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Design of Silt-Stable Canals in Alluvium

By

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Introduction

Canals carrying sediment-laden water and constructed in erodible alluvial materials must be designed to be "silt-stable" or "in regime". Such canals by definition will neither scour nor silt. In practice, it is difficult to satisfy such a rigid design criteria, as it is not possible to avoid silting or scouring under certain conditions. As long as the silting or scouring conditions at any time do not adversely affect, the operation of the canal and the cumulative effect of silting and scouring over a period of time is not of any material consequence, the canal, for all practical purposes, can be considered as silt-stable. In West Pakistan the formulae developed by Lacey form the accepted basis for designing silt-stable canals. Although there are a number of canals in the Indus Basin which can be considered as stable but have dimensions somewhat different from those derived from Lacey's equations, yet for initial construction and for a standard to which maintenance should be directed, Lacey's formulae have been recognized as the safest guide available to the irrigation engineer.

WAPDA is constructing, under the Indus Basin Project, a large system of Link Canals and Barrages costing 2800 million rupees. The total length of the Link Canals is 400 miles and their capacities range from 4000 to 22000 cusecs. In view of the rather disappointing experience of operation of large link canals, the Marala-Ravi (22000 cusecs), Balloki-Suleimanki (15000 cusecs) and the BRBD (7000 cusecs), recently constructed on the basis of Lacey's equations and considering that the formulae developed by Lacey were based on observed data of canals of relatively smaller capacities, there was some doubt about the adequacy of the Lacey method for designing canals of large capacities. WAPDA, therefore, initiated a comprehensive programme of collection of field data on the performance of existing canals. Plans were drawn up jointly by WAPDA, Tipton & Kalmbach and Harza Engineering International, WAPDA's Consultants, and the Irrigation Department to collect sediment samples and make hydraulic measurements at a number of headworks and in a number of canals. This programme is called the Canal and Headworks Observation Programme (CHOP). The canals selected for

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study include some of the large canals in the northern part of West Pakistan as well as several of the Intermediate capacity canals as shown below :

Canal	Capacity (cusecs)	Reach (R. D.)	Canal	Capacity (Cusecs)	Reach (R. D.)
Sidhnai	4,100	13- 23	U. G.	6,200	42- 46
Panjnad	10,500	68- 77	U. G.	5,400	106-109
Panjnad	8,200	137-141	M-R Link	22,000	20- 26
Abbasia	1,100	9- 14	M-R Link	21,000	154-160
Haveli	4,880	21- 27	U.C.C.	16,500	23- 29
Rangpur	2,150	11- 15	U.C.C.	15,900	100-105
L. C. C.	5,930	147-151	L.J.C.	4,500	160-166

The programme was carefully planned and executed under competent supervision. Equipment was imported to use the latest measuring and sediment sampling techniques of the U.S. Geological Survey. A considerable amount of data was collected during 1961 and 1962. It is believed that the CHOP data provides the best information available at any time on the hydraulic features of the existing canals.

Preliminary analysis of the CHOP data by WAPDA's Consultants led to the following conclusions :

(*a*) The observed bed widths and the section areas of existing canals are larger than those obtained from Lacey's formulae.

(*b*) The observed velocities are lower than those obtained from Lacey's equations.

(*c*) The observed values of Manning's roughness factor "N" are higher than those obtained from Lacey's design.

(*d*) Lacey's formula $P=2.67Q^{1/2}$ is not correct. The observations show that the value of the coefficient in most cases is 3.0 instead of 2.67.

(*e*) The single value of the silt-factor "f" assumed in Lacey's design is inconsistent with the widely different values of fvr and frs obtained from the observed data.

It was concluded that a canal designed on the basis of Lacey's formulae would not carry its full designed discharge initially and a "curing period" would be required for adjustments in the bed width and the canal section before it can take the full designed discharge. A new method was suggested for designing the Link Canals incorporating certain modifications in the Lacey method to reflect the results of the CHOP data. The most important change in the "suggested method" was in respect of the coefficient in Lacey's equation for wetted perimeter which was increased from 2.67 to 3.0. Graphical relationships were developed using the CHOP data, past data of Punjab and Sind canals and the data of some American canals for designing silt-stable canals.

In a separate paper[1] the writer has demonstrated that in the preliminary analysis of the CHOP data which led to the development of the "suggested method", consideration was not given to maintaining the geometry of the canal section at each observation site and the hydraulic parameters were not computed on the basis of the full supply discharge for testing the validity of Lacey's equations.

If these factors are considered in the analysis of the CHOP data the validity of the "suggested method" is not established. On the other hand the results of the analysis support the Lacey method except that there are certain apparent inconsistencies in the Lacey method particularly in respect of the higher values of the roughness factor N. the widely different values of the silt factors frs and fvr and the flatter side slopes of the canal sections actually attained in the field which differ substantially from the theoretical values obtained from Lacey's equations.

In this paper the development of the "regime theory" in the Indo-Pakistan subcontinent is discussed, a method for the analysis of the CHOP data is presented and the results are compared with the theoretical Lacey's design in order to verify the validity of the "regime theory" for designing silt-stable canals of large capacities. The inconsistencies in the Lacey method mentioned above are discussed and certain modifications are suggested in the present design practice.

Development of the "Theory" of Regime Channels

Some of the early canal systems constructed in the Indus Basin were the Western Jamna (1825), the Upper Bari Doab (1859), Sirhind (1872) and the Lower Swat (1880). The design tool available to the irrigation engineers at that time was the formula developed by Chezy (1775) from consideration of the resistance of channels to flow :

$$V = CR^{1/2} \quad S^{1/2} \ldots\ldots\ldots\ldots\ldots(1)$$

in which V is the velocity, C a coefficient incorporating the frictional resistance and S is the slope of the channel. Ganguillet and Kutter (1870), Manning (1890) and Bazin (1897) evolved different formulae for determining the coefficient C in Chezy's equation. These formulae were extensively used but were found unsatisfactory for designing canals carrying heavy sediment loads.

In 1895, Kennedy,[2] Executive Engineer, Punjab Irrigation, published his "theory" of silt transport after observations, extending over a number of years on 30 selected sites on the channels of the Upper Bari Doab system which he considered to be in regime. He was the first to formulate the basic law that shallower canal sections are *ipso facto* capable of transporting greater silt loads which is now almost universally recognized as an empirical, but well established, design basis. His basic assumptions were that the vertical components of eddies supported silt particles; the silt-transporting power of a channel was dependent solely upon its velocity which controls the eddies; the silt-transporting power was also dependent upon the depth which limits the effect of the eddies; and the silt-transporting power of a channel was not influenced by its bed width. On the basis of these assumptions and using the observed data of UBDC, Kennedy developed his famous equation.

$$V_o = 0.84D^{0.64} \dots\dots\dots\dots (2)$$

in which Vo is the "critical velocity" which was defined as the non-silting non-scouring velocity and D is the depth of the channel. Kennedy's equation correlates the velocity with depth, the width of the section being ignored. Notwithstanding this limitation, the equation implied a reduction in the permissible depth which caused the width of the section to be materially increased as compared to the design practice followed at that time. Subsequently Kennedy[3] (1904) gave certain "rough rules" for the ratio of bed-width to depth for designing silt-stable canals. The canal systems in the Punjab which were designed on the basis of Kennedy's formula were Lower Chenab (1900), Lower Jhelum (1901), Upper Chenab (1912), Lower Bari Doab (1913), and Upper Jhelum (1915) which are amongst the most important canal systems in Pakistan having a total design capacity of about 52000 cusecs.

The next contribution to the problem was from Capt. A. Garret (1913), who produced a set of hydraulic diagrams for non-silting canals with discharges of 1 to 12,000 cusecs, bed slopes 1 in 100 to 1 in 10,000 and for values of Manning's N ranging from 0.018 to 0.03. Garret's diagrams were based on Kennedy's equation. Mr. F. W. Woods[4] (1917), Chief Engineer Punjab recognizing that a number of designs could be worked out from Kennedy's diagram for the same value of Vo developed Kennedy's "rough rules" to define bed-width to depth ratios. Mr. E. S. Lindley[5] (1919), Executive Engineer, Punjab Irrigation, carried out an extensive survey of the Lower Chenab Canal system and made 786 observations on channels totalling 2700 miles in length. On the basis of this data he developed the following equations :

$$V = 0.95D^{0.57} \dots\dots\dots\dots\dots\dots (3)$$

$$V = 0.59B^{0.355} \dots\dots\dots\dots\dots\dots (4)$$

$$B = 3.80D^{1.61} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Lindley's main hypothesis was that the sediment load carried in a channel controlled the bed width in the same way as it unquestionably defined the depth. These results were considered as an outstanding development in designing silt-stable canals as they demonstrated the important effect of the geometry of the canal section on its sediment transport capability. Woods[6] (1927) further analysed Lindley's data and developed the following general formulae :

$$D = B^{0.434} \ldots\ldots\ldots\ldots (6)$$

$$V_o = 1.34 \ \mathrm{Log}_{10}B \ldots\ldots\ldots (7)$$

$$S = \frac{1}{2 \times \log_{10}Q \times 1000} \ldots\ldots (8)$$

Attention is drawn to the fact that, according to Woods' formulae, for any given discharge, there was only one slope under which the canal would remain silt-stable. Thus all the three basic variables of a stable canal section were defined and the "degree of freedom" was eliminated.

The Sutlej Valley Canals (1926-32) with a total capacity of 48000 cusecs taking-off from Ferozepur, Suleimanki, Islam and Panjnad Headworks and the Sukkur Canals (1932) having a total capacity of 47000 cusecs, were designed on the basis of Kennedy's formulae taking into account the improvements suggested by Lindley and Woods. Lacey's preliminary results of investigations were available at that time but his equations were not sufficiently developed to be used as a basis for design.

Mr. Gerald Lacey[7] (1929) was appointed by the Irrigation Department to put some order in the mass of available data and produce, if possible, a standard method for designing silt-stable canals. Lacey did not produce any new unpublished information on the problem but rearranged the available data and reduced the number of independent parameters to a minimum. His studies indicated that a geometric conception of depth was out of place when dealing with the forces generating a channel and moulding its boundary and wetted perimeter and that the depth D in Kennedy's formula should be replaced by the hydraulic mean depth R. He recalculated all available data on the basis of V and R and plotted on a logarithmic scale a series of parallel straight lines and obtained the formula :

$$V_o = KR^{1/2} \ldots\ldots\ldots (9)$$

in which, V_o has the same significance as Kennedy's V_o, and K is a constant depending on the size and quantity of silt. For many years the "silt-grade" upon which Kennedy founded his formula was recognized as a standard. Lacey accepted the same standard, designated it as a "silt factor", $f=1$ and produced the formula :

$$Vo = 1.1547\sqrt{fR} \ldots\ldots\ldots\ldots (10)$$

or

$$fvr = 0.75\,\frac{V^2}{R}.$$

From Lindley's data, Lacey plotted Vo against the product of the section area and the square of the silt factor pertaining to the particular channel and developed the equation :

$$Af^2 = 4.0\ Vo^5 \ldots\ldots\ldots\ldots (11)$$

Eliminating 'f' from equations (10) and (11) he produced the following relationship between the wetted perimeter and discharge :

$$P = 2.668Q^{1/2} \ldots\ldots\ldots (12)$$

These are the three standard formulae upon which Lacey's "regime theory" is based. They are referred to as Lacey's Regime Equations. They can be cast into various other useful forms.

For developing the flow formulae, Lacey accepted the basic Chezy formula and assuming that in alluvial channels, the rugosity coefficient N was a function of the silt envelope and independent of all other factors, he developed by using Chezy and Manning's formulae, the following equations :

$$V = \frac{1.3458}{Na}.R^{3/4}.S^{1/2} \ldots\ldots\ldots\ldots\ldots (13)$$

in which Na is a measure of the absolute rugosity of the silt envelope. From data of channels in regime, Lacey calculated the value of Na from equation (13) and derived the equation :

$$Na = 0.0225\ f^{1/4} \ldots\ldots\ldots\ldots (14)$$

The above equations are referred to as Lacey's Flow formulae. They can be cast into the following useful forms :

$$So = \frac{1}{1844.3}\ \frac{f^{5/3}}{Q^{1/6}} \ldots\ldots\ldots\ldots (15)$$

$$V = 16.046\ R^{2/3}\ S^{1/3} \ldots\ldots (16)$$

$$frs = 192\ R^{1/3}\ S^{1/2} \ldots\ldots\ldots (17)$$

Regime dimension diagrams based on regime equations were plotted for a range of discharges of 4 to 100 cusecs and 100 to 20,000 cusecs which give, for known values of Q and f, the values of B and D. Similarly regime slope diagrams were plotted based on flow equations which give, for known value of Q and f, the slope S. They are referred to as Lacey's Diagrams.

Lacey's method was accepted officially by the Central Board of Irrigation in 1934 as a standard practice for designing silt-stable canals. Some of the major canal systems in Pakistan designed on the basis of Lacey's formulae were Haveli (1939), Thal (1946), BRBD Link (1951), B-S Link (1954), M-R Link (1956), Kotri (1955), Taunsa (1958) and Guddu canals (1962). The total capacity of these canals is 152,000 cusecs. Also many older canals were successfully remodelled in accordance with his method. The significance of Lacey's formulae $Vo = KR^{1/2}$ may have been even deeper than realized at that time by Lacey, for, interpreted dimensionally, his equation meant that for silt-stable flows Froude Number was a constant. In fact squaring the formulae and dividing by the acceleration of the force of gravity "g", we obtained

$$\frac{V^2o}{Rg} = \text{Constant} = F.$$

That Lacey's formula was capable of being interpreted in this manner was first suggested by Tehikoff[8]. The constancy of Froude Number may be characteristic of a much more general law than Lacey's silt formula. For instance, Chezy's equation, if applied to a set of channels with the same rugosity and slope may also be interpreted as expressing the constancy of this number.[9]

Dr. M. K. Bose[10] (1936) of the Punjab Irrigation derived the following formula after statistical analysis of the field data of a number of canals in the Punjab :

$$S \times 10^3 = 2.09m^{0.86}/Q^{0.21} \quad \ldots\ldots\ldots\ldots(18)$$

in which 'm' is the weighted mean diameter of the bed material. Sir Claude Inglis (1936) in his discussion on Dr. Bose's paper pointed out that the value of silt factor 'f' in Lacey's regime and flow formulae was not the same. He suggested that the regime formula should be rewritten as follows :

$$V = 16R^{2/3} \quad S^{1/3} \quad (fvr/frs)^{1/2} \quad \ldots\ldots\ldots\ldots(19)$$

in which $(fvr/frs)^{1/2}$, was defined as a measure of divergence from regime. His analysis indicated that the weighted mean diameter of the material exposed on the bed varied as $Q^{1/10}$ for the Lower Jhelum and Lower Chenab Canals.

Dr. M. K. Bose and Dr. J. K. Malhotara[11] (1939) carried out investigation of the inter-relation of silt indices and discharge elements for some regime channels in the Punjab and derived the following formulae :

$$P = 2.68Q^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(20)$$

$$S = 0.00209d^{0.86}/Q^{0.21} \quad \ldots\ldots\ldots\ldots(21)$$

$$R/P = S^{1/4}/6.25d \quad \ldots\ldots\ldots\ldots\ldots\ldots(22)$$

in which 'd' is the weighted mean diameter of the sediment in millimeters.

Both the silt factor 'f' of Lacey and the weighted mean diameter 'd' of Bose, define the size of the sediment but not the sediment charge or the rate at which sediment is transported. Sir Claude Inglis[12] (1948) recognized this limitation and after analysing the data of channels of the Lower Chenab system produced a set of dimensional equations to take care of the sediment charge. He concluded that sediment charge had small effect on the area of a channel, relatively large effect on the slope and shape, and considerable effect on the width of the channel. The formulae developed by Inglis[13] were too complicated for use in actual practice.

Thomas Blench[14] (1951), using Lacey's equations as a starting point, developed a "Generalized Regime Theory." He pointed out that Lacey used a single factor 'f' thereby averaging out the relative importance of the bed and side effects. This assumption enabled Lacey to work in terms of the wetted perimeter and the hydraulic radius. As the greater part of the observed data used by Lacey referred to wide and shallow canal sections, the same exponents would remain valid if the average bed width and the depth were substituted in place of P and R. On this basis Blench developed the following formulae :

$$\frac{V^2}{D}=b \quad \ldots\ldots\ldots\ldots\ldots\ldots(23)$$

$$\frac{V^3}{B}=s \quad \ldots\ldots\ldots\ldots\ldots\ldots(24)$$

$$\frac{V}{gDS}=\frac{C(VB)}{(v)} \quad \ldots\ldots\ldots\ldots(25)$$

in which 'b' and 's' are constants which were defined as "bed factor" and 'side factor", 'v' is the kinematic viscosity of water, and 'C' is a constant. These equations were said to provide a complete solution to the design problem.

In the brief review presented above, only outstanding contributions to the development of the "theory" of regime canals are included. With the controversy that followed the publication of Lacey's equations, several new empirical formulae were presented by other authors. They are not included in the review as they did not present any new thought but only a re-arrangement of the equations with new values of constants.

While an empirical approach to the solution of the sediment transportation problem was followed in the Indo-Pakistan sub-continent. French, German and American research aimed at finding a solution on a rational basis taking into consideration the forces and other mechanical factors which cause a submerged sediment particle to rise from the bed of a channel and to remain in suspension for considerable periods of time. The contributions of E. W. Lane, C. M. White and H. A. Einstein are of special significance as they influenced the thinking of the authors of the " regime theory."

