

USE OF GEOMORPHIC ASSESSMENT
TO PREDICT CHANNEL STABILITY
by

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SUMMARY:

A geomorphic assessment was used to design an alluvial channel in southcentral Indiana. Both rigid boundary and mobile boundary analytical procedures were evaluated using the geomorphic assessment.

KEYWORDS:

Channel design, channel stability, geomorphology, sedimentation

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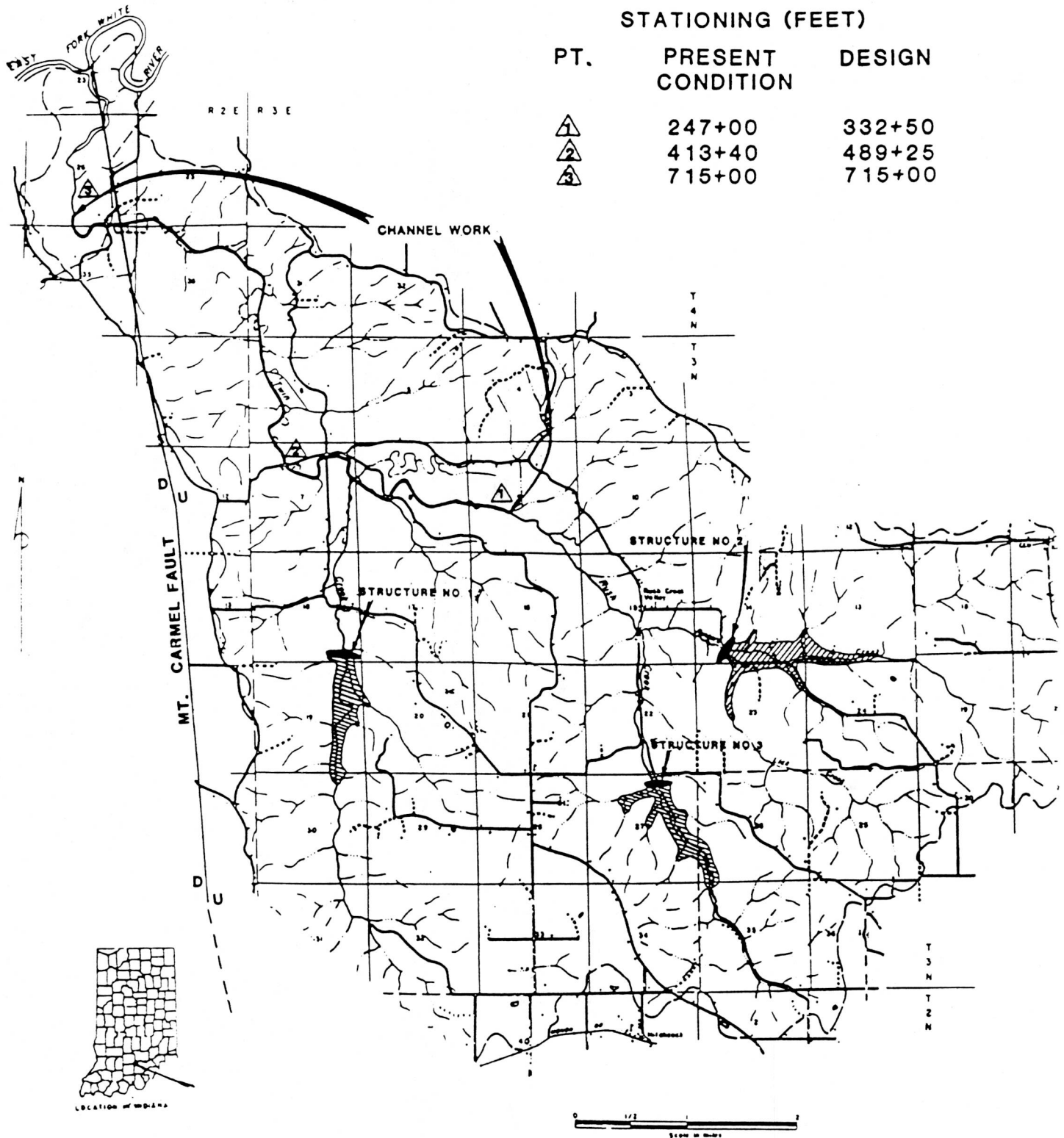
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TWIN-RUSH CREEK WATERSHED PROTECTION AND FLOOD PREVENTION PROJECT



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ABSTRACT

A geomorphic assessment was used to design Twin Rush Creek, an alluvial channel in southcentral Indiana which is currently under construction. Results of rigid boundary analyses (allowable velocity and allowable tractive stress) using TR-25, Design of Open Channels (USDA-SCS, 1977), are compared with a mobile boundary approach using a geomorphic assessment as a tool. The procedure for performing a geomorphic assessment is provided in an overview of a case study.

