CHANGES IN STREAM CHANNEL CHARACTERISTICS AT TRIBUTARY JUNCTIONS: IMPLICATIONS FOR RIVER MANAGEMENT

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Abstract

Channel changes at tributary junctions were documented using field investigations from Ikpoba river basin in Edo State, Nigeria. Relationships at tributary junctions show that channel cross-section does not, in most cases increase, just as slope and roughness fail to always decrease at junctions. Channel cross-sectional variables at junctions do not correlate with basin variables when measured at pools. In the same manner, slope and roughness changes fail to show correlation with the changes in basin variables. Only width and width-depth ratio were the variables of which change at junctions were significantly correlated with changes in the independent variables. At any rate, such changes, no matter how small, have a wide range of implications for river management especially in the area of flood control, engineering works, water resource management, fisheries and aquatic lives.

Introduction

Previous pertinent studies aimed at explaining the possible changes in stream channel downstream have been carried out using the hydraulic geometry approach. This method, as it were, results to using a power function to relate changes to increasing discharge downstream. To a considerable extent, results arrived at, show a very strong relationship which, as a matter of fact, ought not to be because of some incremental discharges at junctions that explains changes in channel characteristics (Miller, 1958; Park, 1975; Thorns, 1977a; Richards, 1980; Gippel, 1985; Roy and Woldengerg, 1986; and Roy, 1988). This paper therefore examines the effectiveness of hydraulic geometry in explaining changes in stream characteristics at tributary junctions and its implications for river management. Three equations are fundamental to the study of channel changes at tributary junctions. These are that of Miller (1958), expressed as:

$$X_a = K,(X_b+X_c) \qquad (1)$$

where *a* is the channel below the junction, *b* and *c* are the two connecting channels, and *K*, the coefficient. That of Richard's (1980), was based on Shreve Magnitude (M) in such a manner that:

2

$$WR = C_l MR\ K \qquad (2)$$

where *WR* is the mainstream tributary channel width, *MR* is the ratio of change in Shreve Magnitude, *C*, is a constant close to unity and K_2, a regional exponent. Leopold and Maddock's (1953) equation is of the form:

$$X = C_2 Q^{K} 2 \qquad (3)$$

where *Q* is discharge and C_2, a regional characteristic coefficient. These equations are power functions respectively.

A number of workers have used different methods to show inter-comparison analysis of channel geometry characteristics. Leopold and Maddock (1953) used mean annual flood. Frequency of occurrence has been used for regional comparison not undermining the fact that Kennedy (1972) and Williams (1978) have warned on its shortcomings on the ground of variability. At other instances, taking into consideration the non-availability of flow records, basin area *(A)* has been used (Gippel, 1985; Rhoades, 1986). In other instances too, total upstream channel length *(L)* has been used instead of discharge (Gregory, 1977a; 1977b). A wide range of hydraulic exponents and coefficients for as many rivers worldwide were noted in Park's (1977) study. At the individual level, many studies have shown some relationship though some considerable degrees of scatter were equally involved. This scatter, as it were, is a function of some factors of which bank sediment is one (Petts and Thorns, 1987), bank vegetation (Simon and Hupp, 1982), bed materials (Kellerhals, 1967), gradient (Leopold and Wolman, 1957), roughness (Wilcock, 1967) and, flow variability (Schuum, 1969; Pickup and Warner, 1976), or random systematic local variations (Mosely, 1981; Aziegbe, 2003).

Subset data from individual channels have been known to display characteristic hydraulic geometry downstream that is completely at variance with 'downstream' regional data set (Gippel, 1985; Rhoades, 1986; Aziegbe, 1990; Odemerho, 1992; Ebisemiju, 1989, 1991). These observations from different studies made Richards (1982) to suggest that definition of full spatial variation of channel geometry may eventually take into consideration a family of multivariate regression models. Leopold and Maddock (1953) had previously argued for a re-definition of the concept of hydraulic geometry although Gippel (1985) argues for its retention.

