PATTERN OF STREAM CHANNEL SIZE RESPONSE TO AGRICULTURAL LANDUSE CATEGORIES IN SOUTHERN NIGERIA

J. O. A. Mogborukor

Abstract

The study examined the effect of agricultural land use on stream channel size. It was discovered that stream channel enlargement occurs in response to change in stream flow regime which followed the conversion of the natural rainforest to different agricultural activities in the Orogodo river basin in southern Nigeria. Stream basin draining areas subjected to traditional agricultural activities tend to develop relatively larger stream channel bankfull cross-sectional areas than those draining areas under fallow of various lengths or forest cover. Stream hydraulic geometry is also significantly altered by agricultural practices. The individual relationship of stream channel width, depth and velocity to changing discharges, as expressed in the hydraulic exponent values, is shown to change as basin surface passes from one traditional agricultural land use phase to another. To reduce peak flow discharge, good land management practices and modern farming methods should be encouraged within the basin in order to increase infiltration capacity.

Introduction

Several studies have demonstrated that the morphology and hydraulic geometry of stream channels in erodible materials are adjusted to the prevailing hydrological and sedimentological regime (Leopold and Maddock, 1953; Leopold, 1968; Lewis, 1968; troxell and Leopold, 1971; Hammer, 1972; Knox, 1977; Knight, 1979; Morisawa and Laflure, 1979). Implicity or explicitly expressed in some of these studies is that human activities in a watershed tend to increase the volume of runoff and peak flow magnitudes, which in turn, lead to stream channel enlargement. Regional studies in both Britain and Eastern United States have confirmed significant channel enlargement of streams draining urbanized watersheds (Hammer, 1973; and Knight, 1979).

Similar stream channel enlargement were observed for most headwater and tributary channels draining agricultural basins in Wisconsin (Knox; 1977). In the Orogodo river basin, two factors have contributed to large scale devegetation (Ikomi and Owabor,1979). First, is the increasing population and second, is the introduction of cash crops. Both factors place high demand on land.

Consequently, the soil resources is no longer protected hence soil erosion is predominant in the basin. Increase in soil erosion and run off generation appear to be common result of the interaction between the traditional farming system and today's high population densities and cash cropping. A stream channel in equilibrium with its basin environment will manifest this condition by a balance among its channel morphology, hydraulic geometry, and network properties. However, with the apparent stress placed on the land resources through agricultural practices in the face of increasing population and decrease in the available lands, potential increase in the sediment supply and runoff to river systems become ever more probable. These increase in the sediment and runoff would likely be large enough that the streams could not make internal adjustments to maintain their previous equilibrium state. Thus, agricultural practices utilized in the study basin introduce imbalances into the stream channel system. Such imbalance should initiate significant adjustments in both the form and size of channel dimensions. Knox (1977), Odemerho (1982) and Hasholt (1997) showed that such conditions to “natural” channel discharges resulting from the conversion of natural land cover to agricultural uses had significant influences on the modern channel-cross section. Besides, the common bankfull-frequency hypothesis suggests that the degree of channel alteration proceeds in proportion to the amount of the additional discharge generated by the type and level of human activities in the basin. Thus, it is anticipated in this study that basin areas subjected to greater intensity of human activities, such as prolonged farming under high population pressure and inefficient management practices, will induce greater channel adjustment than those under fallow or forest conditions.

The analysis of agricultural landuse categories in the study area distinguishes stream channel size dimensions associated with stream basin predominant land use categories as: cultivated land, fallow land, and forest land. This is approached through relating the measured stream channel size index to a surrogate of stream discharge associated with each landuse category found in the stream basin.

The basin field situation, is such that, it passes through cycle of land use phases. That is, from cultivation through fallow to forest and then back to cultivation. As a result of this, it is anticipated that the adjustment of the channel size is in a state of flux.