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A channel stability analysis using a geomorphic assessment was performed on Twin Rush Creek, an alluvial channel in southcentral Indiana. Under the authority of the Small Watershed Protection and Flood Prevention Act (PL-566), the main channel of the creek was planned for enlargement to reduce agricultural flood damages. Construction began in late spring of 1986.

The tractive stress and allowable velocity design procedures using Technical Release No. 25 (TR-25), "Design of Open Channels," (USDA--SCS, 1977) had resulted in a prescription for total armoring of the constructed channel with rock armor to prevent channel bottom and bank erosion. Based on visual observations of the channel, and because of the costs involved, the need for the rock was questioned. Using the Modified Regime approach, a geomorphic assessment of the channel was made. Based on this assessment, it was recommended that no rock was needed to stabilize the channel except in some short reaches. This resulted in a savings of many construction dollars.

The purpose of this paper is to provide an overview of a case study using a geomorphic assessment and the results obtained. The need for expensive armoring was assessed by examining the total stream system using a geomorphic analysis. Specific channel design recommendations were formulated for Twin Rush Creek which supplemented the previous analyses.

Using a geomorphic approach for channel stability design in the case of Twin Rush Creek and other watersheds has resulted in a significant savings of public money. Simultaneously, the geomorphic approach has provided planners and design engineers with a useful tool for analyzing dynamic stream systems, and a greater understanding of the relationships between their channel perimeter materials and the energy of flow.

The purposes of this project, authorized under PL-566, are to reduce floodwater damages to agricultural land, control excessive soil erosion through application of conservation land treatment measures, and provide additional municipal and industrial water supply. The project consists of three floodwater retarding structures which were constructed in 1968, 1969, and 1980; and 7.2 miles of channel enlargement which is currently under construction. This is shown on the generalized project map, Figure 1. One floodwater retarding structure also stores water for municipal water supply.

Geologic Setting

Bedrock in and along the Twin Rush channel is Borden Shale, a Mississippian-aged unit which is primarily nonfissile siltstone. In the surrounding hills which were carved by glacial meltwaters, younger limestones crop out, some bearing siliceous geodes.

The strike of the Mt. Carmel Fault both bisects and parallels the lower portions of the stream near the confluence with the East Fork of the White River. (Refer to Figure 1.) Limestone outcrops are thickest and best exposed west of the fault which is the downthrown block in terms of relative movement. Solution channels and sinkholes occur in the limestone west of the fault.

Unconsolidated deposits date from the Pleistocene Age (glaciation) and lie unconformably on Borden Shale. The lowest or oldest deposit is silt and clay (CL and CL-ML) of lacustrine origin. This material is the accumulation of fine sediment particles that were eroded and deposited in a large lake formed in the Twin Rush Creek valley shortly after the last episode of continental glaciation, Wisconsinan, about 21,000 years ago. This was one of several lakes formed in tributaries of the White River due to the damming effect of the vast accumulations of clay, silt, sand and gravel that were flushed from the melting ice mass.

Surficial materials in the Twin Rush Creek valley are mainly sandy and clayey silts (CL and CL-ML) which are cohesive. This is alluvium which ranges in age from post-Pleistocene to the present.

GEOMORPHIC ASSESSMENT

A geomorphic interpretation of the stability of an alluvial channel system is based on the perceived and recorded historical conditions of the channel through time, and a thorough inspection of existing conditions. An assessment of future conditions of the channel can then be made with the anticipated changes which man will impose upon it.

Table 1. Planform Relationships--Present condition channel--Twin Rush Creek Watershed, Indiana.

Reach	Stationing (ft x .01)	PRESENT CONDITION	CHANNEL	Valley Length		Channel Length		Channel Sinuosity		Valley Slope		Original Channel Slope		Existing Channel Slope		Recomputed Sinuosity	
				VI (ft)	VS (ft)	VI (ft)	VS (ft)	(1) Po	(1) Vs	(ft/ft)	(ft/ft)	(ft/ft)	(ft/ft)	(ft/ft)	(ft/ft)	(3) Pc	(3) Vs
1	105.5 to 134			2400		2850		1.19		0.00587		0.00494		0.00571		1.03	
2	134 to 248			9784		11400		1.17		0.00225		0.00193		0.00155		1.45	
3	248 to 328		Co.Rd.	7165		8000		1.12		0.00088		0.00079		0.00078		1.13	
4	328 to 380		Co.Rd.	4591		5200		1.13		0.00081		0.00072		0.00067		1.21	
5	380 to 415		Co.Rd.	3430		3500		1.02		0.001		0.00098		0.00134		0.75	
6	415 to 464			3620		4900		1.35		0.00081		0.00060		0.00067		1.21	
7	464 to 520			4147		5600		1.35		0.00083		0.00061		0.00036		2.31	
8	520 to 556			2213		3600		1.63		0.00139		0.00085		0.00133		1.05	
9	556 to 604			3585		4800		1.34		0.00086		0.00064		0.00021		4.10	
10	604 to 636			2795		3200		1.14		0.00043		0.00038		0.00034		1.26	
11	636 to 712			5570		7600		1.36		0.00114		0.00084		0.00036		3.17	
12	712 to 744			3200		3200		1.00		0.00161		0.00161		0.00156		1.03	
13	744 to 800		White River	4925		5600		1.14		0.00059		0.00052		0.00043		1.37	

