Sediment Behavior of Sangro Distributary, Mirpurkhas Sub-division, Sindh

Field Report

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1. INTRODUCTION

1.1 General

When water resources are dwindling, population growth rate is high and the capacity of governments/agencies to develop new irrigation schemes is poor, dependence on the existing irrigation systems increases daily. With the passage of time operation and maintenance cost has steadily increased and the inability of concerned authorities to meet these costs, has adversely affected the performance of these systems. Sedimentation is one of the most serious maintenance problems faced by most of the irrigation canals, especially in the Indian subcontinent (Pakistan, India).

Heavily sediment-laden water coming from different watersheds of the Indus basin carries about 350000 acre feet of suspended sediment every year. According to an estimate, about 200000 acre feet of these sediments is deposited in reservoirs and irrigation canals. The bed of Jamrao Canal has silted up by 7-9 feet, as compared to its design bed level of 1932. Similarly, Marala-Ravi Link Canal was faced with severe sedimentation problems shortly after construction which forced the government to construct a new head work, causing a heavy economic burden. As a result, canal had lost one third of its original conveyance capacity.

In Sindh, the Irrigation Department receives a special budget for canal maintenance, mostly for desilting, which accounts for the half of the Operation and Maintenance budget. Machines (excavators) can operate during the canal closure (generally the annual closure, in January), but only two machines are available for the 200 distributaries of the Eastern Nara Canal Circle, among which 85 would require yearly desilting. A rotation program is organized over three years.

The present study is an attempt to study the sediment problem in Sangro Distributary in Jamrao Canal Irrigation System under Sukkur Barrage.

1.2 Objective

The main objective of this study is to monitor and evaluate the siltation phenomenon into the Sangro Distributary Irrigation System.
The sub-objectives were:
* to understand the sedimentation process in an irrigation system;
* to explore the measurement methods;
* to prepare a campaign on a longer term and a larger system; and
* to build a data set for the modeling.

The measurement campaign took place for nine weeks between July13, 1997 and September 13, 1997.

1.3 Study Locale

This study was conducted on the Sangro Distributary Irrigation System of West Branch Canal, which is a section of the Mirpurkhas Sub-division of Jamrao Canal. Remodelling Jamrao Canal, completed in June 1994, was to increase its capacity by about 50% percent of the original design. However, extra supplies should be available only after the completion of Nara Canal's remodelling.

1.3.1 Mirpurkhas Sub-division.

Jamrao Canal is the first major off-take of the Nara Canal system, and serves a culturable command area of about 900,000 acres. From an administrative standpoint, the Jamrao Canal Division of the Nara Canal Circle has been divided into five sub-divisions.

Mirpurkhas Sub-division comprises of Jamrao Canal (from RD 291 to 443) and West Branch Canal (RD 0 to 143), as well as their distribution system in the given reaches (Figure I). The distribution system consists of 6 distributaries, 5 minors (off-taking directly from main canals), about 100 direct outlets from the main canal, and about 400 outlets from the off-taking distributaries and minors. The salient characteristics of the distributaries and minors are given in Table 1.

Table 1. Major Off-takes in Mirpurkhas Sub-division

S.No	Name of Channel	Parent Channel	Off-take (RD)	Q Design (Cus)	GCA (ac)	CCA (ac)
1	Mirpur Disty.	Jamrao	343	64	20965	20693
2	Doso Daharoro Dy.	Jamrao	343	76.5	23574	22373
3	Kahu Visro Minor	Jamrao	383	18	5898	5838
4	Kahu Minor	Jamrao	385	44.5	15137	14984
5	Sanro Disty.	Jamrao	408	70	18349	18100
6	Bareji Disty.	Jamrao	408	42		14318
7	Lakhakhi Dsity	West Branch	38	64	17826	17723
8	Bhittaro Minor	West Branch	69	27	4628	4512
9	Sangro Disty	West Branch	88	105	30806	29029
10	Daulatpur Minor	West Branch	115	49	13853	13556
11	Bellaro Minor	West Branch	143	42	13522	1344

Sangro is the largest distributary of the sub-division, off-taking the West Branch at RD 88 on the left side. This is a 15 km long distributary serving a culturable command area of 29029 acres through two minors, Jarwari and Chahu, and 60 outlets. Flows into the distributary and the minors are regulated with the help of gated head regulators, while most of the outlets are the adjustable proportional module (APM) type, with a few open flume type in the tail reaches. Two cross-regulators have also been provided at the off-takes of the two minors, as shown in Appendix 1.

The two-gated head regulator of the Sangro Distributary looks in good condition, since repair works had been carried out during the annual closure in January 1997. However, there are still some leakages on both sides, as well as on the bottom (when closed). The head and cross regulators of

Jarwari and Chahu Minors are not manipulated much, and not often, and are in good working condition. Most outlets have been tampered with, where width and height (B & Y) have been increased to meet farmers' demand for extra supplies.

The physical condition of the distributary itself is in bad shape due to poor maintenance over longer periods of time, especially in the head reach. The embankments have vanished in most of the head reach, where, even free board has been encroached, due to the bed raising. A few points in the head and middle reaches that are susceptible to breaching or spill-over, are exceptions, either because of cattle trespassing or banks erosion. Most of the channel along the length can withstand water pressure. The tail reach is mostly in cutting, probably due to repeated heavy silt clearance by water users, where lift irrigation is also practiced. The cross sections and curves have deteriorated considerably over time. Although thick vegetation all along the channel guards against animals trespassing and provides safety to the banks, it also causes sediment deposition at points where the branches are hanging down in the channel to interfere with the velocity of flow.

Jarwari Minor off-takes Sangro Distributary at RD 10 on the left side, to serve a culturable command area of 7178 acres with the help of 26 outlets (see flow diagram, Appendix 1). Overall, the Jarwari Minor cross section is quite good, with the exception of a few points near dwellings where animals are trespassing and other uses have damaged the embankments. Vegetation exists on the banks; its effect on flow velocity however, is not important. Some of the tail reach commands, passing through a part of Mirpur town, is now occupied by dwellings and buildings. Two outlets in the tail reach have been sanctioned as safe for drinking and other municipal purposes for a part of Mirpur town, which is why Jarwari Minor is always running, even during the rotational closure of Sangro Distributary (except during the annual closure of Nara Canal). The tail of the minor does not receive water permanently.

Chahu Minor off-takes Sangro Distributary at RD 29 on the right side, to serve a culturable command area of 9948 acres, with the help of 18 outlets. The physical condition of the channel is comparatively quite good; berms are quite strong and enough free board is available. Although some small reaches have vegetation on the banks, it does not however, disrupt the flow velocity. The channel's longitudinal, as well as cross-sections, seem to be in good condition and devoid of serious problems. There are fewer points that would be vulnerable to breaches.

In this study, the tail portions of both minors have not been observed, either because they don't receive water (Jarwari), or because of access difficulties along the canal (last 2 miles of Chahu minor).

1.3.2 Operation/Regulation

Although the operation of the head regulator of the Sangro Distributary corresponds to water demand downstream and the availability of water in the main canal, the head regulators of Jarwari and Chahu Minors are, however, rarely manipulated. Usually, the discharge at the distributary head is more than what it had originally been designed for and may vary from day to day. Fluctuations in the main canal and the influence of water users occasionally affect flow regulations in the system significantly. The head regulators of two minors are usually kept fully open. The first cross-regulator is used for flow regulation into Jarwari Minor, while the second cross-regulator near Chahu Minor head, usually, remains open. The daily observations during the period November '96 to October '97 suggest that the tail of the distributary normally receives water. Rotational closures

during the water shortage periods are implemented, lasting about one week, almost every month. However, in order to feed Jarwari Minor, which supplies water for drinking and municipal uses to a part of Mirpur town in the tail reach, water is not closed completely.

Outlets are supposed to draw due shares of water and sediment all the time. Due to severe tampering and poor maintenance of the channel, the operational performance has changed considerably. Similarly, operation falls within the Irrigation Department's purview. However, observations suggest that the same has been taken over by the water users. The farmers' practice of outlet closures and openings sometimes causes flooding at the tail.

1.3.3 Work done by DSS and ISRIP

Another IIMI team is working on the introduction of a decision support system (DSS) aimed at improving the operational management of the irrigation system in Mirpurkhas Sub-division. Sangro Distributary is also one of their selected channels where they monitor the daily operation, delivery performance and physical characteristics. The daily water level measurements and gate openings of the selected points are taken along the channel up to the tail end. The head regulators and outlets are calibrated in order to know the daily withdrawals by these off-takes. Topographic and walk-thru surveys were also conducted during the annual closure in January-February 1997. Details about the project and the study locale are given in [3].

Similarly, ISRIP, under the LBOD[1] project, is also taking monthly discharge measurements and sediment samples at RD 0+300 of Sangro Distributary where the same measurements for the first two outlets (1-L and 2-L) are taken. Similar work is also undertaken at Chahu head and one of its outlets each month. These observations were conducted from February 1995 to December 1997.

1.4 Data to be Collected

As per objective of the study, the following three types of information have been collected.

    1. Physical data, which includes;

        a. design longitudinal and cross sections;
        b. design dimensions and discharges etc.; and
        c. actual longitudinal and cross-sections at the beginning and the end of the campaign.

    2. Hydraulic data, which includes;

        a. discharge measurements at selected points in order to know the hydraulic behavior of the system; and
        b. vertical velocity profiles at selected points.

    3. Sediment data, which includes;

        a. bed material characteristics;
        a. sediment inflow into the system (depth integrated samples);
        a. sediment diversions at distributors;

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[1] Left Bank Outfall Drainage project

       a. sediment diversion at sample outlets; and

       a. point samples at selected points.

A sketch of the system is presented below.
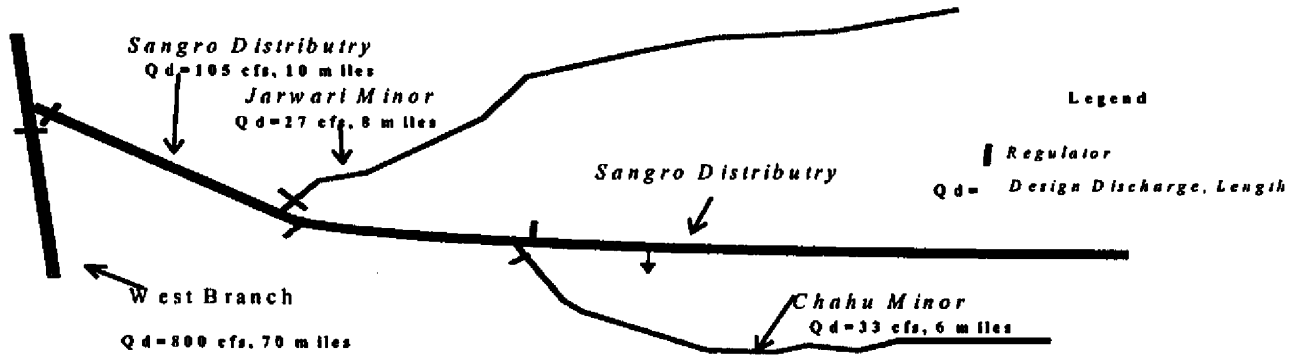

Figure 1: Sketch of the Sub-system

The studied system includes 62 outlets and two distributary-minor diversions. In Part II, the report will present the measurement methods used during the campaign, followed by the field work, in Part III. A presentation of the collected is then given with a quick analysis. Recommendations for the next measurement campaign is given in conclusion.

2. MEASUREMENT METHODS

2.1 Hydraulic

These measurements aim at estimating the inflow/outflow as well as the vertical velocity profiles. The measurement methods are classical. The main structures must be calibrated; head regulators of the canals, cross-regulators, outlets. The outlets have (in theory) fixed dimensions, and few measurements are required for a good calibration. The width (B), the height (Y), the water elevation from the crest upstream, and downstream from the outlet (Hu and Hd), are measured, as well as the discharge in the watercourse (Q), by using a currentmeter, or, a cutthroam flume. The calibration of gated structures require more measurements (with different gate openings) for a good calibration.

Lastly, rating curves at the tail-ends should also be known if an hydraulic model is to be used. The discharge measurements in the fields have generally been done with currentmeters, Pigmy model for shallow waters (depth less than 1.5 foot), or type A otherwise. The two-point method (0.2-0.8 times the water depth) is preferable to the 0.6 method whenever the presence of the bed does not affect the measurement; for the type A currentmeter, the distance between the bed and the device should be at least 0.5 foot, whereas, a minimum of 0.2 foot is acceptable for the Pigmy. The accuracy of one discharge measurement is around 5%, in general. For more details about procedures, we should refer to Ref [1].
Velocity profiles are also measured with currentmeters. These measurements also allow calculating the average velocity in the vertical, from which the two-point and 0.6 methods differ from less than 5%.

Daily levels are collected in order to know the water inflow and outflow. Fixed gauges either are seldom installed on the system, or, are rusted. Painted marks are established at key points and the water level is taken with a portable staff. The accuracy, due to water variations, reading errors, positioning of painted marks, etc., is not mere than 1cm (0.03 foot), in general. This error is not of importance in many cases, but avoids the utilization of discharge coefficients for submerged flow conditions where the fall is very low (a few centimeters).

2.2 Topographic

2.2.1 Check the Level...

Topographic measurements are classically done with a level and a staff (graduated in feet) in small channels. Sonic sounders are preferably used with a boat (deep waters). The level must be regularly checked because a deviation may appear in the lenses. One method is level verification, presented in Figure 2.
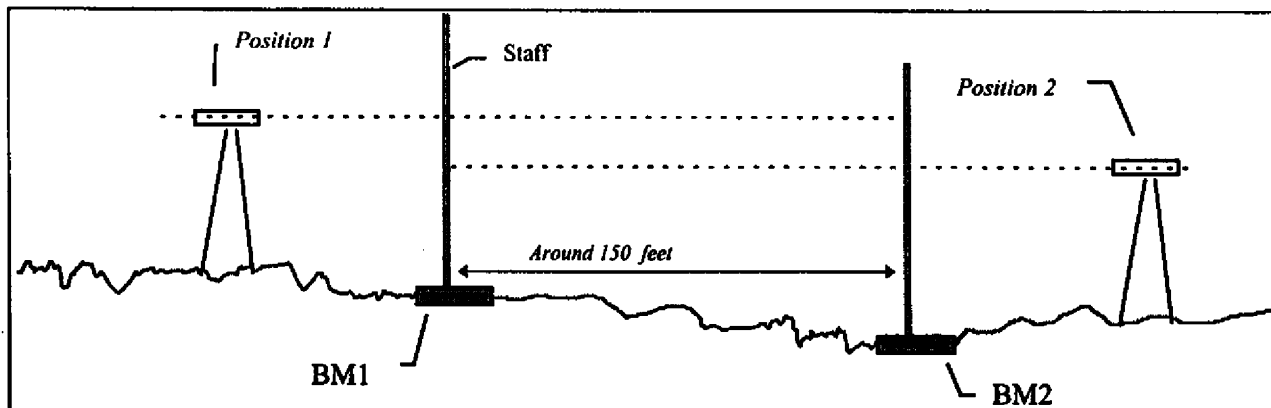
Figure 2: Level Verification

The elevation of BM2 with respect to BM1 should not depend on the position of the level. A difference of 0.01 is acceptable. When leveling over long distances, the level should always be at the same distance from the two staffs. Indeed, the error due to the level will be all the higher, as the distances between the two staffs are different, as shown below.
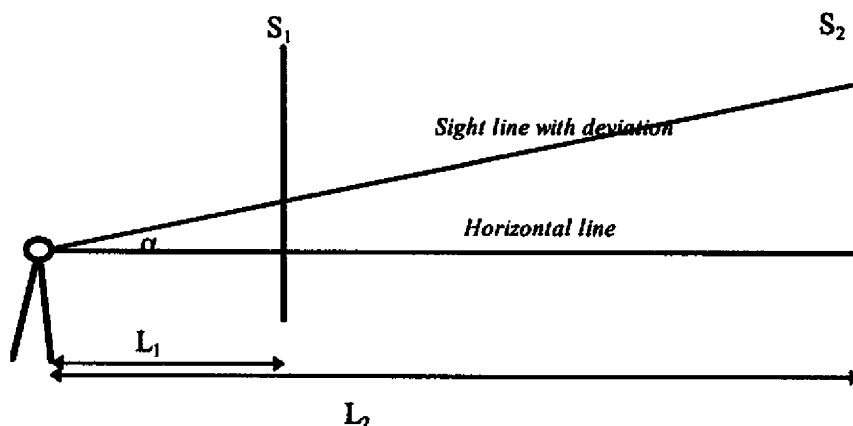
The relevant measured quantity is the difference of reading between the two staffs. The error introduced in this difference, due to defections in the level, say a sight line with a deviation of α in the vertical direction as shown in the drawing, equals $E=(L_2 - L_1)\tan\alpha$ which equals 0 when the level is equidistant from both staff rods.

2.2.2 Canal Topography

For each cross section, a benchmark is established before all the benchmarks can be levelled in a second stage. In this case, the biggest topography errors come from reading. These can be avoided with a double leveling (using two levels), or, by closing the leveling. The criterion for the closure is generally around 0.02 feet of error between two benchmarks distant from a few kilometers, say around 5km, giving an error of 0.001‰, which is low compared to the natural ground slope (in average 0.1‰).

Reading errors may also appear while taking the height of the instrument with respect to the benchmark (unsystematic), but, this error should be inferior to a few millimeters. Due to the tractive force as shown in the following figure, a systematic error appears in a flowing sandy channel.
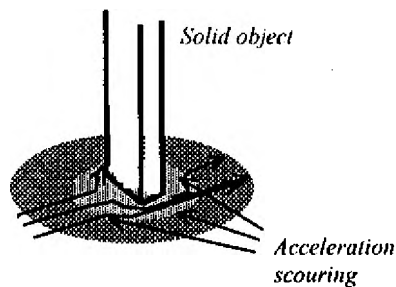
The scouring around the solid object provokes the subsidence of the sand supporting the object. The error involved depends on the rapidity to read the rod. The error is generally between 0.5 and 1 inch (1 to 2.5 cm) in the flowing canal.

Anyway, it would be irrelevant to expect a higher accuracy, knowing the irregularities of the mobile bed, due to hydraulic effects (ripples) or the presence of cattle in the canal.

The different topographies to be compared should also be taken in the same conditions, since the effect produces a systematic error.

2.3 Suspended Samples

Most of the devices presented in the following sections have been developed by the George Washington University. For details about these, refer to ACOP and US Geological Survey manuals (ref [4], [5], [6]).

This sampler is supposed to measure the mean concentration in a section. This mean concentration is, in this case, defined as follows :

$$C = \frac{Q_{solid}}{Q_{water}} \qquad [1]$$

On small channels, a portable sampler, developed by the George Washington University, is used (DH48) as shown here :
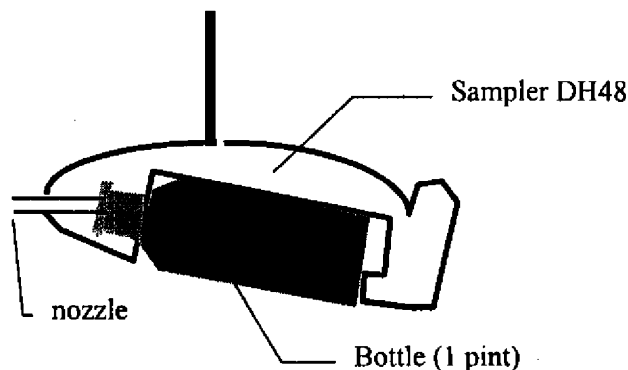
Figure 3: Depth Integrated Sampler DH 48

More details about this sampler are given in ref [5].

The sampler is designed to fill the bottle through a nozzle where water enters at the flow velocity. Air is evacuated from the sampler through a delivery.

The layer near the bed (0.25 foot, or 3 inches) is not sampled. This layer includes the bed load and a part of the suspended load. Therefore, the method of sampling should make a correction in order to take into account the not-sampled layer, which is not an easy procedure.

The second difficulty consists in collecting the sample. The method is called 'equal transit rate', so that the concentration of the sample verifies the equation above. The sampler is moved down, then up, on the whole sampled layer, in one or several verticals of the section at a constant velocity (*transit rate* or *sampling velocity*). This velocity should not exceed 0.4 times the flow velocity (ref [4]).

If the bottle is only half filled, there should be no fear about not having dnough solid particles to ensure accuracy of the lab analysis. If the bottle is nearly full (more than 80%), the evacuation of air may have been disturbed, and the sample should be taken again.

In watercourses, one or two verticals are supposed to be representative enough of the section, all the more because the samples are generally collected in the « boil » of the outlets (cf. « boiled samples »). In distributaries, 5 equispaced verticals are made. Two or three bottles per vertical are preferred in wider canals in order to minimize the sampling error due to stochastic effects. In main canals, ten verticals are generally collected, with two or three bottles per vertical.

The next calculation shows that all the bottles in a section should be moved **up and down at the same velocity.**

Let us note $C(y,z)$ the concentration at the depth z and the cross abscissa y, $\lambda(y,z)$ the vertical velocity of the sampler, $V(y,z)$ the velocity of the flow. The sampler is designed to collect water through the nozzle at the same velocity as the flow. Therefore the discharge in the nozzle is equal to $V(y,z).A$, A being the nozzle area. The sample is collected from z=0 to z=a.

