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AT-A-STATION HYDRAULIC GEOMETRY OF TARALI RIVER, MAHARASHTRA: AN IMPACT OF HUMAN INTERVENTION ON CHANNEL

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ABSTRACT

The section of Tarali channel for about 4.325 km in direction upstream from its confluence with River Krishna has been studied through field survey carried out in 7 sessions for the present research work. Of the 90 cross-sections, 7 have been selected for the analysis of 'at-a-station' conditions from Dec 1994 and April 1997 survey session. In the discussions, set of seven scatter plot representing width, depth and velocity conditions for 94 and 97 survey sessions have been considered. The discussion focuses on how hydraulic geometry changes from one location to another location of the channel. Velocity and river discharge at selected cross sectional location are calculated using Manning's formula of the open channel flow. The study also deals with the relationship between the measures of channel form and the processes operating in the channel.

KEYWORDS: River Discharge, Velocity, Channel Width-depth, Wetted perimeter, b-f-m-diagram.

INTRODUCTION

In view of human intervention i.e. widespread silt excavation in Umbraj, which is carried on along the banks of Tarali and Krishna rivers has resulted in positive and negative impacts in the region. The observation of such condition at Umbraj along River Tarali indicates serious signs of alarming environmental problems. Site visit revealed that excavation was not only enormous but it has also encroached large chunk of agricultural lands. As a consequence, this has resulted in altering the geometry of the river channel. Therefore, it is necessary to study the variation in river cross section and the processes of adjustment of the channel in response to human intervention. Hydraulic geometry which was first introduced by Leopold and Maddock (1953) , gives the inter-relationship between river discharge, other hydraulic variables such as width, depth, velocity and friction [1].

If the channels are considered to be containers, the discharge becomes the content accommodated within this container. The liquid materials contained in the containers are supposed to be assuming the shape of the containers. However, when the content is not static, and has tendency to not only to increase and decrease in quantity but also has a freedom to enter into and exit from the container, it is bound to influence the shape of the container itself. With the discharges getting collected into the channel from the catchment areas it is not just the change in the quantity of the water that gets collected, but with it the energy also is getting concentrated in the channel. With greater the amount of the water that gets collected in the channel the more will be the energy and as a result greater will be the alterations possible in the morphology of the channel. However, the maximum amount of the water that can be contained in the channel will be till the rim of the banks and that is what is called as the bankfull discharge. Therefore bankfull discharges are called channel-forming discharges. However, this does not mean that the discharges below bankfull conditions do not influence or alter the channel shape and morphology. The changes in discharges, particularly the positive ones, get reflected in the properties of river channels and these can be best described through the study of hydraulic geometry.

During the study it has noticed that, variations in the channel longitudinal profile and the cross sections as well as plan form over a period of about three years (1994 to 1997) are more likely to be caused by human interventions rather than by normal processes of adjustment of channel properties to the discharge. The discharge data presented for the period under consideration does not relate to any catastrophic event, though some discharges were on higher side of the average. In the present study an attempt has been made to summarize the channel characteristics of Tarali River under consideration through a set of hydraulic geometry equations.

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MATERIALS AND METHODS

Hydraulic geometry of un-instrumented channel:

The study of hydraulic geometry summarizes the channel cross section through a set of equations with discharge as the independent variable and a variety of variables as dependent variables. Discharge is computed as a product of velocity and the cross sectional area, Q = A*V. The cross sectional area can be obtained through measurement of width (w) and depth (d) of the cross section. Thus the equation A*V = Q will become w*d*v = Q. Besides there, three variables that determine the discharge other variables such as slope, sediment concentration and roughness of the bed influence the velocity of water traveling through channel and hence also influence the discharge quantity. Therefore the study of hydraulic geometry generally includes set of six equations, one each for the dependent variables mentioned above. However, in an un-instrumented watershed obtaining the information on the last three variables namely sediment load, water surface slope and roughness, becomes difficult and hence only three equations can be tried under such conditions.

Variables width and depth can be directly measured in the field and velocity can be derived using Manning's formula, $V = 1/n (R^{2/3} * S^{1/2})$, where 'V' is velocity of river water, 'R' is hydraulic radius, 'S' is slope, and 'n' is manning's roughness factor [1], [2].

The hydraulic geometry of a channel cross section is described through a set of power equations. The three equations for the variables of width, depth and velocity against discharge take following form [1], [2], [3].

$w = aQ^b$

$d = cQ^f$

$v = kQ^m$

These equations can also be written in the following form.

$w*d*v = ackQ^{b+f+m}$

For the equation given above to be valid it is necessary that the product of the intercepts of the three equations as well as the sum of the exponent values have to be equal to 1. Hydraulic geometry study is generally carried out for at- a-station and down stream conditions.

