Stream-variable Response to a Change in Surficial Geology: Middle Fork, Big Walnut Creek, Hendricks County, Indiana

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Introduction

The Middle Fork of Big Walnut Creek flows across a contact between Wisconsinan glaciolacustrine sediments (upstream) and outwash (downstream) in northwestern Hendricks County, Indiana (Figure 1). Preliminary field observations suggested that cor-

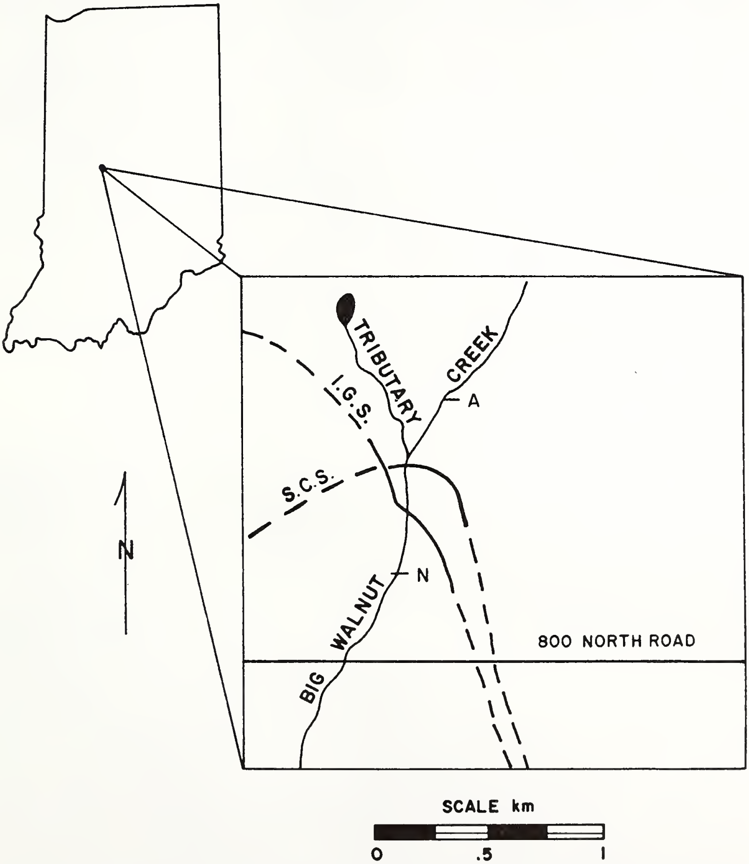

FIGURE 1. Location of study area. The study reach of Middle Fork, Big Walnut Creek is between stations A and N. S.C.S. and I.G.S. indicate positions of the contact between Wisconsinan glaciolacustrine sediments (upstream) and outwash (downstream) as mapped by the Soil Conservation Service (6) and the Indiana Geological Survey (1), respectively.

responding changes occur in the geometry of the channel cross sections in this area (Figure 2).

The purposes of this study are to determine: (1) if this reach of Big Walnut Creek is in equilibrium with its geologic setting, and (2) how sediment and stream-channel characteristics reflect a difference in the geology of the surficial materials along the study reach of the stream.

FIGURE 2. General channel form in upstream (A) and downstream (B) parts of study reach.

Fourteen stations were established in March 1985, during moderate streamflow, along a study reach of 791 meters (Figure 3). The stations were established at pools midway between riffles. At each station, water-surface elevation and cross-section geometry were determined, and suspended sediment and bed material were sampled.

