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A NEW APPROACH FOR THE DESIGN OF ALLUVIAL CANAL SYSTEMS IN PAKISTAN

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ABSTRACT

The surface water of the indus River and its tributaries is one of the major water resources of Pakistan. The design of the existing irrigation system is mostly based on the regime theory put forward by Gerald Lacey during the period 1924-1934. Some cansls that were designed using the Lacey theory have not been satisfactory. A common problem is siltation. In this research study Lacey's empirical formulae have been modified to include the effect of the concernation of transported sediment. Alluival Channel Observation Project (ACOP) data from a number of cansls have been analyzed and equations have been developed for the design of stable silt canals. the use of Lacey's slope equation requires selection of the proper value of the silt factor, which is dependent on silt grade and silt charge. The Indus Basin of Pakistan has been divided into three basic units : Indus, Jhelum and Chenab. A separate equation for calaulating the silt factor for each unit was developed which can be used to determine the value of equilibrium slope.

The design methodology developed as a result of this research will sharply reduce the construction and maintainance costs of the irrigation network in Pakistan. This approach can also be used elsewhere in the world to develop similar equations for the design of silt-stable canals.

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1. INTRODUCTION

The objective of this study is to provide a procedure for the design of an efficient canal system requiring little or no maintenance. The cansl should be capable of coveying the required supply of water to the entire irrigated area, without the need for dredging or excavation of sediment for the full life of the project. Without proper deisgn, the network of the system may fail, and this will result in disaster to the area.

Dealing with sediment is one of the major difficulties in canal system design, yet one of its most important aspects. Generally it is common for canal water to be taken directly from a river in which there is a natural supply of sediment. The source of this sediment is erosion of the catchment land surface, land slips, channel migration and degradation, and other geomorphic processes. Fluvival sediment transport consists of the material forming the stream beds, travelling both close to the bed as a contact load and in suspension, plus the finest fractions of the sediment yield from the catchment which are classified as wash load.

Whether the sediment enters the canal or not depends on several factors :

* the range of sizes being transported by the river
* the transport rates, or concentractions involved
* their variability as river conditions change seasonally and during floods
* the effectiveness of the intake works in excluding the intermediate and coarser fractions (the finest wash load is so uniformly distributed that it cannot be controlled by the hydraulic performance of the intake structure)
* the sediment transporting capacity of the canal system, which depends on its hydraulic and other paremeters such as velocity, gradient, depth, and width.

The sediment transporting capacity of the canal system must be matched to the supply, as must its water transporting capacity. However, there are overriding constraints on the quality of the sediment and on the range of the size which can be accepted in a canal system. Exessive quantitites and different sizes of sediment can only be conveyed by rapid flows invoving steep gradients which are inconsistent with unlined earth channels. This research is confined only to transport of the alluvival materials with d50 in the range of 0.08 to 0.35 mm.

The available methods for the design of unlined sediment transporting channels fall into two categories. The regime method relies on the functions describing channel cross-section and gradient in terms of discharge, bed sediment properties, bank material, and (in some formulae) transport rate. What might be called the phsical method relies on formula describing processes that govern channel behavior and stability (namely bed sediment transport), the resistance to flow by whatever sediment features characterize the bed and banks, and the resistance to scour (or other failure mechanissms) of the material forming the banks. Thousands of miles of canals in Pakistan have operated successfully,some of them for many decades, under their original regime design. But, today there are many problems with some portions of the canal system, some of which wsere caused by improper original design. There is urgent need of an appropriate procedure to redesign the canals to be remodelled. The regime theory is expected to lay an important role in providing clear guidelines based on many decades of experience. The empirical evidence from the Canal and Headworks Observation Progrm (CHOP), the Alluival Channel Observation Program (ACOP), the Irrigation System Management and Rehabilitation Program (ISMRP), and the modern concepts of fluid mechanics and sediment transport are utilized to modify the regime theory. Most of the channels designed under Lacey's therory have gone through adjustment in geometric parameters and operate without any problems. Herein, the fundamentals of the regime theory are re-examined in three parts : the concepts of alluvial channels in regime, the database, and the formulations.

2. ALLUVIAL CHANNEL SYSTEM IN PAKISTAN

The Indus irrigation system in Pakistan, consisting of a contiguous network of about 60,000 miles of alluvial canals and their sub systems, is the largest system of its kind in the world. The system serves a culturable command area of 34.5 million acres and has a diversion capacity of about 250,000 cubic feet per second. It encompasses 3 storage reserviors, 19 barrages (headworks), 12 link canals, 43 canal commands, and some 90,000 watercourses. The length of such watercourses and farm channels is about 1 million miles. Currently, the total annual surface water diversion at the canal heads of the Indus Basin irrigation system is about 100 million acre feet.

The Pakistan irrigation system is primarily based on the Lacey design theory of regime channels. At the time of adoption of the standard design equation, knowledge about sediment theory was scanty, and hence, the standard design practices were lacking. Such inadequacies, when coupled with other deficiencies, such as sediment discharge imbalance, hydrualic bottlenecks, inadequate operational practices, and low standards of maintenance, caused serious degradation of the irrigation system tending towards total

collapse. Generally, the sediment inflow at canal headeowrks is greater than the sediment transport capacity of branches, distributaries, and minors comprising the system. For individual canal systems, the sediment inflow is also greater than the net sediment export with irrigation water supplies delivered at the outlets. As a result, huge quantities of sediment accumulate in the channels and must be periodically removed in some of the canals. The causes and magnitude of sediment discharge imbalance vary between different provinces (states) and between different systems within a province, depending on available slope, design, and operation practices.

During the design and operation of the canal system, it has been noticed that the regime equations are applicable in the cases of steady operational discharges, small bed material load, steep cohesive erodible banks, uniform sections, mild slope, low Froude number, smooth alignment, and bed mateial in the sand size range.