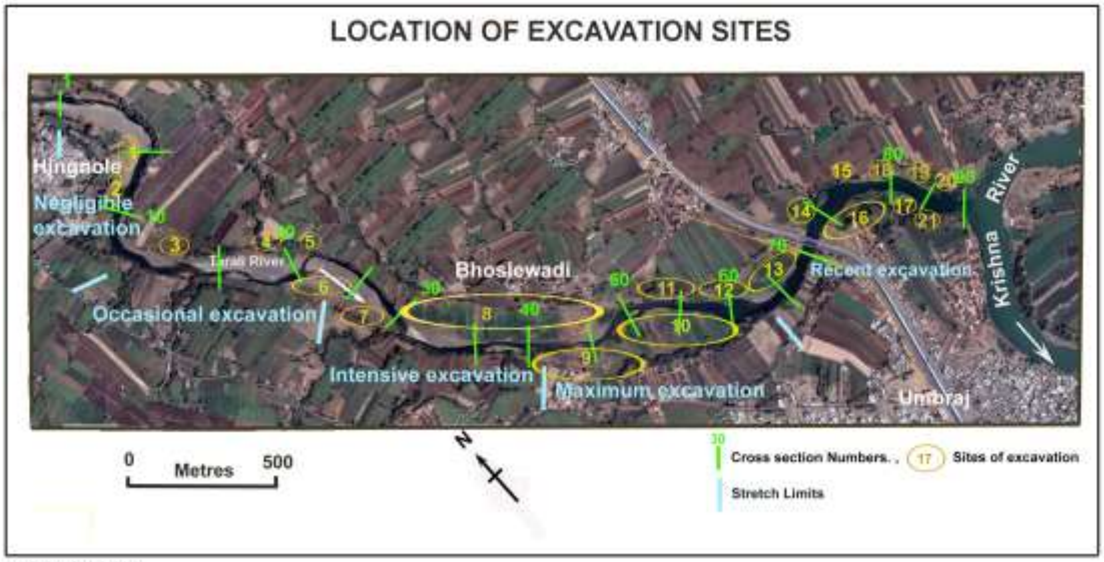
Hydraulic Geometry of Tarali River:

As mentioned earlier the section of Tarali channel has been studied through field survey carried out in 7 sessions. Of the 90 cross-sections, 7 have been selected for the analysis of 'at a station' conditions from Dec 94 and April 97 survey session (fig 1). Following procedure was adopted for generating the required data sets (Sapkale,2008).

In order to obtain velocity at different depth levels of the cross section Manning formula was used. The formula requires computation of hydraulic radius 'R' at successive depth. According to Sapkale (2008), the slope (S) of the channel at each of the selected cross section was computed by taking the lowest bed level values of the given cross section and the similar value of the previous cross section. In order to get value of hydraulic radius the cross section area and wetted perimeter values were obtained at different depth levels [3]. The roughness factor 'n' was taken to be 0.03. This value has been used and recommended for most of the river gauging stations in Western Maharashtra. Details of the computation (as determined by Sapkale in 2008) of cross sectional area and wetted perimeter are explained below and have also been given in the following table 1 a, b & c.

The estimation of velocity and discharge required for describing hydraulic geometry of the channel heavily depends on proper measurement of the cross section(s) and use of values of slope factor and roughness factor. The details of cross section measurement are given in the following table in first two columns (Table 1a). Width and depth of each compartment, identified on the basis of the depth values, are given in column 3 and 4. Next column records total depth of the channel in each compartment. The estimation of wetted perimeter and the area of the compartment is carried out and the values are recorded in col. 8 and 11. The sum of col. 8 gives us the full length of wetted perimeter of the cross section and the sum of col. 11 records the total area of the cross section (A). These two quantities are then used to calculate the hydraulic radius (R) of the cross section (Sapkale, 2008). However, this becomes the 'R' for entire channel and not for each compartment. The compartment wise values of area and hydraulic radius are calculated in the next table (Table 1b).

The table 1b records hydraulic radius and area of each depth compartment. Velocity calculations are given in col. 9 and 10. The basic data for this calculations is given in the right top corner of the table. Finally col. 10 and 11 record the estimated values of velocity and discharge of each depth compartment. Col. 2 and 6 record the depth and width of each depth compartment. The values used for the calculations of power equations are given in table 1c. In this manner calculations for 7 cross section selected for hydraulic geometry analysis were completed. Further discusions on the relationship between the river parameters have been carried on the basis of scattered diagrams.



