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EFFECTIVE STREAM POWER AND SEDIMENT TRANSPORT

BY

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INTRODUCTION

In the past several decades, there have been numerous attempts to determine the relationship between flow parameters and the rate of sediment transport. This subject plays a dominant role in a variety of hydraulic engineering problems, such as the design and operation of irrigation canals, control of reservoir sedimentation, scouring problems and the removal of suspended solid sediment in the process of water purification. In consequence, a great number of papers have been written and different methods for evaluating the sediment transport rate were established (9).

In fact, most of the available formulas were established on the basis of flume experiments operated at shallow depths. It becomes obvious, therefore, that some river phenomena, such as bed forms, can not be reproduced in the laboratory because of scale effects. Calculated values of sediment transport rate by the various available formulas vary within wide limits, making the given formulae suitable only for those conditions for which they were derived.

The purpose of this paper is to introduce the concept of effective stream power for predicting the sediment transport rate. Both the shape of the channel cross section and its hydraulic roughness were taken into account in the derivation of the presented simple formula.

Published field data for different streams in USSR covering a wide range of flow variables are herein presented in supporting the suggested formula for predicting the sediment concentration.

EFFECT OF SEDIMENT LOAD ON FLOW PARAMETERS

In nature, the water and sediment at the head of a reach of channel are imposed on the reach. The size and shape of the channel cross section and the slope of the water surface adjust themselves to the amount and variation of discharge and the supply of sediment.

Depending upon the time factor and the local conditions of a channel cross section, the increased energy consumption needed to suspend sediment particles may be achieved by changing one, or more than one, hydraulic or geometric property of the channel. For example, the process of widening or

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narrowing a channel cross section requires a longer time than that necessary for slope adjustment. After a considerable period of a flow of a certain discharge with a given sediment concentration, the existing slope may be changed later if any adjustment in the shape of the cross section or in its hydraulic roughness takes place. The material of which the channel sides are formed plays a vital role in the adjustment of the wetted perimeter.

The sediment transport phenomenon is such a complex matter that no single parameter, can adequately describe the flow condition or make it possible to predict the sediment transport rate.

The writer studied Zamarin's (15) field observation on more than 100 cross sections for different canals on a stretch of the Amudar'ya River in USSR. The range of different measurements are shown in Table 1.

In addition to the above mentioned data, these published observations included also the hydraulic radius and the Manning's coefficient values, n. The water depth was given for some canals.

Analysis of Zamarin's field data showed that the increased energy consumption needed to suspend sediment particles can be attributed to the change in any parameter in Manning's formula and not essentially to a decrease or an increase in one specified parameter. Data observations shown in Table 2 are given as examples to illustrate the following:-

1. For a specified water discharge, Q and mean fall velocity of suspended particles, ω , an increase in sediment concentration, C, leads to an increase in the mean velocity of flow, V.
   For a given shape of cross section, the increase in velocity may be due to a decrease in roughness resulting from damping effects. Data observations No. 26, 36 shown in Table 2 for two different canals indicate that the increase in velocity is due to an increase in the water surface slope and the hydraulic radius.
2. For given values of n and ω , an increase in both Q and C leads also to an increase in the mean velocity of flow. One of the causes of increasing V may be the increase in hydraulic radius, R, as can be seen from data observations No. 60, 66. In another place, the increase in V is due to an increase in both water surface slope, S and hydraulic radius and due to a decrease in Manning's n, as can be seen from data observations No. 71, 72.
3. For given values of ω and n, an increase in sediment concentration and a decrease in water discharge can lead to an increase in water surface slope. Generally, in this case, the hydraulic radius decreases due to a decrease in Q, as can be seen from data observations No. 5, 8.

4. For a given water slope, S, an increase in sediment concentration leads also to an increase in the mean velocity of flow. In this case, the increase in V is due to an increase in hydraulic radius and/or a decrease in Manning's coefficient, n, as can be seen from data observations No. 35, 36 and No. 34, 40.
5. For a given sediment concentration, an increase in ω leads to an increase in the mean velocity of flow or an increase in one, or more than one, parameter in Manning's formula, namely, R, S and 1/n. This case is illustrated by data observations No. 47, 50, No. 53, 58 and No. 55, 56.
6. For given values of V, C and n, an increase in ω lead to an increase in the other parameters in Manning's formula, namely, R and S. This case is shown in data observations No. 55, 56 and No. 24, 25.
7. For given values of V, n and ω, an increase in C leads also to an increase in the other parameters in Manning's formula, namely, R and S, as can be seen from data observations No. 50, 53 and No. 21, 12.
8. For given values of Q, V, S, R and ω, an increase in sediment concentration leads to an increase in the last parameter in Manning's formula, i.e. it leads to an increase in 1/n.

