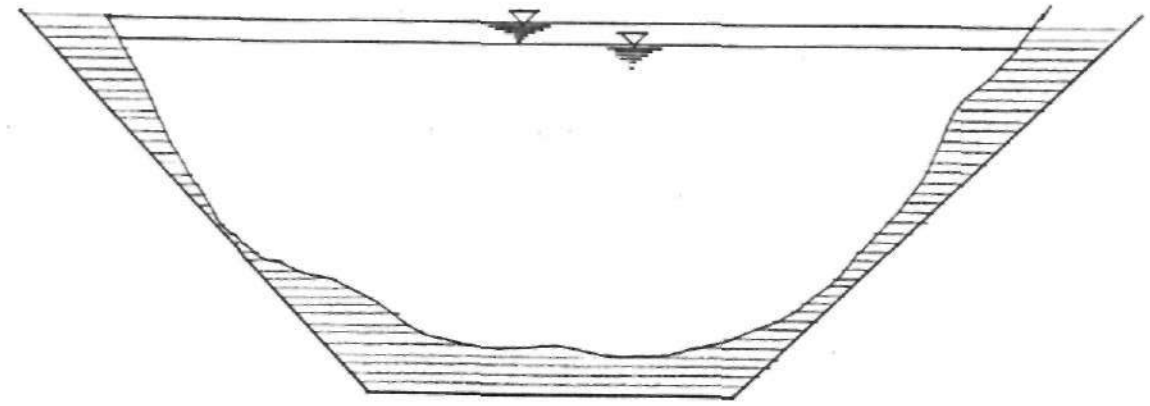


FIG. 4.6(d) SECTION K F C· I

Scale: Hor· 1 Cm = 0·1
Vert: 1 Cm = 0·12

Table 4.6 (d) Geometric Properties for the Unlined Reach at Section KFC 1

Canal Geometry	Designed Value	Measured Value
A	0.36 m^2	0.33 m^2
Ws	1.50 m	1.13 m
d_m	0.4 m	0.31 m
P	1.93 m	1.65 m
R	0.19 m	0.2 m

For section KLC 1, there was no deposition nor scouring. On the other hand, for section KLC 2, there was deposition of sediments to the magnitude of 748.24 m^3 and subsequent scouring (841.77 m^3) at both sides of the canal section. The designed (0.49m/s) and measured (0.44m/s) velocities do not vary significantly to cause scouring of the canal but the scouring was as a result of the activities of cattle grassing near the sides of the canals. Since the canal at this section was operated at a velocity lower than the designed velocity, deposition sediments results. For section KLC 1, in which the designed velocity (0.40 m/s) is much higher than the measured velocity (0.20 m/s), deposition of sediments is expected to be experienced but scouring was the case. This was due to irregular opening of the night storage reservoir gate by the farmer This results in high flows. The effect of this scouring was felt downstream of the field channels which gets silted up often. At the time of study, the measured velocity of one of the field channels at section KFC 1 was 0.18 m/s as against the designed velocity of 0.30 m/s. This result in deposition of sediment in the channel. The long term effect of this will be that at a point there would not be flow at the downstream end and the continuity equation of flow will be affected.

Table 4.7 Volume of sediment Deposition and Scour at Sections

Deposition and Scour in the Section				
	KLC 1	KLC 2	KDC 1	KFC 1
Deposition	-	748.24 m3	60m3	30m3
Scour	-	841.77m3	240m3	-

4.6 Particle (Sediment) Size

Appendix A4 shows the result of sieve analysis on soil sample KLC 2 and the corresponding particle size distribution curve is shown in Figure 5. Appendix A5 shown the sieve analysis results from sample KDC 1 and the corresponding particle size distribution curve is shown in Figure 6. Appendix A6 also shows the result of sieve analysis done on soil sample KFC 1 and the corresponding particle size distribution curve is shown in figure A7.

The particle size distribution curves were plotted using percentage finer against sieve sizes. The curves are of the same pattern but are slightly different from particle size distribution of graded sand samples. Samples KLC 2 and KDC 1 have d50 = 0.20mm while sample KFC 1 has d50 = 0.30mm as presented in Table 4.7.