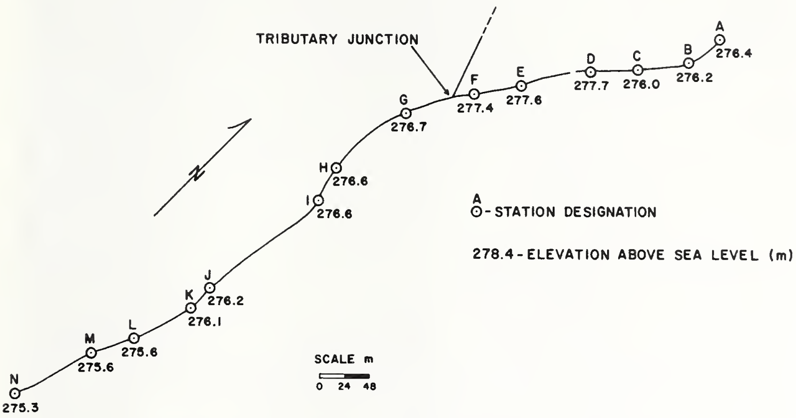

Figure 3. Map of the study reach showing locations and elevations of stream surface at stations. Also shown is the location of the tributary junction.

Geology of Surficial Materials

Hendricks County, Indiana, is located in the Tipton Till Plain of central Indiana (10). The thickness of Wisconsinan surficial materials ranges from zero to greater than 61m. These materials include till, outwash, and glaciolacustrine sediments. Holocene alluvium occurs along streams (1).

The study reach was chosen with its midpoint at the contact between the glaciolacustrine sediments and outwash. The glaciolacustrine sediments upstream from this contact are mostly poorly-laminated sandy silts and clays (Figure 4), although th overall grain size ranges from clay to coarse sand with widely scattered small pebbles The soils formed in the glaciolacustrine sediments are poorly-drained sandy loams o the Rensselaer-Whitaker association (6).

The outwash downstream from the contact is moderately to poorly sorted and stratified (Figure 5). The grain size ranges from clay to cobbles. The soils formed in th outwash are well-drained gravelly clay loams of the Ockley-Martinsville-Fox associatio (6).

External Variables

Aerial photographs taken from 1946 to 1978 reveal that channelization occurre along parts of Big Walnut Creek, including the study reach, prior to 1946. Channeliza tion resulted in a straight channel pattern, which has been maintained over the last 4 years. However, no other effects of channelization upon the stream were noted.

Within the study reach, Big Walnut Creek is joined by a small tributary (Figure 1 and 3). This tributary flows approximately 600 meters from a small pond which ac to moderate flow and trap sediment. The tributary channel is small compared to tha of the main stream. It had negligible flow during the period of the study and showe no evidence of previous high flow.