On the basis of laboratory experiments in a flume 27 cm. wide, operated at a fixed values of flow depth, discharge, slope and mean flow velocity in each set of experiments, Vanoni and Nomicos (12) showed that the friction factor of a stream carrying suspended sediment is less than a comparable one without sediment. They also showed that the reduction of friction factor due to the suspended sediment is of importance only in streams carrying a very high suspended load over a flat bed, and is of minor importance when there are dunes on the bed. The special conditions in operating the flume experiments as illustrated by Vanoni and Nomicos lead to the above mentioned conclusions, since all the parameters in Manning's formula are kept constant except Manning's coefficient.

Again, an increase in sediment concentration leads to an increase in one, or more than one, parameter in Manning's formula including mean velocity, water surface slope, hydraulic radius (or wetted perimeter) and 1/n. Such increase in one, or more than one, parameter may cause a decrease in other parameters with lesser effect.

In other words, for any change in sediment discharge and/or particles size in an alluvial channel, the required adjustment for equilibrium may be achieved not essentially by changing the bed roughness or by reforming the bed cofiguration only. For a given Q, C and ω the bed roughness may be changed due to a change in the other parameters in Manning's formula.

Maddock (6) called attention to a spectacular example of such an adjustment in the Maraloa-Ravi Link Canal in West Pakistan. At about 6.5 and 48 Km. downstream from the intake, the channel width, discharge, sediment size and concentration were the same in the both sites. In the upper site the slope was approximately 1:5000 and the depth was about 3.66 m. when the discharge was 425 cubic meters per second. In the lower site the slope was approximately 1:9000 and the depth was about 2.44 m and hence the velocity was 1.5 times that in the upper site. Due to the local conditions presented in the difference between the two sites in both parameters water surface slope and water depth, the adjustment was in the bed roughness. In the upper site the bed was dune covered and in the lower site it was flat. Although it is generally recognized that the hydraulic roughness of alluvial channels is a variable that depends on bed form, no agreement has been reached on how a specific roughness is to be expressed.

Experiments by Balakaev (2) with a three-dimensional model to study the effect of sediment concentration on the change of water surface slope at different discharges and constant hydraulic radius, R = 3.00 m., showed that for an overall increase in slope as the sediment concentration increases there is a maximum slope corresponding to a sediment concentration up to 3.0 Kg/m^3. With further increase in the sediment concentration, the water surface slope decreases and approaches the slope of clear water. However, Balakaev did not give any explanation for such observations.

THE STREAM POWER CONCEPT

The concept of stream power was introduced by many investigators in the field of sediment transport rate.

Louis M. Laushey (5) considered that the power expended to keep a particle in suspension is at least $W'.\omega$, in which W' = the submerged weight of particle and ω = the fall velocity. Laushey divided the mixture into clear water and solid sediment to consider that the stream power per unit channel length for the mixture is equal to the power expended for the clear water protion plus that for the solid sediment portion. Laushey used ω/v for the equivalent sediment slope and derived the following equation for maximum transport capacity, C'_t, in percentage by weight.

$$\% C'_t = 1.07 \frac{V.S}{\omega} \qquad \text{......(1)}$$

in which V = mean velocity, S = water surface slope.

In the above formula, the effect of shape of the channel cross section is not taken into consideration. On the basis of field data, it seems clear that the exponent on V.S is slightly more than one and this fact is supported by the author for the case of increasing proportions of bed load to total load.