Indeed, during the elementary time unit dt, the quantity of water entering the bottle is
$$dV = A.V(x,y).dt$$

Integrating with respect to z, we have the volume collected in the bottle in the vertical:
$$V_y = \int_0^a A/\lambda.V.dz + \int_a^0 A/\lambda.V.dz$$
(the two integrals represent the upward and downward movements)

Similarly, the quantity of sediments is
$$dS = C.A.V(x,y).dt$$
and the weight of sediments in one bottle (vertical y) equals :
$$S_y = \int_0^a A/\lambda.C.V.dz + \int_a^0 A/\lambda.C.V.dz \qquad [2]$$

A is a constant, but λ could depend on y, preventing from major simplifications. If we assume λ constant, we can write S and V as follows :
$$S_Y = 2.A/\lambda.q_s$$
$$V_Y = 2.A/\lambda.q$$

where q_s and are respectively solid and fluid discharges per unit width.
Now we must assume that the verticals are equispaced as follows:

Vert. 1   Vert. 2   Vert. 3   Vert. 4   Vert. 5
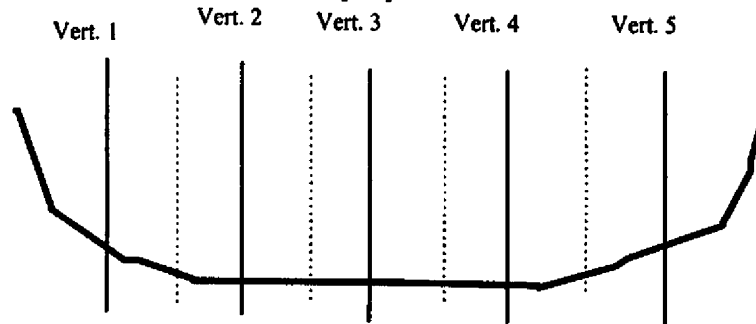
and represent a sub-section of the same width L.
Then the total volume of collected water is

$$V=V_1+V_2+...+V_n$$

or

$$V= \sum_{y=1}^{n} 2A/\lambda.q$$

Factorizng 1/L and A/λ, we will extract the fluid discharge in its discretized form, provided L is small enough:

$$V=\frac{1}{L}. 2A/\lambda. \sum_{y=1}^{n} q.L \ \# \ \frac{2A}{\lambda L}.Q \ [3]$$

Similarly, the quantity of collected sediements will write as follows:

$$S=\frac{1}{L}. 2A/\lambda. \sum_{y=1}^{n} q_s.L \ \# \ \frac{2A}{\lambda L}.Qs \ [4]$$

and finally, the measured concentration (ratio of sediment weight to water volume):

$$S/V=Q_s/Q \ [5]$$

As a conclusion, the method of equal transit rate gives access to the mean concentration in the section defined as $C=Q_s/Q$, provided:
- *the vertical velocity λ of the sampler is constant and the same in all the verticals of the section.*
- *the section is divided in a sufficient number of verticals n;*
- *the verticals are equispaced as follows: if W is the water width, the first vertical is located at W/2n=L/2 from the left bank, then the verticals are equispaced by L=W/n.*

If one condition is missing, the previous simplifications are no more possible and there is no reason for our concentration to fulfill the expected relation.

We insist on that point because it is quite difficult to achieve, and we are generally tempted to fill all the bottles as much as possible in order to get the maximum quantity of sediments in the minimum space.

A methodology is given by the US Geological survey (ref [4]), and charts to determine the nozzle size and the sampling velocity (or *transit rate*) for a given depth.

This methodology is quite awkward to apply in the field, and is not used by ISRIP. Assuming that the field team collecting has enough experience to determine the nozzle size, a table achieving a simple equal transit rate, is presented in Appendix 2.

Therefore the following procedure is proposed:

1- Collect one bottle with the maximum acceptable quantity of water, in the vertical, where the sampling velocity necessary to fill the bottle is the highest in the section (generally where the flow velocity is maximum). Note the time and the depth of sampling;

2- Before collecting the other bottles, note the depth of sampling;

3- Note the **pseudo-sampling velocity** given in table 2, appendix 2, the depth of the vertical is read horizontally at the top, the duration of the sample is read vertically on the left, the pseudo-sampling velocity is read at the intersection of the selected row and column. This pseudo-sampling velocity should be the same for all the bottles of the sample;

4- For each vertical, note the depth;

5- In the previous table, select the column corresponding to this depth, and search this column for the value of the pseudo-sampling velocity, and note the corresponding time on the left side of the row; and

6- Collect the bottle, down to the bottom and up to the surface, so that the duration of the operation lasts the time noted in (5).

Instead of 3, any device able to measure the vertical velocity of the sampler, can be used.

When used from a boat (wide canals or rivers), the sampler is linked to a wire manipulated with a winch.

2.4 Boiled Samples

Downstream from any structure, the flow is disturbed. When the turbulence is sufficient to mix the different layers of the flow (water and particles) altogether, this part of the flow is called « boil » and the concentration is supposed to be statistically homogeneous.

A « boiled sample » is collected in the boil of a structure with any kind of device. Nevertheless, it is preferable to use the integrating sampler and move it on the whole vertical, in case the mixing is not perfect.

This is the technique used in the watercourses, downstream from the outlets or even in the concrete structure of the off-take.

In this case, bottles can be filled a little, since the principle of « equal transit rate » is of no interest here.

2.5 Pump Samples

Pumps are used to establish vertical profiles of concentration. There are two main methods of pump sampling:

- pumping in bottles; and
- pumping in a sieve, in order to measure the concentration of the coarsest particles only.

The first method allows measuring the total concentration by analyzing a volume of water. The main limitation is the collected quantity, because several samples are necessary to establish vertical profiles (and most of the time horizontal as well), involving huge volumes of water to store. During this campaign, we have collected between 1 or 2 liters per sample.

The second technique allows collecting a large amount of water. Pumping during one minute at 100ml/s extracts the sediments of 6 liters of water. The main advantage is the quantity of collected sediments (the higher, the more accurate the analysis), and the pumping duration can be adjusted to the concentration. The second interest is the collection time, long enough to minimize the stochastic effects. Nevertheless, the concentration of fine particles (generally a 62μ sieve is the smallest used) is not known; moreover, the accuracy of the concentration is dependent on the reliability of the pump and the measurement of its discharge.

The device is presented as follows:
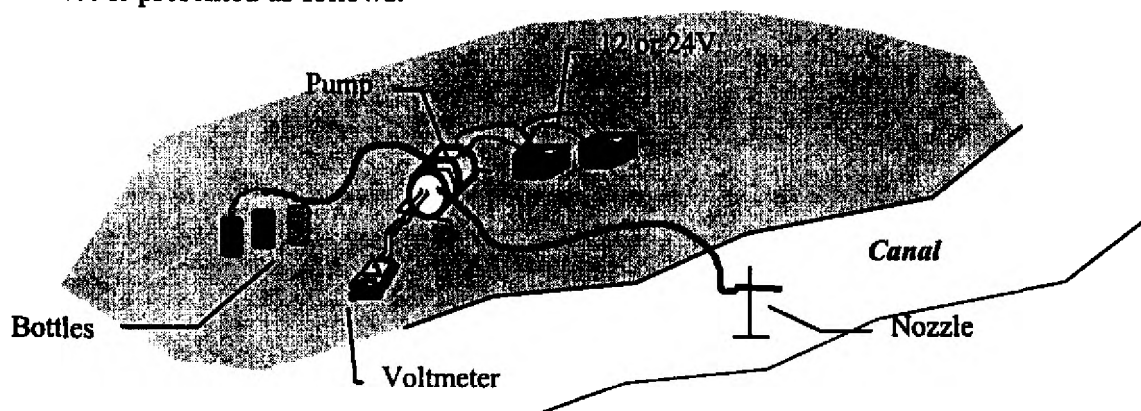
Figure 4: Pump Sampling Disposition

Operation of the Pump:

The main difficulty of pump sampling is to pump at the flow velocity so as to avoid the disturbance, due to the presence of a nozzle in the water.

The first stage consists of establishing the rating curve (discharge versus voltage) of the pump; for different stabilized voltages, the discharge is measured, thanks to a graduated tube and a star watch.

The nozzle is placed in the middle of the canal (average point for all the sampling depths).

Let's assume the accuracy of the star watch to $\delta t=0.5s$; the one of the tube to $\delta V=20ml$; the minimum volume used to calculate the discharge is around 800ml; and, the time 8s. The maximum error on the discharge is:

$$E=\frac{\delta t}{t}+\frac{\delta V}{V}=9\%$$

Nevertheless, the establishment of a rating curve reduces the inaccuracy of the correspondence voltage/discharge).

The pump is not, theoretically, sensitive to the sampling depth; the relevant variable for the pump efficiency is the power to supply between the nozzle (inflow) and the delivery (outflow). The following figure shows that the pressure in the pipe at the water surface level is independent on the nozzle depth:
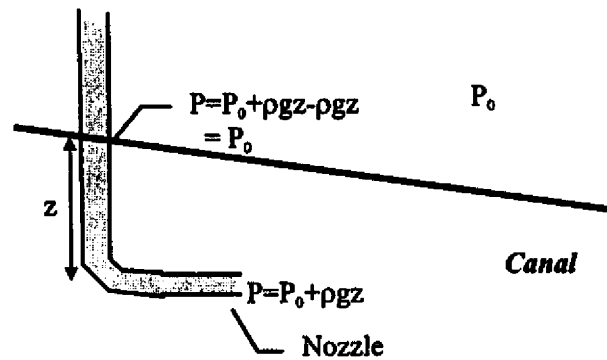
We have also tested the sensitivity to the delivery height. Moving it by 2 meters can provoke a difference of 20% of discharge for a similar voltage (actually, this kind of pump is designed to be insensitive to this height). Therefore, we propose to keep the delivery at a constant height once the rating curve is established, with the advice to check the discharge of the pump whenever a new voltage is selected.

The second stage of pump sampling consists of measuring the flow velocity at the sampling locations.

Finally, a nozzle and a voltage allowing to pump at the flow velocity, are selected. The water is collected in bottles, or, poured into the canal when a sieve is used. Obviously, once the voltmeter is stabilized to the desired voltage, the length of the pipe must be taken into account before filling the bottles or the sieve. The pump is also often used from a boat, with the nozzle fixed to a tare. Since the height between the water surface and the delivery slightly changes in these conditions of utilization, the rating curve is almost always the same. At present, pumping in a sieve has not been tested yet.

2.6 Bed Samples

Collecting bed samples in the flowing canal in order to avoid collecting the very fine particles, which may have deposited while the canal was emptying is advised. This very fine layer of silt and clay, visible during the closure periods, is not linked to the sediment transport, since it is flushed away as soon as water appears.

For deep waters, where a boat is required, the sampler, fixed to a wire, consists of a circular gate which is closed, thanks to a spring (BM54, ref[4]). The sampled layer is approximately 2 inches deep. In shallow waters, we use a bed sampler (BMH53) extracting a column of soil, up to 1 foot long:
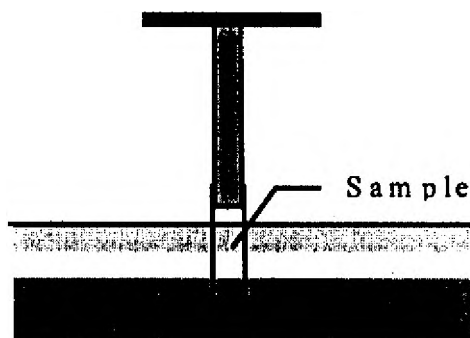
Figure 5: Bed Sampler in Shallow Water

When the column is removed from the sampler, it is easy to select the portion of bed which we want to analyze, since the bed material is not disturbed during the sample collection very much. All these devices are also presented in [4] and [6].

2.7 Laboratory Analysis

All the samples collected with the devices presented above are analyzed in a laboratory. The methods presented below have also been developed by the George Washington University. Datasheets are presented in Appendix 2.

2.7.1 Sample Composition

For suspended samples, the concentration is determined as the weight of solid particles over the volume of water.

The first stage consists of weighing the water contained in the sample; each bottle of the sample is weighed, then the water is removed. This is done at least 48h afterwards. A small quantity of water is kept in order to wash the sediments from the sides of the bottle, and all the bottles of similar samples are composed into a single bottle. This composed sample is sieved at 62 microns (lower limit for sand). The sand particles will be analyzed separately from silt and clay. The water is weighed with an accuracy of 1g, the weight of water for each bottle being more or less 300g. The error on the water weight is, therefore, around 0.3%. Note that the sediment weight is included as well, but the percentage of solid particles is generally negligible. The bed samples are also sieved. The finer particles are dissolved in distilled water if the grading curve is required.

2.7.2 Analysis of Coarser Particles

All the solid particles are weighed with an electronic balance. The accuracy is (in theory) 0.0001g.
The total weight is measured in order to calculate the total sand concentration. The grading curve is also established for the following ranges:

* 62-88 μm
* 88-125 μm
* 125-250 μm
* 250-350 μm
* 350-500 μm
* 500-700 μm

* 700-1000 µm

When the quantity of sand to analyze is sufficient (more than 10mg), the grading curve is established with the fall velocity through a column of calm distilled water:
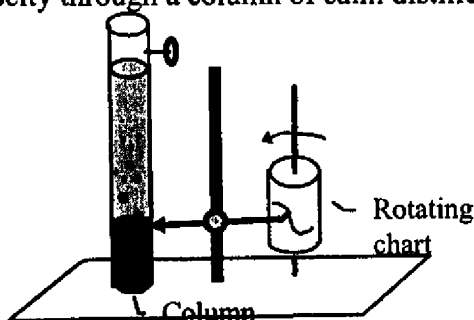
The percentages of the different classes are measured with a ruler on the chart. A relationship between the settling velocity and the diameter (Stokes law) is used, depending on the water temperature.

When the weight of sand is too low, the sieve method is preferred. Both methods should be consistent. They give similar results on different samples of the same canal, but a comparison should be done on the same samples in order to assess the discrepancy between both methods.

2.7.3 Analysis of Finer Particles

We use the « pipette method » based on the fall velocity as well. Fifty (50) ml of clear water is collected from the composed sample for the dissolved salts correction.
The composed sample should then contain from 20 to 50ml, poured into a tube in which distilled water is added up to 500ml. The temperature is measured.

The water in the tube is stirred and the particles are supposed to be well mixed. A pipette of 20ml is collected and poured into a dish. After drying in the oven, the weight of this sample will give the quantity of the sediments finer than 62µm.

The second pipette of 20ml is taken after the particles coarser than 31µm have settled (approximately one-and-a-half minutes after stirring the tube, but this time depends on the viscosity, say, on the temperature). The pipette is emptied into a dish, dried, and the weight of solid particles gives the quantity of sediments finer than 31 microns.
The process is iterated for the ranges finer than 16µm, 8µm, 4µm and 2µm. The times of deposition are given by tables with respect to the temperature, established according to Stokes law, and the relation kinematic viscosity ν, versus temperature T.

$$w = \frac{1}{18\nu}\, g.\delta.d^2 ,$$

with δ density of sand in water, and
$$\nu = \nu(T)$$
Normally, the operation lasts between one and a half and two hours for usual temperatures.

2.8 Other Methods

2.8.1 Field Methods

There are many other samplers which will not be detailed here because of our lack of experience. One of these consists of an open pipe in which the water can flow freely. Thanks to a wire and an elastic, two gates are closed instantaneously, and water is trapped in the pipe, mainly used in oceanography.

Following this idea, a sampler has been designed and tested during this measurement campaign, which also consists of a pipe in which the water should flow freely. One liter of canal water is trapped instantaneously, thanks to two sluices operated with a spring. Further analyses will conclude on the reliability of the prototype.
Delft is also using radar systems to measure concentrations instantaneously (no details available). The French Commission of Atomic Energy (CEA) has also successfully explored the use of tracer elements for sediment measurements. An application program of activable tracers in the Jamrao Canal system is being developed.

We can also quote the turbidimetry which allows to measure continuously the wash load component of the flow, particularly appropriate in big rivers for erosion yields of large basins.

2.8.2 Laboratory Methods

Other techniques have been developed to measure the composition of dry samples. CEMAGREF, for instance, is using a laser for the determination of grain size distributions. The laser directly measures the equivalent radius of the particles of a mixture. All the different methods will give distinct results. Stokes law is said to be appropriate for sand size particles, generally finer than 100 μm (see Appendix 2). For coarser particles, this law normally underestimates the diameter, given a fall velocity.

For finer particles (clay, fine silt), flocculation may increase the fall velocity of the particles, which become aggregated. Therefore, the pipette method will overestimate the fall velocities of the individual particles, thus, their individual diameters as well.
We can add that:
- cohesive particles don't seem to be present in the bed (at least in significant proportions), therefore, the choice of the method is not essential for the understanding and the prediction of the deposition/erosion processes; and
- the fall velocity is more important than the diameter, as far as suspension is concerned.

Whichever method is used, the fall velocity can be determined simply, as long as we know how the diameters of the grading curves have been measured or computed.

In conclusion, we will advise that the method of analysis remains unchanged once selected.

3. METHODOLOGY OF THE FIELD WORK

During the two months of the campaign, 500 samples have been taken as follows:
- 31 bed samples
- 155 depth integrated samples
- 205 point integrated samples
- 6 test samples (pump)
- 6 test samples (Cemagref sampler)

The sampling sites are depicted in the following sketch:
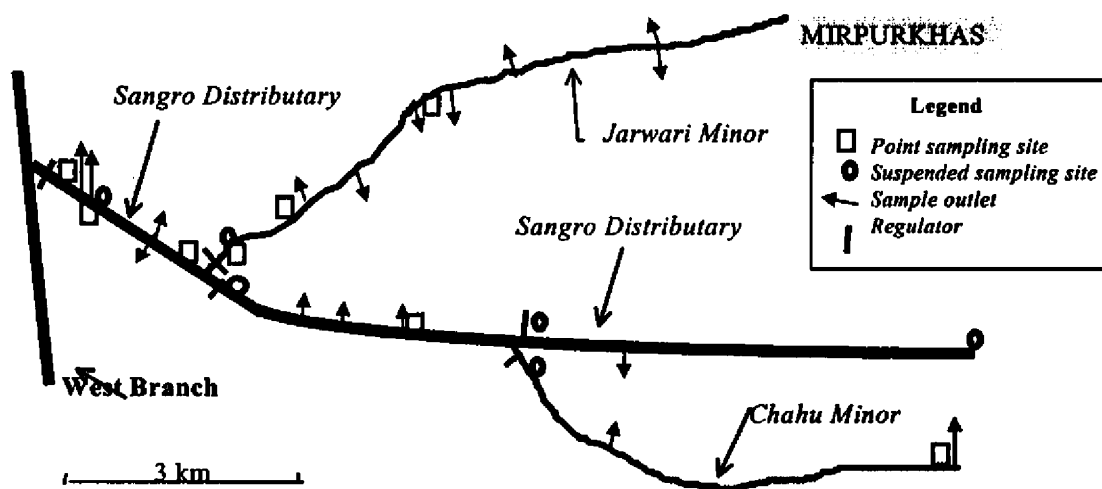
Figure 6: Sketch of the Sub-system and the Measurement Points

3.1 Sediment Inflow

In order to measure the sediment inflow, depth integrated samples have been taken as often as possible at the head of the system. On average, one sample was taken every two days.

Practically, it should be avoided to take the suspended samples in the « boil » of the head regulator, because the concentration might be much higher than the concentration actually flowing into the system:
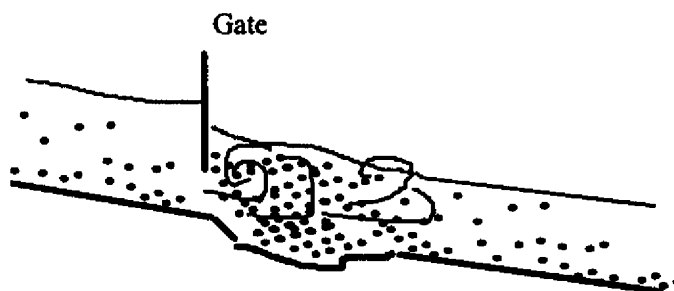
In the boil of the gate, more particles are lifted and kept in suspension in the vicinity of the gate. Therefore, they do not participate in the sedimentation process in the sub-system, and should not be measured. In our case, we have taken the samples at 275 feet from the gate (RD 0+275).

In order to assess the unsampled layer, transverse and vertical profiles of concentration were taken at the same location. On average, the sediment inflow was measured once a week at the other channels (Jarwari and Chahu Minors).

3.2 Sediment Evolution Along the System

Bed samples were collected every 5 RD (1.5 km), upstream and downstream of the two cross-regulators. The samples were normally taken in the center line, except at a few locations where the bed material was also collected on both sides of the bed. Only the upper layer (1 inch) was analyzed, which almost insures that the collected material was « fresh » bed material load.

The long concentration profile could also be measured by depth-integrated samples taken on the same day at different locations of the system. This task is quite difficult, since it is necessary:

- to have almost steady conditions (hydraulic and sedimentologic), or to taken into account the advection of the particles (more difficult to achieve, since the different layers of the flow will have different advection velocities); and
- to take enough samples in order to limit the standard error of the measurement.

Twelve long profiles of concentrations were undertaken on Sangro Distributary, 5 on Jarwari and 3 on Chahu Minor.