(1) $Po = Cl/Vl$

(2) $Cso = Vs/Po$

(3) $Pc = Vs/Cse$

Shale bedrock is seen at other points along the channel and in some exploration borings. Other bedrock highs may be encountered during construction and are anticipated.

Extent of modification: Channel straightening and shortening has occurred in the watershed since man began clearing and cultivating the land. Table 2 is a qualitative description of cultural alterations of the channel.

Table 2. Manmade channel alterations, Twin Rush Creek, IN

<u>Present Condition Station (ft. x .01)</u>	<u>Description</u>	<u>Age</u>
264 to 270	Clearing, relatively stable	?*, avg. 3" DBH** trees
322 to 380	Clearing with some reconstruction. No trees, relatively stable.	4 to 5 yrs ago, last time
380 to 407	2 to 3-ft high berm, constructed on rt. bank. Clearing, relatively stable.	?, avg. 6-10" DBH trees
430 to 431	Clearing, banks unstable due to poor logging operations.	1 month to ongoing
448	Tributary realignment with main channel, rel. stable.	?
469 to 480	Cleanout and clearing. Relatively stable cutoff.	After 1966. Avg. 6-8" DBH trees
490 to 491	Meander bend cutoff.	?
550	Cutoff, relatively stable.	? avg 4-6" DBH trees
600.5 to 614	Cleanout, relatively stable.	?
675 to 678	Meander bend cutoff, relatively stable.	?

*Unknown

**Diameter Breast Height

A channel traverse was performed from the headwaters to the outlet. Samples of representative channel bank and bottom materials were taken and later analyzed for grain size distribution and plasticity (cohesion). Plasticity index was used as an indicator of degree of cohesion. During the traverse all observations were located relative to the channel station. The location and type of riparian vegetation was especially important to the overall understanding of the channel's stability. The age of a tree and its location on the bank, for example, is direct evidence of streambank and bottom dynamics. Cultural information such as location and date of installation of a bridge, drainage outlet pipe, etc., also provided indirect evidence of system dynamics.

Planform changes: Sinuosity relationships displayed in Table 1 show the system is in a state of relative equilibrium. Sinuosity ratios generally increase in the downstream direction. Downstream from the colluvial fan which partially blocks the channel at station 700+00, sinuosity ratios decrease due to entrenchment and a very restrictive flood plain. When sinuosity ratios are recomputed on the basis of valley slope vs. channel slope, values generally exceed 1.0 indicating a relatively stable system.

Hydraulic changes: The three floodwater retarding structures control storm runoff from 51 percent of the watershed. When the East Fork of the White River is at high stage, backwater affects the lower reaches of Twin Rush Creek.

Sediment sources: Coarse sediment is derived from tributaries that have steep gradients in shale bedrock and short flood plain traverses. Shale bedload is deposited predominantly at the break in slope where tributaries enter the flood plain. Shale bedload is common upstream of station 240+00 and localized downstream where the main channel intercepts tributaries near the edge of the flood plain. The shale bedload has, therefore, only a localized armoring effect on the bottom and is not as significant as the shale bedrock control points.

Landslips in the vicinity of station 190+00 were identified during the field investigations. Landslips are locally significant sources of sediment where the channel abuts upland shale knobs. Landslips also bring additional trees and debris into the channel, forming log jams. The potential for the formation of landslips is greatest wherever the stream impinges against the shale uplands at the edge of the flood plain.

Surface drainage ditches have also provided sediment to the channel. This sediment is primarily silt and clay and is readily transported into Twin Rush Creek.

Sediment is also produced from localized streambank erosion. Streambank erosion due to flow deflection by trees, roots, and logs is occurring at relatively low rates, mainly in the alluvial valley fill. Channel banks are mostly unvegetated due to flow effects and canopy.

Channel perimeter sediments: Alluvial and lacustrine sediments in the channel have uniform grain sizes ranging from about d₅₀ of 0.01 mm to 0.02 mm. Silt and clay content ranges from 92 percent to 100 percent. The lacustrine soils are virtually sand-free. See Figure 3 for grain size distribution.