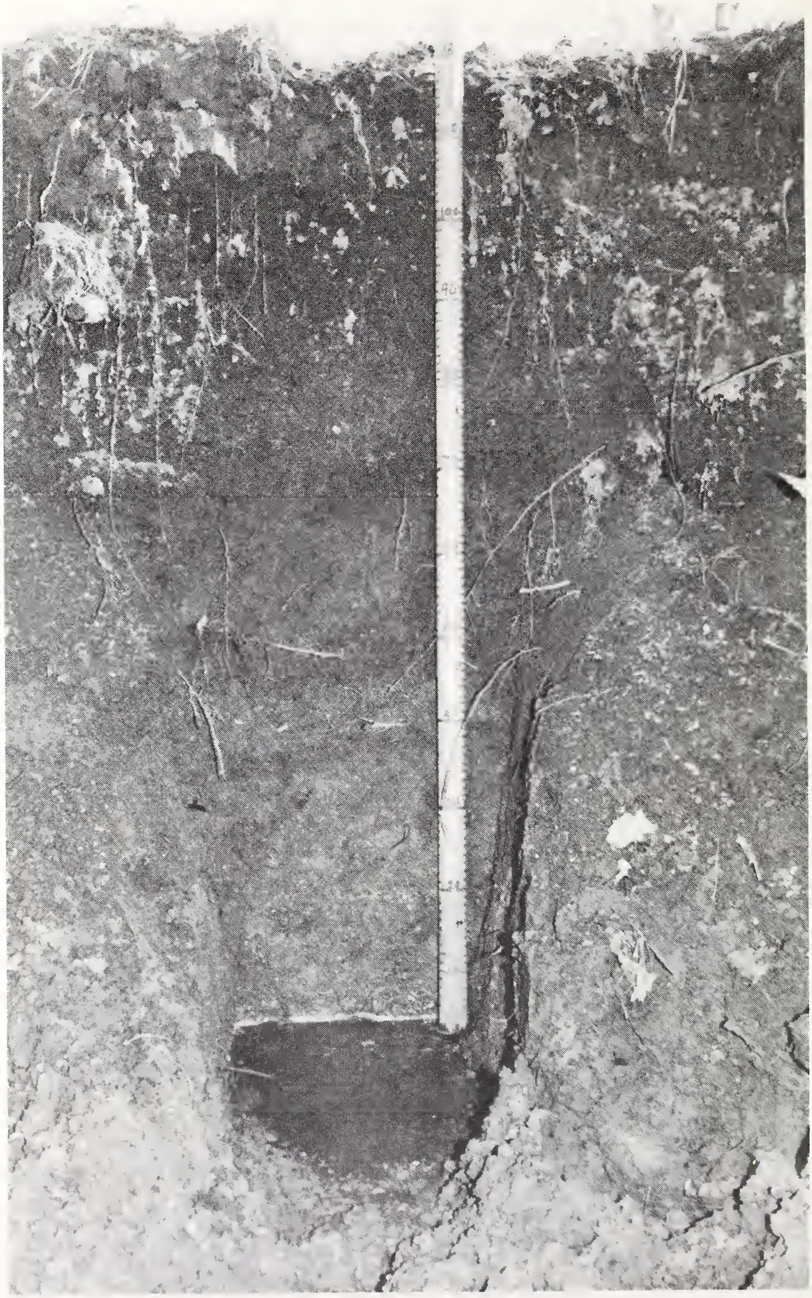

FIGURE 4. Glaciolacustrine sediments along upstream part of study reach. The exposure is 1.2 meters thick.