Source : Google Earth

Figure:1- Location of Excavation Sites and Cross Sections across Tarali Channel

Table 1-a Details of the computation of cross sectional area and wetted perimeter

1 m height	2 m distance	3 Compartment width	4 depth	5 Total depth	6 tan Θ	7 cos Θ	8 hyp length wetted peri	9 area triangle	10 area rectangle	11 compartment total area
572	75.5	14.5	1	1	0.0689655	0.9976303	14.534442	7.25	0	7.25
571	61	23.5	1	2	0.0425532	0.999096	23.521264	11.75	23.5	35.25
570	37.5	9	1	3	0.1111111	0.9938838	9.0553849	4.5	18	22.5
569	28.5	9.5	1	4	0.1052632	0.9945055	9.5524863	4.75	28.5	33.25
568	19	2	1	5	0.5	0.8944272	2.236068	1	8	9
567	17	1.5	1	6	0.6666667	0.8320529	1.80277	0.75	7.5	8.25
566	15.5	2	1	7	0.5	0.8944272	2.236068	1	12	13
565	13.5	0.5	1	8	2	0.4472137	1.1180336	0.25	3.5	3.75
564	13	3	1	9	0.3333333	0.9486834	3.1622773	1.5	24	25.5
563	10	0	1	10	0	1	0	0	0	0
562	10	0	1	11	0	0.6726728	0	0	0	0
561	10	1	0.1	11.1	0.1	0.9950377	1.004987	0.05	11	11.05
560.9	9	9	0	11.1	0	1	9	0	99.9	99.9
560.9	0				0	1	0	0	0	0
560.9	11.5	11.5	0	11.1	0	1	11.5	0	127.65	127.65
562	28.5	17	1.1	11.1	0.0647059	0.9979131	17.035551	9.35	170	179.35
563	50	21.5	1	10	0.0465116	0.9989202	21.523241	10.75	193.5	204.25
564	81.5	31.5	1	9	0.031746	0.9994967	31.515863	15.75	252	267.75
565	92	10.5	1	8	0.0952381	0.9954955	10.547511	5.25	73.5	78.75
566	109.5	17.5	1	7	0.0571429	0.9983715	17.528545	8.75	105	113.75
565	112	2.5	-1	6	-0.4	0.9284768	2.6925822	-1.25	17.5	16.25
564	113	1	-1	7	-1	0.7071068	1.4142136	-0.5	8	7.5
563.5	122.5	9.5	-0.5	8	-0.0526316	0.9986179	9.5131479	-2.375	80.75	78.375
563.5	133.5	11	0	8.5	0	1	11	0	93.5	93.5
564	167	33.5	0.5	8.5	0.0149254	0.9998887	33.503728	8.375	268	276.375
565	168	1	1	8	1	0.7071068	1.4142136	0.5	7	7.5
566	168.5	0.5	1	7	2	0.4472137	1.1180336	0.25	3	3.25
566	171.5	3	0	6	0	1	3	0	18	18
567	177	5.5	1	6	0.1818182	0.9838713	5.5901618	2.75	27.5	30.25
568	180.5	3.5	1	5	0.2857143	0.9615251	3.6400507	1.75	14	15.75
569	186	5.5	1	4	0.1818182	0.9838713	5.5901618	2.75	16.5	19.25
570	196.5	10.5	1	3	0.0952381	0.9954962	10.547503	5.25	21	26.25
571	207.5	11	1	2	0.0909091	0.995894	11.045352	5.5	11	16.5
572	218	10.5	1	1	0.0952381	0.9954962	10.547503	5.25	0	5.25

Wetted Perimeter 297.49115 Cross sectional area 1854.2
Hydraulic Radius 6.2327905

Note : The above computation is based on field work data, shown here only for one cross section.

Table 1-b Details of the computation of wetted perimeter, velocity, discharge

Wetted peri bankfull		297.4911									
Area bankfull		1854.2						Slope= 0.05 / 26		0.001923S	
Hydraulic radius bankfull		6.232791						0.043853		0.043853S^0.5	
						Total		`1/n(R^0.6667*s^0.5)		33.33333`1/n	
						Area Horizontal	Wetted perimeter Triangle	Velocity calculations			
HEIGHT	DEPTH	WP	A	R	Width			`r^0.6667		Velocity	Discharge
572	11.1	297.4911	1854.2	6.232791	293.5	306	25.08195	3.386997	0.14853	4.950989	9180.123
571	11	272.4092	1568.45	5.757698	268.5	285.75	34.56662	3.21261	0.140882	4.696075	7365.559
570	10	237.8426	1324.7	5.56965	234	243.75	19.60289	3.14227	0.137798	4.593255	6084.685
569	9	218.2397	1102.7	5.052701	214.5	222	15.14265	2.944687	0.129133	4.304436	4746.502
568	8	203.097	900.45	4.433595	199.5	202.25	5.876119	2.698934	0.118356	3.945202	3552.458
567	7	197.2209	702.95	3.564277	194	197.5	7.392932	2.333455	0.102329	3.410958	2397.733
566	6	189.828	514.2	2.708768	187	188.75	5.236068	1.943251	0.085217	2.840574	1460.623
565	5	184.5919	332.45	1.801	181.5	181.75	11.66554	1.480304	0.064916	2.163854	719.3734
564	4	172.9264	135.2	0.781836	180	197.25	34.67814	0.848672	0.037217	1.240558	167.7235
563	3	138.2482	75.2	0.543949	60	60	21.52324	0.666341	0.029221	0.974033	73.24729
562	2	116.725	22.95	0.196616	38.5	52.25	17.03555	0.338108	0.014827	0.494234	11.34267
561	1	99.68945	20.8	0.208648	21.5	2.15	12.50499	0.351766	0.015426	0.514198	10.69532
560.9	0	87.18446	20.8	0.238575	20.5	0	20.5	0.384647	0.016868	0.562263	11.69506
1	2	3	4	5	6	7	8	9	10	11	12