Channel banks are generally steep: partly as the result of poorly constructed channel meander bend cutoffs and straightening, and partly due to the cohesiveness and high silt and clay content of the channel perimeter soil materials.

Lateral accretion (bank building) of fine sediment on channel banks was observed at numerous locations, primarily in the lower reaches downstream from station 700+00, due to the backwater effects of the White River. Lateral accretion deposits were seen in reaches that were also experiencing bank erosion by deflection by trees growing on the inside bank. Research is needed to understand the mechanism and process of accumulation of lateral accretion deposits in the middle and upper reaches on banks which convey relatively high velocities of water flow (greater than three feet per second).

Riparian vegetation: Flood plain land use is about 85 percent cropland, 13 percent forest land, and 2 percent grassland and miscellaneous land. The forest land is in large lots in poorly drained small areas along the channel. Although small in number of acres, these riparian corridors provide valuable wildlife habitat. Tree size, density, and relative bank location are also important in determining the age and stability of channel reaches which have been modified by man.

Morphological characteristics: Figures 4 through 11 display comparison plots of present condition geometric and energy parameters along the channel with the changes anticipated through the proposed design alteration.

It is important to initially concentrate on existing conditions of the channel in as much detail as possible in order to understand why the channel has a certain geometric configuration and whether that regime is stable or not. Note that all dimensions are for the bankfull condition.

Top width: Figure 4 shows the existing channel generally increases in top width in the downstream direction. The middle reaches are somewhat constricted. The channel upstream from station 250+00 is wide and shallow due to the presence of shale bedrock. This widening process in the upper reaches does not appear to be very active as streambanks were observed to be relatively stable. The colluvial fan near station 700+00 exerts a strong influence on the channel by armoring the bottom, providing significant bed grade control, and causing the widest top width along the channel (80 feet). There is also a large log jam at this point, and the fan is in the process of creating an island with two separate channels.

Depth: Figure 5 shows little correlation between depth of channel and station, except that the channel becomes significantly deeper below the colluvial fan at station 700+00.

Flow area: Figure 6 shows that the channel is somewhat constricted below station 400+00 but has a large capacity in the lower reach as the channel deepens as it approaches the White River.

Top width/depth: Figure 7 shows that the middle reaches are obviously constricted.

Hydraulic characteristics of the channel: The physical characteristics of a channel are a function of the materials which comprise the channel banks and bottom, and the amount of energy being conveyed by the flow of water. The discharge of water and sediment through the system must therefore be evaluated to determine the effects on the materials which form the channel banks and bottom.

Discharges: Figure 8 shows that the bankfull channel discharges in the middle reaches are very constricted compared to the upstream and downstream reaches.

Velocity: Figure 9 shows that the present bankfull velocities are mostly below the allowable velocity of two feet per second as determined by rigid boundary analysis in TR-25. Velocities are as high as three feet per second for short reaches. These reaches appear to be relatively stable. Channel roughness ("n") values of 0.038 to 0.080 were used to estimate these present velocities.

Friction slope: Figure 10 shows the friction slope in the channel and is erratic due to the numerous log jams and constrictions in the channel. Friction slope is an expression of the energy available in the system and is equivalent to the water surface profile in open channel flow. Numerous log jams and constrictions in the channel produce the erratic plot in Figure 10.

Tractive stress: Figure 11 shows the tractive stresses in the channel using the TR-25 rigid boundary procedure. This procedure is a method for evaluating stresses at the interface between flowing water and the materials which comprise the channel boundary. For fine-grained soils with d₅₀ values less than 0.1 mm, the allowable tractive stress is determined by TR-25 methods to be 0.025 lbs/sq.ft. The d₅₀ grain sizes of channel perimeter sediments in Twin Rush Creek range from 0.009 mm to 0.022 mm. Tractive stresses for present bankfull conditions are mostly under the allowable stress of 0.025 lbs/sq.ft.