3.3 Sediment Sharing at Off-takes

The simplest way to measure the sediment diversion, is to take one integrated sample in the parent channel, and one in the off-taking channel.
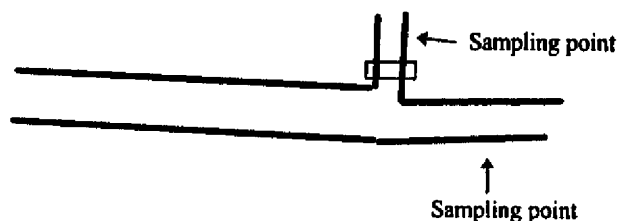
The upstream sediment discharge is calculated by addition of the sediment discharge in the off-take, and in the parent channel downstream from the off-take. When the off-take is a minor, depth-integrated samples are done in both channels. On Jarwari and Chahu minors, 7 samples have been collected in this way.

For the outlets we use boil sampling, as near as possible to the concrete structure, in order to avoid excessive concentrations, as shown in §3.1. All the outlets could not be sampled. We have preferred to select « representative » ones, and carry out several measurements for each. Sixteen outlets have been observed according to this procedure. On average, 5 measurements per outlet have been carried out.

3.4 Accuracy of Sediment Measurements

The accuracy can be observed:
- by comparing different methods; and

- by observing the discrepancy of several measurements of the same quantity.

In the sub-system, the discrepancy of the head concentration will be analyzed.
We will also compare pump samples and depth-integrated samples at each pump sampling site.

3.5 Topographic Evolution

The measurement campaign started with a topography of the whole sub-system. A total of 80 cross-sections have been taken;
- two or three upstream and downstream important singularities (regulators), with a length step of about 30m; and
- on cross-sections near almost each off-take.

Benchmarks were established, allowing to take the cross-sections at the same locations at the end of the campaign, as well as during the 1998 annual closure.

3.6 Hydraulic Behavior

The cross-regulators were calibrated by IIMI (DSS field station) during the year 1998. IIMI also reads the water levels at all the regulators daily, which allows the establishment of daily head hydrographs for each canal.

For each outlet, we have also measured the discharge and the dimensions, then the discharge coefficient. Several measurements are necessary for a good calibration but this could not be achieved during the short term of the campaign. Downstream rating curves were also established for the three channels.

Lastly, the roughness calibration was done with two sets of steady water levels obtained in September.

4. DATA ANALYSIS

This analysis is illustrated by different graphs presented in the appendices.

4.1 Hydraulic Inflow

The hydraulic inflow into the system is given in Appendix ?, with the daily discharges at the head of the three canals. Note that the head hydrograph in Sangro Distributary has been established, thanks to the calibration of the gates.

The main remarks are:
- the system is flowing either at a high discharge, or at half of its capacity. Indeed, in this period of water shortage at Sukkur Barrage (from off-takes Nara Canal), a rotation program has been imposed in the system. Only Jarwari Minor, from which the water for Mirpurkhas is supplied, was allowed to run;
- the discharge is almost constant during each regime; and
- the discharges in the canals are much higher than the design capacities; 50% higher in Sangro Distributary, 85% in Jarwari, 20% in Chahu Minor.

The system has been closed three times between mid-July 1997 until the closure period of January 1998, due to rotation. The discharges in the outlets are also much higher in the upstream outlets than their design. The difference is lower in the downstream reaches, and the tails of the channels are often faced with shortage.

4.2 Sediment Inflow (Appendix 4)

The total sediment inflow into the system was quite stable during the campaign. The concentration generally varied between **1500 to 2000 ppm**, a little less than 1500 ppm after the monsoon season. Nevertheless, the sand concentration was much more variable. The minimum sand concentration was **20ppm** in early September, and more than **170ppm** by mid-August. Assessing the share between actual variability and sampling error will be difficult.

This concentration will depend on:
- sand availability in the West Branch;
- operation and regulation of the West Branch. The variability of the upstream water level of Sangro Head regulator is shown in Appendix 4. Low concentrations in Sangro can be explained by low concentrations in the West Branch, due to ponding effect upstream from the 18th mile cross-regulator of the West Branch; and
- natural variability during the monsoon season (when rains falls in the vicinity of the system).

4.3 Dynamics of the Sediments (Appendix 5)

The sand concentration generally decreases along Sangro Distributary when the head concentration is high. When the concentration is lower than 70ppm at Sangro head, it seems to increase until Jarwari cross-regulator, then to decrease. The tail reach is normally the one with the lowest concentration. At a few points, the concentration varies within a short range.

In Jarwari Minor, the concentration also decreases when the sediment inflow is high (>50ppm). Four out of the 5 sets of data converge towards a concentration of 20-25ppm at the tail. We cannot say a lot on Chahu Minor, except that the three sets of data converge towards a concentration around 15-25 ppm.

All these remarks can be linked to the concept of « equilibrium » concentration or « transport capacity »; the concentration seems to converge towards a given value (at least a given range of concentrations), which becomes lower as the discharge decreases. Nevertheless, the high variability of all the concentrations at a same point, illustrate the difficulty to properly model the sediment behavior.

4.4 Bed Composition (Appendix 6)

We can say, as a first approximation, that the bed contains mainly sand, with very little silt and clay. The medium diameter is around **100µm**.

In Sangro Distributary, the diameter decreases from head to tail. In the last reach, downstream Chahu cross-regulator, the bed material is mainly silt:
- little sand arrive, in this part;
- silt may have deposited; and
- the channel has been excavated in order to extract more water towards the tail; pumps are generally used in the tail reach.

In Jarwari Minor, the medium diameter clearly decreases from head to tail. At head, its value is the same as in Sangro Distributary (first reach), then reaches the value of **80µm** at the tail. In Chahu Minor, the medium diameter at head is 100µm (it is 105µm in Sangro Distributary at Chahu cross-regulator), then **80µm** at its tail.

According to some authors, the wash load limit can be found from the bed composition, either d_0 or d_{10}. Practically, d_0 is not easy to estimate. Actually, it is probably 0µm, as d_{10} varies between 90µm at Sangro head and 20µm at the tail of the three channels. All the samples have been analyzed by VA tube. However, 9 of them have also been analyzed by laser method. The comparison id presented below:

Table 2: Comparison of Analysis Methods (All Particles Included)

(The samples analyzed by VA tube are in grey)

CANAL	REACH	D10	D15	D50	D85	D90
Chahu	0+200	65.0	69.3	97.9	123.6	136.8
Chahu	0+200	33.5	41.4	87.8	147.9	163.0
Chahu	26+000	21.9	29.9	74.5	111.4	117.9
Chahu	26+000	8.9	16.0	52.9	112.9	131.5
Jarwari	0+135	87.1	90.4	108.4	133.6	149.5
Jarwari	0+135	54.3	68.4	114.6	170.1	192.7
Jarwari	24+600	29.9	43.0	76.7	114.1	123.7
Jarwari	24+600	28.3	35.6	74.6	136.1	161.4
Sangro	0+166	89.4	91.7	108.1	124.5	139.3
Sangro	0+166	48.1	66.7	116.1	171.4	198.4
Sangro	10+200	72.0	82.0	107.4	140.7	153.8
Sangro	10+200	31.7	41.0	92.0	151.3	164.3
Sangro	25+000	64.7	71.4	102.3	124.2	138.8
Sangro	25+000	18.7	25.5	60.8	117.1	132.7
Sangro	35+000	17.3	22.2	57.2	121.5	138.2
Sangro	35+000	3.7	6.4	41.7	111.1	124.5
Sangro	50+500	4.1	7.1	25.6	66.9	83.4
Sangro	50+500	2.8	4.0	20.2	55.4	62.0

We can observe a big difference between both methods for fine particles, especially those which are expected, as said in xxx. In the following tables, we compare the grading curves of the coarser particles only, say, we have excluded the particles finer than 50µ in Table 3, and finer than 62µ in Table 4. The rows in grey are the analyses made by VA tube, while the other ones were made by laser.

Table 3: Comparison of Analysis Methods for the Particles Coarser than 50µ

(The samples analyzed by VA tube are in grey)

CANAL	REACH	D10	D15	D50	D85	D90
Chahu	0+200	68.9	73.0	99.8	124.2	138.7
Chahu	0+200	62.4	67.1	101.7	157.1	169.1
Chahu	26+000	62.1	65	85.2	116.7	121.5
Chahu	26+000	55.3	57.9	83.4	146.4	165.6
Jarwari	0+135	88.4	90.9	108.7	134.1	149.9
Jarwari	0+135	74.3	82.5	119.7	172.5	200.1
Jarwari	24+600	63.9	66.1	81.4	119.2	130.7
Jarwari	24+600	58.2	62.3	90.4	157.1	176.3
Sangro	0+166	90.1	92.4	108.5	124.6	139.9
Sangro	0+166	75.0	83.7	122.2	174.1	206.7
Sangro	10+200	78.2	87.9	108.5	142.1	154.7
Sangro	10+200	63.9	69.0	105.1	159.1	169.5
Sangro	25+000	73	79.3	104.4	124.9	141.2
Sangro	25+000	55.9	58.8	85.9	137.9	157.6
Sangro	35+000	55.7	58.6	96.3	144.4	156.6
Sangro	35+000	56.4	59.6	91.9	143.6	156.6
Sangro	50+500	53.4	55.1	74.1	115.1	122.4
Sangro	50+500	52.5	53.8	64.4	109.1	119.5

Table 4: Comparison of Analysis Methods for the Particles Coarser than 62µ

(The samples analyzed by VA tube are in grey)

CANAL	REACH	D10	D15	D50	D85	D90
Chahu	0+200	70.1	74.2	100.3	124.3	139.4
Chahu	0+200	70.5	74.7	106.8	160.6	171.4
Chahu	26+000	67.2	69.8	88.0	118.1	122.4
Chahu	26+000	68.1	71.1	96.7	159.5	174.3
Jarwari	0+135	88.5	91.0	108.8	134.3	150.0
Jarwari	0+135	78.1	86.1	121.0	173.1	202.0
Jarwari	24+600	66.1	68.2	82.6	120.5	133.2
Jarwari	24+600	68.6	71.9	100	165.1	196.0
Sangro	0+166	90.2	92.5	108.6	124.7	140.0
Sangro	0+166	88.4	90.9	108.9	135.1	149.4
Sangro	10+200	81.0	88.8	108.9	142.7	155.1
Sangro	10+200	71.3	75.9	109.4	161.6	171.2
Sangro	25+000	74.4	80.6	104.8	125.0	141.7
Sangro	25+000	68.4	71.6	97.7	150.0	165.6
Sangro	35+000	71.6	76.4	107.3	152.0	161.7
Sangro	35+000	69.5	73.3	103.0	150.9	161.5
Sangro	50+500	67.4	70.1	90.0	122.9	135.7
Sangro	50+500	67.0	69.5	87.0	123.9	139.3

The difference is much less important. These tables lead us to the following conclusions:
- our method of analysis is satisfying for sand particles;
- we should be careful with the grading curves of fine particles (silt and clay). Fortunately, these particles hardly deposit in normal flowing conditions;
- the difference between both methods for fine particles is systematic and is most probably not due to measurement errors. Therefore, both methods are a priori appropriate, but only one should be used for the whole work. This also makes the application of the criterion mentioned above for wash load doubtful; and
- the difference is not systematic for the coarser particles. For d50, it varies from 0.3 to 21% in Table 4, with an average difference of 7%.

4.5 Silt-drawing Capacities

The table presented in Appendix ..? gives the silt-drawing capacities of the outlets, calculated as follows:

$$SDC(Sand) = \frac{C_{sand}(outlet)}{C_{sand}(channel)} * 100$$

$$x\ SDC(Silt/clay) = \frac{C_{silt+clay}(outlet)}{C_{silt+clay}(channel)} * 100$$

etc.

The average and the standard errors are then calculated on all the measurements.

We can say that all the outlets take their due share of silt and clays: the silt-drawing capacities for fine particles are very near 100% ,with a low discrepancy. The behavior is different for sand. In Sangro, the outlets seem to draw more sand than the parent channel, especially in the head reaches. One reason is probably the raise of the bed due to siltation, which forces the outlets to take water from the lowest part of the flow. Tampering is also generally done from the crest. We will also note the high discrepancy of the sand-drawing percentages. The calculations of silt-drawing capacities done with one measurement only, should be used cautiously. In Jarwari, the first outlet seem to take a small quantity of sand. This is actually an open flume with a very high crest. The next one, an APM, takes more than its due share, located in the most silted part of the channel. The other ones, APM and open flumes, have a sand-drawing percentage lower than 70%, with a very low discrepancy. In Chahu Minor, all the outlets seem to take their due share of sediments (slightly more).

4.6 Topographic Evolutions

In order to compare the topographies, we have applied a procedure consisting of calculating from the cross-section data, the « mean bed level ». This procedure consists of:
- determining the limits of the bed, generally in the fields or from the visual analysis of the cross-section data. This may be, in some cases, quite subjective, but the bed limits at different dates should be consistent; and
- calculating the mean bed level between these two limits, according to the scheme presented below:

section 1
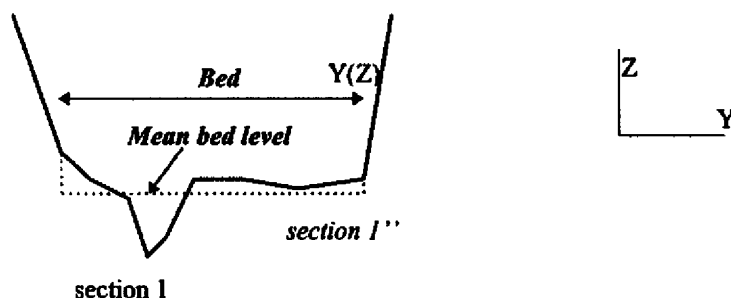
The mean bed level is defined as:

$$Z = \frac{1}{Bed\ width} \int_{bed} Z(Y)dY \qquad [6]$$

The bed evolutions for the three canals are presented in Appendix. ?. The bed variations, even if they are low (maximum 15cm), are quite clear in the upper reaches of each canal, and homogeneous over 2.5 to 3 kilometers. The transient effect of the canal opening has also been observed. Indeed, we may suppose that the sediments would be flushed away when the gates are being opened.

Cross-sections during the canal closure, and after, are compared. Let's note that the bed should be a little bit higher (1 cm or so) when the canal is not running (as explained in 2.2). We cannot conclude from this observation that the transient phenomenon involves significant bed scouring. One reason is that the operation is slow enough to prevent this scouring. Actually, the scouring of the bank must also be avoided (breaches would appear), and opening the gates more quickly would be dangerous.

Another explanation may be the presence of very fine sediments over the sandy bed, deposited during the canal closure. And lastly, the present topographies are compared with the design (1960).

The difference is quite impressive:
- the upper reaches are 1.5 feet higher than the design beds in Jarwari and Chahu Minors, 3 feet in Sangro Distributary. The upper reaches of Jarwari Minor have been excavated in April 1997, the maintenance procedure consisting, theoretically, in dredging up to the design bed;
- the lower reach of Sangro is lower than the design ones. This is probably due to excessive maintenance carried out by the tail farmers, who want to extract as much water as possible towards the tail, where pumping is commonly practiced; and
- the slope of the three canals seem to be homogeneous, whatever the design of the slope. Moreover, this slope is more or less the same for the three canals. Table 5 summarizes these bed slopes.

Table 5 : Slopes of the Three Canals			
	Design slope	**July 1997**	**September 1997**
Sangro Distributary	1/11000, 1/6000, 1/4500 Average 1/6250	1/3946	1/3991
Jarwari Minor	1/6500	1/4360	1/4446
Chahu Minor	1/5150	1/4194	1/4108

The slope of Jarwari Minor is the highest, probably because it had been excavated three months before the campaign.

4.7 Vertical Profiles of Concentration

The vertical profiles of concentration presented in this report, have been established in shallow water. The different points are quite near to each other, and this is a reason why they can hardly be fitted by a power function, as suggested by Schmidt theory. The concentration is generally higher near the bed and in the center line.

We will also remark that the concentrations are generally higher in the central verticals. This will also explain low silt-drawing capacities of outlets.

Some strangely high values may be due to pumping of bed material, since the nozzle was very near the bed. Moreover, the velocity is also quite inaccurate in close vicinity of the bed, involving a big difference between the actual velocity and the pumping velocity. That may be a reason why we also observe low values in some verticals.

The last feature is the low quantity of water, which is collected each time. In this regard, it is advised to collect as much water as possible, which is why pumping in a sieve (50μ, 62μ...) may be more appropriate, since it allows to collect water for a few minutes for each sample. The concentration in particles finer than the sieve diameter would be obtained with one integrated sample, since vertical profiles of silt and clay are quite homogeneous in the vertical, as shown in Appendix 9.

4.8 Vertical Profiles of Velocity

While collecting pump samples, velocity profils have also been established. A quick analysis has been done in order to check the usual « 0.6 method » and « 0.2-0.8 method ». The average velocity in a vertical was calculated as follows:

$$V = \frac{1}{H} \cdot \int_0^H v(z).dz$$

H is the water depth.

The table given in Appendix..? shows that the « 0.2-0.8 method » is generally more accurate, even though both methods overestimate the velocity. Nevertheless, it is limited by the dimensions of the currentmeter, which cannot be approach by less than 2 inches (Pygmy model), or 6 inches (A type). Both methods are accurate within 10% of the mean velocity, but the error is generally lower than 5%.

4.9 Consistency Between the Different Data

4.9.1 Sediment Inflow/Outflow and Bed Evolutions

A mass balance should be done for this purpose. First, in view of the long concentration profiles, these seem to be higher at the system head, than at its tail, which is consistent with the bed evolutions presented in Appendix 8.

Achieving a mass balance would suppose sediment outflows at each off-take. These quantities have not been measured, and estimating them would suppose the construction of a model (model of sediment and water diversion). This is not the purpose of the present analysis. However, this work will be done in the next stage. The deposited volumes will be estimated by comparison of the final and initial topographies (calculation using SIC graphical results program).

4.9.2 Depth-integrated/Point-integrated Samples

Table 6 summarizes the mean concentrations in the sections measured by the depth-integrated sampler, and the concentrations calculated from the concentration profiles.

Table 6: Integrated Sediment Concentrations Measured by Pump Sampling													
						Point-integrated Samples				Depth-integrated Samples			
Channel	RD	Date	nb of vert.	Q (m³/s)	Area (m²)	Total conc.	Sand conc.	31-62 conc.	0-31 conc.	Total conc.	Sand conc.	31-62 conc.	0-31 conc.
Chahu	26+100	13/08/97	4	0.453	1.2615	2446	200	212	2033	2180	25	183	1971
Jarwari	7+900	09/08/97	4	1.000	2.9068	2146	35	297	1820	1669	34	58	1577
Jarwari	0+135	16/08/97	5	1.060	2.1783	2102	226	272	1611	1518	58	200	1260
Jarwari	1+989	21/08/97	5	1.273	2.511	1626	68	295	1262	1928	50	270	1608
Sangro	0+166	08/08/97	5	4.296	8.2754	2082	79	282	1721	1908	57	95	1755
Sangro	0+275	08/08/97	5	3.987	7.8941	2081	57	240	1783	1739	33	108	1598
Sangro	9+308	11/08/97	5	4.164	7.3735	2024	46	230	1747	1874	127	156	1554
Sangro	28+600	19/08/97	5	2.161	4.3704	1515	35	238	1242	1375	51	374	950
Sangro	28+750	19/08/97	3	1.762	3.6112	1511	38	208	1265	1375	51	374	950

Large differences between both methods suggest that the measurement should be discarded, such as for Chahu minor (RD 26+100), Jarwari minor (RD 0+135), and Sangro Distributary (RD 9+308). This analysis should be refined with the observation of the concentration profiles. Some points in these profiles are not consistent, and should be discarded for the calculation of the mean concentration.

The total concentration is quite near with both methods, which is expected, since fine particles account for the main part of the sediments. However, there is often quite a big difference for the range 31μ-62μ, possibly due to the natural temporal variability of the silt and clay concentrations (and also the grain size distribution) . Indeed, it takes at least half an hour to collect all the samples in the 4 or 5 verticals.

4.9.3 Bed Grading Curves/Suspension Grading Curves

The following table gives a few values of the medium diameter at different locations, with a cut-off at 62μ. The diameters indicated for the suspended material are the average values of all the measurements done at the location.

Table 7 : Comparison of the Grin Size Distributions for Suspended and Bed Material					
	Suspended material			Bed material		
	D_{10}	D_{50}	D_{90}	D_{10}	D_{50}	D_{90}
Sangro RD 0+275	72	94	128	92	114	160
Sangro RD10+208	78	105	141	81	109	155
Sangro RD 28+150	66	83	115	72	107	162
Jarwari RD 0+135	72	98	130	74	106	149
Jarwari RD 24+600	68	87	127	66	82	133
Chahu RD 0+200	70	91	132	70	106	171

These diameters are very near to each other. The size of the bed material, nevertheless, is always higher than the one of the suspended material, which is expected, since the coarser particles tend to deposit before the finer ones.

4.9.4 Bed Evolutions/Bed Material Size

We can see from the bed material long profile size that the diameter tends to decrease from upstream to downstream. This is consistent with the deposition/erosion processes within the system (coarser particles deposit first, finer particles are lifted preferentially). In the lower reach of Sangro, lower than the design bed, the bed material is mainly silt and clay. Indeed, no deposition seems to occur in this part, which is why little sand, supposed to come from the suspended phase, should be found in the bed.