The study Area and Method

This study was carried out in Orogodo river basin. The river stretches for about 50km in length. It is located in Delta State of Nigeria. It lies between latitude 5^0 10’ and 6^0 20' North and longitude 6^0 10' and 6^0 20' East (Fig I). The streams is fed principally by ground seepape from acquifer in the thick rain forest zone of Mbiri and secondarily by precipitation, Municipal effluence and surface run-off from riparian communities. It flows through Agbor main town, Owa-Ofie, Ekuma-Abavo, Oyoko and ends in a swamp between Obazagbon-Nugu and the oil rich town of Oben is Edo State.

The river basin is made up of the soil type known as ferrasols, which precisely the red and brown soil in abundantly free iron oxides. The weathering profile consist mostly of red and yellow earth and loose, poorly sorted sand, intermixed in places with clay deposits. The ferrasols are mostly loamy, sandy and in some places sandy with clay loam. It’s nature makes for easy cultivation and also suffer from excessive internal drainage and intense leaching.

The study area is located in the humid tropical setting. The natural vegetation of moist tropical rainforest has been destroyed by shifting cultivation over much of the area. Today the landscape is mosaic of different stages of agricultural vegetation and deteriorated derived savanna community. The mean annual rainfall ranges from 1120mm in the north to 1490mm in the south. Over 60 percent of the rainstorm have maximum intensities greater than 25mm hr^{-1} (Lal, 1976) which means that majority of rain events cause actual soil loss in this area.

Due to population pressure on land, steeper slopes and marginal lands are increasingly being put into traditional cultivation. Also, the tendency towards reduced fallow to the point of continuous cultivation is common place. The environmental manifestation of these trends include augmented stream flow and sediment discharge.