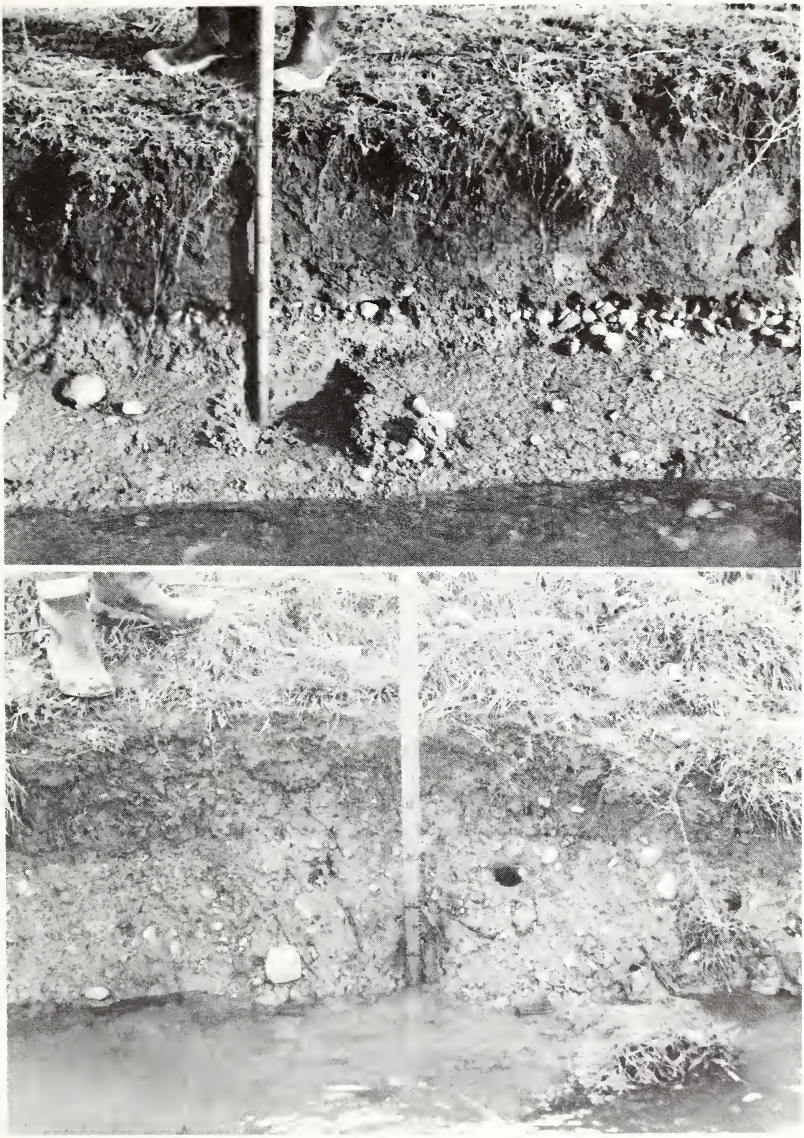

Figure 5. Outwash along downstream part of study reach. The exposures are 0.6 meters thick.

Agricultural drain tiles add some discharge along the study reach. However, at the time of the study, no discharge from the tiles was observed, and the effects along the study reach were assumed to be minimal.

Channel-bank modification occurs at livestock-watering sites, but the effects are localized, and such sites were avoided during collection of data.

Methodology

Stations were mapped, and elevations were determined with plane table and alidade. Elevations were established at the water surface and used to determine stream slope.

Bed-material samples were obtained at the thalweg of each station by taking the uppermost 3 to 6 centimeters of bed material with a manual cannister sampler. Samples were analyzed for grain size using the dry-sieving method (2). All grain-size determinations are based on the modified Wentworth scale (4).

A US DH-48 depth-integrating wading-type sampler was used to collect samples of suspended sediment. One sample was taken at the thalweg of each station (3). The concentration of suspended sediment was determined using the evaporation method (2).

The geometry of the cross section at each station was determined by establishing a level line across the stream and measuring depth across the channel at 20-centimeter intervals.

Results and Discussion

The following discussion of the variables measured or determined along the study reach will be made with reference to stations A through N (Figure 3, Table 1). Trends and clusters in the data will be related to distance downstream within the reach. The discussion of suspended sediment, bed material, stream slope, and channel shape will focus upon a consideration of the hydraulic geometry of the study reach.

TABLE 1. Data collected at stations along the study reach of Big Walnut Creek.

							Bed Material		
Station	Elevation (m)	Distance Downstrm. (m)	Channel Width (m)	Channel Depth (m)	W/D	Mean Gr. Sz. (ϕ)	Vol. % Gravel	Wt. % Silt + Clay	Susp. Sed. Conc. (mg/l)
A	278.4	0	5.92	0.52	11.6	1.68	1	1.20	23.2
B	278.2	39.6	4.24	0.57	7.4	0.82	4	0.61	25.8
C	278.0	88.4	5.80	0.64	9.1	1.28	2	0.20	21.0
D	277.7	134.1	5.28	0.62	8.5	0.09	39	0.25	13.3
E	277.6	201.2	4.88	0.45	11.9	1.34	7	0.15	20.8
F	277.4	246.9	6.24	0.71	8.4	0.07	28	0.05	37.3
G	276.7	315.5	4.80	0.51	9.5	N/A	43	N/A	31.8
H	276.6	403.9	5.20	0.33	15.6	1.05	25	0.23	31.6
I	276.6	440.5	6.84	0.25	27.2	0.50	33	0.08	31.6
J	276.2	576.6	5.80	0.31	18.7	−0.25	60	0.13	23.3
K	276.1	602.0	6.00	0.35	17.1	−0.55	67	0.08	28.0
L	275.8	663.0	6.32	0.28	22.6	−0.66	75	0.04	35.8
M	275.6	708.7	5.64	0.37	15.2	−0.36	60	0.08	34.2
N	275.3	791.0	5.52	0.45	12.8	1.41	13	0.89	26.0

Suspended Sediment

The concentration of suspended sediment shows no significant changes or trends downstream through the study reach. Furthermore, the tributary does not introduce significant amounts of suspended sediment (Table 1).