Chih Ted Yang (4) expressed mathematically the unit stream power in terms of mean velocity and energy slope by V.S and suggested the following equation as the best correlation between total sediment transport, C_t, in parts per million, and stream power per unit weight of water.

$$\log C_t = a + b \log (V.S - V.Scr) \qquad ......(2)$$

in which a and b are constants, $V.S_{cr}$ is the critical unit stream power required to start the movement of sediment particles, and (V.S-V.Scr) is the effective unit stream power which is available to transport sediment. The Chih Ted Yang's formula was supported by reliable existing flume data as reported by him. The author replaced the water depth by a width-depth ratio to eliminate the scale effect and ignored the dimensional requirements for the coefficient a, which varies from $10^5 - 10^8$. In formula (2), the effect of sediment size particles is completely ignored. Chih Ted Yang recommended further studies for the effect of variations of bed configurations, gradation and channel geometry on sediment transport capacity.

Thomas Maddock (7) proposed the following formula for the maximum concentration of sediment for a given rate of expenditure of energy per unit of mass,

$$V.S = 10^{-3}\, \phi(d).\, C_t^{3/4} \qquad ......(3)$$

in which C_t is the concentration, in parts per million, by weight of the moving sediment of median diameter, d. Values of $\phi(d)$ for different sizes of sediment are obtained from a given graph. The given relation between mean diameter of moving sediment particles and $\phi(d)$ in equation (3) is based on flume experiments only.

The importance of the combined effect of velocity and slope on the rate of sediment transport was noticed recently by many investigators with different functional relationships.

Howard. H. Chang (3) introduced the concept of minimum stream power for stable alluvial canal design. The author considered that, an alluvial channel with given water discharge and sediment in flow tends to establish its width, depth and slope such that the stream power per unit channel length, γQS, or slope is minimum.

THE EFFECTIVE STREAM POWER

Following Ven Te Chow (14), Olsen and Florey and other engineers in the U.S.Bureau of Reclamation have used the membrane analogy and analytical and finite-difference methods for determining the distribution of tractive force in various channel cross-sections. The pattern of distribution varies with the shape of the section but is practically unaffected by the size of the section.

In trapezoidal sections ordinarily used in canals, the tractive force per unit channel length is closely given by:

$$\text{Tractive force/m}' = \gamma S y (b + y\sqrt{1+m^2}) \qquad \ldots\ldots(4)$$

in which b = channel bed width, y = channel water depth, S = water surface slope, γ = unit weight of water, m : 1 = channel side slopes.

In a uniform flow, the tractive force per unit channel length is apparently equal to the effective component of the gravity force acting on the body of water, parallel to the channel bottom and equal to γRPS, where P is the wetted perimeter and R is the hydraulic radius.

Substituting the tractive force value in equation (4), the following equation may be written:

$$R = P_o \cdot \frac{y}{p} \qquad \ldots\ldots(5)$$

where $P_o = (b + y\sqrt{1+m^2})$ and is defined herein as the effective wetted perimeter. For uniform side slopes, P_o = the wetted perimeter of the section up to the middle water depth.

For very wide channels, the new parameter P_o is close to P and hence, R = y.

In a previous study, the writer (10), (11) proposed a formula for determining the mean velocity of flow in stable channels carrying clear water without solids in suspension.

The suggested formula was supported by field data collected for main channels carrying clear water for a long period, more than 10 years.

The collected data comprises flow measurements for different discharges and slopes, mainly for main canals in Egypt after the construction of High Aswan Dam and Nile closure in 1964.

At the present time, these channels are considered to be in a nearly stable state, since the measured cross sections were not subjected to any cleaning or modifications during the period 1964 - 1976.

Based on the mentioned field measurements, the relation between R and P_o is closely given by:

$$R^{2/3} = 2S^{0.17} \sqrt{P_o} \qquad \text{......(6)}$$

Range of application of the above mentioned formula is limited by the following conditons:

a) Stable channels carrying clear water.
b) The wetted surface area is formed in the normal agricultural soil.
c) In the above mentioned formula, P_o is measured up to the middle water depth.
d) The constant given in formula (6) may vary with soil material. Solving formula (6) with Manning's formula, the suggested formula for determining the mean velocity of flow in stable channels carrying clear water is written as follows:

$$V = \frac{2}{n} S^{0.67} \sqrt{P_o} \qquad \text{.......(7)}$$

in which V = mean flow velocity in meters per second,
n = Manning's coefficient.