The Indus Basin has been divided into three distinct units : the Indus, Jhelum, and Chenab. These three units have altogether different bed material characteristics from source to point of outfall. The sediment transported in the Indus unit is considered finer when compared to either the Jhelum or Chenab. Most of the sediment concentration in the Indus River is transported as bed load, whereas the Chenab River normally has a substantial quantity of fine material in suspension. The Indus is clasified as a braiding river, and the Chenab as a meandering type of river. The Jhelum River carries less bed or suspended load when compared to the other rivers because of the number of check dams constructed in its catchment. The Indus unit carries a heavy sediment load. Runoff conditions of the Indus and the Chenah are quite similar, with a high peak in July and low winter flows. The Jhelum is an early rise river, and its peak is normally reached in June. there is also a different pattern of seasonal variation of silt. The flashy type streams joining these rivers have different sediment characteristics, and there is wide variation in the number joining each river. These three units have different physiographical, geological, vegetational, climatological, and hydrological characteristics.

The Indus Basin irrigation system is designed to carry large volumes of water for long distances to serve a very large number of farmers. the canal embankments are the most important feature of the system, as they confine the water supply. The canal banks have been constructed from locally available soil, and the water level is often well above the surrounding land. A failure of an embankment causes considerable economic damage to the surrounding areas, not only by covering the farm land with a layer of sandy bed material,

but also by causing the loss of crops and the time and money spent to grow them. A failure also interrupts the supply of water to downstream users who may suffer considerable damage if the water is not quickly returned.

Canal failures are usually due to inadequate operation and maintenance procedures. Faulty operation of canal cross regulators is sometimes the cause of failure and is due to inattention to freebaord conditions and backwater effects. Canal structures seldom fail except for piping failures. they become inoperative due to lack of maintenance so that water cannot be distributed correctly. Embankment failures may occur occasionally downstream of structures due to inadequate stilling of the flow, and subsequent eddy action of the water which slowly erodes the canal banks.

In the past, the level of maintenance on canal structures decreased from the main head and the cross regulators in the downstream direction. The less important the structure, the less maintenance received. This represents the discrete utilization of a limited budget. A little effort spent at the start of the problems can save considerable time and cost at a later stage. Deferred maintenance may serve in the beginning when things are new and working well, but the canal will progressively deteriorate with time and massive amounts of repairs will be required.

3. SPECIFIC OBJECTIVES OF THE STUDY

The specific objectives of this study include :

* modify Lacey's regime therory considering recent data and developments in the field of sediment transport
* establish relationships of bed width, depth, and slope for a given discharge
* determine the silt factor relationship for the three major sources of canal supply, i.e., the rivers, Indus Chenab and Jhelum
* determine the equilibrium slope for a given discharge based on different types of bed materials
* finally, develop a sound technique for the design of stable alluival canals. The tasks and methodlolgies necessary to accomplish this are fully described in the next para.

4. METHODS, PROCEDURES AND FACILITIES

4.1 Data Collection

Under the ACOP and ISM Project, hydraulic, sediment and morphologic data have been collected by WAPDA for the entire main canal system and are avilable for analysis. WAPDA also performed equilibrium experiments on selected study reaches in a canal system.

An important criterion of the selection of the study reaches, is that they be straight channel reaches (8,000 - 10,000 ft in length), have uniform, steady flow, be uninterrupted by structures or constraints, and be in a visible inflow-outflow balance.

The massive data available pertain to hydraulic, sediment load, bed morphology, air temperature, water temperature, and sediment size distribution. The derived variables include Froude number, Manning's coefficient and average boundary shear stress.

4.2 Procedure

Under the Pakistan system of canal classification, the canals can be grouped based on discharge delivered at the head such as minor, disty, major disty, branch canal, main canal and link canal. In this study these categories are divided into three groups :

Group I	discharge	5 to 50 cfs
Group II	discharge	50 to 500 cfs
Group III	discharge	500 to 10,000 cfs

Regime equatations were formulated for each of the three groups of canals. A set of 20 canals in each category were analyzed to determine the suitable relationship for the following :

* top bed width (B_t)
* mean depth (D)
* bed slope (S)

The selected canals in each group are in regime and do not have any major problem in distributing canal supplies. All canals beds are in the ripple zone. For all cases, the discharge is considered constant and one sediment type is considered. The object is,

therefore, to formulate a relationship for the geometry of the stable alluival canal by taking discharges (Q) as the only independent variable. This will provide dependable values for all design purposes within the three basin systems.

4.2.1 Width Predictor

Lacey related top width of the canal directly to the discharge. the same concept was utilized to write statistical model in the following general form :

$$\beta_t = \beta_o + \beta_1 + Q^{1/2} + \beta_2 Q + \beta_3 Q^2 + e_i \quad (1)$$

where

β_t = dependent variable, top width (ft)

Q = independent variable, flow rate (cfs)

β_o = Y intercept

$\beta_1, \beta_2, \beta_3$ = partial regression coefficients

e_i = Random error (normally and independently distributed with constant variance)

A set of 20 values for each of the categories of canal were used to determine the relationships. Only the significant terms of equation (I) have been included in the developed equations.

4.2.2 Depth Predictor

For depth the following relationship was used, keeping in view the work done by other researchers in this field.

$$D = \beta_o + \beta_1 Q^{1/3} + \beta_2 Q + \beta_3 Q^2 + e_i \quad (2)$$

where

D = Depth as dependent variable (ft)

The rest of the variables have been defined above. A set of 20 values for each of the categories of canal was used to determine the relationships.

According to long-term observations by the authors, there is fairly good agreement between observed depth of alluival channels and the depth predicted by regime equations, at least as long as the climatic and soil conditions are similar to those in Pakistan.

4.2.3 Slope Relationships

Determining the correct slope is one of the most critical factors in table channel design. If a channel is constructed with an excessive slope, the upper end of the channel begins to degrade and over a period of years will adjust to a new slope that suits existing conditions. The other danger is selecting a slope that is too small to maintain velocities capable of conveying the influx sediment through the system. According to researchers, slope may be considered to be either a dependent variable or indepdent variable, depending upon the time frame and the geological setting. In case of self formed sand bed canals, the slope is assumed to be a dependent variable and can be determined as a function of discharge, bed material and bed load transport. In case of gravel bed channels, it may be controlled by resistant rock outcrops, which on an engineering time scale means that slope may be an independent or imposed variable. In this study, the slope is considered as a function of discharge, silt factor, sediment concentration and sediment grade.