Lacey's empirical approach was severely criticised on the ground that it was not based on a theoretical solution of the problem of sediment transportation reducing the observed engineering phenomenon to rational Newtonian mechanics. This criticism was also due to the fact that the "regime theory" did not find universal application and was inconsistent with the observed data of canals in other countries. For instance, the data of the Imperial Valley Canals in the United States indicated that instead of the silt factor "f" increasing with the size of the bed material as Lacey's theory shows, the silt factor actually decreased. Lane[15] (1935) carried out a comprehensive study of stable channel shapes and concluded that Lacey's equations were deficient in that they accounted for only the silt grade and not the silt charge. He stressed that the quantity of solids in motion was an important factor in the shape of stable channels in alluvium. Lacey in his discussion on Lane's paper observed that the ratio V^2/R for any grade of silt epitomized "turbulence" irrespective of the silt charge. Lacey[16] (1939) attempted to support the theoretical significance of his empirical equations and produced a new theory described as the "Shock Theory" which again was not the usual rational theory of "shock" of analytical mechanics but a general idea yielding a plausible explanation of his empirical formulae. In attempting to explain his empirical method as a "theory" based on rational mechanics, Lacey exposed himself to severe criticism from authors of the American, French and German research who pointed out many fallacies in his method. Lacey[17] (1946) continued to defend the physical significance of his equations and produced a new set of equations introducing another factor vs. the terminal velocity of falling particles. His new equations were neither fully accepted in India and Pakistan nor by the American research group. The solutions presented by Lane, White and Einstein, however, influenced the development of formulae presented by Inglis, Bose and Blench and although they attempted to make Lacey's empirical formaulae appear more rational, their equations involved so many constants which were not tested by measurements that their application in practice was found difficult. Lacey's original equations were simple, agreed well with the field data and continued to be accepted as a sound practical basis for designing silt-stable channels. Although the design methods suggested by Lane, White and Einstein were founded on a rational theoretical basis, they failed to provide the engineer a practical criterion for designing silt-stable channels under the conditions prevailing in India and Pakistan.

Limitations of CHOP Data

The CHOP data is based on observations on short reaches of canals which are limited to a length of one mile in most cases. The validity of the data for the full length of the canal which are over 50 miles in length in most cases depends on the extent to which the selected reach is representative of the whole canal. Even in the short reaches the range of variations in the observed data is very large. Table 1 gives the range of hydraulic parameters, observed add computed, for various canals obtained from the basic CHOP data. The dimensions of the canal prism vary from section to section within a few thousand feet and even at the same section they are different at each time of observation. If the canal reaches selected had been longer in order to be more representative of the whole canal, the range of variations would have been probably larger. Under such conditions it is difficult to determine which part or section of a canal represents "regime conditions" for testing the validity of Lacey's regime equations. If it is assumed that all canals included in the CHOP data are in regime then it follows that :

(*a*) there is a range of slopes within which a canal can operate in regime;

(*b*) a canal can have different bed widths and bed depths at different sections and can still be considered as a regime canal;

(*c*) having different values of the basic dimensions of bed width, depth and slope, there will be a range of values of the other parameters within which the canal can be considered as in regime.

The data does not give the history of operation of the canals, the changes that were made in the past and the effect of such changes on the dimensions of the canals. For instance the Upper Chenab Canal constructed in 1912 was operating satisfactorily up to 1951. During 1952 it was proposed to widen the canal on both sides in order to increase its capacity from 13500 to 18500 cusecs in the reach RD 0 to 133. The canal was actually widened on the right side but the widening on the left side was abandoned as the additional capacity was provided in the M-R Link. After the construction of the M-R Link the sediment entry conditions in the Upper Chenab Canal were adversely affected and silt up to 4 feet depth was deposited in the head reach. The regime of the UCC RD 23-29 was unquestionably affected by the silt deposits to a greater extent than those in the reach RD 100-105. Similarly the M-R Link in the reach RD 20-26 is affected by large silt deposits while the reach RD 154-160 is not influenced by the adverse sediment deposits to the same extent. The data of UCC RD 23-29 and of M-R Link RD 20-26 is not representative of canals in regime.

In the reach RD 143-151 of the LCC the original design data compares with the observed data as follows :

	Last Designed 1908	Revised Design 1930	Observed 1962
Q ..	4907	4863	5640
B ..	150	145	173
D ..	9.6	9.5	9.2
I/S ..	6666	6666	5500

It would appear that the canal has taken a different regime slope after 1930. The history of the canal shows that under the original design conditions the canal was in regime and there were no operational difficulties. After 1930, however, the 3.2 feet fall at RD 161 was lowered by 3.0 feet in order to reduce the water levels as an anti-waterlogging measure. It was assumed that by lowering the fall the bed of the canal would scour uniformly in the reach RD 140 to 161 and would take an ultimate slope of 1: 666. In actual operation, however, the bed did not scour uniformly. The water levels immediately upstream of the remodelled fall were lowered but in the upper reaches the reduction in the water levels was not as great. A slope of 1: 5500 was attained against the original design slope of 1: 6666. It would not be correct to conclude on the basis of the CHOP data that the regime slope of LCC is 1: 5500.

It is interesting to note that the Lower Chenab and Upper Gogera, two perennial channels, taking off from their parent Lower Chenab Canal (Upper), have almost the same full supply discharge but have different characteristics in respect of bed width, depth, slope and sediment as shown in the following table which gives the observed data adjusted for the full supply discharge :

	LCC RD 147-151	UG RD 42-46	UG RD 106-109
Q ..	5930	6200	5400
B ..	158-179	192-195	131-143
D ..	9.4-10.1	9.5-9.7	9.9-11.0
I/S ..	5000	6373	6123
fvr ..	0.83-1.02	0.83-0.91	0.91-0.93
frs ..	1.36	1.15	1.28-1.22
N ..	0.026-0.029	0.023-0.026	0.025
$P/\sqrt{Q}$ ..	2.53-2.82	2.73-2.88	2.25-2.27
Suspended Sediment (ppm)..	617-2660	524-4150	419-1560
d50 ..	0.261-0.282	0.140-0.245	0.165-0.248

In the original design both the LCC and UG had the same slope but the artificial changes made on the LCC described above resulted in a steeper slope which also influenced the other parameters of the channel. A similar study of the history of operations of other canals will lead to a fuller appreciation of the CHOP data.

The above comments are not intended to doubt the usefulness of the CHOP data which gives accurate measurements of the existing conditions on certain reaches of the canals. Such systematic observations were not carried out at any time in the past and they provide the best information so far available for testing the validity of Lacey's equations and for establishing a basis for designing the new link canals.

Method of Analysis

The CHOP data gives actual measurements at a number of fixed points in selected reaches of the canals made at different times in a flow season. The measured values are the discharge, the area, the bed width, the water surface width, the average depth, the bed depth, the water surface elevation and the sediment concentrations. As an illustration, the data of Sidhnai Canal observed on June 24, 1962 is given below :

			Width		Depth		
R. D.	Q	Area	Bed.	Surf.	Avg.	Bed.	W. S. El.
13000	3800	1407	165	184	8.0	8.0	459.820
18000		1465	150	176	8.0	8.9	459.412
23000		1658	130	173	9.6	10.9	459.112
Avg.	3800	1510	148	178	8.5	9.3	..

A study of the data at each RD of a canal shows that the canal sections, in certain cases, have characteristic features different from those at the other sections. Where the width is small the depth is generally large and *vice versa*. That there should be such variations in a canal within a short distance is rather surprising but knowing that the measurements were made with greater care. It seems the canal sections, in spite of identical conditions of discharge and sediment, have individual characteristics of their own. If the data of all the sections is grouped and the average of the measured values computed as shown in the above table to arrive at a representative section of the canal reach as a whole, the characteristic features of the canal sections will be disturbed. A correct method of analysis which aims at maintaining the geometry of the canal section at each RD is presented in Table 2. The data at each RD of a canal observed at different times is tabulated and the average of all the observations computed. The observations when the discharge in the canal was high and within a relatively small range of variation, are selected and a separate average of the selected observations is computed. The average of the selected observations is assumed to represent the characteristics of the canal section at that particular RD. This method of analysis reduces the range of variations, minimizes the effect of errors in measurements and evens out the temporary shoaling or scouring effects within the observation season. The average values thus derived are more representative of the canal geometry at the particular site. The difference in the two methods of analysis is illustrated in Figure 1.

The next step in the analysis is the determination of the full supply discharge of the canal. For most canals included in the CHOP data, the original design full supply discharges were considerably lower than their present capacities. As the irrigation demand increased, the canals were required to carry supplies in excess of their design full supply discharges. During the past few decades, reclamation operations were started which imposed additional burden on the canal capacities. In most cases the canals were not widened but the additional supplies were just pushed or forced into the system after remodelling those structures which caused restrictions in the water-way. In some cases the falls were lowered as an anti-waterlogging measure as well as to reduce the restrictions in the water-way. As more water was forced into the canal, the section increased but the erosion of the bed and sides was not uniform throughout the length of the canal. At some places the bed was easily eroded while the sides armoured with grass berms resisted erosion. At other places the erosion pattern was quite the reverse. All these changes affected the regime. After the canals had operated for a sufficiently long time with the higher supplies, a new regime was established. It is not surprising to find, as the CHOP data reveals, that at certain sections the geometry of the canal is quite different from that at other sections.

A study of the actual operations of the canals during the last six years (1957-62) was carried out to determine the full supply discharges. The range of high flows and the number of days during which the canal operated in this range were tabulated. The frequencies of selected maximum discharges were computed from which a value for the full supply discharge of the canal was determined. The full supply discharge fixed for the canal is not necessarily the maximum discharge ever carried by the canal but it is the maximum discharge carried by the canal for a period of time sufficient to influence the dimensions and shape of the canal section. The determination of the full supply discharge is important as it influences the computed values of P, $P/\sqrt{Q}$, R, N, fvr and frs. Although in actual operations the discharge in a canal varies from time to time depending upon the available supplies and the irrigation requirements, the canal must be designed for the maximum discharge which it is required to carry at any time. In Lacey's equations, the discharge Q is the maximum discharge or the full supply discharge of the canal. The selection of the silt factor and the computation of the canal dimensions are for the full supply discharge and not for any lower discharge. If a canal designed and constructed for a full supply discharge of, say, $Q=10{,}000$ cusecs, carries a lower discharge of 9,000, 8,000 or 7,000 cusecs etc., the dimensions D, A & P for the lower discharges will also be lower and the corresponding computed values of R, fvr, frs and $P/\sqrt{Q}$ will be different from the design values for the full supply discharge as shown in Table 3. The changes in the wetted perimeter will be relatively small but the ratio $P/\sqrt{Q}$ increases considerably with decrease in the discharge.

Having determined the full supply discharge, further analysis of the hydraulic parameters for each section of the canal is carried out in Table 4. The hydraulic parameters given in the first column are based on the observed data as analysed in Table 2. The observed data is adjusted for the full supply discharge in column 2 and the hydraulic parameters corresponding to the full supply discharge are computed. Column 4 gives the theoretical data computed from Lacey's equations assuming the observed slope as the regime slope of the canal. The adequacy of Lacey's equations is tested by comparing the data given in columns 2 and 4. Lacey's design given in column 4 is based on an assumed side slope of 1/2 : 1 for the canal prism. For a true comparison with the Lacey section, the hydraulic parameters were computed in column 3 from the data given in column 2 assuming theoretical side slopes of 1/2 : 1 but keeping the bed width and depth unchanged. Similar studies were carried out for all the canals included in the CHOP data and the results are compared in Table 5 and plotted in Figures 2 to 6.

The above study led to the following conclusions :

(*a*) The observed bed width of all canals is smaller than Lacey's theoretical width except in the case of Lower Jhelum and Rangpur.

(*b*) The CHOP data confirms the validity of Lacey's formula $P=2.67\ Q^{1/2}$. In most cases, except Lower Jhelum RD 160-166, Panjnad RD 137-141 and Rangpur, the value of the co-efficient is somewhat less than 2.67.

(*c*) The observed section area is higher than for Lacey's theoretical section. The computed section area, however, agrees fairly well with Lacey's section except in the case of UCC RD 23-29 and Panjnad. This shows that Lacey's assumption of 1/2 : 1 side slopes is not valid for large canals.

(*d*) The roughness factor "N" for the observed canal section is higher than that computed for Lacey's section.

(*e*) The observed value of the silt factor frs agrees well with the theoretical value. But the values of silt factor fvr are quite different from those of frs. This shows that the assumption of frs=fvr in Lacey's equations is not valid.

Manning's Roughness Factor "N"

Manning's roughness factor "N" in pipes represents a more or less permanent characteristic of the boundary surface. This is also true for certain channels where the banks and bed are rigid. In most sediment-laden channels, however, roughness is not a permanent characteristic but changes with the configuration of the bed. When the bed is smooth, the roughness is different from that which applies to the same channel when the bed is moulded into ripples and dunes. The form of bed roughness depends primarily on the slope, depth, fall-velocity or effective fall-diameter of the bed material and the shape of the channel. There are several other variables whose effect on the bed form is of minor importance.

Leopold and Maddock[18] have demonstrated that at constant discharge, suspended-sediment load is related to the shape factors, that is, width, velocity and depth. It was also noted that at constant width and discharge, increased suspended-sediment load would be associated with increased velocity. But because Q and B are constant, the product of velocity and depth must be constant. Any increase in velocity, therefore, must require a decrease of depth. In the Manning's formula $V=1.486\ R^{2/3}\ S^{1/2}/N$ an increase in velocity and a decrease of depth requires an increase in the factor $S^{1/2}/N$ which must be achieved by an increase in the channel slope or a decrease of roughness or both. The changes which occurred in the lower reaches of the Colorado river after the construction of the Hoover Dam confirm the above observations. When the sediment load of the Colorado river was stored in Lake Mead, clear water released from the reservoir caused degradation in the channel reach below Hoover Dam. A decrease in sediment load which was originally carried primarily in suspension was accompanied by an important increase in bed roughness, while the slope remained essentially constant.

Einstein and Barbarossa [19] divided the bed resistance into two parts. The first part of the resistance is transmitted to the bottom by shear on the roughness of the grainy sand surface. The second part is transmitted to the boundary in the form of normal pressures at the different sides of each sand dune or ripple. From river measurements they found that the second part which is the form resistance of the bed irregularities is a function of the sediment transport rate alone.

Vanoni and Brooks[20] observed that two depths of flow were possible for a given combination of slope and discharge. When the sediment discharge was small, the depth was large, the velocity was small and the bed was rough. When the sediment discharge was large, the depth was small and the bed was smooth. Vanoni has also demonstrated that an increase in suspended load tends to decrease channel resistance and thus causes an increase in velocity. As the slope of the water surface in a canal tends to remain about constant at a station the increase in the concentration of suspended load with discharge is associated with a decrease of roughness.

From the experiments performed by the USBR on the San Luis Valley Canals, Lane [21] showed that the roughness factor N increases as the size of the material becomes larger. A study was also made which showed that the roughness is a function of the ratio of the size of the particle to the hydraulic radius.

Simons and Richardson[22] carried out flume studies of alluvial channels . nd made a detailed classification of the regime flows, the forms of bed roughness, and the basic concepts pertaining to resistance to flow. In the "tranquil flow regime", which is the normal condition of flow in a canal, the following results were obtained:

(*a*) With a plane bed and no movement of bed material, the bed was soft and easily disturbed. The value of Manning's N for no bed material movement was approximately 0.015.

(*b*) With the movement of the bed materials, ripples started. As ripples formed in the bed, slope and depth increased and Manning's N increased from 0.015 to 0.022. As the ratio of the depth of flow to ripple height increased Manning's N ranged from 0.019 to 0.027.

(*c*) When the slope or depth were increased beyond a certain limit, ripples were modified to dunes and Manning's N varied from 0.018 to 0.035.

From the above discussions it appears that at least three factors effect bed roughness, (*a*) particle size of bed material, (*b*) bed configuration, and (*c*) suspended sediment load. Decreasing sediment size results in a decrease of roughness but the roughness due to bed configuration may be more important than that due to particle size and sometimes decreased particle size may result in larger or more effective bed ripples which will increase roughness. An increase in suspended load tends to change the bed form from dunes to ripples or from ripples to plane bed, and results in increase in velocity and a reduction in roughness.

In order to study the changes in the roughness factor under various conditions of flow, the CHOP data has been analysed in Table 6. The observations were grouped separately for each RD to preserve the channel shape characteristics. The roughness factor for each observation at each RD was computed for the full supply conditions using Manning's formulae. The analysis leads to the following conclusions :

(*a*) For the same discharge and bed width, a decrease in velocity is associated with an increase in depth. If the slope remained substantially unaltered, an important increase in bed roughness is caused. Conversely an increase in velocity is associated with a decrease in depth and if the slope remained substantially unaltered an important decrease in roughness is caused.

(*b*) The roughness factor decreased with increase in the suspended sediment load as long as the slope remained substantially the same.

(*c*) The roughness factor is not constant in all seasons. It is high during the period October to June when the suspended sediment load is small and the bed material size is relatively large due to washing out of the fine material from between the larger particles. During the period July to September, when the suspended sediment load is relatively large, the roughness factor, for the same discharge and bed width, is small.