Bed Material

From the samples of bed material, analyses were made for the weight percent of silt + clay, mean grain size, and volume percent of gravel. No significant trends or groupings were apparent in the weight percent of silt + clay along the study reach.

The plot of mean grain size versus distance downstream shows two groupings or clusters in the data (Figure 6). Stations A through F have an average mean grain size of about 0.9ϕ, whereas stations H through N have an average mean grain size of about 0.2ϕ. A Student t-test indicates a significant difference in mean grain size between the two groups at a confidence level of 0.10.

Two groupings are also apparent in the plot of volume percent gravel versus distance downstream (Figure 7). Stations A through G have an average of about 18 volume percent gravel, whereas stations H through N have an average of about 48 volume percent. A Student t-test indicates a significant difference in abundance of gravel between the two groups at a confidence level of 0.025.

Stream Slope

The slope of the water surface along the entire study reach is 0.0039 (Figure 8). The slope is interrupted and deviates from this value between stations F and H. This "bench" in the slope is probably a consequence of the tributary junction between stations F and G (Figure 3). Because the tributary does not contribute a significant amount of suspended sediment to the main stream (Figure 3, Table 1), the additional discharge supplied by the tributary apparently results in scouring of the channel between stations F and G. Below that point, the stream's sediment load is increased, and the channel is aggraded between stations G and H. Below station H the stream resumes its original channel slope (Figure 8). Excluding the "bench" from the profile would result in an essentially constant slope.

However, such a constant slope might not be expected when considering the change in bed material along the stream. Although Schumm (9) suggests that the introduction of coarse bedload material should result in a steepening of the stream slope, such steepening does not occur along the reach in our study area where the stream encounters the gravel-rich outwash.

Channel Shape

According to Ritter (5), the introduction of a different type of load may result in a change in channel shape instead of a change in gradient. Such a change is apparent in our study reach. Cross sections at stations G and J have been selected as typical of the upstream and downstream parts of the study reach, respectively (Figure 9). The difference is quite apparent.

A plot of channel width versus distance downstream (Figure 10) shows very little change (regression slope = 0.0009) along the study reach. However, a plot of channel depth versus distance downstream (Figure 11), shows the data in two groupings, stations A through G and stations H through N. A Student t-test indicates a significant difference in channel depth between the two groups at a confidence level of 0.01. A plot of the width/depth ratio versus distance downstream (Figure 12) again shows two groupings. Channel shape is believed to be independent of discharge (8) but dependent on sediment type (5).

The channel shape in the study reach is apparently controlled by the geology of the surficial materials. If the materials in which the channel is cut are highly cohesive, as in the glaciolacustrine sediments of the upstream part of the study reach, the channel will be deep. If the bank materials lack cohesion, as in the outwash of the downstream part of the study reach, the channel will be shallow (8).

Hydraulic Geometry and Dynamic Equilibrium

A constant slope throughout the study reach, even with the change in surficial materials, suggests that the stream is in equilibrium with its geologic framework. The

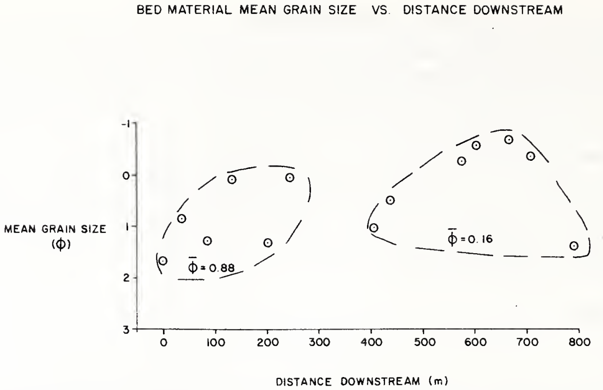

FIGURE 6. Mean grain size of the bed material versus distance downstream.