5. CONCLUSION

This intensive measurement campaign has given an idea about the sedimentation process in a small system during a short period:

- the bed variations over a period of high sediment inflow have been measured;
- the temporal variability of this sediment inflow has been observed;
- the spatial distribution of the sediments all over the system has been observed (concentrations and bed material);
- an idea of the sediment-sharing through different types of off-takes has been obtained; and
- an idea of the sediment distribution in a cross-section has been ascertained.

This report has also presented the different measurement methods used in the fields, and in the laboratory, and an attempt to assess their accuracy has been made. Remarks and advice have also been made for further campaigns (topography measurement, sediment sampling).

The period of observation (9 weeks) was very short, and the bed variations are sometimes very low, given the accuracy of the field measurements. As expected, it appeared that the canal, which had the highest bed variations, was the one desilted a few months before the campaign. Therefore, we should recommend the selection of such a favorable configuration for this kind of study.

The next steps of the work will consist of:

- collecting topographies of the same system in January 1998;
- collecting the sediment inflow into the system; and
- constitute a data set for sediment transport modeling of the system.

The same kind of observation will be undertaken on two similar systems during *Kharif* 1998, as part of a campaign on the whole Jamrao Canal system.

6. GLOSSARY

Units utilized in the report:

Length

1 meter (m)	= 3.2808 feet
1 feet (ft)	= 0.3048 meter
1 RD (reduced distance)	= 1000 feet
1 kilometer (km)	= 0.6214 mile
1 mile	= 1609 meters
	= 5280 feet (in the irrigation system) or 1524 m

Area

1 acre	= 0.405 hectare
1 hectare (ft)	= 2.47 acres
1 square meter (m²)	= 10.764 square feet
1 square foot (sqft)	= 0.0929 square meter

Volume

1 cubic meter (m³)	= 35.314 cubic feet
1 cubic foot (ft³)	= 0.0283 cubic meter
1 acre foot	= 1234 cubic meters
1 liter	= 0.2642 US gallon
1 liter	= 0.2201 imperial gallon

Discharge

1 cubic meter per sec.	=35.314 cubic feet per second (cusec or cfs)
1 cubic foot per second	=28.320 liters per second (l/s) or 0.0283 m³/s (cumec)

A few definitions :

Related to Irrigation...

Main canal: channel supplying water to the whole irrigation division. The main canal takes water directly from the reservoir or river. The discharge is generally around 100 m³/s at the head.

Branch canal: the branch canal takes water from the main canal and conveys water to the different parts of the irrigated areas.

Distributary: channel taking water from the branch canal and supplying the minor distributaries (or minors) or watercourses.

Minor distributary or minor: the smallest channel where regulation is done, supplying water to watercourses.

Watercourse: irrigation ditch supplying water to the plots.

Outlet: structure used for water distribution between the channels and the watercourses, generally made of concrete, sometime also iron. There are mainly four types of outlets in Pakistan, i.e. Adjustable Proportionate Module (APM) outlet, Open Flume, Open Flume with Roof Block (OFRB), and pipe.

APM outlet: outlet with fixed height and width, designed to draw sediments proportionally to the water discharge.

Open flume outlet: outlet with fixed width and no roof.

Head regulator: gated structure used for controlling the discharge in the channel

Cross regulator: structure (usually provided with gates) across the channel for controlling the water level.

Rating Curve: the relationship between the water depth and discharge at the particular section in the channel, is called rating curve.

Crest: bottom edge of any hydraulic structure.

Gross command area(GCA): total area which can be irrigated by a certain outlet or irrgation project, including the lands covered by roads, villages etc.

Culturable command area (CCA): the portion of GCA which is actually cultivated. The CCA equals the GCA minus unculturable area.

Related *to* Sediment *transport....*

Bed load: sediment particles moving on, or near, the bed by rolling , sliding or jumping. Usually the coarser particles are found in the bed load.

Suspended load: sediments moving in suspension throughout the wetted section of the channel. The fine particles silt and clay are mostly found in suspended load.

Bed material load: in a flowing channel, portions of the sediments interacting with the bed. These particles can fall (deposition) or be lifted (erosion). The bed material load consists of bed load and a part of the suspended load.

Wash load: This refers to the finest portion of the sediments that are conveyed through the channel, therefore, the wash load is not found in the bed. These particles can come from very far lands, 'washed' by rain falls, the run-off water containing very fine eroded particles. The wash load is a part of the suspended load.

Total load: all the sediments contained in the water; the sum of suspended load and bed load, and also the sum of the wash load plus the bed material load.

Transport capacity: the capacity of the channel to transport a certain amount of sediment without scouring or depositing.

Sediment discharge: weight or volume of sediments crossing a section per unit of time. The units are kg/s, m^3/s, tons/day, MAF/year (million acre-feet/year)...

Concentration: weight of sediments per unit of volume, or weight of water. The units are kg/m^3, g/l, mg/l, ppm (part per million). 1 ppm equals 1g of sediments per million grams of water, which is approximately 1 cubic meter ; therefore, 1ppm equals (approximately) 1 mg/l.

Sediment: solid particles derived from the rocks, or other biological material, and transported by any media, like water or air, is called sediment

Fall velocity (settling velocity): vertical velocity reached by a particle falling freely in still water. The fall velocity for a grain of diameter (d) is often assessed with Stokes law, established for a spherical grain of diameter (d).

Diameter: representative dimension of a particle or a mixture of homogeneous particles. This diameter is assessed « measured » with a sieve (sieve diameter), a laser (the diameter of a particle

is the diameter of the sphere having the same volume), the fall velocity of the particles, or with a tape in case the particles are boulders.

Particle size distribution: grading curve for a given sediment mixture, usually in terms of percentages by weight for different ranges of size.

Median size diameter: the size of the sediment particles, for which 50 percent by weight, are finer.

7. APPENDICES

1- Study Locale Description

2- Measurement Methods

3- Hydraulic Data

4- Sediment Inflow

5- Concentration Long Profiles

6- Bed Material Samples

7- Sediment Drawing Capacities of Outlets

8- Topographic Evolutions

9- Vertical Profiles

Appendix 1: Location Maps
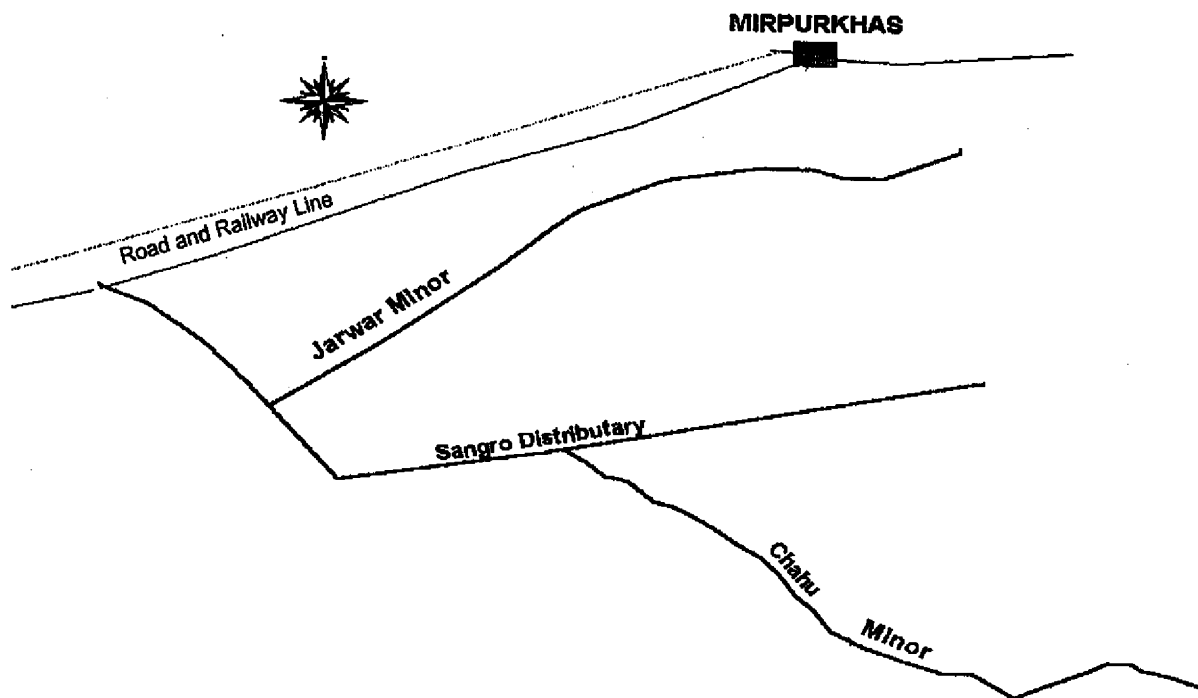
Location Map of Sangro Distributary and its Off-taking Minors.

Sangro Flow Diagram

Head

Label	Chainage
1L, 2L	0+200
1R	0+500
3L	1+572
2R, 4L	6+683
	6+757
Jarwari XR	9+329
5L	9+715
6L	12+788
3R	13+386
4R	14+600
7L	18+162
8L	18+710
5R	19+189
6R	22+895
9L	24+220
7R	24+900
8R, 10L 7R	26+840
	27+033
11L	27+733
12L	28+048
13L	
XR2	28+300
9R	34+200
14L	39+100
15L	39+250
PIPE	40+700
11R, 16L, 17L	41+170
18L	45+150
19L	46+260
12R	46+600
20L	47+530
13R	47+600
	49+300

Tail

Jarwari Flow Diagram

Head

	outlet	
	concrete bridge	
	drain	
	wooden bridge	

1L — 2+071

2L — 3+804
1R — 4+286

6+843

2R — 7+641
3R — 7+983

12+320

4R — 13+602
3L

5R — 17+694

4L — 19+147

6R, Water supply — 20+158

20+730

7R, 5L — 21+171

8R — 22+738

6L — 23+338

9R, 7L — 24+547

Tail

Chahu Flow Diagram

Head

outlet

concrete bridge

drain

wooden bridge

1L — 1+186

1R — 3+500

2L — 5+465

7+750

2R — 9+615

12+925

3L

13+602
14+151

3R, 4L

17+694

4R — 21+498

5L — 23+603

6L — 26+174

Tail

Desilting by machine in Digri Sub-division (March 1997).

Removal of sand heaps after the desilting of Jarwari (July 1997)

Digitized by Google

Manual desilting of Chahu Minor during the rotational closure (August 1997).

Appendix 2: Measurement Methods

Part 1: Laboratory Analysis Data Sheet

PARTICLE SIZE ANALYSIS,SIEVE-PIPETTE METHOD

ANALYSED DATA

IIMI PS.V-3,P-1		
Tag.No.2161,2162		
Date	7-10-97	by:N.Shaheen
Portion used	2 composed	
Disp.agent	Nil	

Pipette Suspension

Sedi.	1.665	gm.
Vol.	500	cc.
Concen	1881	ppm.
D16=		
D50=		
D84=		
Sigma=		

DISSOLVED SOLIDS

50	cc.dispersed native	
	DISH NO.P-19	
G.WT	31.6317	gm.
TARE WT.		gm.
NET	0.0129	gm.
dis.conf=net wt.*(vol.pipet/vol.cyld)		
Disol. cored.	0.000516	0.0005

SAND PORTION

Sand wt.	0.0562	gm
Conc.	64	ppm
Location	12.5Ft.L/B TD 3.9 SD 0.5	

Total Sample data

stream	Sangro	
Location	RD=9+808	
Date	11-8-97	
G.H	Nozelsize 1/2	
Composite		
No. bottles	2	
wt.sample	885	gm
wt. sed.	1.7212	gm
mean con	1945	ppm
Dis. solid	258	ppm
Spec. cond.	NIL	
other chem.	NIL	

SIEVE ANALYSIS

	0.7	0.5	0.35	0.25	0.175	0.125	0.088	0.062
Size. mm	0.7	0.5	0.35	0.25	0.175	0.125	0.088	0.062
Gross wt. gm.								
Tare wt. gm.								
Net. wt. gm.					0.0009	0.0033	0.0223	0.0297
% of sand					1.60142	5.87189	39.6797	52.847
% finer				100	98.3986	92.5267	52.847	7E-15
% with total				100	0.05229	0.19173	1.29561	1.7255
%finer than					99.9	99.8	98.5	96.7

Pipet Method

Cylinder No.6	Vol. of pipet	Volume of cylinder			Volume factor	25
	conc.				Resid.	
Size. mm	0.062	0.031	0.016	0.008	0.004	0.002
Clock time						
Temperature	30C	30C	30C	30C	30C	30C
Fall distance	10cm	10cm	10cm	10cm	5cm	3cm
Setting time	0:00:00	0:01:31	0:06:06	0:24:22	0:48:42	1:57:00
Container no.	K-1	K-2	K-3	K-4	k-5	K-6
Gross wt. in gm.	80.2636	76.1755	78.409	80.7738	88.881	79.5751
Tare wt. in gm.						
Net wt. in gm.	0.0671	0.0608	0.0492	0.0364	0.0206	0.0104
D.S. Correction	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Net sediment.	0.0666	0.0603	0.0487	0.0359	0.0201	0.0099
Finer than	1.665	1.5075	1.2175	0.8975	0.5025	0.2475
% finer than	96.7	87.6	70.7	52.1	29.2	14.4

Depth in Vertical:

time	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50
4	4.0	3.2	2.7	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6
6	6.0	4.8	4.0	3.4	3.0	2.7	2.4	2.2	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.0	0.9
8	8.0	6.4	5.3	4.6	4.0	3.6	3.2	2.9	2.7	2.5	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2
10	10.0	8.0	6.7	5.7	5.0	4.4	4.0	3.6	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.9	1.8	1.7	1.7	1.6	1.5
12	12.0	9.6	8.0	6.9	6.0	5.3	4.8	4.4	4.0	3.7	3.4	3.2	3.0	2.8	2.7	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8
14	14.0	11.2	9.3	8.0	7.0	6.2	5.6	5.1	4.7	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.8	2.7	2.5	2.4	2.3	2.2	2.2
16	16.0	12.8	10.7	9.1	8.0	7.1	6.4	5.8	5.3	4.9	4.6	4.3	4.0	3.8	3.6	3.4	3.2	3.0	2.9	2.8	2.7	2.6	2.5
18	18.0	14.4	12.0	10.3	9.0	8.0	7.2	6.5	6.0	5.5	5.1	4.8	4.5	4.2	4.0	3.8	3.6	3.4	3.3	3.1	3.0	2.9	2.8
20	20.0	16.0	13.3	11.4	10.0	8.9	8.0	7.3	6.7	6.2	5.7	5.3	5.0	4.7	4.4	4.2	4.0	3.8	3.6	3.5	3.3	3.2	3.1
22	22.0	17.6	14.7	12.6	11.0	9.8	8.8	8.0	7.3	6.8	6.3	5.9	5.5	5.2	4.9	4.6	4.4	4.2	4.0	3.8	3.7	3.5	3.4
24	24.0	19.2	16.0	13.7	12.0	10.7	9.6	8.7	8.0	7.4	6.9	6.4	6.0	5.6	5.3	5.1	4.8	4.6	4.4	4.2	4.0	3.8	3.7
26	26.0	20.8	17.3	14.9	13.0	11.6	10.4	9.5	8.7	8.0	7.4	6.9	6.5	6.1	5.8	5.5	5.2	5.0	4.7	4.5	4.3	4.2	4.0
28	28.0	22.4	18.7	16.0	14.0	12.4	11.2	10.2	9.3	8.6	8.0	7.5	7.0	6.6	6.2	5.9	5.6	5.3	5.1	4.9	4.7	4.5	4.3
30	30.0	24.0	20.0	17.1	15.0	13.3	12.0	10.9	10.0	9.2	8.6	8.0	7.5	7.1	6.7	6.3	6.0	5.7	5.5	5.2	5.0	4.8	4.6
32	32.0	25.6	21.3	18.3	16.0	14.2	12.8	11.6	10.7	9.8	9.1	8.5	8.0	7.5	7.1	6.7	6.4	6.1	5.8	5.6	5.3	5.1	4.9
34	34.0	27.2	22.7	19.4	17.0	15.1	13.6	12.4	11.3	10.5	9.7	9.1	8.5	8.0	7.6	7.2	6.8	6.5	6.2	5.9	5.7	5.4	5.2
36	36.0	28.8	24.0	20.6	18.0	16.0	14.4	13.1	12.0	11.1	10.3	9.6	9.0	8.5	8.0	7.6	7.2	6.9	6.5	6.3	6.0	5.8	5.5
38	38.0	30.4	25.3	21.7	19.0	16.9	15.2	13.8	12.7	11.7	10.9	10.1	9.5	8.9	8.4	8.0	7.6	7.2	6.9	6.6	6.3	6.1	5.8
40	40.0	32.0	26.7	22.9	20.0	17.8	16.0	14.5	13.3	12.3	11.4	10.7	10.0	9.4	8.9	8.4	8.0	7.6	7.3	7.0	6.7	6.4	6.2
42	42.0	33.6	28.0	24.0	21.0	18.7	16.8	15.3	14.0	12.9	12.0	11.2	10.5	9.9	9.3	8.8	8.4	8.0	7.6	7.3	7.0	6.7	6.5
44	44.0	35.2	29.3	25.1	22.0	19.6	17.6	16.0	14.7	13.5	12.6	11.7	11.0	10.4	9.8	9.3	8.8	8.4	8.0	7.7	7.3	7.0	6.8
46	46.0	36.8	30.7	26.3	23.0	20.4	18.4	16.7	15.3	14.2	13.1	12.3	11.5	10.8	10.2	9.7	9.2	8.8	8.4	8.0	7.7	7.4	7.1
48	48.0	38.4	32.0	27.4	24.0	21.3	19.2	17.5	16.0	14.8	13.7	12.8	12.0	11.3	10.7	10.1	9.6	9.1	8.7	8.3	8.0	7.7	7.4
50	50.0	40.0	33.3	28.6	25.0	22.2	20.0	18.2	16.7	15.4	14.3	13.3	12.5	11.8	11.1	10.5	10.0	9.5	9.1	8.7	8.3	8.0	7.7
52	52.0	41.6	34.7	29.7	26.0	23.1	20.8	18.9	17.3	16.0	14.9	13.9	13.0	12.2	11.6	10.9	10.4	9.9	9.5	9.0	8.7	8.3	8.0
54	54.0	43.2	36.0	30.9	27.0	24.0	21.6	19.6	18.0	16.6	15.4	14.4	13.5	12.7	12.0	11.4	10.8	10.3	9.8	9.4	9.0	8.6	8.3
56	56.0	44.8	37.3	32.0	28.0	24.9	22.4	20.4	18.7	17.2	16.0	14.9	14.0	13.2	12.4	11.8	11.2	10.7	10.2	9.7	9.3	9.0	8.6
58	58.0	46.4	38.7	33.1	29.0	25.8	23.2	21.1	19.3	17.8	16.6	15.5	14.5	13.6	12.9	12.2	11.6	11.0	10.5	10.1	9.7	9.3	8.9
60	60.0	48.0	40.0	34.3	30.0	26.7	24.0	21.8	20.0	18.5	17.1	16.0	15.0	14.1	13.3	12.6	12.0	11.4	10.9	10.4	10.0	9.6	9.2
62	62.0	49.6	41.3	35.4	31.0	27.6	24.8	22.5	20.7	19.1	17.7	16.5	15.5	14.6	13.8	13.1	12.4	11.8	11.3	10.8	10.3	9.9	9.5
64	64.0	51.2	42.7	36.6	32.0	28.4	25.6	23.3	21.3	19.7	18.3	17.1	16.0	15.1	14.2	13.5	12.8	12.2	11.6	11.1	10.7	10.2	9.8
66	66.0	52.8	44.0	37.7	33.0	29.3	26.4	24.0	22.0	20.3	18.9	17.6	16.5	15.5	14.7	13.9	13.2	12.6	12.0	11.5	11.0	10.6	10.2
68	68.0	54.4	45.3	38.9	34.0	30.2	27.2	24.7	22.7	20.9	19.4	18.1	17.0	16.0	15.1	14.3	13.6	13.0	12.4	11.8	11.3	10.9	10.5
70	70.0	56.0	46.7	40.0	35.0	31.1	28.0	25.5	23.3	21.5	20.0	18.7	17.5	16.5	15.6	14.7	14.0	13.3	12.7	12.2	11.7	11.2	10.8
72	72.0	57.6	48.0	41.1	36.0	32.0	28.8	26.2	24.0	22.2	20.6	19.2	18.0	16.9	16.0	15.2	14.4	13.7	13.1	12.5	12.0	11.5	11.1
74	74.0	59.2	49.3	42.3	37.0	32.9	29.6	26.9	24.7	22.8	21.1	19.7	18.5	17.4	16.4	15.6	14.8	14.1	13.5	12.9	12.3	11.8	11.4
76	76.0	60.8	50.7	43.4	38.0	33.8	30.4	27.6	25.3	23.4	21.7	20.3	19.0	17.9	16.9	16.0	15.2	14.5	13.8	13.2	12.7	12.2	11.7
78	78.0	62.4	52.0	44.6	39.0	34.7	31.2	28.4	26.0	24.0	22.3	20.8	19.5	18.4	17.3	16.4	15.6	14.9	14.2	13.6	13.0	12.5	12.0
80	80.0	64.0	53.3	45.7	40.0	35.6	32.0	29.1	26.7	24.6	22.9	21.3	20.0	18.8	17.8	16.8	16.0	15.2	14.5	13.9	13.3	12.8	12.3