(*d*) The roughness factor is minimum in the month of maximum sediment load. The minimum values of the roughness factor are as follows :

Canal	Minimum values of roughness factor	Month of max. sediment load
Abbasia	0.0180-0.0188 (Aug.)	Aug.
Rangpur	0.0197-0.0210 (Aug.)	Aug.
Sidhnai	0.0134-0.0189 (Aug.)	Oct.
Lower Jhelum	0.0212-0.0219 (July)	July
Lower Chenab	0.0248-0.0290 (July)	July
UG 42-46	0.0240-0.0247 (Spt.)	Sept.
UG 106-109	0.0227-0.0250 (Aug.)	Aug.
Panjnad 68-77	0.0236-0.0243 (Aug.)	Aug.
Panjnad 137-141	0.0211-0.0221 (Aug.)	Aug.
UCC 23-29	0.0236-0.0261 (July)	July
UCC 100-105	0.0216-0.0262 (July)	July

It will be noticed that even during the months of July and August the roughness factors on Lower Chenab, Upper Gugera and Upper Chenab are relatively high. One special feature of these canals is the low temperature of water which is 15° to 20°C lower compared to other canals. The effect of temperature on the roughness factor is discussed in Dr. Simons paper.[13] A decrease in temperature increases the viscosity of the water and decreases the fall velocity of the sand particles. Consequently, if a sand bed is covered with ripples and the temperature of the water is decreased, the mobility of the particles is increased due to the decrease in effective fall diameter of the sand, larger ripples form, and resistance to flow increases.

In designing silt-stable canals on the basis of Lacey's equations the roughness factor N does not appear in the calculations. The only important factor that governs the design is the silt factor " f ". The stability of the canal section depends on whether it has the required capacity to transport the sediment load. The canal should be able to carry without deposit about 80% of the annual sediment load during the monsoon months of July to September, August being the month of maximum load. The maximum hazard of silting occurs in the month of August and to a lesser extent in July and September. The geometry of the canal section should be fixed taking into consideration the flow and sediment conditions during July to September and the silt factor must relate to these conditions. During the remaining months, the sediment loads are generally low and any harmful deposits during the monsoon months should be picked up so that in the annual cycle as a whole the channel neither silts nor scours. Thus if the flow and sediment conditions during July to September were to govern the design and if during this period the month of August is most critical, it follows that the roughness factor in August is pertinent to the design. As demonstrated above, the roughness factor in August is generally the lowest and the computed value of N based on Lacey's section generally agrees with the observed value for this month. The fact that Lacey's design gives a low value of N compared to the bulk of the observed values in the year as a whole, does not seem to have any practical significance.

Lacey's Silt Factor "f"

There has been much controversy as to the precise nature of the value of Lacey's silt factor "f". It is generally accepted that "f" embraces all considerations of quantity, shape, material and size of the silt. Many authors have criticised the inconsistency between the single value of "f" assumed in the Lacey's regime and flow equations and the two different values of fvr and frs actually attained in the field for most canals. Sir Claude Inglis commenting on the apparent differences in the values of fvr and frs stated that Lacey's "f" is equivalent to the square route of the product of fvr and frs. Ning Chien[24] analysed Lacey's regime "theory" on the basis of Einstein's bed-load function and found, within the limits of the observed flows from which the regime theory was derived, that the silt factor fvr depends on the sediment concentration and the channel flow while the silt factor frs is a function of the bed material size. Using this functional relationship between sediment characteristics and Lacey's silt factors, the depth and slope of an alluvial channel in regime can be determined either by the Einstein's bed-load function or by Lacey's regime theory, with practically no difference between the two. Ning Chien derived the following formulae :

$$\mathrm{fvr} = 0.061\ (\mathrm{qt}/\mathrm{q})^{0.715}$$

$$\mathrm{frs} = 1.18\ (\mathrm{qt}/\mathrm{q})^{0.052}$$

$$\mathrm{frs} = 2.2\ \mathrm{d}^{0.45} \qquad (\mathrm{qt}/\mathrm{q})^{0.052}$$

in which "qt" is the sediment transport rate per unit width, including both the bed load and the suspended load, "q" is the discharge per unit width and "d" is the mean diameter of the bed material. While fvr depends strictly on the suspended sediment load, frs is practically independent of the load and is mainly a function of the bed material size. There is no relationship between fvr and the size of the bed material.

The analysis of CHOP data in Table 6 demonstrates the effect of suspended sediment load and bed material size on the values of fvr and frs. Figure 7 gives the relationships between N, R, fvr and suspended sediment loads for different canals. There is a remarkable similarity in the relationships for all the canals without any exception. The study leads to the following conclusions :

(*a*) In the case of Abbasia and Rangpur canals, the average values of fvr and frs are nearly equal. This is also true for Sidhnai canal RD 15 and 18 and Lower Jhelum RD 163. In all other cases the average values of frs are higher than the average values of fvr, the only exception being the Sidhnai canal RD 13 where fvr is higher than frs.

(*b*) The values of fvr are different for different canals. They are also different for the same canal at each RD and at each time of observation. The value of fvr is highest when the suspended sediment load is maximum. As the roughness factor N is minimum when the suspended sediment load is maximum, it follows that the high value of fvr is associated with a low value of the roughness factor N and *vice versa*.

(*c*) The range of variations in the values of fvr at each RD of a canal is generally larger compared to the range in the values of frs. In other words the value of frs, comparatively, is nearly a constant for each canal. It is also observed that frs does not vary with the seasonal changes in the suspended sediment load.

(*d*) The values of frs are generally higher for canals having larger sizes of the bed material (d50).

Canals in Pakistan usually carry large suspended sediment and bed loads and the prevention of silting is the most important consideration in their design. Scouring problems are usually not important because there are no canals which carry sediment-free water from reservoirs and it is neither practical nor economical to provide very steep slopes as to make scouring the governing factor in the design in view of the very flat topography of the country, high ground water table and limitations of command of the irrigated area.

In Lacey's equations, frs is the most important silt factor which determines the water surface slope and the capacity of the canal to transport the bed-load. The silt factor fvr, on the other hand, determines the dimensions and shape of the canal. Since frs determines the capacity of the canal to transport the bed load and since it is always equal to or greater than fvr, it follows that frs governs the design. For this reason Lacey's "f" selected for design corresponds to the value of frs and not fvr. The same value of frs is used for fvr in the regime equations to determine the dimensions of the canal. The factor frs is nearly a constant for a canal and can be estimated more precisely on the basis of experience while fvr varies from time to time depending upon the extent of suspended sediment load carried by the canal. The apparent inconsistency in this method is that a higher value of fvr is used in the design than that indicated by the observed data. For a canal of a given discharge, a large error in the value of frs would make the design unworkable. For instance, if Q = 10,000 cusecs, the slope will be 1:7250 for frs = 1.1 and 1:12300 for frs = 0.8 (Table 7). On the other hand a similar error in fvr does not seem to be as serious. For instance, if Q = 10,000 cusecs, the dimensions of the canal for different values of fvr will be as follows (Table 7) :

fvr.	B	D	A	V	B/D
1.1	243	10.6	2637	3.8	23.0
0.8	241	11.8	2925	3.4	20.4

The bed width remains practically unaffected and only the depth changes. Any error in the value of fvr, therefore, does not affect a workable design as it is relatively a simple matter to accommodate the extra depth. In selecting the higher value of frs for fvr the canal is provided a higher bed-width to depth ratio and, therefore, greater capacity to transport the bed loads which again is conducive to prevention of silting. Therefore the apparent inconsistency in the assumption of fvr=frs in the design has no practical consequence.

Stability of Side Slopes

Lacey's formulae are based on an assumed side slope of 1/2: 1 for a stable canal section. The sides of small channels may remain stable for this slope but the stability of the banks of large canals with 1/2:1 slopes is questionable. Kennedy recognized this fact and fixed the maximum permissible velocity in his formula $Vo=0.84D^{0.64}$ at 3.5 feet per second as any higher velocities would be dangerous for the stability of the banks. The maximum permissible depth for the above velocity is 9.3 feet. Any additional area required for higher discharges should be provided for by increasing the width. Lacey did not prescribe any upper limit for depth. Some of the large irrigation canals in operation have depths up to 13 feet.

The stability of a particle on the bed of a canal depends on two forces only, the drag or the tractive force and the resistance. On the other hand the stability of a particle on the side of a canal is also affected by the slope of the side in addition to the drag and the resistance. The drag is proportional to the depth and the hydraulic slope. Since the hydraulic slope is supposed to be constant, the drag increases directly with depth. In large canals where the depth is also large, the drag on the sides is greater than for small canals and from stability considerations their side slopes should be flatter. Another factor is the effect of high ground water table on the stability of the bank slopes when the canal is empty. This effect is very significant in canals having large depth. The CHOP data shows that the actual side slopes of large canals are in the order of $2\frac{1}{2}$: 1 in the lower half of the section and about 1:1 in the upper half (Table 8). Lacey's assumption of 1/2:1 side slopes is, therefore, not valid for large canals. The CHOP data shows that the section area due to flatter side slopes in large canals is 5 to 13 per cent higher than that of a section having side slopes of 1/2:1. In order that Lacey's design should conform to stable slopes actually attained in the field, it is necessary to proivde side slopes flatter than 1/2:1. The standard design of canal sections for main canals and branches as prescribed in the Manual of Irrigation Practice is adequate for canals in filling as there is sufficient provision in the form of future silted berms to accommodate side slopes flatter than 1/2:1 But for large canals in cutting, which are initially constructed with side slopes of 1:1, there is insufficient provision to accommodate flatter side slopes.

For Link Canals of large capacities, WAPDA has provided side slopes of 3:1 in the lower half of the section and 2:1 in the upper half. The CHOP data confirms the adequacy of these slopes. In view of the additional area provided by the flatter side slopes the bed width can be slightly reduced. As a standard practice it is proposed to reduce the designed bed width to the extent of the full supply depth as shown in Fig. 8. The canal section constructed to this design will have an additional wetted perimeter equivalent to 2.145 D and an additional area equivalent to 1.25 D^2 compared to Lacey's section. If the ground water table is not high the side slopes could be slightly steeper. For the Trimmu-Sidhnai Link, WAPDA has provided a slope of 3 : 1 in the lower half of the section and $1\frac{1}{2}$: 1 in the upper half.

Development of a rational method for designing silt-stable canals

The empirical approach used in Pakistan for designing silt-stable canals is not based on a rational solution of the problem of sediment transportation. Lane's Tractive Force Method[25] and Einstein's Bed Load Function[26] are recognized as rational methods for designing silt-stable canals. The suitability of the various design methods for the following categories of unstable canals as classified by Lane are discussed below:

(*a*) Canals in which the banks or bed are scoured without objectionable deposits being formed;

(*b*) Canals where objectionable sediment deposits occur without scour being produced;

(*c*) Canals in which scour and objectionable deposits both are present.

The first category of instability (scour without deposit) occurs when sediment-free water is present in a canal. It will also occur in a canal which carries sediment in relatively small quantities compared to its capacity to transport sediment. For prevention of instability in such canals, only an analysis of the forces that cause scouring is necessary. The Tractive Force Method has been used successfully for designing such canals. Most of the canals in the United States which are fed from reservoirs are of this category. Such problems have not been encountered in Pakistan as the canals carry heavy sediment loads and prevention of silting is the governing factor in their design. When the Mangla Dam is completed, the canals immediately fed by the reservoir may have to be remodelled on the basis of the tractive force criteria as the Lacey method will no longer apply.

The second category of instability (deposit without scour) occurs in lined canals or canals constructed in scour-resistant materials into which large quantities of coarse sediment enter with the flowing water. For prevention of instability in such canals it is necessary to ensure that the sediment entering the canal at the upstream end is carried out at the downstream end without any deposits. Every canal when flowing at its designed discharge has a definite maximum capacity to carry sediment of a certain size range. If material in excess of this size range enters into the canal, deposits will occur. Problems of this category of canals occur in India and Pakistan where the sediment loads are usually very high. They are usually designed on the basis of Manning's formula taking the roughness of the lining material into account and to ensure that the canal has adequate capacity to transport sediment, the design is tested by the Lacey method. The tractive force method is not applicable to such cases and their analysis must be made on the basis of sediment transportation. Lined canals in the United States do not have such problems of instability as water is usually sediment-free or contains relatively small sediment loads compared to the capacity of the canal to transport such loads.

The third category of instability (scour and deposit) usually occurs when water containing large quantities of coarse sediment enters a canal the banks and bed of which are composed of material which has little resistance to scour. The prevention of instability in such canals involves an analysis of the combination of scour and transportation problems. Such canals must have sufficient shear acting on the bed to transport the sediment loads and at the same time the shear on the sides must not be great enough to scour the sides. Also the shear on the bed must not be so large as to scour the original material of the bed. The laws of transportation of sediment are important in the design of such canals. Considerable progress in determining these laws has been made. Probably the most advanced work along this line in recent years is the work of Dr. H. A. Einstein[6]. The theoretical and rational approach of Einstein aimed at a complete solution of the problem of sediment transportation. While several interesting and possibly significant attempts have been made to produce practical solutions for design of canals on the basis of Einstein's approach, none of them has yet achieved recognition as a practical basis for design of canals. On the other hand, Lacey's approach, however unsatisfactory from a purely theoretical point of view, has provided a reliable design criteria for a practical solution of the sediment transportation problems encountered in Pakistan. It is hoped that the CHOP data in its present form or by extending its scope to include additional information can be used to determine the various variables in Einstein's equations so that a rational method based on sound theoretical principles could be developed for designing silt-stable canals in Pakistan. Until this is done, Lacey's equations would continue to remain the best design tool available to the irrigation engineer.

Conclusions

The CHOP data broadly confirms the validity of the Lacey method for designing silt-stable canals under the conditions encountered in Pakistan. It reveals, however, certain apparent inconsistencies in respect of side slopes, roughness factor 'N' and the silt factors frs and fvr. Lacey's assumption of 1/2:1 side slopes for a stable section is not valid for large canals. The side slopes should be flatter as suggested in this paper. The roughness factor 'N' obtained from Lacey's section generally agrees with the observed values during July, August and September when sediment loads are heavy and the conditions of stability are critical. The higher values of N observed during the remaining months of the year are not critical for the adequacy of the design. The observed values of frs are usually higher than those of fvr. The factor frs determines the capability of the canal to transport sediment and is the most important factor governing the design. The apparent inconsistency in the assumption of frs=fvr although the observed values are widely different does not affect the adequacy of the design. Lane's Tractive Force method is not applicable for designing canals which carry heavy sediment loads. Einstein's bed-load function is recognized as a rational method for designing such canals. It is hoped that the CHOP data in its present form or by extending its scope to include additional information can be used to develop a practical method for designing silt-stable canals based on Einstein's equations.

TABLE 1.—CHOP DATA-1962: RANGE OF HYDRAULIC PARAMETERS

Canal & RD		Discharge Q	Area A	Bed Width B	Surface Width WS	Bed Depth D	Slope I/S	Suspended Sediment ppm	Bed Material Size (mm) d50
	1	2	3	4	5	6	7	8	9
Abbasia	9-14	878-975	419-519	55-70	73-82	5.6- 7.3	9250-13400	142-4840	0.167-0.198
Rangpur	11-15	1790-1960	755-871	105-129	129-141	6.0- 6.7	8210-10400	251-3770	0.170-0.176
LJC	160-166	3030-3870	1130-1495	160-205	190-229	5.5- 7.9	6000-7600	255-3820	..
Sidhnai	13-18	3330-3980	1156-1658	125-170	173-186	6.8-11.2	7980-14300	124-8530	..
Upper	42-46	4590-6200	1580-2040	130-200	204-222	8.1- 9.7	6220-6700	524-4150	0.140-0.245
Gogera	106-108	4330-5250	1410-1620	130-165	151-194	8.2-11.4	5630-6910	419-1560	0.165-0.248
LCC	147-151	4860-5640	1540-1852	150-200	189-215	8.7-10.9	5000-5510	617-2660	0.261-0.282
UCC	23-29	5350-14400	1960-4290	300-340	317-370	5.7-12.5	4620-6100	141-2260	0.230-0.258
	100-105	6790-14200	2400-3590	250-315	316-345	7.7-11.3	4050-6170	181-2310	0.168-0.266
Panjnad	68-77	8960-9860	3072-3378	220-251	254-287	12.1-13.4	9700-11570	425-3650	0.175-0.197
	137-141	6850-7320	2370-2665	190-225	243-256	10.2-12.1	8970-11200	411-4180	0.139-0.163
MR Link	20-26	12800-15500	3000-4190	350-384	380-410	8.1-10.9	3410-6200	806-1680	0.199-0.200
	154-160	12400-15000	2510-2880	340-355	360-380	7.0-8.2	8040-9200	987-2000	0.126-0.130

TABLE 2.—ANALYSIS OF CHOP DATA: ABBASIA CANAL R.D. 9,000—14,000

R.D.	Date	Q	Area	Velocity	WIDTH		DEPTH		l/S
					Bed	Surface	Average	Bed	
9,000	*June, 28	975	475	2.05	63	74	6.4	6.8	13,400
	July, 27	901	419	2.15	63	74	5.6	6.0	11,300
	*Aug., 21	972	421	2.31	66	73	5.8	6.0	11,700
	Sept., 20	905	465	1.95	57	76	6.1	6.6	9,250
	Oct., 20	978	452	1.94	57	75	6.0	6.6	9,280
	Average	926.2	446.4	2.08	61.2	74.4	6.0	6.4	10,986
	*Average	973.5	448.0	2.17	64.5	73.5	6.1	6.4	12,550
11,000	*June, 28	975	475	2.05	70	82	5.7	6.2	13,400
	July, 27	901	432	2.09	65	80	5.4	5.6	11,300
	*Aug., 21	972	442	2.20	69	82	5.3	5.9	11,700
	Sept., 20	905	488	1.85	68	82	6.0	6.5	9,250
	Oct., 20	878	454	1.93	60	82	5.5	6.1	9,280
	Average	926.2	458.2	2.02	66.4	81.6	5.6	6.1	10,986
	*Average	973.5	458.5	2.12	69.5	82.0	5.5	6.1	12,550
14,000	*June, 28	975	464	2.10	65	78	5.9	6.3	13,400
	July, 27	901	434	2.08	60	77	5.6	6.1	11,300
	*Aug., 21	972	427	2.28	68	78	5.4	6.0	11,700
	Sept., 20	905	519	1.74	61.5	78	6.7	7.3	9,250
	Oct., 20	878	421	2.09	55	78	5.4	6.0	9,280
	Average	926.2	453.0	2.06	61.9	77.8	5.8	6.3	10,986
	*Average	973.5	445.5	2.19	66.5	78.0	5.7	6.2	12,550

*Observations when discharge is close to the full supply discharge.