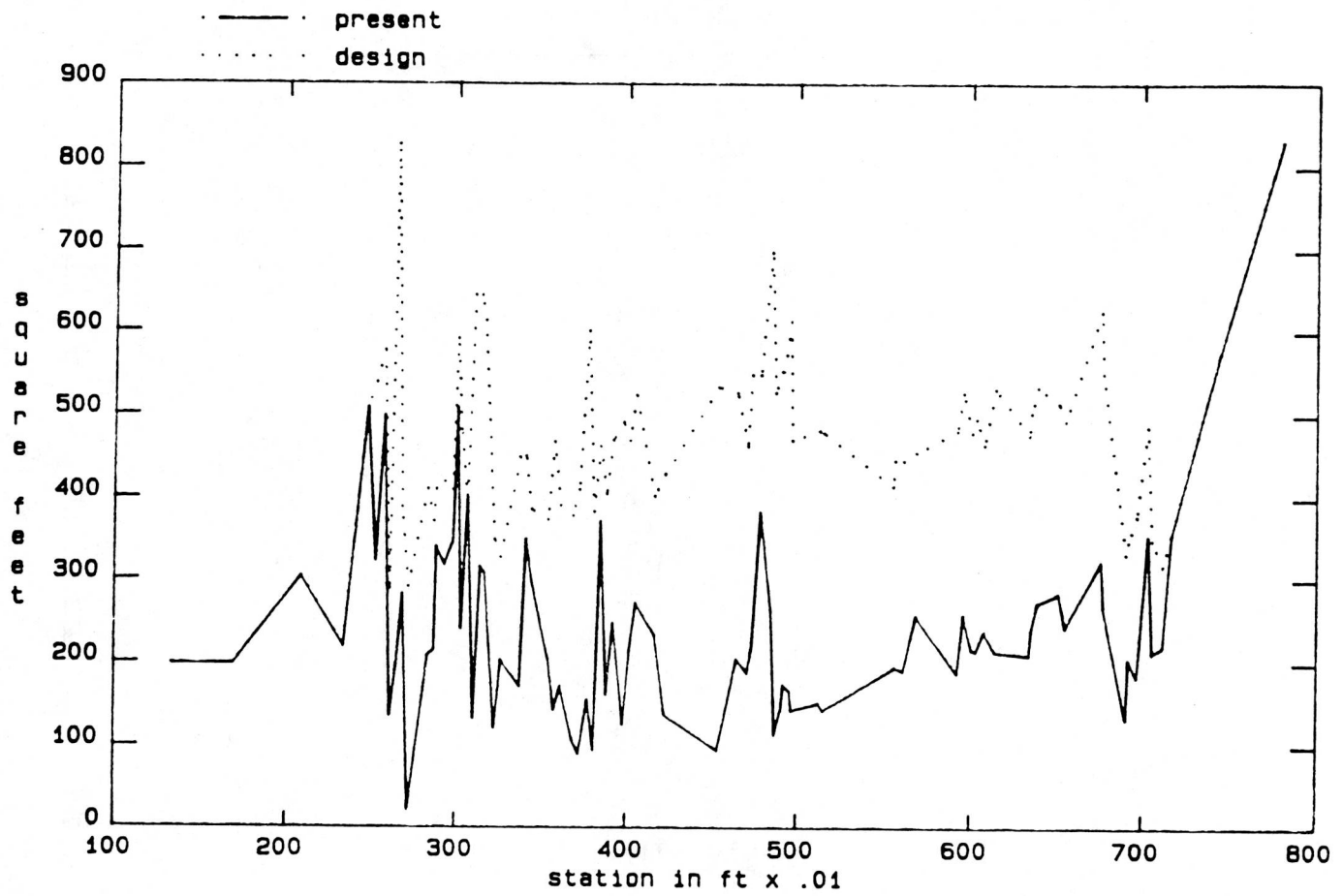


Figure 6 - Present and design flow area vs. station

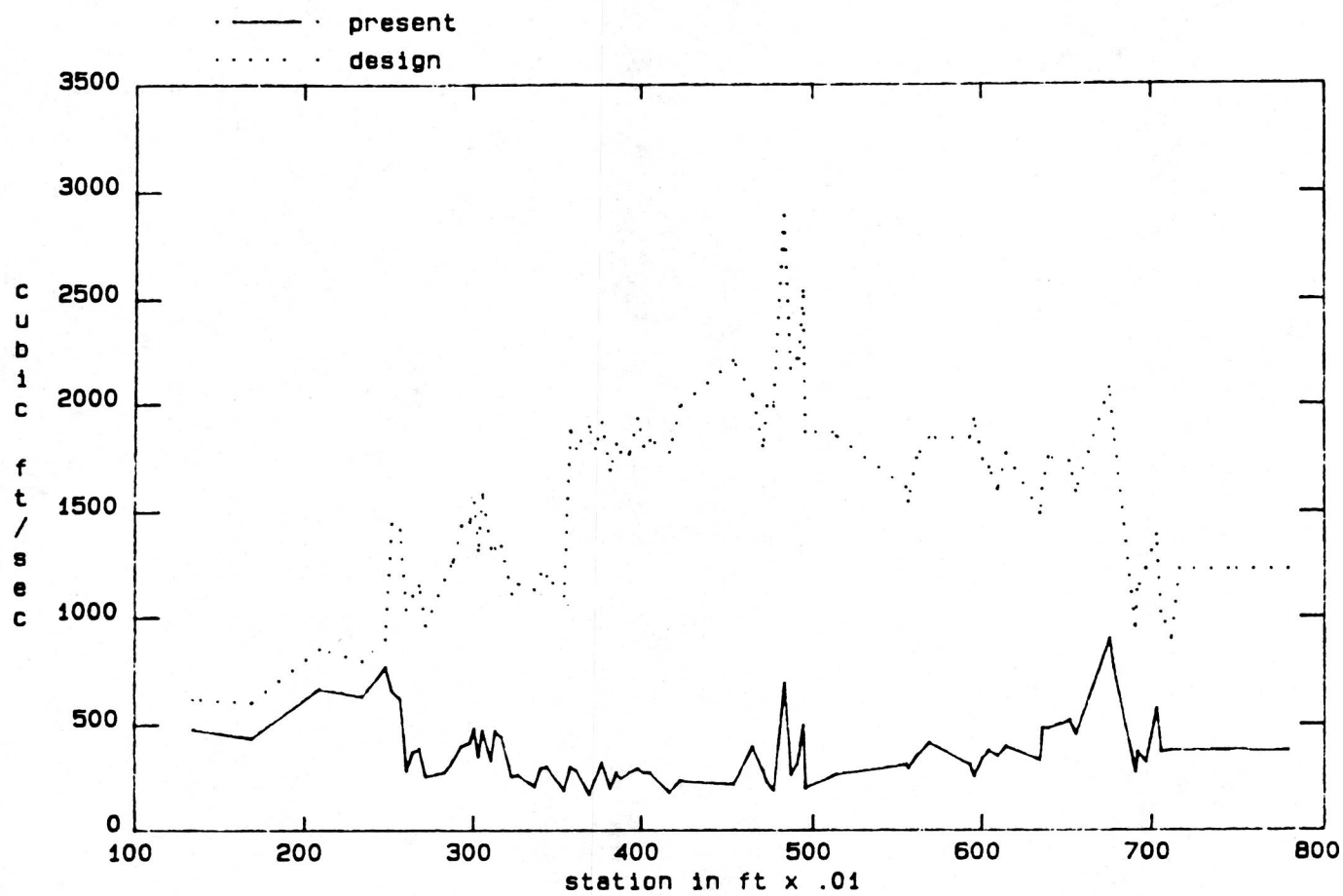


Figure 8 - Present and design bankfull discharge vs. station

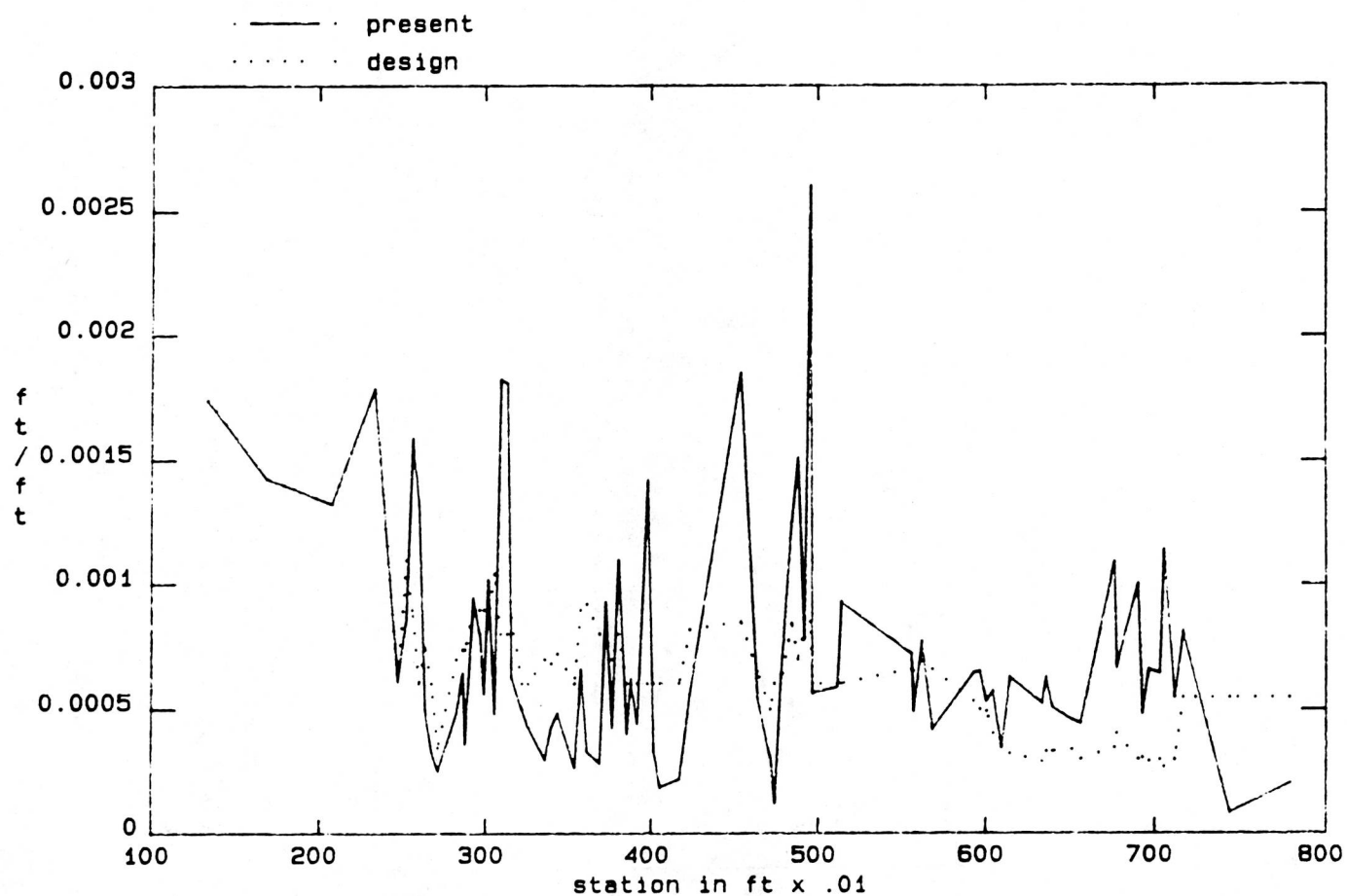


Figure 10 - Present and design friction slope vs. station

Proposed modifications

Planned channel: Approximately 7.2 miles of channel work are planned to reduce flooding and provide the desired economic benefits. No additional floodwater retarding dams are planned. The channel will be deepened by an average of two feet and widened to a uniform 30-foot bottom width from station 715+00 to station 436+00 and to a 20-foot bottom width to the upper end of construction. Top widths will vary according to the channel depth.

In order to make up for the damage or loss of aquatic habitat due to the channel excavation, fish pools with flow deflectors and riffles are included in the final channel design. In addition, the channel bottom will be tilted to one side to concentrate low flow for a fish travelway. Fish pools will be three feet deeper than the design grade line, and will be installed at a frequency of 15 per mile (total of 108). A riffle composed of riprap will be installed in conjunction with each pool. Four concrete maintenance crossings will also be installed across the channel.