Therefore, a simple model of channel change at tributary junction can be derived as: the ratio of change in a channel variable at junctions (downstream dimension divided by upstream dimension of the main tributary), *XR*, is related by a power function to the ratio of change in discharge (or its surrogate) at junctions, *QR*, such that $XR = C|Q^{K}{}_2$.

This model is of the view that if a relationship is established, then, it should have a coefficient near unity and an exponent close to that of the regional relationship (Gippel, (985). This necessitates the discharge surrogates *(A)* and *(L)* to increase downstream by corresponding channel changes.

In this study, equations 1 and 2 were rigorously tested and anlysed using data collected from junctions sampled from Ikpoba River Basin, Edo State.

The Study Area

The Ikpoba River Basin is located within the geographic co-ordinates of latitudes 6°17'N and 6°26'N of the Equator and longitudes 5°35'E and 5°41'E of the Greenwich Meridian (fig.l). It has an area of 520.3km^2 (Aziegbe, 2003). The river basin is underlain by deeply weathered sedimentary rock that is often referred to as the Benin Formation (Ogunkule et al, 1980).Annual rainfall ranges between 800mm and 1,500mm (Udo, 1978).

Materials and Method

Cross sectional data were obtained using the horizontal-axis-ott current meter mounted on a wading rod. hi some cases, where the stream could not be waded, a weighted cord on a mobile pulley suspended from a line spanning the channel was used. This makes it possible to measure depth at any point across the transverse. Channel top width represents the sum of their widths, channel capacity is the sum of their areas. Capacity, when divided by width, represent width-depth ratio. Since lack of flow, vegetation obstruction and some channel irregularities prevented the measurement of actual energy profile; the method of Park (1977) was used. In this method, the fall in elevation from the furthest upstream to the furthest downstream riffle, through a survey reach was taken. The Cowan (1956) method was used to estimate channel roughness. The variables of interest are bed and bank material, surface irregularities, and variations in cross-sectional slope and size, obstructions and vegetations. For a meaningful study, stream sections were reduced to sub-sections and roughness estimated for each. Using Einstein and Bank's (1960) method, which assumes the total force resisting to flow is equal to the sum of forces resisting to the flow in the sub-divided areas, equivalent roughness *(n/)* was calculated for the whole section. The Manning equation was used to estimate bankfull discharge *(QP)*. Brown (1971) and Gippel (1985) used this method previously and commented it possesses some promising potentials in fluvial studies. And because the Manning method was difficult to correlate with channel variables (Kinghton, 1980), a discharge surrogate was employed (Gippel, 1985;Aziegbe, 2003). The total upstream channel length, which was found to be a better surrogate than Basin Area *(A)* and stream length *(L)* were measured by planimetering and crenulation methods. The values of Shreve Magnitude *(M)* (blue line network) were also determined to know how effective the tributary junction model of Richards (1980) is. Richard used the crenulation method although Werrity (1972) had previously questioned its continued usage because of the tediousness involved, time consumption, operator's subjectivity and variance.

Data used in this study were derived from field measurements and from 1:50,000 Federal Survey Topographic Sheets of Nigeria (1964). Miller's (1958) study was based on 15 junctions, Park (1975) studied 13, Richards (1980) measured 10, Gippel (1985) based his study on 17 junctions. That of Rhoades (1986) was computed for 25 while Roy and Woldenberg (1986) studied 37. However, this study considers 10 junctions (Fig.l) due to equipment and budget constraints.

Apart from the regular variables of interest in hydraulic geometry (width- depth ratios *(F)* were also measured. And because the streams measured were largely unguaged, the measurements were therefore taken at riffle-pool section because it tends to provide notable source of systematic local channel variation (Gippel, 1985;Aziegbe, 2003). Pioneering workers who used this method include (Park, 1975; 1976; Gregory, 1976). Where it becomes difficult to identify a rifile-pool sequence, as is normally the case in most respects, cross-sections were surveyed 5-times and 10-times the channel width from the junction. Tne 5-times data were taken as 'pool' data while the 10-times were taken as 'riffle' data. This is in line with Leopold and Wolman (1957), and, Keller (1972) who noted that the spacing of two riffle-pool sequences averaged around 5 channel widths.