Following Varshney (13), Lindley, Lacey, Inglis, Joglekar and many other investigators used the wetted perimeter as an important parameter in the regime concept.

In India, the C.W.P.R.S. Pune (13) analysed data comprising 167 observations on the Punjab, 73 on the Uttar Pradesh, 28 on Bengal and 86 on Sind canals and has evolved "regime type fitted equations". These equations are suggested for designing stable channels carrying a sediment load within the range of data tested. From the given regime type fitted equations for Punjab canals, as an example, the relation between R and P may be written as follows:

$$R^{2/3} = 1.9 \sqrt{P}\; S^{0.25} \qquad \text{.......(8)}$$

It seems clear that the construction of formula (8) is similar to that in formula (6), previously suggested. The increased value of exponent on S is attributed to the transported sediment load.

By a different way, Orlov (8) derived a similar formula for stable channels in the stretch of Amudar'ya River in USSR. The Arlov's formula included the mean channel width, B, instead of the effective wetted perimeter and is written as follows:

$$V = \frac{0.15}{n} \sqrt{B.S} \qquad \text{......(9)}$$

In the field of sediment transport, it is important to take into account the shape of the channel cross section and its hydraulic roughness. Both of these parameters are included in the suggested formula (7) by P_o and 1/n respectively.

Now, if formula (7) is applied for channels in regime, carrying a certain concentration of sediment, the calculated slope, So, will be expected to be lesser than the existing slope, S. In other words, the exponent on the water surface slope, S, is expected to increase if the existing parameters are applied in formula (7), which may be written as follows:

$$V = \frac{2}{n} \cdot S^{\alpha} \cdot \sqrt{P_o} \qquad \ldots\ldots(10)$$

in which α = the new exponent on S due to the transported sediment load. Thus, any adjustment in the channel roughness and/or in its wetted perimeter can be taken into consideration by the new exponent on S.

For a given channel geometry, hydraulic roughness and water discharge, the adjusted water surface slope for a stream carrying suspended sediment is more than a comparable one without sediment. Thus, for any cross section carrying suspended sediment, by applying formula (7) we can calculate the decreased slope, So, for a comparable case without sediment. The decreased slope, So, is herein defined as the effective slope. The effective stream power per unit weight of water is here-in equal to V.So.

As mentioned previously, many investigators used the increased, or the existing unit stream power for predicting the sediment transport rate. It is more reasonable to assume that the sediment transport rate is related to the initial or to the effective unit stream power V.So. It is well known that the solution of many engineering problems is based on the initial conditions. In other words, the sediment concentration is assumed to be a function of V.So instead of V.S.

THE SEDIMENT TRANSPORT CAPACITY

Concentration of suspended sediment, C, is expressed here as the weight in kilogram of the rate of suspended solids per cubic meter of water. The submerged weight of solid particles per cubic meter = $\frac{\gamma_s - \gamma}{\gamma_s} \cdot C$, in which γ_s = specific weight of sediment particles, γ = specific weight of water in $\frac{kg}{m^3}$.

Thus, for a unit volume of water, the work per unit time required to suspend the sediment particles is at least

$\frac{\gamma_s - \gamma}{\gamma_s} . C. \omega$, in $\frac{Kg}{m^3} . \frac{m}{sec}$, in which ω = mean fall velocity of sediment particles.

As mentioned previously, it is reasonable for us to assume that the power expended in sediment transport is directly proportional to the effective stream power in

$\frac{Kg}{m^3} . \frac{m}{sec}$

or $$\frac{\gamma_s - \gamma}{\gamma_s} . C. \omega \propto S_o . V \qquad ......(11)$$

in which V = mean velocity of flow, S_o = the effective water surface slope and is calculated from the previoosly mentioned formula:

$$S_o^{0.67} = \frac{V}{2/n \sqrt{P_o}} .$$

Formula (11) may be written as follows,

$$C = K.E. \frac{S_o . V}{\omega} \qquad ......(12)$$

in which K = a constant value, considering that γ_s = constant, E = coefficient of proportionality. Such a coefficient, E, was introduced in different forms by Velikanov M.A, Gastynskii A.N., Abal'Yants and others. Velikanov and Gastynskii (1) defined the coefficient of proportionality as "coefficient of useful action".