Table 4.8: The Sizes of the Bed Materials

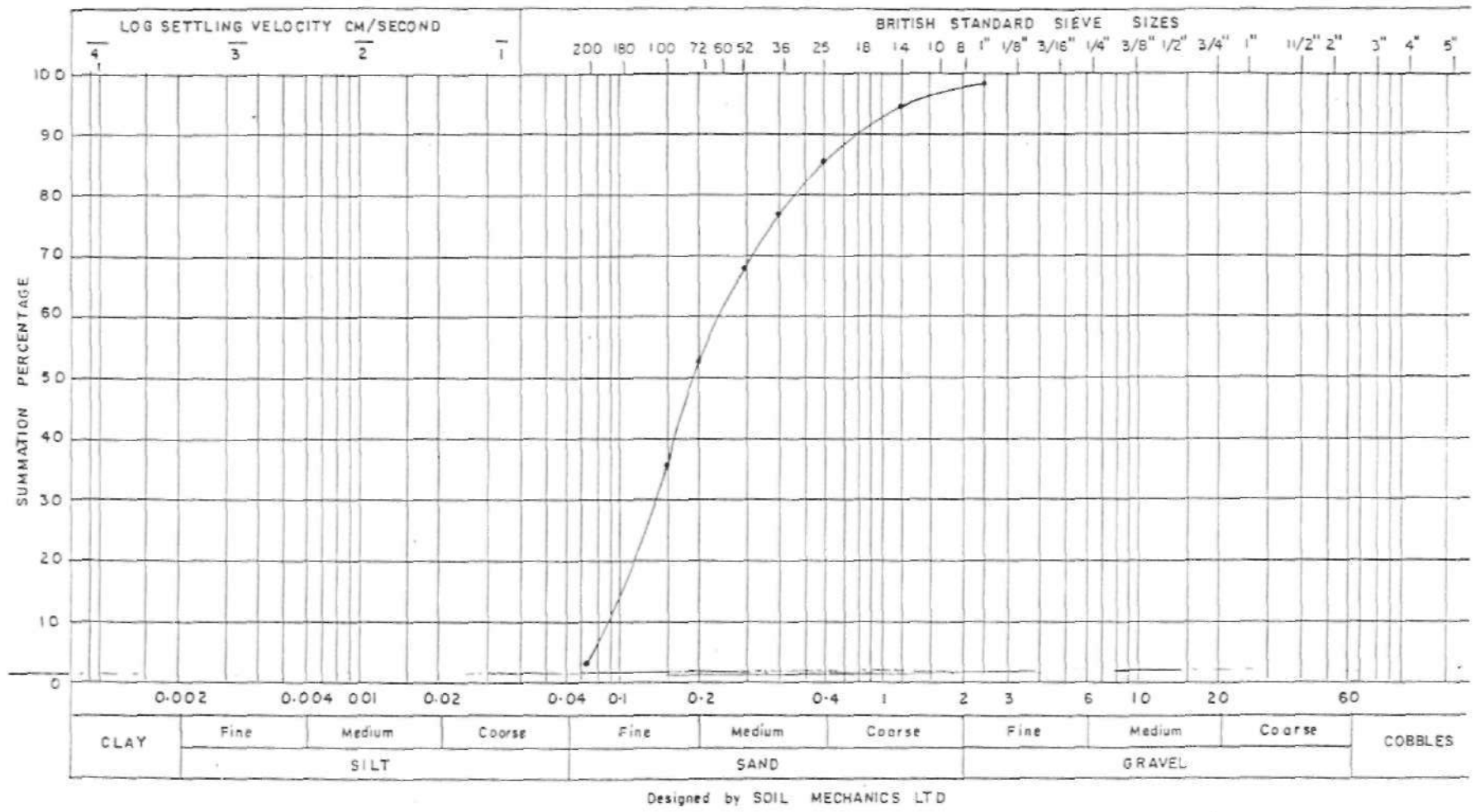
Size /Sample	d_{50} (mm)
KLC 1	0.20
KDC 1	0.20
KFC 1	0.30