The proposed channel design grades are 0.00034 ft/ft from 715+00 to 642+00 and 0.00090 ft/ft from 642+00 to 332+50. Side slopes are to be constructed 2.5H:1V. By cutting off meander bends and generally straightening the channel for improved hydraulic efficiency, channel length in the area of work will be reduced by about 1.5 miles or about 17 percent. As shown on Table 3, about 1.2 miles of the channel length reduction is planned below station 531+00 or about the lower one-half of the design channel length. This is an effective reduction in channel length of about 34 percent in the lower half of the proposed channel work.

Table 4 displays sinuosity ratios for the proposed channel. Note that the expected sinuosity ratios are nearly 1.0 when comparing channel length vs. valley length, indicative of the proposed channel straightening, realignment, and reduction in overall length. When sinuosity ratios are recomputed on the basis of valley slope vs. channel slope, however, the values fall slightly below 1.0 for the most part. Such values below 1.0 normally indicate that the channel will not be comfortable or in a stable regime in its valley.

Effect of planned channel: An intuitive understanding of the historical and existing conditions of the channel are necessary before attempting to predict the response of the channel system to any proposed changes in channel dimensions or flow regime. Analysis of the proposed modification, which includes channel enlargement and no additional flow controls, provides a means of comparing the new regime with historical and existing conditions of the channel.