TABLE 3.—EFFECT OF VARIATION IN SUPPLIES IN A CANAL ON THE HYDRAULIC PARAMETERS

Q	B	D	A	V	I/S	P	R	fvr	frs	N	$P/\sqrt{Q}$
1	2	3	4	5	6	7	8	9	10	11	12
10,000	242.5	10.06	2718	3.68	8475	267.0	10.2	1.00	1.00	0.021	2.67
9,000	242.5	10.29	2548	3.53	8475	265.5	9.6	0.97	0.98	0.021	2.80
8,000	242.5	9.59	2372	3.37	8475	263.9	9.0	0.95	0.96	0.021	2.95
7,000	242.5	8.85	2185	3.20	8475	262.3	8.3	0.93	0.94	0.021	3.14
6,000	242.5	8.07	1990	3.02	8475	260.5	7.6	0.90	0.91	0.021	3.36
5,000	242.5	7.23	1779	2.81	8475	258.7	6.9	0.86	0.88	0.021	3.66
4,000	242.5	6.33	1555	2.57	8475	256.7	6.1	0.81	0.84	0.021	4.06

TABLE 4—ANALYSIS OF CHOP DATA

Hydraulic Parameters	Observed Data Average*	Observed Data Adjusted for F.S.D.	Computed Data with 1/2: 1 side slopes	Lacey's Design
1	2	3	4	5
ABBASIA CANAL R. D. 9,000				
Q	974	1100	1100	1100
B	65	65	65	75
D	6.4	6.9	6.9	6.5
A	448	485	473	509
V	2.17	2.27	2.33	2.16
P	80	81	80	89
R	5.6	6.0	5.9	5.7
I/S	12550	12550	12550	12550
fvr	0.63	0.64	0.69	0.61
frs	0.63	0.65	0.64	0.63
N	0.019	0.019	0.019	0.020
$P/\sqrt{Q}$	2.56	2.44	2.41	2.68
ABBASIA CANAL R.D. 11,000				
Q	974	1100	1100	1100
B	70	70	70	75
D	6.1	6.6	6.6	6.5
A	459	500	484	509
V	2.12	2.20	2.27	2.16
P	87	88	85	89
R	5.3	5.7	5.7	5.7
I/S	12550	12550	12550	12550

TABLE 4—(*Continued*)

Hydraulic Parameters	Observed Data Average	Observed Data Adjusted for F.S.D.	Computed Data with 1/2: 1 side slopes	Lacey's Design
1	2	3	4	5
fvr	0.64	0.64	0.66	0.61
frs	0.62	0.64	0.64	0.163
N	0.019	0.019	0.019	0.020
$P/\sqrt{Q}$	2.79	2.65	2.56	2.68
ABBASIA CANAL R.D. 14,000				
Q	974	1100	1100	1100
B	67	67	67	75
D	6.2	6.7	6.7	6.5
A	446	485	472	509
V	2.18	2.27	2.33	2.16
P	84	84	82	89
R	5.3	5.8	5.8	5.7
I/S	12550	12550	12550	12550
fvr	0.67	0.67	0.70	0.61
frs	0.62	0.64	0.69	0.63
N	0.018	0.019	0.018	0.020

(Sheet 1)

TABLE 5—COMPARISON OF OBSERVED & COMPUTED CHOP DATA WITH LACEY

Canal & RD		Bed Width (B)		Bed Depth (D)		Area (A)			Velocity (V)			Wetted Perimeter (P)		
		O	L	O	L	O	C	L	O	C	L	O	C	L
		1	2	3	4	5	6	7	8	9	10	11	12	13
Abbasia	9	65	75	6.9	6.5	485	473	509	2.27	2.33	2.16	81	80	89
	11	70	75	6.6	6.5	500	484	509	2.20	2.27	2.16	88	85	89
	14	67	75	6.7	6.5	485	472	509	2.27	2.33	2.16	84	82	89
Rangpur	11	118	108	6.8	7.3	890	826	815	2.42	2.60	2.64	137	133	124
	13	118	108	6.8	7.3	852	826	815	2.52	2.60	2.64	137	133	124
	15	123	108	6.7	7.3	872	847	815	2.47	2.54	2.64	140	138	124
Sidhnai	13	153	152	7.7	9.0	1333	1208	1409	3.08	3.39	2.91	188	170	172
	18	148	152	8.7	9.0	1434	1326	1409	2.86	3.09	2.91	181	168	172
LJC	160	162	160	8.6	8.3	1548	1430	1363	2.91	3.15	3.30	195	181	179
	163	185	160	7.5	8.3	1517	1416	1363	2.97	3.18	3.30	219	202	179
	166	203	160	7.5	8.3	1605	1551	1363	2.80	2.90	3.30	233	220	179
LCC	147	158	187	9.7	8.4	1713	1580	1606	3.46	3.75	3.69	195	180	206
	149	177	187	10.1	8.4	1895	1839	1606	3.13	3.22	3.69	214	200	206
	151	179	187	9.4	8.4	1881	1727	1606	3.15	3.43	3.69	217	200	206

(Sheet 1)

TABLE 5—COMPARISON OF OBSERVED & COMPUTED CHOP DATA WITH LACEY

Canal & RD		Bed Width (B)		Bed Depth (D)		Area (A)			Velocity (V)			Wetted Perimeter (P)		
		O	L	O	L	O	C	L	O	C	L	O	C	L
		1	2	3	4	5	6	7	8	9	10	11	12	13
UG	42	195	190	9.7	9.0	1987	1939	1750	3.12	3.20	3.54	227	217	210
	44	185	190	9.5	9.0	1909	1803	1750	3.25	3.44	3.54	220	206	210
	46	182	190	9.5	9.0	1851	1774	1750	3.35	3.49	3.54	215	203	210
	106	143	176	9.9	8.6	1655	1465	1551	3.26	3.69	3.48	189	165	195
	107	131	176	11.0	8.6	1583	1502	1551	3.41	3.60	3.48	165	156	195
	109	141	176	10.3	8.6	1600	1505	1551	3.38	3.59	3.48	173	164	195
Panjnad	68	236	247	13.7	11.6	3420	3328	2932	3.07	3.16	3.58	272	267	273
	71	236	247	13.5	11.6	3387	3278	2932	3.10	3.20	3.58	275	266	273
	74	251	247	13.0	11.6	3517	3348	2932	2.99	3.14	3.58	289	280	273
	77	243	247	13.3	11.6	3447	3321	2932	3.05	3.16	3.58	284	273	273
	137	207	220	11.9	10.8	2798	2534	2434	2.97	3.28	3.41	259	234	244
	139	202	220	11.7	10.8	2678	2432	2434	3.10	3.41	3.41	255	228	244
	141	209	220	12.0	10.8	2873	2580	2434	2.89	3.22	3.41	255	236	244
UCC	23	335	317	13.0	11.4	4611	4640	3679	3.58	3.72	4.48	374	364	343
	26	313	317	13.2	11.4	4449	4219	3679	3.71	3.91	4.48	358	342	343
	29	313	317	13.5	11.4	4440	4317	3679	3.72	3.82	4.48	348	343	343
	100	291	313	12.0	10.8	3766	3564	3439	4.22	4.46	4.62	333	318	337
	103	306	313	11.2	10.8	3675	3490	3439	4.33	4.56	4.62	346	331	337
	105	323	313	11.3	10.8	3571	3488	3439	4.45	4.56	4.62	333	328	337

(Sheet 2)

TABLE 5.—COMPARISON OF OBSERVED & COMPUTED CHOP DATA WITH LACEY

Canal & RD		fvr			frs			Manning's N			P/√Q		
		O	C	L	O	C	L	O	C	L	O	C	L
		14	15	16	17	18	19	20	21	22	23	24	25
Abbasia	9	0.64	0.69	0.63	0.65	0.64	0.63	0.019	0.019	0.020	2.44	2.41	2.67
	11	0.64	0.66	0.63	0.64	0.64	0.63	0.019	0.019	0.020	2.65	2.56	2.67
	14	0.67	0.70	0.63	0.64	0.69	0.63	0.019	0.018	0.020	2.53	2.47	2.67
Rangpur	11	0.68	0.78	0.79	0.81	0.80	0.82	0.022	0.020	0.021	2.95	2.86	2.67
	13	0.77	0.82	0.79	0.80	0.80	0.82	0.021	0.020	0.021	2.95	2.86	2.67
	15	0.74	0.79	0.79	0.80	0.80	0.82	0.021	0.020	0.021	3.01	2.97	2.67
Sidhnai	13	1.00	1.21	0.77	0.73	0.73	0.77	0.017	0.015	0.020	2.94	2.66	2.67
	18	0.74	0.91	0.77	0.76	0.76	0.77	0.019	0.018	0.020	2.83	2.62	2.67
LJC	160	0.81	0.94	1.05	1.07	1.07	1.05	0.025	0.023	0.018	2.91	2.70	2.67
	163	0.96	1.08	1.05	1.02	1.02	1.05	0.022	0.022	0.018	3.27	3.01	2.67
	166	0.85	0.89	1.05	1.02	1.03	1.05	0.024	0.023	0.018	3.48	3.28	2.67
LCC	147	1.02	1.20	1.31	1.36	1.36	1.31	0.026	0.024	0.022	2.53	2.34	2.67
	149	0.83	0.85	1.31	1.36	1.38	1.31	0.029	0.029	0.022	2.78	2.60	2.67
	151	0.86	1.03	1.31	1.35	1.35	1.31	0.028	0.026	0.022	2.82	2.60	2.67

(Sheet 2)

TABLE 5.—COMPARISON OF OBSERVED & COMPUTED CHOP DATA WITH LACEY

Canal & RD		fvr			frs			Manning's N			P/√Q		
		O	C	L	O	C	L	O	C	L	O	C	L
		14	15	16	17	18	19	20	21	22	23	24	25
UG	42	0.83	0.86	1.13	1.15	1.16	1.13	0.026	0.025	0.022	2.88	2.76	2.67
	44	0.91	1.01	1.13	1.15	1.15	1.13	0.024	0.023	0.022	2.79	2.62	2.67
	46	0.98	1.05	1.13	1.14	1.15	1.13	0.023	0.023	0.022	2.73	2.58	2.67
	106	0.91	1.14	1.14	1.18	1.19	1.15	0.025	0.022	0.022	2.57	2.25	2.67
	107	0.91	1.01	1.14	1.22	1.22	1.15	0.025	0.024	0.022	2.25	2.12	2.67
	109	0.93	1.05	1.14	1.21	1.20	1.15	0.025	0.023	0.022	2.36	2.23	2.67
Panjnad	68	0.56	0.60	0.90	0.92	0.89	0.94	0.026	0.025	0.019	2.65	2.61	2.67
	71	0.59	0.62	0.90	0.92	0.92	0.94	0.025	0.024	0.019	2.68	2.60	2.67
	74	0.55	0.62	0.90	0.91	0.88	0.94	0.026	0.024	0.019	2.82	2.73	2.67
	77	0.58	0.61	0.90	0.91	0.91	0.94	0.025	0.024	0.019	2.77	2.67	2.67
	137	0.61	0.75	0.87	0.91	0.91	0.89	0.024	0.022	0.020	2.84	2.57	2.67
	139	0.69	0.82	0.87	0.90	0.91	0.89	0.023	0.021	0.020	2.80	2.50	2.67
	141	0.55	0.71	0.87	0.92	0.91	0.89	0.026	0.023	0.020	2.80	2.59	2.67
UCC	23	0.78	0.85	1.40	1.49	1.49	1.41	0.031	0.030	0.022	2.91	2.83	2.67
	26	0.83	0.93	1.40	1.49	1.49	1.41	0.030	0.028	0.022	2.79	2.66	2.67
	29	0.81	0.87	1.40	1.51	1.50	1.41	0.031	0.029	0.022	2.71	2.67	2.67
	100	1.18	1.33	1.57	1.53	1.53	1.50	0.026	0.024	0.022	2.64	2.52	2.67
	103	1.33	1.49	1.57	1.50	1.50	1.50	0.024	0.023	0.022	2.74	2.63	2.67
	105	1.39	1.47	1.57	1.50	1.50	1.50	0.024	0.023	0.022	2.64	2.60	2.67

O=Observed C=Computed L=Lacey

(Sheet 1)

TABLE 6.—ANALYSIS OF CHOP DATA ABBASIA CANAL RD 9000-14000

Date	Observed					Computed for full supply Discharge=1100 Cs								Suspended Sediment ppm	Bed Material d50
	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs		
R. D. 9															
*June, 28	975	63	6.8	74	13400	7.3	512	82	6.2	2.15	0.0202	0.56	0.63	454	
July 27	901	63	6.0	74	11300	6.7	471	80	5.9	2.34	0.0195	0.70	0.69	3330	
*Aug., 21	972	66	6.0	73	11700	6.5	456	81	5.6	2.41	0.0180	0.78	0.66	4840	0.198
Sept., 20	905	57	6.6	76	9250	7.4	526	82	6.4	2.09	0.0255	0.51	0.81	2320	
Oct., 20	878	57	6.6	75	9280	7.6	527	81	6.5	2.09	0.0257	0.50	0.81	142	0.167
Average	926	61	6.4	74	10986	7.1	498	81	6.1	2.21	0.0214	0.60	0.71		
*Average	974	64	6.4	74	12550	6.9	485	81	6.0	2.27	0.0193	0.64	0.65		
R.D. 11															
*June, 28	975	76	6.2	82	13400	6.7	516	88	5.9	2.13	0.0197	0.58	0.62	454	
July, 27	901	65	5.6	80	11300	6.3	488	85	5.7	2.25	0.0198	0.67	0.68	3330	

*Aug., 21	972	69	5.9	82	11700	6.4	483	88	5.5	2.28	0.0188	0.71	0.66	4840	0.198
Sept., 20	905	68	6.5	82	9250	7.3	554	89	6.2	1.99	0.0262	0.48	0.80	2320	
Oct., 20	878	60	6.1	82	9280	7.0	528	87	6.1	2.08	0.0248	0.53	0.79	142	0.167
Average	926	66	6.1	82	10986	6.9	523	88	5.9	2.10	0.0220	0.56	0.70		
*Average	974	69	6.1	82	12550	6.6	499	88	5.7	2.20	0.0192	0.64	0.64		
R. D. 14															
*June, 28	975	65	6.3	78	13400	6.8	503	84	6.0	2.19	0.0194	0.60	0.62	454	
July, 27	901	60	6.1	77	11300	6.9	496	83	6.0	2.22	0.0208	0.62	0.69	3330	
*Aug., 21	972	68	6.0	78	11700	6.5	466	85	5.5	2.36	0.0181	0.76	0.66	4840	0.198
Sept., 20	905	61	7.3	78	9250	8.2	589	86	6.8	1.87	0.0296	0.38	0.83	2320	
Oct., 20	878	55	6.0	78	9280	6.9	491	83	5.9	2.24	0.0225	0.64	0.79	142	0.167
Average	926	61	6.3	78	10986	7.0	507	83	6.1	2.17	0.0218	0.58	0.71		
*Average	974	66	6.2	78	12550	6.7	485	84	5.8	2.27	0.0189	0.67	0.64		

*Observation when discharge is close to the full supply discharge.