A modified silt factor is required if Lacey's slope equation is to be used for determining equilibrium slope. In the past its value has been either assumed based on experience or obtained from adjoining successful operating canal systems. The difficulty arises from the fact that the interaction between the water sediment mixture and the alluvial sand molds the bed into different arrays of configuration such as ripples, dunes, antidunes, etc. This change in bed form changes the roughness, which in turn changes both the depth and the velocity of flow. Under these circumstances the most likely approach would seem to be empirical, based on observed parameters associated with canals known to have operated successfully. Twenty canal data sets have been selected for each unit of the Indus basin and relationships have been determined using the total sediment concentration for each of the three units. The effect of temperature variation is not completely understood. It is known, however, that the viscosity of the water-sediment complex changes with temperature which changes the ability of the liquid to transport sediment. An attempt has been made to collect data from areas of different climate and environment, so that the effect of temperature variation is indirectly incorporated. Water temperature ranges from 50° to 85° F in the Indus Basin.

5. ANALYSIS OF DATA

Data sets for different canal groups have been selected from equilibrium experiments conducted by WAPDA on different canals during the period 1974-87. The data sets selected are for regime canals that have been stable over a period of time. The maximum value of stream power is 0.15, and the Froude number is limited to 0.35. Thus, the channels do not experience transitional and super-critical flows. The data sets include observations taken from Thal, Muzaffargarh, Depalpur, Mailsi, Lower Jhelum, Haveli, Lower Chenab, Upper Chenab, Bahawalpur, Rahimyar Khan and Lower Bari Doab Canal of the Punjab Irrigation Department. Some observations have also been taken from other provinces of Pakistan. The data were sorted into three groups for analysis.

5.1 Analysis of Data for Discharge Range of 5 to 50 cfs

5.1.1 Width Predictor

Basically the regime rules state : Bed width $\propto Q^{1/2}$

The width of an alluival channel is very important for its hydrualic performance. A number of researchers have indicated that the width depends on a large number of variables such as density, cohesion of the banks, grain sizes of the bank and bed material, discharge, depth and water surface slope in the canal. Based on Lacey's the width only depends upon the discharge over the bed of the canal. An analysis has been performed using simple linear regression. Top surface with (B) in feet is the dependent variable and discharge in cfs is the independent variable in the regression analysis. A maximum R^2 (coefficient of determination) concept was used to obtain the best value of the exponent of the independent variable. The prediction equation is :

$$B_+ = 0.045164 + 2.10\,Q^{0.57} \quad (3)$$

The value of the regression constant is so small that the equation for all practical purposes can be reduced to :

$$B_+ = 2.10\,Q^{0.57} \quad (4)$$

5.12 Depth Predictor

According to the fundamental rules of the Lacey's regime theory,

$D \propto Q^{1/3}$

Keeping in view this relationship, efforts were made to find a relationship between D (ft) and Q (cfs). For this range of discharge, it was found that the depth of flow is a power function of the discharge intensity. The resulting equation is :

$$D = -3.38533 + 4.011490\, q^{0.34} \quad (5)$$

The variable q is the discharge per foot of width of channel.

The equation recommended for practical use is :

$$D = 4\, q^{0.34} - 3.4 \quad (6)$$

5.2 Analysis of Data for Discharge Range of 50 to 500 cfs

5.2.1 Width Predictor

A set of 20 observations was used for regression analysis. The hydrualic data of canals is given in Tables 1 and 2. The resulting equation is :

$$B_t = 2.527344 + 1.486922\, Q^{0.56} \quad (7)$$

The recommended equation for practical use is:

$$B_t = 2.5 + 1.487\, Q^{0.56} \quad (8)$$

5.2.2 Depth Predictor

The result of regression analysis for this variable is :

$$D = 0.609019\, Q^{0.34} - 0.52305 \quad (9)$$

The recommended equation for practical use is:

$$D = 0.61\, Q^{0.34} - 0.5 \quad (10)$$

The description of data set and regression results are presented in Tables 3 and 4. The plots of both top width and depth versus discharge are given in Figures 1 and 2 respectively.

5.3 Analysis of Data for Discharge Range of 500 to 10,000 cfs.

The canals taken in this group consist of mostly branch and main canals that run at or near full capacity. There are no structure of diversion in these canals and, therefore, very little disturbance to flow. The data collected are representaive of the system and accepted as standard by both national and international authorities (International Alluvial Seminar 1985, Lahore - Pakistan).

5.3.1 Width Predictor

For the regression analysis of this group, 20 observations were selected and the resulting equation is :

$$B_t = 7.699163 + 1.353715\, Q^{0.57} \quad (11)$$

For practical use by the design engineers the equation reduces to :

$$B_t = 7.7 + 1.354\, Q^{0.57} \quad (12)$$

5.3.2 Depth Predictor

The normal depth of flow in the canal is the result of balancing the downstream component of the gravity force acting on the fluid and the shear and pressure forces of the canal boundary resisting movement of the fluid. The observed depths for the canals designed using Lacey's concept are less than the design depths. The resulting equation is:

$$D = 0.771941\, Q^{0.33} - 2.12449 \quad (13)$$

for practical purposes the equation reduces to :

$$D = 0.77\, Q^{0.33} - 2.1 \quad (14)$$

All regression equations developed herein have certain limitations. These sets of equations do not define actual physical relationships. Their use as estimating equations is valid when limited to the range of values used in each group to derive the equations.

5.4 Slope Relationship for indus River

The detail of canals considered for finding relationship between silt factor and total bed material load is given in Table 5. The relationship developed is given in Table 7. The resulting equation for silt factor for this river can be written :

$$f_c = \frac{(0.46 + 0.0046\, C_t)^{2/3}}{1 + \frac{C_t}{465}} \quad (15)$$

f_c = calculated silt factor

C_t = total concentration of bed material load (ppm)

After calculation of the silt factor, fc can be substituted for f. The slope equation can then be used to determine optium slope. The observed and calculated slope are compared in Figure 3. The graphical represnetration (Figure 3) indicates that both are in fair agreement. The summary of data for the Indus River is given in Table 6.