Appendix 2 : Table of pseudo-sampling velocities for given Sampling times and depths in the vertical

Cross-section measurement at Sangro head (July 1997).
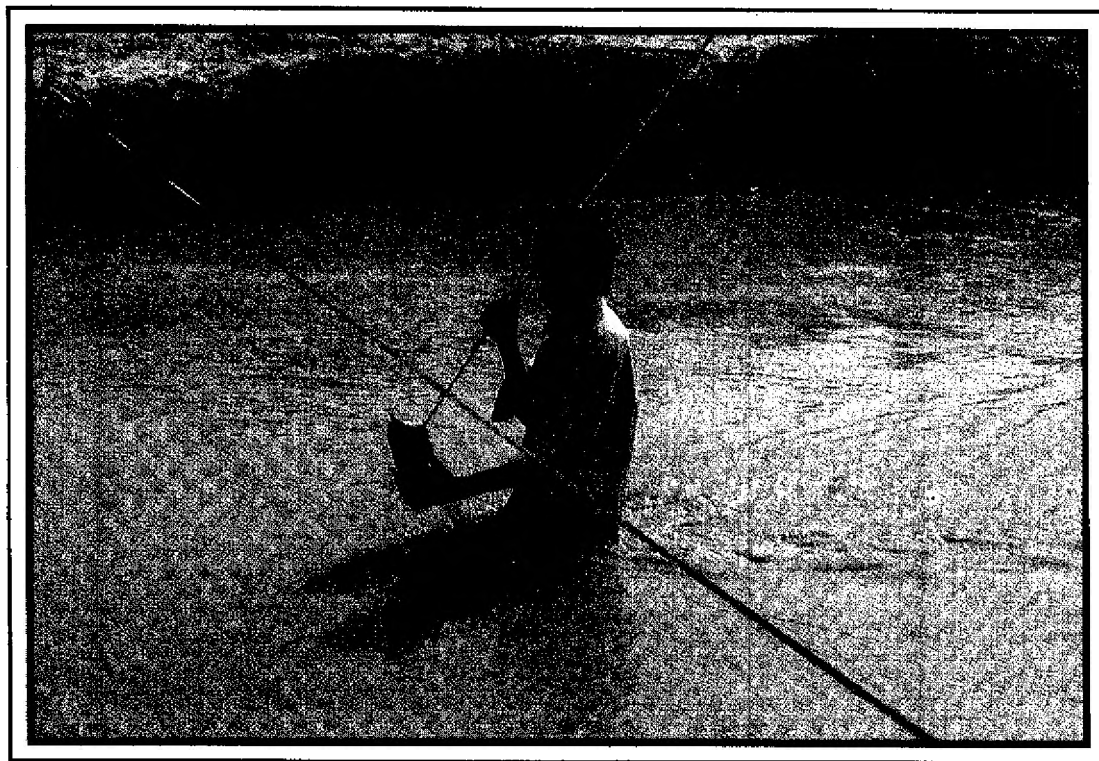
Depth-integrated sampling in Sangro Distrebutary, with DH48 (August 1997).

Current-metering in Chahu Minor (August 1997).

Pump-sampling in Sangro Distributary (Calibration of the pump) (August 1997).

Boil sampling in Sangro 1L (July 1997).

Bakri-ka-doodh sampling for the tea-break (September 1997)..

Appendix 3: Hydraulic Inflow into the System

Gate Calibration of Sangro Head Regulator:

Fourteen discharge measurements have been carried out by the DSS field team in Mirpurkhas. The following discharge rating has been obtained:

$$Q = 0.71 \ W.(G_o+0.03).\sqrt{2g \ (h_u-h_d)}$$

where W (width), G_o (gate opening), h_u, h_d (upstream and downstream head) are in feet, Q in cfs and g in lbs/s.

Ten measurements have been used for the discharge coefficient calibration, giving a standard error of 0.05.

The discharge at Sangro Distributary Head during the measurement campaign (until the annual closure 1998) is presented below:

Discharge at Sangro Distributary Head

Sediment Behavior of Sangro Distributary in Mirpurkhas Sub-division, Sindh.

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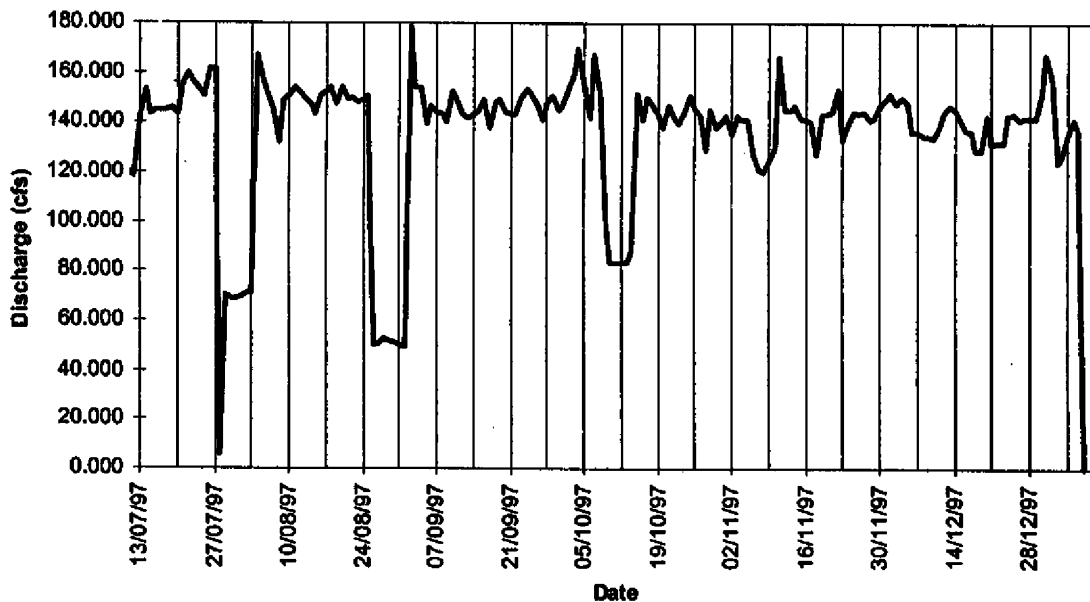
Appendix 4: Sediment Inflow into the System

The concentrations of sand, and the total concentration, have been reported here. A few measurements have been done after the campaign.

Evolution of Sand Concentration at Sangro Head
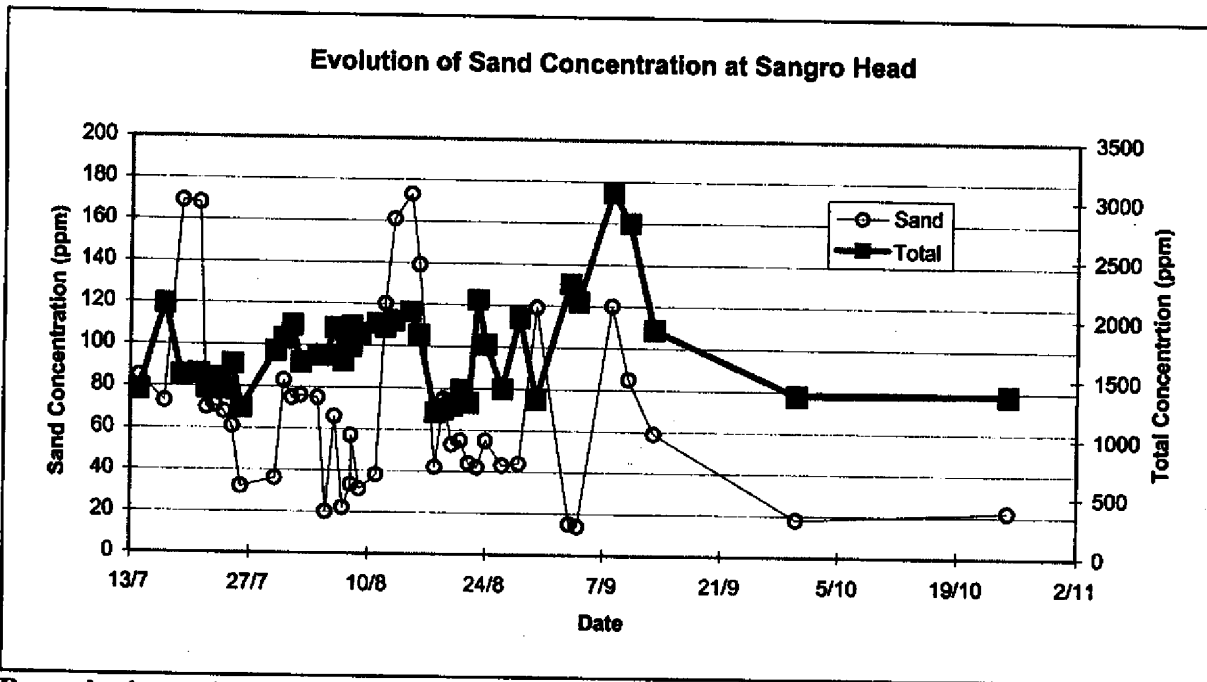
Remark : 1ppm=1 part per million # 1mg/l=0.001 kg/^{m3}

Sand Concentration versus Upstream Water Level
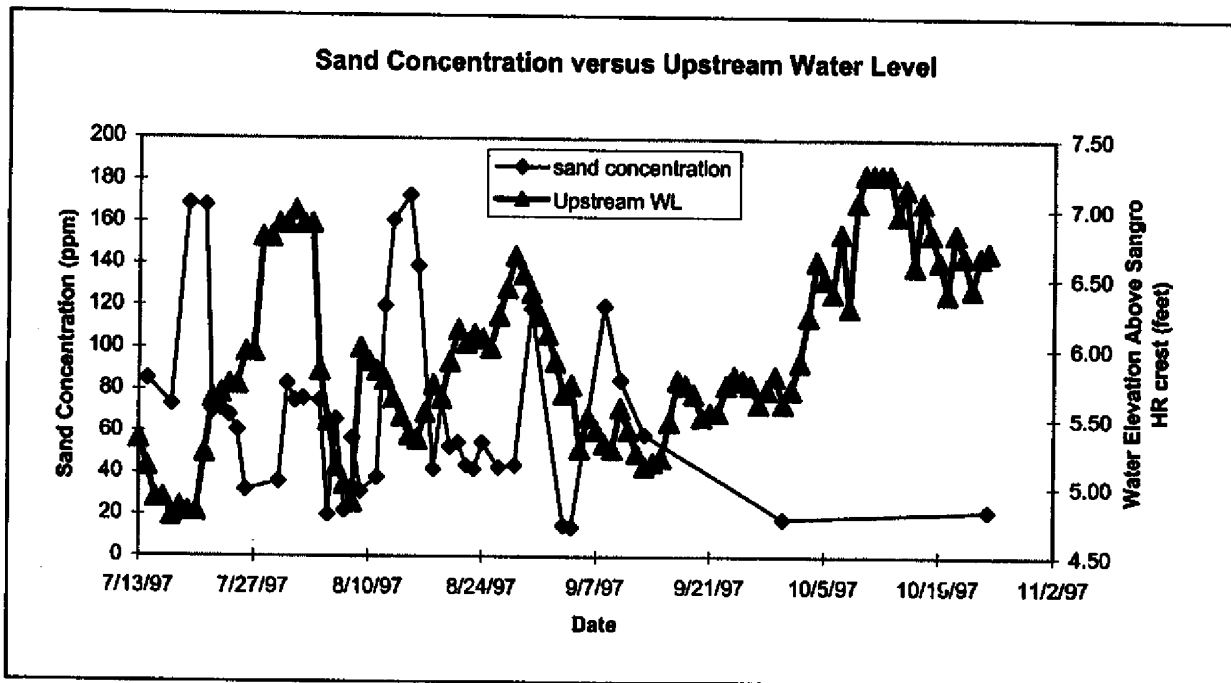
Appendix 5: Long Profiles of Concentrations

Long profiles of concentrations (concentrations measured the same day at different locations) have been established for the three channels. Those of Sangro distributary are displayed on two separate charts for the legibility on the different curves. Mainly sand concentration evolutions are presented, since silt and clay profiles do not have a visible trend (erosion or deposition). Small triangles at the bottom of the charts show the outlet positions.

Sand Concentration Along Sangro Distributary at Different Dates
Depositing Trend
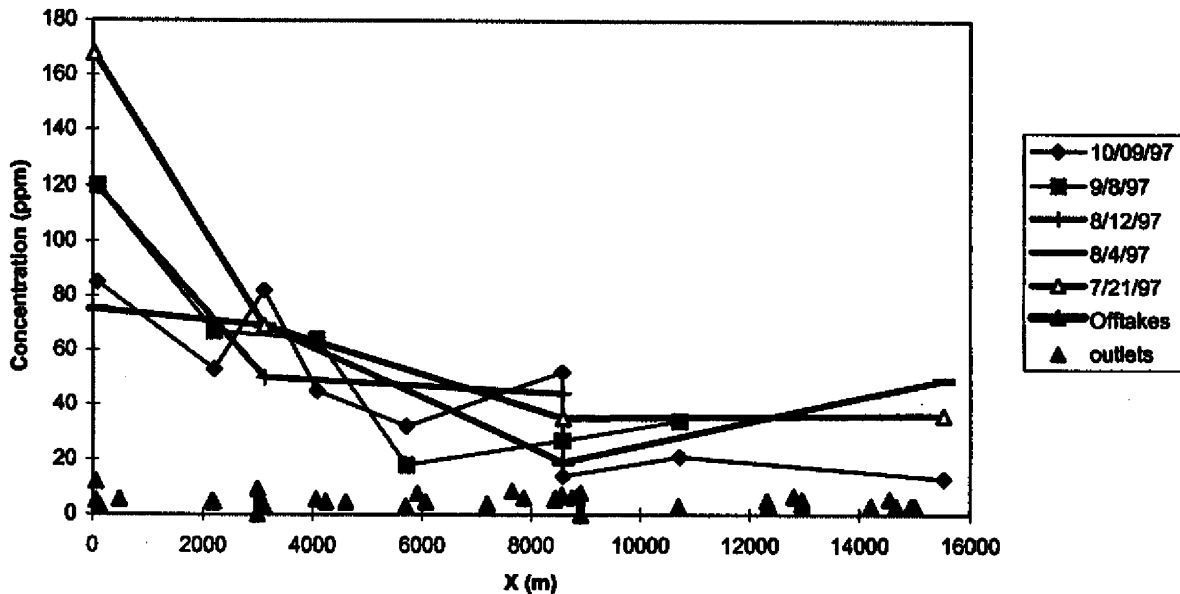
Sand Concentration Along Sangro Distributary at Different Dates
Stable or Ccouring Trend (at Head)

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Sediment Behavior of Sangro Distributary in Mirpurkhas Sub-division, Sindh.

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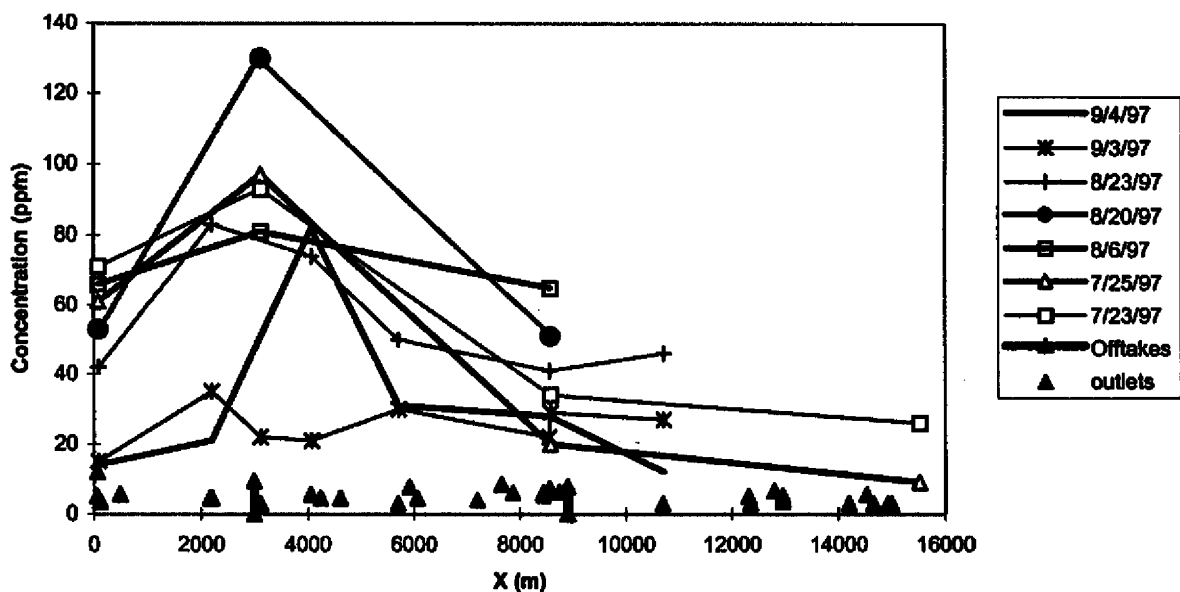
Sand Concentration Along Jarwari Minor at Different Dates
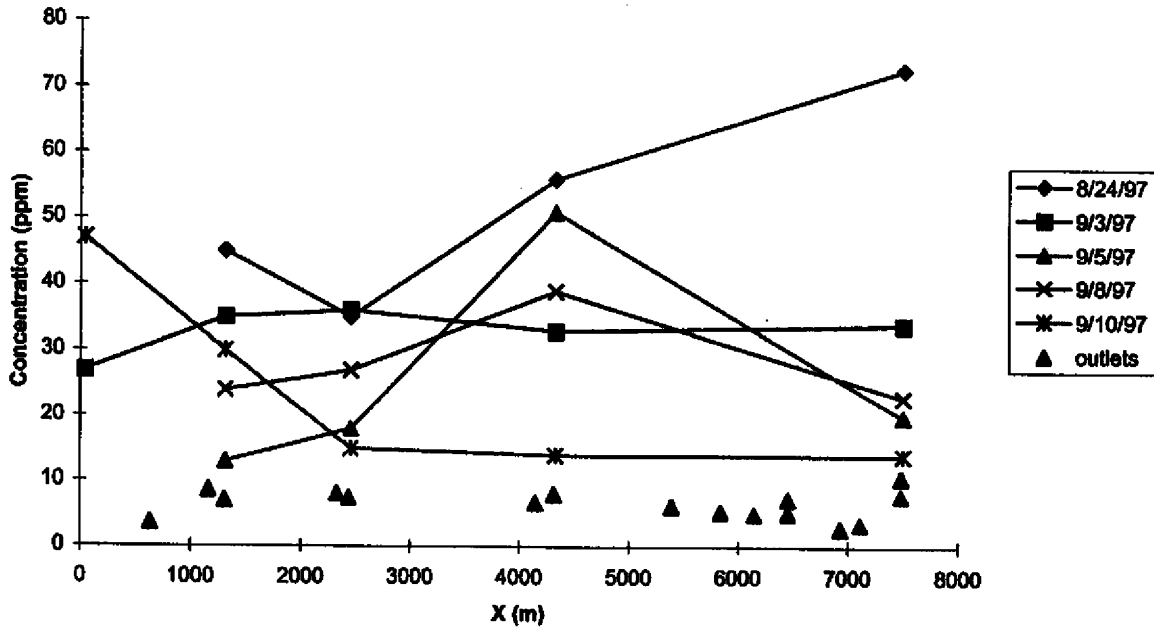
Sand Concentration Along Chahu Minor at Different Dates

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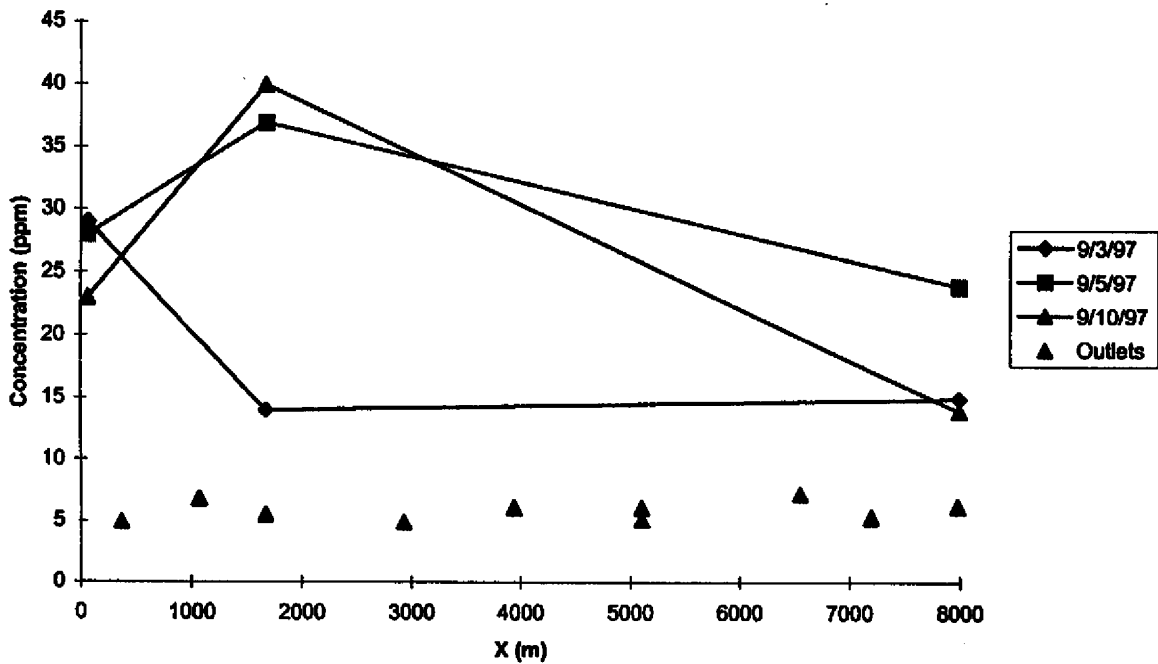
Appendix 6: Bed Samples Grading Curves