Junction in this study represents the joining of a minor and a main stream (fig. 2). The latter consists of the major tributary upstream from the junction and the receiving stream downstream from the confluence. Discharge as estimated at bankfull correlates with the discharge surrogates *(A andL).* Results of the least squares regression performed on the variables yielded the equations below:

$Q^{bf}=1.23A^{078}$(r = 0.085),and,

$Q^{bf}=0.60L^{102}$(r = 0.91)

Channel variables for both pool and riffle correlate with the basin variables. The exponents are in the range with other studies reported worldwide. The result of the regression equations calculated for each pair variable is shown in Table 1.

Channel cross-section at tributary junctions, in most cases, does not show an increase. In the same manner, slope and roughness do not decrease at tributary junctions always. Scatter of a considerable degree was noted at tributary junctions (Fig. 3). Channel cross-sectional variables at junctions failed considerably to show correlation with basin variables when measured at pools. Slope and roughness also fail to show correlation with changes in basin variables (Fig. 4).

From this study, it follows that the Shreve magnitude model (Richards, 1980), and the hydraulic geometry, as applied in the Ikpoba river basin, failed in most respect to show adequately changes in channel morphology. Only width-depth ratios were the variables that change at junctions and also show significant correlation with the independent variables.

Discussion and Interpretation

Errors linked with the non-derivation of well-defined relationship at tributary junctions could be explained away in many ways. First, is the errors, which are due to measurement. Cross-sectional survey was carried out a number of times for a single site and results averaged. Statistical problems could as well have contributed. Data were reduced to ratio for effective junction analysis. And considering the large data set involved which were generated during the measuring process, errors could have crept in during the analyses unknowingly.

Geomorphic and hydraulic explanations abound for the wide scatter observed in the plots. For example, as tributaries join, their flow are added but the peaks of their respective hydrographs do not necessarily coincide (Leopold, 1974). This situation was observed in the channel studied. As observed by Gippel (1985), if the degree to which joining flows are asynchronous is spatially variable, similar variability could be expected in the degree of morphological change at junctions.

Perhaps, too, sediment nature could as well account for the nature of result because as noted by several workers sediment contrasting nature can result into abrupt channel adjustment at junctions (Knighton, 1980; Richards, 1980; Schuum, 1968; Aziegbe, 2003).

Mutual adjustment of channel variables represents one of the numerous ways a channel alter its cross-section, profile and plan form, to discharge and sediment inputs. Therefore, changes at tributary junctions depend on their mutual adjustments (Park, 1975). Consequently, and as observed by Andrews (1979), over a considerable time, hydraulic adjustment will be rationed out mutually amongst all variables. Considering Schuum's (1969) channel metamorphosis in the context of spatial change at tributary junction, discharge and bed load inputs determine increase in width and possibly width-depth ratio. In any case, the direction of the change remains indeterminate. As observed in this study, width and width-depth ratio changes at junctions correlated positively with discharge surrogate although they actually decrease with discharge (Table 2). As observed by Gippel (1985), Richards and Greenhalgh (1984), and as applied in this case, the combinations of resultant changes are just too many and varied to allow a deterministic model of morphological change at tributary junctions.

Implications for River Management

The management of natural river systems and the design of artificial channels for water conveyance have given the study of fluvial processes a strong applied context (Hart, 1986). At tributary junctions, flow are added to the major channel and this tend to have some geomorphic significance in terms of bank erosion processes depending on the cohesion, non-cohesion or stratification of the channels. The stability of the basin and the eroded sediments are of geomorphic significance for 'on-site' and 'off-site' considerations. Basically, river management considerations as related to this study include.

Engineering Works

Citing engineering projects like dam and bridge require knowledge of the landscape sensitivity (Coates, 1976). In other words, it is important to know whether landforms are at a critical point in their secular development, and what morphological responses are therefore likely to occur during extreme events before and after engineering intervention. Disasters have been recorded worldwide due to dam breaks resulting from geologic/geomorphic instabilities. At the moment, serious bank erosion is affecting Ikpoba river downstream from the dam and at the bridge head. River bank erosion is geomorphically important in affecting changes in the river courses and in the development of flood plains (Hook, 1979, 1980; Simon, 1991; Thorne 1991), which are important in river engineering works.