5.5 Slope Relationship for Jhelum River

With the construction of Mangla Dam on River Jhelum in 1967, the sediment entry into the system has been significantly restricted. Most of the canals in head reaches are scouring material downstream of the diversion and depositing the entrained material in the lower reaches. However, the lower part of the system i.e., Lower Jhelum Canal and its offtakes are still in regime, because of the distant location from Mangla Dam. The resulting equations is :

$$f_c = \frac{(0.5 + 0.005\, C_t)^{3/4}}{1 + \frac{C_t}{470}} \qquad (16)$$

The design slope can then the determined making use of Lacey's slope equation.

5.6 Slope Relationship for Chenab River

The resulting equation for silt factor becomes :

$$f_c = \frac{(0.33 + 0.0033\, C_t)^{7/8}}{1 + \frac{C_t}{395}} \qquad (17)$$

The value of the exponent of the denominator obtained for the silt factor is 7/8. This value is different than 3/4 obtained for the Jhelum River.

A comparision of results by different regime methods for discharge oif 4000 cfs is presented in Table 8. The new design method has edge over the others in respect of channel slope. A steeper slope means better sediment transport capacity for an alluival channel. The computed bed width and depth are very indentical to values of other methods. The summary of proposed design equation for stable regime canals is given in Table 9.

Table 10 shows an application of these developed equations for typical channel discharges of 50, 500 and 5000 cfs.

6. CONCLUSIONS AND RECOMMENDATIONS

The general objective of this study was to develop a new design procedure for silt stable canals. This objective was achieved through modification of Lacey's regime equations. The design procedure was compared with several commonly used procedures.

The major modification of Lacey's regime theory was to include the sediment (concentration and sediment size) in the slope equation. For a regime canal, it is essential that the sediment transport capacity O.K. the intake rate of sediment supply at head.

The suggested approach can be regarded as a good criteria for the design of silt stable canals with sediment transport giving fairly dependable average values for engineering application. These equations are applicable within the following range of variables :

Bed material size	0.08 to 0.35 mm
Discharge	5 to 10,000 cfs
Bed material	non cohesive
Bed form	ripple and dunes
Froude number	less than 0.35

Some specific conclusions drawn from this study were :

1. The design of stable silt canals is site specific and universal application of the design methodology is not at this time possible. Each canal has a different relationship for velocity and depth (Hazra, 1963). In the proposed procedure, the hydraulic geometry of the alluvial canals is expressed as simple exponential functions of the discharge only. The values of the exponent vary from region to region and with the size of the canal. This approach is unique in the sense that for the first time mass scale observed data of the regime canals were available for formulation of the design guidelines.

2. The suggested approach for the design of stable silt canals is very simple to apply and suits the practicing engineer's need. There is no trial and error procedure involved and no assumption of basic parameters is necessary in the design process.

3. Hydraulic geometry relations are better defined for top width and flow depth in the channel when based on discharge as the single independent variable.

4. The silt factor (f) in the regime equation was quantified during this study. Because modern sediment transport formulas are inaccurate, the silt factor better incorporates the sediment transport concept. With the availability of data, complete in the sediment transport sense, the explicit relations for silt factor have been obtained for all active rivers of the Indus Basin. It was shown that about 98% of the measured slopes are with $\pm$ 10% of the computed slopes. The calculated silt factlr relation is both accurate and efficient.

   Design construction, maintenance and monitoring of the silt excluders and silt ejector must be such that most of the coarser material (>0.062 mm) is excluded from the canal. The suggested design approach assumes that sediment concentration in the vicinity of 500 ppm (excluding wash load) or even less is maintained. For this purpose, additional research is needed to develop reliable cost effective silt extractor. Setting basins at the point of diversion can also be helpful, but require substantial maintenance.

6. The intertransfer of supply between rivers through link canals is causing problems due to different sediment characteristics and needs to be evaluated seperately. It is essential that the concentration of sediment entering the canal be controlled.

7. The value to be used in the calculation of the silt factor is the average value during the annual period of operation. There will be seasonal variations and it is essential that large charges of sediment be excluded from the canal. It is desirable to keep the same value of silt factor throughout the system from head to tail.

8. The presence of a huge quantity of fine particles (wash load) in suspension affects the turbulence characteristics, specific weight and the apparent viscosity of flow and thereby increases the sediment transport capacity of the canal. It has been observed that the magnitude of the silt factor decreases at very high rates of sediment concentration.

9. The upper limit of velocity for the design of stable silt canals in the Indus Basin ranges from 3.5 to 3.7 ft/sec.

10. In this study, the stability of side slopes has not been considered. The existing practice is to assign value on the basis of the angle of repose alone, which is not a sufficient criteria. It is strongly recommended that additional research be done to check the stability of the slopes, especially where the channel is deep.

7. RECOMMENDATIONS FOR FUTURE STUDY

The relationships developed in this study for the design of stable silt chanls have general applicability in the Indus Basin. If the channels are constructed or remodelled using this new concept of design, the system should be monitored to study the interaction of hydrulic and sediment transport conditions. Data colelcted from the rebuilt system could then be used to adjust the coefficients in the Lacey equation if needed.

Ultimately, when better bed material equations become available, the transport capacity of the channel will be matched to the annual sediment input at the channel head. This should become a step in the design procedure.