Part 1 : Samples Analyzed by ISRIP (VA Tube + Pipette Method)

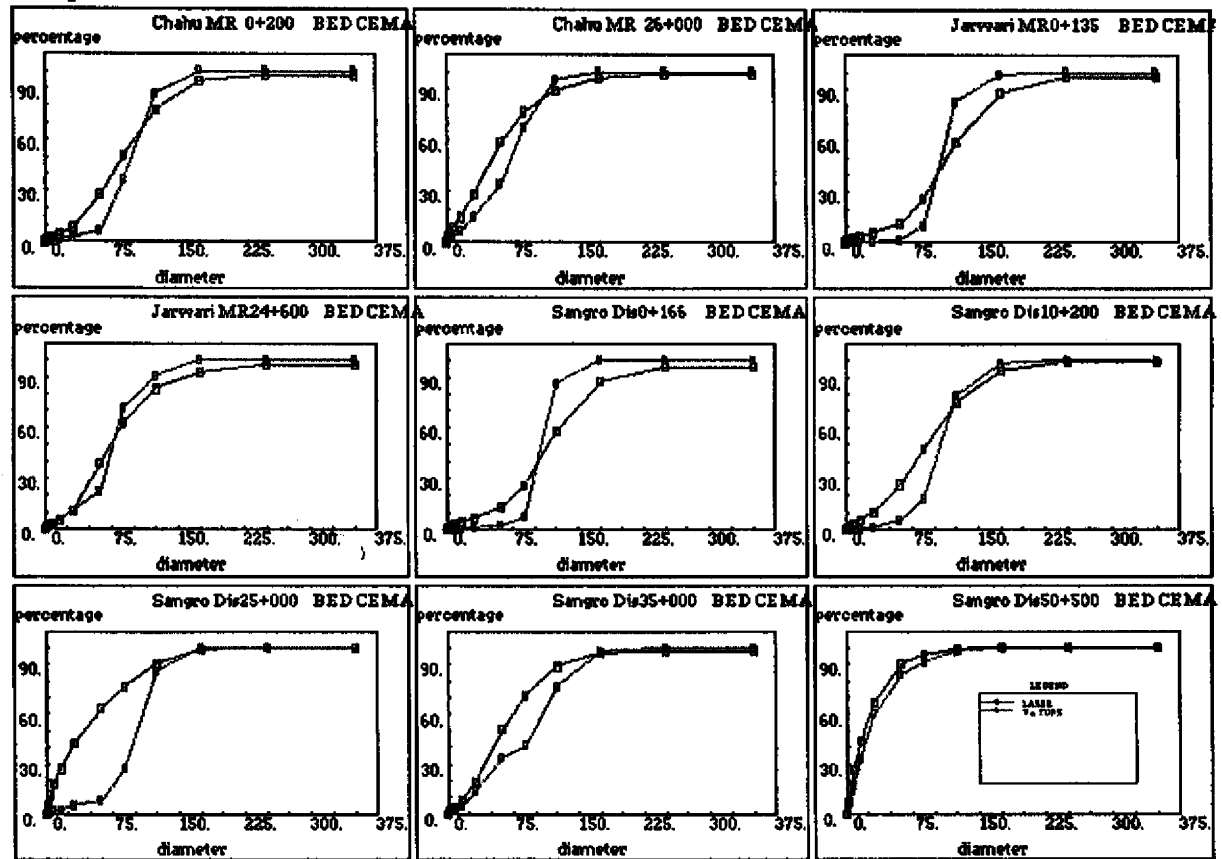The particles finer than 62µ where analyzed by pipette method, the sand by visual accumulation tube.
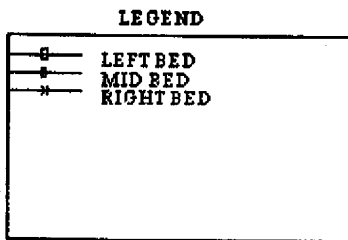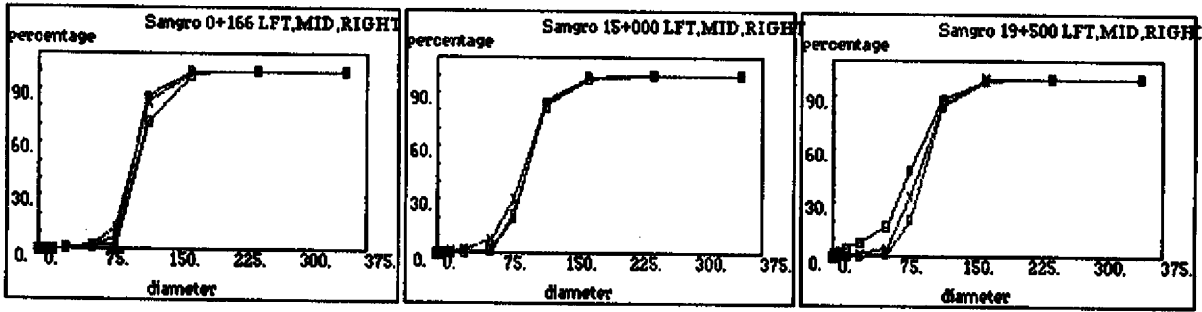
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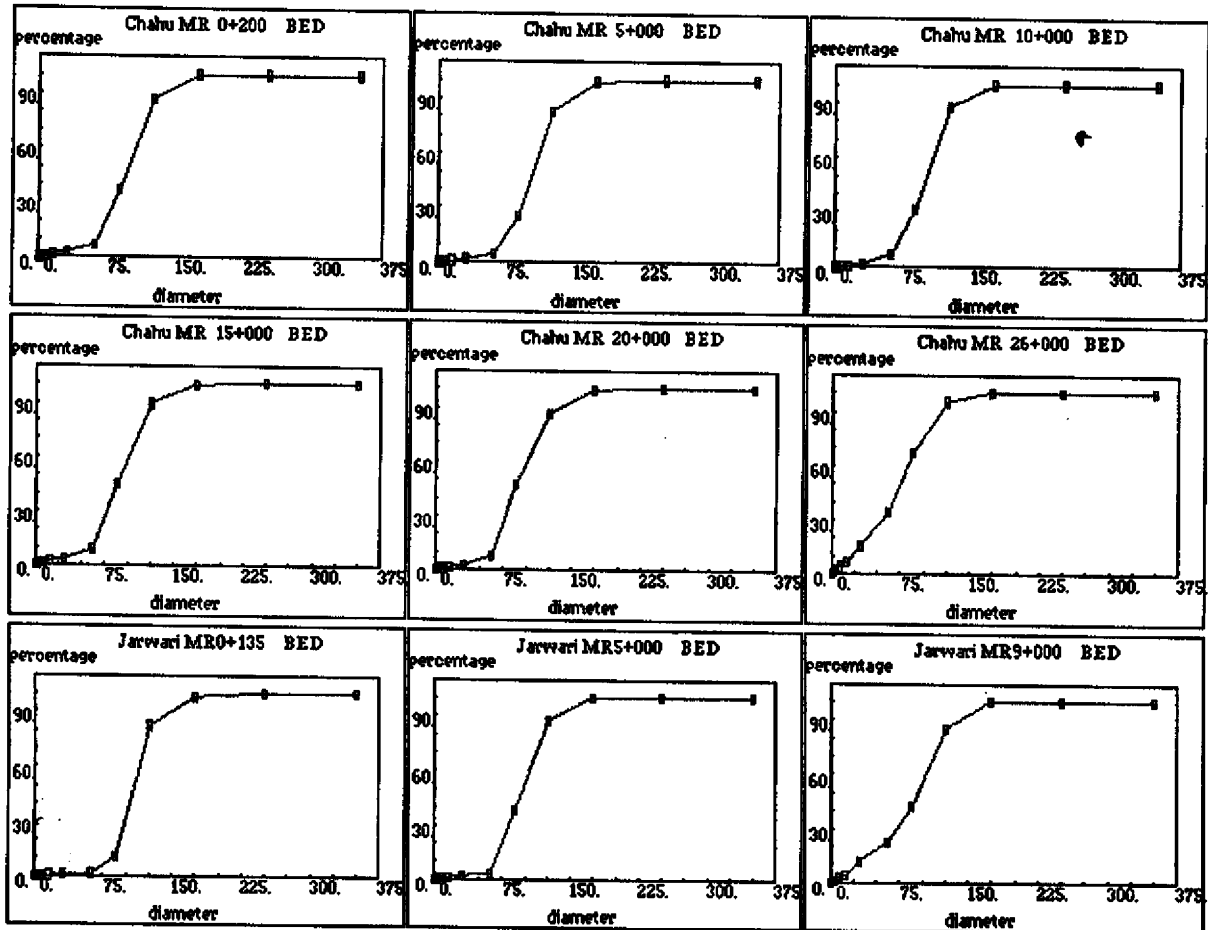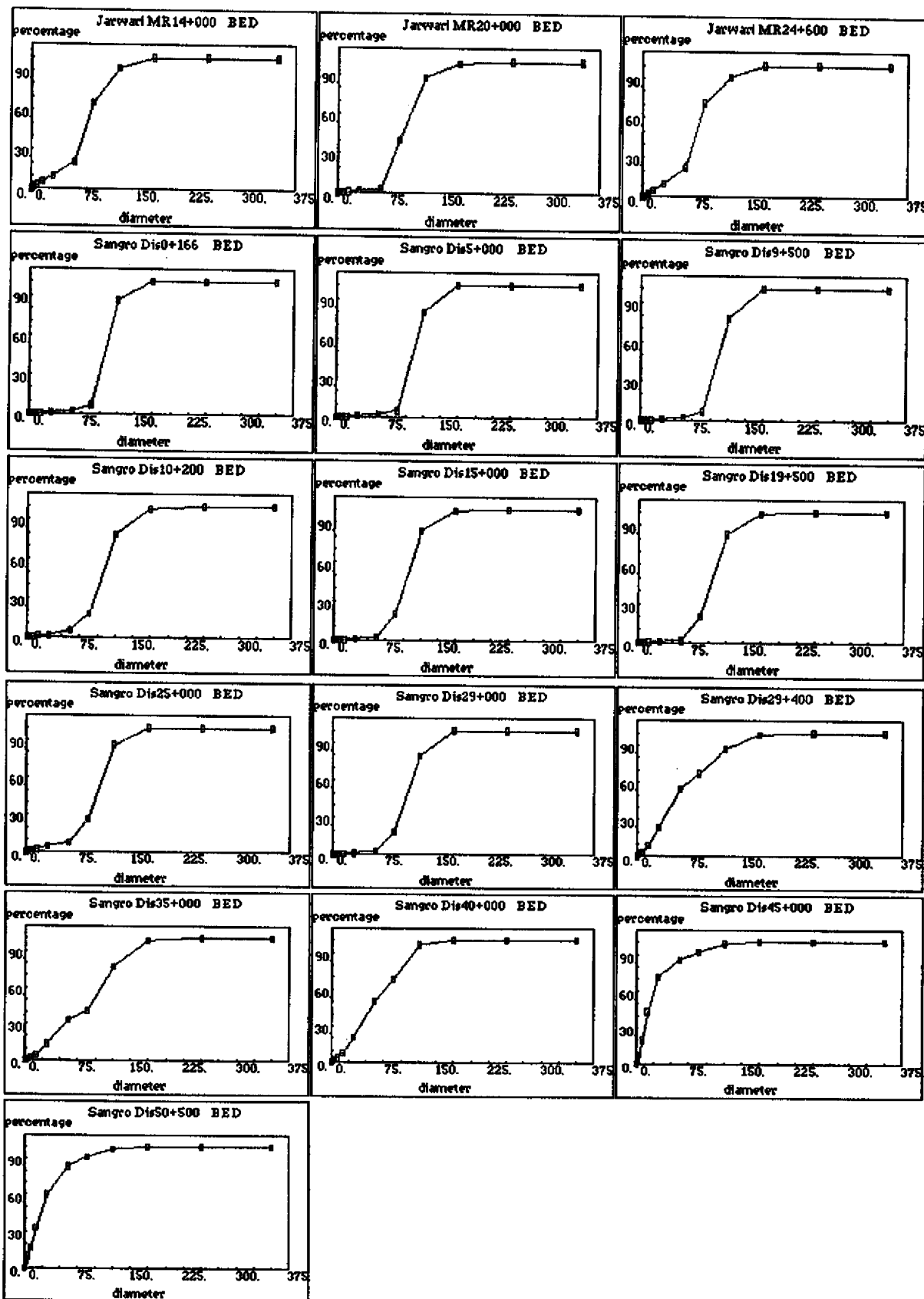
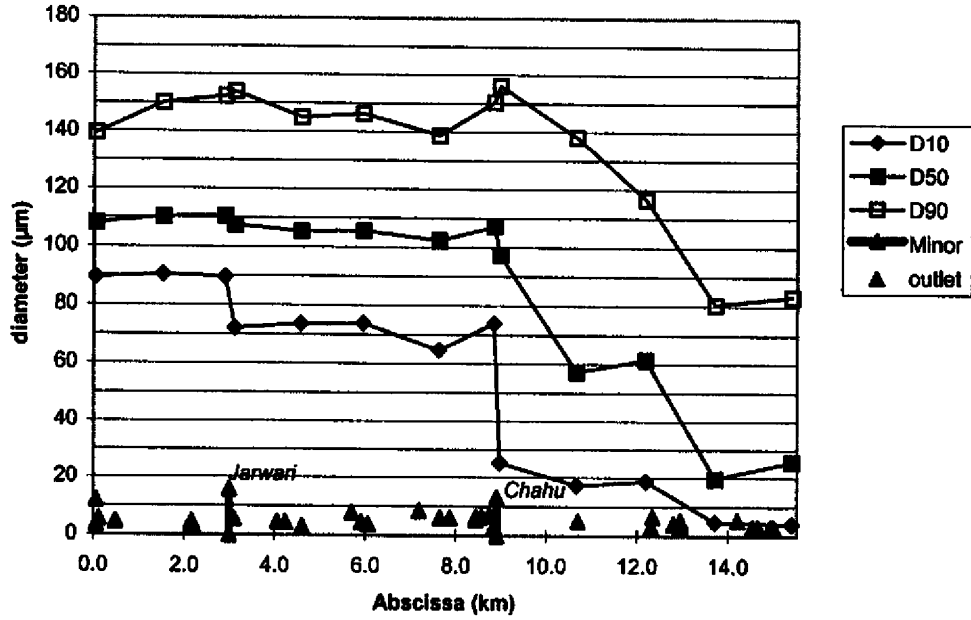## Part 2 : Samples Analyzed by Laser Method
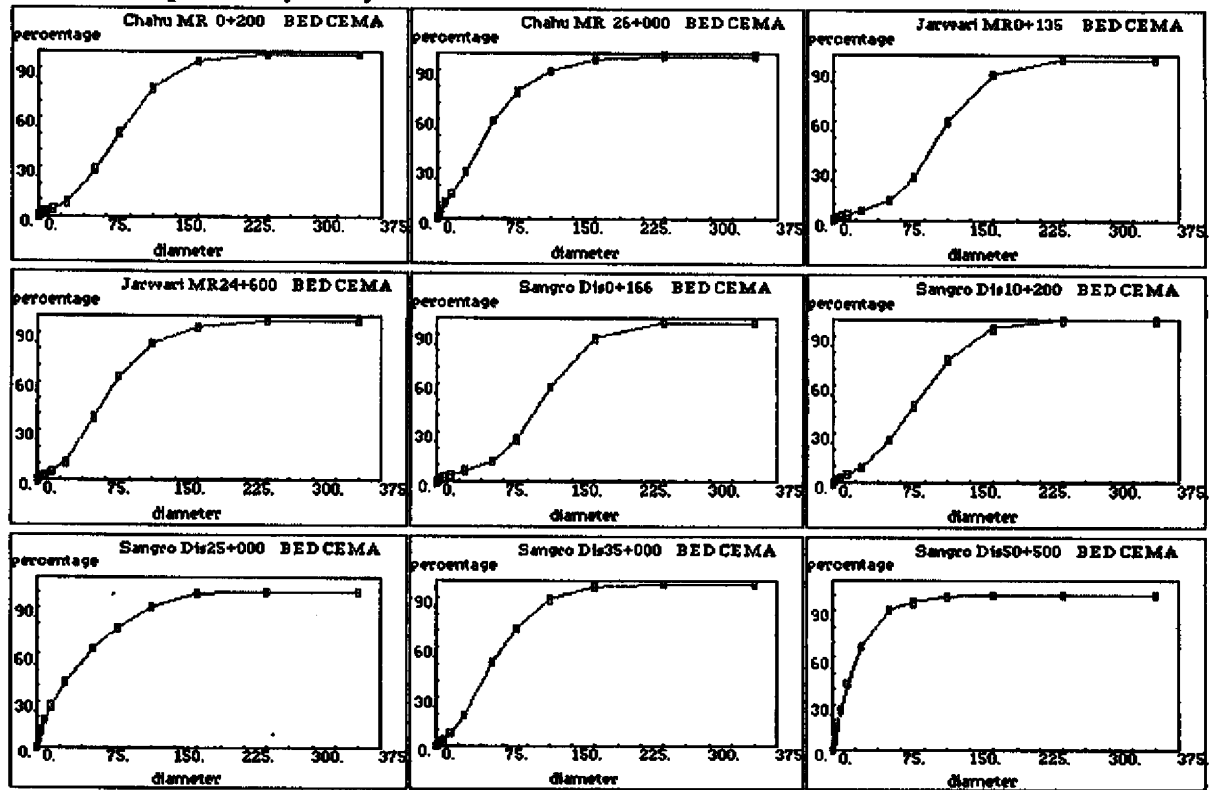
Comparison of Both Methods:

Part 3: Comparison of Bed Samples Across the Section

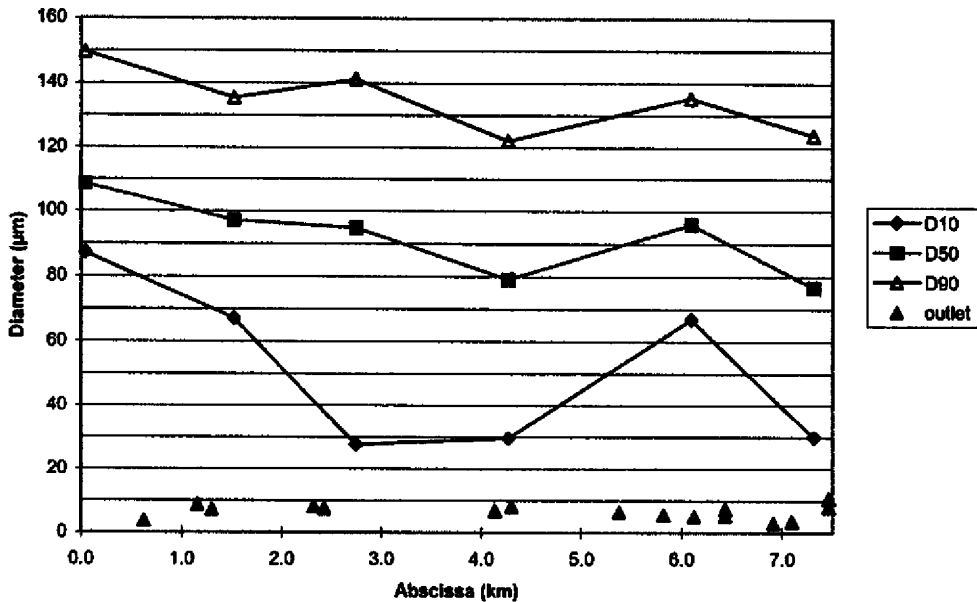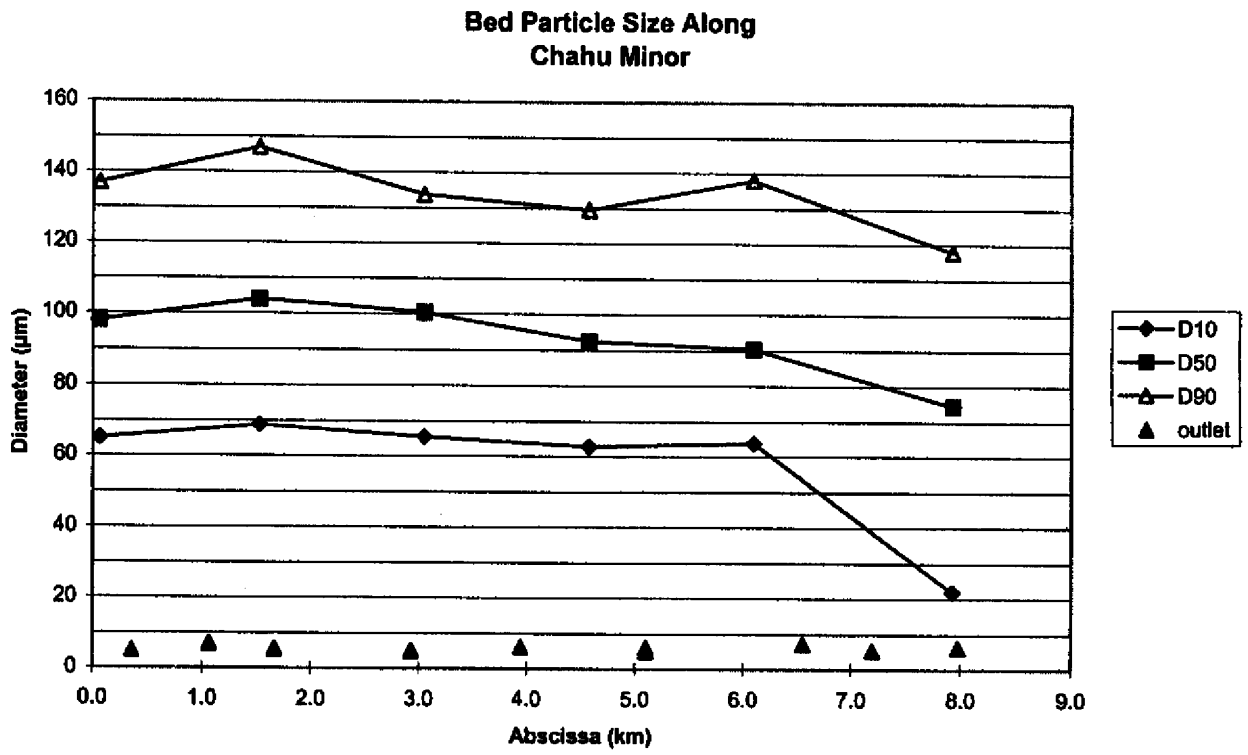The right and left bed samples were taken at 1/3 of the total width

LEGEND

—□—	LEFT BED
—■—	MID BED
—×—	RIGHT BED

Part 4: Bed Material Sizes Along the System

**Bed Particle Size Along
Sangro Distributary**

**Bed Particle Size Along
Jarwari Minor**

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**Bed Particle Size Along
Chahu Minor**

Appendix 7: Outlet Silt-drawing Capacities

The table summarizes the percentages of concentration extracted by sample outlets, where σ is the standard variation between the different ratios (concentrations in the outlet/concentration in the channel).