PARTICLE SIZE DISTRIBUTION

FIGURE 5

LOCATION Nº. KLC 2 BORE HOLE Nº. ____ SAMPLE Nº. ____ PRETREATMENT DETAILS ____

DATE OF TEST 20/2/92 DESCRIPTION ____

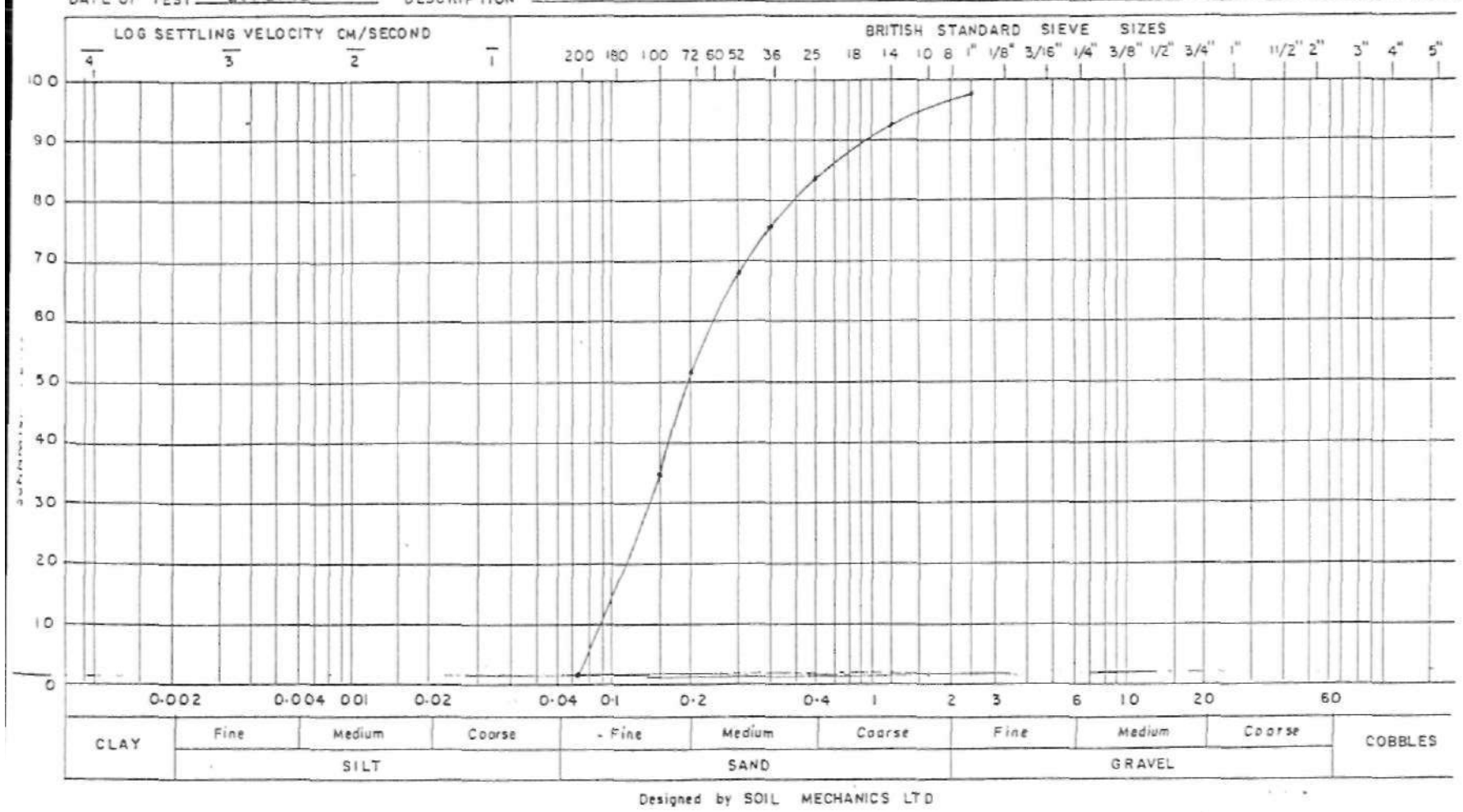


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PARTICLE SIZE DISTRIBUTION

FIGURE 6

LOCATION Nº. KDC1
DATE OF TEST 20/2/92
BORE HOLE Nº. ———— SAMPLE Nº ———— PRETREATMENT DETAILS ————
DESCRIPTION ————



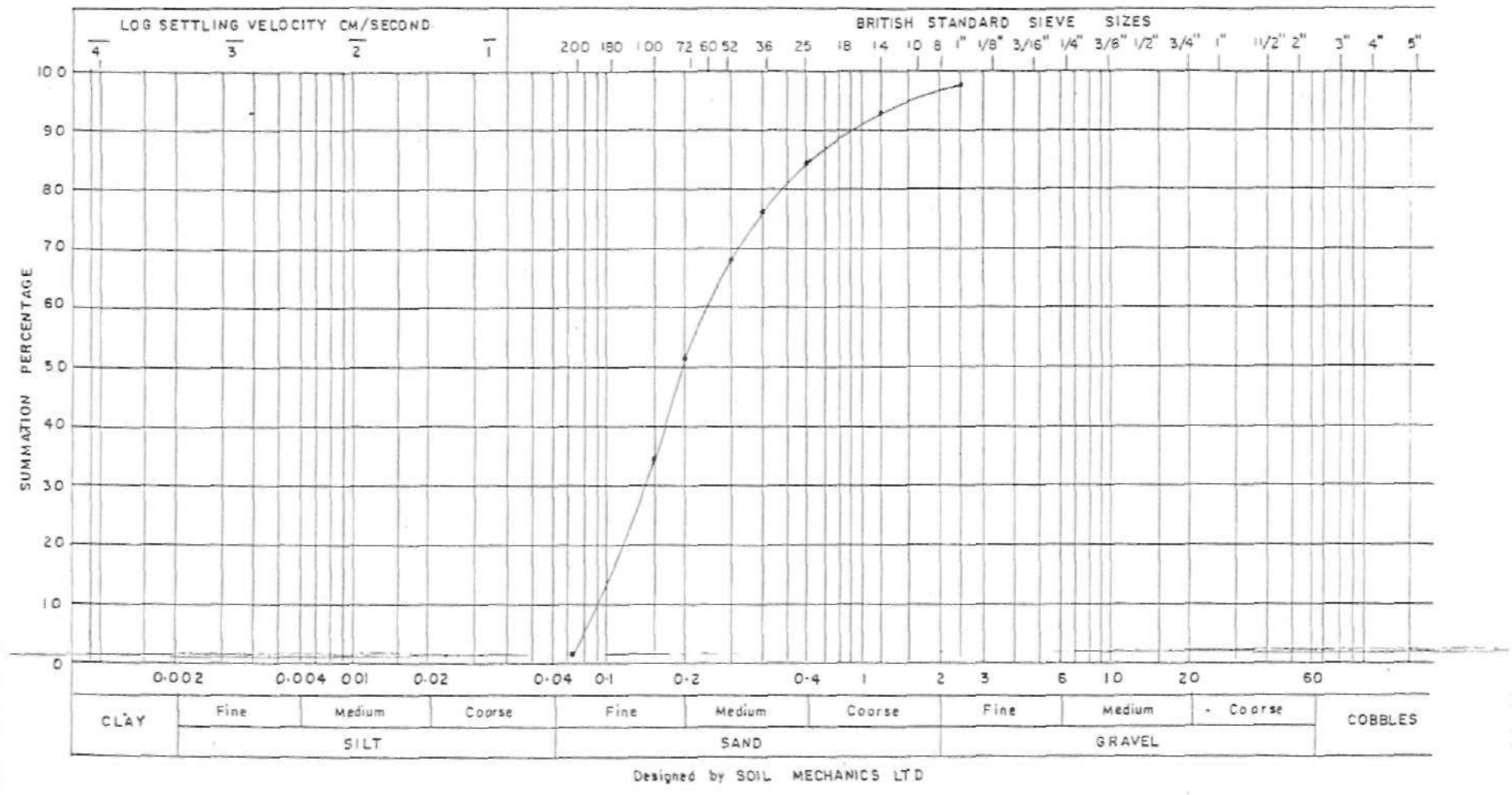
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PARTICLE SIZE DISTRIBUTION

FIGURE 7

LOCATION Nº. KFC1 BORE HOLE Nº. ——— SAMPLE Nº ——— PRETREATMENT DETAILS ———

DATE OF TEST 20/2/92 DESCRIPTION ———



Designed by SOIL MECHANICS LTD

This particle size distribution indicates that the sediment being transport though the canal system is predominantly silt and clay. As a result, it promotes rapid vegetative growth of weeds. The result of this size distribution was used in selecting the critical velocity ratio used in the critical shear stress concept to determine deposition and/or scour for the design and observed flow.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Introduction

This study has examined the silting characteristics of distributaries in the Kadawa sector of the Kano River Project between February and May 1992 for the 1991/92 dry season farming. The criteria used for examining the silting characteristics of the system include :

(i) Sediment discharge to selected sections of the canals in the project area.