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Table 1 : DISCHARGE RANGE 50 TO 500 CFS

List of Canals

1. Khikhi Disty RD 108 + 000
2. Jharkil Disty
3. Dasu Disty
4. Dasu Disty RD 50
5. Hayat Disty RD 50
6. Hayat Disty RD 110 + 500
7. Hayat Disty RD 76 + 000
8. Janiwala Disty
9. Hukkam Disty RD 93 + 500
10. Tarkhani Disty (Thal)
11. Tandlianwala Branch
12. Chelenwan Branch
13. Inayat Disty RD 54
14. Bhagat Disty
15. Bhagat Disty RD 61 + 000
16. Tarkhani Disty RD 38 + 800 (L.G.)
17. Haveli Disty
18. Khakhi Disty Rd 22 + 000
19. Nehranwala Disty
20. Shujra Disty

Table 2: HYDRAULIC DATA OF CANALS Discharge range Q = 50 to 500 cfs								
S. #	Q cfs	B_t ft	D ft	1/S ft/ft	d_{50} mm	G	T_w F°	C_t ppm
1	64.6	16.0	1.92	2697	0.143	1.30	67.1	3631
2	146.0	29.0	2.50	6267	0.095	1.52	70.7	188
3	263.0	29.5	4.00	5235	0.156	1.32	77.0	598
4	143.0	26.0	2.70	3901	0.156	1.30	80.6	543
5	314.0	39.0	3.40	5355	0.268	1.56	67.1	393
6	183.0	30.0	2.80	4486	0.211	1.69	70.7	382
7	278.0	35.0	3.50	5206	0.235	1.60	68.5	299
8	57.2	20.0	1.77	2976	0.175	1.30	75.2	663
9	85.0	21.0	2.30	4542	0.065	1.77	63.5	295
10	73.0	17.5	2.30	5331	0.112	1.33	71.6	462
11	441.8	55.0	4.45	7813	0.140	1.40	62.6	419
12	378.9	47.8	3.64	5464	0.125	1.20	86.9	---
13	342.0	34.5	3.60	5213	0.150	1.58	62.6	246
14	423.0	43.5	4.50	9867	0.263	1.34	66.2	477
15	319.0	41.0	3.90	6431	0.252	1.47	71.6	331
16	208.6	33.5	3.25	5155	0.125	1.20	80.6	21
17	116.5	24.5	3.03	4184	0.108	1.30	86.9	9799
18	237.1	34.5	3.55	3067	0.124	1.30	65.3	91
19	312.0	42.0	4.03	6061	0.109	1.40	82.4	2148
20	79.0	20.5	2.10	4551	0.191	1.20	80.6	293

Table 3: REGRESSION ANALYSIS FOR TOP WIDTH DISCHARGE RANGE 50 TO 500 CFS

Q cfs	B ft	D ft	$Q^{0.56}$	$Q^{0.34}$
64.65	16.00	1.82	10.32567	4.126608
146.00	29.00	2.50	16.29437	5.443521
263.00	29.50	4.00	22.65558	6.649438
143.00	26.00	2.70	16.10601	5.405230
314.00	39.00	3.40	25.01961	7.062461
183.00	30.00	2.80	18.49151	5.878051
278.00	35.00	3.50	23.37034	6.776028
57.29	20.00	1.77	9.649929	3.960470
85.00	21.00	2.30	12.03578	4.529001
73.00	17.50	2.30	11.05250	4.300607
441.82	55.00	4.45	30.29265	7.932013
378.98	47.80	3.64	27.79874	7.528865
342.00	34.50	3.60	26.24548	7.270576
423.00	43.50	4.50	29.56314	7.815481
319.00	41.00	3.90	25.24194	7.100498
208.00	33.50	3.25	19.89830	6.145636
116.59	24.50	3.03	14.36581	5.042719
237.15	34.50	3.55	21.38025	6.419598
312.03	42.00	4.03	24.93158	7.047364
79.00	20.50	2.10	11.55237	4.417669

Regression Output:

Constant	2.527344
Std Err of Y Est	3.422132
R Squared	0.901479
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	1.486992
Std Err of Coef.	0.115866

Table 4: REGRESSION ANALYSIS FOR DEPTH DISCHARGE RANGE 50 TO 500 CFS				
Q cfs	B ft	D ft	$Q^{0.56}$	$Q^{0.34}$
64.65	16.00	1.82	10.32567	4.126608
146.00	29.00	2.50	16.29437	5.443521
263.00	29.50	4.00	22.65558	6.649438
143.00	26.00	2.70	16.10601	5.405230
314.00	39.00	3.40	25.01961	7.062461
183.00	30.00	2.80	18.49151	5.878051
278.00	35.00	3.50	23.37034	6.776028
57.29	20.00	1.77	9.649929	3.960470
85.00	21.00	2.30	12.03578	4.529001
73.00	17.50	2.30	11.05250	4.300607
441.82	55.00	4.45	30.29265	7.932013
378.98	47.80	3.64	27.79874	7.528865
342.00	34.50	3.60	26.24548	7.270576
423.00	43.50	4.50	29.56314	7.815481
319.00	41.00	3.90	25.24194	7.100498
208.60	33.50	3.25	19.89830	6.145636
116.59	24.50	3.03	14.36581	5.042719
237.15	34.50	3.55	21.38025	6.419598
312.03	42.00	4.03	24.93158	7.047364
79.00	20.50	2.10	11.55237	4.417669

Regression Output:	
Constant	-0.52305
Std Err of Y Est	0.271397
R Squared	0.900697
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	0.609019
Std Err of Coef.	0.047663