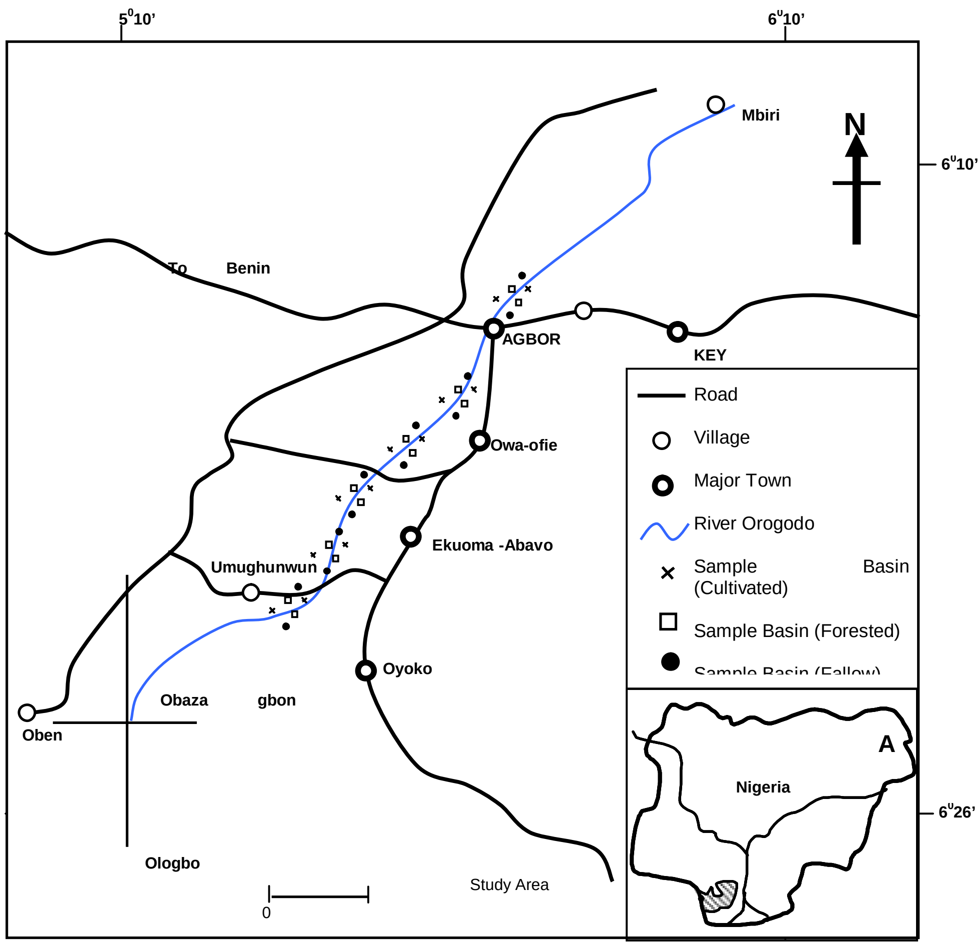

FIG. 1: MAP OF THE STUDY AREA SHOWING THE SAMPLING

Long term change in stream channel capacity and hydraulic geometry may be studied directly by monitoring the changes of individual stream sections over time as the basin passes from one form of agricultural land use to another. Or, channel changes may be inferred by comparison of stream sections in basins under different traditional agricultural land use stages having similar climatic and physiographic conditions. This intervention approach is adopted in this investigation covering a distance of 25km. at each site, the pattern of channel size response to stream discharge in area of agricultural activities was studied in detail. Bank full stream channel cross-sectional areas were measured during the low flow months of December through March.

At-a-station weekly measurements of stream hydraulic variables consisting of stream channel width, depth, velocity and discharge were conducted, for each of the four basins. The major land use types considered consist of cultivated lands, 1-3 years fallow land 7-8 years fallow lands, and forest land. A horizontal axis ott type current meter mounted on a wading rod was used in the field measurements of stream velocity.

The drainage basin land use types and their spatial characteristics were obtained by stereoscopic examination of 1:40, 000 scale aerial photographs. These were checked and updated by reconnaissance survey.

Result

A land use survey of the basin revealed that 12 of the sites had predominantly agricultural landuses most of the time. While 60percent of the remaining 8 sites lay under fallow condition most of the time. Forty percent of the area is under permanent forest or in forest reserves and residential uses.

Stream Channel Size Response to Agricultural Land Use

It was discovered that sites under cultivation tend to have relatively larger stream bank full cross-sectional areas than those under either forest or fallow cover (Table I) Depending on the farming practices, channel size may vary within each major land use category. For example, the average channel size for basin section under cultivation was found to be 7.22 m^2 , while basin section where farming activities is practiced very close to the stream channel, channel sizes are as large as 9.46m^2.

Table 1: Stream Channel Size Variation In Relation to Land Use

Basin surface under agricultural land use	Average bankfull stream cross-sectional area (m^2)
Cultivated basin	7.22
Basin with valley side cultivation	9.46
Basin in fallow	5.66
Basin under forest	3.44

Source: Field work 2002-2008

Dune and Leopold (1978) demonstrated that channel size in the natural, undisturbed state might best be expressed as a function of drainage area. The average relation between channel size and basin area for the natural, undisturbed basin (i.e basins section under forest cover) is expressed by the equation:

$$C = 0.95D_a^{0.50}$$

Where C is bankfull channel cross-section size and D_a is drainage area. Figure 2 presents a plot of stream cross-section area as a function of drainage area for basins under cultivation, fallow and forest cover. It shows that the cross-sectional area of channels draining areas that are under cultivation lies above the mean line for natural, unaltered. The cross-sectional area of stream channel draining fallow area also lie above the mean line for the natural basin; but the measure for channels in fallow areas generally is less than those under cultivation. The scatter of points in figure 2 shows that the points representing catchments sections under natural conditions are closer to each other and to the regression line. On the other hand, the greater scatter of points observed among points representing cultivated section which reflect the level of disorderliness introduced into the fluvial system by human agricultural activities. The average relation between channel size and basin area for the basin area altered by cultivation is expressed as:

$$C = 1.19_a^{0.80}$$

While the average relation for basin area under fallow is:

$$C = 1.158D_a^{0.54}$$

While basin area under cultivation and those under fallow were combined, the average relation gives the equation:

$$C = 1.46D_a^{0.67}$$

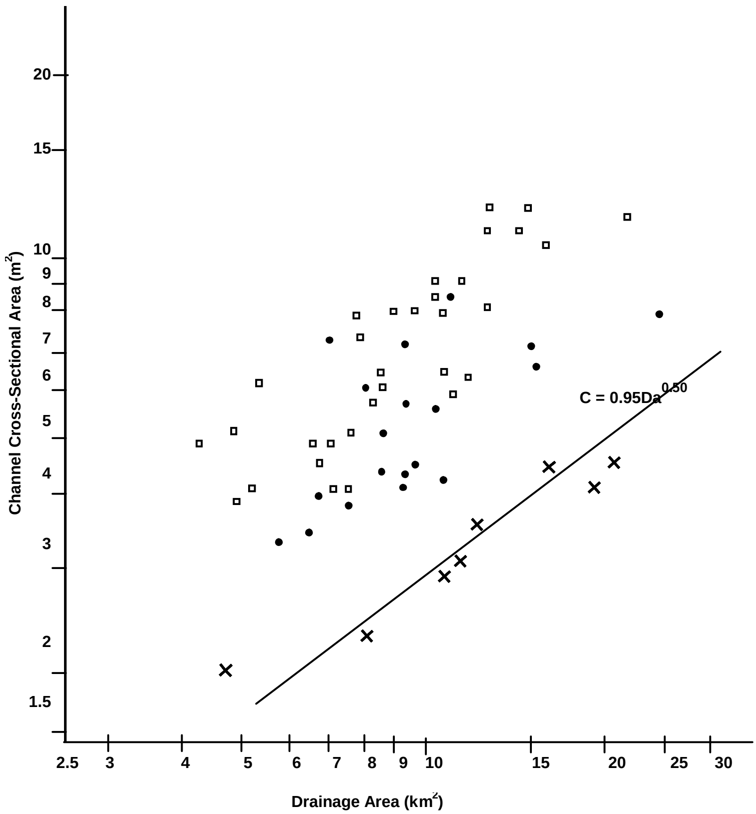

Fig. 2: Channel cross-sectional area as a function of drainage area x represents channel whose immediate upstream catchments is under forest, dot for fallow basins, and open blocks for cultivated basins

Thus, it is very probable that the larger channel size in stream reaches draining cultivated sections of the basin could be the result of increased peak discharge that is associated with prolonged farming activities. Conversely, the relatively smaller channel size of stream reaches draining fallow sections of the basin are likely the result of relatively lower peak discharges due to a relatively enhanced infiltration capacity under protective vegetal cover.

At-A-Station Relation Of Stream Variables Under Different Agricultural Land Use Phases.

The analytical procedure in this section is to compute the rate of change of the stream hydraulic variables-width, depth, and velocity-with respect to changes in discharge associated with the various land use phases in seven stations. Weekly measurement of stream hydraulic variables and discharges were done on stream section under continuous cultivation; fallow and forest.

A simple repression analysis was performed to determine the at-a-station relation of stream width, depth, and velocity to change in discharge. The general relations achieved in the regression analysis are expressed as a simple power function:

$w =_a Q^b$

$d =_c Q^f$ and

$v =_k Q^m$

Where Q is discharge, w,d,v are width, depth, and velocity. The values a, c, k, are the intercept of the repression lines at a discharge of one cubic meter per second. The exponents b, f, m represent the slope of regression lines when the hydraulic variables are plotted logarithmically on both axis.

Two general forms of adjustment to changes in discharge were revealed, although the rate of change as expressed in the exponent values vary from station to station (figure 2.1, 2.2 and 2.3). The rates of change for two of the stations, as expressed by the exponents b, f and m have the general form m>f>b. This indicates that with a changing discharge, velocity increase at the highest rate and width increases at the lowest rate. Leopold and Maddock (1953), Leopold and Miller (1956), Lewis (1968) and Richords (1993) observed similar general forms of adjustment in their studies. The other form of adjustment pattern (f>m>b) for the third station indicates that depth increases at the highest rates and width increases at the lowest rate. The (m>f>b) form of adjustment was associated with stream reaches whose immediate upstream catchments area are still under rapid urban development, while the (f>m>b) form was associated with basins where the urban development process has long ceased. Table 2 shows that basin area under cultivation conformed to the m>f>b pattern while the forested and fallow basin areas conformed to the f>m>b.