(Sheet 2)

TABLE 6.—ANALYSIS OF CHOP DATA RANGPUR CANAL RD 11000-15000

	Observed					Computed for full supply Discharge=2150 Cs									
Date	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs	Suspended Sediment ppm	Bed Material d50
R. D. 11															
May, 24	1840	124	6.2	140	10000	6.8	901	145	6.2	2.39	0.0210	0.69	0.78	482	
*June, 22	1900	115	6.6	141	8300	7.1	923	145	6.4	2.33	0.0241	0.64	0.90	968	
*July, 18	1960	120	6.4	140	10400	6.8	902	145	6.2	2.38	0.0207	0.69	0.76	1120	
*Aug., 30	1960	120	6.1	140	9000	6.4	844	144	5.9	2.55	0.0201	0.83	0.82	3770	0.176
Sept., 10	1870	120	6.1	140	8210	6.6	862	144	6.0	2.49	0.0218	0.78	0.88	1630	
Oct., 23	1790	120	6.0	134	8475	6.7	860	139	6.2	2.50	0.0218	0.76	0.87	251	0.170
Average	1887	119	6.2	139	9064	6.7	883	144	6.1	2.43	0.0214	0.73	0.83		
*Average	1940	118	6.4	140	9233	6.8	890	145	6.1	2.42	0.0213	0.72	0.83		
R. D. 13															
May, 24	1840	105	6.9	131	10000	6.91	846	135	6.3	2.54	0.0200	0.77	0.79	482	

*June	22	1900	110	6.3	133	8300	6.8	849	137	6.2	2.53	0.0218	0.77	0.89	968	
*July	18	1960	124	6.7	131	10400	7.1	898	140	6.4	2.39	0.0210	0.67	0.77	1120	
*Aug.,	30	1960	120	6.3	130	9000	6.7	821	137	6.0	2.62	0.0197	0.86	0.84	3770	0.176
Sept.,	10	1870	120	6.1	131	8210	6.6	821	137	6.0	2.62	0.0207	0.86	0.88	1630	
Oct.,	23	1790	115	6.1	132	8475	6.8	849	137	6.2	2.53	0.0215	0.77	0.88	251	0.170
Average		1887	115	6.3	131	9064	6.8	845	137	6.2	2.54	0.0207	0.78	0.84		
*Average		1940	118	6.4	131	9233	6.8	852	138	6.2	2.52	0.0207	0.77	0.83		

R. D. 15

May,	24	1840	119	6.3	132	10000	6.9	874	138	6.3	2.46	0.0206	0.72	0.79	482	
*June,	22	1900	120	6.2	133	8300	6.7	864	139	6.2	2.49	0.0221	0.75	0.88	968	
*July	18	1960	129	6.7	135	10400	7.1	925	145	6.4	2.32	0.0217	0.63	0.77	1120	
*Aug.,	30	1960	120	6.1	133	9000	6.4	829	139	6.0	2.59	0.0200	0.84	0.82	3770	0.176
Sept.,	10	1870	125	6.1	135	8210	6.6	860	142	6.1	2.50	0.0219	0.77	0.88	1630	
Oct.,	23	1790	115	6.5	129	8475	7.2	871	135	6.5	2.47	0.0228	0.70	0.89	251	0.170
Average		1887	121	6.3	133	9064	6.8	870	140	6.2	2.47	0.0213	0.74	0.84		
*Average		1940	123	6.3	134	9233	6.7	872	141	6.2	2.47	0.0211	0.74	0.82		

(Sheet 3)

TABLE 6.—ANALYSIS OF CHOP DATA SIDHNAI CANAL RD 13000-23000

		Observed				Computed for full supply Discharge=4100 Cs									
Date	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs	Suspended Sediment ppm	Bed Material d50
R. D. 13															
May, 26	3470	170	7.5	185	11900	8.3	1468	193	7.6	2.79	0.0189	0.77	0.72	229	
*June, 24	3800	165	8.0	184	13700	8.4	1481	191	7.8	2.77	0.0180	0.74	0.67	190	
*July, 30	3870	160	7.7	186	12100	8.0	1386	191	7.3	2.96	0.0172	0.90	0.71	1150	
*Aug., 22	3780	150	6.9	185	14300	7.2	1256	189	6.6	3.26	0.0134	1.21	0.61	5760	
*Sept., 19	3883	150	7.6	183	11470	7.9	1354	187	7.2	3.03	0.0171	0.96	0.73	1280	
Oct., 4	3330	144	6.8	184	9710	7.7	1322	188	7.0	3.10	0.0178	1.03	0.81	8530	
*Oct., 5	3750	144	7.1	184	8150	7.5	1275	187	6.8	3.22	0.0183	1.14	0.90	8250	
*Oct., 6	3980	150	7.2	184	7980	7.3	1249	187	6.7	3.28	0.0180	1.20	0.91	5720	
Oct., 21	3350	150	7.3	184	13800	8.2	1410	189	7.5	2.91	0.0167	0.85	0.65	124	
Average	3690	153	7.3	182	11457	7.8	1356	189	7.2	3.02	0.0171	0.95	0.73		
*Average	3843	153	7.4	184	11283	7.7	1333	189	7.1	3.08	0.0168	1.00	0.73		
R. D. 15															
Sept., 19	3883	162	8.4	182	11470	8.7	1490	189	7.9	2.75	0.0200	0.72	0.75	1280	

Oct., 21	3350	153	8.2	184	13800	9.3	1589	190	8.4	2.58	0.0203	0.59	0.68	124
Average	3616	157	8.3	183	12635	8.9	1521	189	8.1	2.70	0.0197	0.68	0.71	
R. D. 18														
May, 26	3470	165	8.4	176	11900	9.2	1551	187	8.3	2.64	0.0211	0.63	0.74	229
*June 24	3800	150	8.9	176	13700	9.3	1535	183	8.4	2.67	0.0197	0.64	0.68	190
*July, 30	3870	150	8.6	176	12100	8.9	1453	182	8.0	2.82	0.0192	0.75	0.73	1130
*Aug., 22	3780	160	8.8	175	14300	9.2	1530	184	8.3	2.68	0.0190	0.65	0.66	5760
*Sept., 19	3883	147	8.4	176	11470	8.7	1424	182	7.8	2.88	0.0189	0.80	0.75	1280
Oct., 4	3330	140	7.5	176	9710	8.5	1393	181	7.7	2.94	0.0200	0.84	0.83	8530
*Oct., 5	3750	140	8.0	177	8150	8.4	1369	181	7.6	2.99	0.0215	0.88	0.93	8250
*Oct., 6	3980	140	8.0	177	7980	8.1	1311	180	7.3	3.13	0.0200	1.01	0.93	5720
Oct., 21	3350	150	8.3	177	13800	9.4	1550	184	8.4	2.65	0.0197	0.63	0.68	124
Average	3690	149	8.3	176	11457	8.8	1451	182	8.0	2.83	0.0196	0.75	0.76	
*Average	3843	147	8.4	176	11283	8.7	1434	182	7.9	2.86	0.0194	0.78	0.76	
R. D. 23														
June, 24	3800	130	10.9	173	13700	11.4	1744	179	9.7	2.35	0.0246	0.43	0.71	190
July, 30	3870	125	11.2	173	12100	11.6	1679	179	9.4	2.44	0.0247	0.47	0.76	1150
Average	3835	127	11.1	173	12900	11.6	1720	179	9.6	2.38	0.0248	0.44	0.74	

(Sheet 4)

TABLE 6.—ANALYSIS OF CHOP DATA LOWER JHELUM CANAL RD 160000-166000

Date	Observed					Computed for full supply Discharge=4500 Cs								Suspended Sediment ppm	Bed Material d50
	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs		
R. D. 160															
*June, 16	3870	160	7.9	190	7600	8.6	1543	195	7.9	2.92	0.0257	0.81	0.99	467	
July, 25	3030	160	6.3	192	7060	8.0	1456	197	7.4	3.09	0.0218	0.97	1.02	3820	
*Oct., 18	3850	164	7.7	190	6000	8.5	1533	196	7.8	2.94	0.0257	0.83	1.15	255	
Average	3583	161	7.3	191	6887	8.4	1517	196	7.7	2.97	0.0235	0.86	1.05		
*Average	3860	162	7.8	190	6800	8.6	1548	196	7.9	2.91	0.0246	0.80	1.07		
R. D. 163															
*June, 6	3870	200	6.9	214	7600	7.6	1520	221	6.9	2.96	0.0209	0.95	0.95	467	

July,	25	3030	200	5.6	217	7060	7.1	1536	223	6.9	2.93	0.0219	0.93	0.99	3820
*Oct.,	18	3850	170	6.9	214	6000	7.6	1558	217	7.2	2.89	0.0248	0.87	1.12	255
Average		3583	190	6.5	215	6887	7.5	1544	221	7.0	2.91	0.0225	0.91	1.01	
*Average		3860	185	6.9	214	6800	7.6	1539	219	7.0	2.92	0.0227	0.91	1.02	
R. D. 166															
*June,	6	3870	205	6.9	226	7600	7.6	1598	231	6.9	2.82	0.0219	0.86	0.95	467
July,	25	3030	205	5.5	226	7060	7.0	1529	232	6.6	2.94	0.0212	0.98	0.98	3820
*Oct.,	18	3850	200	6.8	229	6000	7.5	1655	233	7.1	2.72	0.0261	0.78	1.12	255
Average		3583	203	6.4	227	6887	7.3	1579	232	6.8	2.85	0.0225	0.90	1.00	
*Average		3860	202	6.9	228	6800	7.6	1628	232	7.0	2.76	0.0239	0.82	1.02	

(Sheet 5)

TABLE 6.—ANALYSIS OF CHOP DATA LOWER CHENAB CANAL RD 147000-151000

Date	Observed					Computed for full supply Discharge=5930 Cs									
	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs	Suspended Sediment ppm	Bed Material d50
R. D. 147															
May, 3	4860	165	8.7	191	5450	9.8	1750	198	8.8	3.39	0.0253	0.98	1.28	617	
June, 10	5360	165	9.3	191	5510	9.9	1765	198	8.9	3.36	0.0256	0.95	1.28	1090	
July, 26	5290	165	9.0	193	5500	9.6	1736	199	8.7	3.42	0.0248	1.01	1.27	2660	
*Aug., 11	5540	160	9.5	190	5000	9.9	1726	197	8.8	3.44	0.0260	1.01	1.36	2330	
*Sept., 8	5640	163	9.3	191	5000	9.6	1721	197	8.7	3.45	0.0258	1.03	1.35	1790	0.261
*Oct., 13	5610	150	9.5	189	5000	9.8	1711	214	8.0	3.47	0.0242	1.13	1.31	680	0.282
Average	5383	161	9.2	191	5365	9.7	1725	200	8.6	3.44	0.0247	1.03	1.28		
*Average	5597	158	9.4	190	5000	9.7	1713	203	8.4	3.46	0.0251	1.07	1.34		
R. D. 149															
May, 3	4860	185	8.7	208	5450	9.8	1924	216	8.9	3.08	0.0281	0.80	1.28	617	
June, 10	5360	180	9.1	200	5510	9.7	1870	208	9.0	3.17	0.0273	0.84	1.28	1090	

July,	26	5290	180	9.2	200	5500	9.9	1940	208	9.3	3.06	0.0290	0.76	1.30	2660	
*Aug.,	11	5540	170	9.3	210	5000	9.7	1894	215	8.8	3.13	0.0286	0.83	1.36	2330	
*Sept.,	8	5640	185	9.3	209	5000	9.6	1915	216	8.9	3.10	0.0291	0.81	1.36	1790	0.261
*Oct.,	13	5610	175	10.9	206	5000	11.3	1915	214	8.9	3.10	0.0291	0.81	1.36	680	0.282
Average		5383	179	9.4	206	5365	10.0	1913	213	9.0	3.10	0.0283	0.80	1.30		
*Average		5597	177	9.8	208	5000	10.1	1894	215	8.8	3.13	0.0286	0.83	1.36		
R. D. 151																
May,	3	4860	175	8.7	209	5450	9.8	1917	215	8.9	3.09	0.0280	0.80	1.28	617	
June,	10	5360	185	9.0	212	5510	9.6	1921	218	8.8	3.09	0.0276	0.81	1.27	1090	
July,	26	5290	170	8.7	209	5500	9.3	1835	214	8.6	3.23	0.0260	0.91	1.26	2660	
*Aug.,	11	5540	200	9.0	208	5000	9.4	1901	221	8.6	3.12	0.0283	0.85	1.35	2330	
*Sept.,	8	5640	170	9.1	215	5000	9.4	1883	219	8.6	3.15	0.0280	0.87	1.35	1790	0.261
*Oct.,	13	5610	169	9.2	214	5000	9.5	1878	219	8.6	3.16	0.0279	0.87	1.35	680	0.282
Average		5383	178	9.0	211	5365	9.5	1880	217	8.7	3.15	0.0272	0.86	1.29		
*Average		5597	179	9.1	212	5000	9.4	1881	220	8.6	3.15	0.0280	0.87	1.35		

(Sheet 6)

TABLE 6.—ANALYSIS OF CHOP DATA UPPER GOGERA BRANCH RD 42000-46000

Date	Observed					Computed for full supply Discharge—6200 Cs								Suspended Sediment ppm	Bed Material d50
	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs		
R. D. 42															
May, 1	4590	172	8.2	218	6300	9.8	1969	232	8.5	3.15	0.0247	0.88	1.15	971	
June, 11	5070	185	8.6	219	6500	9.7	1991	225	8.8	3.11	0.0253	0.82	1.14	1310	
July, 27	5300	148	9.2	212	6700	10.1	1981	217	9.1	3.13	0.0253	0.81	1.13	2310	
*Aug., 8	6200	200	9.7	222	6300	9.7	2040	229	8.9	3.04	0.0264	0.78	1.17	1923	0.192-0.245
*Sept., 7	5580	198	9.2	220	6600	9.8	1982	228	8.7	3.13	0.0247	0.84	1.12	4150	0.140
*Oct., 12	5600	186	8.9	218	6220	9.5	1937	224	8.7	3.20	0.0249	0.88	1.17	524	0.146
Average	5390	182	9.0	218	6437	9.8	1984	225	8.8	3.13	0.0252	0.83	1.15		
*Average	5793	195	9.3	220	6373	9.7	1987	227	8.8	3.12	0.0254	0.83	1.15		
R. D. 44															
May, 1	4590	180	8.1	218	6300	9.7	1969	224	8.8	3.15	0.0253	0.85	1.16	971	

June,	11	5070	168	8.8	216	6500	9.9	1978	221	9.0	3.13	0.0255	0.82	1.15	1310	
July,	27	5300	175	8.8	212	6700	9.7	1951	218	8.9	3.18	0.0245	0.85	1.12	2310	
*Aug.,	8	6200	195	8.8	213	6300	8.8	1800	220	8.2	3.44	0.0221	1.08	1.13	1923	0.192-0.245
*Sept.,	7	5580	180	9.2	215	6600	9.8	1939	221	8.8	3.20	0.0244	0.87	1.13	4150	0.140
*Oct.,	12	5600	180	9.2	213	6220	9.8	1988	219	9.1	3.12	0.0263	0.80	1.19	524	0.146
Average		5390	180	8.8	215	6437	9.6	1937	221	8.8	3.20	0.0247	0.87	1.15		
*Average		5793	185	9.1	214	6373	9.5	1908	220	8.7	3.25	0.0242	0.91	1.15		
R. D. 46																
May,	1	4590	140	8.2	209	6300	9.8	1914	214	8.9	3.24	0.0248	0.88	1.17	971	
June,	11	5070	170	8.9	211	6500	10.0	1962	217	9.0	3.16	0.0252	0.83	1.15	1310	
July,	27	5300	130	9.0	215	6700	9.9	1924	219	8.8	3.22	0.0240	0.88	1.12	2310	
*Aug.,	8	6200	195	8.9	210	6300	8.9	1800	218	8.2	3.44	0.0221	1.08	1.13	1923	0.192-0.245
*Sept.,	7	5580	170	9.4	212	6600	10.0	1907	217	8.8	3.25	0.0240	0.90	1.13	4150	0.140
*Oct.,	12	5600	180	8.9	204	6220	9.5	1843	211	8.7	3.36	0.0237	0.97	1.17	524	0.146
Average		5390	164	8.9	210	6437	9.7	1892	217	8.7	3.28	0.0239	0.93	1.14		
*Average		5793	182	9.1	209	6373	9.5	1850	216	8.6	3.35	0.0233	0.98	1.14		

(Sheet 7)

TABLE 6.—ANALYSIS OF CHOP DATA UPPER GOGERA BRANCH RD 106100-108900

Date	Observed					Computed for full supply Discharge=5400 Cs									
Date	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs	Suspended Sediment ppm	Bed Material d50
R. D. 106															
May, 2	4330	165	8.2	182	6180	9.4	1628	191	8.5	3.32	0.0237	0.97	1.16	772	
June 9	4780	155	9.0	181	5630	9.7	1647	188	8.8	3.28	0.0257	0.92	1.25	419	
*July 16	5250	145	9.8	183	5730	10.0	1657	188	8.8	3.26	0.0257	0.91	1.24	1070	
*Aug., 7	5190	153	9.4	194	5700	9.6	1659	198	8.4	3.25	0.0250	0.94	1.22	1560	0.165-0.171
*Sept., 6	5060	130	9.8	182	6150	10.2	1653	187	8.8	3.27	0.0247	0.91	1.18	1100	0.182
*Oct., 11	5050	144	9.5	180	6910	9.9	1653	186	8.9	3.27	0.0235	0.90	1.10	514	0.248
Average	4943	149	9.3	184	6050	9.8	1658	190	8.7	3.26	0.0248	0.92	1.19		
*Average	5138	143	9.6	185	6123	9.9	1655	190	8.7	3.26	0.0246	0.92	1.18		
R. D. 107															
May, 2	4330	146	9.6	164	6180	11.0	1700	175	9.7	3.18	0.0270	0.78	1.22	772	