After a thorough study of available field data, the equation

$$E.K = 140 \frac{S - S_o}{S} \qquad ......(13)$$

provides the best correlation in formula(12)for predicting the sediment concentration.

Then, equation (12) may be written as

$$C = 140 \frac{S - S_o}{S} . \frac{VS_o}{\omega} \qquad ......(14)$$

in which, C = sediment concentration in Kg weight/m^3. Formula (14) gave good results for different channels of different sizes. To illustrate the importance of the effective stream power concept for predicting the sediment concentration, the field data shown in Table 3 are chosen as an example from different channels having nearly the same fall velocity of sediment particles.

Observations No. 8, 9 are publised by Abal'Yants (1). In 1953, he measured the flow parameters at a specified cross section of a small channel branched from the main canal "Shavat" in Yzbekistan, USSR. Observations No 12, 48 are published by Zamarin (15) for canal "Gazavat" and canal "Shavat" respectively.

From the data shown in Table 3, as an example, it is apparent that the relations between sediment concentration and $V.S/\omega$ is less than satisfactory, especially for different channel sizes. Calculations of sediment concentration by using the suggested formula No.(14) are shown in Table 4.

In 1974, Balakaev (2) measured the flow parameters at a specified section of the Kara Kum Canal and made a comparison between the observed sediment concentration and that calculated by 15 various published formulas in USSR.

The value of the sediment concentration, C, is calculated for a discharge, $Q = 100\ m^3/sec$, average velocity, $V = 0.95$ m/sec., average depth, $y = 2.3$ m, bed with = 40 m, water surface slope, $S = 0.00012$, hydraulic radius, $R = 2.0$m, length of wetted perimeter, $P = 52.6$ m, average fall velocity of the suspended sediments, $\omega = 0.00148$ m/sec, and observed sediment concentration, $C = 2.595\ Kg/m^3$.

Balakaev found that the value of calculated sediment concentration by the various formulas varies within 2.23-11.52 Kg/m^3.

For the same above mentioned data, the effective wetted perimeter $P_o = 46.4$ m, effective water surface slope $S_o = 0.000048$, and applying formula (14).

$$\therefore C = 140 \times 0.6 \times \frac{0.000048 \times 0.95}{0.00148} = 2.588\ Kg/m^3.$$

The calculated value for C by the suggested formula (14) is nearly the same as that observed.

Field data published by Zamarin (15) for "Canal Palavan" are shown in Table 5 with a comparison between the observed sediment concentration and that calculated by formula (14), noting that Zamarin neglected observations No 3,4,5.

A comparison between the sediment concentration observed by Zamarin (15) for different canals and that calculated by formula (14) is shown on Fig.(1). Fig.(2) shows the same comparison, but for Abal'Yant's observations (1).

SUMMARY AND CONCLUSIONS:

Based on the concept that the concentration of sediment is directly proportional to the initial or effective unit stream power $V.S_o$, a simple formula was developed to predict concentration rates of sediment in alluvial channels and rivers. The effective water slope, So, is calculated by another suggested formula for a comparable case of clear water. Both the shape of the channel cross section and its hydraulic roughness are taken into account in calculating the effective water slope, So. The effective wetted perimeter or the length of the wetted perimeter up to the half depth of water, P_o, is a new parameter used here for calculating S_o.

The published field data for different streams in USSR covering a wide range of flow parameters support the introduced simple formula.

The analysis of the field data available to the writer showed that the increased energy consumption needed to suspend sediment particles is not necessarily caused by changing one specified parameter. For any change in sediment discharge and/or its particle size, the required adjustment for equilibrium is achieved by a change in one, or more than one, parameter in Manning's formula including mean velocity, water surface slope, hydraulic radius (or wetted perimeter) and Manning's coefficient.