Flood Control

Knowledge of the hydrological characteristics of adjoining rivers is necessary to be able to determine their flood frequencies (return periods), and hence adequately control flood disasters, as is, currently experienced downstream of the Ikpoba river dam. On many occasions there have been loss of lives, properties and viable agricultural lands due to flooding. Now that it has been observed that adjoining rivers can cause flooding because of added flow, effective control of flooding in Ikpoba river seems on sight,

Water Resources

Water resources must be planned and managed. Eroded sediments have been known to bring about turbidity and water pollution. Odemerho (1988), and Edokpolor (1995) have proved this for the Ikpoba river, An aspect of river management is to control sediment pollution and silting of dams. When it is realized that hydrographic survey records for the Ikpoba dam is rare, coupled with the fact that the river is being rapidly degraded, there is therefore an urgent need to bring these to a halt, moreso, that sediment plays a pivotal role in the optimal use of water resources (Dareshak, 1990).

Fisheries and Aquatic Lives

Undegraded water is vital to the health of a river's ecosystem. Unfortunately, the Ikpoba river drains agricultural and urban basins for most of its course. The river basin is both intensively and extensively farmed with all methods of crop improvements like fertilizer applications. Fertilizer, it must be noted, is one of non-point sources of river pollution. At tributary junctions, stream loadings increases in pollutants (Edokpolor, 1995). There is need for caution in the use of all manners of additives in the basin because the ecosystem is currently threatened (Kadiri, 1987; Udom, 1981; Ohagi, 1983).

Conclusion

No meaningful trend in morphological changes at tributary junctions was observed in the channels investigated in this study. Controls over channel morphology are complex as to warrant an explanation of changes at tributary junctions using the hydraulic geometry per se, which a number of workers have documented its inherent shortcomings (Thornes, 1977a; Pickup and Reigger, 1979; Richards, 1982). Any attempt at explaining morphological change at tributary junctions must take into consideration the river network (Gippel, 1985).

That notwithstanding, incremental discharges at tributary junctions can have cumulative effects that cannot be undermined in engineering works, flood control measures, water resource planning and management including ecosystem considerations.

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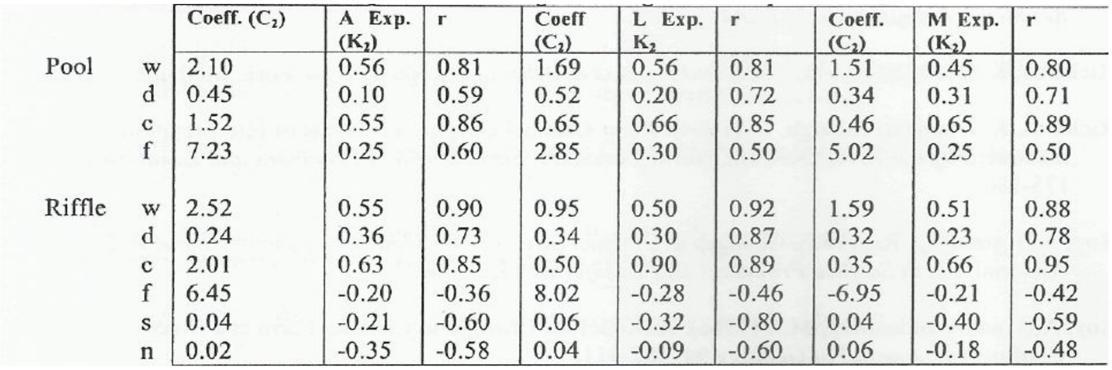