Figure 1

Plot of Top Width Vs Discharge
Discharge Range 5o to 500 cfs

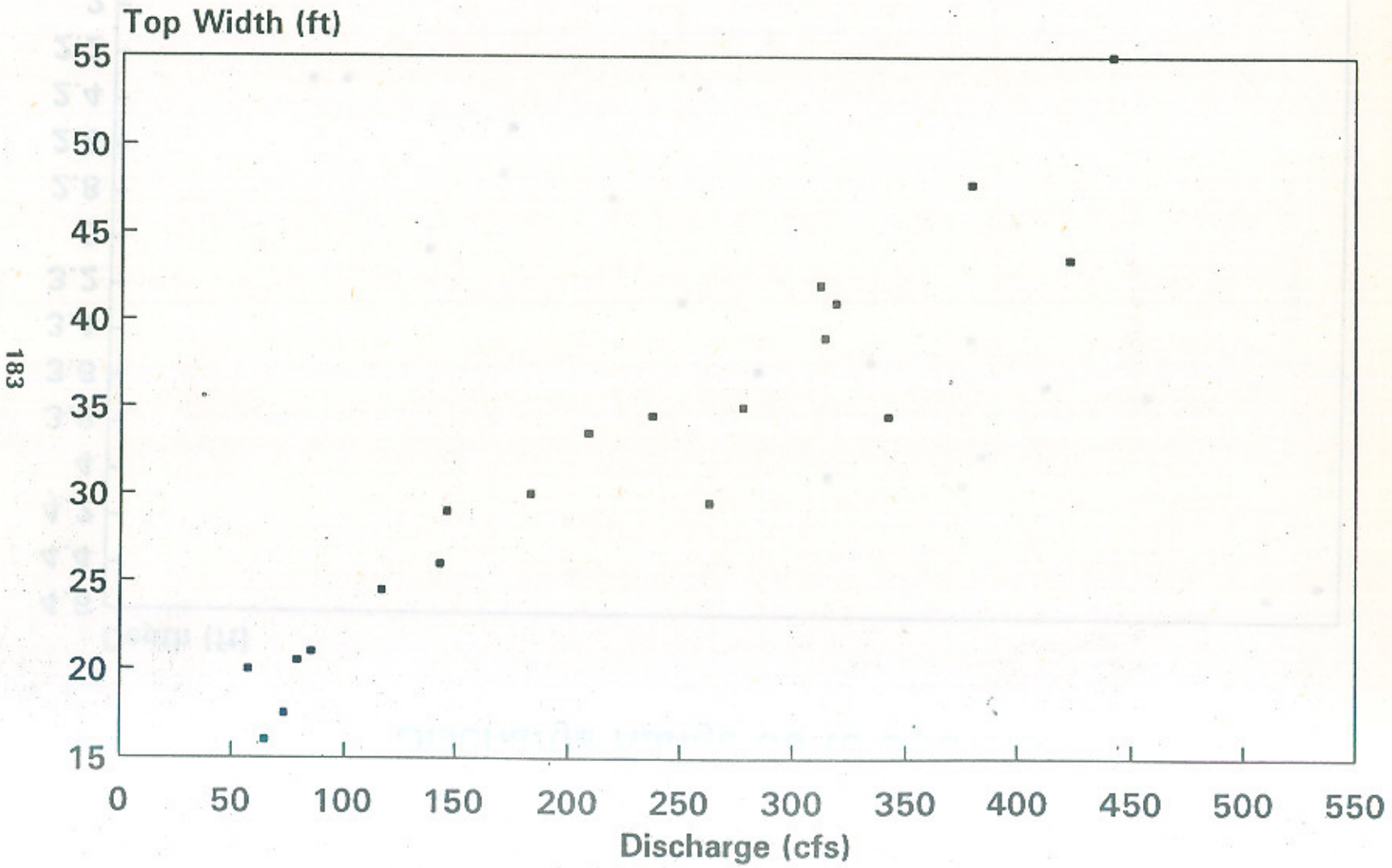


Figure 2

Plot of Depth Vs Discharge

Discharge Range 5o to 500 cfs

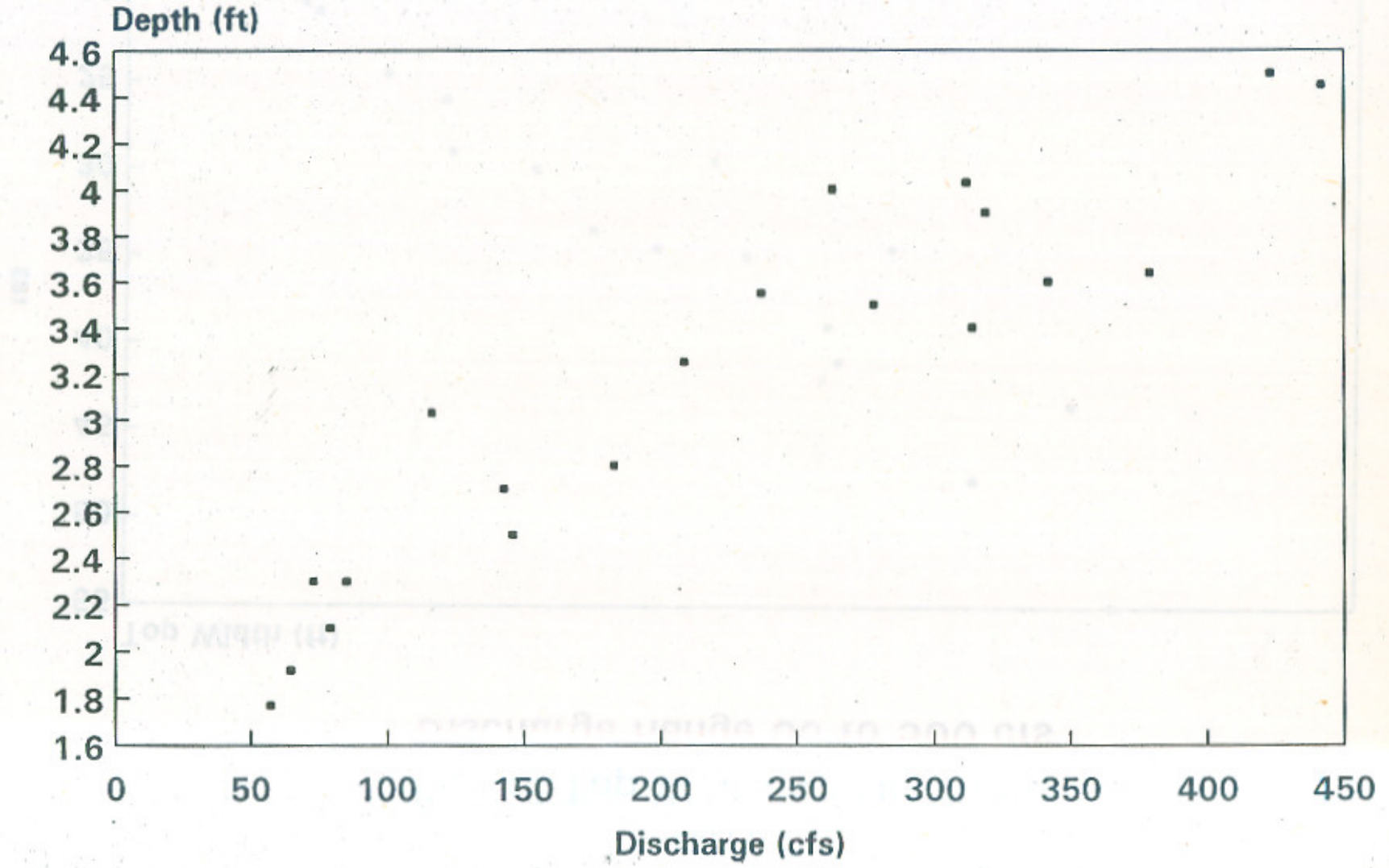


Table 5: INDUS RIVER

List of Canals

1. Mitha Tiwana Minor
2. Notak Minor
3. Dasu Disty
4. Tarkhani Disty RD 35 + 000
5. Moharan Disty RD 30 + 000
6. Damberwala Disty RD 32 + 000
7. Hukkam Disty
8. Dullewala Branch RD 23 + 000
9. Hayat RD 50 + 000
10. Inayat Disty
11. Dullewala Disty
12. Thal Main Line Upper RD 22 + 000
13. Hukkam Disty RD 93 + 000
14. T.P. Link RD 19 + 000
15. Dinga Minor
16. Kesho Minor
17. Tarkhani Disty RD 74 + 327
18. T.P. Link RD 174 + 500
19. Hayat Disty RD 76 + 000
20. Hayat Disty RD 110 + 500

Table 6: SUMMARY OF DATA FOR THE INDUS RIVER Data of Canals				
S #	Discharge cfs	Slope ft/ft (1/S)	Total Concentration ppm	Median Diameter of Bed Material d_{50} mm
1	28	3722	361	0.119
2	16	3366	484	0.130
3	263	5235	610	0.156
4	41	3621	335	0.099
5	36	3424	414	0.091
6	192	4636	534	0.148
7	174	7567	41	0.153
8	768	9522	86	0.210
9	314	5355	393	0.268
10	457	6714	224	0.160
11	273	5173	341	0.141
12	7610	10390	1636	0.315
13	85	4542	213	0.070