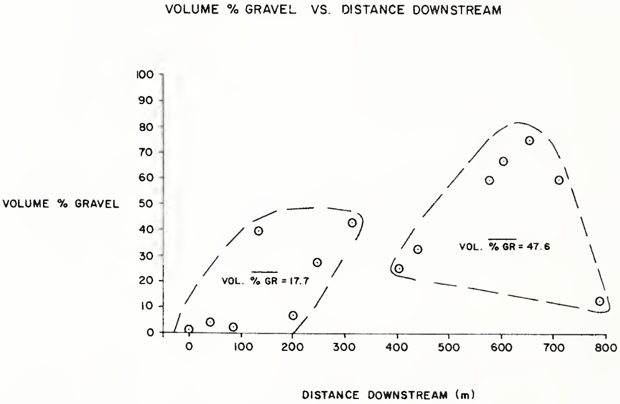

FIGURE 7. Volume percent gravel in the bed material versus distance downstream.

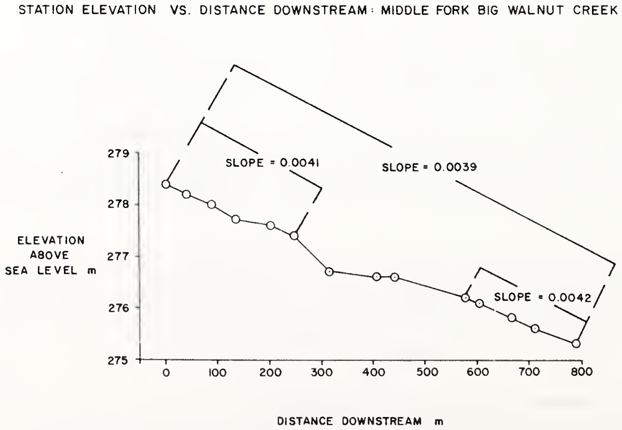

FIGURE 8. Longitudinal profile of the study reach of Big Walnut Creek.

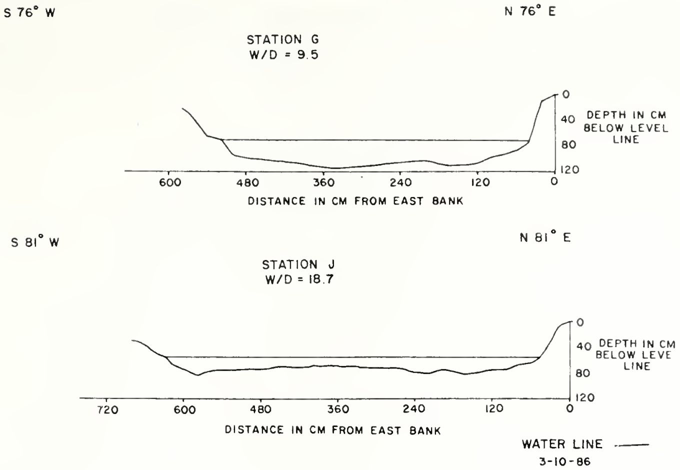

Figure 9. Representative channel cross sections for upstream (Station G) and downstream (Station J) parts of study reach.

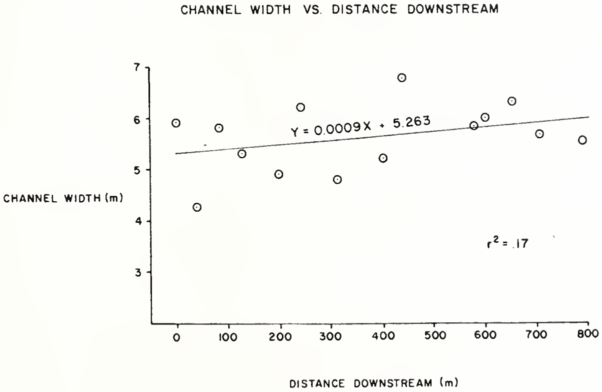

Figure 10. Channel width versus distance downstream.