Table 2: At-a-Station Hydraulic Geometry

$W =_a Q^b$ $d =_e Q^f$

$V =_k Q^m$

Station number	**Hydraulic Exponent***		
	b	f	m
Cultivation section			
Stations 8	0.05	0.46	0.50
Station 11	0.04	0.45	0.50
Fallow section			
Station 12	0.07	0.48	0.45
Station 13	0.08	0.47	0.43
Forested section			
Station 3	0.11	0.63	0.36
Station 7	0.09	0.60	0.35

Source: Field work 2002-2008

*The hydraulic exponent-b, f, m-are all significant at the 0.01 significant level.

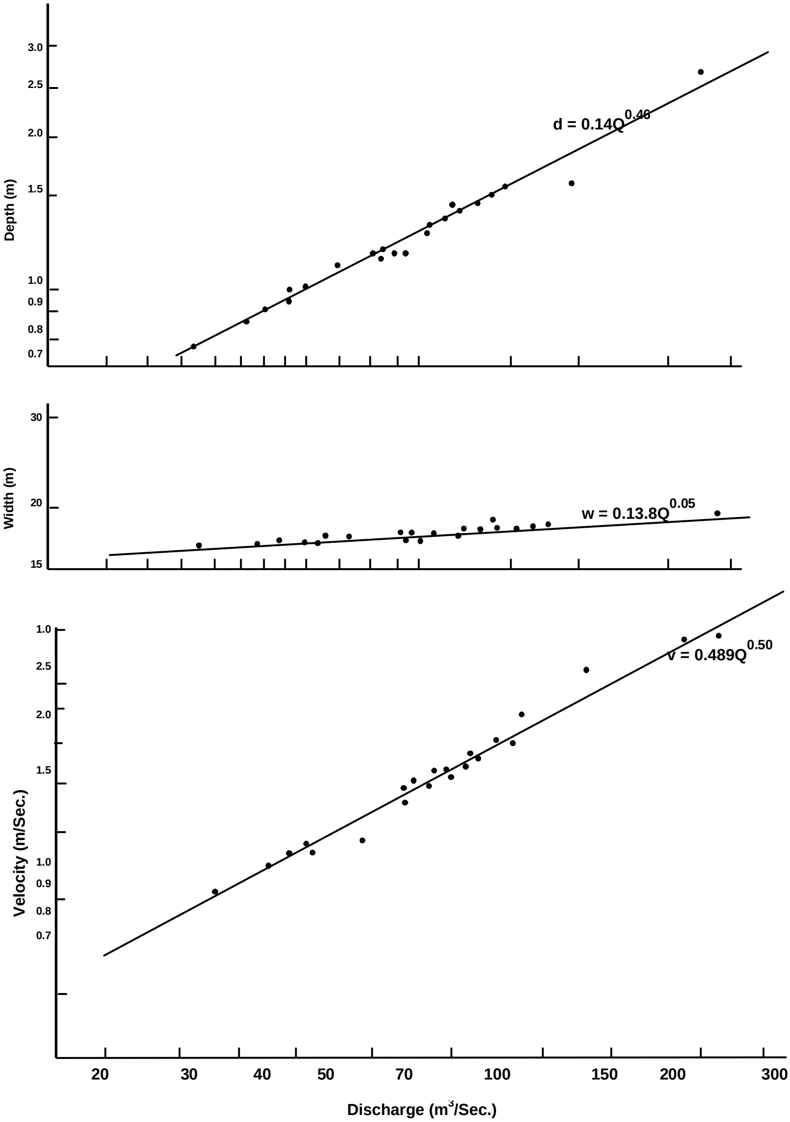

Fig. 2.1: Adjustments of width, depth and velocity to discharge at Station 8 (Cultivated basin section)