APPENDIX I. - REFERENCES

1. Abal'Yants, S.Kh., "Transport of Sediments in Small Irrigation Canals", Technical Bulletin No. 92, Institute of Water Problems and Hydraulics, Tashkent, USSR, 1955, PP 3-9.
2. Balakaev, B.K., "Regulation of the Sediment Regime of the Lenin Kara-Kum Canal." Journal of the Hydrotechnical Construction, Moscow, No. 5, May, 1978, PP. 13-18, Russian Text.
3. Chang, Howard H., "Stable Alluvial Canal Design". Journal of the Hydraulics Division, ASCE, Vol. 106, No. HY5, Proc. Paper 15420, May, 1980, PP.873-891.
4. Chih Ted Yang, "Unit Stream Power and Sediment Transport". Journal of the Hydraulics Division, ASCE, Vol. 98, No. HY10, Proc. Paper 9295, October, 1972, PP. 1805-1825.
5. Louis M. Laushey, "Unit Stream Power and Sediment Transport". Journal of the Hydraulics Division, ASCE, Vol.99, No. HY9, Discussion, September, 1973, PP.1642-1645.

6. Maddock, Thomas Jr., "Instability of Flat Bed in Alluvial Channels", by Harry H. Hill, et al., Journal of the Hydraulics Division, ASCE, Vol. 96, No. HY4, Paper 7189, April, 1970, PP. 1080-1081.

7. Maddock, Thomas Jr., "Hydraulic Relations for Sand-Bedded Streams", Sedimentation, Symposium to Honor Professor H.A.Einstien, Chapter 15, Available, P.O. Box 606, Fort Collins, Colorado, U.S.A. 80521.

8. Orlov, E.Y., "Calculations of Regime Flow in Nonscouring and Non-silting Canals". Journal of Hydrotechnical Problems, Yzbek Academy Publishing House, Issue I, Tashkent, USSR, 1955, PP. 75-85.

9. "Sediment Transportation Mechanics: Fundamentals of Sediment Transportation", Task Committe on Preparation of Sedimentation Manual, Committe on Sedimentation of the Hydraulice Division, Vito A. Vanoni, Chmn; Journal of the Hydraulics Division, ASCE, Vol. 97, No. HY12, Proc. Paper 8591, Dec., 1971. PP. 1985.

10. Sharl Sh. Sakla, "The Effective Wetted Perimeter and a New Form for Chezy's Formula.", Journal of the Egyptian Society of Engineers No. 2, June, 1980, Cairo, Arab Republic of Egypt.

11. Sharl Sh. Sakla, "Egyptian Canal Sections for the Present Regime", Journal of the Egyptian Society of Engineers, No. 3, Sept., 1980, Cairo, Arab Republic of Egypt.

12. Vanoni, V.A. and Nomicos, G.N., "Resistance Properties of Sediment-Laden Streams"., Journal of the Hydraulics Division, ASCE, Vol. 85, No. HY5, Proc. Paper 2020, May, 1959, PP. 77-107.

13. Varshney, R.S., "Theory and Design of Irrigation Structures", Volume I, Chapter 7, Reprint 1979 M/s Nem Chand and Bros, Roorkee, India.

14. Ven Te Chow, Open Channel Hydraulics, Chapter 7, McGRAW-HILL Book Company, New York, 1959.

15. Zamarin, Y.A., "Transportation Capacity and Permissible Flow Velocity in Canals", Russian Text, State Construction Press, Moscow, Union of Soviet Socialist Republic, 1951.

APPENDIX II.-NOTATION

The following symbols are used in this paper:

A = Water area;
b = channel bed width;
B = mean channel width;
C = Sediment concentration by weight per unit volume;
C_t = Sediment concentration in parts per million;
d = median diameter of sediment;
E = proportionality coefficient;
g = gravitation acceleration;
y = average depth of flow;
K = constant;
$m:1$ = channel side slopes;
n = Manning" roughness coefficient;
p = length of wetted perimeter;
p_o = effective length of wetted perimeter;
Q = discharge;
R = hydraulic radius;
S = water surface slope;
S_o = effective water surface slope;
V = average velocity over the cross section;
α = exponent on S;
γ = unit weight of water;
γ_s = unit weight of sediment;
ω = fall velocity of sediment in still water;
θ = angle of repose for the soil material.