(ii) Establishing the bed profile cross-section of the selected sections of the canals.

(iii) Hydraulic efficiency of the canals.

(iv) Volume of sediment deposition and scour in the selected canal sections.

5.2 Conclusions

The following conclusions were drawn from this study :

(i) From the sieve analysis of the soil samples, the sediment transported through the canal system is predominantly silt and clay. This aids rapid vegetative growth of weeds.

(ii) About 1082 m3 of sediment were scour, out of which 838 m3 are deposited as at the time of study in the selected portions of the canal system. The balance of 244m3 are carried to the downstream end of the canal system.

(iii) The sediment concentration in the selected sections of the canal during the period February to July 1992 ranged between 0.076 g/l/day and 1.575 g/l/day and 1.99 g/day and 3.26 g/day for the sediment in suspension and sediment in contact with bed

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respectively. The average rate of sediment concentration is 0.847 g/l/day and 0.262 g/l/day for sediment in suspension and sediment in contact with bed respectively.

(iv) It was identified that the suspended sediment concentration is uniform at all points in the cross-section. Also, it was identified that the transport of the bed material load is primarily dependent on the carrying capacity of the flow and is governed by hydraulic parameters, particularly the flow velocity as shown in Table 4.2 (b)

(v) The amount of the bed load (2.62g/day) is small as compared with total sediment load (23.22g/day) . The bed load discharge is found to be 11.3% of the total sediment load. This shows that most of the loads are in suspension and the canal bed is relatively uniform. This might be due to catchment erosion of the top soft soil of the area.

(vi) It was identified that the canals are not properly maintained. The distributary field canals are infested with weeds . As a result, its hydraulic efficiency was 56%. On the other hand, the hydraulic efficiency of the lined Kadawa lateral canal was 91%. This lined section is not infested with weeds.

(vii) It was identified that the velocity of flow in the Kadawa distributary canal is high as to cause scouring. As a result, there is more scouring than deposition at these sections of the canal. On the other hand, the velocity of flow in the field channel is very low and greater percentage of sediment scoured from other sections is deposited.

5.3 Recommendation

The following recommendation on how to reduce the siltation problem and improve on the efficiency of the canal in the selected section were made.

(i) proper maintenance of the canals is essential. The management authority should emphasize on the maintenance of the canal. Partial closure of the canals in May and June is recommended to allow the clearing of weeds. Continued hand clearance of weeds is envisaged.

(ii) A detailed diagnostic investigations and rehabilitation of canals in the Kadawa irrigation scheme is recommended. The study should concentrate on improving the estimation of canal water requirements and the upgrading of the distribution system to deliver the required volumes of water. For this to be achieved siltation and weed growth in the canals require an adequate attention. Also, the upgrading of both management and infrastructure is required

(iii) The irrigators should be trained on how to operate the turnouts so as to attain designed upstream head and to advice the tenants to desist from the indiscriminate clearing of the field channels as this affect the channel geometry.

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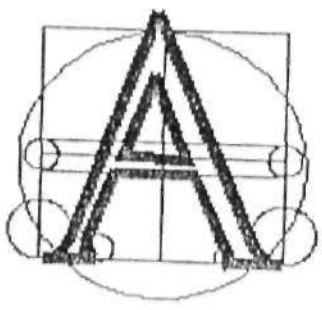
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APPENDIX