June,	9	4780	145	10.2	166	5630	11.0	1693	176	9.6	3.19	0.0280	0.80	1.29	419	
*July,	16	5250	130	11.4	161	5730	11.6	1632	168	9.7	3.31	0.0270	0.85	1.28	1070	
*Aug.,	7	5190	130	10.1	154	5700	10.3	1441	161	9.0	3.75	0.0227	1.17	1.25	1560	0.165-0.171
*Sept.,	6	5060	130	10.5	151	6150	10.9	1600	161	9.9	3.38	0.0258	0.87	1.23	1100	0.182
*Oct.,	11	5050	135	10.7	162	6910	11.1	1657	171	9.7	3.26	0.0260	0.82	1.13	514	0.248
Average		4943	136	10.4	160	6050	11.0	1625	169	9.6	3.32	0.0260	0.86	1.23		
*Average		5138	131	10.7	157	6123	11.0	1583	166	9.5	3.41	0.0250	0.92	1.21		
R. D. 109																
May,	2	4330	150	9.1	164	6180	10.4	1623	176	9.2	3.33	0.0249	0.90	1.19	772	
June,	9	4780	145	9.8	166	5630	10.5	1626	175	9.3	3.32	0.0250	0.89	1.28	419	
*July,	16	5250	140	10.8	166	5730	11.0	1613	174	9.3	3.35	0.0260	0.91	1.26	1070	
*Aug.,	7	5190	155	9.5	168	5700	9.7	1544	178	8.7	3.50	0.0238	1.06	1.24	1560	0.165-0.171
*Sept.,	6	5060	140	9.9	164	6150	10.3	1626	172	9.5	3.32	0.0256	0.87	1.21	1100	0.182
*Oct.,	11	5050	130	9.9	164	6910	10.3	1619	170	9.5	3.34	0.0240	0.88	1.12	514	0.248
Average		4943	143	9.8	165	6050	10.3	1603	174	9.2	3.37	0.0249	0.93	1.21		
*Average		5138	141	10.0	166	6123	10.3	1601	174	9.2	3.37	0.0247	0.93	1.20		

(Sheet 8)

TABLE 6.—ANALYSIS OF CHOP DATA PANJNAD CANAL RD 68000-77000

Date	Observed					Computed for full supply Discharge = 10500 Cs								Suspended Sediment ppm	Bed Material d50
	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs		
R. D. 68															
June, 26	9340	232	13.2	260	9700	14.2	3540	272	13.0	2.97	0.0281	0.53	0.99	425	
*July, 28	9670	230	13.4	260	10000	14.1	3482	271	12.8	3.02	0.0269	0.51	0.97	2440	
*Aug., 19	9860	245	13.1	260	11300	13.6	3410	276	12.4	3.08	0.0243	0.57	0.88	3650	0.197
Sept., 23	9230	230	12.8	259	11470	13.8	3434	271	12.7	3.06	0.0247	0.55	0.88	882	0.175
Oct., 18	8960	220	12.6	254	11570	13.9	3402	265	12.8	3.09	0.0245	0.56	0.88	451	0.190
Average	9412	231	13.0	259	10808	13.9	3454	271	12.7	3.04	0.0256	0.55	0.92		
*Average	9765	235	13.2	260	10650	13.8	3446	274	12.6	3.05	0.0255	0.55	0.97		
R. D. 71															
June, 26	9340	222	12.8	265	9700	13.7	3489	274	12.7	3.01	0.0273	0.53	0.98	425	
*July, 28	9670	230	13.1	264	10000	13.8	3475	274	12.7	3.02	0.0267	0.54	0.97	2440	
*Aug., 19	9860	245	12.8	264	11300	13.3	3352	278	12.1	3.13	0.0236	0.61	0.88	3650	0.197
Sept., 23	9230	248	12.7	268	11470	13.7	3539	282	12.5	2.97	0.0258	0.53	0.88	882	0.175

Oct., 18	8960	246	12.1	262	11570	13.3	3393	277	12.2	3.09	0.0237	0.59	0.86	451	0.190
Average	9412	238	12.7	265	10808	13.4	3408	277	12.3	3.08	0.0247	0.58	0.91		
*Average	9765	235	13.0	264	10650	13.6	3413	276	12.4	3.08	0.0250	0.57	0.96		

R. D. 74

June, 26	9340	228	12.3	287	9700	13.2	3588	294	12.2	2.93	0.0273	0.53	0.97	425	
*July, 28	9670	251	12.6	272	10000	13.2	3523	285	12.4	2.98	0.0267	0.54	0.96	2440	
*Aug., 19	9860	250	12.3	286	11300	12.8	3483	295	11.8	3.01	0.0241	0.58	0.87	3650	0.197
Sept., 23	9230	250	12.4	285	11470	13.4	3663	295	12.4	2.87	0.0259	0.50	0.87	882	0.175
Oct., 18	8960	250	12.1	281	11570	13.3	3599	292	12.3	2.92	0.0252	0.52	0.87	451	0.190
Average	9412	246	12.3	282	10808	13.1	3560	292	12.2	2.95	0.0257	0.53	0.90		
*Average	9765	250	12.4	279	10650	13.0	3517	290	12.1	2.99	0.0252	0.55	0.95		

R. D. 77

June, 26	9340	240	13.3	276	9700	14.3	3646	287	12.7	2.88	0.0285	0.49	0.99	425	
*July 28	9670	235	12.9	275	10000	13.6	3533	284	12.4	2.97	0.0268	0.53	0.96	2440	
*Aug., 19	9860	250	12.6	273	11300	13.1	3417	285	12.0	3.07	0.0238	0.59	0.87	3650	0.197
Sept., 23	9230	240	12.6	276	11470	13.6	3569	286	12.5	2.94	0.0254	0.52	0.88	882	0.175
Oct., 18	8960	235	12.4	274	11570	13.6	3474	283	12.3	3.02	0.0244	0.56	0.87	451	0.190
Average	9412	240	12.8	275	10808	13.6	3506	285	12.3	2.99	0.0254	0.55	0.91		
*Average	9765	242	12.8	274	10650	13.4	3474	284	12.2	3.02	0.0252	0.56	0.96		

(Sheet 9)

TABLE 6.—ANALYSIS OF CHOP DATA PANJNAD CANAL RD 137000-141000

Date	Observed					Computed for full supply Discharge=8300 Cs								Suspended Sediment ppm	Bed Material d50
	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs		
R. D. 137															
*June, 27	7180	198	11.2	256	9340	12.2	2866	262	10.9	2.90	0.0261	0.58	0.96	844	
July, 29	6990	190	12.1	254	9340	13.4	2920	261	11.2	2.84	0.0271	0.54	0.97	2660	
*Aug., 20	7320	213	10.7	250	11200	11.5	2720	258	10.5	3.05	0.0221	0.67	0.84	4180	0.163
Sept., 24	6850	210	10.9	252	8970	12.2	2896	260	11.1	2.87	0.0272	0.56	0.99	910	0.139
*Oct., 19	7060	210	10.7	252	9660	11.8	2781	259	10.7	2.98	0.0246	0.62	0.93	411	0.151
Average	7080	204	11.1	253	9702	12.2	2836	260	10.9	2.93	0.0253	0.59	0.94		
*Average	7187	207	10.9	253	10067	11.9	2798	260	10.8	2.97	0.0244	0.62	0.91		
R. D. 139															
*June, 27	7180	200	10.6	250	9340	11.6	2690	256	10.5	3.09	0.0239	0.68	0.93	844	

July, 29	6990	220	10.2	249	9340	11.3	2644	257	10.3	3.14	0.0232	0.72	0.94	2660	
*Aug., 20	7320	210	10.7	248	11200	11.5	2638	256	10.3	3.15	0.0211	0.72	0.83	4180	0.163
Sept., 24	6850	215	11.6	248	8970	13.0	3013	258	11.7	2.75	0.0294	0.49	1.01	910	0.139
*Oct., 19	7060	195	10.7	249	9660	11.8	2682	255	10.5	3.09	0.0235	0.68	0.93	411	0.151
Average	7080	208	10.8	249	9702	11.9	2739	256	10.7	3.03	0.0242	0.65	0.93		
*Average	7187	202	10.7	249	10067	11.7	2678	256	10.5	3.10	0.0229	0.69	0.90		
R. D. 141															
*June, 27	7180	208	11.0	250	9340	12.0	2850	257	11.1	2.91	0.0263	0.57	0.97	844	
July, 29	6990	220	10.8	247	9340	12.0	2836	257	11.0	2.93	0.0260	0.58	0.96	2660	
*Aug., 20	7320	225	11.3	245	11200	12.2	2860	257	11.1	2.90	0.0241	0.57	0.86	4180	0.163
Sept., 24	6850	220	10.7	243	8970	12.0	2822	254	11.1	2.94	0.0266	0.58	0.99	910	0.139
*Oct., 19	7060	195	10.7	248	9660	11.8	2908	254	11.4	2.85	0.0269	0.53	0.95	411	0.151
Average	7080	214	10.9	247	9702	12.0	2855	256	11.2	2.91	0.0260	0.57	0.94		
*Average	7187	209	11.0	248	10067	12.0	2873	256	11.2	2.89	0.0257	0.56	0.92		

(Sheet 10)

TABLE 6.—ANALYSIS OF CHOP DATA UPPER CHENAB CANAL RD 23000-29000

	Observed					Computed for full supply Discharge=16500 Cs									
Date	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs	Suspended Sediment ppm	Bed Material d50
R. D. 23															
May, 9	10300	330	9.7	360	6100	12.9	4522	372	12.2	3.65	0.0258	0.82	1.32	214	
July, 11	5350	330	5.7	351	5200	11.2	3890	365	10.7	4.24	0.0236	1.26	1.41	989	
*July, 30	13200	325	11.5	355	5020	13.1	4558	366	12.5	3.62	0.0312	0.79	1.52	2260	
*Aug., 24	14400	340	12.0	370	5300	13.0	4660	380	12.3	3.54	0.0307	0.76	1.46	805	0.230
*Sept., 8	14000	340	11.6	368	5080	12.8	4572	378	12.1	3.61	0.0304	0.81	1.49	471	0.230
Oct., 9	10040	330	9.4	367	4830	12.7	4521	379	11.9	3.65	0.0305	0.84	1.53	224	0.258
Oct., 28	7310	330	7.8	360	4620	12.7	4374	374	11.7	3.77	0.0300	0.91	1.57	141	0.250
Average	10657	332	9.7	362	5164	12.6	4429	373	11.9	3.73	0.0289	0.88	1.47		
*Average	13867	335	11.7	364	5133	13.0	4611	375	12.3	3.58	0.0309	0.78	1.49		
R. D. 26															
May, 9	10300	310	10.3	344	6100	13.7	4600	357	12.9	3.59	0.0291	0.75	1.35	214	
July, 11	5350	310	6.3	335	5200	12.4	4074	350	11.6	4.05	0.0261	1.06	1.45	989	

*July,	30	13200	310	11.9	348	5020	13.6	4542	358	12.7	3.63	0.0315	0.78	1.53	2260	
*Aug.,	24	14400	320	11.9	355	5300	12.9	4485	364	12.3	3.68	0.0296	0.83	1.46	805	0.230
*Sept.,	8	14000	310	11.5	345	5080	12.7	4214	354	11.9	3.92	0.0274	0.97	1.48	471	0.230
Oct.,	9	10040	330	10.2	354	4830	13.7	4669	369	12.7	3.53	0.0330	0.74	1.57	224	0.258
Oct.,	28	7310	310	8.0	340	4620	13.2	4208	357	11.8	3.92	0.0289	0.98	1.58	141	0.250
Average		10657	314	10.0	346	5164	13.0	4354	358	12.2	3.79	0.0289	0.88	1.48		
*Average		13867	313	11.8	349	5133	13.1	4414	359	12.3	3.74	0.0296	0.85	1.49		
R. D. 29																
May,	9															
July,	11	5350	320	6.0	333	5200	11.8	3951	350	11.3	4.18	0.0248	1.16	1.44	989	
*July,	30	13200	320	12.0	342	5020	13.7	4591	356	12.9	3.59	0.0321	0.75	1.54	2260	
*Aug.,	24	14400	300	12.5	317	5300	13.6	4259	332	12.8	3.87	0.0289	0.88	1.48	805	0.230
*Sept.,	8	14000	320	12.0	349	5080	13.2	4509	360	12.5	3.66	0.0314	0.80	1.51	471	0.230
Oct.,	9	10040	340	10.3	360	4830	13.9	4946	376	13.2	3.34	0.0357	0.63	1.59	224	0.258
Oct.,	28	7310	310	7.8	340	4620	12.7	4006	354	11.3	4.12	0.0267	1.13	1.55	141	0.250
Average		10717	318	10.1	340	5008	13.1	4358	354	12.3	3.79	0.0295	0.88	1.51		
*Average		13867	313	12.2	336	5133	13.5	4440	350	12.7	3.70	0.0304	0.82	1.51		

(Sheet 11)

TABLE 6.—ANALYSIS OF CHOP DATA UPPER CHENAB CANAL RD 100000-105000

	Observed					Computed for full supply Discharge=15900 Cs									
Date	Q	B	D	Ws	I/S	D	A	P	R	V	N	fvr	frs	Suspended Sediment ppm	Bed Material d50
R. D. 100															
*June, 21	14100	285	11.2	326	4750	12.0	3741	334	11.2	4.25	0.0254	1.21	1.52	1290	
*July, 31	13200	300	10.2	330	4050	11.4	3646	338	10.8	4.36	0.0262	1.32	1.67	2310	
*Aug., 25	14200	290	11.3	325	5100	12.1	3770	334	11.3	4.22	0.0248	1.18	1.45	1000	0.168
*Sept., 9	13800	290	11.3	323	5000	12.3	3843	329	11.7	4.14	0.0262	1.10	1.49	1350	0.250
Oct., 10	9980	260	10.3	325	5710	13.6	4192	333	12.6	3.79	0.0281	0.86	1.53	364	0.215
Oct., 29	6790	280	8.1	320	6170	13.5	4198	373	11.3	3.79	0.0251	0.95	1.28	181	0.232
Average	12012	284	10.4	325	5130	12.3	3842	340	11.3	4.14	0.0252	1.14	1.45		
*Average	13825	291	11.0	326	4725	12.0	3766	334	11.3	4.22	0.0258	1.18	1.53		
R. D. 103															
*June, 21	14100	315	9.9	345	4750	10.7	3696	353	10.5	4.30	0.0241	1.32	1.49	1290	
*July, 31	13200	310	9.1	335	4050	10.2	3269	343	9.5	4.86	0.0216	1.86	1.60	2310	

*Aug., 25	14200	310	10.9	340	5100	11.7	3842	349	11.0	4.14	0.0249	1.17	1.44	1000	0.168
*Sept., 9	13800	290	11.2	336	5000	12.2	3926	344	11.4	4.05	0.0263	1.08	1.48	1350	0.250
Oct., 10	9980	290	9.4	336	5710	12.4	4038	346	11.7	3.94	0.0257	1.00	1.36	364	0.215
Oct., 29	6790	250	7.9	333	6170	13.2	4205	345	12.2	3.78	0.0265	0.88	1.31	181	0.232
Average	12012	294	9.7	338	5130	11.5	3766	346	10.9	4.22	0.0242	1.23	1.43		
*Average	13825	306	10.3	339	4725	11.2	3675	349	10.5	4.33	0.0239	1.34	1.49		

R. D. 105

*June, 21	14100	310	9.5	332	4750	10.2	3332	340	9.8	4.77	0.0207	1.74	1.46	1290	
*July, 31	13200	300	10.1	316	4050	11.3	3499	328	10.7	4.54	0.0250	1.44	1.67	2310	
*Aug., 25	14200	310	10.7	323	5100	11.5	3728	337	11.1	4.27	0.0242	1.23	1.45	1000	0.168
*Sept., 9	13800	290	11.1	320	5000	12.1	3750	329	11.4	4.24	0.0251	1.18	1.48	1350	0.250
Oct., 10														364	0.215
Oct., 29	6790	300	7.7	320	6170	12.8	4032	335	12.0	3.94	0.0252	0.97	1.31	181	0.232
Average	12418	302	9.8	322	5014	11.4	3620	333	10.9	4.39	0.0232	1.33	1.43		
*Average	13825	302	10.4	323	4725	11.3	3571	334	10.7	4.45	0.0236	1.39	1.50		

TABLE 7.—EFFECT OF VARIATION IN SILT FACTOR ON THE DIMENSIONS AND SLOPE OF A CANAL

Discharge	frs	I/S	fvr	Dimensions				B/D
				B	D	A	V	
10,000	1.2	6275	1.2	244	10.3	2566	3.9	23.7
10,000	1.1	7250	1.1	243	10.6	2637	3.8	23.0
10,000	1.0	8470	1.0	242	10.9	2720	3.7	22.2
10,000	0.9.	10100	0.9	242	11.3	2809	3.6	21.4
10,000	0.8	12300	0.8	241	11.8	2925	3.4	20.4
10,000	0.7	15450	0.7	239	12.4	3020	3.3	19.3