Table 1 _ RANGE OF MEASURED FIELD DATA

Discharge, Q, in cubic meters per sec.	Mean velocity, V, in meters per second	Water slope S×10000	Sediment concentration, C, in kg. wt. per cubic meter	Mean fall velocity of suspended particles, ω, in mm/sec.
0,4 – 120.0	0,3 – 0,9	8,10 – 0.18	0,5 – 6,7	0,4 – 7,7

Table 3 _ OBSERVATIONS DIFFERENT CANALS

Observation No.	Q, in m³/sec.	V, in m/sec	S ×10000	Wetted perimeter, P, in m	Manning coeff., n	ω, in mm/sec.	C, in kg/m³	$\frac{S \times V}{\omega}$
8	0,194	0,368	2,56	2,27	0,0177	0,87	3,88	0,108
9	0,122	0,313	2,99	1,77	0,0201	0,86	3,48	0,109
12	1,700	0,37	5,66	20,88	0,0232	0,88	1,53	0,238
48	67,60	0,74	1,56	64,30	0,0213	0,81	3,48	0,143

Table 2 _ EXAMPLES FROM THE FIELD OBSERVATIONS

Observation No.	Q, in m³/sec.	Hydraulic radius, R, in m.	S, ×10 000	Manning coeff., n	V, in m/sec	ω, in mm/sec	C, in kg/m³
26	7,90	0,79	2,12	0,0197	0,63	1,23	3,73
36	7,98	0,72	1,06	0,0172	0,48	1,24	1,43
60	95,80	2,11	1,38	0,0222	0,87	1,20	4,63
66	42,20	1,31	1,43	0,0223	0,64	1,26	1,71
71	11,10	0,90	0,85	0,0238	0,36	0,65	1,80
72	6,90	0,83	0,75	0,0283	0,27	0,65	1,16
5	25,10	0,81	2,24	0,0203	0,64	1,35	3,36
8	53,70	1,36	1,56	0,0197	0,78	1,35	2,59
35	10,86	0,82	1,06	0,0161	0,56	0,52	1,80
36	7,98	0,72	1,06	0,0172	0,48	1,24	1,43
34	12,36	0,90	1,22	0,0181	0,57	1,58	2,75
40	6,80	0,66	1,22	0,0186	0,45	0,37	1,14
47	69,00	1,44	1,48	0,0206	0,75	0,89	3,80
50	106,50	1,81	1,44	0,0215	0,83	1,65	3,80
53	118,20	2,01	1,24	0,0216	0,82	1,68	2,50
58	57,00	1,24	1,92	0,0216	0,74	2,92	2,49
55	82,60	1,59	1,40	0,0224	0,78	1,36	3,23
56	77,90	1,54	1,80	0,0229	0,78	2,34	3,25
24	7,90	0,78	2,46	0,0205	0,65	0,73	3,50
25	9,00	0,85	2,29	0,0205	0,66	0,81	3,45
12	1,70	0,22	5,66	0,0232	0,37	0,88	1,53
21	5,83	0,60	1,67	0,0235	0,39	0,90	0,76

Table-4 CALCULATIONS OF SEDIMENT CONCENTRATION

Observation No.	Effective wetted perimeter, P_0, in m.	Effective water slope, $S_0 \times 10\,000$	$\frac{S - S_0}{S}$	Sediment concentration, C, in kg/cu. m.	
				Calculated	Observed
8	1,26	1,634	0,3617	3,50	3,88
9	1,14	1,675	0,4398	3,75	3,48
12	19,45	0,320	0,9435	1,77	1,53
48	61,20	0,337	0,7840	3,38	3,48

Table-5 OBSERVATIONS FROM PALAVAN CANAL

Observation No	Q in m^3/s	V in m/s	P in m	S ×10000	n	ω in mm/s	P_0 in m	S_0 ×10000	C, in kg/m^3	
									Calculated	Observed
1	18,0	0,58	45,0	1,88	0,0181	0,41	39,0	0,257	4,39	4,42
2	14,2	0,54	44,3	1,94	0,0180	0,41	38,6	0,231	3,75	3,95
6	91,0	0,84	53,4	1,92	0,0264	1,17	43,2	0,727	4,54	4,56
7	96,9	0,84	53,9	1,88	0,0271	1,42	43,5	0,752	3,74	3,87
8	53,7	0,78	50,6	1,56	0,0197	1,35	41,8	0,431	2,52	2,59
9	50,7	0,78	49,2	1,76	0,0204	1,37	41,1	0,460	2,70	2,53
10	46,7	0,73	49,6	1,72	0,0212	1,30	41,3	0,439	2,57	2,57