APPENDIX A1
DISCHARGE MEASUREMENT: COMPUTATION BY MID-SECTION METHOD
LOCATION : KLC 1 DATE : 25TH FEBRUARY 1992

DIST. FROM LEFT BANK (m)	DEPTH OF FLOW (m)	DEPTH OF OBS.(M)	REVOLUTION	TIME (s)	VELOCITY AT POINT(m/s)	VELOCITY MEAN IN VERTICAL	MEAN WIDTH (m)	AREA (m2)	DISC. (m3/s)
0.00	0.00	-	-	-	-	-	-	-	-
0.25	0.45	0.6d	130	50	0.3062	0.3062	0.2500	0.1125	0.0345
0.50	0.61	0.2d	170	50	0.2874	0.3468	0.2500	0.1525	0.0529
		0.8d	130	50	0.3062				
0.75	0.93	0.2d	79	50	0.2025	0.2442	0.2500	0.2325	0.0568
		0.8d	120	50	0.2858				
1.00	1.10	0.2d	81	50	0.2066	0.2361	0.2500	0.2750	0.0649
		0.8d	110	50	0.2655				
1.25	1.40	0.2d	74	50	0.1925	0.2199	0.2500	0.3500	0.0770
		0.8d	101	50	0.2472				
1.50	1.42	0.2d	53	50	0.1549	0.2336	0.2500	0.3550	0.0829
		0.8d	133	50	0.3123				
1.75	1.42	0.2d	72	50	0.1889	0.2476	0.2500	0.3550	0.0879
		0.8d	130	50	0.3062				
2.00	1.45	0.2d	40	50	0.1316	0.2311	0.2500	0.3625	0.0838
		0.8d	142	50	0.3305				
2.25	1.42	0.2d	53	50	0.1549	0.1818	0.2500	0.3550	0.0645
		0.8d	82	50	0.2086				
2.50	1.35	0.2d	60	50	0.1674	0.2195	0.2500	0.3550	0.0645
		0.8d	113	50	0.2716				
2.75	1.15	0.2d	77	50	0.1978	0.2215	0.2500	0.2875	0.0637
		0.8d	100	50	0.2452				
3.00	0.95	0.2d	89	50	0.2188	0.2442	0.2500	0.2375	0.0580
		0.8d	112	50	0.2696				
3.25	0.57	0.2d	89	50	0.1406	0.2275	0.2500	0.1425	0.0324
		0.8d	134	50	0.3143				
3.50	0.38	0.6d	84	50	0.2127	0.2127	0.2500	0.0950	0.0202
3.75	0.00	-	-	-	-	-	-	-	-

TOTAL DISCHARGE = 0.7795 m3/s

APPENDIX A2
DISCHARGE MEASUREMENT: COMPUTATION BY MID-SECTION METHOD
LOCATION : KDC 1 DATE : 25TH FEBRUARY 1992

DIST. FROM LEFT BANK (m)	DEPTH OF FLOW (m)	DEPTH OF OBS.(m)	REVOLUTION	TIME (s)	VELOCITY AT POINT (m/s)	VELOCITY MEAN IN VERTICAL	MEAN WIDTH (m)	AREA (m2)	DISC. (m3/s)
0.00	0.00	-	-	-		-	-	-	-
0.25	0.30	0.6d	72	50	0.1889	0.1889	0.2500	0.0750	0.0142
0.50	0.41	0.6d	74	50	0.1925	0.1925	0.2500	0.1025	0.0197
0.75	0.53	0.2d	81	50	0.2066	0.1978	0.2500	0.1325	0.0262
		0.8d	72	50	0.1889				
1.00	0.57	0.2d	130	50	0.3062	0.3468	0.2500	0.1425	0.0494
		0.8d	170	50	0.3875				
1.25	0.60	0.2d	79	50	0.2025	0.2544	0.2500	0.1500	0.0382
		0.8d	130	50	0.3062				
1.50	0.65	0.2d	120	50	0.2858	0.2462	0.2500	0.1625	0.0400
		0.8d	81	50	0.2066				
1.75	0.67	0.2d	74	50	0.1925	0.2290	0.2500	0.1675	0.0384
		0.8d	110	50	0.2655				
2.00	0.67	0.2d	101	50	0.2472	0.2798	0.2500	0.1675	0.0469
		0.8d	133	50	0.3123				
2.25	0.60	0.2d	79	50	0.2025	0.2442	0.2500	0.1500	0.0366
		0.8d	120	50	0.2858				
2.50	0.52	0.2d	77	50	0.1978	0.1826	0.2500	0.1300	0.0237
		0.8d	60	50	0.1674				
2.75	0.38	0.6d	84	50	0.2127	0.2127	0.2500	0.0950	0.0202
3.00	0.25	0.6d	100	50	0.2452	0.2452	0.2500	0.0625	0.0153
3.25	0.20	0.6d	90	50	0.2249	0.2249	0.2500	0.0500	0.0112
3.50	0.00	-	-	-	-	-	-	-	-