Outlet name			Nb meas.	Average ratio C(off-take)/C(parent)						Type	width ft	height ft
				Sand	σ	silt/clay	σ	Total	σ			
1L Sangro	0.2	1.6	11	202	167	117	27	119	24	APM	0.24	1.15
2L Sangro	0.2	8.0	11	204	94	115	17	120	17	APM	0.69	1.88
4L Sangro	7.1	1.6	4	113	59	101	22	101	22	APM	0.24	0.83
2R Sangro	7.1	1.6	5	185	119	105	23	106	23	APM	0.20	0.60
5L Sangro	10.2	1.5	1	28	0	124	0	117	0	APM	0.26	1.42
6L Sangro	13.3	2.7	5	83	41	111	24	110	23	APM	0.22	1.00
7L Sangro	18.7	2.3	5	138	81	107	8	107	8	APM	0.44	1.25
11L Sangro	28.1	4.3	5	148	59	124	18	124	19	APM	0.35	
12L Sangro	28.7	3.4	1	29	0	124	0	117	0	OF	0.30	
13L Sangro	29.0	3.4	1	41	0	140	0	132	0	OF	0.24	
9R Sangro	35.1	3.7	5	103	29	96	9	96	9	OF+pipe	0.34	
1L Jarwari	2.1	0.3	1	66	0	89	0	88	0	OF	0.16	
1R Jarwari	4.3	2.1	5	157	78	132	57	133	57	APM	0.35	0.89
2R Jarwari	7.6	2.5	5	78	24	101	33	100	32	APM	0.30	1.65
3R Jarwari	8.0	2.2	6	68	18	113	32	112	31	APM	0.41	0.98
3L Jarwari	14.2	2.4	5	63	35	102	19	101	18	APM	0.53	0.56
9R Jarwari	24.5	4.8	5	63	33	103	13	103	13	OF	0.42	
7L Jarwari	24.5	3.7	5	66	31	109	15	108	15	OF	0.33	
2L Chahu	5.5	2.4	5	108	75	110	17	109	16	APM	0.43	0.85
6L Chahu	26.2	3.6	6	116	52	103	21	103	21	APM	0.66	0.85

Sediment Behavior of Sangro Distributary in Mirpurkhas Sub-division, Sindh.

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Appendix 8: Topographic Evolutions

The topographies of the three channels are presented below. An average bed level has been calculated for each cross-section. The design bed level has been provided by the Irrigation Department.
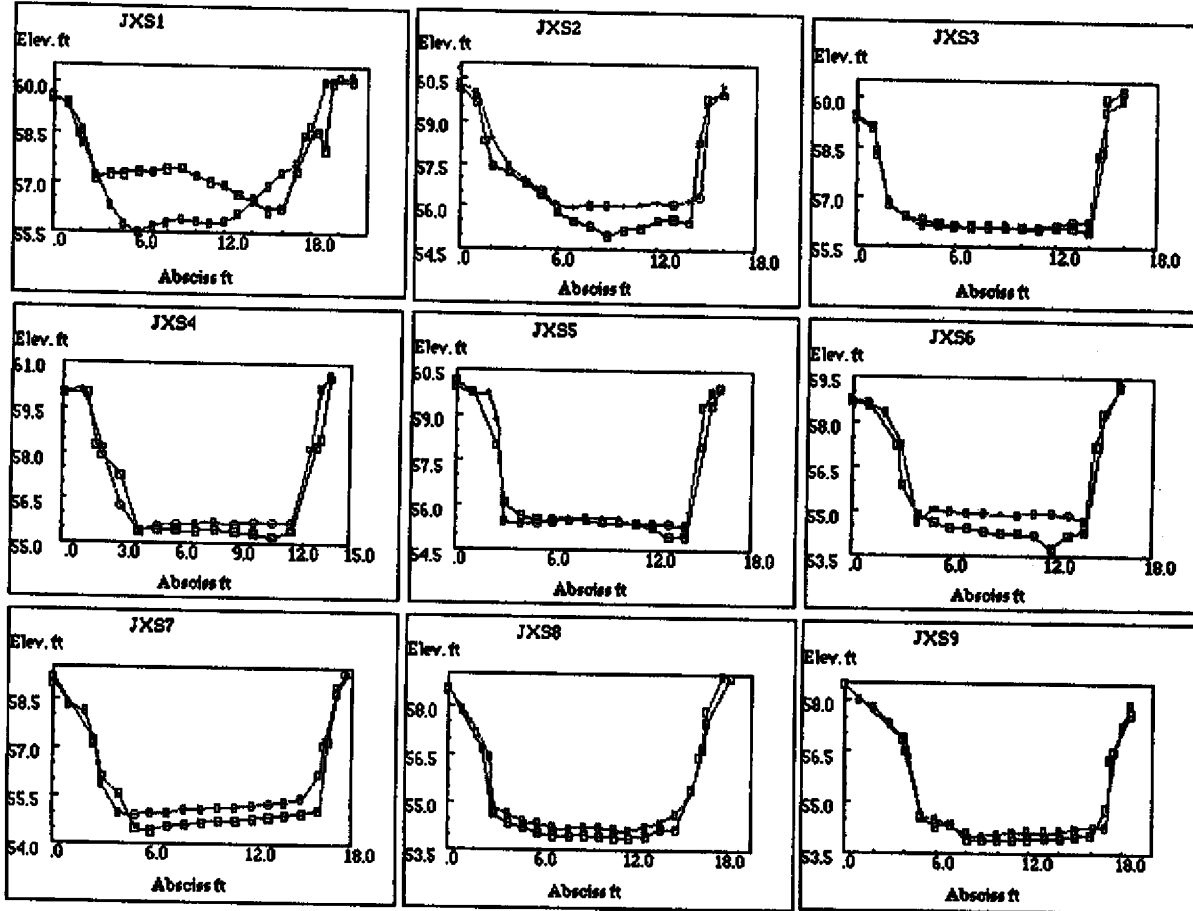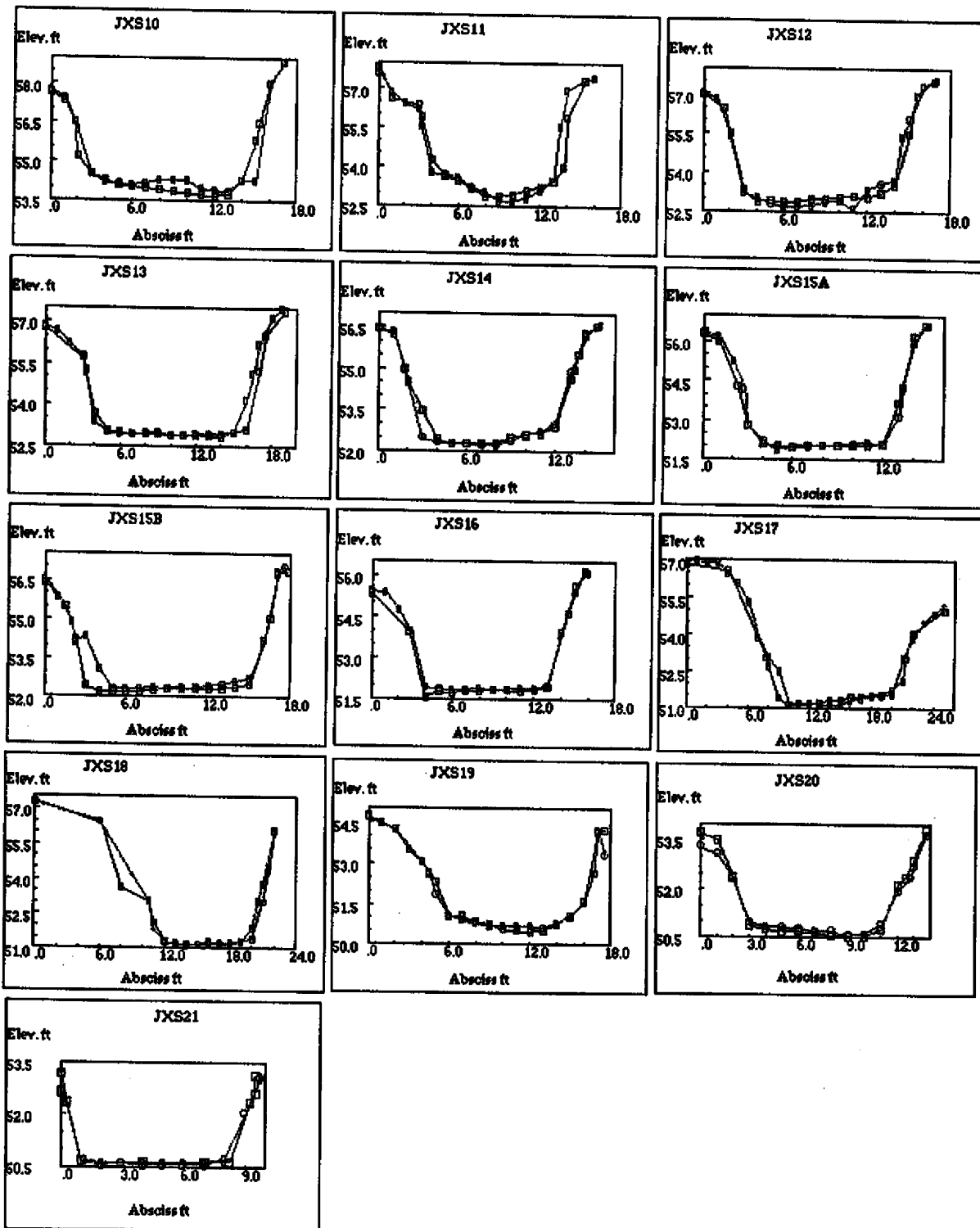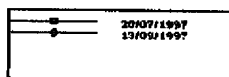*(A few elevations may be wrong, bench marks will be checked in the fields later)*

Bed Elevation
Sangro Distributary
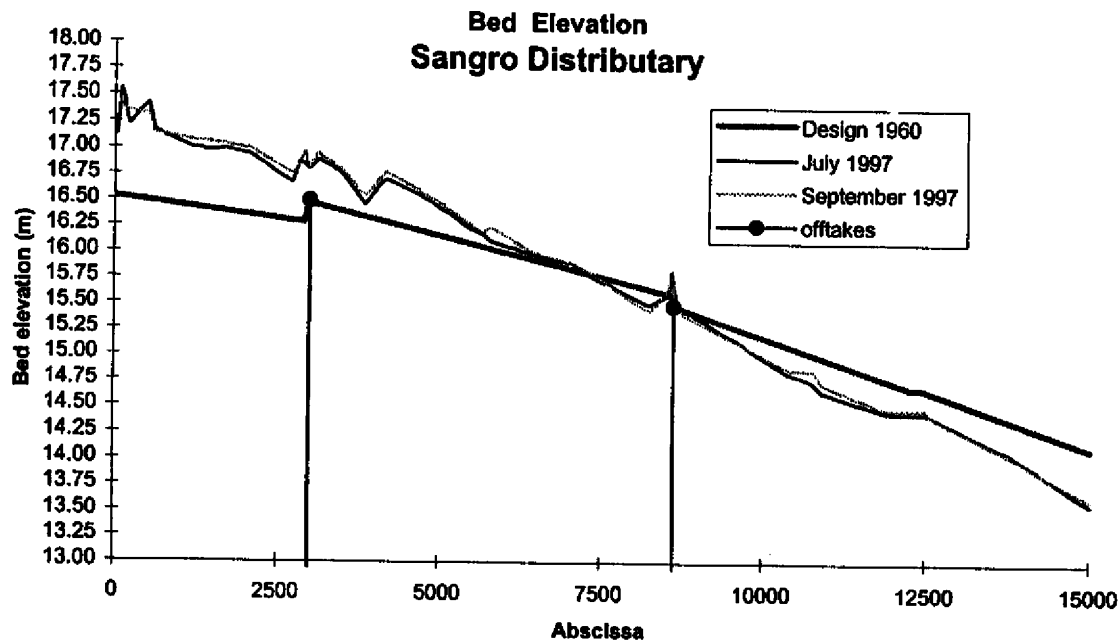
Bed Elevations of Jarwari Minor

Bed Elevations
Chahu Minor
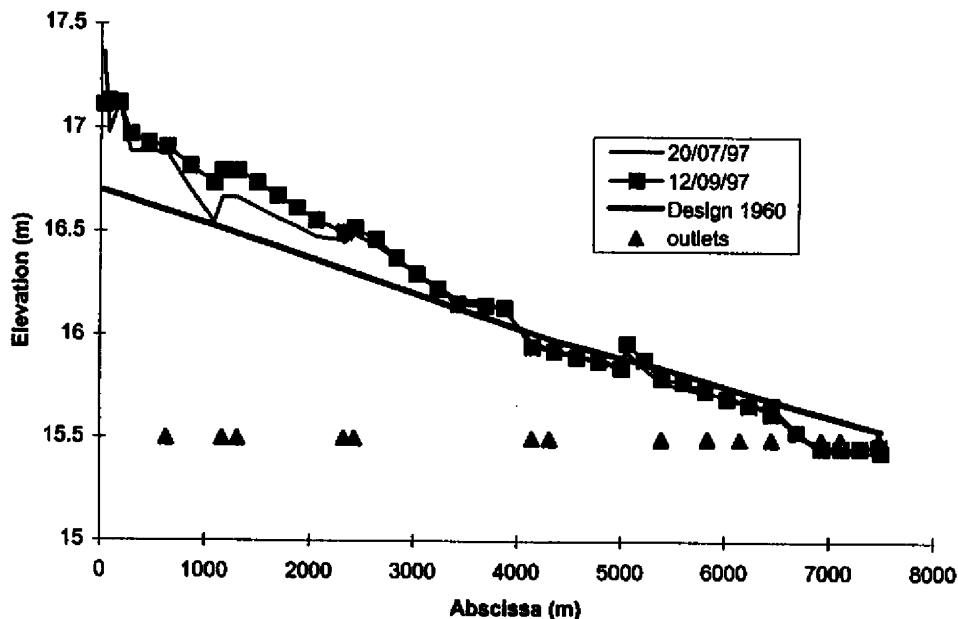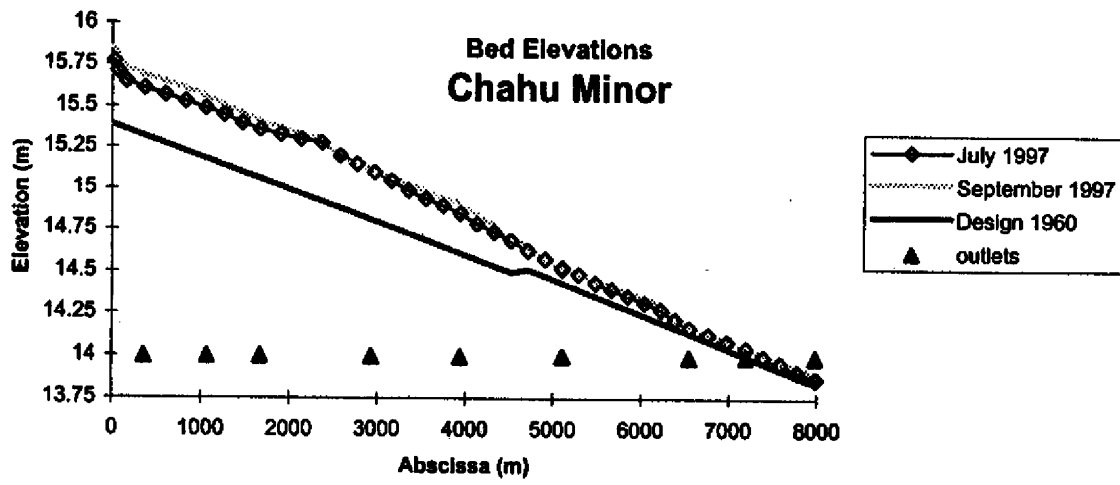
Appendix 8b: Observed Cross-sections

JARAWARI MINOR

Sediment Behavior of Sangro Distributary in Mirpurkhas Sub-division, Sindh.