14	8668	10319	1736	0.134
15	107	4686	306	0.180
16	24	3583	525	0.250
17	3.4	2304	433	0.093
18	3189	7617	1280	0.162
19	278	5206	299	0.235
20	182	4486	802	0.211

Table 7: COMPUTATION OF EQUILIBRIUM SLOPE RIVER INDUS						
Q cfs	1/S ft/ft	CT ppm	f cal	S cal	CAL slope	OBS slope
28.0	3722	361	0.931537	0.000286	3613.505	3722
16.0	3366	483	0.949927	0.000313	3185.393	3366
263.0	5235	610	0.955950	0.000198	5030.642	5235
41.0	3621	335	0.925120	0.000256	3895.840	3621
36.0	3424	414	0.941579	0.000270	3710.510	3424
192.0	4636	534	0.953531	0.000208	4793.355	4636
174.0	7567	41	0.687585	0.000122	8140.544	7567
768.0	9522	86	0.760191	0.000113	8821.290	9522
314.0	5355	393	0.938038	0.000186	5348.059	5355
457.0	6714	224	0.881752	0.000158	6313.860	6714
273.0	5173	341	0.926700	0.000187	5331.728	5173
7610.0	10393	1636	0.890375	0.000100	9936.243	10390
85.0	4542	213	0.875559	0.000207	4824.070	4542
8668.0	10319	1736	0.882420	0.000097	10307.95	10319
107.0	4686	306	0.916555	0.000215	4644.294	4686
24.0	3583	525	0.953026	0.000294	3390.061	3583
3.4	2304	433	0.944346	0.000402	2483.733	2304
3189.0	7617	1280	0.919230	0.000122	8147.233	7617
278.0	5206	299	0.914237	0.000182	5470.215	5206
182.0	4486	802	0.952165	0.000209	4762.115	4486