Table 1-c: Final data used for power equations

Discharge	Velocity	Width	Depth
Q	V	W	D
9180.123	4.950989	293.5	11.1
7365.559	4.696075	268.5	11
6084.685	4.593255	234	10
4746.502	4.304436	214.5	9
3552.458	3.945202	199.5	8
2397.733	3.410958	194	7
1460.623	2.840574	187	6
719.3734	2.163854	181.5	5
167.7235	1.240558	180	4
73.24729	0.974033	60	3
11.34267	0.494234	38.5	2
10.69532	0.514198	21.5	1
11.69506	0.562263	20.5	0.9

RESULTS AND DISCUSSIONS

At a Station Hydraulic Geometry of Tarali Channel:

The plots of scatter and the power equations derived for each of the set of data have been shown in figure(s) 2.1 to 2.7. Each figure includes a set of seven scatter plot representing width, depth and velocity conditions for 94 and 97 survey sessions. Dec 94 and June 97 surveys were chosen as these represent the first and last surveys undertaken for assessing the conditions along Tarali channel. During this period surveys were conducted twice each year representing the pre and post monsoon conditions. One more survey was conducted in Oct 2002 to get an idea about the conditions of brick kiln activity after a break of 5 years. However, for 2002 hydraulic geometry analysis was not carried out. Table no. 2 records value of the coefficient (exponents in power equations) for each of the equation obtained. The values of explained variance (R2) are given in table no. 3. It may be observed from the table 3 that the values of explained variance are generally of high order. Only in case of equation of width against discharge for CS 15 and CS 30 these values are less than 0.5. The fact is that the R2 values are higher indicates that the increase in the dependent variables like width depth and velocity is explained by the increasing discharge [3], [4].

Width Discharge relationship :

The 'b' values of equations explaining the width discharge relation range from 0.21 to 0.55 in case of Dec 94 conditions and from 0.18 to 0.44 in case of June 97. CS 1 and 15 show low values of exponent and indicate that the

Table 2 . Exponents of Power equations Dec 94 and June 97:

Cross Section No.	Dec 94			June 97		
	b	f	m	b	f	m
01	0.292548	0.502068	0.205384	0.318623	0.475593	0.205784
15	0.218009#	0.537922*	0.244069	0.224636	0.513037*	0.262327
30	0.441451	0.436717	0.121832	0.382493	0.420822	0.196685
45	0.555147*	0.424986	0.019867#	0.370635	0.40799	0.221375
60	0.444379	0.275339#	0.280281	0.181489#	0.477059	0.341452
75	0.341635	0.317423	0.340943*	0.285308	0.286255#	0.428436*
90	0.450177	0.443173	0.10665	0.443305*	0.412613	0.144082#
Mean	***0.342918***	***0.367204***	***0.164878***	***0.275811***	***0.374171***	***0.225018***

* Maximum Value # Minimum Value

Table 3. Explained Variance of Power equations:

	94			97		
Cs no	Width	Depth	Velocity	Width	Depth	Velocity
01	0.8235	0.9471	0.9364	0.7407	0.9521	0.881
15	0.799	0.9918	0.9699	0.4704	0.8293	0.8828
30	0.7455	0.8082	0.6506	0.2379	0.6273	0.7055
45	0.8096	0.9459	0.7393	0.8315	0.9457	0.967
60	0.6642	0.9354	0.995	0.9083	0.9803	0.9879
75	0.8895	0.9435	0.998	0.8072	0.9479	0.9992
90	0.9428	0.9491	0.8886	0.9755	0.9669	0.9643

rate of change of width with respect to discharge in these cross sections is moderate to low. The cross sections for Dec 94 and June 97 have also been shown on the diagram along with the scatter plots. It may be seen that the cross sections are deep and narrow and hence the width does not change much with increasing discharge. The exponent values of width in case of cross sections 30 onwards increase though the trend is not continuous. For cross sections 75 and 90 the exponent values decrease to some extent. The width at cross sections 30, 45, and 60 increases considerably mainly as a result of excavation along the banks. If one considers the changes from 94 to 97, similar trend may be observed. The graph of CS 1 and 15 for 94 and 97 have similar pattern but the graphs for CS 30 to 60 show significant variations. The exponent value of trend line for CS 45 and 60 noted to be 0.55 and 0.44 are reduced to 0.37 and 0.18. However, there is considerable change in the value of intercepts. Obviously the intercept values record increase in June 97.