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Observed Cross-sections of Chahu Minor

LEGEND
16/07/1997
09/09/1997
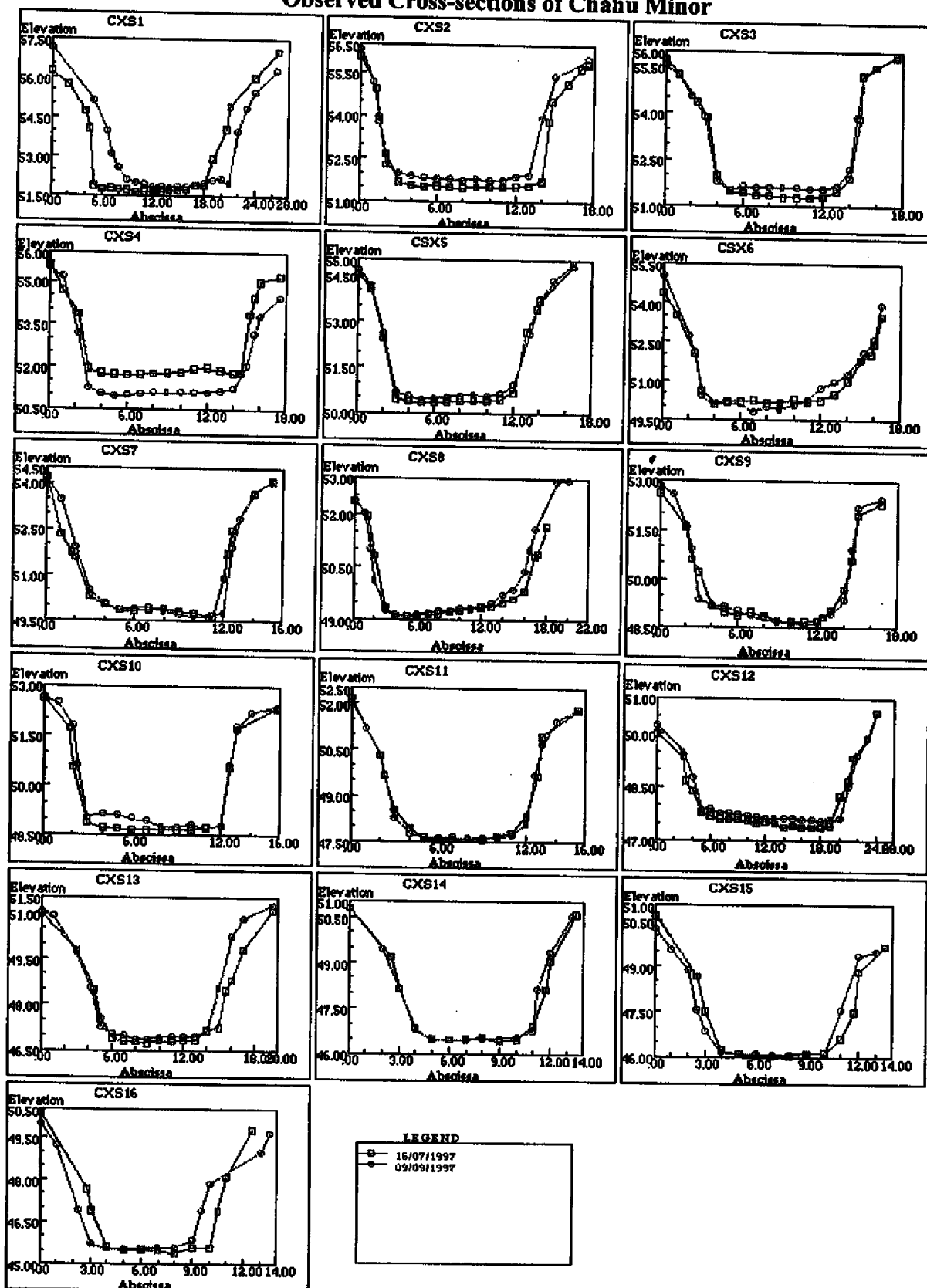
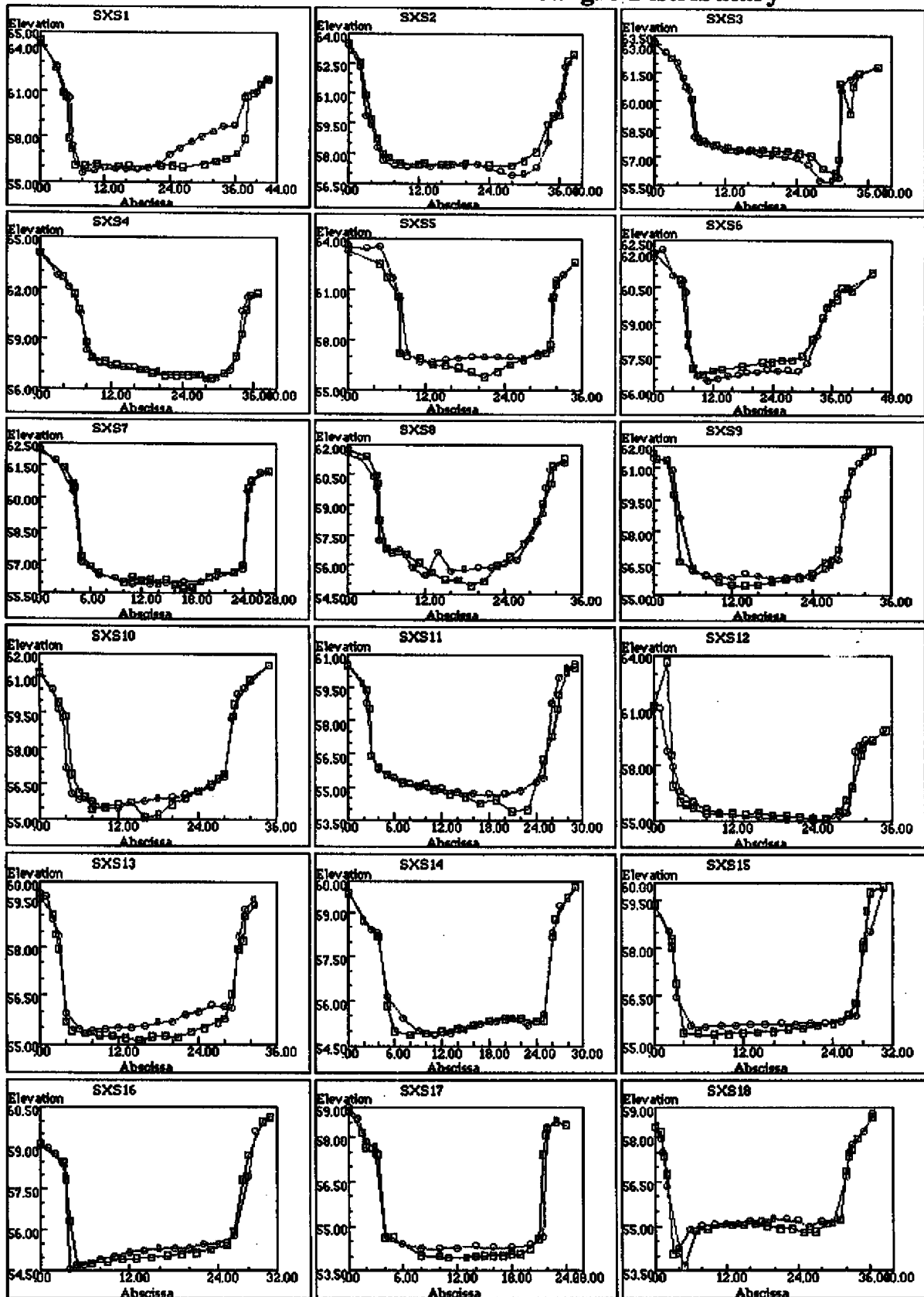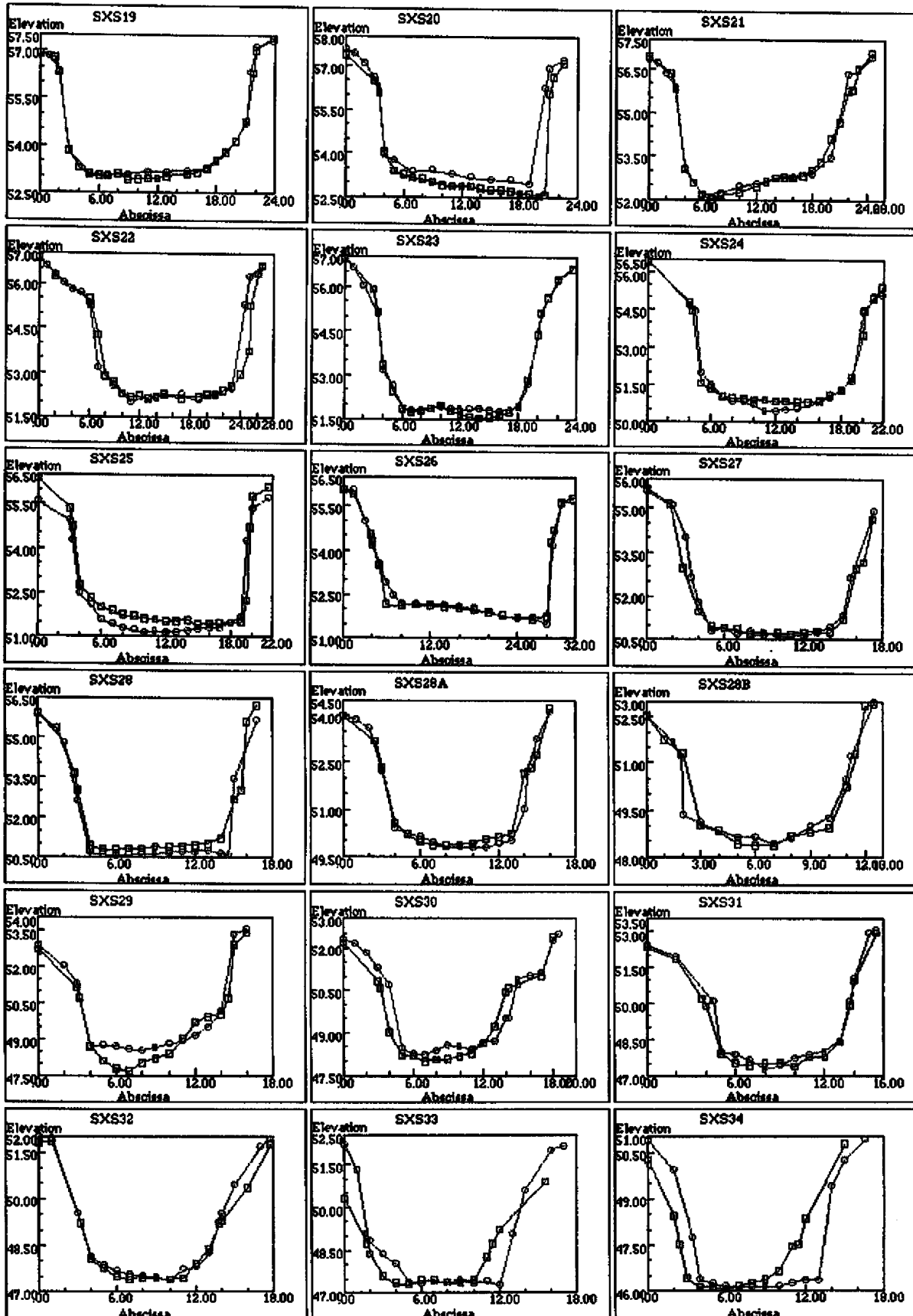# Observed Cross-sections for Sangro Distributary

Sediment Behavior of Sangro Distributary in Mirpurkhas Sub-division, Sindh.

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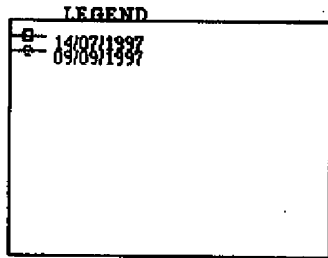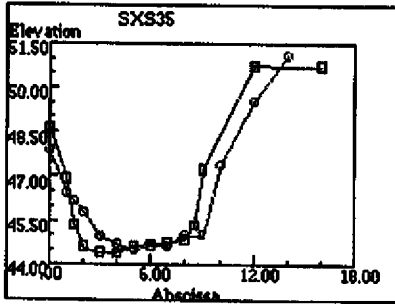
Appendix 9: Vertical Profiles

Part 1: Velocity Profiles

The vertical velocity profiles measured during the pump sampling are presented below.
The units are :

      - m/s for the velocity in X-axis (1m/s=3.28 ft/s);
      - m for the Y-axis (1m=3.28 ft/s).
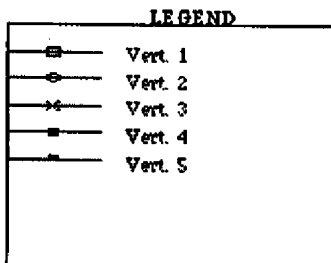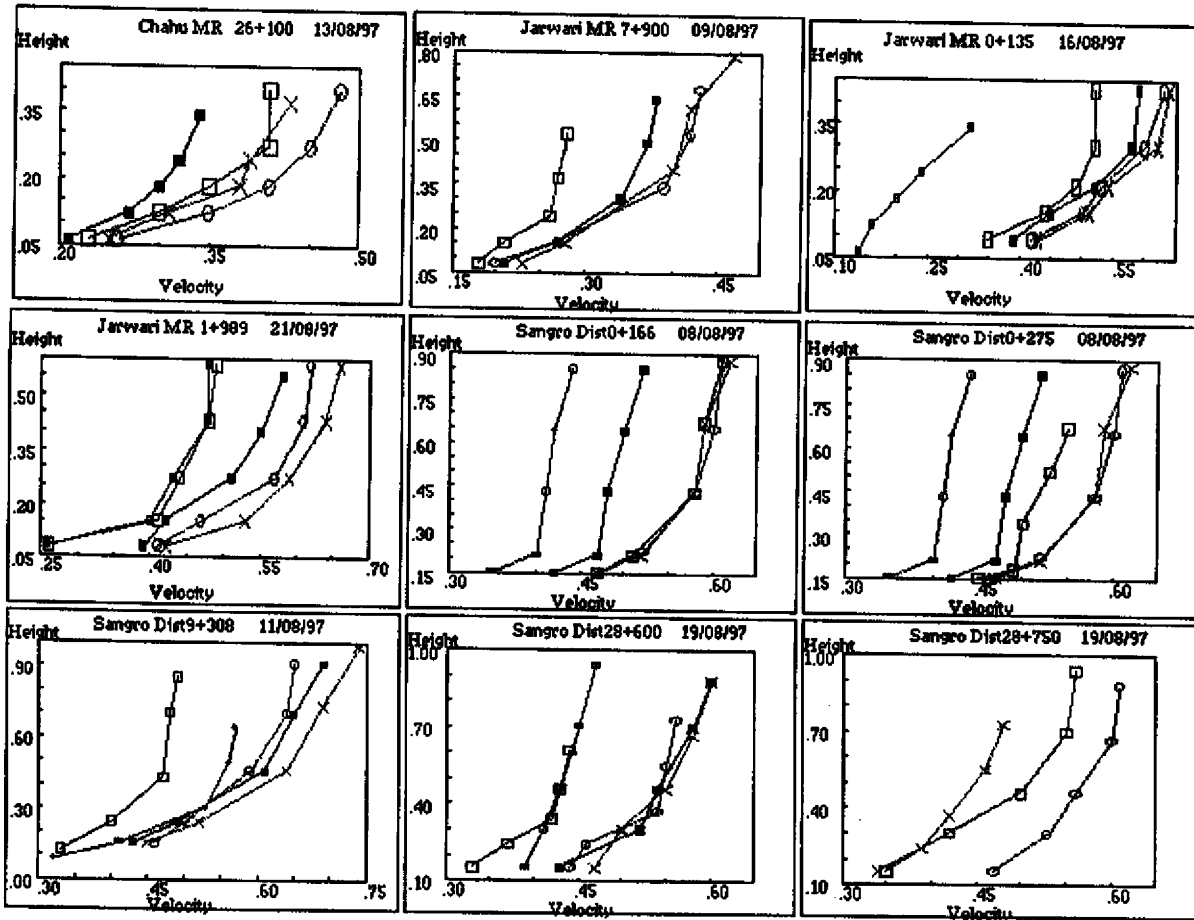
All the verticals are equidistant from each other.

Sediment Behavior of Sangro Distributary in Mirpurkhas Sub-division, Sindh.

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Part 2: Concentration Profiles
1/ Sand

2/ Concentration of Coarser Silt (31-62μ)

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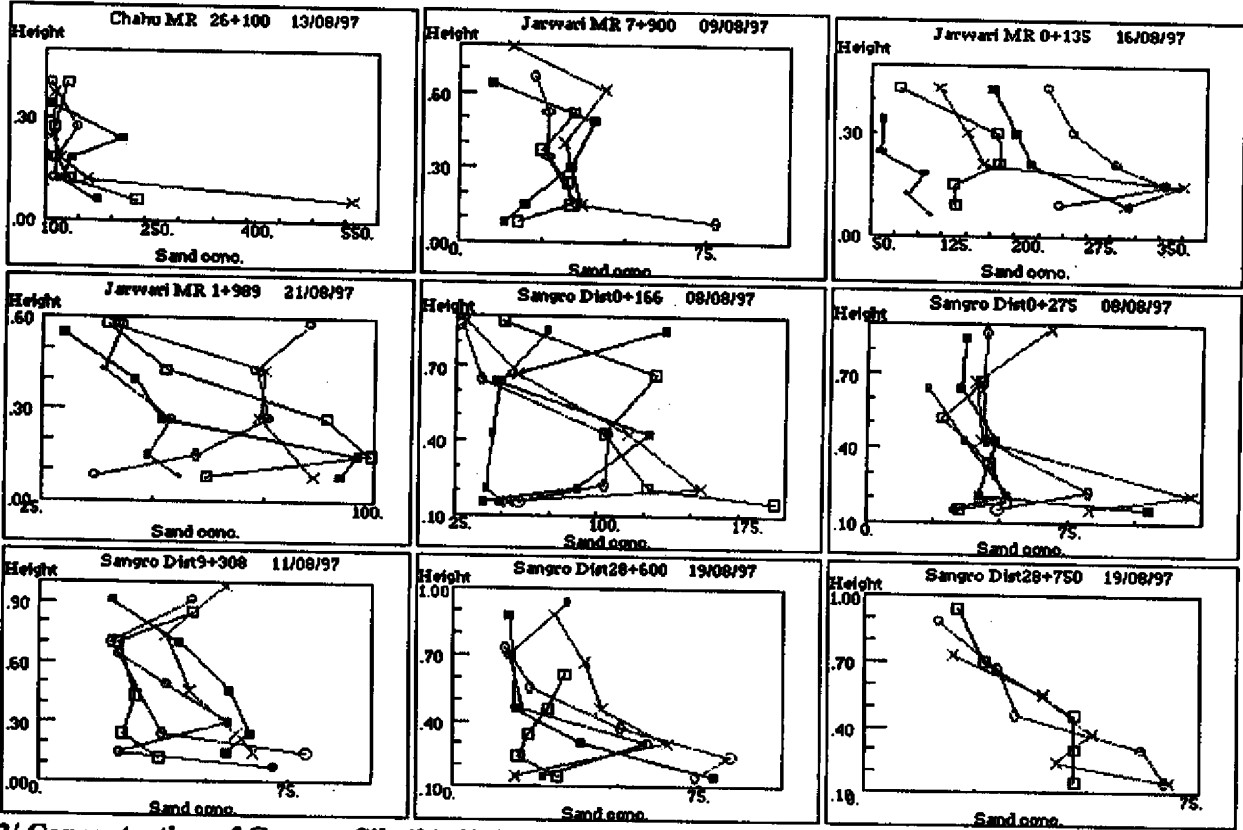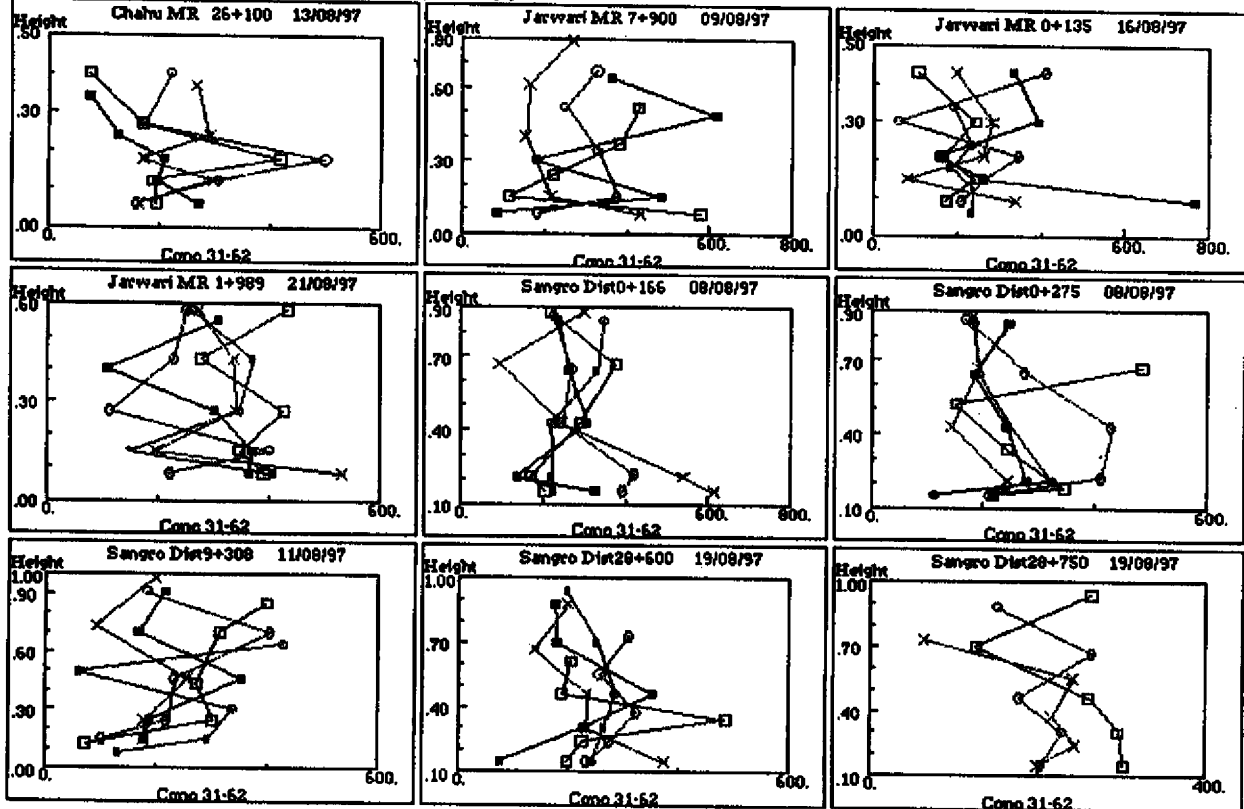| Report No.	Title	Author	Year
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Report No.	Title	Author	Year
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R-51	Water Measurement Training for Subsystem Management of Hakra 4-R Distributary by the Water Users Federation	Waheed-uz-Zaman Anwar Iqbal Abdul Hamid Gaylord V. Skogerboe	May 1998
R-52	Comparison of Different Tools to Assess the Water Distribution in Secondary Canals with Ungated Outlets	Mobin ud Din Ahmad E.G. van Waijjen Marcel Kuper Steven Visser	May 1998
R-53	Sediment Behavior of Sangro Distributary, Mirpurkhas Sub-division, Sindh	Gilles Belaud Abdul Hakeem Khan Ghulam Nabi	May 1998
R-54	Evaluation of the Integrated Approach Developed in the Context of the IIMI-CEMAGREF Collaboration in Pakistan	Patrice Garin Marcel Kuper Frederic Labbe Pierre Strosser	May 1998