TABLE 8.—OBSERVED SIDE SLOPES OF CANALS

Canal	R. D.	Bed Width	Depth	Left Side Slope		Right Side Slope	
				Lower half	Upper half	Lower half	Upper half
Abbasia	9	66	6.0	0.83: 1	0.33: 1	0.58: 1	0.58: 1
	11	69	5.9	1.69: 1	0.51: 1	1.35: 1	0.85: 1
	14	68	6.0	1.17: 1	1.50: 1	1.17: 1	0.50: 1
Sidnai	13	150	6.9	3.04: 1	2.03: 1	3.33: 1	1.74: 1
	18	144	8.8	2.61: 1	0.91: 1	2.16: 1	1.36: 1
Lower Chenab	1,47	158	9.4	2.55: 1	0.85: 1	1.49 :1	1.91: 1
	1,49	177	9.8	2.55: 1	0.81: 1	2.45: 1	0.81: 1
	1,51	179	9.1	3.18: 1	0.66: 1	3.08: 1	0.88: 1
Upper Gogera	42	195	9.3	1.72: 1	1.07: 1	1.82: 1	0.86: 1
	44	185	9.1	2.41: 1	0.65 :1	2.30: 1	0.66 :1
	46	182	9.1	2.31: 1	1.09: 1	2.86: 1	0.77: 1
	1,06	143	9.6	2.39: 1	2.91: 1	4.47: 1	0.83: 1
	1,07	131	10.7	1.40: 1	1.40: 1	2.24: 1	0.56: 1
	1,09	141	10.0	0.85: 1	0.85: 1	1.10: 1	0.70: 1
Panjnad	68	234	13.1	1.68: 1	0.31: 1	1.15: 1	0.84 :1
	71	228	12.8	2.30: 1	0.51: 1	1.41: 1	1.41: 1
	74	250	12.3	2.11: 1	0.81: 1	2.03: 1	0.89: 1
	77	250	12.6	1.03: 1	0.79: 1	0.91: 1	0.91: 1
	1,37	213	10.7	2.76: 1	0.70: 1	2.62: 1	0.84: 1
	1,39	210	10.7	2.24: 1	1.31: 1	1.78: 1	1.78: 1
	1,41	225	11.3	1.06: 1	0.70: 1	0.88: 1	0.88: 1
Upper Chenab	23	335	11.7	1.78: 1	1.11: 1	2.13: 1	0.85: 1
	26	313	11.8	2.54: 1	0.93: 1	2.28: 1	1.27: 1
	29	313	12.2	1.55: 1	0.82: 1	2.05: 1	0.49: 1
	1,00	291	11.0	2.18: 1	0.54: 1	1.81: 1	1.09: 1
	1,03	306	10.3	2.04: 1	1.16: 1	1.65: 1	1.65: 1
	1,05	306	10.4	1.25: 1	0.57: 1	0.91: 1	1.91: 1

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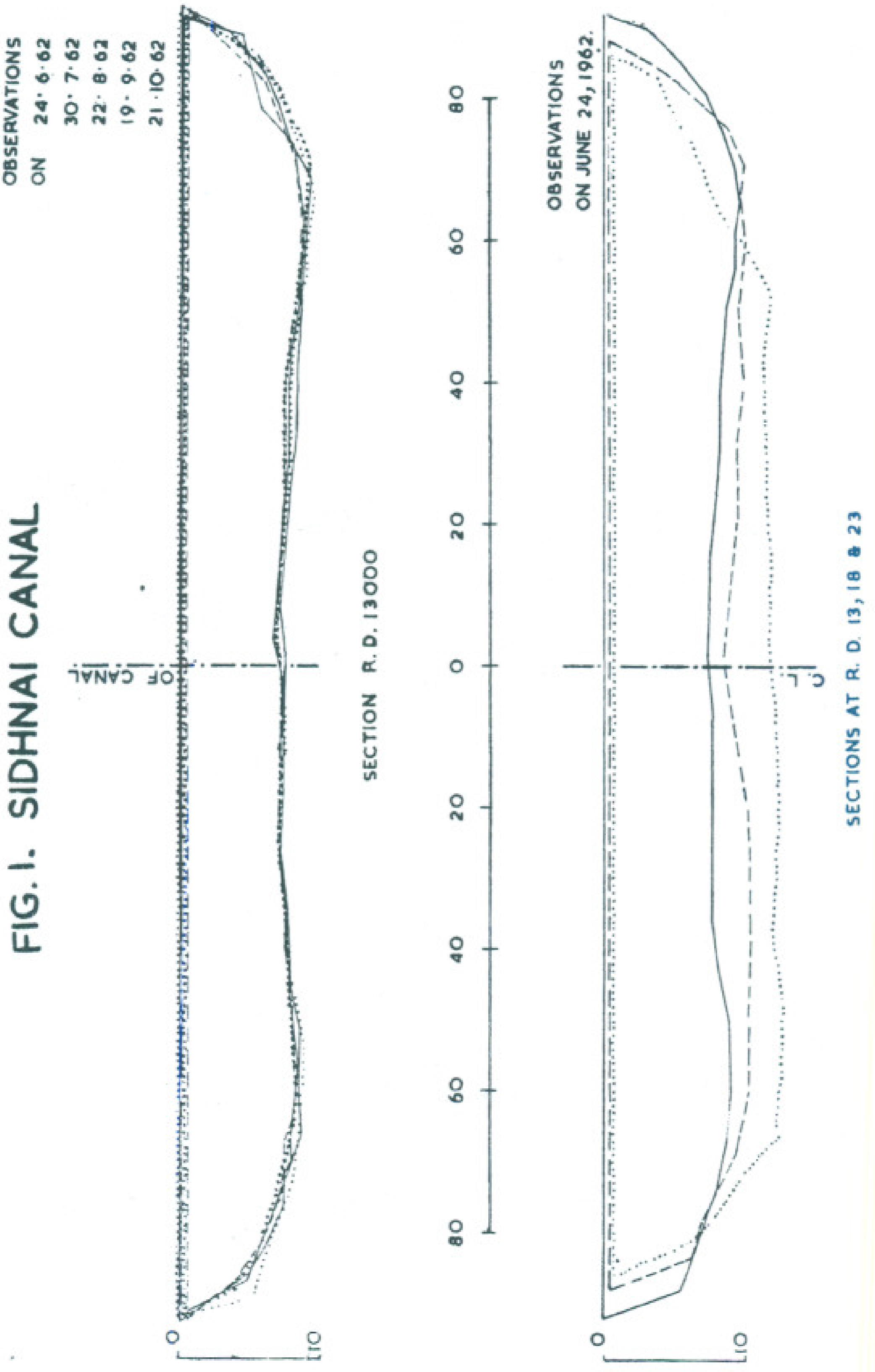
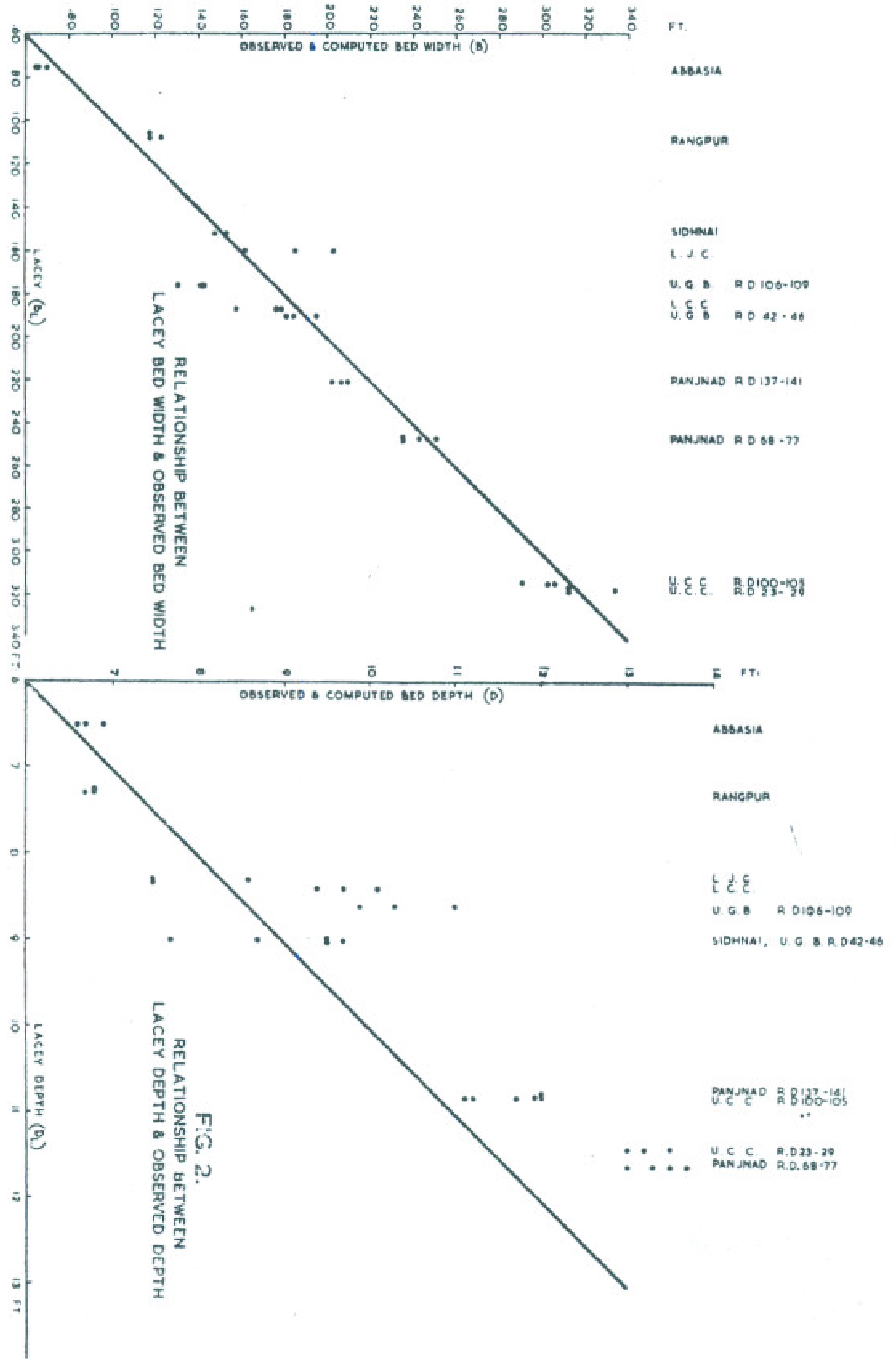


FIG. I. SIDHNAI CANAL

SECTIONS AT R. D. 13, 18 & 23



RELATIONSHIP BETWEEN LACEY BED WIDTH & OBSERVED BED WIDTH

FIG. 2.