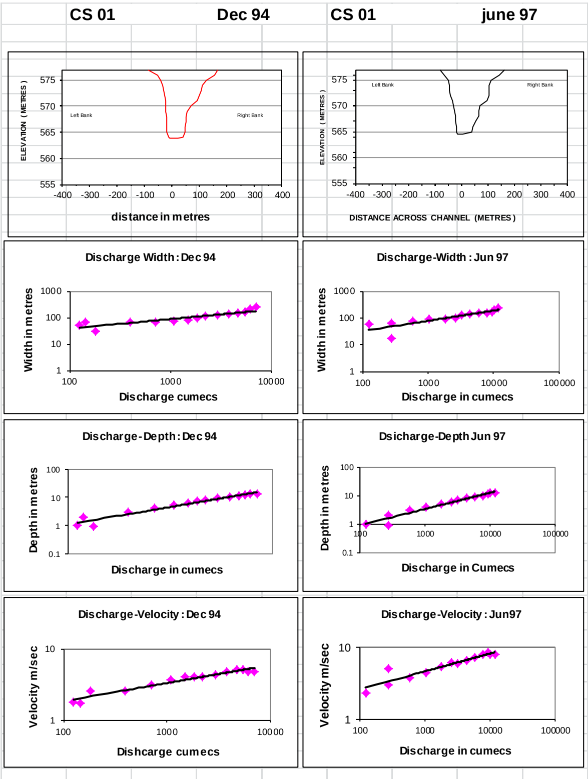


Figure : 2.1- Scatter Diagram of CS - 1

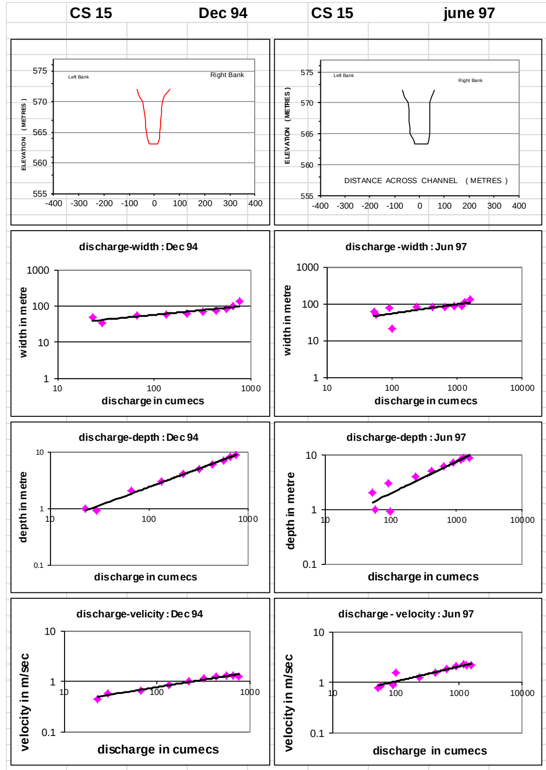


Fig. 2.2 - Scatter Diagram of CS - 15

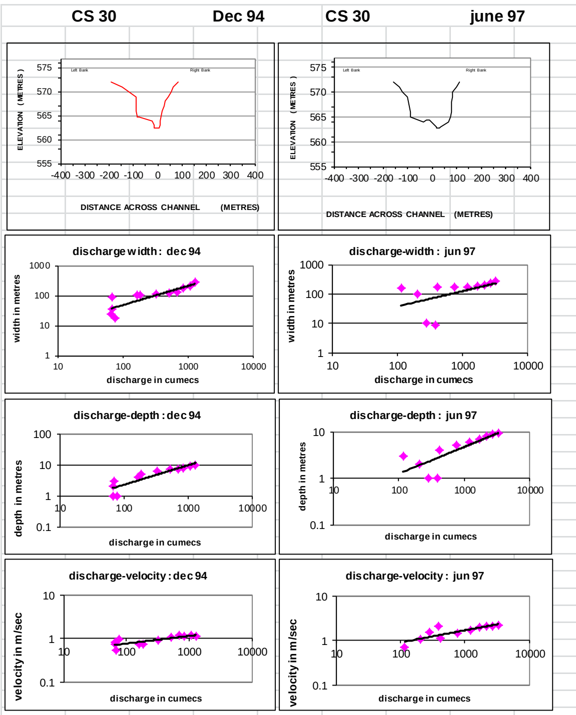


Figure 2.3: Scatter Diagram of CS - 30

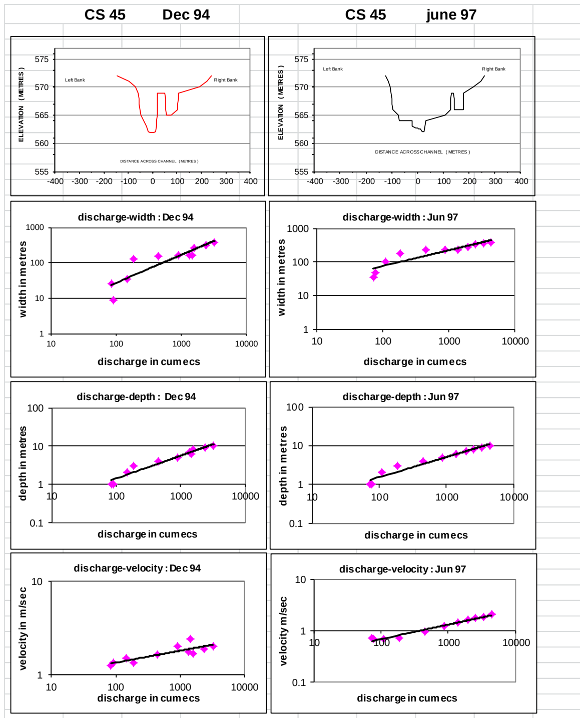


Figure 2.4: Scatter Diagram of CS - 45

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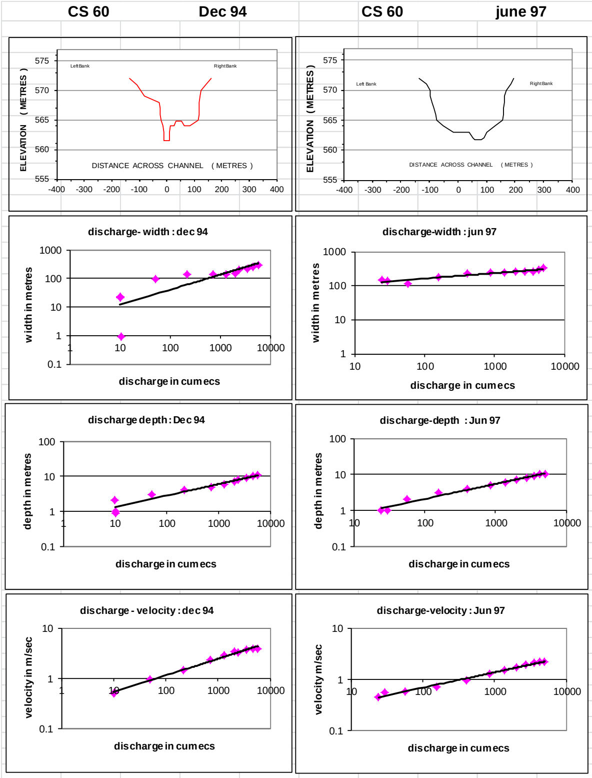