Performance of the channel under man's known alteration through the years, as shown in Table 2, is the basis for the prediction of the system's response to any additional changes imposed on it.

Table 4. Planform Relationships--Proposed channel--Twin Rush Creek Watershed, Indiana.

Reach	Stationing (ft x .01)	Valley length (ft) V1	Channel length (ft) C1	Sinuosity (1) Po	Valley Slope (ft/ft) Vs	Original Channel Slope(2) (ft/ft) Cso	Design Channel Slope (ft/ft) Cse	Recomputed Sinuosity (3) Pc
DESIGNED CHANNEL								
3	332.5 to 409	7165	7650	1.07	0.00088	0.00082	0.0009	0.98
4	409 to 455.4	4591	4640	1.01	0.00081	0.00080	0.0009	0.90
5	455.4 to 489.25	3385	3385	1.00	0.001	0.00100	0.0009	1.11
6	489.25 to 531	3620	4175	1.15	0.00081	0.00070	0.0009	0.90
7	531 to 576	4147	4500	1.09	0.00083	0.00076	0.0009	0.92
8	576 to 590	1400	1400	1.00	0.00139	0.00139	0.0009	1.54
9	590 to 626	3585	3600	1.00	0.00086	0.00086	0.0009	0.96
10	626 to 652	2600	2600	1.00	0.00043	0.00043	0.00034	1.26
11	652 to 715	5570	6300	1.13	0.00114	0.00101	0.00034	3.35
Construction begins								

(1) $Po = C1/V1$
 (2) $Cso = Vs/Po$
 (3) $Pc = Vs/Cse$

Velocity: Design channel flow velocities at bankfull conditions will range from two to five feet per second. This is a substantial increase from the present one to three feet per second velocities. (See Figure 9.) A channel roughness ("n") value of 0.04 was used to estimate design flow velocities.