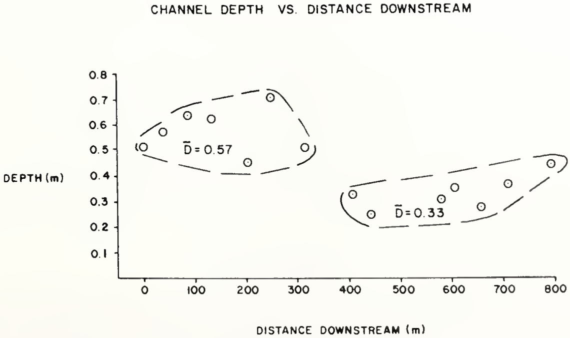

Figure 11. Channel depth versus distance downstream.

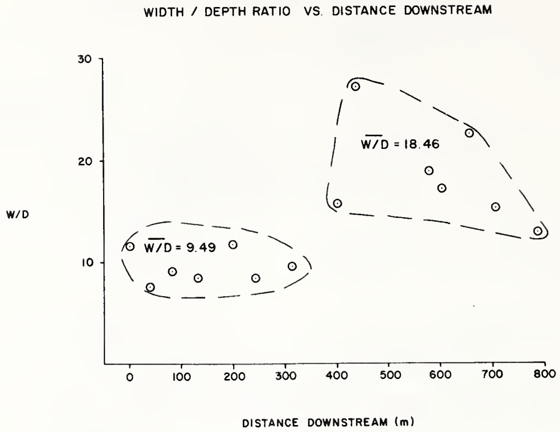

FIGURE 12. Width/depth ratio versus distance downstream.

data indicate that other hydraulic variables are actively responding to the change in bed material in order to maintain that equilibrium.

Our approach to understanding how this response is occurring is based on the flow equation

$$Q = AV$$

where Q = discharge, A = cross sectional area, and V = velocity. With constant discharge along the study reach

$$Q_1 = Q_2 \text{ or } W_1D_1V_1 = W_2D_2V_2$$

where 1 and 2 designate the upstream and dosnstream parts of the study reach.

The Manning equation was used to obtain estimates of average velocity for channel cross sections in the two parts of the study reach. The Manning equation is

$$V = 1.49/n\ R^{2/3}S^{1/2}$$

where V = velocity, n = Manning roughness coefficient, R = hydraulic radius, and S = stream slope. Roughness coefficients were estimated from published tables (7). Using $n_1 = 0.030$ and $n_2 = 0.035$, estimated average velocities are $V_1 = 1.30$ m/sec and $V_2 = 1.96$ m/sec. The velocity increases by about 50 percent from the upstream part to the downstream part of the study reach.

This analysis indicates that velocity and depth are the actively-adjusting hydraulic variables, permitting the stream to sustain an equilibrium with its geologic framework. Where gravel-rich sediment from the outwash is introduced, an increase in velocity is needed to transport the sediment load. Because the channel width remains almost constant, a decrease in depth is needed to satisfy the flow equation. Not only does the stream show a 50 percent increase in velocity in the part of the study reach through the outwash, but a decrease in depth effectively increases the ratio of velocity acting on the channel bottom to velocity acting on the channel sides (8). This results in an increased capability to transport bedload, and a simultaneous decrease in the cross-sectional area.

Conclusions

The responses of particular stream variables to internal and external factors are well observed along the study reach of Big Walnut Creek. An increase in grain size of the surficial materials surrounding the stream occurs between stations G and H. This change in surficial materials results in distinct changes in channel shape and velocity in order to provide the energy necessary to transport the coarser load, and at the same time permit the stream to maintain a constant slope of the water surface. The response of specific internal variables to changing lithologic controls maintains the dynamic equilibrium of the system.

Acknowledgments

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