Figure 2.5 : Scatter Diagram of CS - 60

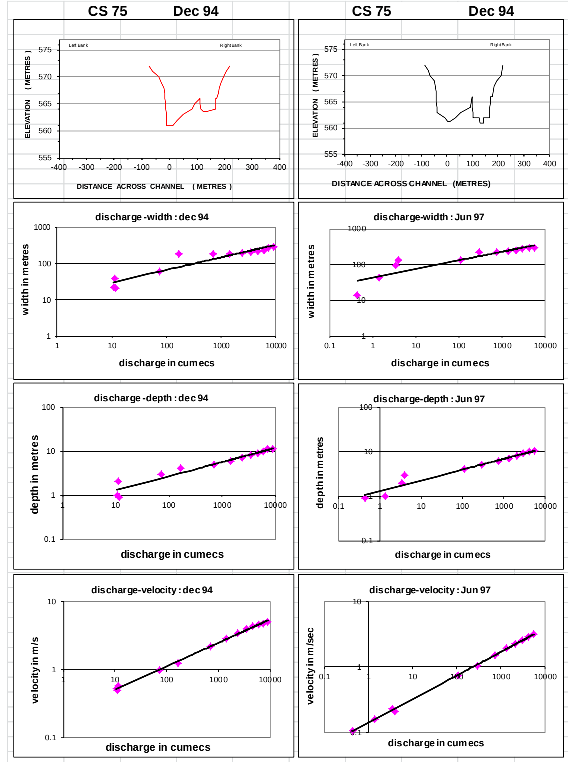

Figure 2.6: Scatter Diagram of CS - 75

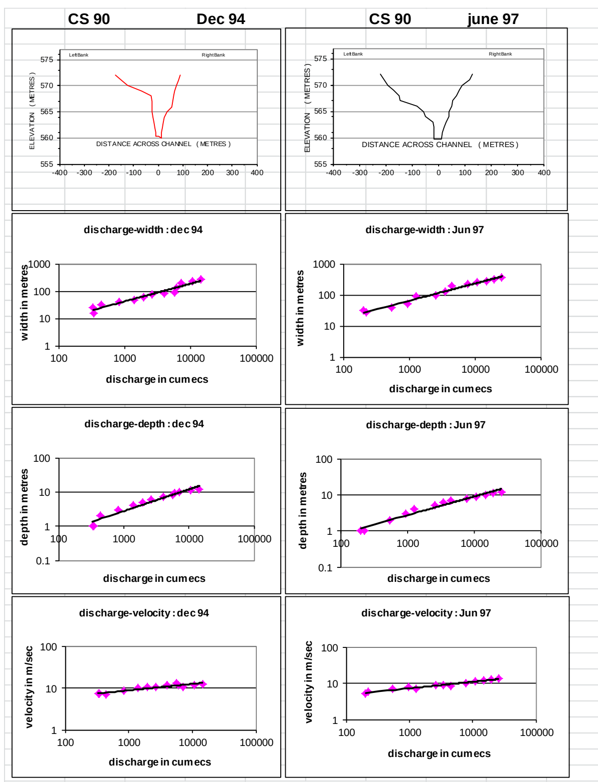

Figure 2.7 : Scatter Diagram of CS - 90

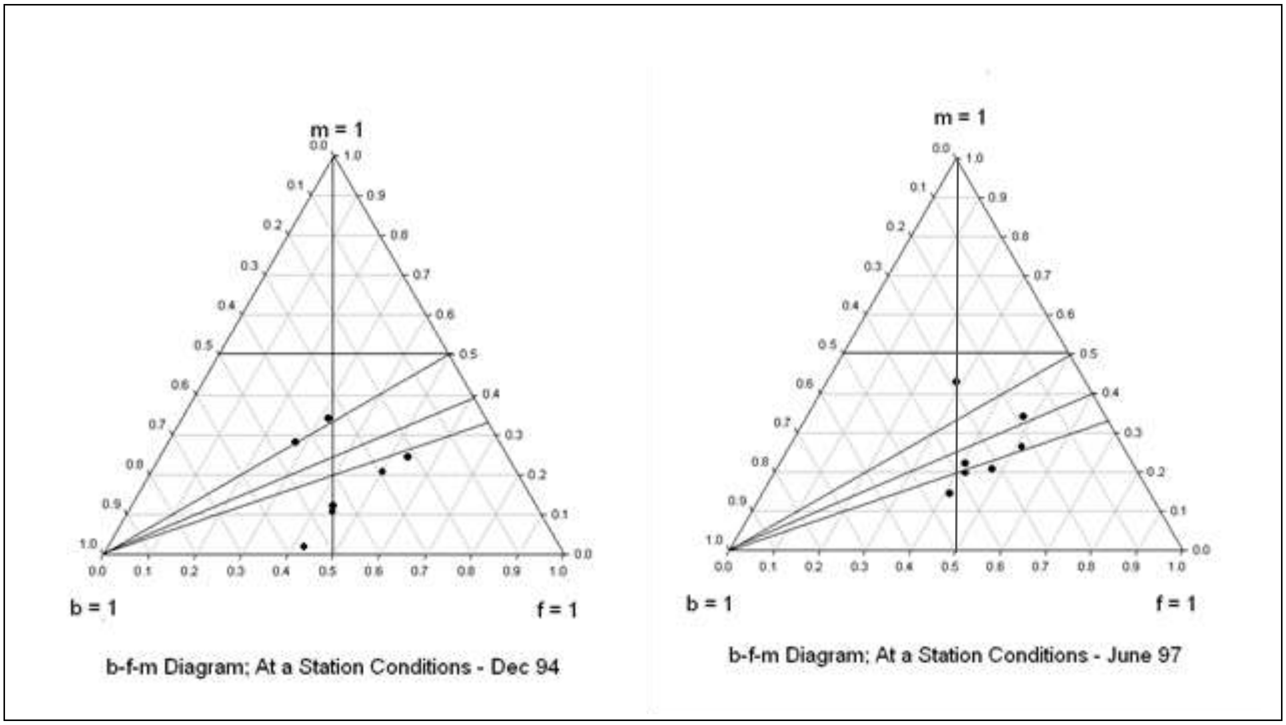

Figure 2.8: Ternary Diagram

Depth Discharge relationship :

The ‘f’ values of equations explaining the depth discharge relation range from 0.27 to 0.54 in case of Dec 94 conditions and from 0.28 to 0.51 in case of June 97conditions. The scatter plots of depth and discharge shown in figures clearly show that the slope of trend line is considerably steeper than that of the width scatters in case of CS 1 and CS 15. This indicates that the depth increases rapidly with increasing discharge. The exponent values, ‘f’, in case of CS 1 and 15 are 0.50 and 0.54 respectively. The exponent values for CS 30, 45, 60 and 75 drop down suggesting moderate to low increase in depth with increase in discharge.

Velocity Discharge relationship :

The ‘m’ values of equations explaining the velocity discharge relation range from 0.02 to 0.34 in case of Dec 94 conditions and from 0.14 to 0.43 in case of June 97. The lowest exponent value in case of velocity equations is 0.019867 and this is associated with the equation for CS 30 in Dec 94. If velocity does not increase with increasing discharge it would only mean that the width and depth, contributing to cross sectional area, increase providing the required cross sectional area to accommodate the increasing discharge. This is well represented in the exponent values of width and depth equation for this cross section. For all the cross sections the exponent values of velocity equations are lower than the exponents for width and depth equations. This would mean that the changes in the depth and width are more prominent that those in velocity.