TOTAL DISCHARGE = 0.3907 m3/s

APPENDIX A3

DISCHARGE MEASUREMENT: COMPUTATION BY MID-SECTION METHOD

LOCATION : KFC 1 DATE : 25TH FEBRUARY 1992

DIST. FROM LEFT BANK (m)	DEPTH OF FLOW (m)	DEPTH OF OBS.(M)	REVOLUTION	TIME (s)	VELOCITY		MEAN WIDTH (m)	AREA (m2)	DISC. (m3/s)
					AT POINT (m/s)	MEAN IN VERTICAL			
0.000	0.00	-	-	-	-	-	-	-	-
0.125	0.20	0.6d	90.00	50	0.2249	0.2249	0.1250	0.0250	0.0056
0.250	0.27	0.6d	60.00	50	0.1674	0.1674	0.1250	0.0338	0.0057
0.375	0.31	0.6d	67.00	50	0.1799	0.1799	0.1250	0.0388	0.0070
0.500	0.35	0.6d	82.00	50	0.2188	0.2188	0.1250	0.0438	0.0100
0.625	0.35	0.6d	60.00	50	0.1674	0.1674	0.1250	0.0438	0.0073
0.750	0.36	0.6d	72.00	50	0.3123	0.3132	0.1250	0.0450	0.0141
0.875	0.33	0.6d	100.00	50	0.2452	0.2544	0.1250	0.0413	0.0101
1.000	0.28	0.6d	53.00	50	0.1549	0.1549	0.1250	0.0350	0.0054
1.125	0.00	-	-	-	-	-	-	-	-

TOTAL DISCHARGE = 0.0652 m3/s

APPENDIX A4

SIEVE ANALYSIS ON KLC 2

Gross mass of soil (Mo) : 93.50g Mass passing 2mm sieve (M1) : 92.30g

Mass retained on 2mm sieve : 1.20g Date : 20th February, 1992

Sieve number	Opening size (mm)	Mass of soil retained (g)	Fraction retained	Cumulative fraction retained	Fraction passing (%)
7	2.00	1.20	0.01	0.01	98.70
14	1.18	3.50	0.037	0.05	95.00
25	0.60	6.30	0.067	0.117	88.30
36	0.43	9.50	0.102	0.219	78.10
52	0.30	11.40	0.122	0.341	65.90
72	0.21	14.50	0.155	0.496	50.40
100	0.18	17.20	0.184	0.68	32.00
200	0.08	28.40	0.304	0.984	1.60
PAN	0.08	1.50	0.016	1.00	0.00

APPENDIX A5 **SIEVE ANALYSIS ON KDC 1**

Gross mass of soil (Mo) : 94.30g **Mass passing 2mm sieve (M1) : 93.70g**

Mass retained on 2mm sieve : 0.60g **Date : 20th February, 1992**

Sieve number	Opening size (mm)	Mass of soil retained (g)	Fraction retained	Cumulative fraction retained	Fraction passing (%)
7	2.000	0.60	0.006	0.006	99.40
14	1.180	6.10	0.065	0.071	92.90
25	0.600	18.10	0.192	0.263	73.70
36	0.425	10.30	0.109	0.372	62.80
52	0.300	12.90	0.137	0.509	49.10
72	0.212	13.20	0.140	0.649	35.10
100	0.180	7.50	0.080	0.729	27.10
200	0.075	25.20	0.267	0.996	0.40
PAN	0.075	0.40	0.004	1.000	0.00

APPENDIX A6

SIEVE ANALYSIS ON KFC 1

Gross mass of soil (Mo) : 87.30g **Mass passing 2mm sieve (M1) :** 85.80g

Mass retained on 2mm sieve : 1.50g **Date : 20th February, 1992**

Sieve number	Opening size (mm)	Mass of soil retained (g)	Fraction retained	Cumulative fraction retained	Fraction passing (%)
7	2.000	1.50	0.017	0.017	98.30
14	1.180	3.10	0.036	0.053	94.70
25	0.600	5.50	0.063	0.116	88.40
36	0.425	8.60	0.099	0.215	78.50
52	0.300	10.00	0.115	0.330	67.00
72	0.212	13.50	0.155	0.485	51.50
100	0.180	15.00	0.172	0.659	34.30
200	0.075	29.10	0.332	0.989	1.10
PAN	0.075	1.00	0.011	1.000	0.00