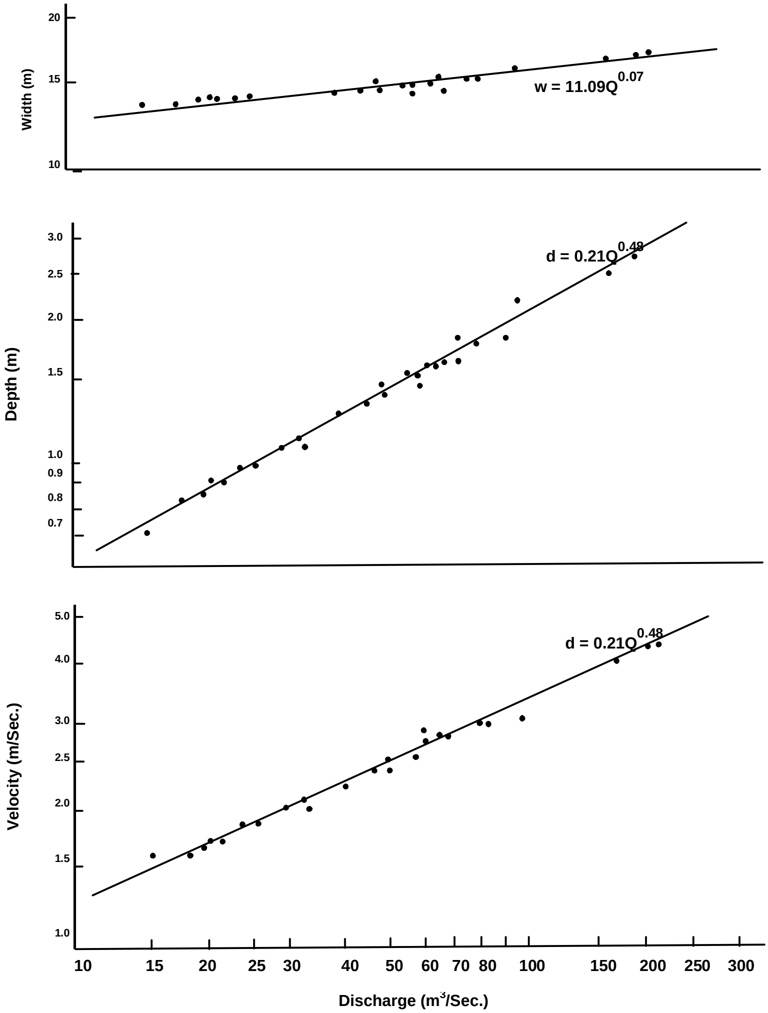

Fig. 2.2: Adjustments of width, depth and velocity to discharge at Station 12 (fallow basin section)