RELATIONSHIP BETWEEN LACEY DEPTH & OBSERVED DEPTH

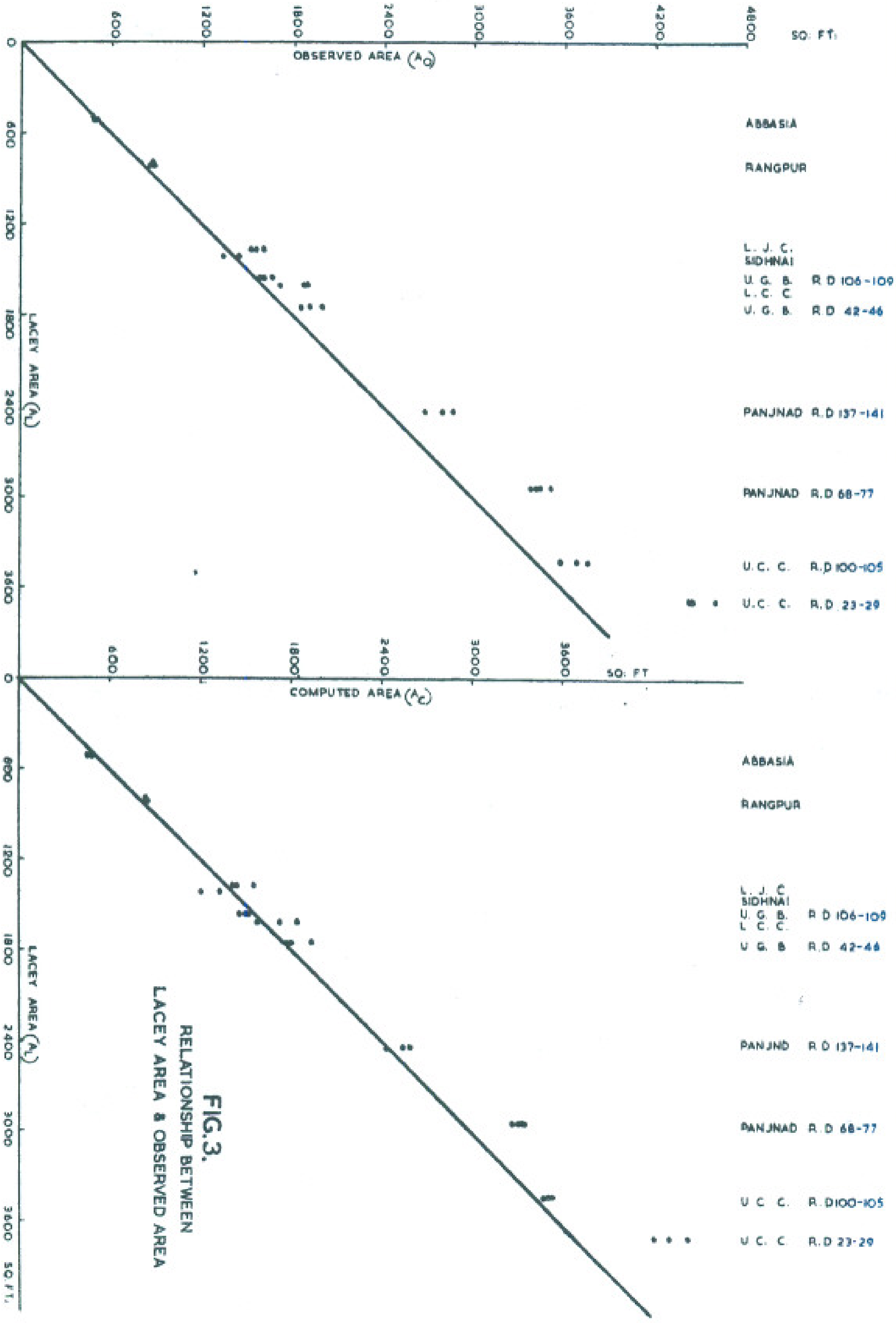


FIG. 3.
RELATIONSHIP BETWEEN
LACEY AREA & OBSERVED AREA

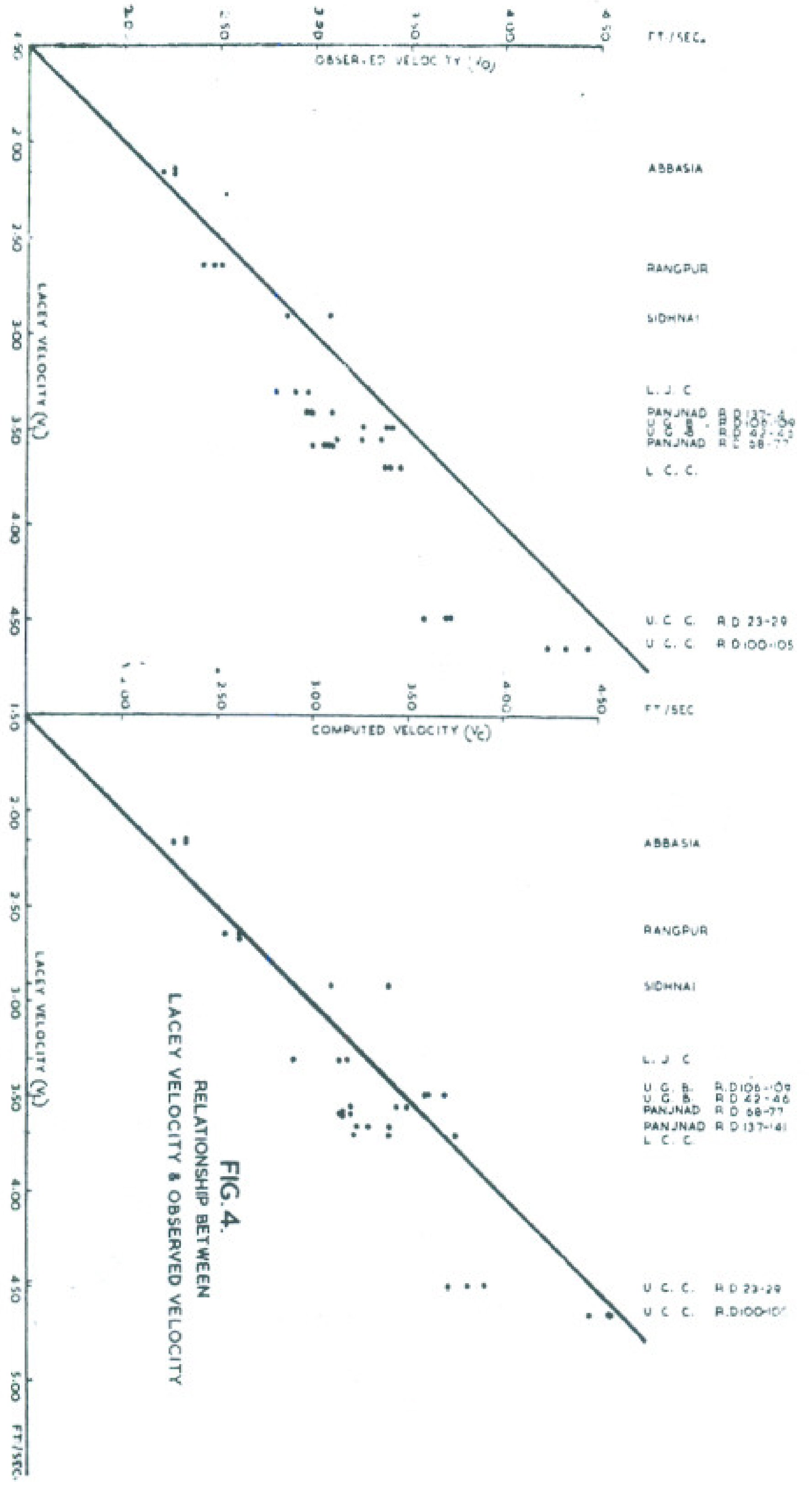


FIG. 4.
RELATIONSHIP BETWEEN
LACEY VELOCITY & OBSERVED VELOCITY

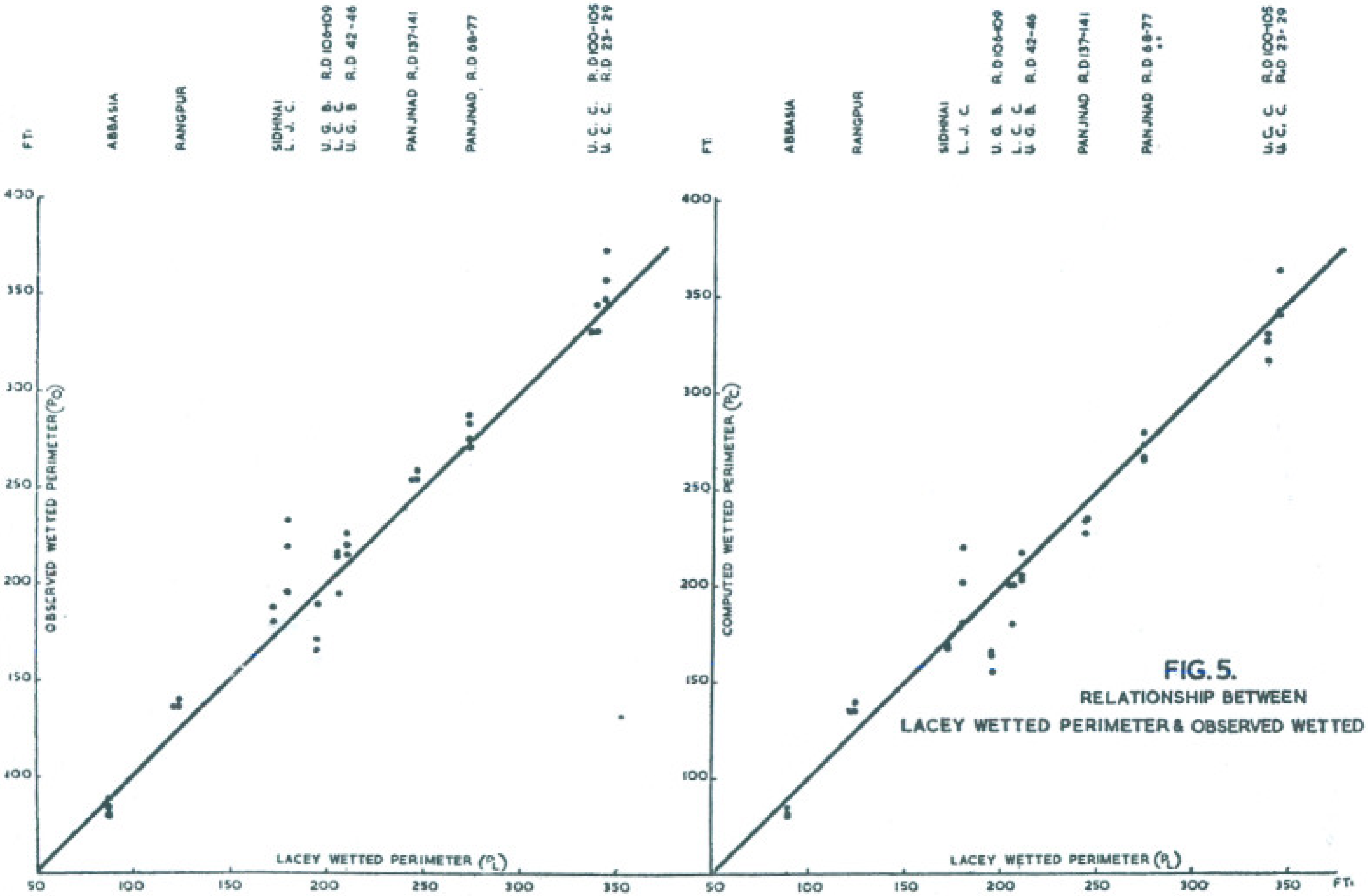


FIG. 5.
RELATIONSHIP BETWEEN
LACEY WETTED PERIMETER & OBSERVED WETTED PERIMETER.

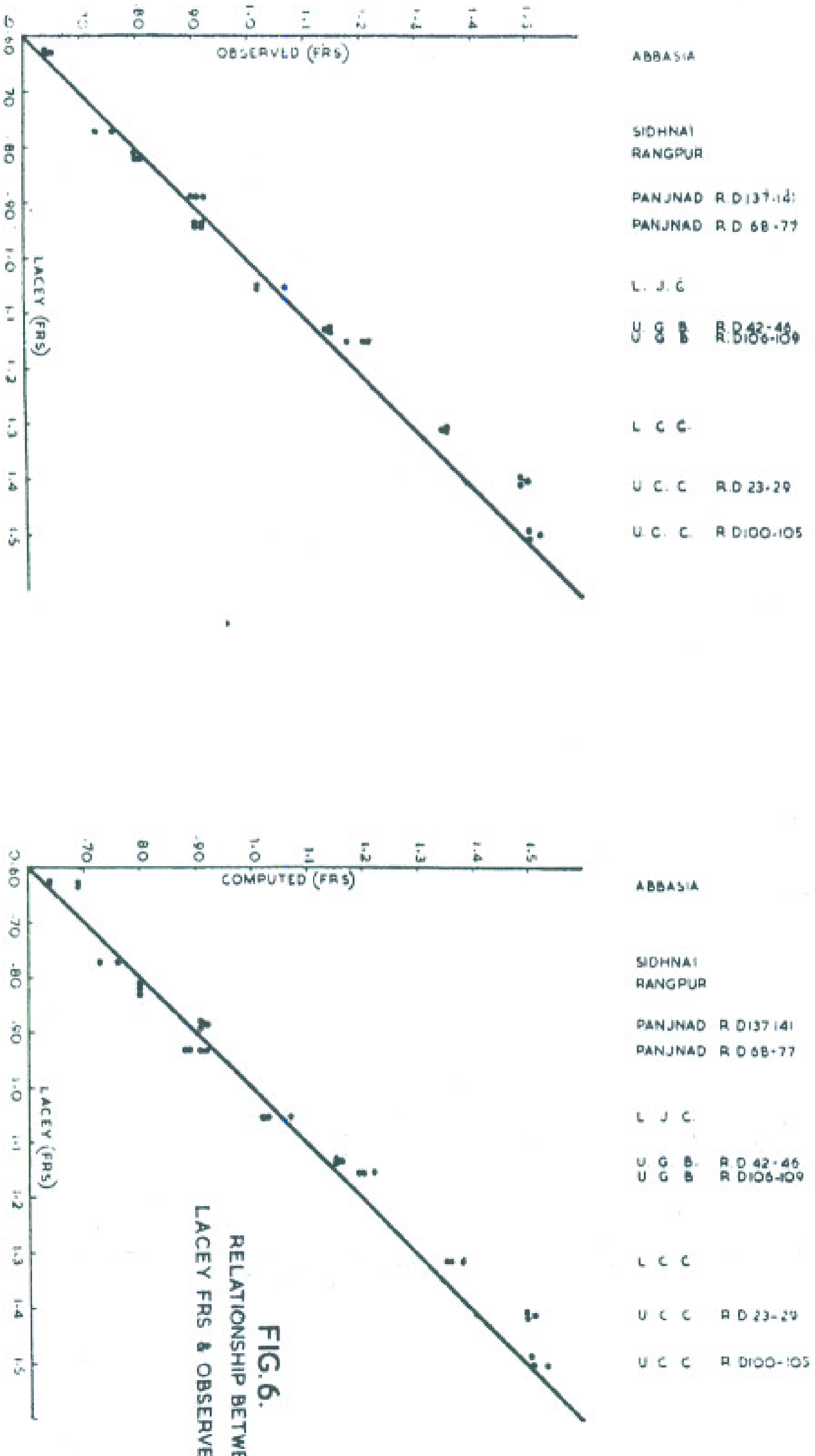
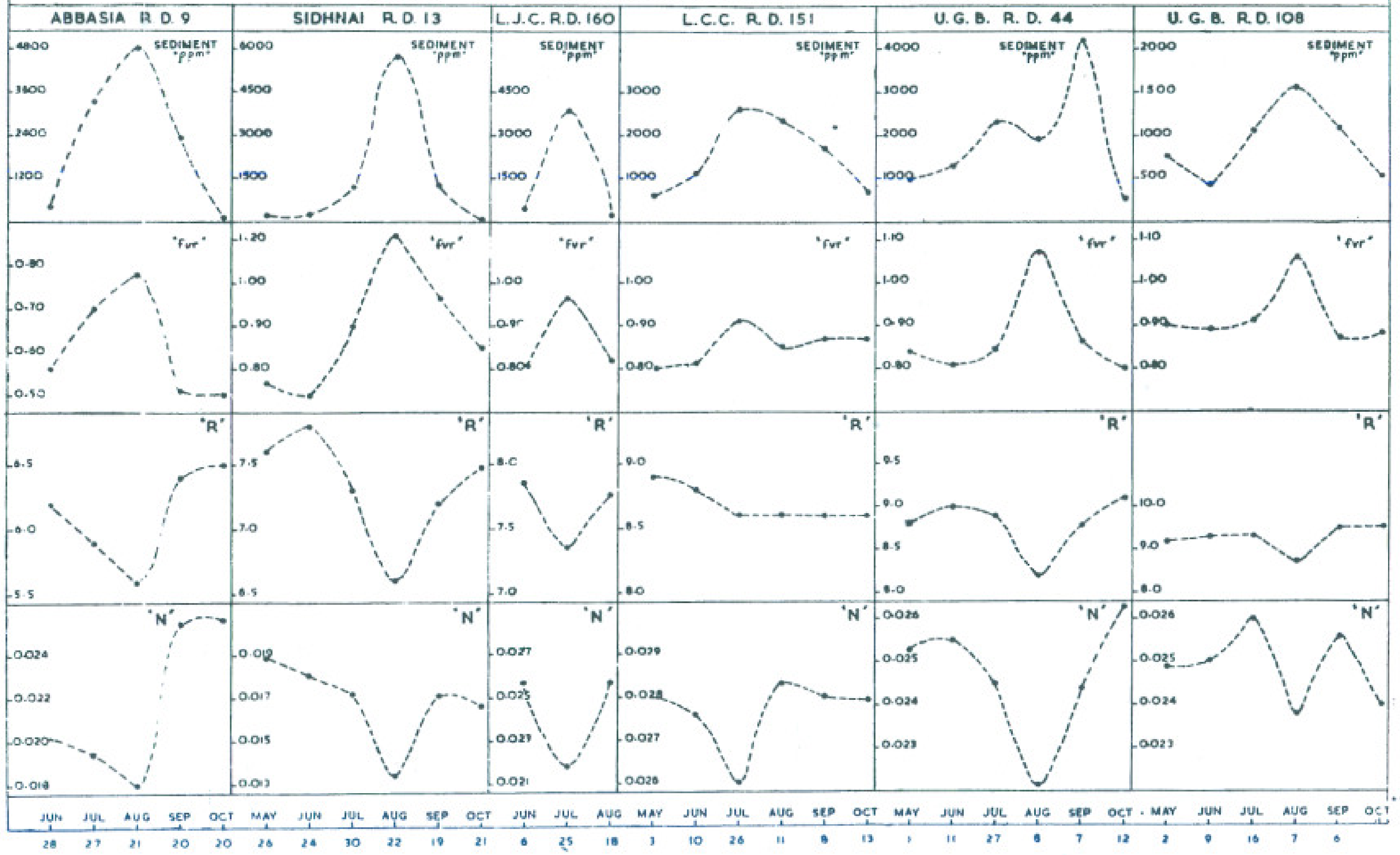


FIG. 6.
RELATIONSHIP BETWEEN
LACEY FRS & OBSERVED FRS

SHEET I

FIG:-7 RELATIONSHIP BETWEEN N, R, fvr & SUSPENDED SEDIMENT LOAD



SHEET II

FIG:-7 RELATIONSHIP BETWEEN N, R, fvr & SUSPENDED SEDIMENT LOAD

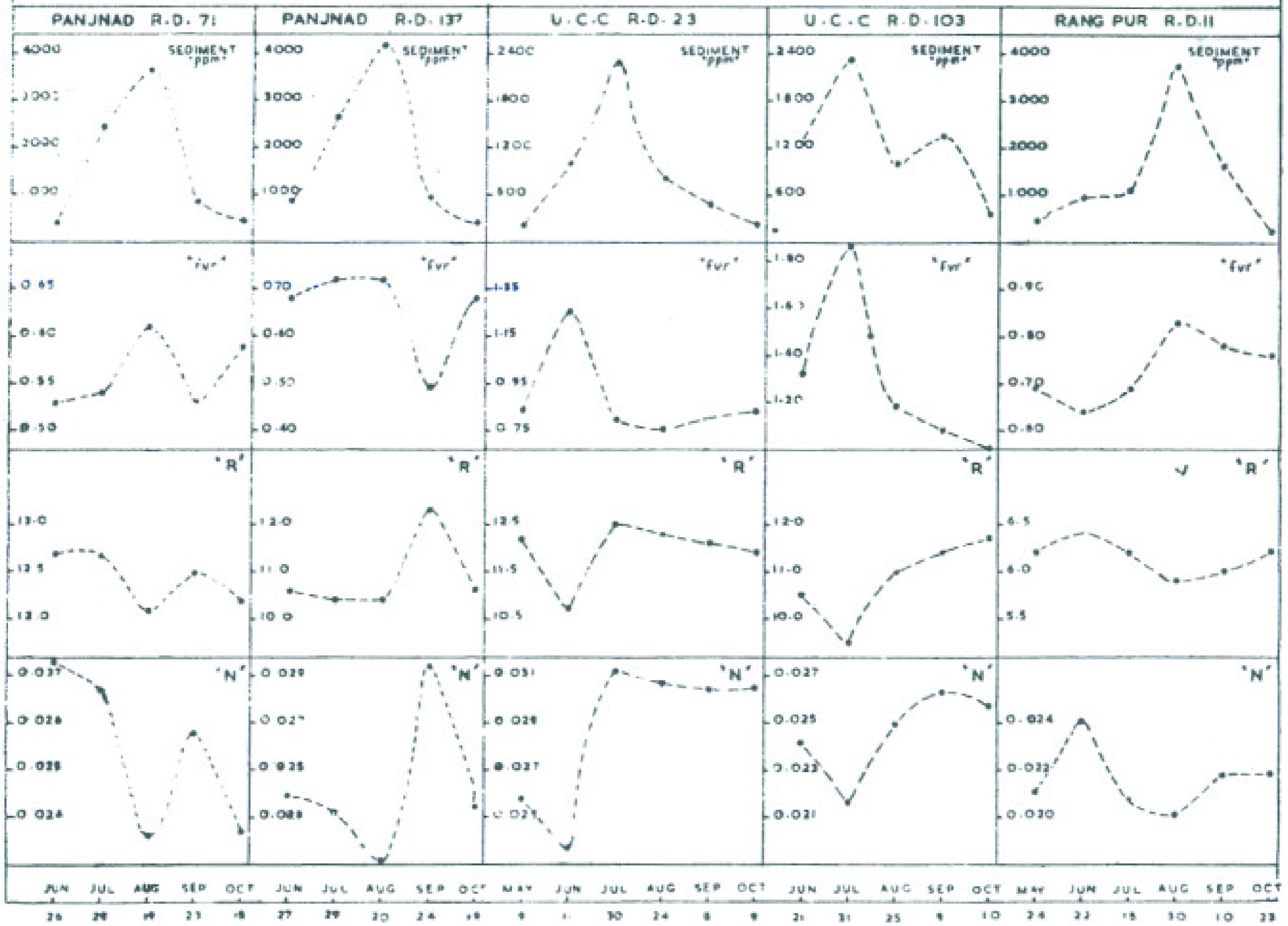
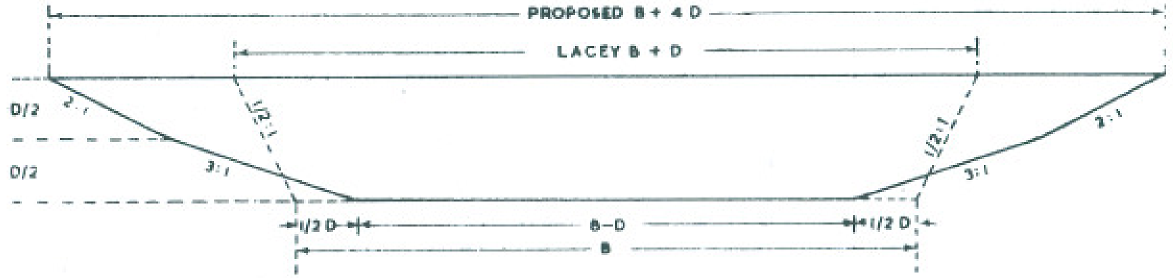


FIG. 8.

SUGGESTED SECTION



1. LACEY SECTION $P = B + 2{\cdot}236\ D$

$A = BD + 0{\cdot}5\ D^2$

2 PROPOSED SECTION $P = B + 4{\cdot}381\ D$

$A = BD + 1{\cdot}75\ D^2$

3. ADDITIONAL (2 − 1) $\Delta P = 2{\cdot}145\ D$

$\Delta A = 1{\cdot}25\ D^2$