Figure 3

Comparison of Observed and Predicted Slope River Indus

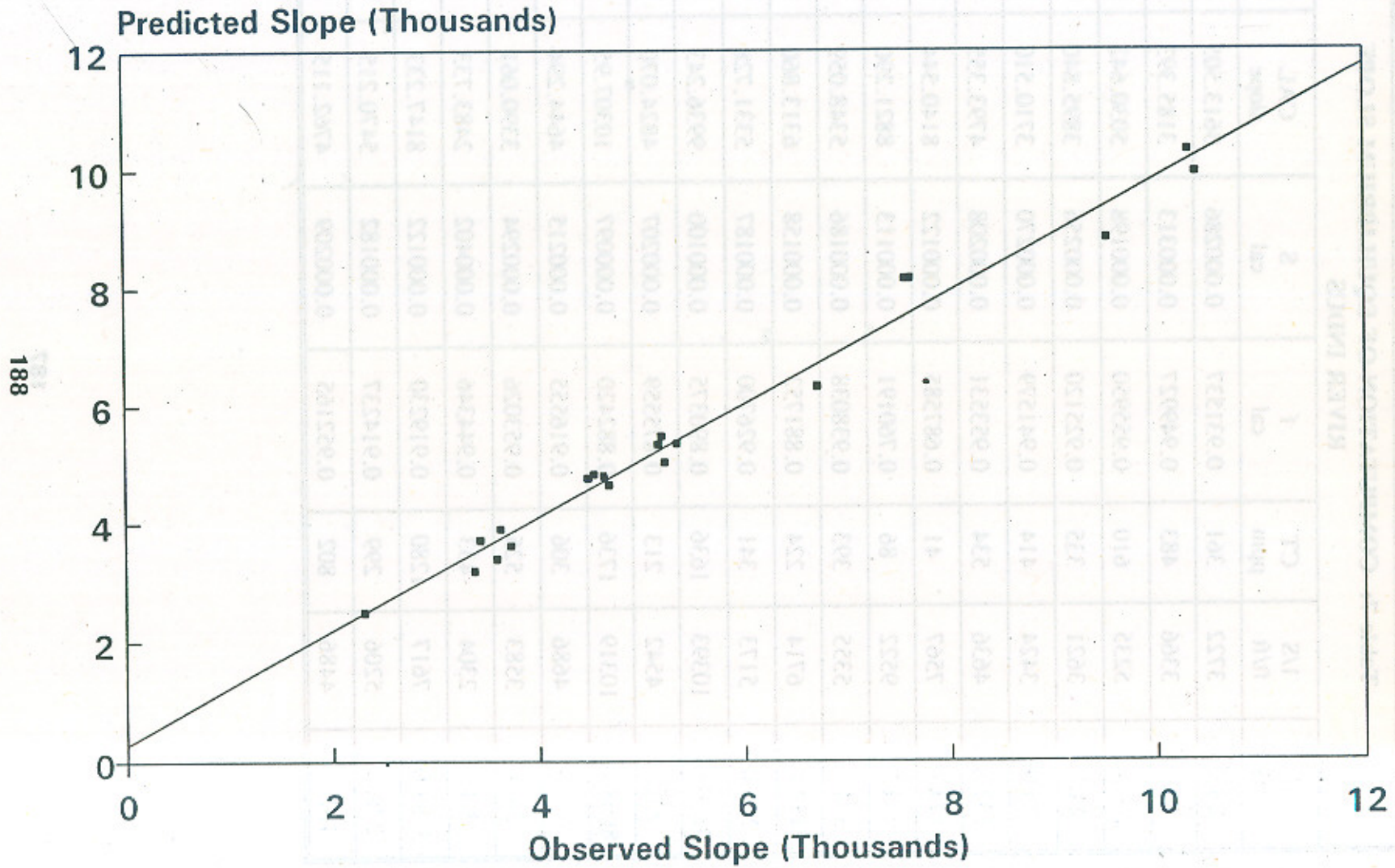


Table 8

COMPARISON OF RESULTS BY DIFFERENT METHODS
Q = 4000 CFS CT = 200 PPM D_{50} = 0.25 MM

REGIME METHODS	B_t ft	B ft	D ft	S ft/ft
Lacey	168.8	152.2	8.8	0.000095
Blench	152.2	137.8	9.6	0.000098
Simen & Albertin	163.04	148.0	10.1	0.000056
Chang Rational	180.0	0.0	8.4	0.0040
Shahid	160.75	142.75	9.79	0.00010

Table 9: SUMMARY OF PROPOSED DESIGN EQUATIONS FOR STABLE REGIME CANALS

DISCHARGE RANGE 5 TO 50 CFS

$$B_t = 2.1\ Q^{0.57}$$
$$D = 4q^{0.34} - 3.4$$
$$B_o = 0.89\ (B_t) - 0.8$$

DISCHARGE RANGE 50 TO 500 CFS

$$B_t = 2.5 + 1.487\ Q^{0.56}$$
$$D = 0.61\ Q^{0.34} - 0.5$$
$$B_o = 0.89\ (B_t) - 0.8$$

DISCHARGE RANGE 500 TO 10,000 CFS

$$B_t = 7.7 + 1.354\ Q^{0.57}$$
$$D = 0.77\ Q^{0.33} - 2.1$$
$$B_o = 0.89\ (B_t) - 0.8$$

CALCULATED SILT FACTOR ($C_t < 500$ ppm)

$$f_c = \frac{(0.46 + 0.0046\ C_t)^{2/3}}{1 + \frac{C_t}{465}} \quad \textit{FOR INDUS}$$

$$f_c = \frac{(0.33 + 0.0033\ C_t)^{7/8}}{1 + \frac{C_t}{395}} \quad \textit{FOR CHENAB}$$

$$f_c = \frac{(0.5 + 0.005\ C_t)^{3/4}}{1 + \frac{C_t}{470}} \quad \textit{FOR JHELUM}$$

Table 10: DESIGN EXAMPLE

GIVEN:

(I) Q = 50, 500 and 5000 cfs
(II) SAND BED AND COHESIVE BANKS (banks formed by sediment deposition)
(III) SEDIMENT LOAD 500 PPM, SOURCE RIVER INDUS
(IV) SEDIMENT SIZE $0.1 < d_{50} < 0.5$ mm

DETERMINE:

(I) MEAN WIDTH
(II) SLOW DEPTH
(III) SLOPE

SOLUTION:

Q = 50 cfs

$$B_t = 2.1 + Q^{0.57}$$

$$B_t = 2.1 + (50)^{0.57} = \underline{19.53 \text{ ft}}$$

$$B_o = 0.89\ (19.53) - 0.8 = \underline{16.50 \text{ ft}}$$

$$D = 4\ q^{0.34} - 3.4$$

$$D = 4 \left(\frac{50}{19.53}\right)^{0.34} - 3.4 = \underline{2.1 \text{ ft}}$$

$$f_c = \frac{(0.46 + 0.0046\ C_t)^{2/3}}{1 + \frac{C_t}{465}}$$

$$f_c = \frac{(0.46 + 0.0046 \times 500)^{2.3}}{1 + \frac{500}{465}} = 0.951$$

$$S = \frac{(0.951)^{5/3}}{1840 \times (50)^{1/6}} = \frac{1}{3856} = \underline{0.000259 \text{ ft}} \qquad (1 \text{ in } 3861)$$

Q = 500 cfs

$B_t = 2.53 + 1.487\ Q^{0.56}$

$B_t = 2.1 + 1.487\ (500)^{0.56}$, $B_t =$ 50.80 ft

$D = 0\ 61\ Q^{0.34} - 0.52$

$D = 0.61\ (500)^{0.34} - 0.52 =$ 4.5 ft

$$S = \frac{(0.951)^{5/3}}{1840(500)^{1/6}} = \frac{1}{5659} =$$ 0.000177 ft (1 in 5650)

Q = 5000 cfs

$B_t = 7.7 + 1.354\ Q^{0.57}$

$B_t = 7.7 + 1.354\ (5000)^{0.57}$, $B_t =$ 181.4 ft

$B_o = 0.89\ (181.4) - 0.8 =$ 160.7 ft

$D = 0.77\ Q^{0.33} - 2.1$

$D = 0.77\ (5000)^{0.33} - 2.1 =$ 10.69 ft

$$S = \frac{(0.951)^{5/3}}{1840\ (5000)^{1/6}} = \frac{1}{8298} =$$ 0.000120 ft (1 in 8333)