The b-f-m diagram:

Exponent values of the equations derived for summarizing the relationship of width, depth and velocity can best be represented through a ternary diagram developed by Rhodes (1977 and 1987) [5], [6]. The fact that b, f and m values add up to unity facilitates such a representation. The b-f-m diagram is not just a tool for representing the tri-variate data set but also facilitates interpretation of the relationship for at a station and downstream conditions. Rhodes (1977) has proposed division of the diagram on the basis of relative proportion of the exponent values. In order to interpret the plot it is necessary to understand the divisions suggested and the basis of identification of these divisions [5], [6].

Divisions of 'b-f-m' diagram:

The ternary diagram is divided into 10 sectors identified on the basis of 5 lines. The exponents' b, f and m basically are the rates of change of width, depth and velocity respectively. The ratios of these exponents are used to delineate different sectors of the ternary diagram. According to Rhodes These are as follows:

1. b/f=1 or b = f: The ratio of rate of change of width to the rate of change of depth highly relates to width depth ratio. This ratio also facilitates interpretation related to the shape of the channel. Condition b>f indicates that the channel become wider and shallower with increasing discharge. Such channels are considered to be better able to transport bed load. As against this if b<f indicates that the depth is increasing faster with increasing discharge than the width. Under such conditions w/d ratio decreases with increasing discharge and such channels become narrower and deeper and are more suited for the transport of suspended load. Lower values of b/f also indicate that the channel materials are more cohesive and the higher values suggest that the channel materials are less cohesive. This is the only division where 'b' (width) is taken into consideration. Rest other divisions are identified with reference to the ratio of rate of change of velocity (m) and rate of change of depth (f).
2. Division along m=f based on m to f ratio relates to velocity depth ratio and throws light on the competence of the channel. The channels having values of this ratio equal to or exceeding unity are supposed to have greater competence. Those channels where the rate of change of velocity is less than that of depth are considered to be having low competence.
3. A line representing condition m=b+f relates to velocity and cross sectional area. The points plotting above this line represent channels that experience very rapid increase in velocity with discharge. It also indicates that the mean velocity is increasing faster than the cross sectional area. Such channels are quite stable i.e. neither bed nor banks are subject to significant erosion by the velocities attained.
4. m/f = 2/3. This condition relates to Manning's roughness coefficient. m/f>2/3 indicates that the ratio s1/2/h increases with increasing discharge and if the value is <2/3 the slope factor – roughness ratio decreases with increasing discharge. These conditions are purely function of size and character of sediments.
5. m/f = 1/2 : This division is considered to give some idea on sediment transportation and relates to the increase or decrease of sediment concentration.

Ternary diagram for at-a-station Hydraulic Geometry of Tarali channel:

The b-f-m values obtained for 7 cross sections are represented in ternary diagrams shown in figure 2.8. The two diagrams shown relate to Dec 94 and June 97 conditions.

It may be noted from the diagrams that none of the points either for 94 or 97 conditions lie in sectors 1, 2, 4, 5 and 7. The Absence of point in the area above the line m=b+f means that the velocity does not increase rapidly than the cross section area. On the contrary the cross section area appears to be increasing with increasing discharge. Such increase in cross sectional area indicates that the bed and bank of the channel is sufficiently erodible.

The points 1 and 2 representing CS 1 and 15 do not show any significant dislocation on the graph from 94 to 97 and they appear in sector 10. This sector has b<f; m/f<0.5; indicating decrease in sediment transportation rate and the depth is increasing faster than width. The lower values of b to f ratio also suggest larger concentration of suspended load.

Points 4, 5 and 6 representing CS 45, 60 and 75 show greater variability in terms of their locations on ternary diagram. CS 45, which had near zero value of 'm' in Dec 94, records substantial increase in value of 'm' (from 0.019 to 0.22) in June 97. Also there is equally substantial fall in values of 'b'. This indicates that the velocity is increasing faster than the cross sectional area with the increase in discharge suggesting greater competence of flow. CS 60 shows lowering of value of 'b' and the same is compensated by increase in values of 'f' and 'm'. The lowering of value of 'b' indicates that in June 97 the channel is showing tendency of becoming deeper and narrower compared to its Dec 94 conditions. CS 75 shows slight increase in the value of 'm' from 94 to 97.

CS 90 does not record much change in its location from Dec 94 to June 97. The points representing this cross section lie in sector 10 and are located very close to the line 'b=f'.

CONCLUSION

The discussions above suggest that the channel under consideration has at least three distinct segments. Each of the segment has different nature of response and hence when considered as a single unit the power equations for downstream cross sections are showing low values of width and depth exponents. The central section that is subjected to intensive excavation activity appears to be disturbing the relationships of discharge with other variables.

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