Friction slope: The designed slope of the water surface profile, or friction slope, will be substantially reduced in all reaches due to improvements of the channel's hydraulic efficiency by removing log jams and enlarging constricted reaches. (See Figure 10.)

Tractive stress: As illustrated by Figure 11, tractive stresses will be significantly increased in the middle reaches due primarily to increases in velocities evaluated at the bankfull condition. For some reaches the predicted tractive stresses will be more than double the allowable values computed by TR-25 rigid boundary analysis.

Comparison with other improved channels: Table 5 displays the ratios of computed tractive stress values (T) and TR-25 allowable tractive stress values (Ta) for Twin Rush Creek, Muddy Fork of Silver Creek (Harvey et.al.,1984), and Elk Creek (Harvey et.al.,1984). Elk Creek was constructed in 1963 and is relatively stable today. Muddy Fork is planned for enlargement. Both Muddy Fork and Elk Creek are located in the same general physiographic area as Twin Rush Creek.

Table 5. Computed mean values of tractive stress vs. allowable tractive stress (T/Ta).

<u>channel</u>	<u>T/Ta (n=0.04)</u>
Elk Creek	1.47
Muddy Fork	
Total length	1.55
Lower reach	0.87
Upper reach	2.63
Twin Rush	
Total length	1.47
Lower reach	1.25
Middle reach	1.88
Upper reach	1.34

RECOMMENDATIONS

Based on this geomorphic assessment, the following recommendations were made for the final channel design for Twin Rush Creek. These are presented to illustrate the degree of specific detail obtained from a geomorphic assessment.

1: The colluvial fan deposit near station 700+00 is near the strike of the Mt. Carmel Fault and is a prominent channel feature that has provided in-stream grade control and bottom stability. It was therefore recommended that this control point be replaced in the same place and at design grade in the form of a riprapped hard point. In addition, another riprapped hard point should be established on design grade at an upstream location equivalent in elevation.

2: Placement of rock armoring in all proposed channel work reaches is not necessary. Studies in Muddy Fork of Silver Creek and Elk Creek (Harvey et.al., 1984) have shown that the presence of bank materials of high percentage silt and clay promote erosion resistance due to cohesion. In Twin Rush Creek, the strength and erosion resistance of channel bank materials increases with depth, ranging from soft but cohesive alluvial channel fill silts and clays to lacustrine silty clays and shale bedrock.

3: Channel shortening and meander bend cutoffs will not cause channel erosion and enlargement by degradation in reaches that are shortened less than 30 percent, according to studies in Elk Creek Watershed (Harvey et.al., 1984). Man-made cutoffs in Twin Rush Creek have remained relatively stable.

4: Rock armoring, however, was recommended in a reach from design station 576+00 to 590+00. About 2,200 feet of existing channel will be cut off or about a 61 percent reduction in reach length. This length reduction will increase flow velocities from the present 2 to 3 ft/sec to 4 to 5 ft/sec, necessitating 1,400 lineal feet of armoring in this reach.

5: Selective armoring and placement of rock materials are not precluded and should be installed during construction according to the specific site conditions as identified by the project technical specialists.

6: The contact between the plastic lacustrine silty clays (CL and CL-ML) and the overlying soft but cohesive silty and clayey alluvial valley fill (ML and CL-ML) is smooth with no weak paleosols or sand and gravel lenses that could differentially erode and cause slumpage of banks through loss of toe support. This contact, however, is the most critical zone of potential erosion. Therefore, wherever this contact appears low on the bank during construction (3 feet or less above design grade), consideration should be given for selective rock armoring or placement of riprap to prevent bank failure due to loss of toe support.

CONCLUSIONS

The geomorphic approach to channel design has been successful in gaining a better understanding of the relationships between soils and materials which form the channel and the energy of flow conveyed. In Twin Rush Creek Watershed, approximately one million dollars was saved, specifically by the reduction of rock armoring previously prescribed through TR-25 rigid boundary analyses for allowable velocity and allowable tractive stress.

ACKNOWLEDGEMENTS

The study results contained herein are based largely on the procedures and results of Harvey, Watson, and Schumm (1984). Their work was done under contract with SCS to assess the need for rock armoring in the proposed enlargement of Muddy Fork of Silver Creek, a channel in the same physiographic region as Twin Rush Creek.

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