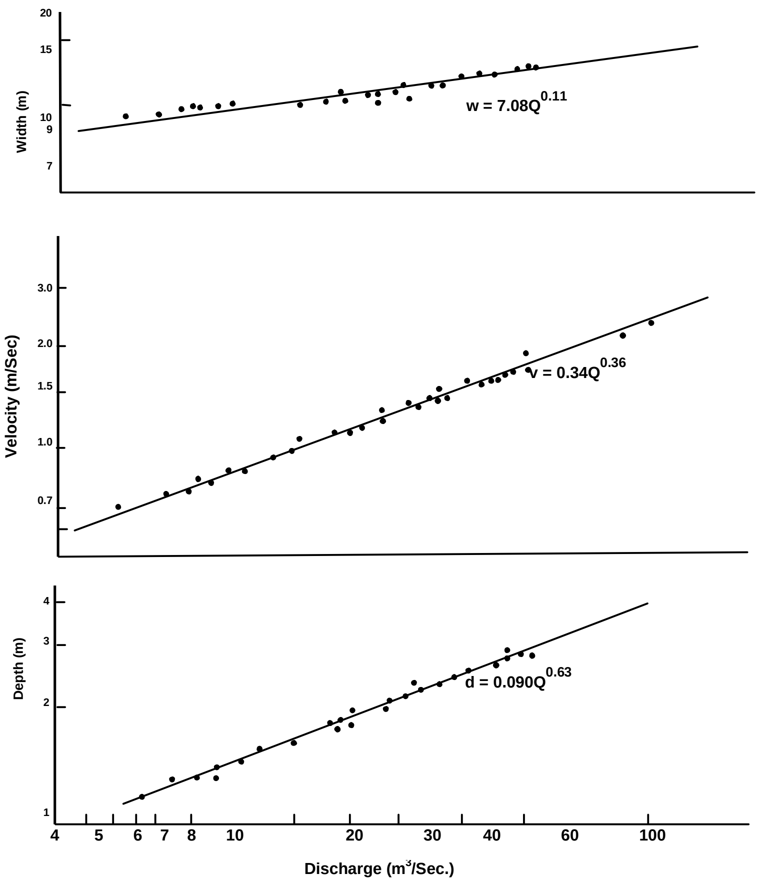

Fig.2.3: Adjustments of width, depth and velocity to discharge at Station 12 (forested basin section)

Discussion

The two sections (stations 8 and 11) adjust to increasing discharge primarily by a relatively high rate of velocity increase. The catchments areas immediately upstream of the two sections are under continuous and prolonged traditional agricultural activities. The four sections (stations 3, 7, 12 and 13), on the other hand, adjust to increasing discharge by a relatively high rate of depth increase. The catchments immediately up stream of the sections is in each case under fallow and forest cover. However, stations 12 and 13 which is under fallow have a more equitable distribution of exponent values among the velocity and the depth parameters. But stations 3 and 7 have a disproportionately high 'f' exponent value, showing a major adjustment in depth. Morisawa and Laflure (1979) and Odemerho (1992) have demonstrated that streams try to adjust during watershed development by developing a new channel configuration. This change, of course, imposes new relation in the hydraulic variables.

The primary effect of agricultural land use in this study is the increase in stream discharge. The stream adjusts to this increased discharge by increasing its velocity as shown by the exponent values obtained for stations 8 and 11. It is probable that the stream increase in velocity to the point where it achieves sufficient competence to effect channel size adjustment. This is suggested by the fact that while the basin is under fallow (stations 12 and 13), the stream adjust by increasing its depth more than its velocity. Thus, it is possible that increase in velocity experienced under the cultivation phase may have led to increased channel adjustment activities and overbank peak flow as reflected in the relatively higher depth and width exponent values of the fallow sections of the basin. Compared with the basin catchments under forest (stations 3 and 7), with less runoff, the stream reduces its velocity further to attain that competence sufficient to maintain the new channel configuration until a new equilibrium relation is achieved.

Conclusion and Recommendations

Stream channel size is consistently larger for basin sections draining areas subjected to prolonged cultivation than for those under fallow. This is due to the increase in storm stream flow resulting from farming activities. The stream adjust to this increased discharge by first increasing its velocity to attain sufficient flow competence. This initiates channel scour and size adjustment. Under fallow the stream velocity is lower. It appears to stabilize at a velocity that is just sufficient to maintain the new stable channel configuration. Further adjustment continues until a new equilibrium relation is achieved among hydraulic variables. However, the stream adjustment is in a state of flux, since the basin studied is frequently, cultivated.

Changes in stream flow regime and channel morphology associated with agricultural practices are of considerable consequences in basin management. The serious problems that arises include: (i) decreased channel conveyance due to increasing deposition of sediments: (ii) more frequent and severe flash flooding: (iii) increased channel erosion; (iv) reduced water quality as a result of increased period of low flow and (v) reduction in aesthetic and recreational value of streams. It is suggested that an integrated program of basin land use and structural alternatives are viable solutions to these problems.

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