		Coeff. (C_2)	A Exp. (K_2)	r	Coeff (C_2)	L Exp. K_2	r	Coeff. (C_2)	M Exp. (K_2)	r
Pool	w	2.10	0.56	0.81	1.69	0.56	0.81	1.51	0.45	0.80
	d	0.45	0.10	0.59	0.52	0.20	0.72	0.34	0.31	0.71
	c	1.52	0.55	0.86	0.65	0.66	0.85	0.46	0.65	0.89
	f	7.23	0.25	0.60	2.85	0.30	0.50	5.02	0.25	0.50
Riffle	w	2.52	0.55	0.90	0.95	0.50	0.92	1.59	0.51	0.88
	d	0.24	0.36	0.73	0.34	0.30	0.87	0.32	0.23	0.78
	c	2.01	0.63	0.85	0.50	0.90	0.89	0.35	0.66	0.95
	f	6.45	-0.20	-0.36	8.02	-0.28	-0.46	-6.95	-0.21	-0.42
	s	0.04	-0.21	-0.60	0.06	-0.32	-0.80	0.04	-0.40	-0.59
	n	0.02	-0.35	-0.58	0.04	-0.09	-0.60	0.06	-0.18	-0.48

Significance: r-0.05, P = 0.01. Symbols are as defined in the text **Source:** Result of Statistical Computation.

Table 2: Coefficients and Exponents for Change at Tributary Junctions

		Coeff. (C,)	AR Exp. (K_2)	r	Coeff (C,)	LR Exp. K_2	r	Coeff. (C,)	MR Exp. (K_2)	r
Riffle	WR	-	-	-	0.74	0.60	0.50	-	-	-
Pool	LR	0.81	0.75	0.55	0.62	0.87	0.54	0.73	0.80	0.58

Significance: r*= 0.05, P = 0.01 Symbols are as defined in the text **Source:** Result of Statistical Computation.

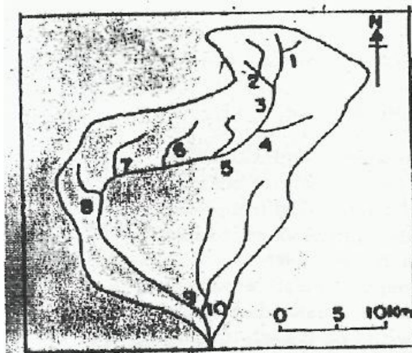

Fig.1: Ikpoba river basin show-
junctions.

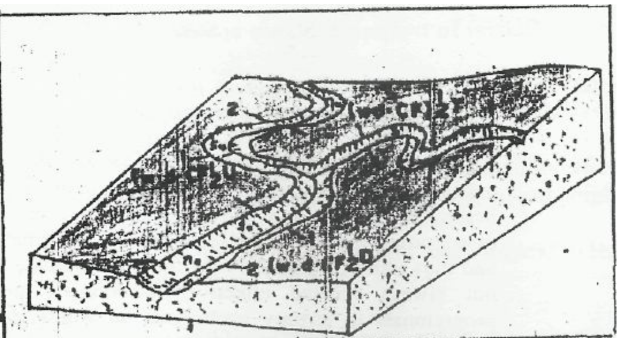

Fig.2: Idealised channel junction site, showing measurement scheme. 1 denotes second pool or five channel widths from junction; 2 denotes fourth riffle or ten channel widths from junction. U and D denote upstream and downstream of junction on trunk channel; T denotes tributary channel.

Adapted from Gippel, (1985).

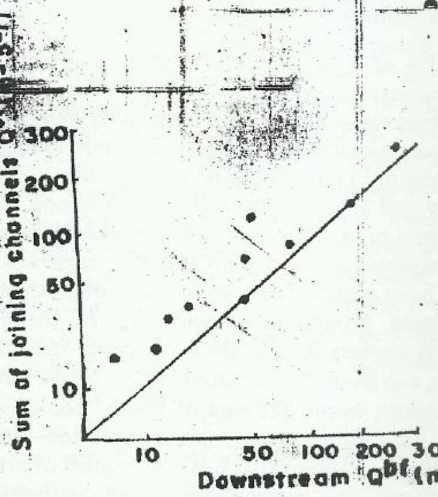

Fig.3: Relationship between sum of estimated bankfull discharg of joining channels and estimated bankful discharge for each site..

Fig. 4: Plots of Width, Dept, Capacity and Width/dept Ratio, Measured at Relifle Sections, Against Total Upstream Channel Length (Regional Relationship